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Identification of sorghum genotypes with resistance to the sugarcane aphid *Melanaphis sacchari* under natural and artificial infestation

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With 4 figures and 3 tables

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Abstract

Sugarcane aphid, *Melanaphis sacchari* is an endemic pest of sorghum during postrainy season, and there is a need to develop cultivars with resistance to this pest. Evaluation of a diverse array of sorghum genotypes under natural and artificial infestation resulted in identification of seven lines (ICSB 215, ICSB 323, ICSB 724, ICSR 165, ICSV 12001, ICSV 12004 and IS 40615) with moderate levels of resistance to aphid damage. Under artificial infestation, 10 lines suffered <20% loss in grain yield as compared to 72.4% grain loss in the susceptible check, Swarna. The genotypes ICSR 165, ICSB 724, IS 40615, DSV 5 and ICSB 323 exhibited moderate levels of resistance to aphid damage (damage rating, DR <5.0) and also had high grain yield potential (>30 q/ha). In another experiment, ICSB 215, ICSB 695, ICSR 161, Line 61510, ICSV 12004, Parbhani Moti and IS 40618 exhibited high grain yield potential (>25 q/ha) and exhibited <50% variation in grain yield as compared to more than 80% in the susceptible check, in CK 60 B. The genotypes RSV 1211, RS 29, RSV 1338, EC 8-2, PU 10-1, IS 40617 and ICSB 695 though showed a susceptible reaction to aphid damage, but suffered relatively low loss in grain yield, suggesting that these lines have tolerance to aphid damage. Principal coordinate analysis suggested that the genotypes with aphid resistance are quite diverse and can be used to breed for aphid resistance and high grain yield potential and also in breeding for aphid resistance in sorghum with adaptation to the postrainy season.

Key words: sugarcane aphid — *Melanaphis sacchari* — sorghum — screening — sources of resistance

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important cereal crops in the semi-arid tropics (SAT). In India, sorghum is grown on over 10.4 million ha, with annual production of 8 million tonnes. The productivity levels of sorghum under subsistence farming are quite low (500–800 kg/ha), mainly because of biotic and abiotic constraints. Nearly 150 insect species have been reported as pests on sorghum (Jotwani et al. 1980, Sharma 1993), of which sorghum shoot fly, *Atherigona soccata* (Rond.), spotted stem borer, *Chilo partellus* (Swin.), Oriental armyworm, *Mythimna separata* (Walk.), shoot bug, *Peregrinus maidis* (Ashmead) sugarcane aphid, *Melanaphis sacchari* (Zehnt.), sorghum midge, *Stenodiplosis sorghicola* (Coq.), mirid head bugs, *Calocoris angustatus* (Leth.) and *Eurystylus oldi* (Pop.) and head caterpillars, *Helicoverpa armigera* (Hub.), *Eublemma*, *Cryptoblabes* and *Pyroderces* are the major pests worldwide. Annual losses due to insect pests have been estimated to be $1089 million in the SAT (ICRISAT 1992). In India, nearly 32% of sorghum crop is lost due to insect pests during the rainy season (Borad and Mittal 1983), and 26% during the postrainy season (Daware et al. 2012).

Sugarcane aphid, *M. sacchari* is an important pest in Asia, Africa, Australia and the USA (Sharma et al. 1997) and becomes a serious pest in the drought-stressed sorghum crop during the postrainy season in India. It also acts as a vector of sugarcane yellow leaf virus, one of the important viruses of sugarcane that occur in most of the sugarcane growing countries (Smith et al. 2000). The nymphs and adults suck the sap from the under surface of the mature leaves. The infested leaves dry and turn yellow or brown. The infestation starts in the lower leaves and spreads to the upper leaves. Under heavy infestation, the plants are severely stunted. Sugarcane aphid, *M. sacchari* density and damage to the plants are highly correlated (Hagio 1992), and both winged and wingless forms exhibit a strong preference for the susceptible sorghum varieties (Kawada 1995). The aphids secrete honeydew, which falls on leaves and on the ground, on which sooty moulds grow. The insect multiplies by parthenogenesis, that is, the females give birth to apterous nymphs, which moult four times before becoming adults. Under crowded conditions or when host plants are stressed, they produce winged forms (alates), which moult five times before becoming adults (Meksongsee and Chawanapong 1985). Each adult female gives birth to 60–100 nymphs in 13–20 days. The adults live for about 10–16 days.

The incidence of *M. sacchari* is high during periods of prolonged drought during the rainy season, and *M. sacchari* is a regular pest during the postrainy season. The sugarcane aphid, *M. sacchari* infestation in the sorghum has been observed to be quite high during the flowering and grain-filling stages (Fang 1990). Long dry spells of drought and suitable environmental conditions result in heavy infestation of *M. sacchari* (Raetano and Nakano 1994). In addition to leaf feeding, *M. sacchari* also affects grain quality of the sorghum in terms of diastatic power, malt loss and abrasive hardness index. This results in poor quality of sorghum beer and milling quality. Reduced grain hardness resulting from aphid feeding may also result in increased flour losses during the milling process (van den Berg et al. 2003).

Because of increasing importance of *M. sacchari* in sorghum production, several efforts have been made in the past to identify sources of resistance to *M. sacchari.* CSH 16 (Ghuguskar et al. 1999), EC 434430 (Sarath Babu et al. 2000), and ICSV 197, ICSV 745 and ICSV 112 (Sharma and Dhillon 2005) have shown moderate levels of resistance to *M. sacchari* in India; while PAN 8446, SNK 3939 and NS 5511 have been reported to be resistant to this aphid in South Africa (van den Berg 2002).

Agronomic practices, natural enemies, host plant resistance and synthetic insecticides have been employed for minimizing the extent of losses due to insect pests. Insecticides are costly, and at times beyond the reach of resource-poor farmers in the semi-arid tropics (Sharma 1985). Application of chemical insecticides for aphid control under subsistence farming conditions may not be economic, and at the same time cause environmental and operational hazards. It is important to identify aphid-resistant sorghum cultivars for controlling this pest. Therefore, we evaluated a diverse array of sorghum genotypes to identify cultivars with resistance to this pest under natural infestation across locations and artificial infestation inside the nylon net under field conditions.

Materials and Methods

Plant material: The experiments were conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India; Marathwada Agricultural University (MAU), Parbhani; Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharastra; Centre for Rabi Sorghum (CRS), Solapur, Maharashtra; and Directorate of Sorghum Research (DSR), Rajendranagar, Hyderabad, Andhra Pradesh, India, during the rainy and postrainy seasons. In the first year, a set of 102 lines was evaluated during the postrainy season across four locations under natural infestation, and based on the expression of resistance to sugarcane aphid, *M. sacchari;* a set of 30 lines including the resistant IS 40618 (TAM 428) and the susceptible checks (Swarna and CK 60 B) was selected for further testing under natural and artificial infestation inside the cage. The experimental plots were given a basal dose of di-ammonium phosphate at 150 kg/ha. Each entry was sown in two row plots, 2 m long, and the rows were 75 cm apart. At Parbhani, Solapur and Rahuri, the rows were 45 cm apart. There were three replications in a randomized complete block design (RCBD). The seeds were sown at a depth of 5 cm below the soil surface. The field was irrigated immediately after sowing. One week after seedling emergence, thinning was carried out to maintain a spacing of 10 cm between the plants. No insecticide was applied in the experimental plots. Interculture operations were carried out at 15 and 30 days after seedling emergence (DAE). Hand weeding was carried out as and when required. The crop was irrigated at intervals of 20–30 days. The material was tested at four locations over two seasons (2010/12 postrainy seasons, October to March).

Evaluation of germplasm and breeding lines for resistance to *M. sacchari* under nylon net and natural conditions

The test material was screened under natural and artificial infestation at ICRISAT, wherein the test material was infested with the aphid-infested leaf cuttings (stapled to 5th leaf at the flag leaf stage) and covered with a nylon net to exclude the natural enemies at the flag leaf stage till maturity (Sharma et al. 2013). Observations were recorded on aphid damage at the physiological maturity on a 1–9 scale (1 = <10.0% of the leaf area infested with aphids on the lower 1–2 leaves, with no apparent damage to the leaves; 2 = lower 1–2 leaves showing aphid infestation, and 10–20% of the infested leaf area covered with aphids and showing damage symptoms; 3 = lower 2–3 leaves showing aphid infestation, and 20–30% of the infested leaf area covered with aphids and showing damage symptoms, with moderate levels of honeydew/black moulds on the leaves/soil; 4 = lower 3–4 leaves showing aphid infestation, and 30–40% of the infested leaf area covered with aphids and showing damage symptoms, with moderate levels of honeydew/black moulds on the leaves/soil; 5 = lower 4–5 leaves showing aphid infestation, and 40–50% of the infested leaf area covered with aphids and showing damage symptoms, with moderate levels of honeydew/black moulds on the leaves/soil; 6 = aphid infestation up to 5–6 leaves, and 50–60% of the infested leaf area covered with aphids and showing damage symptoms, and heavy honeydew/black moulds on the leaves, and on the soil below; 7 = aphid infestation up to 6–7 leaves, and 60–70% of the infested leaf area covered with aphids and showing damage symptoms, and heavy honeydew/black moulds on the leaves, and on the soil below; 8 = aphid infestation up to 7–8 leaves, and 70–80% of the infested leaf area covered with aphids and showing damage symptoms, and heavy honeydew/black moulds on the leaves, and on soil the below; and 9 = heavy aphid infestation up to the flag leaf, and >80% of the leaf area covered with aphids and showing aphid damage (drying up symptoms), heavy honeydew/black moulds on the leaves, and on the soil below). Data were also recorded on plant height, days to 50% flowering, agronomic desirability (1 = good and 5 = poor) and grain yield at maturity/harvest.

Statistical analysis

Data were subjected to analysis of variance. Significance of differences between the genotypes was tested by F-test, while the treatment means were compared by least significant differences (LSD) at $P \leq 0.05$. The mean performance of the test entries was assessed across locations, and the standard error of the mean was used to assess the stability of resistance of the test genotypes as a percentage variation of the mean across locations. The association of genotypic resistance to aphid with the grain yield was also computed for each trial, and bi-plot was used to identify genotypes with resistance to aphids and high yield potential for use in breeding programmes and/or for cultivation by the farmers *per se.* The diversity among the genotypes was assessed based on aphid damage scores under natural and artificial infestation, and the agronomic traits using principal coordinate analysis.

Results

Expression of resistance to sugarcane aphid, *M. sacchari* in a diverse array of sorghum genotypes across seasons and locations

Of the 30 lines evaluated for resistance to sugarcane aphid over two seasons and four locations, 10 lines (ICSB 323, ICSB 724, ICSR 161, ICSR 165, IS 40615, C 43, ICSV 12001, ICSV 12004, RS 29 and Long SPS 43) exhibited an aphid damage rating of <4.5 as compared to 4.5 in the resistant check, IS 40618, and 8.2 in the susceptible check, Swarna across seasons and locations (Table 1). Of these, Line 61510, ICSV 12001, IS 40618 and Long SPS 43 were more stable in their reaction to aphid damage (<25% variation in aphid damage ratings across seasons and locations). The plant height ranged from 97.7 cm in IS 40618 to 222.5 cm in RSV 1093; while days to 50% flowering ranged from 68.7 in IS 40617 to 82.8 in DSV 5, suggesting that there is considerable variation in the germplasm with resistance to sugarcane aphid. The average grain yield of 21 lines

Table 1: Evaluation of 30 sorghum lines for resistance to sugarcane aphid, *M. sacchari* under natural conditions across four locations (2010–2011 post rainy seasons)

Genotype	Aphid damage rating[1]		Plant height (cm)		Days to 50% flowering		Grain yield (q/ha)	
	Mean (range)	Stability[2]	Mean (range)	Stability[2]	Mean (range)	Stability[2]	Mean (range)	Stability[2]
ICSB 205	4.7 (3.7–7.0)	28.2	116.9 (98.8–143.0)	14.7	74.3 (64.0–80.7)	8.0	21.7 (11.3–39.4)	54.7
ICSB 215	4.8 (3.0–7.0)	31.8	123.4 (92.5–167.0)	20.0	72.1 (62.0–80.7)	11.8	25.8 (16.2–38.2)	36.4
ICSB 321	5.1 (3.3–7.0)	29.8	132.5 (62.5–208.0)	35.3	74.6 (67.5–80.3)	7.0	35.2 (16.0–57.0)	55.8
ICSB 323	3.3 (2.0–6.0)	46.1	114.6 (78.8–159.0)	23.7	73.2 (67.0–81.3)	8.8	32.9 (12.2–61.5)	65.0
ICSB 695	5.0 (3.0–7.0)	29.4	113.9 (93.8–140.0)	14.7	74.3 (65.5–81.3)	7.8	23.6 (13.5–39.5)	44.9
ICSB 724	3.9 (3.0–6.0)	28.4	115.0 (77.5–148.0)	21.3	74.8 (67.0–80.0)	7.2	27.8 (16.0–52.8)	52.4
ICSR 161	4.4 (2.0–6.0)	35.6	129.9 (102.5–166.0)	17.8	71.4 (64.0–79.3)	9.7	30.3 (19.6–47.3)	44.4
ICSR 165	3.4 (2.0–5.7)	38.2	154.2 (111.3–213.0)	22.5	75.3 (67.5–90.3)	12.4	39.8 (19.2–66.3)	53.6
Line 61510	5.4 (4.0–6.7)	18.0	135.7 (68.8–196.0)	32.2	74.2 (65.0–81.3)	9.1	23.1 (11.3–37.7)	46.9
ICSV 12001	3.8 (3.0–4.3)	13.2	116.3 (77.5–171.0)	29.4	79.5 (69.0–89.0)	9.1	25.5 (4.7–45.3)	59.6
ICSV 12004	3.6 (2.0–6.7)	49.5	115.4 (80.0–161.0)	23.8	73.5 (67.0–82.3)	9.1	35.1 (13.5–53.3)	50.0
RS 29	3.8 (2.0–7.0)	45.6	128.4 (87.5–172.0)	23.5	76.2 (69.0–87.3)	9.2	37.2 (10.7–62.3)	54.7
RSV 1093	6.4 (4.0–8.0)	27.9	222.5 (150.0–305.0)	24.3	74.1 (67.5–79.3)	6.3	30.7 (8.5–72.9)	80.5
RSV 1211	6.1 (3.7–8.3)	29.4	214.3 (157.5–288.0)	21.0	78.5 (63.3–86.3)	11.4	24.3 (1.3–53.0)	76.5
RSV 1338	6.4 (4.0–8.0)	30.6	198.1 (125.0–294.0)	31.2	75.4 (67.0–84.0)	8.6	31.8 (9.5–75.1)	81.0
IS 40615	4.0 (3.0–6.3)	30.4	121.2 (92.9–158.7)	22.2	71.3 (64.0–78.3)	8.2	32.3 (18.3–72.0)	71.1
IS 40617	4.9 (3.7–8.0)	35.7	98.0 (84.2–112.0)	12.0	68.7 (59.0–79.3)	12.7	33.7 (16.9–80.8)	79.9
C 43	4.3 (3.0–6.3)	25.7	111.8 (91.3–138.0)	15.3	72.8 (64.0–83.0)	10.8	31.8 (12.7–50.0)	52.3
DSV 5	6.1 (3.3–8.0)	33.0	221.4 (137.5–314.0)	27.5	82.8 (75.0–89.0)	7.3	24.0 (0.3–43.2)	76.3
EC 8-2	6.0 (4.0–8.0)	24.5	204.2 (123.8–309.0)	30.6	76.3 (68.0–84.3)	8.4	25.3 (7.5–53.3)	75.8
Hathi Kuntha	6.4 (5.0–7.7)	14.3	183.5 (122.5–221.0)	19.5	69.3 (55.0–81.7)	16.1	14.9 (3.5–32.1)	76.4
Local 453	5.3 (3.0–8.3)	36.7	200.7 (110.0–289.0)	30.7	79.1 (73.0–86.7)	6.3	27.4 (11.3–67.2)	83.5
Long SPS 43	4.0 (2.7–5.0)	24.4	121.4 (78.8–163.0)	23.0	75.6 (67.0–82.0)	9.3	44.4 (16.9–84.5)	59.3
M 35-1	5.8 (4.0–8.0)	30.7	191.9 (110.0–264.0)	26.5	74.5 (65.0–82.3)	8.8	25.1 (3.5–53.6)	73.1
M 35-1 × 9808	5.6 (3.0–8.3)	40.4	195.2 (126.3–284.0)	29.9	77.2 (67.0–86.0)	8.5	31.6 (7.8–71.7)	78.0
Parbhani Moti	6.4 (3.0–8.3)	33.6	197.8 (135.0–284.0)	25.7	73.7 (65.5–84.0)	10.2	28.7 (17.1–52.7)	48.3
PU 10-1	5.8 (4.0–8.3)	33.4	211.7 (175.0–290.0)	20.9	76.8 (69.0–86.0)	9.1	23.4 (1.8–40.4)	65.8
CK 60 B	8.0 (7.0–9.0)	8.3	109.4 (82.5–133.3)	18.3	72.3 (58.0–92.0)	17.6	14.6 (3.9–32.3)	80.4
IS 40618 - R	4.5 (3.0–6.3)	25.6	97.7 (73.8–116.0)	14.4	72.2 (63.0–78.0)	9.4	26.5 (14.4–39.4)	40.0
SWARNA - S	8.2 (7.3–9.0)	7.3	113.6 (85.4–139.0)	19.3	72.4 (63.5–80.3)	8.8	8.5 (1.6–12.1)	50.8
Mean	5.2 (4.3–6.6)	18.7	150.2 (103.6–204.2)	22.9	74.5 (66.8–82.6)	7.5	28.2 (14.8–47.1)	42.7
SE ±	0.5	–	7.8	–	2.0	–	6.1	–
Fp (58, 29)	<0.001	–	<0.001	–	<0.001	–	0.1	–
LSD (P = 0.05)	1.3	–	21.9	–	5.5	–	17.2	–

[1]Damage rating (1 = a few aphids present on the lower 1–2 leaves, with no apparent damage to the leaves, and 9 = heavy aphid infestation up to the flag leaf, and >80% of the leaves showing aphid damage (drying up symptoms), heavy honeydew/black moulds on the leaves and on the soil below).
[2]Percentage variation over mean across seasons and locations.

was >25 q/ha, of which ICSB 215, ICSB 695, ICSR 161, Line 61510, ICSV 12004, Parbhani Moti and IS 40618 exhibited <50% variation in grain yield as compared to >80% variation in RSV 1093, RSV 1338, IS 40617 and CK 60 B. Aphid damage ratings (X) explained 50.4% of the total variation in grain yield [Y = 49.70-4.21X (R^2 = 50.4%)]. Sugarcane aphid damage rating was positively correlated with plant height (r = 0.45*), but negatively correlated with grain yield (r = –0.71**). Plant height and days to 50% flowering were correlated positively (r = 0.53*).

Based on the relationship between aphid damage and grain yield, the genotypes Long SPS 43, ICSR 165, ICSV 12004, RS 29, IS 40615, ICSB 323, ICSB 724, C 43, ICSR 161 and ICSB 215 exhibited moderate levels of resistance to aphid damage and showed a grain yield potential of >2,57 t/ha, while RSV 1211, PU 10-1, Hathi Kuntha, CK 60 B, EC 8-2, DSV 5, Line 61510 and Swarna exhibited high susceptibility to aphid damage and also had low grain yields under natural aphid infestation in the field (Fig. 1a). The genotypes ICSV 12001, IS 40618 (TAM 428), ICSB 205 and ICSB 695 exhibited moderate levels of resistance to *M. sacchari*, but had a yield potential of <25.0 q/ha. Principal coordinate analysis based on aphid damage rating, plant height, days to 50% flowering and grain yield indicated that the genotypes having high grain yield potential and resistance to *M. sacchari* were placed in groups A and B; while those with resistance to aphid, but with low grain yield potential were placed in groups B and C. The results suggested that the genotypes with aphid resistance are quite diverse and can be used to develop cultivars with aphid resistance and high grain yield potential (Fig. 1b).

Expression of resistance to sugarcane aphid, *M. sacchari* in maintainer and restorer lines of sorghum under natural and artificial infestation

Of the 30 maintainer and restorer lines with adaptation to postrainy season evaluated for resistance to sugarcane aphid, 23 lines exhibited moderate levels of resistance during the 2010 and 2011 postrainy seasons under natural infestation (Table 2). Of these, only seven lines (ICSB 215, ICSB 323, ICSB 724, ICSR 165, ICSV 12001, ICSV 12004 and IS 40615) (damage scores 4.3–5.0 compared to 5.7 of the resistant check, IS 40618, and 9.0 of the susceptible check, Swarna) exhibited resistance under artificial infestation inside the nylon net. Eleven lines (ICSB 215, ICSB 695, ICSR 165, RS 29, RSV 1338, IS 40615, IS 40617, DSV 5, EC 8-2, PU 10-1 and IS 40618) suffered <20% loss in grain yield under artificial infestation as compared to 72.4% loss in grain yield in Swarna. The sorghum genotypes

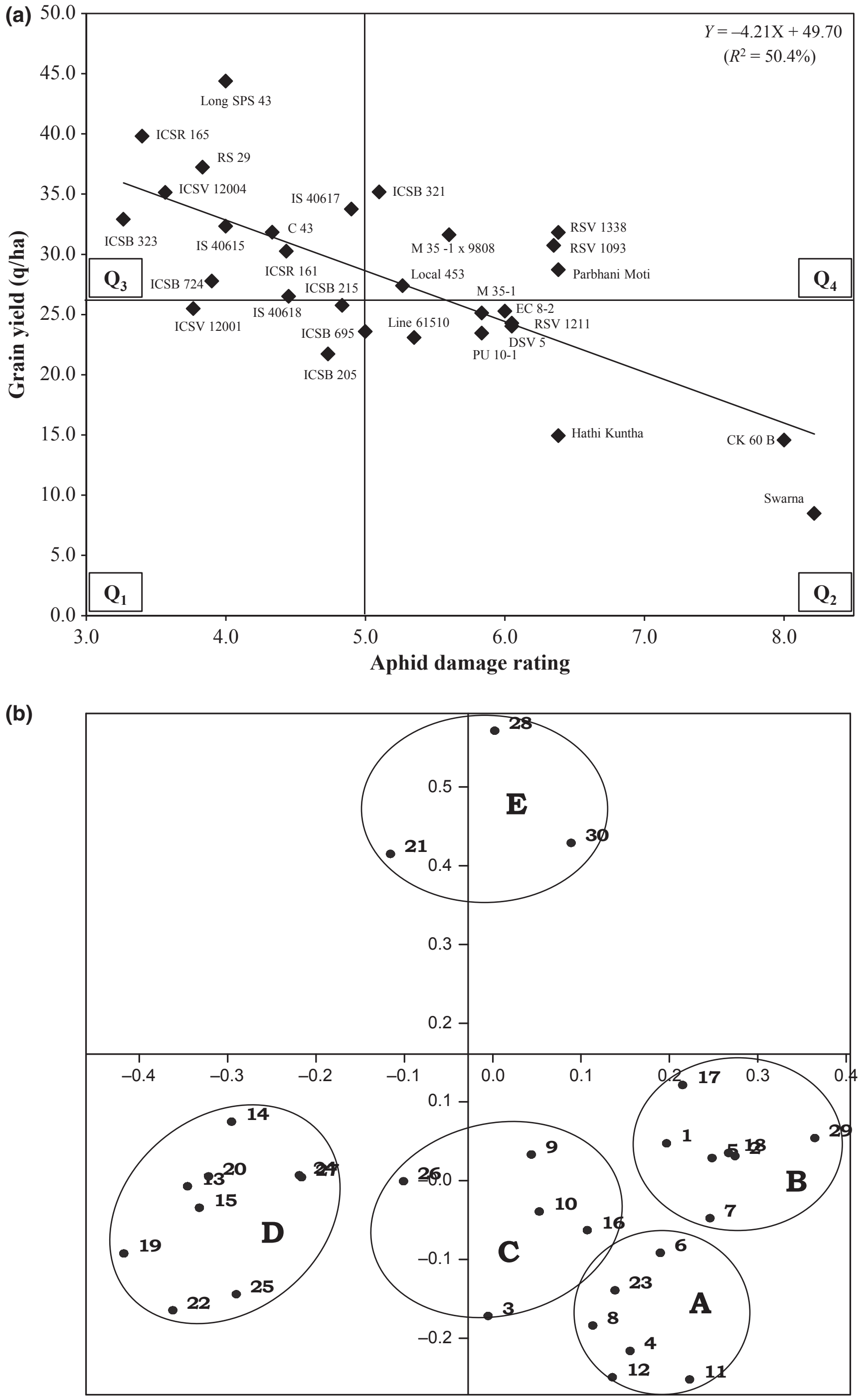

Fig. 1: (a) Relationship between sugarcane aphid *M. sacchari* damage and grain yield under natural infestation in 30 sorghum genotypes. (b) Diversity among the 30 sorghum genotypes (Principal component analysis) based on sugarcane aphid, *M. sacchari* damage under natural infestation and agronomic traits. (1 = ICSB 205; 2 = ICSB 215; 3 = ICSB 321; 4 = ICSB 323; 5 = ICSB 695; 6 = ICSB 724; 7 = ICSR 161; 8 = ICSR 165; 9 = Line 61510; 10 = ICSV 12001; 11 = ICSV 12004; 12 = RS 29; 13 = RSV 1093; 14 = RSV 1211; 15 = RSV 1338; 16 = IS 40615; 17 = IS 40617; 18 = C 43; 19 = DSV 5; 20 = EC 8-2; 21 = Hathi Kuntha; 22 = Local 453; 23 = Long SPS 43; 24 = M 35-1; 25 = M 35-1 × 9808; 26 = Parbhani Moti; 27 = PU 10-1; 28 = CK 60 B; 29 = IS 40618 (TAM 428 - R); 30 = Swarna - S)

ICSB 215, ICSR 165, IS 40615 and IS 40618 with resistance to aphid damage also suffered lower loss in grain yield, and these lines can be used in breeding programme for aphid resistance with adaptation to postrainy season. Under natural infestation, aphid damage ratings were negatively correlated with days to 50% flowering ($r = -0.51^{**}$) and grain yield ($r = -0.67^{**}$). Aphid damage ratings and loss in grain yield were positively correlated ($r = 0.67^{*}$). Under artificial infestation, leaf damage by the *M. sacchari* was negatively correlated with days to 50% flowering ($r = -0.26^{**}$) and grain yield ($r = -0.41^{**}$). However, aphid damage ratings and loss in grain yield were positively correlated ($r = 0.45^{*}$), while grain yield and loss in grain yield under artificial infestation were negatively correlated ($r = -0.61^{**}$).

The genotypes ICSR 165, ICSB 724, ICSB 321, ICSB 215, ICSV 12004, IS 40615, IS 40618, DSV 5, RSV 1093 and ICSB

Table 2: Evaluation of sorghum genotypes for resistance to sugarcane aphid, *M. sacchari* under natural and artificial infestation in the field (ICRISAT, postrainy season)

Genotype	Aphid damage rating[1] Natural infestation 2010	Natural infestation 2011	Artificial infestation 2011	Mean value of plant height & (Range)	Mean value of days to 50% flowering & (Range)	Grain yield (q/ha) Natural infestation 2011	Artificial infestation 2011	Grain yield loss (%)
ICSB 205	4.0	4.0	7.3	137 (130–143)	69 (64–78)	39.4	26.0	34.0
ICSB 215	3.0	4.0	4.7	150 (127–167)	70 (65–78)	38.2	30.8	19.4
ICSB 321	4.0	3.3	5.0	173 (140–208)	71 (67–78)	55.7	33.5	39.9
ICSB 323	4.0	2.3	4.3	144 (130–159)	70 (67–74)	49.6	34.0	31.5
ICSB 695	4.0	4.7	8.0	130 (123–140)	69 (66–74)	26.8	25.2	6.0
ICSB 724	3.0	3.7	4.3	139 (130–148)	72 (67–80)	52.8	39.9	24.4
ICSR 161	5.0	6.0	9.0	156 (147–166)	68 (63–76)	42.4	21.1	50.2
ICSR 165	4.0	3.0	4.0	198 (170–213)	68 (67–70)	57.1	46.2	19.1
Line 61510	5.0	4.7	8.0	176 (153–196)	70 (65–78)	37.7	16.8	55.4
ICSV 12001	4.0	3.3	4.3	153 (130–171)	76 (74–80)	45.3	24.7	45.5
ICSV 12004	4.0	2.7	4.7	147 (130–161)	69 (68–70)	53.2	30.6	42.5
RS 29	4.0	3.3	6.3	161 (147–172)	70 (68–72)	62.3	51.6	17.2
RSV 1093	4.0	4.7	6.0	285 (253–305)	71 (68–76)	72.9	47.4	35.0
RSV 1211	5.0	3.7	7.3	276 (240–300)	75 (71–82)	53.0	39.8	24.9
RSV 1338	4.0	4.0	6.7	256 (203–294)	73 (69–80)	75.1	62.8	16.4
IS 40615	4.0	3.7	5.0	128 (117–147)	68 (64–76)	32.8	33.8	−3.0
IS 40617	4.0	3.7	6.0	110 (107–112)	64 (62–68)	32.1	31.7	1.2
C 43	4.0	4.0	7.3	130 (123–138)	68 (64–76)	50.0	33.7	32.6
DSV 5	4.0	3.3	5.3	289 (263–314)	80 (75–88)	43.2	37.3	13.7
EC 8-2	4.0	4.7	6.0	277 (230–309)	73 (68–82)	53.3	46.1	13.5
Hathi Kuntha	5.0	6.0	6.7	214 (203–221)	57 (55–58)	32.1	23.2	27.7
Local 453	3.0	5.3	6.0	266 (233–289)	77 (73–82)	67.2	47.1	29.9
Long SPS 43	5.0	4.3	8.7	151 (133–163)	73 (68–82)	55.4	31.2	43.7
M 35-1	4.0	5.0	8.3	239 (207–264)	69 (65–74)	53.6	37.7	29.7
M 35-1 × 9808	3.0	3.3	6.7	251 (223–284)	75 (73–80)	71.7	50.8	29.1
Parbhani Moti	3.0	4.7	6.3	252 (210–284)	70 (66–78)	52.7	35.2	33.2
PU 10-1	4.0	4.7	6.0	256 (223–290)	72 (70–76)	40.4	35.8	11.4
CK 60 B	7.0	9.0	8.3	127 (122–133)	60 (58–63)	20.6	6.5	68.4
IS 40618 - R	3.7	4.0	5.7	107 (102–116)	68 (63–78)	35.6	29.5	17.1
SWARNA - S	8.7	9.0	9.0	139 (137–142)	66 (64–70)	11.6	3.2	72.4
Mean	4.3	4.4	6.4	187 (167–204)	70 (67–76)	47.1	33.8	28.2
SE ±	0.2	0.4	0.6	8.0	1.0	5.0	4.3	–
Fp (58, 29)	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	–
LSD (P = 0.05)	1.2	1.2	1.8	31.0	4.0	14.2	12.3	–

R, resistant; S, susceptible checks.

[1]Damage rating (1 = a few aphids present on the lower 1–2 leaves, with no apparent damage to the leaves, and 9 = heavy aphid infestation up to the flag leaf, and >80% of the leaves showing aphid damage (drying up symptoms), heavy honeydew/black moulds on the leaves, and on the soil below).

323 had moderate levels of resistance to aphid damage (DR <5.8) and also had high grain yield potential (>27.5 q/ha) (Fig. 2a). On the contrary, the genotypes C 43, ICSB 205, ICSR 161, Line 61510, Hathi Kuntha, ICSB 695, CK 60 B and Swarna were susceptible to *M. sacchari* and also exhibited low grain yield under aphid infestation. ICSV 12001 showed resistance to aphid damage, but had a relatively low grain yield potential. Principal coordinate analysis based on aphid damage rating, plant height, days to 50% flowering and grain yield under natural and artificial infestation and percentage loss in grain yield indicated that most of the genotypes exhibiting resistance to *M. sacchari* and high grain yield potential were placed in group B, while RSV 1093 was placed in group A (Fig. 2b).

The genotypes ICSR 165, ICSB 724, ICSB 215, DSV 5, IS 40618 and IS 40615 suffered <25% loss in grain yield and also exhibited moderate levels of resistance to aphid damage (DR <5.8), while Swarna, CK 60 B, Line 61510, ICSR 161 and Long SPS 43 suffered >40% loss in grain yield and also exhibited high susceptibility to aphid damage (Fig. 3). The genotypes ICSV 12001, ICSV 12004, ICSB 321 and ICSB 323 exhibited resistance to aphid damage, but suffered high loss in grain yield under artificial infestation; while RSV 1211, RS 29, RSV 1338, EC 8-2, PU 10-1, IS 40617 and ICSB 695 though were susceptible to aphid damage, but suffered relatively low loss in grain yield.

Under natural infestation, aphid damage ratings explained only 16% of the variation in grain yield (Y) [Y = 56.05-3.49X (R^2 = 16.7%)]; while under artificial infestation, aphid damage ratings explained 20% of the variation in grain yield loss [Y = −3.80 + 5.24X (R^2 = 20%)]. The results suggested that grain yield potential and loss in grain yield are not directly linked to aphid damage under natural and artificial infestation and that it is possible to combine high grain yield potential with resistance/tolerance to the sugarcane aphid, *M. sacchari*.

Evaluation of advanced breeding lines for resistance to sugarcane aphid, *M. sacchari* under natural infestation

Of the 31 lines evaluated for resistance to sugarcane aphid, *M. sacchari* resistance, 13 lines (ICSV 12003, ICSV 12004, ICSV 12005, IS 40615, SLR 8, SLR 28, SLR 31, SLR 39, SLV 25, IS 33722, EC 8-2, PU 10-1 and DJ 6514) showed moderate levels of resistance (damage scores <4.5 in at least 3 out of 4 tests) as compared to 3.8–6.0 of the resistant check, IS 40618,

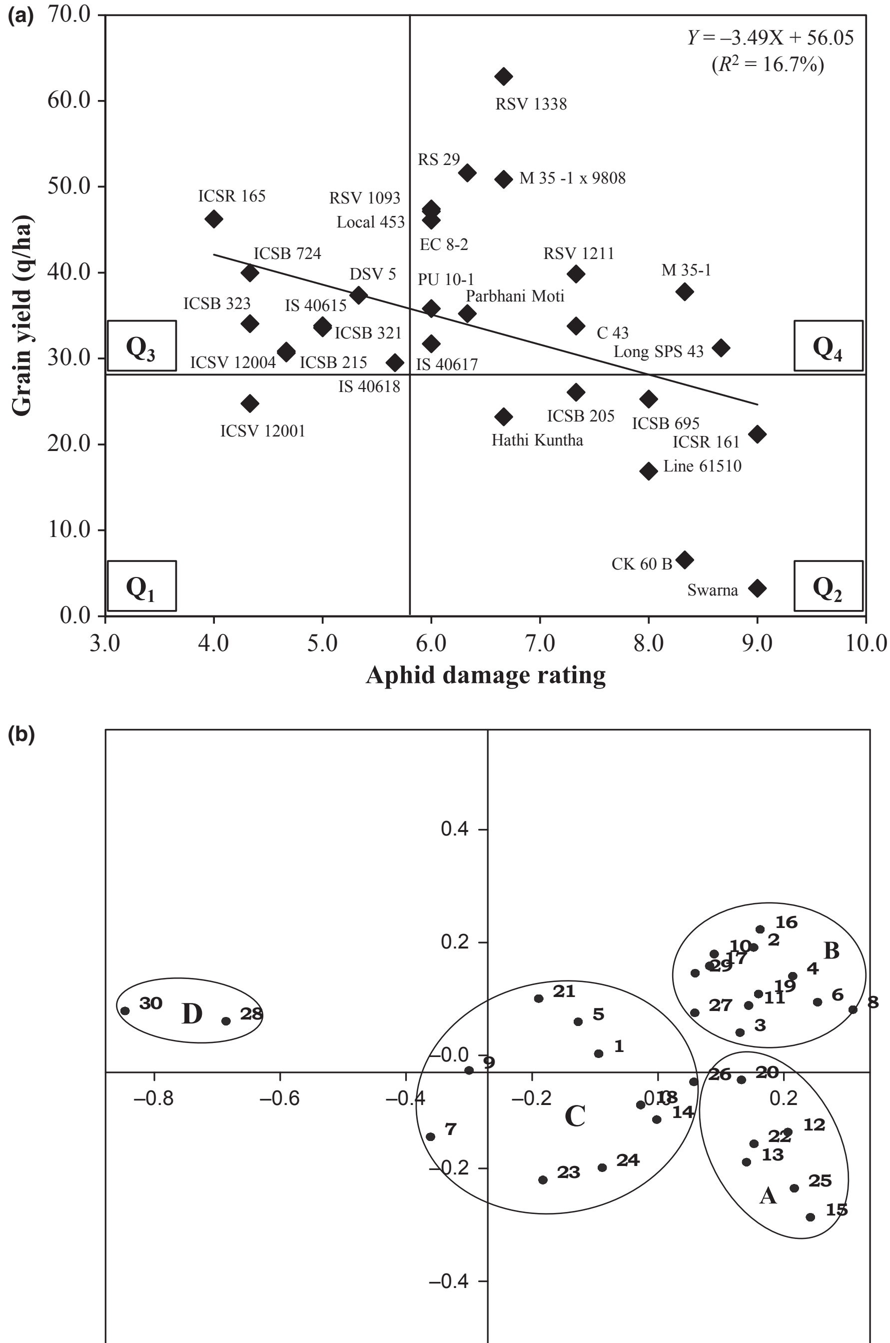

Fig. 2: (a) Relationship between sugarcane aphid *M. sacchari* damage and grain yield under artificial infestation in 30 sorghum genotypes. (b) Diversity among the 30 sorghum genotypes (principal component analysis) based on sugarcane aphid, *M. sacchari* damage under natural and artificial infestation and agronomic traits. (1 = ICSB 205; 2 = ICSB 215; 3 = ICSB 321; 4 = ICSB 323; 5 = ICSB 695; 6 = ICSB 724; 7 = ICSR 161; 8 = ICSR 165; 9 = Line 61510; 10 = ICSV 12001; 11 = ICSV 12004; 12 = RS 29; 13 = RSV 1093; 14 = RSV 1211; 15 = RSV 1338; 16 = IS 40615; 17 = IS 40617; 18 = C 43; 19 = DSV 5; 20 = EC 8-2; 21 = Hathi Kuntha; 22 = Local 453; 23 = Long SPS 43; 24 = M 35-1; 25 = M 35-1 × 9808; 26 = Parbhani Moti; 27 = PU 10-1; 28 = CK 60 B; 29 = IS 40618 (TAM 428 - R); 30 = Swarna - S)

and 6.7–8.1 of the susceptible check, Swarna (Table 3). Severity of aphid damage was greater during the rainy season under natural infestation, which may be because of prolonged duration of crop growth and interaction with leaf diseases. The aphid-resistant lines were poor agronomically, except ICSV 12003, ICSV 12004 and IS 40615, which had agronomic scores of 2.1, 2.4 and 2.0, respectively. The aphid damage scores under natural and artificial infestation were positively correlated (r = 0.80**, significant at P 0.01), but negatively correlated with agronomic scores (r = −0.56*, significant at P 0.05). Principal coordinate analysis based on aphid damage ratings and grain yield under natural and artificial infestation, and agronomic score indicated that of the genotypes exhibiting resistance to aphids under natural and artificial infestation, ICSV 12004 and ICSV 12005

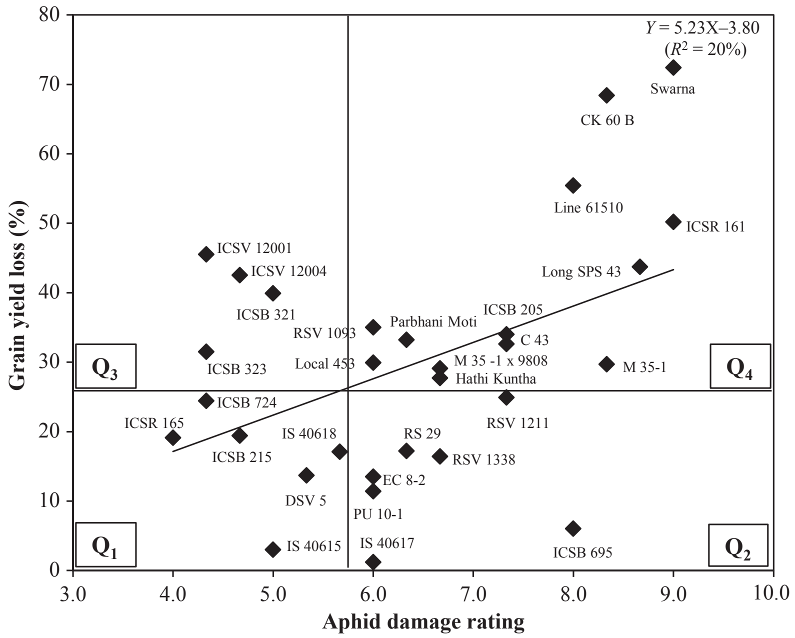

Fig. 3: Relationship between sugarcane aphid *M. sacchari* damage and grain yield loss (%) under artificial infestation in 30 sorghum genotypes

Table 3: Relative susceptibility of sorghum breeding lines under natural and artificial infestation (ICRISAT, rainy and post rainy seasons)

	Aphid damage rating[1]				
	Natural infestation		Artificial infestation		
Genotype	Rainy season Mean ± SE	Postrainy season Mean ± SE	Rainy season Mean ± SE	Postrainy season Mean ± SE	Agronomic score* Mean ± SE
Line 61510	4.6 ± 0.56	4.4 ± 0.99	4.7 ± 1.58	5.0 ± 1.54	2.0 ± 0.31
ICSV 12001	5.2 ± 0.68	3.0 ± 0.33	5.3 ± 1.81	2.8 ± 0.59	2.5 ± 0.38
Line 61579	5.8 ± 0.40	5.7 ± 0.84	5.3 ± 1.81	5.0 ± 0.88	1.9 ± 0.32
ICSV 12002	5.4 ± 0.20	4.6 ± 0.80	4.3 ± 1.47	4.0 ± 0.19	1.7 ± 0.29
ICSV 12003	5.1 ± 0.59	3.6 ± 0.68	4.0 ± 1.36	3.4 ± 0.59	2.1 ± 0.32
ICSV 12004	4.4 ± 0.53	2.7 ± 0.51	3.3 ± 1.13	3.0 ± 0.33	2.4 ± 0.36
ICSV 12005	3.6 ± 0.22	3.3 ± 0.51	3.0 ± 1.02	4.1 ± 1.54	2.9 ± 0.44
Line 61602	5.8 ± 0.40	4.6 ± 0.80	4.7 ± 1.58	4.4 ± 0.91	2.0 ± 0.32
IS 40615	5.8 ± 0.40	4.1 ± 0.59	4.0 ± 1.36	3.0 ± 0.58	2.0 ± 0.31
IS 40616	5.8 ± 0.67	5.0 ± 0.69	5.3 ± 1.81	4.1 ± 1.06	2.5 ± 0.39
IS 40617	6.3 ± 0.19	4.8 ± 0.78	4.7 ± 1.58	3.9 ± 0.59	2.4 ± 0.37
IS 40620	3.7 ± 0.19	4.9 ± 1.28	3.0 ± 1.02	6.8 ± 2.22	4.0 ± 0.61
SLR 8	4.4 ± 0.06	3.8 ± 0.29	4.0 ± 1.36	5.0 ± 1.64	4.4 ± 0.67
SLR 27	4.6 ± 0.29	4.4 ± 0.73	4.0 ± 1.36	5.0 ± 1.50	4.4 ± 0.67
SLR 28	4.5 ± 0.54	4.0 ± 0.39	4.0 ± 1.36	5.3 ± 1.71	4.3 ± 0.66
SLR 31	4.6 ± 0.22	4.2 ± 0.68	4.3 ± 1.47	4.2 ± 1.13	4.4 ± 0.66
SLR 35	4.8 ± 0.11	4.1 ± 0.87	3.7 ± 1.25	4.9 ± 1.44	3.7 ± 0.56
SLR 39	4.3 ± 0.19	4.0 ± 0.33	4.0 ± 1.36	4.3 ± 1.02	4.5 ± 0.69
SLR 41	5.2 ± 0.67	4.0 ± 0.69	4.3 ± 1.47	4.7 ± 1.35	4.6 ± 0.70
SLV 25	4.3 ± 0.38	3.9 ± 0.29	4.0 ± 1.36	4.4 ± 1.28	4.6 ± 0.70
IS 33722	4.6 ± 0.20	3.8 ± 0.48	4.0 ± 1.36	4.1 ± 1.06	4.4 ± 0.68
IS 3420	4.4 ± 0.29	4.2 ± 0.68	4.7 ± 1.58	4.7 ± 1.20	4.1 ± 0.63
EC 8-2	4.6 ± 0.29	3.7 ± 0.58	4.0 ± 1.36	4.1 ± 0.91	4.3 ± 0.66
PU 10-1	4.0 ± 0.19	3.6 ± 0.22	4.0 ± 1.36	4.3 ± 1.17	4.5 ± 0.69
IS 21807	6.3 ± 0.19	6.1 ± 0.44	5.7 ± 1.92	7.2 ± 1.61	2.2 ± 0.34
IS 21808	5.6 ± 0.56	5.2 ± 0.29	5.0 ± 1.70	6.6 ± 1.95	2.4 ± 0.37
DJ 6514	3.6 ± 0.29	4.2 ± 0.73	4.0 ± 1.36	5.4 ± 1.66	3.4 ± 0.54
ICSV 745	4.6 ± 0.29	5.4 ± 0.99	4.0 ± 1.36	6.9 ± 1.46	2.2 ± 0.33
CK 60 B	7.0 ± 2.34	5.0 ± 1.67	6.7 ± 2.26	4.3 ± 1.44	2.3 ± 0.34
IS 40618 - R	6.0 ± 0.58	3.8 ± 0.40	5.3 ± 1.81	4.0 ± 0.58	2.2 ± 0.34
SWARNA - S	7.2 ± 0.17	8.1 ± 0.89	6.7 ± 2.26	7.8 ± 1.22	1.9 ± 0.29
Mean	5.0	4.4	4.5	4.8	3.1
SE ±	0.4	0.5	0.5	0.7	0.2
Fp (60, 30)	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (P = 0.05)	1.1	1.4	1.3	1.9	0.5

R, resistant; S, susceptible checks.
[1]Damage rating (1 = a few aphids present on the lower 1–2 leaves, with no apparent damage to the leaves, and 9 = heavy aphid infestation up to the flag leaf, and >80% of the leaves showing aphid damage (drying up symptoms), heavy honeydew/black moulds on the leaves and on the soil below).
*Agronomic score (1 = Good, 5 = poor).

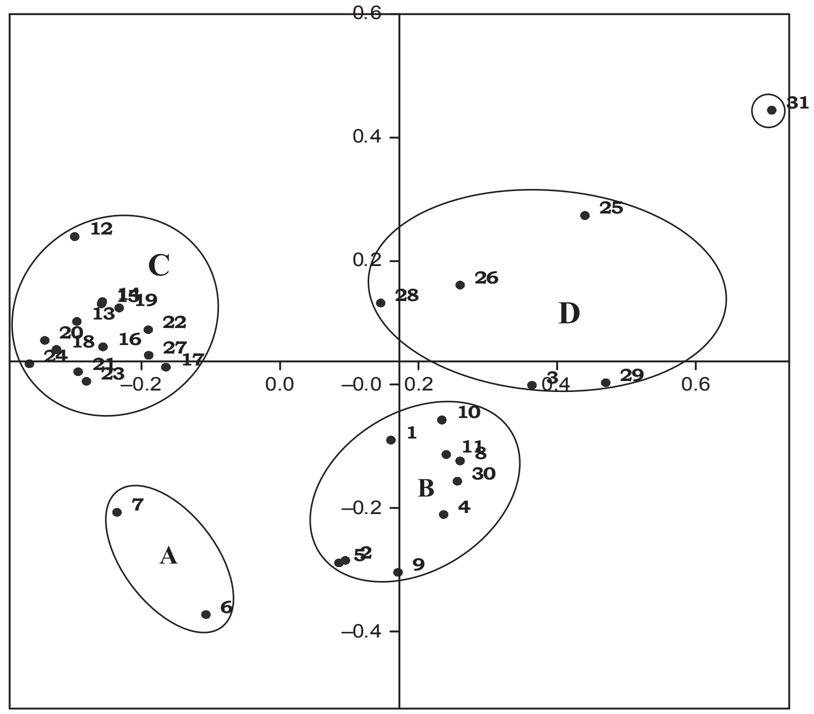

Fig. 4: Diversity among the 31 sorghum breeding genotypes (principal component analysis) based on sugarcane aphid, *M. sacchari* damage under natural and artificial infestation and agronomic traits. (1 = Line 61510; 2 = ICSV 12001; 3 = Line 61579; 4 = ICSV 12002; 5 = ICSV 12003; 6 = ICSV 12004; 7 = ICSV 12005; 8 = Line 61602; 9 = IS 40615; 10 = IS 40616; 11 = IS 40617; 12 = IS 40620; 13 = SLR 8; 14 = SLR 27; 15 = SLR 28; 16 = SLR 31; 17 = SLR 35; 18 = SLR 39; 19 = SLR 41; 20 = SLV 25; 21 = IS 33722; 22 = IS 3420; 23 = EC 8-2; 24 = PU 10-1; 25 = IS 21807; 26 = IS 21808; 27 = DJ 6514; 28 = ICSV 745; 29 = CK 60 B; 30 = IS 40618 (TAM 428 - R); 31 = Swarna - S)

were placed in group A, ICSV 12003 and IS 40615 in group B, while the rest of the genotypes were placed in group C (Fig. 4).

Discussion

Of the 30 lines evaluated for resistance to sugarcane aphid across seasons and locations, seven lines exhibited moderate levels of resistance to aphid damage, of which Line 61510, ICSV 12001, IS 40618 and Long SPS 43 were more stable in expression of resistance to aphid damage. The genotypes ICSB 215, ICSB 695, ICSR 161, Line 61510, ICSV 12004, Parbhani Moti and IS 40618 exhibited high grain yield potential (>25q/ha) and <50% variation in grain yield as compared to >80% variation in CK 60 B under aphid infestation. In another experiment, 13 lines (ICSV 12003, ICSV 12004, ICSV 12005, IS 40615, SLR 8, SLR 28, SLR 31, SLR 39, SLV 25, IS 33722, EC 8-2, PU 10-1 and DJ 6514) showed moderate levels of resistance to *M. sacchari* across testing regimes and seasons. However, the agronomic desirability of these lines was poor, except ICSV 12003, ICSV 12004 and IS 40615. The genotypes RSV 1211, RS 29, RSV 1338, EC 8-2, PU 10-1, IS 40617 and ICSB 695 showed a susceptible reaction to aphid damage, but suffered relatively low loss in grain yield, suggesting that these lines have tolerance to feeding by *M. sacchari*. In earlier studies, sorghum hybrid CSH 16 has been reported to be resistant to *M. sacchari* in India (Ghuguskar et al. 1999) and PAN 8446, SNK 3939 and NS 5511 in South Africa (van den Berg 2002). The midge-resistant genotypes ICSV 197, ICSV 745 and ICSV 112, which have moderate levels of resistance to *M. sacchari*, also had low population of aphids (Sharma and Dhillon 2005).

The genotypes ICSR 165, ICSB 724, IS 40615, DSV 5 and ICSB 323 exhibited moderate levels of resistance to aphid damage and high grain yield potential (>30 q/ha) across locations. ICSR 165, ICSB 323, ICSB 724, ICSB 215 and IS 40615 suffered <30% loss in grain yield and also exhibited moderate levels of resistance to aphid damage. There was a positive association between aphid damage scores under natural and under artificial infestation inside the nylon net, suggesting that artificial infestation inside the nylon net is useful to screen for resistance to *M. sacchari*. A negative correlation was observed between agronomic scores and susceptibility to *M. sacchari*, but grain yield potential and loss in grain yield were not associated with aphid damage, suggesting that it is possible to combine high grain yield potential with low susceptibility to *M. sacchari*.

Both winged and apterous forms exhibit a strong preference for susceptible sorghums (Kawada 1995), and the nymphal development is prolonged in resistant sorghums, in addition to reduced longevity and fecundity (Liu et al. 1990, Kawada 1995). Therefore, there is a need to assess the role of antixenosis, antibiosis and tolerance components of resistance to *M. sacchari* to identify lines with diverse mechanisms/genes for resistance to this insect. Aphid numbers increase at a faster rate on genotypes with high amounts of nitrogen, sugar, free amino acids and total chlorophyll content (Mote and Shahane 1994, Tsumuki et al. 1995); while genotypes with high phosphorus, potassium and polyphenol content are less preferred by the aphids (Mote and Shahane 1994). Aconitic acid has been shown to have antifeedant effect on aphids (Rustamani et al. 1992). Aphid infestation resulted in an 18.5–55.8% decrease in total phenol content over the healthy leaves, suggesting induction of stress in aphid-infested plants (Sharma and Dhillon 2005). There is a need to have a critical look at the role of biochemical components of the host plant in conferring resistance to *M. sacchari*, and the effect of aphid damage on the stalk and juice quality of sweet sorghums and fodder/grain quality of the dual-purpose sorghums.

Cytoplasmic male sterility influences the expression of resistance to *M. sacchari* (Dhillon et al. 2006), and the restorer lines have a greater effect on the expression of resistance to *M. sacchari* in the F_1 hybrids (Sharma et al. 2006). Therefore, we need to develop restorer lines with high levels of resistance to *M. sacchari* to produce hybrids with resistance to this insect. Principal coordinate analysis suggested that the genotypes with aphid resistance are quite diverse and can be used to breed for aphid resistance and high grain yield potential. The genotypes ICSV 12004, ICSV 12005, ICSB 215, ICSR 165, IS 40615 and IS 40618 exhibited resistance to aphid damage and also suffered low loss in grain yield, and these can be used to breed for aphid-resistant sorghums with adaptation to postrainy season. There is need to assess relative contribution of various morphological and biochemical traits in conferring resistance to *M. sacchari* and use them as marker traits to select for resistance to this pest. Information on sources and mechanisms of resistance will also be useful for gene pyramiding to increase the levels and diversify the basis of resistance to *M. sacchari*.

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References

van den Berg, J., 2002: Status of resistance of sorghum hybrids to the aphid, *Melanaphis sacchari* (Zehntner) (Homoptera: Aphididae). S. Afr. J. Plant Soil **19**, 151—155.

van den Berg, J., A. J. Pretorius, and M. van Loggerenberg, 2003: Effect of leaf feeding by *Melanaphis sacchari* (Zehntner) (Homoptera: Aphididae), on sorghum grain quality. S. Afr. J. Plant Soil **20**, 41—43.

Borad, P. K., and V. P. Mittal, 1983: Assessment of losses caused by pest complex of sorghum hybrid, CSH-5. In: B. H. Krishnamurthy Rao, and K. S. R. K. Murthy (eds), Crop Losses due to Insect Pests, 271—278. Entomological Society of India, Rajendranagar, Hyderabad, India.

Daware, D. G., V. R. Bhagwat, P. P. Ambilwade, and R. J. Kamble, 2012: Evaluation of integrated pest management components for the control of sorghum shoot pests in rabi season. Indian J. Entomol. **74**, 58—61.

Dhillon, M. K., H. C. Sharma, G. Pampapathy, and B. V. S. Reddy, 2006: Cytoplasmic male-sterility affects expression of resistance to shoot bug, *Peregrinus maidis*, sugarcane aphid, *Melanaphis sacchari*, and spotted stem borer, *Chilo partellus* in sorghum. Int. Sorghum Millets Newsl. **47**, 66—68.

Fang, M. N., 1990: Population fluctuation and timing for control of sorghum aphid on variety Taichung 5. Bull. Taichung Dist. Agric. Improv. Stn. **28**, 59—71.

Ghuguskar, H. T., R. V. Chaudhari, and N. V. Sorte, 1999: Evaluation of sorghum hybrids for tolerance to aphids, *Melanaphis sacchari* (Zehntner) in field conditions. PKV Res. J. **23**, 55—56.

Hagio, T., 1992: Host plant resistance and its inheritance in sorghum to sugarcane aphid (*Melanaphis sacchari* Zehntner). Bull. Chugoku Natl Agric. Exp. Stn. **10**, 17—26.

ICRISAT. 1992: The Medium Term Plan. Volume II. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India.

Jotwani, M. G., W. R. Young, and G. L. Teetes, 1980: Elements of integrated control of sorghum pests. FAO Plant Production and Protection Paper. Food and Agriculture Organization, Rome, Italy.

Kawada, K., 1995: Studies on host selection, development and reproduction of *Melanaphis sacchari* (Zehntner). Bull. Res. Inst. Bioresour. Okayama Univ. **3**, 5—10.

Liu, J., F. G. He, G. M. Qu, and G. X. Zhang, 1990: The effect of resistant sorghum on the fecundity and mortality of the sorghum aphid. Acta Phytophylactica Sinica **17**, 343—347.

Meksongsee, B., and M. Chawanapong, 1985: Breeding sorghum for resistance to shoot fly and midge. In: V. Kumble (ed.), Proceedings, International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, Texas, USA, 57—64. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, Andhra Pradesh, India.

Mote, U. N., and A. K. Shahane, 1994: Biophysical and biochemical characters of sorghum varieties contributing resistance to delphacid, aphid and leaf sugary exudations. Indian J. Entomol. **56**, 113—122.

Raetano, C. G., and O. Nakano, 1994: Influence of climatic conditions on the occurrence of sugarcane aphid, *Aphis sacchari* (Zehntner) (Hemiptera: Aphididae) on sugarcane. Cient. Jaboticabal **22**, 303—306.

Rustamani, M. A., K. Kanehisa, H. Tsumuki, and T. Shiraga, 1992: Further observations on the relationship between aconitic acid contents and aphid densities on some cereal plants. Bull. Res. Inst. Bioresour. Okayama Univ. **1**, 9—20.

Sarath Babu, B., H. C. Sharma, A. Surender, R. D. V. J. Prasada Rao, S. K. Chakravarty, S. D. Singh, and G. A. Girish, 2000: Sorghum germplasm from Thailand showing resistance to sugarcane aphid, *Melanaphis sacchari* Zehntner. Indian J. Plant Genet. Resour. **13**, 186—187.

Sharma, H. C., 1985: Future strategies for pest control in sorghum in India. Trop. Pest Manag. **31**, 167—185.

Sharma, H. C., 1993: Host–plant resistance to insects in sorghum and its role in integrated pest management. Crop Prot. **12**, 11—34.

Sharma, H. C., and M. K. Dhillon, 2005: Reaction of different sorghum genotypes to infestation by the sugarcane aphid, *Melanaphis sacchari* Zehntner. Indian J. Entomol. **67**, 291—296.

Sharma, H. C., F. Singh, and K. F. Nwanze (eds), 1997: Plant Resistance to Insects in Sorghum. ICRISAT, Patancheru 502 324, Andhra Pradesh, India.

Sharma, H. C., M. K. Dhillon, and G. Pampapathy, 2006: Multiple resistance to sorghum shoot fly, spotted stem borer, and sugarcane aphid in sorghum. Int. J. Trop. Insect Sci. **26**, 239—245.

Sharma, H. C., S. P. Sharma, and R. S. Munghate, 2013: Phenotyping for resistance to the sugarcane aphid *Melanaphis sacchari* (Hemiptera: Aphididae) in *Sorghum bicolor* (Poaceae). Int. J. Trop. Insect Sci. (in press).

Smith, G. R., Z. Borg, B. E. L. Lockhart, K. S. Braithwaite, and M. J. Gibbs, 2000: Sugarcane yellow leaf virus: a novel member of the *Luteoviridae* that probably arose by inter-species recombination. J. Gen. Virol. **81**, 1865—1869.

Tsumuki, H., K. Kanehisa, and S. S. Moharramipour, 1995: Sorghum resistance to the sugarcane aphid, *Melanaphis sacchari* (Zehntner) amounts of leaf surface wax and nutritional components. Bull. Res. Inst. Bioresour. Okayama Univ. **3**, 27—34.