

# Identification of Diverse Sources of Resistance to Shoot Fly (*Atherigona soccata*) in sorghum, *Sorghum bicolor*

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**Abstract** – Sorghum shoot fly, *Atherigona soccata* is a major constraint in sorghum production, and host plant resistance is one of the components of managing shoot fly damage in sorghum. Therefore, we evaluated 102 sorghum lines for shoot fly resistance, and to understand the underlying mechanisms of resistance. Data were recorded on shoot fly damage and morphological traits across three seasons. Thirty-one sorghum genotypes exhibited resistance to shoot fly (<37.0% plants with deadhearts as compared to 92.7% in the susceptible check, Swarna), of which 25 genotypes showed non-preference for oviposition and antibiosis against *A. soccata*. Genotypes x environment interactions were significant, which had a considerable bearing on expression of resistance to *A. soccata*. Similarity matrix analyses placed the shoot fly-resistant genotypes into different groups, which can be utilized to enhance the levels and broaden the basis of resistance to *A. soccata*. Leaf glossiness, seedling vigor, leaf sheath pigmentation and trichome density were associated with expression of resistance/ susceptibility to *A. soccata*, and these traits can be used to select shoot fly resistant sorghums.

**Keywords** – Sorghum, Shoot Fly, Resistance Mechanisms, Antixenosis, Antibiosis.

## I. INTRODUCTION

Sorghum, *Sorghum bicolor* is one of the most important food grain crops in the semi-arid tropics (SAT) of Asia, Mediterranean Europe, Americas, Australia and Africa. It is the fifth most important cereal crop after wheat, maize, rice and barley. Sorghum is a staple food for the people living in semi-arid regions of Asia and Africa. Several biotic and abiotic constraints limit sorghum productivity in the SAT. Around 150 insect pests attack sorghum [1], of which sorghum shoot fly, *Atherigona soccata* (Rondani) is an important pest that destabilizes the sorghum yields in the semi-arid tropics [2].

Sorghum shoot fly, *A. soccata* infests the sorghum plants during the seedling stage at 7-30 days after seedling

emergence (DAE) [(3), (4)]. The female shoot fly lays white, prolonged, spindle-formed eggs individually on the lower surface of the leaves, parallel to the leaf midrib. Maggot emerges from the egg in 2-3 days, crawls along the leafsheath and reaches the growing point, cuts it, which then begins to decay and the larva starts feeding on the decaying leaf tissue, resulting in drying up of the central leaf, which is referred to as a deadheart [5], resulting in reduced plant stand. The plant produces axillary tillers if there is enough moisture and nutrients in the soil. Shoot fly incidence is high in late-sown crop during the rainy season and in the early sown crop during the post-rainy season [6]. Continuous rainfall or very dry weather conditions, and the temperatures below 18° C and above 35° C reduce shoot fly survival [7].

Almost 32% of sorghum harvest is lost to insect pests during the rainy season [8], and 26% in the post-rainy season in India [9]. Shoot fly causes about 86% and 45% losses in food grains and fodder, respectively [10]. These losses can be reduced by cultivating shoot fly-resistant varieties, well timed planting, and proper application of insecticides [11]. Host plant resistance (HPR) is one of the important strategies to control shoot fly in sorghum. HPR is compatible with other methods of pest control and there is no cost involvement for farmers. It is important to grow sorghum varieties with stable resistance to shoot fly for sustainable crop yield [1].

In sorghum, shoot fly resistance can be due to antixenosis, antibiosis and/or tolerance [(12), (13)]. Considerable progress has been made in identifying sorghums with shoot fly resistance [14]. Further, the levels of resistance to shoot fly change with the insect density and environmental conditions [(12), (2), (15)]. The current studies attempted to identify a diverse array of sorghum germplasm accessions, and improved sorghum genotypes for stability of resistance to sorghum shoot fly, and identify the morphological markers responsible for resistance to this pest, which can be utilized in breeding programs to develop shoot fly-resistant genotypes.

Table 1. Mean sum of squares (analysis of variance) of sorghum genotypes evaluated for resistance to shoot fly, *A. soccata* (ICRISAT, Patancheru, 2013-15).

Sources of variation	Df	Leaf glossy score	Seedling vigor	Leafsheath pigmentation	Plants with shoot fly eggs (%)	Shoot fly deadhearts (%)
Replication	2.00	0.57	0.43	0.65	668.64	7.26
Genotype	101.00	13.25**	2.23**	3.45**	629.36**	1201.38**
Season	2.00	21.38**	1.37**	58.62**	53055.10**	12259.33**

Sources of variation	Df	Leaf glossy score	Seedling vigor	Leafsheath pigmentation	Plants with shoot fly eggs (%)	Shoot fly deadhearts (%)
Genotype*Season	202.00	1.60**	0.94**	0.59**	183.36**	124.72**
Error	303.00	0.18	0.14	0.08	70.12	59.86
Total	610.00					

\*\* Mean sum of squares significant at  $P \leq 0.01$ .

## II. MATERIALS AND METHODS

Experiments were conducted during the 2013 to 2015 rainy seasons at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Hyderabad, Telengana, India. The test material consisted of a diverse array of 102 sorghum genotypes including the resistant (IS 18551) and susceptible checks (Swarna). The test material was planted in two replications in the field during the rainy seasons using a randomized complete block design (RCBD). The experimental plots were given a basal dose of di-ammonium phosphate (@100 kg ha<sup>-1</sup>). Each entry was sown in 2 rows, 2 m long, with a row to row distance of 75 cm. Thinning was carried out one week after seedling emergence, and a plant population of 40 plants/ plot was maintained. No insecticide was applied in the experimental plots. Interculture was carried out at 15 and 30 days after seedling emergence (DAE). Hand weeding was carried out as and when required.

Interlard fish-meal technique was used to increase the shoot fly population in the test material [16]. Data were recorded on the numbers of shoot fly eggs per plant, and plants with shoot fly eggs at 21 DAE, and shoot fly deadhearts at 28 DAE. Plants with shoot fly eggs and deadhearts were expressed as a percentage of the total number of plants per plot. Data on leaf glossiness, seedling vigor and leafsheath pigmentation were recorded at 7-10 DAE, and trichome density on adaxial and abaxial leaf surfaces at 12 DAE. Seedling vigor was recorded at 10 DAE on a 1-3 scale (1 = highly vigorous, and 3 = poor plant vigor) [12]. Leaf glossiness was scored visually on a 1-5 scale at the fifth leaf stage, when the expression of this trait is most apparent, in the early morning hours, when there was maximum reflection of light from the leaf surface (1 = highly glossy and 5 = non-glossy) [(12), (13)]. Leafsheath pigmentation was visually scored on a 1-3 rating scale at 7 DAE (1 = leafsheath and plumule with deep pink pigmentation, and 3 = leafsheath and plumule green in color).

The density of trichomes on abaxial and adaxial surfaces of leaf was recorded at 12 DAE by taking a 2.5 cm<sup>2</sup> portion from the center of the fifth leaf [17]. The leaf samples were taken from three plants at random and placed in alcohol and acetic acid (1:2) in stoppered glass vials (10 ml capacity) for 24 h to clear the chlorophyll and subsequently transferred into lactic acid (90%) as a preservative. To record the trichome density, the leaf sections were mounted on a glass slide in a drop of lactic acid and observed at 10x magnification under a stereomicroscope. The numbers of trichomes on the adaxial (upper) and abaxial (lower) leaf surfaces were counted and showed as number of trichomes in a 10x microscopic field.

Data were subjected to ANOVA (Analysis of variance) using Genstat software version 14.0 [18]. The significance of differences between the genotypes was judged by F-test, while the genotypic means were compared by least significant (LSD) at  $P \leq 0.05$ . The data were also subjected to simple correlation analysis to identify the association of morphological traits with shoot fly resistance. Similarity matrix analysis was carried out using Genstat to assess the diversity among the genotypes tested.

## III. RESULTS AND DISCUSSION

### *Expression of Resistance of Sorghum against shoot fly, Atherigona soccata.*

The genotypic and environmental interactions were highly significant ( $P \leq 0.01$ ) for percentage of plants with shoot fly eggs, plant with shoot fly deadhearts, and the morphological traits (leaf glossy score, seedling vigor and leafsheath pigmentation) (Table 1). The mean sums of squares for environmental effects were greater than the mean sum of squares of genotypic effects, suggesting that environmental factors influenced the expression of resistance to shoot fly.

There were significant differences between the genotypes for percentage of plants with shoot fly eggs, plants with shoot fly deadhearts, and the morphological traits (leaf glossy score, seedling vigor and leafsheath pigmentation) ( $P \leq 0.01$ ) (Table 2). During the 2013 rainy season, the percentage of plants with shoot fly eggs varied from 28.7% in IS 18551 to 87.7% in the susceptible check, Swarna. The genotypes ICSV 25019, ICSV 25026, ICSV 25027, ICSV 25092, ICSV 25112, ICSV 708, IS 17726, IS 18368, IS 2312, PS 35805 and IS 18551 exhibited nonpreference for oviposition (39.6 to 47.8% plants with eggs) as compared to the susceptible check, Swarna (87.7%, plants with shoot fly eggs). Whereas during the 2014 rainy season, the genotypes ICSV 25092, ICSV 702, ICSV 705, IS 2146, IS 2205, IS 2312, and IS 18551 exhibited nonpreference for oviposition (33.5 to 47.0% plants with eggs as compared to 89.2% plants with eggs in Swarna). The genotypes ICSV 25039, ICSV 93089, IS 1104, IS 2122, IS 2123, IS 5470, IS 5490, IS 5566, IS 5522 and IS 6566 exhibited resistance to shoot fly.

Percentage of plants with shoot fly deadhearts ranged from 25.2% in the resistance check, IS 18551 to 94.1% in the susceptible check, Swarna during the 2013 rainy season, 20.7% in IS 18551 to 93.3% in Swarna during the 2014 rainy season, and 30.3% in IS 18551 to 83.5% in IS 21871 during the 2015 rainy season. Twenty-nine genotypes (ICSV 25010, ICSV 25019, ICSV 25026, ICSV 25027, ICSV 25039, ICSV

25092, ICSV 25112, ICSV 25135, ICSV 702, ICSV 705, ICSV 708, ICSV 713, ICSV 93089, ICSV 25006, IS 2122, IS 2123, IS 2146, IS 2205, IS 2312, IS 5470, IS 5490, IS 5566, IS 5604, IS 1054, IS 18662, IS 4646, IS 5480, IS 18551 and PS 35805 showed resistance to shoot fly damage during the rainy seasons. Twenty-six genotypes (ICSV 25010, ICSV 25019, ICSV 25039, ICSV 25107, ICSV 386, ICSV 702, ICSV 705, ICSV 707, ICSV 708, ICSV 711, ICSV 713, ICSV 717, ICSV 93018, ICSV 93046, ICSV 95077, IS 1051, IS 1104, IS 18563, IS 18662, IS 20643, IS 2122, IS 2123, IS 2205, IS 5480, IS 8671 and PS 35805) had lower numbers of plants with deadhearts (25% less) than the percentage of

plants with shoot fly eggs during the 2015 rainy season, suggesting that these genotypes exhibited antibiosis mechanism (genotypes with significantly lower number of plants with deadhearts than the plants with eggs) of resistance against *A. soccata*. However, such difference were not observed during the 2013 and 2014 rainy seasons, because the percentage of plants with shoot fly deadhearts were recorded on one week later than the egg counts, and continuous oviposition by the shoot fly females due to favourable weather conditions might have influenced the number of plants with deadhearts.

Table 2. Expression of sorghum genotypes against shoot fly, *A. soccata* across rainy seasons (ICRISAT, Patancheru, 2013-15).

Genotype	Leaf glossy score <sup>a</sup>			Seedling vigor <sup>b</sup>			Mean	Leafsheath pigmentation <sup>c</sup>			Mean	Number of plants with shoot fly eggs (%)			Mean	Shoot fly deadhearts (%)			Mean
	2013R	2014R	2015R	2013R	2014R	2015R		2013R	2014R	2015R		2013R	2014R	2015R		2013R	2014R	2015R	
DJ 6514	5.00	4.00	5.00	3.00	3.00	1.50	2.50	2.00	3.00	3.00	2.67	56.00	66.27	82.47	68.25	85.07	90.00	71.66	82.24
ICSV 1	4.33	2.00	3.50	1.67	1.00	1.00	1.22	1.33	2.33	2.00	1.89	62.18	65.57	82.47	70.07	80.52	67.62	69.53	72.56
ICSV 197	4.67	4.33	5.00	2.67	3.00	1.50	2.39	3.00	3.00	3.00	3.00	59.47	66.25	82.47	69.40	86.85	90.00	70.50	82.45
ICSV 25006	1.67	3.00	2.50	2.00	2.00	1.50	1.83	1.00	3.00	2.00	2.00	52.81	52.81	72.10	59.24	68.33	57.04	57.49	60.95
ICSV 25010	4.49	2.00	4.00	2.67	2.67	2.00	2.44	1.00	3.00	2.00	2.00	45.67	52.41	77.08	58.39	62.70	63.68	50.80	59.06
ICSV 25019	1.67	1.00	2.00	2.33	1.67	1.00	1.67	1.00	2.00	1.50	1.50	39.79	49.02	79.27	56.03	50.06	53.19	35.68	46.31
ICSV 25022	3.33	2.00	2.50	2.67	1.00	1.00	1.56	1.67	2.33	1.50	1.83	55.67	55.51	69.67	60.28	58.96	61.46	50.02	56.81
ICSV 25026	2.67	1.00	2.00	2.67	2.00	1.00	1.89	1.33	2.33	1.00	1.56	39.68	53.64	73.10	55.47	58.90	58.54	50.77	56.07
ICSV 25027	2.67	1.00	2.50	2.67	1.00	1.00	1.56	1.00	2.33	1.50	1.61	42.78	56.57	79.27	59.54	66.68	62.41	70.32	66.47
ICSV 25039	1.33	1.00	2.00	2.33	2.00	1.50	1.94	1.33	3.00	2.00	2.11	60.62	33.53	71.63	55.26	51.41	40.16	41.06	44.21
ICSV 25066	3.33	3.00	3.00	2.00	1.00	2.00	1.67	3.00	3.00	3.00	3.00	47.80	57.86	83.01	62.89	78.34	61.56	69.30	69.73
ICSV 25092	4.00	2.00	3.50	2.67	2.00	2.50	2.39	1.33	2.00	2.50	1.94	39.18	41.86	76.29	52.44	70.88	60.13	59.25	63.42
ICSV 25107	1.00	1.00	3.00	1.00	1.00	2.00	1.33	1.00	2.00	1.00	1.33	51.85	67.19	90.00	69.68	69.93	70.92	63.51	68.12
ICSV 25110	1.67	1.00	2.00	2.33	1.67	1.00	1.67	3.00	3.00	3.00	3.00	48.96	66.45	76.76	64.06	72.47	67.55	65.42	68.48
ICSV 25112	1.00	1.00	1.00	1.67	1.67	1.00	1.44	1.00	2.00	1.00	1.33	41.16	64.42	58.49	54.69	65.45	65.96	45.76	59.06
ICSV 25117	4.33	1.00	3.50	1.67	1.00	2.00	1.56	1.33	3.00	2.00	2.11	56.61	49.63	82.66	62.97	81.97	62.59	65.32	69.96
ICSV 25135	4.33	3.00	3.50	2.67	2.00	2.00	2.22	2.33	3.00	2.00	2.44	56.54	59.42	72.50	62.82	66.13	68.31	51.11	61.85
ICSV 25227	4.33	3.00	5.00	2.67	2.00	2.00	2.22	3.00	3.00	3.00	3.00	59.90	86.76	90.00	78.89	83.41	85.39	74.32	81.04
ICSV 386	5.00	3.00	3.50	2.67	1.00	1.00	1.56	3.00	3.00	3.00	3.00	55.43	72.94	90.00	72.79	74.62	85.64	64.95	75.07
ICSV 391	4.33	4.00	4.50	2.33	1.67	2.50	2.17	1.33	2.00	2.00	1.78	51.22	62.92	82.26	65.47	76.46	78.53	74.10	76.36
ICSV 700	1.67	1.00	3.00	1.33	1.00	2.00	1.44	1.33	3.00	1.50	1.94	62.58	57.77	82.26	67.54	76.37	68.51	61.35	68.74
ICSV 702	3.00	2.00	3.00	2.00	2.00	1.50	1.83	1.33	3.00	2.00	2.11	45.22	47.01	77.11	56.45	66.47	49.35	44.25	53.36
ICSV 705	2.00	1.00	2.00	1.67	1.00	1.00	1.22	1.67	3.00	2.00	2.22	45.75	36.64	77.08	53.16	58.12	46.74	37.75	47.54
ICSV 707	1.67	2.00	1.50	1.67	1.00	1.00	1.22	1.67	2.00	1.50	1.72	53.78	47.29	82.66	61.24	76.91	59.43	52.50	62.95
ICSV 708	2.67	1.00	2.00	2.67	2.00	1.50	2.06	1.00	2.00	1.50	1.50	40.18	48.06	74.25	54.16	56.60	57.32	46.48	53.47
ICSV 711	3.33	2.00	3.00	2.67	2.00	1.50	2.06	2.00	3.00	3.00	2.67	53.76	68.24	82.47	68.16	63.65	72.87	54.71	63.74
ICSV 713	4.01	2.00	3.00	2.00	2.00	2.50	2.17	1.67	3.00	2.00	2.22	48.50	60.08	90.00	66.19	60.44	60.95	45.16	55.52
ICSV 714	4.00	1.00	2.50	1.67	1.00	2.00	1.56	3.02	2.00	3.00	2.67	57.38	50.09	68.10	58.52	78.45	59.62	47.93	62.00
ICSV 717	0.99	2.00	2.50	1.33	1.33	1.50	1.39	1.00	2.00	1.00	1.33	47.78	62.56	82.66	64.33	72.45	62.17	46.14	60.25
ICSV 730	4.00	1.00	2.50	2.33	1.67	1.50	1.83	1.33	3.00	3.00	2.44	59.73	71.91	82.66	71.43	79.07	75.77	58.58	71.14
ICSV 745	5.00	2.67	4.50	2.67	2.00	1.05	1.90	3.00	3.00	3.00	3.00	63.12	74.70	70.06	69.29	86.80	86.80	54.84	76.15
ICSV 88032	4.00	3.33	4.00	2.55	2.00	1.05	1.87	1.67	3.00	2.00	2.22	59.18	65.92	82.66	69.25	81.80	75.60	61.72	73.04
ICSV 89036	4.67	4.00	4.50	2.33	2.67	3.00	2.67	3.00	3.00	3.00	3.00	62.67	85.75	79.27	75.90	90.00	79.47	69.77	79.75
ICSV 89057	4.00	4.00	4.00	2.55	3.00	2.50	2.68	1.02	3.00	3.00	2.34	61.99	76.05	82.66	73.57	72.97	82.10	83.54	79.54



ICSV 93009	5.00	4.00	4.50	2.67	2.00	2.50	2.39	2.67	3.00	3.00	2.89	50.60	73.52	75.00	66.37	84.08	90.00	71.98	82.02
ICSV 93012	5.00	5.00	4.50	3.00	2.67	1.50	2.39	3.00	3.00	3.00	3.00	51.38	58.22	82.66	64.09	76.57	86.89	62.47	75.31
ICSV 93018	4.67	4.00	4.50	2.33	2.33	2.00	2.22	3.00	3.00	3.00	3.00	54.61	86.76	90.00	77.12	78.10	80.06	53.62	70.59
ICSV 93020	5.00	5.00	4.50	3.00	2.00	2.00	2.33	3.00	3.00	3.00	3.00	49.07	76.80	90.00	71.96	79.55	83.78	83.18	82.17
ICSV 93046	4.00	3.00	2.50	2.67	2.00	1.50	2.06	1.33	3.00	2.00	2.11	49.30	58.11	90.00	65.80	66.93	73.99	51.09	64.00
ICSV 93089	1.00	1.00	2.00	2.00	1.00	1.00	1.33	1.00	2.00	1.00	1.33	46.09	43.39	67.40	52.29	59.52	55.43	58.28	57.74
ICSV 95071	4.00	4.00	3.50	3.00	1.00	2.00	2.00	3.00	3.00	3.00	3.00	59.80	72.28	79.27	70.45	86.97	80.35	60.55	75.96
ICSV 95077	4.67	4.00	5.00	2.33	3.00	2.50	2.61	2.00	2.00	2.00	2.00	57.11	81.45	90.00	76.19	81.41	86.97	62.58	76.99
ICSV 95082	5.00	3.00	5.00	2.67	2.00	3.00	2.56	2.97	3.00	3.00	2.99	62.49	70.35	78.97	70.60	84.06	75.59	70.23	76.63
ICSV 96011	4.67	3.00	4.50	3.00	1.00	2.00	2.00	1.00	2.00	1.00	1.33	54.08	65.43	82.47	67.33	82.59	83.73	67.13	77.82
ICSV 96031	4.67	4.00	4.00	2.67	2.00	1.50	2.06	1.33	2.00	1.50	1.61	54.45	66.84	75.00	65.43	82.41	71.22	57.45	70.36
IS 1044	4.67	5.00	4.00	1.67	2.00	2.50	2.06	1.33	3.00	2.00	2.11	66.17	53.74	74.49	64.80	83.36	65.94	59.09	69.46
IS 1051	4.33	5.00	4.50	2.00	3.00	2.00	2.33	1.00	3.00	1.50	1.83	53.81	65.47	90.00	69.76	74.34	75.10	63.44	70.96
IS 1054	1.49	2.00	3.50	1.67	1.67	2.50	1.94	2.00	3.00	2.00	2.33	49.68	56.67	78.63	61.66	59.01	61.00	58.61	59.54
IS 10712	4.33	4.00	4.50	2.00	1.00	2.00	1.67	1.00	2.00	1.00	1.33	62.92	74.88	57.07	64.96	85.69	86.85	59.28	77.27
IS 1104	2.00	3.00	2.50	1.67	2.00	2.00	1.89	2.00	3.00	2.00	2.33	52.01	45.30	90.00	62.44	70.08	54.70	60.86	61.88
IS 12308	4.33	2.00	3.50	1.67	1.00	1.00	1.22	1.33	3.00	2.00	2.11	58.47	74.43	78.97	70.62	81.18	62.27	65.16	69.54
IS 13100	4.33	4.00	3.50	1.33	2.00	2.00	1.78	1.33	3.00	2.00	2.11	58.69	70.90	71.33	66.97	76.37	63.81	69.70	69.96
IS 14108	4.33	5.00	4.50	1.00	3.00	2.50	2.17	1.00	1.00	1.00	1.00	68.69	59.97	90.00	72.89	90.00	79.80	80.26	83.35
IS 14334	4.33	5.00	4.50	1.49	2.00	2.50	2.00	2.67	3.00	3.00	2.89	59.42	72.61	82.26	71.43	82.69	86.66	79.97	83.11
IS 15107	4.00	5.00	5.00	1.67	2.00	3.00	2.22	1.00	1.00	1.00	1.00	68.55	86.71	82.47	79.24	90.00	90.00	73.63	84.54
IS 17610	4.33	4.00	5.00	1.00	2.00	3.00	2.00	1.00	2.00	1.00	1.33	66.81	56.81	90.00	71.21	90.00	69.87	73.19	77.69
IS 17645	4.67	5.00	5.00	1.67	3.00	3.00	2.56	1.33	2.00	1.50	1.61	66.02	76.90	90.00	77.64	90.00	85.39	80.78	85.39
IS 17726	2.00	1.00	2.50	1.67	1.00	2.00	1.56	2.51	3.00	2.50	2.67	39.54	51.61	90.00	60.38	58.81	51.90	65.40	58.70
IS 18368	2.33	4.00	3.50	1.67	2.00	3.00	2.22	2.00	3.00	2.50	2.50	42.73	57.16	79.27	59.72	68.65	61.36	60.69	63.57
IS 18563	4.67	5.00	4.50	1.67	2.00	2.00	1.89	1.00	1.00	1.00	1.00	59.12	81.52	90.00	76.88	80.05	85.25	64.18	76.49
IS 18579	2.00	3.00	3.00	1.00	2.00	3.05	2.02	1.67	2.00	1.50	1.72	50.50	47.21	76.76	58.16	74.69	52.90	57.00	61.53
IS 18662	1.67	3.00	3.50	1.00	2.33	1.50	1.61	1.00	3.00	1.50	1.83	49.55	55.52	90.00	65.02	66.67	65.61	62.55	64.94
IS 18677	4.00	5.00	4.50	1.67	2.00	2.00	1.89	1.33	3.00	2.50	2.28	66.00	70.15	90.00	75.38	83.53	68.71	71.05	74.43
IS 18698	4.67	3.00	5.00	3.00	2.00	2.50	2.50	1.00	1.00	1.00	1.00	54.15	70.45	71.80	65.47	85.69	80.83	78.61	81.71
IS 19512	4.00	5.00	4.50	2.33	3.00	2.50	2.61	1.00	1.00	1.00	1.00	57.25	50.89	77.65	61.93	70.34	72.52	65.03	69.30
IS 19955	4.67	5.00	4.50	2.67	2.00	2.00	2.22	3.00	3.00	3.00	3.00	60.16	75.60	90.00	75.25	84.77	83.31	80.78	82.95
IS 20024	5.00	5.00	3.50	3.00	3.00	2.50	2.83	2.00	3.00	2.00	2.33	54.54	75.00	78.97	69.50	78.50	90.00	71.32	79.94
IS 20643	4.33	5.00	5.00	1.46	3.00	2.50	2.32	1.00	2.00	1.00	1.33	58.28	61.92	90.00	70.07	80.29	68.93	60.35	69.86
IS 20740	4.67	5.00	5.00	1.33	3.00	2.50	2.28	1.00	1.00	1.50	1.17	61.76	72.41	83.16	72.44	83.53	85.32	66.97	78.61
IS 2122	1.67	3.00	1.00	1.33	1.00	1.00	1.11	1.00	3.00	1.00	1.67	46.78	43.09	76.38	55.42	59.26	51.25	44.84	51.78
IS 2123	1.00	4.00	1.50	1.00	1.00	1.00	1.00	1.67	2.00	1.50	1.72	55.00	43.54	82.66	60.40	68.31	47.26	56.30	57.29
IS 21443	4.67	5.00	4.50	2.67	3.00	2.50	2.72	3.00	3.00	3.00	3.00	53.01	66.91	74.25	64.72	90.00	83.38	78.61	84.00
IS 21444	5.00	5.00	5.00	2.67	3.00	3.00	2.89	2.33	3.00	3.00	2.78	65.79	69.55	90.00	75.11	87.08	83.10	70.46	80.21
IS 2146	1.00	1.00	1.50	1.00	1.00	1.00	1.00	1.00	2.00	2.00	1.67	44.84	42.94	63.96	50.58	62.23	57.13	47.12	55.49
IS 21871	4.67	3.00	5.00	3.00	3.00	3.00	3.00	2.33	1.00	3.00	2.11	56.48	61.49	90.00	69.32	85.85	86.23	83.54	85.21
IS 21879	5.00	4.00	4.00	2.33	2.00	3.00	2.44	3.00	3.00	3.00	3.00	53.24	79.05	71.24	67.84	85.90	90.00	68.55	81.48
IS 21881	5.00	3.00	4.50	2.67	2.00	2.50	2.39	3.00	3.00	3.00	3.00	62.41	83.28	74.25	73.31	82.63	86.49	65.32	78.15
IS 2205	1.00	1.00	2.00	1.00	1.00	2.00	1.33	1.33	3.00	1.50	1.94	47.25	39.08	79.55	55.29	67.35	50.94	49.48	55.92
IS 2312	1.33	2.00	2.50	1.33	1.00	2.00	1.44	1.00	3.00	2.00	2.00	41.93	44.21	73.64	53.26	61.04	59.43	51.25	57.24
IS 27329	5.00	4.33	5.00	1.46	3.00	3.00	2.49	3.00	3.00	3.00	3.00	68.21	66.85	90.00	75.02	83.66	86.89	82.98	84.51
IS 3461	4.33	4.00	4.00	3.00	3.00	2.00	2.67	1.00	2.00	1.00	1.33	48.48	68.20	77.11	64.60	74.11	81.36	63.92	73.13
IS 4646	1.00	1.00	1.50	1.00	1.00	1.50	1.17	1.00	3.00	2.00	2.00	50.90	50.25	82.66	61.27	68.10	56.03	57.97	60.70
IS 4757	4.00	3.00	4.50	1.00	2.00	2.50	1.83	1.00	3.00	2.00	2.00	63.02	69.29	90.00	74.10	81.05	68.72	69.08	72.95
IS 4995	4.67	4.00	4.00	1.33	2.00	1.50	1.61	1.00	3.00	1.00	1.67	56.68	70.08	77.11	67.96	81.13	67.04	66.47	71.55
IS 5469	0.99	4.00	3.50	1.00	1.00	1.50	1.17	1.67	3.00	1.50	2.06	54.98	51.11	77.11	61.07	69.18	54.30	61.72	61.73

IS 5470	1.33	3.00	1.50	1.33	1.00	1.50	1.28	1.33	3.00	1.50	1.94	51.15	45.92	65.61	54.23	57.03	46.71	43.55	49.10
IS 5480	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.33	3.00	2.00	2.11	49.26	63.22	90.00	67.49	62.94	58.98	37.67	53.20
IS 5490	2.00	2.00	3.00	1.33	2.00	1.50	1.61	1.67	3.00	2.50	2.39	46.16	40.39	76.05	54.20	59.00	46.11	57.10	54.07
IS 5566	1.33	2.00	2.50	1.33	1.00	1.50	1.28	1.00	2.00	1.50	1.50	48.43	47.00	73.10	56.18	55.34	52.13	56.11	54.53
IS 5604	1.00	1.00	1.50	1.00	1.00	1.50	1.17	1.33	2.00	1.50	1.61	51.52	48.75	65.71	55.33	66.49	48.70	58.39	57.86
IS 5622	1.33	3.00	3.00	1.00	2.00	1.50	1.50	1.33	3.00	1.00	1.78	49.45	46.52	78.97	58.31	70.62	60.50	54.20	61.77
IS 6566	1.00	1.00	2.50	1.33	1.00	1.50	1.28	1.00	3.00	1.50	1.83	57.26	36.28	77.11	56.88	66.95	60.55	60.16	62.55
IS 7005	4.33	3.00	4.50	2.67	2.00	2.50	2.39	1.00	1.00	1.00	1.00	62.50	53.37	76.76	64.21	82.16	78.66	59.92	73.58
IS 8151	4.00	3.33	4.50	2.00	1.00	1.50	1.50	1.00	2.00	1.00	1.33	64.42	77.37	90.00	77.26	90.00	84.49	78.29	84.26
IS 8549	1.67	1.00	4.95	1.33	1.00	2.96	1.76	1.00	2.00	1.00	1.33	49.33	52.21	77.11	59.55	67.40	59.88	60.03	62.44
IS 8671	4.00	4.33	4.50	1.67	3.00	1.50	2.06	1.00	2.00	1.50	1.50	68.92	76.08	82.03	75.68	86.61	81.13	53.57	73.77
IS 8891	4.67	4.00	3.00	1.49	2.00	1.00	1.50	1.33	1.00	1.00	1.11	62.90	73.48	90.00	75.46	84.56	78.02	67.13	76.57
IS 9807	4.00	4.00	4.00	3.00	2.00	2.50	2.50	1.00	1.00	1.00	1.00	56.35	61.62	90.00	69.32	74.58	83.86	73.19	77.21
PS 35805	2.00	1.00	2.50	2.33	1.00	1.00	1.44	1.67	3.00	2.00	2.22	38.99	49.48	65.61	51.36	52.24	49.14	50.80	50.73
TAM 2566	4.33	4.00	4.00	1.67	2.00	2.00	1.89	1.00	3.00	1.50	1.83	60.76	72.73	77.43	70.31	90.00	86.76	54.55	77.10
IS18551(R)	1.00	1.00	2.50	1.33	1.00	1.50	1.28	1.00	2.00	1.50	1.50	28.74	23.21	50.18	34.04	25.15	20.67	30.25	25.36
Swarna(S)	5.00	5.00	5.00	2.49	3.00	2.50	2.66	1.67	3.00	2.00	2.22	87.73	89.19	93.42	90.11	94.07	93.31	82.52	89.97
Vr	24.32 <sup>1</sup>	217.26 <sup>1</sup>	15.42 <sup>1</sup>	5.61 <sup>1</sup>	31.06 <sup>1</sup>	10.66 <sup>1</sup>	15.78 <sup>1</sup>	12.07 <sup>1</sup>	104.43 <sup>1</sup>	20.69 <sup>1</sup>	45.73 <sup>1</sup>	4.38 <sup>1</sup>	6.04 <sup>1</sup>	3.68 <sup>1</sup>	4.70 <sup>1</sup>	6.56 <sup>1</sup>	9.94 <sup>1</sup>	8.37 <sup>1</sup>	8.29 <sup>1</sup>
Mean	3.38	3.00	3.51	1.99	1.85	1.90	1.91	1.65	2.51	1.95	2.04	54.53	61.33	79.98	65.28	74.23	69.63	61.64	68.50
SE ±	0.30	0.10	0.29	0.28	0.13	0.20	0.20	0.21	0.07	0.16	0.15	4.14	5.56	4.39	4.70	4.61	4.58	4.03	4.41
LSD	0.82	0.27	0.82	0.78	0.36	0.55	0.56	0.60	0.18	0.45	0.41	11.54	15.50	12.25	13.09	12.87	12.78	11.23	12.29

<sup>1</sup>F-test significant at  $P \leq 0.01$ ; R, rainy season; (R), resistant check; (S), susceptible check. <sup>a</sup> Leaf glossy score, 1 = highly glossy, and 5 = non-glossy; <sup>b</sup> Seedling vigor, 1 = high seedling vigor, and 3 = poor seedling vigor; <sup>c</sup> Leafsheath pigmentation, 1 = highly pigmented, and 3 = non-pigmented.

### Morphological Traits Associated with Resistance to Shoot Fly, *A. Soccata*

There were significant differences among the genotypes for leaf glossiness, seedling vigor and leaf sheath pigmentation across rainy seasons. The genotypes ICSV 25019, ICSV 25026, ICSV 25039, ICSV 25107, ICSV 25110, ICSV 25112, ICSV 705, ICSV 707, ICSV 708, ICSV 717, ICSV 93089, IS 17726, IS 2122, IS 2123, IS 2146, IS 2205, IS 2312, IS 4646, IS 5470, IS 5480, IS 5566, IS 5604, IS 6566 and PS 35805 exhibited high levels of leaf glossiness, while the susceptible check, Swarna, and the genotypes exhibiting susceptibility to shoot fly were nonglossy. The genotypes ICSV 1, ICSV 25107, ICSV 25112, ICSV 700, ICSV 705, ICSV 707, ICSV 717, ICSV 93089, IS 12308, IS 2122, IS 2123, IS 2146, IS 2205, IS 2312, IS 4646, IS 5469, IS 5470, IS 5566, IS 5604,

IS 5622, IS 6566, IS 8151, IS 8891, PS 35805 and IS 18551 exhibited high seedling vigor, whereas ICSV 25019, ICSV 25107, ICSV 25112, ICSV 708, ICSV 717, ICSV 93089, ICSV 96011, IS 10712, IS 14108, IS 15107, IS 17610, IS 18563, IS 18698, IS 19512, IS 20643, IS 3461, IS 5566, IS 7005, IS 8151, IS 8549, IS 8671, IS 8891, IS 9807 and IS 18551 showed high leafsheath pigmentation. The correlation coefficients between the morphological traits and the shoot fly damage parameters revealed that, leafsheath pigmentation, seedling vigor and leaf glossiness were significantly and positively correlated with resistance/ susceptibility across seasons (Table 3), whereas trichomes on the abaxial and adaxial leaf surfaces were significantly and negatively correlated with to shoot fly damage.

Table 3. Association of morphological with the expression of resistance to sorghum shoot fly, *A. soccata*, (ICRISAT, Patancheru, 2013-15).

	Leaf glossy score	Seedling vigor	Leafsheath pigmentation	Plants with shoot fly eggs (%)	Shoot fly deadhearts (%)	Trichomes on the abaxial leaf surface	Trichomes on the adaxial leaf surface
Leaf glossy score	1.00						
Seedling vigor	0.66**(0.57**)	1.00					
Leafsheath pigmentation	0.20*(0.37**)	0.16(0.41**)	1.00				
Plants with shoot fly eggs (%)	0.41**(0.56**)	0.27**(0.04)	0.14(0.12)	1.00			
Shoot fly deadhearts (%)	0.70**(0.73**)	0.53**(0.21*)	0.26**(0.29**)	0.49**(0.77**)	1.00		

	Leaf glossy score	Seedling vigor	Leafsheath pigmentation	Plants with shoot fly eggs (%)	Shoot fly deadhearts (%)	Trichomes on the abaxial leaf surface	Trichomes on the adaxial leaf surface
Trichomes on the abaxial leaf surface	-0.41**	-0.21*	-0.12	-0.15	-0.39**	1.00	
Trichomes on the adaxial leaf surface	-0.40**	-0.19*	-0.13	-0.09	-0.37**	0.88**	1.00

The values outside the parentheses are the correlation coefficients of 2015 rainy season, and those inside the parentheses are for 2013 rainy season; the data for trichome density were recorded in 2015 rainy season.

\*, \*\* correlation coefficient significant at P = 0.05 and P = 0.01, respectively.

*Diversity among the Sorghum Genotypes with Resistance to Shoot Fly, A. Soccata*

Similarity matrix analysis based on biological parameters (deadhearts at 28 DAE; and plants with shoot fly eggs at 21 DAE) and morphological traits (leaf glossiness, seedling vigor and leafsheath pigmentation) placed the test genotypes into six groups at 0.95 level of similarity index (Fig. 1). The test genotypes were grouped into resistant, moderately resistant and susceptible categories based on their level of resistance. Among the six groups, 31 resistant, 19 moderately resistant and 52 susceptible (Table 4).

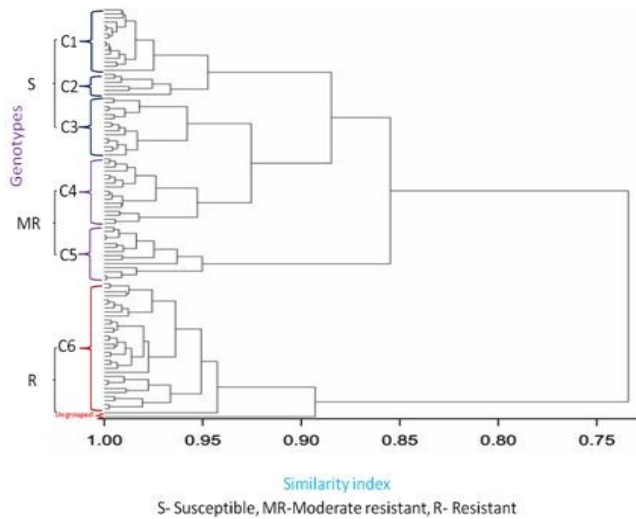


Fig. 1. Phylogenetic tree (Similarity matrix analysis) of 102 sorghum genotypes based on shoot fly damage and morphological traits.

Table 4. Clustering of 102 sorghum genotypes (at 0.95% level) based on similarity index.

Cluster	No of genotypes	Genotypes
C1	16 (S)	DJ 6514, IS 21443, ICSV 93012, ICSV 89036, ICSV 93009, IS 21879, ICSV 95082, IS 21881, ICSV 197, ICSV 93020, IS 27329, IS 19955, IS 14334, ICSV 25227, ICSV 93018, IS 21444.
C2	6 (S)	ICSV 89057, IS 20024, IS 21871, ICSV 95077, IS 17645, SWARNA.
C3	15 (S)	ICSV 25010, ICSV 25092, ICSV 25135, IS 18368, ICSV 713, ICSV 93046, ICSV 391, ICSV 96031, IS 1051, IS 1044, ICSV 88032, IS 13100, IS 4757, TAM 2566, IS 18677.

C4	17 (MR)	ICSV 96011, IS 17610, IS 8671, IS 20643, IS 14108, IS 15107, IS 20740, IS 18563, IS 18698, IS 9807, IS 7005, IS 19512, IS 3461, IS 10712, IS 4995, IS 8151, IS 8891.
C5	14 (MR)	ICSV 25006, ICSV 702, IS 1054, IS 1104, ICSV 714, IS 17726, IS 5490, IS 711, ICSV 730, ICSV 25110, ICSV 25066, ICSV 386, ICSV 745, ICSV 95071.
C6	32 (R)	ICSV 1, IS 12308, ICSV 25117, IS 5469, ICSV 25022, IS 5622, IS 18662, ICSV 25027, ICSV 700, ICSV 705, PS 35805, IS 2312, IS 5470, ICSV 707, IS 6566, IS 2205, IS 4646, IS 2146, IS 5604, IS 2122, IS 5566, IS 2123, IS 5480, ICSV 25019, ICSV 25026, ICSV 708, IS 18579, IS 8549, ICSV 25107, ICSV 717, ICSV 25112, ICSV 93089.
Ungrouped	2 (R)	ICSV 25039, IS 18551.

Out of 102 genotypes tested, 31 sorghum exhibited resistance to shoot fly, 25 genotypes showed antixenosis for oviposition, and 26 (ICSV 25010, ICSV 25019, ICSV 25039, ICSV 25107, ICSV 386, ICSV 702, ICSV 705, ICSV 707, ICSV 708, ICSV 711, ICSV 713, ICSV 717, ICSV 93018, ICSV 93046, ICSV 95077, IS 1051, IS 1104, IS 18563, IS 18662, IS 20643, IS 2122, IS 2123, IS 2205, IS 5480, IS 8671 and PS 35805) also exhibited antibiosis to *A. soccata* (genotypes with significantly lower number of plants with deadhearts than the plants with eggs). Antixenosis, antibiosis and tolerance are the major components of resistance to shoot fly damage in sorghum [(19), (12), (2), (13)]. In the current studies, some of the sorghum genotypes expressed non-preference for shoot fly oviposition, while some showed antibiosis. The seasonal variation in shoot fly resistance in sorghum occurs due to direct effect of climatic factors on survival and development of shoot fly, and the indirect effects on plant growth and biochemical composition of the host plants [20].

The correlation coefficients between the shoot fly damage and morphological traits suggested that leaf glossiness and leafsheath pigmentation were significantly and positively associated with resistance/ susceptibility to shoot fly damage. Trichomes on the abaxial and adaxial leaf surfaces were negatively and significantly correlated with shoot fly damage. Based on the deadheart incidence and morphological traits, Similarity matrix analysis indicated considerable diversity among the genotypes tested. Average linkage clusters placed with shoot fly resistant and susceptible genotypes into separate groups.

Genotypes placed in different groups and with diverse combination of characteristics associated with resistance to sorghum shoot fly can be utilized to broaden the genetic base, and increase the levels of resistance to sorghum shoot fly, *A. soccata*. Oviposition by sorghum shoot fly is significantly and negatively linked with trichome density [(21), (2), (13)]. Trichome density and leaf glossiness contribute to resistance to shoot fly damage, and their inheritance is governed by additive gene action [(12), (2)]. Light pink pigmented plants with low chlorophyll content are also less susceptible to shoot fly damage [(22), (2)]. The present studies suggested that leaf glossiness, trichomes and leafsheath pigmentation can be used as morphological markers to select for shoot fly resistance in sorghum.

#### IV. CONCLUSION

Sorghum genotypes with different mechanisms, and placed in different groups based on shoot fly damage and morphological traits can be utilized in increasing the levels and diversifying basis of resistance to shoot fly, *A. soccata*. Leaf glossiness, leafsheath pigmentation, and trichome density can be used as the marker traits to select shoot fly-resistant sorghums. Genotypes showing stable resistance to shoot fly damage, and placed in separate groups can be used in the sorghum improvement programs for developing shoot fly-resistant varieties for sustainable crop production.

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##### Conflict of Interest Statement:

The authors declare that they have no competing interests.

#### HIGHLIGHTS

- We evaluated 102 sorghum lines for shoot fly resistance, and to understand the underlying mechanisms of resistance.
- Genotype x environment interactions were significant, which had a considerable bearing on expression of resistance to *A. soccata*.
- Leaf glossiness, seedling vigor, leaf sheath pigmentation and trichome density were associated with expression of resistance/ susceptibility to *A. soccata*, and these traits can be used to select shoot fly resistant sorghums.
- Similarity matrix analyses placed the shoot fly-resistant genotypes into different groups, which can be utilized to enhance the levels and broaden the base of resistance to *A. soccata*.

#### REFERENCES

- [1] Sharma H.C. Host plant resistance to insects in sorghum and its role in integrated pest management. *Crop Prot.* 1993; 12: 11-34.
- [2] Dhillon M. K., H. C Sharma, R Singh, J. S Naresh. Mechanisms of resistance to shoot fly, *Atherigona soccata* in sorghum. *Euphytica.* 2005; 144: 301-312.
- [3] Nwanze K. F., Reddy Y. V. R., Soman P. The role of leaf surface wetness in larval behaviour of the sorghum shoots fly, *Atherigona soccata*. *Entomol. Exp. Applic.* 1990; 56: 187-195.
- [4] Vadariya S. K., Effect of weather factors on population of shoot fly, *Atherigona soccata* (Rondani) on sorghum crop. *Int. J. Pl.Prot.* 2014; 7: 263-264
- [5] Deeming J. C., Some species of *Atherigona rondani* (Dipterans: Muscidae) from northern Nigeria, with special reference to those injurious to cereal crops. *Bull. Entomol.* 1971; 61: 133-190.
- [6] Jotwani M.G., K.P. Srivastava. Studies on sorghum lines resistance against shoot fly, *Atherigona soccata* Rond. *Indian J. Entomol.* 1970; 31: 1-3.
- [7] Jotwani M.G., Investigations on Insect Pests of Sorghum and Millets with Special Reference to Host Plant Resistance. Final Technical Report, (1972-1977). Research Bulletin of the division of Entomology, Indian Agricultural Research Institute, New Delhi, India, 1978.
- [8] Borad P.K., Mittal V.P. Assessment of losses caused by pest complex to sorghum hybrid, CSH 5. In: Krishnamurthy Rao, B. H., Murthy, K.S.R.K. (Eds.), *Crop Losses due to Insect Pests*, Entomology Society of India, Rajendranagar, Hyderabad, Andhra Pradesh, India, pp. 1983; 271-278.
- [9] Daware, D.G., Bhagwat, V. R., Ambilwade, P. P., Kamble, R. J. Evaluation of integrated pest management components for the control of sorghum shoot pests in Rabi season. *Indian J. Entomol.* 2012; 74, 58-61.
- [10] Sukhani, T.R., Jotwani, M.G. Efficacy of mixtures of carbofuran treated and untreated sorghum seed for the control of shoot fly, *Atherigona soccata* (Rondani). *J. Entomol. Res.* 1980; 4, 186-189.
- [11] Sharma H. C. Future strategies for pest control in sorghum in India. *Trop. Pest Manage.* 1985; 31: 167-185.
- [12] Sharma H.C., Nwanze K.F. Mechanisms of Resistance to Insects and their Usefulness in Sorghum Improvement. Information Bulletin No: 55, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. 51 pp. 1997.
- [13] Riyazuddin M.D., Kavi Kishor P.B., Ashok Kumar A., Belum Reddy V.S., Rajendra S.M., Sharma H.C. Mechanisms and diversity of resistance to sorghum shoot fly, *Atherigona soccata*. *Plant Breed.* 2015; 34(4): 423-436.
- [14] Taneja S. L., Leuschner K. Resistance screening and mechanisms of resistance in sorghum to shoot fly. In: Kumble, V. (Ed.), 1985. Proceedings of the International Sorghum Entomology Workshop. Texas A&M University, College Station, TX, pp. 15-21 July, 1984; 115-129, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India.
- [15] Sharma H.C., Dhillon M.K., B.V.S. Reddy. Expression of resistance to sorghum shoot fly in F<sub>1</sub> hybrids involving shoot fly resistant and susceptible cytoplasmic male-sterile and restorer lines of sorghum. *Pl. Breed.* 2006; 125: 473-477.
- [16] Soto P.E. Ovipositional preference and antibiosis in relation to resistance to sorghum shoot fly. *J. Econ. Entomol.* 1974; 67: 265-267.
- [17] Maiti R.K., Bidinger F.R. A simple approach to the identification of shoot fly tolerance in sorghum. *Indian J. Pl. Prot.* 1979; 7: 135-140.
- [18] GenStat, Introduction to Genstat for Windows®. GenStat, 14<sup>th</sup> ed. 2014. Lawes Agricultural Trust, Rothamsted Experimental Station. Harpenden, UK.
- [19] Doggett H., Starks K. J., Eberhart S. A. Breeding for resistance to the sorghum shoot fly. *Crop Sci.* 1970; 10: 528-531.
- [20] Sharma H. C. Climate change effects on insects: implications for crop protection and food security. *J. Crop Imp.* 2014; 29: 229-259.
- [21] Omori T., B. L. Agrawal., L.R. House. Componential analysis of the



- factors influencing shoot fly resistance in sorghum [*Sorghum bicolor* (L.) Moench]. Jpn. Agric. Res. Q. 1983; 17: 215-218.
- [22] Singh, B. U., B. S., Rana, and N. G. P. Rao. Host plant resistance to mite (*Oligonychus Indicus* H.) and its relationship with shoot fly (*Atherigona soccata* Rond.) resistance in sorghum. J. Entomol. 1981, Res. 5, 25-40.

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