Mechanisms and Diversity of Resistance to Shoot Fly, *Atherigona soccata* in *Sorghum bicolor*

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Abstract

The reaction of a diverse array of sorghum genotypes to sorghum shoot fly, Atherigona soccata *in terms of antixenosis for oviposition, antibiosis, and recovery resistance under greenhouse and field conditions to identify genotypes with stable resistance to the insect was studied. Antixenosis for oviposition was observed under multi- and dual-choice conditions in case of IS 1054, IS 1057, IS 2146, IS 4664, IS 2312, IS 2205, SFCR 125, SFCR 151, ICSV 700, and IS 18551. However, antixenosis for oviposition was not apparent under no-choice conditions. Antibiosis (expressed in terms of prolonged larval and pupal development, and/or larval and pupal mortality,) was observed in case of IS 2146, IS 4664, IS 2312, SFRC 125, ICSV 700, and IS 18551. The genotypes IS 1054, IS 1057, IS 2146, IS 2205, and IS 4664 showed lower percentage of tiller deadhearts than the susceptible check, Swarna. IS 2312, SFCR 125, SFCR 151, ICSV 700, and IS 18551, which exhibited antixenosis, antibiosis, and tolerance components of resistance, may be used in sorghum improvement to develop sorghum cultivars with resistance to this pest. Genotypes with diverse combination of characteristics associated with resistance to sorghum shoot fly can be used in breeding programmes to broaden the genetic base and increase the levels of resistance to this pest.*

Keywords: *Sorghum bicolor*, sorghum shoot fly, *Atherigona soccata*, Resistance mechanisms, antixenosis, antibiosis, recovery resistance

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench], which originated in tropical Africa, is an important cereal crop in Asia, Africa, Australia, and the Americas. The crop is damaged by over 150 insect species, of which sorghum shoot fly, *Atherigona soccata* (Rondani) (Muscidae: Diptera) is an important pest in Asia and Africa (Sharma, 1993). Timely planting, manipulation of cultural practices, resistant varieties, and need based application of insecticides can be used for minimizing the losses due to shoot fly. However, planting times in the semi arid tropics (SAT) are dictated by the onset of rains, while chemical insecticides are beyond the reach of resource poor farmers. Therefore, it is important to identify and develop sorghum cultivars with stable resistance to this pest for sustainable crop production. A number of genotypes with resistance to shoot fly have been identified, but the levels of resistance are low to moderate (Jotwani, 1978; Taneja and Leuschner, 1985; Sharma *et al.*, 2003). Resistance to shoot fly, *A. soccata* in sorghum is expressed in terms of antixenosis for oviposition, antibiosis, and tolerance (Sharma and Nwanze, 1997; Dhillon *et al.*, 2005a,b, 2006). The present studies were carried out on a diverse array of sorghum genotypes to identify genotypes with different components of resistance to shoot fly, *A. soccata*.

Materials and methods

The experimental material consisted of 15 diverse sorghum genotypes comprising of seven germplasm accessions (IS 1054, IS 1057, IS 2146, IS 18551, IS 4664, IS 2312, and IS 2205), three improved lines (SFCR 125, SFCR 151, and ICSV 700) identified earlier to be resistant to shoot fly and five commercial cultivars (Swarna, CK 60B, ICSV 745, 296B, and ICSV 112) susceptible to shoot fly (Sharma *et al.*, 1992, 2005). Of these IS 18551 and Swarna served as resistant and susceptible checks, respectively, based on their reaction to shoot fly damage under field conditions (Dhillon *et al.*, 2005a; Sharma *et al.*, 2005). The experiments were conducted under field and greenhouse conditions at the International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India, during the 2004 and 2005 rainy and post-rainy seasons.

Assessment of different components of resistance to shoot fly under multi-choice conditions in the field

The test material was sown in the field during the 2004 and 2005 rainy and post-rainy seasons in a randomized complete block design (RCBD) with three replications. Each genotype was sown in two row plots with 2 m row length. The rows were spaced 75 cm apart. The field was irrigated immediately after sowing during the post-rainy season, while the soil moisture was optimum for crop sowing during the rainy season. One week after seedling emergence, thinning was carried out to maintain a spacing of 10 cm between the plants. Shoot fly infestation was optimized through the use of interlard fish-meal technique (Soto, 1974; Sharma *et al.,* 1992). The infester rows were sown 20 days earlier than the test material. Data on number of eggs seedling^{-1} and numbers of seedlings with eggs were recorded at 14 and 21 days after emergence (DAE). The percentage of plants with deadhearts was recorded at 14, 21, and 28 DAE. Recovery resistance was assessed in terms of percentage tillers with deadhearts at 28 DAE.

Insect culture for studies on antixenosis and antibiosis

To assess antixenosis and antibiosis components of resistance under controlled conditions in the greenhouse, shoot fly females were collected in fishmeal-baited traps from the sorghum crop at the seedling stage in the field (Taneja and Leuschner, 1985; Sharma *et al.*, 1992). The shoot flies were collected in the morning between 0730 to 0900 h in 200 ml plastic bottles through an aspirator, and released inside the wire-mesh screened cages (30 × 30 cm × 30 cm) in the greenhouse (28 ± 2^{0}C and 75 ± 5% RH). The *A. soccata* females were separated from other flies and released in a separate cage. The shoot fly females were provided with 20% sucrose solution in a cotton swab, and a mixture of brewer's yeast and glucose (1: 1) in a petri dish. The sucrose solution was changed daily, while the yeast powder-glucose mixture was changed once in three days. After three days of conditioning, the shoot flies were used for studies on antixenosis and antibiosis components of resistance to this insect.

Antixenosis for oviposition under dual- and no-choice conditions in the greenhouse

Antixenosis for oviposition was studied under dual-choice and no-choice conditions in a wire-mesh screened cage. The screening system consisted of two plastic trays (40 × 30 × 14 cm) one for planting the test material, while the other, fitted with wire-mesh screen on the sides and at the top (10 ×15 cm), was clamped onto the tray with sorghum seedlings (Sharma *et al.*, 1992; Dhillon *et al.*, 2005a). The wire-mesh screen on the top of the plastic tray had a 5 cm diameter hole, which was blocked with a 20 ml plastic cup. The test genotypes were sown in plastic trays having a potting mixture of black soil and farm-yard manure (3:1). Diammonium phosphate (20 g per tray) was mixed with the soil before sowing. Each genotype had four rows, and there were 40 seedlings in each tray. For no-choice tests, only one genotype was sown in each tray. For dual-choice tests, there were two rows of the test genotype and two rows of susceptible check, Swarna. There were six replications for dual-choice tests and three replications for no-choice tests in a completely randomized design (CRD). The test genotypes were exposed to shoot fly females (16 flies seedlings^{-40}) at 9-days after seedling emergence (fifth leaf stage) for 24 h. After 24 h, the shoot fly females were removed from the trays. Data were recorded on the number of eggs per plant and number of plants with eggs. Five days after infestation, data were recorded on the number of seedlings showing deadhearts symptoms, and was expressed as percentage of plants with deadhearts.

Expression of antibiosis to sorghum shoot fly

The test genotypes exposed to shoot flies under no-choice conditions were further used to study survival and development of shoot fly on different genotypes. The plants were tagged for appearance of deadhearts at 12 h intervals to compute the larval period. Four days after deadheart formation, 25 seedlings with deadhearts were taken from each replication and placed in 20 ml glass vials (containing 10 g moistened sand) individually. There were three replications in CRD. The deadhearts were monitored daily to record time to pupation. The number of days from deadheart appearance to pupation plus 1 day (because it takes nearly one day for deadheart formation after egg hatching) was recorded as the larval period (Dhillon *et al.* 2005a). The larvae pupated at the base of the shoot or in the sand. The pupae were placed in moist sand to avoid water loss and pupal mortality because of desiccation. The pupae were sexed into males and females, and the pupal weights were recorded separately for each sex within 24 h after pupation. Mortality during the pupal stage was also recorded.

For fecundity studies, five pairs of shoot flies from each genotype were released in wire-framed cages (30 cm dia., and 30 cm in length) covered with a nylon bag (60 mesh). Adults were provided with 20 % sucrose solution and brewer's yeast and glucose (1: 1) as food for adults described above. Ten sorghum seedlings (raised in plastic pots of 10 cm dia.) of the same genotype (on which the larvae were reared) were exposed to the shoot flies for oviposition till all the females died. The seedlings provided to the shoot flies for oviposition were changed on alternate days, and

data were recorded on number of eggs laid female^{-1}.

Statistical analysis

Data were subjected to analysis of variance, and the significance of differences between the genotypes was tested by *F*-test, while the treatment means were compared by least significant differences (LSD) at P = 0.05. For the dual-choice tests, pair *t*-test (P = 0.05) was used to test the significance of difference between the test genotype and the checks at P = 0.05. Indices for expression of antibiosis to shoot fly were computed as described by Dhillon *et al.* (2005a). Diversity among the sorghum genotypes was assessed through principle component analysis.

Results and discussion

Antixenosis for oviposition

The genotypes IS 1054, IS 1057, IS 2146, IS 4664, IS 2312, IS 2205, SFCR 125, SFCR 151, ICSV 700, and IS 18551 showed antixenosis for oviposition under multi-choice conditions in the field (Table 1). IS 1054, IS 1057, IS 2146, IS 2205, SFCR 151, ICSV 700, CK 60B, and Swarna had more number of eggs seedlings^{-10} than the resistant check, IS 18551 under no-choice conditions in the greenhouse. There were no significant differences in plants with eggs under no-choice conditions in the greenhouse. In dual-choice tests, the genotypes IS 1054, IS 1057, IS 2146, IS 4664, IS 2312, IS 2205, SFCR 125, SFCR 151, and ICSV 700 had lower percentage of seedlings with eggs as compared to the susceptible check, Swarna (Table 2).

Expression of resistance to sorghum shoot fly under multi, dual, and no-choice conditions

There were significant differences among the sorghum genotypes in deadheart formation under multi-choice conditions in the field. The genotypes IS 1054, IS 1057, IS 2146, IS 2312, IS 2205, SFCR 151, ICSV 700, and IS 18551 had lower shoot fly deadhearts than the other genotypes tested at 14, 21, and 28 DAE (Table 1). The genotypes CK

Table1. Antixenosis for oviposition and deadheart formation by *Atherigona soccata* in sorghum genotypes under multi-choice (field) and no-choice (greenhouse) conditions at ICRISAT, Patancheru, 2004-05

	No of eggs seedlings^{-10}			Seedlings with eggs (%)			Deadhearts (%)			Tiller deadhearts (%)	
	Multi-choice		No-choice	Multi-choice		No-choice	Multi-choice		No-choice	Multi-choice	
Genotype	14 DAE	21 DAE	10 DAE	14 DAE	21 DAE *	10 DAE	14 DAE	21 DAE *	28 DAE	14 DAE	28 DAE
IS 1054	4.5	6.5	88.1	42.5	63.1	99.2	9.5	46.4	48.5	66.3	21.1
IS 1057	5.7	8.7	73.3	47.4	68.3	100.0	12.2	46.8	54.6	69.1	25.1
IS 2146	3.3	5.6	86.0	32.2	55.5	100.0	8.6	38.1	42.2	80.8	20.6
IS 2205	4.1	6.0	86.6	32.1	54.2	100.0	8.4	37.0	45.5	76.7	25.6
IS 2312	3.7	5.7	66.3	34.5	53.9	100.0	8.4	32.3	42.8	67.5	27.5
IS 4664	6.4	9.9	57.6	42.6	77.4	98.3	18.3	63.2	64.4	73.6	26.2
SFCR 125	4.9	9.0	63.6	42.0	67.3	100.0	14.7	54.6	60.6	63.8	30.5
SFCR 151	4.3	8.5	86.8	35.3	66.8	100.0	11.3	48.8	54.1	68.5	27.0
ICSV700	5.8	8.3	77.5	42.2	68.5	100.0	12.9	51.0	57.2	75.8	26.2
CK 60B	13.9	13.9	83.5	80.3	92.8	100.0	35.6	82.6	85.9	86.7	41.5
ICSV745	15.4	13.4	57.8	82.0	94.3	98.3	45.3	85.3	91.7	88.3	45.7
296B	12.6	13.2	67.2	72.2	92.9	99.0	32.6	81.5	83.5	90.4	39.2
ICSV112	16.8	14.0	66.5	87.3	93.8	99.2	44.4	86.2	81.8	85.0	51.7
IS18551(R)	3.2	5.4	65.3	29.1	57.6	100.0	6.8	40.4	43.0	62.2	30.7
Swarna (S)	15.3	15.1	70.5	80.4	96.8	100.0	48.6	87.2	92.6	91.6	37.3
F - prob	< 0.001	< 0.001	0.025	< 0.001	< 0.001	0.479	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
LSD	4.1	2.9	20.4	13.9	17.7	NS	17.0	17.5	16.8	14.2	10.8

DAE = Days after emergence; R = Resistant check; S = Susceptible check; LSD = Least significant difference; Data are means of four seasons; * Data means of three seasons

Table 2. Reaction of sorghum genotypes for resistance to *A. soccata*, in dual-choice tests under greenhouse conditions at ICRISAT, Patancheru 2004-05

	No of eggs seedlings $^{-10}$			Seedlings with eggs (%)			Deadhearts (%)		
Genotype	Test genotype	Swarna	t-value	Test genotype	Swarna	t-value	Test genotype	Swarna	t-value
IS 1054	10	21	-2.78*	67.4	93.6	-5.71**	46.1	84.7	-7.58**
IS 1057	13	25	-4.54**	76.5	94.0	-2.47*	42.5	78.5	-12.51**
IS 2146	17	27	-8.81**	78.9	94.6	-2.69*	55.9	87.7	-7.11**
IS 2205	10	18	-3.56*	69.0	88.7	-4.07*	50.0	80.2	-8.55**
IS 2312	11	24	-3.04*	72.6	91.2	-3.5*	52.9	85.3	-11.59**
IS 4664	7	24	-2.61*	63.1	97.2	-5.7**	42.7	89.7	-7.28**
SFCR 125	11	19	-3.73*	73.1	92.9	-5.07**	46.8	82.1	-5.44**
SFCR 151	15	21	-5.26**	76.9	92.5	-2.21*	49.2	85.5	-3.23*
ICSV 700	16	30	-4.58**	81.7	97.3	-5.83**	67.9	83.0	-2.58*
CK 60 B	19	25	-5.83**	88.1	92.6	-1.00	84.6	83.7	0.11
ICSV 745	18	20	-3.06*	88.9	92.3	-0.88	77.5	85.4	-1.92
296 B	13	18	-2.63*	88.1	92.0	-0.53	73.8	87.4	-3.63*
ICSV 112	24	24	0.02	89.0	93.1	-1.12	81.0	85.2	-0.73
IS 18551 (R)	14	24	-2.89*	76.6	93.9	-1.90	36.5	81.9	-5.65**

R = Resistant check; *, ** t test significant at $P < 0.05$ and 0.01, respectively

60B, ICSV 745, 296B, and ICSV 112 did not differ significantly from the susceptible check, Swarna under dual-choice tests in the greenhouse (Table 2). The genotypes IS 1054, IS 1057, IS 2312, SFCR 125, and SFCR 151 were on par with the resistant check, IS 18551 under no-choice conditions in the greenhouse, while CK 60B, ICSV 745, 296B, ICSV 112, and Swarna had more deadhearts as compared to the resistant check, IS18551 under no-choice conditions (Table 1).

Recovery resistance

The genotypes IS 18551, IS 1054, IS 1057, IS 2146, IS 4664, IS 2312, IS 2205, SFCR 125, SFCR 151, and ICSV 700 had lower percentage of tillers with deadhearts compared to the susceptible check, Swarna at 28 days after seedling emergence (Table 1).

Survival and development of shoot fly on different genotypes

Larval survival (differences in percentage seedlings with eggs compared to seedlings with deadhearts in the same genotype) was significantly lower on IS 1057, IS 2146, IS 4664, IS 2312, SFCR 151, and IS 18551 as compared to that on check, Swarna under multi, dual, and no-choice conditions, suggesting the inability of the larvae to reach the growing point and cause a deadheart (Table 3). The larvae either failed to reach the growing point or died due to physico-chemical characteristics of the leaves. The larval period was prolonged by one day on IS 1054, IS 1057, IS 4664, IS 2312, IS 2205, SFCR 125, SFCR 151, ICSV 700, and IS 18551 (10.0 to 10.7 days) as compared to that on the susceptible check, Swarna (9.1 days) (Table 4), while the pupal period was extended by nearly one day on IS 18551, IS 2146, IS 2312, than that on the susceptible check, Swarna. Percent pupation was significantly lower on IS 2146, IS 4664, IS 2312, SFCR 125, ICSV 700, and IS 18551 (58.2 to 65.2%) as compared to that on the susceptible check, Swarna (77.1%), while adult emergence was lower on IS 2146, IS 4664, IS 2312, IS 2205, SFCR 125, ICSV 700, and IS 18551 (33.2 to 42.3%) as compared to the susceptible check, Swarna (55.3 %). There was little variation in pupal weights, but the female pupae were heavier than the male pupae. More numbers of eggs were laid by insects reared on IS 1054, IS 1057, IS 4664, CK 60B, ICSV 745 and IS 18551(172.0 to 191.6 eggs female^{-1}) than the insects reared on the susceptible check, Swarna (149.6 eggs female^{-1}). Growth index was significantly lower on the resistant genotypes such as IS 4664, IS 2312, IS 2205, SFCR 125, ICSV 700, and IS 18551 (5.3 to 6.7) than on the susceptible check, Swarna (8.5). Differences were also significant in terms of relative growth and developmental indices between resistant and susceptible genotypes. Adult emergence index was better on the

Table 3. Mortality of neonate larvae of *A. soccata* on sorghum genotypes at ICRISAT, Patancheru 2004/05

Genotypes	Larval mortality (%)*		
	Multi-choice	Dual-choice	No-choice
IS 1054	16.7	21.3	32.8
IS 1057	21.5	34.0	30.9
IS 2146	17.5	23.0	19.2
IS 4664	14.1	20.4	24.7
IS 2312	21.6	19.7	32.5
IS 2205	17.2	17.7	23.3
SFCR 125	12.7	26.3	36.2
SFCR 151	18.0	27.8	31.5
ICSV 700	17.5	13.8	24.2
CK 60B	10.2	3.6	13.3
ICSV 745	8.9	11.4	10.0
296B	11.4	14.2	8.6
ICSV 112	7.6	8.0	14.2
IS 18551 (R)	17.2	36.6	37.8
Swarna (S)	9.6	8.9	8.4
F-probability	0.04	< 0.001	< 0.001
LSD (P < 0.05)	8.9	11.5	14.3

* Larvae that failed to reach the growing point and / or died before producing deadheart; R = Resistant; S = Susceptible check

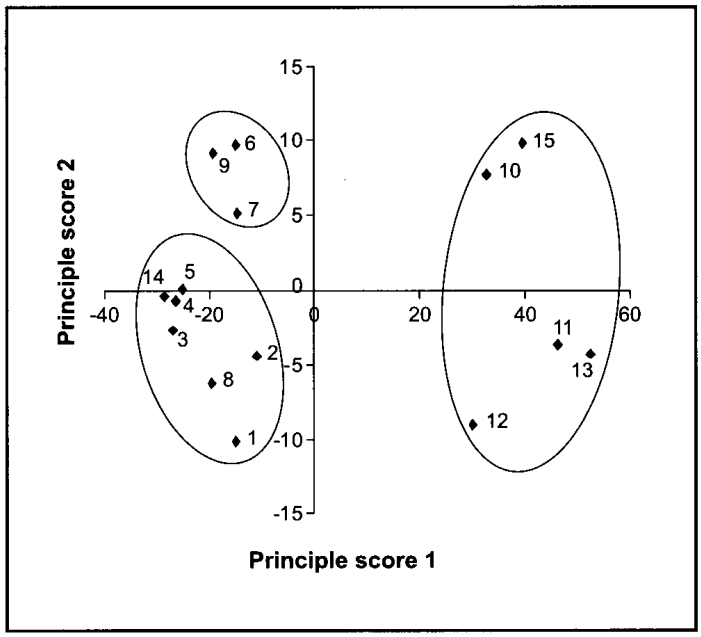

Figure 1. Principle component analysis of 15 genotypes of sorghum based on shoot fly damage parameters per cent deadhearts, percent seedlings with eggs and eggs per 10 seedlings at 14 DAE, tiller deadhearts and larval mortality under field, and development, male and female pupal weights, and adult emergence of shoot fly, *A. soccata* under greenhouse conditions. (1 = IS 1054, 2 = IS 1057, 3 = IS 2146, 4 = IS 2205, 5 = IS 2312, 6 = IS 4664, 7 = SFCR 125, 8 = SFCR 151, 9 = ICSV 700, 10 = CK 60B, 11 = ICSV 745, 12 = 296B, 13 = ICSV 112, 14 = IS 18551, and 15 = Swarna).

susceptible genotypes as compared to that on the other genotypes tested. Fecundity did not differ significantly between resistant and susceptible genotypes (Table 5).

Diversity in resistance/susceptibility to shoot fly among the sorghum genotypes

Based on plants with eggs, eggs per 10 seedlings, deadhearts at 14 DAE, larval mortality at 14 DAE under field conditions; and larval and pupal periods, adult emergence, and fecundity under greenhouse conditions, the principle component analysis revealed considerable diversity among the sorghum genotypes tested. The test genotypes were placed in three groups. Group A comprised of IS 1054, IS 1057, IS 2146, IS 2205, IS 18551, SFCR 151, and IS 2312; group B comprised of, IS 4664, SFCR 125, and ICSV 700; and the group C comprised of CK 60B, ICSV 745, 296B, ICSV 112, and Swarna. All the shoot fly-susceptible genotypes were placed in group C, while the resistant genotypes were placed in groups A and B (Fig. 1), suggesting that shoot fly–resistant genotypes are quite diverse in their interactions with this insect.

Genotypes preferred for oviposition by the females of *A. soccata*, also showed high deadheart formation (Rana *et al.*, 1975; Unnithan and Reddy, 1985). Antixenosis for oviposition is the primary component of resistance to shoot fly, *A. soccata* (Blum, 1967; Singh and Narayana, 1978; Maiti and Bidinger, 1979; Singh and Jotwani, 1980a; Taneja and Leuschner, 1985). However, the differences in oviposition preference between resistant and susceptible genotypes tend to narrow down under no-choice conditions (Soto, 1974; Taneja and Leuschner, 1985; Dhillon *et al.* 2005a,b). The present studies also indicated that though antixenosis for oviposition is the predominant component of resistance to shoot fly under multi-choice conditions in the field, differences in oviposition between the genotypes tested were not significant under no-choice conditions a situation akin to but large-scale planting of a resistant cultivar or very heavy shoot fly pressure under delayed plantings during the rainy season, or early plantings in September during the postrainy season. Antixenosis for oviposition is relative, since there are no known resistant cultivars, which are completely non-preferred for oviposition.

Table 4. Expression of antibiosis components of resistance to *A. soccata* in 15 genotypes of sorghum under greenhouse conditions at ICRISAT, Patancheru

Genotypes	Larval period (days)	Pupal period (days)	Pupation (%)	Adult emergence (%)	Pupal weight (mg)		Fecundity female^{-1}
					Male	Female	
IS 1054	10.7	7.4	78.7	53.0	3.5	5.0	173.1
IS 1057	10.5	7.5	83.7	48.2	3.6	5.2	159.9
IS 2146	9.8	8.1	65.1	42.3	3.8	5.2	148.1
IS 2205	10.0	7.9	70.7	40.3	3.7	5.3	151.0
IS 2312	10.0	8.0	62.2	39.3	3.2	5.5	155.7
IS 4664	10.0	7.6	59.3	35.2	3.5	5.0	172.0
SFCR 125	10.2	7.8	65.2	38.9	3.7	4.9	136.9
SFCR 151	10.1	7.6	74.0	47.9	3.2	5.3	154.7
ICSV 700	10.6	7.8	59.8	33.2	3.5	5.1	155.4
CK 60B	9.9	7.2	76.6	52.8	3.4	4.7	172.6
ICSV 745	9.4	7.3	90.5	69.4	3.7	5.0	191.6
296B	9.5	7.5	87.5	68.0	3.9	4.9	154.5
ICSV 112	9.4	7.8	86.6	71.2	3.7	5.3	146.4
IS 18551 (R)	10.4	8.0	58.2	38.8	3.6	4.9	166.2
Swarna (S)	9.1	7.3	77.1	55.3	4.0	4.6	149.6
F-probability	0.002	0.022	< 0.001	< 0.001	0.474	0.148	0.830
LSD (P < 0.05)	0.7	0.5	12.0	13.4	NS	NS	NS

R = Resistant; S = Susceptible check

Antibiosis component of resistance to shoot fly offers exciting possibilities of exerting pressure against insect feeding and development, resulting in low survival of larvae on the resistant cultivars (Soto, 1974). Retardation of larval growth and development, prolonged larval and pupal development, and reduced larval/pupal survival on the resistant genotypes provides an evidence of antibiosis to shoot fly *A. soccata* in sorghum (Singh and Jotwani, 1980b; Raina *et al.*, 1981; Sharma and Nwanze, 1997; Dhillon *et al.*, 2005a,b). Singh and Jotwani (1980b) observed prolonged larval and pupal periods, smaller larvae, and the mortality of neonates on resistant genotypes, whereas Dhillon *et al.*, (2005b) reported a slight increase in larval and pupal periods. Larval survival, in general decreases with the age of the plants (Ogwaro and Kokwaro, 1981).

Tiller development consequent to deadheart formation in the main shoot and its survival depend on the level of primary resistance as well as shoot fly pressure (Doggett *et al.*, 1970). Tiller survival is related to its faster growth rate with a better chance to escape deadheart formation. Seedling vigor and high rate of recovery are important characteristics of resistant cultivars (Sharma *et al.*, 1977), which may not be related with seedling height (Shivankar *et al.*, 1989; Dhillon *et al.*, 2005b). The shoot fly-resistant genotypes had significantly less tiller deadhearts than the susceptible ones. Varieties with high recovery resistance compensate for yield loss under shoot fly infestation (Rana *et al.*, 1985). The genotypes IS 2312, SFCR 125, SFCR 151, ICSV 700, and IS 18551 showing antixenosis, antibiosis, and/or tolerance components of resistance can be used to develop sorghum cultivars for resistance to this pest. Emphasis should be placed on combining different mechanisms of resistance in the same genetic background to increase the levels and diversifying the number of genes contributing to host resistance to *A. soccata*. Based on principal component analysis, the test genotypes were placed in three groups. While the susceptible genoypes were all placed in one group, the shoot fly-resistant genotypes were placed in two groups, suggesting that there is a considerable potential for increasing the resistance levels and diversifying the genetic bases of resistance to sorghum shoot fly, *A. soccata* in sorghum.

Table 5. Growth indices of *A. soccata* on 15 sorghum genotypes at ICRISAT, Patancheru

Genotypes	Growth index	Relative growth index	Developmental index	Adult emergence index	Fecundity index
IS 1054	7.4	0.9	0.9	1.0	1.2
IS 1057	7.7	0.9	0.9	0.9	1.2
IS 2146	7.0	0.8	0.9	0.7	1.1
IS 2205	6.7	0.8	0.9	0.8	1.1
IS 2312	6.1	0.7	0.9	0.7	1.1
IS 4664	5.3	0.6	0.9	0.6	1.2
SFCR 125	6.6	0.8	0.9	0.7	1.0
SFCR 151	7.7	0.9	0.9	0.9	1.1
ICSV 700	5.8	0.7	0.9	0.6	1.1
CK 60 B	8.2	1.0	1.0	1.0	1.2
ICSV 745	9.7	1.1	1.0	1.2	1.3
296 B	9.2	1.1	1.0	1.2	1.1
ICSV 112	9.4	1.1	1.0	1.3	1.1
IS 18551 (R)	5.8	0.7	0.9	0.7	1.2
Swarna (S)	8.5	1.0	1.0	1.0	1.0
F-probability	< 0.001	< 0.001	< 0.001	< 0.001	0.840
LSD (P < 0.05)	1.6	0.2	0.04	0.3	NS

R = Resistant; S = Susceptible check

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