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COMPONENTAL ANALYSIS OF THE FACTORS INFLUENCING RESISTANCE TO SORGHUM MIDGE, *CONTARINIA SORGHICOLA* COQ.*

H. C. SHARMA, P. VIDYASAGAR and K. LEUSCHNER
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru, A.P. 502 324, India

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Abstract—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 (CSH 1 and Swarna) cultivars. Short floral parts, faster rate of grain development and high tannin content of grain were apparently associated with resistance to sorghum midge, *Contarinia sorghicola* Coq. Genotypic and phenotypic correlations between the factors associated with resistance to sorghum midge were in the same direction (positive or negative) as their association with resistance to this insect. Glume g2, lemma l2, anther and lodicule length, rate of grain development based on dry weight (except oviposition), and tannin content of mature grain showed correlation and path coefficients (direct effects) in the same direction. These characters can serve as a useful criteria to select for resistance to sorghum midge.

Using D^2 and canonical cluster analysis, AF 28 was found to be distinct from other sources of midge resistance. However, based on larvae/100 florets, DJ 6514 was also placed distantly from TAM 2566 and IS 15107. Based on egg numbers, adults emerged and grain damage, DJ 6514 was grouped with TAM 2566 and IS 15107. Susceptible hybrid check, CSH 1 was generally placed distantly from the self pollinated susceptible variety, Swarna. These results indicate that the sources of resistance to sorghum midge are diverse, and there is a distinct possibility of increasing the levels and diversity of resistance to this insect.

Key Words: Sorghum, *Contarinia sorghicola*, resistance, componental analysis

Résumé—Analyse des composantes des facteurs qui influencent la résistance à la cécidomyie du sorgho *Contarinia sorghicola* Coq. : Des études ont été effectuées sur les composantes de la résistance à la cécidomyie du sorgho portant sur quatre cultivars résistants (DJ 6514, AF 28, TAM 2566 et IS 15107) et deux cultivars sensibles (CSH 1 et Swarna). Des parties florales courtes, un développement plus rapide des graines, ainsi qu'une teneur élevée en tanin de la graine étaient apparemment associés avec la résistance à la cécidomyie du sorgho *Contarinia sorghicola* Coq. Des corrélations génotypiques et phénotypiques entre les facteurs asssociés avec la résistance à la cécidomyie avaient la même orientation (positive ou négative) que leur association avec la résistance à cet insecte. La glume g2, la glumelle inférieure l2, la longueur de l'anthére et de la lodicule, le développement de la graine par rapport au poids sec (sauf ponte), et la teneur en tanin de la graine mure ont montré une corrélation et des path-coefficients (effets directs) dans la même orientation. Ces caractéres peuvent servir de critéres utiles de sélection pour la résistance à la cécidomyie.

L'utilisation de D^2 et l'analyse en grappes canonique a permis de mettre en évidence que AF 28 était distinct des autres sources de résistance à la cécidomyie. Cependant, par rapport

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au nombre de larves/100 florets, DJ 6514 était également éloigné de TAM 2566 et IS 15107. Par rapport aux nombres d'oeufs, nombre d'adultes émergés, et endommagement des graines, DJ 6514 était groupé avec TAM 2566 et IS 15107. Le témoin hybride sensible, CSH 1 était généralement éloigné de la variété sensible autogame, Swarna. Ces résultats indiquent que les sources de résistance à la cécidomyie sont diverses, et qu'il existe une possibilité distincte d'amélioration des niveaux et de la diversité de la résistance à cet insecte.

Mots Cléfs: Sorgho, *Contarinia sorghicola*, résistance, analyse des composantes

INTRODUCTION

Sorghum midge, *Contarinia sorghicola* Coq., is a destructive insect pest of grain sorghum *Sorghum bicolor* (L.) Moench, in many parts of the world (Harris, 1976), and resistant cultivars are an important means of minimizing midge damage to sorghum (Sharma, 1985a, b). There are a number of conflicting reports about the nature and mechanisms of resistance to sorghum midge. Short glumes (Ball and Hastings, 1912), cleistogamous glume character (long glumes) (Bowden and Neve, 1953) and nature of glume coupling (Geering, 1953; Bergquist et al., 1974; Rossetto et al., 1975) have been reported to be associated with midge resistance. However, Murty and Subramaniam (1978) reported that glume length, rachis length, and the presence of awns were not associated with midge resistance.

Resistance to sorghum midge appears to be a complex characteristic and depends on the interplay of a number of componental characteristics such as short floral parts, initial faster rate of grain development, and tannin content of grain, which finally sum up the expression of resistance to this insect (Sharma et al., 1990b). In order to obtain a clear picture of the contribution of componental characters, it is necessary to study their correlation and causation to provide a realistic basis for allocation of weightage to each of the factors. It is useful in deciding upon a suitable selection criteria in genetic improvement of sorghum for insect resistance (Omori et al., 1983). This can be obtained through path analysis (Li, 1956). In an insect resistance breeding programme, it is also important to look for genetic diversity to improve the levels of resistance. The sources of resistance to sorghum midge differ in their resistance levels and morphological traits, and can be placed in different groups based on principal component analysis (Sharma et al., 1988). Multivariate statistical techniques such as Mahalanobis D^2 statistic and canonical variate analysis are considered useful to measure genetic diversity (Rao, 1952; Omori et al., 1988). The present study examines the direct and indirect effects of componental characters on expression of resistance to sorghum midge, and identify diverse sources of resistance for improving the levels and diversity of resistance to this insect.

MATERIALS AND METHODS

The studies were conducted on four resistant DJ 6514 (Shyamsunder et al., 1975), TAM 2566 (Johnson et al., 1973), AF 28 (Rossetto et al., 1975), IS 15107 (Sharma, 1985b) and two susceptible (CSH 1 and Swarna) cultivars over four seasons from 1982 to 1984. The cultivars were planted in a randomized 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. Normal agronomic practices were followed for raising the crop.

Assessment of numbers of eggs, larvae, emerging adults and grain damage

The number of eggs, larvae and adults were recorded in six cultivars over four seasons by artificially infesting the sorghum panicles at the top-anthesis stage under headcage described earlier by Sharma et al. (1990b).

Floral morphology

The length of glumes (g1 and g2), lemmas (l1 and l2), palea, style and stigma, and the length and breadth of the lodicule, anther and ovary were recorded on 10 randomly selected florets; from the mid portion of three panicles of 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 (G1), fresh weight (G2),

Fig. 1. Grain size meter developed to measure grain width.

and dry weight (G3). 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 meter (Fig. 1) on alternate days between anthesis and 15 days after anthesis. The rate of grain development between the 3rd and 7th day after anthesis showed maximum association with midge resistance (Sharma et al., 1990b), and it was used in cluster and path coefficient analysis.

Tannin content of grain

The tannin content of a 10-day-old and mature grain was determined by the method of Mertin et al. (1978). The grain samples were collected from three 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

The data were subjected to canonical (Rao, 1952) and path coefficient (Dewey and Lu, 1959) analysis for eggs and larvae/100 florets, grain damage (%) and adult emergence in an attempt to identify sources with diverse mechanisms of resistance, and to understand the direct and indirect contribution of various factors associated with midge resistance.

RESULTS

Number of eggs/100 florets were significantly higher in the sorghum midge susceptible cultivars, CSH 1 and Swarna, than in the midge resistant genotypes AF 28, TAM 2566, DJ 6514 and IS 15107 (Table 1). The number of larvae/100 florets were lowest in AF 28 followed by DJ 6514, TAM 2566 and IS 15107. Fewer adults emerged in the midge-resistant cultivars than in the susceptible checks, CSH 1 and Swarna. Grain damage was least in DJ 6514, closely followed by TAM 2566, AF 28 and IS 15107. Resistance to sorghum midge was associated with short floral parts, faster rate of grain development, and high tannin content of the grain (except in DJ 6514) (Sharma et al., 1990b).

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	No. of eggs/ 100 florets	No. of larvae/ 100 florets	No. of adults emerged/ panicle	Midge damage (% chaffy florets)
DJ 6514	37 (6)[a]	8 (2)[a]	15 (3)[a]	15 (22)[b]
AF 28	21 (4)	6 (7)	24 (4)	33 (34)
TAM 2566	37 (5)	41 (6)	33 (6)	30 (33)
IS 15107	38 (6)	59 (7)	71 (8)	39 (38)
CSH 1 (S)	153 (12)	142 (12)	404 (19)	81 (65)
Swarna (S)	141 (11)	127 (11)	318 (18)	83 (66)
S.E.	(0.9)	(3.2)	(1.2)	(4.1)
LSD	2.5	3.3	3.0	(11.3)
CV (%)	(27.6)	(14.6)	(24.2)	(20.9)

Figures in parentheses are, a = square root transformed values and b = arcsin/% transformed values, S = susceptible check

Table 2. Genotypic and phenotypic correlations between floral parts, rate of grain development and tannin content of grain in six sorghum cultivars

Genotypic correlations

Trait	Glume g1 L	Glume g2 L	Lemma l1 L	Lemma l2 L	Lodicule L	Anther L	Palea L	Grain development G1	Grain development G2	Grain development G3	Tannins (%) (10-day old grain)	Tannins (%) (matured grain)	Multi-factor
Glume g1 L	1.00	1.00**	0.99**	0.75**	0.57**	0.93**	0.93**	-0.61**	-0.65**	-0.60**	-0.57**	-0.39	0.95
Glume g2 L	0.99**	1.00	1.00**	0.76**	0.54**	0.90**	0.94**	-0.70**	-0.69**	-0.68**	-0.58**	-0.42*	0.95
Lemma l1 L	0.98**	0.99**	1.00	0.78**	0.42*	0.84**	0.94**	-0.63**	-0.56**	-0.56**	-0.45*	-0.31	0.92
Lemma l2 L	0.75**	0.75**	0.77**	1.00	0.39	0.79**	0.68**	-0.58**	-0.55**	-0.07	0.18	-0.03	0.94
Lodicule L	0.56**	0.54**	0.40*	0.39**	1.00	0.74**	0.37	0.73**	-0.88**	-0.84**	-0.74**	-0.65**	0.72
Anther L	0.93**	0.89**	0.84**	0.78**	0.72**	1.00	0.79**	-0.60**	-0.61**	-0.59*	0.46*	0.29	0.96
Palea L	0.82**	0.84**	0.85**	0.60**	0.30	0.71**	1.00	-0.85**	-0.33	-0.74**	-0.58**	0.08	0.80
G1	-0.54**	-0.61**	-0.52**	-0.52**	-0.65**	-0.50*	-0.60**	1.00	1.02	0.91**	0.59**	0.53**	-0.86
G2	-0.54**	-0.58**	-0.48*	-0.46**	0.77**	-0.52**	-0.19	0.73**	1.00	0.64**	0.46*	0.99**	-0.81
G3	-0.58**	-0.60**	-0.49*	-0.07**	-0.74**	-0.52	-0.53*	0.68**	0.62**	1.00	1.00	0.89**	-0.56
Tannins 10-day-old grain	-0.46**	-0.47*	0.37	0.16	-0.62**	-0.39	-0.40*	0.43*	0.46*	0.95**	1.00	0.91**	-0.25
Tannins matured grain	0.39	-0.42*	-0.31	0.03	-0.64**	-0.29	-0.06	0.47*	0.82**	0.78**	0.78**	1.00	0.35
Multi-factor	0.91**	-0.91**	0.87**	0.91**	0.68**	0.92**	0.70**	-0.70**	-0.69**	-0.48*	-0.27*	0.34*	

*Significant at $P > 0.05$.
**Significant at $P > 0.01$.
L = Length.

Correlations between the components associated with resistance to sorghum midge

The genotypic and phenotypic correlations between the linear measurements of different floral parts (glume, lemma, palea, lodicule, and anther length) were significant and positive (Table 2). The correlation coefficient pattern between these parameters was in the same direction as their association with susceptibility to sorghum midge. Rate of grain development (between 3rd and 7th day after anthesis) showed significant and negative association with linear parameters of floral parts. Rate of grain development based on width was positively correlated with rate of grain development based on fresh and dry weight. Tannin content of 10-day-old and mature grain showed negative, but relatively lower correlation coefficients with floral parts, but significant and positive association with the rate of grain development.

Direct and indirect (path coefficients) effects of different traits on resistance to sorghum midge

Oviposition. Among the different floral parts, glume g2, lemma l2 and anther length, showed direct positive effects on eggs/100 florets (Table 3). The positive association of other floral parts with oviposition was through glume g2, lemma l2 and anther length. Rates of grain development (G1, G2 and G3) showed positive direct effects on oviposition. Their negative association with oviposition was largely through glume g2, lemma l2 and the tannin content of mature grain. The direct effects and correlation coefficients were negative for tannin content of grain. Glume g2, lemma l2, anther length and tannin content of grain showed correlations and direct effects in the same direction, and thus seem to influence the extent of oviposition in different cultivars.

Larvae. Direct effects of glume g2, lemma l2, lodicule length, and palea length were positive, as

Table 2. Genotypic and phenotypic correlations between floral parts, rate of grain development and tannin content of grain in six sorghum cultivars

Genotypic correlations

Trait	Glume g1 L	Glume g2 L	Lemma l1 L	Lemma l2 L	Lodicule L	Anther L	Palea L	Grain development G1	Grain development G2	Grain development G3	Tannins (%) (10-day old grain)	Tannins (%) (matured grain)	Multi-factor
Glume g1 L	1.00	1.00**	0.99**	0.75**	0.57**	0.93**	0.93**	-0.61**	-0.65**	-0.60**	-0.57**	-0.39	0.95
Glume g2 L	0.99**	1.00	1.00**	0.76**	0.54**	0.90**	0.94**	-0.70**	-0.69**	-0.68**	-0.58**	-0.42*	0.95
Lemma l1 L	0.98**	0.99**	1.00	0.78**	0.42*	0.84**	0.94**	-0.63**	-0.56**	-0.56**	-0.45*	-0.31	0.92
Lemma l2 L	0.75**	0.75**	0.77**	1.00	0.39	0.79**	0.68**	-0.58**	-0.55**	-0.07	0.18	-0.03	0.94
Lodicule L	0.56**	0.54**	0.40	0.39**	1.00	0.74**	0.37	-0.73**	0.88**	-0.84**	-0.74**	-0.65**	0.72
Anther L	0.93**	0.89**	0.84	0.78**	0.72**	1.00	0.79**	-0.60**	-0.61**	0.59*	0.46*	-0.29	0.96
Palea L	0.82**	0.84**	0.85	0.60**	0.30	0.71**	1.00	-0.85**	-0.33	-0.74**	0.58**	0.08	0.80
G1	-0.54**	-0.61**	-0.52	-0.52**	-0.65**	-0.50*	-0.60**	1.00	1.02	0.91**	0.59**	0.53**	-0.86
G2	-0.54**	-0.58**	-0.48	-0.46**	-0.77**	-0.52**	-0.19	0.73**	1.00	0.64**	0.46*	0.99**	-0.81
G3	-0.58**	-0.60**	-0.49	-0.07**	-0.74**	-0.52	0.53*	0.68**	0.62**	1.00	1.00	0.89**	-0.56
Tannins 10-day-old grain	-0.46**	-0.47*	-0.37	0.16	-0.62**	-0.39	-0.40*	0.43*	0.46*	0.95**	1.00	0.91**	-0.25
Tannins matured grain	0.39	-0.42*	-0.31	0.03	-0.64**	-0.29	-0.06	0.47*	0.82**	0.78**	0.78**	1.00	0.35
Multi-factor	0.91**	-0.91**	0.87**	0.91**	0.68**	0.92**	0.70**	-0.70**	-0.69**	-0.48*	-0.27*	-0.34*	

*Significant at $P > 0.05$.
**Significant at $P > 0.01$.
L = Length.

Correlations between the components associated with resistance to sorghum midge

The genotypic and phenotypic correlations between the linear measurements of different floral parts (glume, lemma, palea, lodicule, and anther length) were significant and positive (Table 2). The correlation coefficient pattern between these parameters was in the same direction as their association with susceptibility to sorghum midge. Rate of grain development (between 3rd and 7th day after anthesis) showed significant and negative association with linear parameters of floral parts. Rate of grain development based on width was positively correlated with rate of grain development based on fresh and dry weight. Tannin content of 10-day-old and mature grain showed negative, but relatively lower correlation coefficients with floral parts, but significant and positive association with the rate of grain development.

Direct and indirect (path coefficients) effects of different traits on resistance to sorghum midge

Oviposition. Among the different floral parts, glume g2, lemma l2 and anther length, showed direct positive effects on eggs/100 florets (Table 3). The positive association of other floral parts with oviposition was through glume g2, lemma l2 and anther length. Rates of grain development (G1, G2 and G3) showed positive direct effects on oviposition. Their negative association with oviposition was largely through glume g2, lemma l2 and the tannin content of mature grain. The direct effects and correlation coefficients were negative for tannin content of grain. Glume g2, lemma l2, anther length and tannin content of grain showed correlations and direct effects in the same direction, and thus seem to influence the extent of oviposition in different cultivars.

Larvae. Direct effects of glume g2, lemma l2, lodicule length, and palea length were positive, as

Table 3. Direct and indirect (path coefficients) effects of 12 characters on oviposition by the sorghum midge in six sorghum cultivars

Trait	Glume g1 L	Glume g2 L	Lemma 11 L	Lemma 12 L	Lodicule L	Anther L	Palea L	Grain development G1	Grain development G2	Grain development G3	Tannins (%) (10-day-old grain)	Tannins (%) (matured grain)	r
Glume g1 L	-0.97	1.19	0.75	0.19	0.72	-0.43	0.53	0.008	0.35	0.001	0.11	0.14	0.69
Glume g2 L	-0.96	1.20	0.76	0.19	0.70	-0.42	0.54	-0.01	-0.37	-0.001	0.11	0.15	0.73
Lemma 11 L	-0.95	1.19	0.77	0.19	0.51	-0.40	0.55	-0.01	-0.30	0.00	0.09	0.11	0.70
Lemma 12 L	-0.73	0.91	0.59	0.25	0.50	-0.37	0.39	-0.008	-0.30	0.00	0.04	0.01	0.60
Lodicule L	-0.55	0.65	-0.31	0.10	1.28	-0.34	0.20	-0.01	-0.49	-0.001	0.15	0.23	0.58
Anther L	-0.89	1.07	-0.65	0.20	0.93	-0.47	0.46	-0.008	-0.33	-0.001	0.09	0.10	0.65
Palea L	-0.79	1.01	-0.65	0.15	0.39	-0.33	0.65	-0.009	-0.12	0.001	-0.10	0.02	0.56
G1	0.53	-0.73	0.40	-0.13	-0.84	0.24	0.39	0.02	0.47	0.001	-0.10	0.17	-0.20
G2	0.53	-0.70	0.36	-0.12	-0.99	0.24	-0.12	0.01	0.64	0.001	-0.11	-0.30	-0.36
G3	0.56	-0.72	0.38	-0.02	-0.95	0.24	0.35	0.01	0.40	0.001	-0.23	-0.28	-0.49
Tannins 10-day-old grain	0.45	0.56	0.28	0.04	-0.79	0.18	-0.26	0.007	0.30	0.001	-0.24	-0.28	0.62
Tannins matured grain	0.38	-0.50	0.24	0.01	-0.82	0.13	-0.04	0.007	0.53	0.001	-0.19	0.36	-0.47

L = Length.
r = Correlation coefficient.

Table 4. Direct and indirect (path coefficients) effects of 12 traits on midge larvae in six sorghum cultivars

Trait	Glume g1 L	Glume g2 L	Lemma 11 L	Lemma 12 L	Lodicule L	Anther L	Palea L	Grain development G1	Grain development G2	Grain development G3	Tannins (%) (10-day-old grain)	Tannins (%) (matured grain)	
Glume g1 L	-0.99	0.87	0.56	0.21	0.76	0.29	0.50	-0.37	-0.31	0.07	-0.03	0.07	0.75
Glume g2 L	-0.99	0.87	-0.57	0.21	0.74	-0.28	0.51	-0.04	0.33	0.07	-0.03	0.08	0.74
Lemma 11 L	-0.97	0.86	-0.57	0.22	0.54	-0.27	0.52	-0.04	0.27	0.06	-0.03	0.06	0.71
Lemma 12 L	-0.75	0.66	-0.44	0.28	0.52	-0.25	0.37	-0.04	-0.26	0.01	0.01	0.01	0.88
Lodicule L	-0.56	0.47	-0.23	0.11	1.35	-0.23	0.19	-0.05	-0.44	0.10	-0.05	-0.12	0.50
Anther L	-0.92	0.77	-0.49	0.22	0.98	-0.32	0.43	-0.03	-0.29	0.06	-0.03	-0.05	0.84
Palea L	-0.81	0.73	-0.49	0.17	0.41	-0.22	0.61	-0.04	-0.11	0.07	-0.03	-0.01	0.63
G1	0.54	0.53	0.30	-0.15	-0.88	0.16	-0.37	0.07	0.41	-0.08	0.03	0.09	-0.12
G2	0.54	-0.51	0.27	-0.13	-1.04	0.16	-0.12	0.05	0.57	-0.08	0.03	0.15	-0.33
G3	0.58	-0.53	0.28	-0.02	-1.01	0.17	-0.33	0.05	0.35	-0.12	0.07	0.14	-0.17
Tannins 10-day-old grain	0.46	-0.41	0.21	0.05	-0.84	0.12	-0.24	0.03	0.26	-0.12	0.07	0.14	-0.33
Tannins matured grain	0.38	-0.36	0.18	0.01	-0.87	0.09	-0.04	0.03	0.47	0.10	0.06	0.18	-0.23

L = Length.
r = Correlation.

Table 5. Direct and indirect (path coefficients) effects of 12 traits on adult emergence in six sorghum cultivars

Trait	Glume g1 L	Glume g2 L	Lemma l1 L	Lemma l2 L	Lodicule L	Anther L	Palea L	Grain development G1	G2	G3	Tannins (%) (10-day-old grain)	Tannins (%) (matured grain)	r
Glume g1 L	0.18	0.37	-0.23	0.73	0.06	0.15	-0.19	-0.01	-0.29	0.02	-0.03	0.32	0.81
Glume g2 L	0.18	0.38	-0.29	0.73	0.05	0.14	-0.19	-0.01	-0.31	0.03	-0.03	0.34	0.81
Lemma l1 L	0.17	0.37	-0.23	0.75	0.04	0.14	-0.19	-0.01	-0.26	0.02	-0.02	0.25	0.78
Lemma l2 L	0.13	0.28	0.18	0.97	0.04	0.13	-0.14	0.01	-0.25	-0.001	0.01	-0.02	0.85
Lodicule L	0.10	0.21	-0.09	0.38	0.10	0.12	-0.07	-0.01	-0.42	0.03	-0.04	0.53	0.60
Anther L	0.16	0.34	0.20	0.76	0.07	0.16	-0.16	-0.01	-0.28	0.02	-0.02	0.24	0.89
Palea L	0.14	0.32	-0.20	0.58	0.03	0.11	-0.23	-0.01	-0.10	0.02	-0.03	0.05	0.67
G1	-0.10	-0.23	0.12	-0.51	-0.06	-0.08	0.14	0.01	0.39	-0.03	0.03	-0.39	-0.25
G2	0.10	-0.22	0.11	0.45	-0.08	-0.08	0.04	0.01	0.54	-0.03	0.03	-0.67	0.41
G3	-0.09	0.21	0.11	0.03	-0.06	-0.06	0.11	0.01	0.32	-0.05	0.06	-0.68	-0.31
Tannins 10-day-old grain	-0.08	-0.18	0.09	0.16	-0.06	-0.06	0.09	0.003	0.25	-0.04	0.06	-0.64	-0.52
Tannins matured grain	0.07	-0.16	0.07	0.03	-0.06	0.05	0.02	0.01	0.44	-0.04	0.05	0.82	-0.45

L = Length.
r = Correlation.

were their correlations with the number of larvae/100 florets (Table 4). The indirect effects of the other floral parameters through these traits were also positive. The direct effects of glume g1, lemma l1 and anther length were negative, although their correlations with midge larvae were positive. Direct effects of rates of grain development (G1 and G2), and tannin content of grain were of lower magnitude.

Adult emergence. Adult emergence reflected the total genotypic effects on oviposition and survival of the sorghum midge in different genotypes. Glume g1 and g2, lemma l2, lodicule and anther length contributed directly towards genotypic susceptibility to sorghum midge (Table 5). Indirect effects through them were also positive for other floral parts. The indirect effects of different floral parts were negative through the rates of grain development G1 and G2, but of lower magnitude and positive through G3. Direct effects of G1 and G2 on adult emergence were positive, and that of G3 negative. Tannin content of mature grain showed negative correlations and direct effects.

Grain damage. Glume g2, lemma l2 and lodicule length showed positive direct effects, as also the indirect contribution for other floral parts for susceptibility to sorghum midge (Table 6). Growth rate G3 and tannin content of grain showed negative direct effects as well as correlations with midge damage.

D^2 and canonical cluster analysis. AF 28 was separated from DJ 6514, TAM 2566 and IS 15107 for the parameters measuring resistance to sorghum midge (Table 7). Midge susceptible variety, Swarna was also found to be distinct from midge resistant cultivars and the susceptible hybrid, CSH 1. DJ 6514 was placed separately in groups based on larvae/100 florets. Based on oviposition, the midge resistant and susceptible cultivars were placed in separate groups. The success of oviposition serves as a good criterion to identify diverse genotypes. Adult emergence also placed the genotypes in three groups: DJ 6514, TAM 2566 and CSH 1; AF 28 and IS 15107 and Swarna. Thus, the sources of resistance to sorghum midge have diverse effects on oviposition, infestation, and adult emergence. Canonical clusters based on different parameters are shown in Fig. 2. DJ 6514 and TAM 2566 were generally grouped together (except the groups based on number of larvae/100 florets). AF 28 and Swarna were generally placed distantly from other genotypes.

Table 6. Direct and indirect (path coefficients) effects of 12 traits on midge damage (% chaffy florets) in six sorghum cultivars

Trait	Glume g1 L	Glume g2 L	Lemma l1 L	Lemma l2 L	Lodicule L	Anther L	Palea L	Grain development G1	Grain development G2	Grain development G3	Tannins (%) (10-day old grain)	Tannins (%) (matured grain)	r
Glume g1 L	-1.51	2.22	-1.32	0.12	0.98	-0.24	-0.14	0.78	-1.49	0.16	-0.07	0.20	0.79
Glume g2 L	-1.51	2.23	-1.33	0.11	0.95	0.23	-0.14	0.88	1.60	0.17	-0.07	0.22	0.80
Lemma l1 L	-1.48	2.20	-1.35	0.12	0.70	-0.22	-0.14	0.76	1.30	0.14	-0.06	0.16	0.74
Lemma l2 L	-1.14	1.68	-1.04	0.16	0.68	-0.20	-0.10	0.76	1.27	0.02	0.02	-0.02	0.79
Lodicule L	-0.85	1.22	-0.54	0.06	1.74	-0.19	-0.05	0.95	2.11	0.20	-0.09	0.33	0.59
Anther L	-1.40	1.99	-1.14	0.12	1.26	-0.26	-0.12	0.72	-1.42	0.15	-0.05	0.15	0.82
Palea L	-1.24	1.87	-1.15	0.09	0.52	-0.18	-0.16	0.86	-0.52	0.15	-0.06	0.03	0.49
G1	0.82	-1.36	0.71	-0.08	-1.14	0.13	0.10	1.45	1.99	-0.19	0.07	-0.24	-0.36
G2	0.82	-1.30	0.64	-0.07	-1.34	0.13	0.03	-1.05	2.74	-0.17	0.06	-0.43	-0.49
G3	0.88	-1.35	0.66	-0.01	-1.29	0.13	0.10	-0.98	1.70	-0.27	0.14	-0.41	-0.24
Tannins 10-day-old grain	0.70	-1.04	0.50	0.03	-1.07	0.10	0.07	-0.62	1.26	-0.26	0.15	-0.41	-0.32
Tannins matured grain	0.59	-0.94	0.42	0.004	-1.12	0.07	0.01	-0.68	2.25	-0.22	0.12	-0.52	-0.32

L = Length.
r = Correlation.

Table 7. D^2 cluster analysis of six cultivars based upon four dependent and 14 independent variables

Dependent variable		Clusters	D-Distances A	D-Distances B	D-Distances C
Chaffy florets (%)	A	DJ 6514, TAM 2566 IS 15107, CSH 1 Swarna	58.7	1.7	–
	B	AF 28	–	0.0	–
No. of eggs/100 florets	A	DJ 6514, TAM 2566 IS 15107	38.7	94.5	104.4
	B	CSH 1, Swarna	–	38.9	108.1
	C	AF 28			0.0
No. of larvae/ 100 florets	A	DJ 6514, TAM 2566 IS 15107, CSH 1 Swarna	76.1	187.6	–
	B	AF 28	–		
No. of adults emerged/ panicle	A	DJ 6514, TAM 2566 CSH 1	57.(	211.9	122.8
	B	AF 28, IS 15107	-	109.4	321.4
	C	Swarna	–		0.0

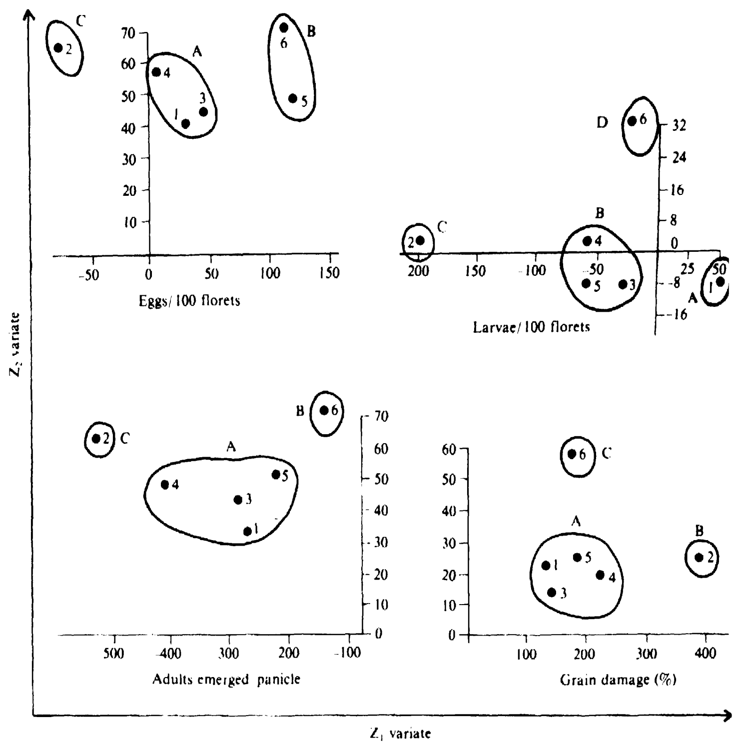

Fig. 2. Canonical clusters of six sorghum cultivars based on chaffy florets, number of eggs/100 florets, number of larvae/100 florets, and adult emergence/panicle. 1 = DJ 6514, 2 = AF28, 3 = TAM 2566, 4 = IS 15107, 5 = CSH 1, and 6 = Swarna.

DISCUSSION

Resistance to sorghum midge mainly consists of cultivar nonpreference to adults, reduced oviposition, and/or antibiosis (Sharma, 1985b). Cultivar nonpreference is an important component of resistance to sorghum midge (Wiseman and McMillian, 1968; Sharma et al., 1988). Nonpreference to adults breaks down in the absence of a favourable host (Harris, 1961; Passlow, 1965; Sharma et al., 1990a). Floral morphology (size and coupling; Ball and Hastings, 1912; Geering, 1953; Bergquist et al., 1974; Rossetto et al., 1975) and tannin content of grain (Santos and Carmo, 1974; Sharma et al., 1990a) play an important role in genotypic resistance to sorghum midge. Success in oviposition to a large extent determines the differences in genotypic resistance to sorghum midge (Sharma et al., 1990b). This seems to be by far the most important component of resistance. Apparently, reduced oviposition is associated with short floral parts, high rates of grain development and higher tannin content of grain (except in DJ 6514). Larval mortality during development in some genotypes suggests antibiosis to be a mechanism of resistance. Smaller size of glumes in relation to that of grain and the faster rate of grain development, may result in lesser space between the glumes and the grain and make it a limiting factor for survival and development of the larvae. The tannin content of grain may act as an antifeedant or antibiotic to the developing larvae (Rossetto, 1985). Johnson (1977) reported that sorghum lines with highest level of midge resistance have a testa, and such lines have a high tannin content (Kofoid et al., 1982).

The genotypic and phenotypic correlation coefficients between the factors associated with resistance to sorghum midge were in the same direction as their association with resistance to sorghum midge. Floral parts were significantly and positively associated with each other, but negatively with the rate of grain development and tannin content of grain. Rate of grain development and the tannin content of grain were positively associated. Thus, midge-resistant genotypes tend to have short florets, a relatively faster rate of grain development, and higher tannin content.

Correlation coefficients and path analysis presented different pictures regarding the major causal factors determining the expression of resistance to sorghum midge. Efficient selection for midge resistance can be based on glume g2, lemma l2, lodicule length, anther length, rate of grain development based on dry weight, and tannin content of mature grain. These factors showed correlation coefficients and direct effects (path coefficients) in the same direction, and thus, contributed directly towards resistance to sorghum midge. The correlation coefficients and direct effects of glume G1, lemma l1, and palea length, and rate of grain development (G1 and G2) were in opposite direction for most of the parameters measuring resistance to sorghum midge. Their positive or negative association with susceptibility to sorghum midge was through other traits. Similar differences in correlations and direct effects have been reported for factors associated with resistance to sorghum shoot fly (Omori et al., 1983).

AF 28 is distinct from other midge resistant sources. DJ 6514 is different from TAM 2566 and IS 15107 in groups based on larval numbers. The two susceptible checks were placed in separate groups (except for eggs/100 florets). These differences may partly be due to hybrid vigour in CSH 1, in addition to other genetic differences between these cultivars. Thus, multivariate analysis was useful not only for identifying diverse sources, but also for differentiating between them for resistance to egg laying, larval numbers and adults emerged. Multivariate analysis has been found to be useful for identifying diverse sources of resistance to shoot fly (Omori et al., 1988), and for classification of sorghum germplasm (Chandrasekharaiah et al., 1969). D^2 and canonical variate analyses indicated that the sources of resistance to sorghum midge are diverse. Different sources of resistance have different combinations of factors associated with resistance, and there is a distinct possibility of increasing the levels and diversity of resistance to this insect.

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