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Full Length Research Paper

Novel source of sorghum tolerance to the African stem borer, *Busseola fusca*

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Sorghum (*Sorghum bicolor*) is an important cereal food crop in semi-arid tropics, but its productivity is curtailed mainly by insect pests and diseases. The African stem borer, *Busseola fusca* Fuller (Lepidopteran: Noctuidae), is among the most injurious pests of sorghum in sub-Saharan Africa and is responsible for >15% sorghum grain yield losses. Sorghum from India with records of stem borer invasion could provide supplementary and novel resources of tolerance to this pest. Utilization of tolerant varieties in combination with other methods of control is likely to offer a sustainable strategy for *B. fusca* management in sorghum production. The objective of this study was to evaluate several local and exotic sorghum genotypes for tolerance to *B. fusca*. Genotype Swarna from India which is known to be susceptible to *Chilo partellus* was used as a susceptible check. There is limited information regarding tolerant/resistant sorghum to *B. fusca*. Seven commercial cultivars and 20 introductions from India were evaluated for *B. fusca* tolerance at Kabete, in central province of Kenya, during long and short rainy seasons in 2010. Selection index were based on leaf damage, dead hearts, exit holes and stem tunneling. The following genotypes named ICSA 467, ICSA 473, MACIA and ICSB 464 were found to be the most tolerant to *B. fusca.* These tolerant genotypes, can be used as novel sources of tolerance, and could be introgressed into the local common varieties since they are well adapted to the local environment.

Key words: *Busseola fusca*, *Sorghum bicolor*, resistance, tolerance, Kenya.

INTRODUCTION

Sorghum (*Sorghum bicolor* [L.] Moench [Poaceae]) production is affected by numerous insect pests such as shoot fly, *Atherigona soccata* Rondani (Diptera: Muscidae), midge, *Stenodiplosis sorghicola* Coquillett (Diptera: Cecidomyiidae), stem borers, *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) and *Busseola fusca* Fuller (Lepidopteran: Noctuidae), green bug, *Schizaphis graminum* Rondani (Hemiptera: Aphididae), head bugs, *Calocoris angustatus* Lethiery (Hemiptera: Miridae) and *Eurystylus oldi* Poppius (Hemiptera: Miridae), and aphids, *Rhopalosiphum maidis* L. (Homoptera: Aphididae) and *Melanaphis sacchari* Zhent (Homoptera: Aphididae) (Dhillon et al., 2005). *B. fusca,* (Lepidopteran: Noctuidae) is an economically important pest of maize, sorghum and pearl millet in sub-Saharan Africa (Kfir et al., 2002). This pest is more important at high altitudes, but co-exists in mid-altitude zones of Kenya with *C. partellus*, another economically important stem borer introduced into Africa from Asia (De Groote et al., 2002; Wale et al., 2006).

Stem borers reduce grain yield through leaf feeding, dead heart formation and stem damage (Karaya et al., 2009). The larvae of *B. fusca* infest sorghum at the seedling stage and thrive till maturity, resulting in substantial loss in grain yield (Sally et al., 2007). The larvae remain protected inside the stems, and thus, are less vulnerable to insecticides and natural enemies (Muhammad et al., 2009). *B. fusca* reduce grain yield by

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more than 15% depending on the pest population density at the time of attack, crop age, and variety (Karaya et al., 2009).

Generally, studies on insect resistance have lagged behind disease resistance due to the extensive use of pesticides and the complex nature of insect-host plant resistance interactions (Songa et al., 2001). In Kenya, much attention has been accorded to *C. partellus,* an introduced pest from Asia consequently neglecting other indigenous economically important stem borers. Research on management of *B. fusca* in sorghum has mainly focused on cultural control, predominantly intercropping, fertilizer use, and recently, genetic engineering (Chabi-Olaye et al., 2005; Markus and Gurling, 2006; Amsalu et al., 2008). Other *B. fusca* management components are host plant resistance, biological control, synthetic pheromones, and chemical insecticides (Songa et al., 2001; Amsalu et al., 2008). However, many sub-Saharan farmers have not adopted majority of these methods owing to their impracticability and cost in-effectiveness.

A major component of integrated pest management strategy in cereals is the use of host plant resistance (Odiyi, 2007). Host plant resistance is an effective, economical and environmentally friendly approach to manage insect pests and diseases (Karaya et al., 2003). Painter (1951) recognized three mechanisms of resistance namely antibiosis, non-preference (antixenosis) and tolerance. Antibiosis refers to a situation where the plant exerts adverse influences on growth and survival of the insect. Antibiosis expressed in terms of larval mortality, slow growth, and delayed development is an important component of resistance to stem borers in sorghum (Kumar et al., 2005). Non preference is where the plant exerts adverse effects on the insect's behavior. Waxes protect plants against desiccation, insect predation, disease and may also physically prevent the movement of an insect across leaf surface. Trichomes affect stem borers behavior by providing a barrier that prevents the insects from landing on the plant, prevent movement and feeding (Muhammad et al., 2009). Tolerance or recovery resistance is where the plant is capable of supporting, without loss of yield or quality, a population of insect pests which would damage a susceptible variety (John et al., 1994). Tiller production in sorghum following damage to the main plant by stem borers is a component of recovery resistance (Kishore et al., 2007). Efforts are continuing to identify sources of stem borer resistance, but high levels of resistance have not been reported (Kfir et al., 2002: Singh et al., 2011). The objective of this study was to identify sorghum sources of tolerance to *B. fusca*.

MATERIALS AND METHODS

Experimental site

Evaluation of sorghum genotypes for tolerance against *B. fusca* was conducted in Nairobi at the University of Nairobi, Kabete campus field station. The experiments were carried out in 2010 during long and short rainy seasons. Kabete lies at latitude of 1° 15" South and longitude of 36° 44" East at an altitude of about 1940 m above mean sea level (Franzel et al., 1999). The long rains fall from March to June, while the short rains occur from October through December. Daily maximum temperatures range from 16 to 23°C (Franzel et al., 1999).

Experimental material and design

To identify sources of tolerance to *B. fusca*, seven East African commercial sorghum cultivars and twenty introduced cultivars from India were used in this study (Table 1). The reason for including exotic sorghum materials was to assess if they possess some level of resistance to this borer. MACIA, KARI MTAMA I and GADAM-E1 HAMAM have good processing qualities for making beer by Kenya Breweries Company. Along with SEREDO, these varieties are preferred by the farmers, and their grain and stover are utilized for food and feed, respectively. The rest of the genotypes evaluated are breeding materials from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

The test material was sown in an α-lattice design, consisting of nine plots in three blocks, replicated twice. The rows were 2 m long and 0.75 m apart, and the spacing between plants within rows was 0.25 m. Recommended practices were followed to raise the crop. First instar neonates of *B. fusca* used in this study were obtained from the International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya.

For each sorghum cultivar, at 30 days after sowing, five plants in each row were artificially infested with five larvae/plant using a camel hairbrush. To avert drowning of larvae in the water held in leaf whorls, sorghum seedling whorls were tapped gently before infestation. Infestation was carried out early in the morning to encourage larval survival.

Parameters evaluated

Stem borer damage in plants

The observations on leaf damage were recorded on per plant basis at two and four weeks after artificial infestation. Percentages of plants with leaf damage were computed by expressing the number of plants showing pinholes damage as a percentage of the total number of plants sampled. Five plants within each row were tagged to indicate the plants for infestation and data was taken systematically from these five marked plants.

Observations on deadheart formation were recorded at 2 and 4 weeks after infestation. Deadheart incidence was computed by expressing the number of plants showing deadhearts as a percentage of the total number of plants sampled. The tagged five plants within each row that were artificially infestation were monitored and data was taken systematically from the five marked plants. At harvest, the number of stem borer exit holes on the stem was counted on each of the five sampled plants. The main stem of plants infested with *B. fusca* larvae were split open from the base to the apex, and the cumulative tunnel length measured in centimeters.

Susceptibility parameters (leaf damage, deadheart incidence, stem tunneling and exit holes) were employed to define the reaction of the sorghum genotypes to *B. fusca*. A selection index based on the four damage parameters considered that is, leaf damage, deadheart incidence, stem tunneling and exit holes was computed by adding the ratios between the genotypic values and the overall mean, and dividing by 4 (number of damage parameters considered) (Tadele et al., 2011).

Table 1. List of sorghum genotypes evaluated for resistance to *B. fusca* at Kabete, Kenya (2010 long and short rainy seasons).

S/N	Genotype name	Pedigree	Source
1	ICSA 464	[(ICSB 11 X ICSV 702)XPS 19349B]5-1-2-2	India
2	ICSB 464	[(ICSB 11 X ICSV 702)XPS 19349B]5-1-2-2	India
3	ICSA 467	[(ICSB 11 X ICSV 700)XPS 19349B]XICSB 13]4-1	India
4	ICSB 467	[(ICSB 11 X ICSV 700)XPS 19349B]XICSB 13]4-1	India
5	ICSA 472	(ICSB 51 X ICSV 702)7-3-1	India
6	ICSB 472	(ICSB 51 X ICSV 702)7-3-1	India
7	ICSA 473	(ICSB 102 X ICSV 700)5-2-4-1-2	India
8	ICSB 473	(ICSB 102 X ICSV 700)5-2-4-1-2	India
9	ICSA 474	(IS 18432 X ICSB 6)11-1-1-2-2	India
10	ICSB 474	(IS 18432 X ICSB 6)11-1-1-2-2	India
11	IS 21879	IS 21879	India
12	IS 21881	IS 21881	India
13	IS 27329	IS 27329	India
14	SWARNA	SWARNA	India
15	DJ 6514	DJ 6514	India
16	TAM 2566	TAM 2566	India
17	IS 2205	IS 2205	India
18	IS 1044	IS 1044	India
19	ICSV 700	(IS 1082 X SC 108-3)-1-1-1-1-1	India
21	IS 8193	IS 8193	India
20	SEREDO	SEREDO	Kenya
22	KARI-MTAMA 1	KARI-MTAMA 1	Kenya
23	GADAM-E1 HAMAM	GADAM-E1 HAMAM	Kenya
24	MACIA	MACIA	Kenya
25	IESV 91104 DL	IESV 91104 DL	Kenya
26	IESV 91131 DL	IESV 91131 DL	Kenya
27	IESV 93042 SH	IESV 93042 SH	Kenya

Morphological traits

These are characteristics of each genotype expressed independent to infestation. For these traits, sampling was done systematically and data was recorded from the five tagged sorghum plants within each row.

Leaf toughness was measured at 45 days after sowing using a penetrometer (Model FT011, ALFOSINE-Italy). The penetrometer was fitted with a 1 mm diameter tip, which was positioned on the leaf lamina, and the peak force required to puncture the leaf blade was recorded. Sorghum leaves from each of the five tagged plants were assessed for hardness using the device mentioned above. The 5th leaf from the base of each of the tagged plants was selected and 5 regions on the leaf lamina randomly pierced using the penetrometer and the peak force recorded. Leaf trichome density was measured on the 5th leaf from the base of each the five tagged plants in each genotype at 30 days after sowing. The leaf samples were well labeled, separated from the main plant, and placed in plastic bags in a cool box for observations in the laboratory. In Each leaf sample was removed from the plastic bag and put on a clean bench and was measured each at a time. A cork borer with a diameter of 1 cm was used to cut randomly 5 samples of leaf discs on each leaf lamina of the harvested leaves. The leaf samples were observed under a dissecting microscope (Model S111Z, England). The number of trichomes on the adaxial (upper) surface of each 1 cm diameter leaf disc sample were counted and expressed as trichome density/cm^2. Leaf glossiness was recorded at 30 days after sowing on a scale of 1 -5 where 1 = highly glossy, 3=moderately glossy, and 5=non glossy.

Seedling vigor was scored at 30 days after sowing on a scale of 1 – 5, where 1 = low vigor (plants showing minimum growth, less leaf expansion and poor adaptation; 3=Moderate vigor; 5=high vigor tall plants with expanded leaves and robustness).

Waxy bloom was recorded on a scale of 1 – 9, where 1= no bloom, 3 = slightly present, 5 = medium, 7 = mostly bloomy, 9 = completely bloomy at 50% flowering. At physiological maturity, plant height was measured in centimeters from the base of the plant to the tip of the panicle. Plant color was visually assessed on the leaf sheath on a scale of 1 – 2 where 1 = tan and 2 = pigmented. Time to panicle emergence was recorded as the number of days from the date of sowing to the date of panicle emerged in a plot.

Time to flowering was recorded as the number of days from the date of sowing to the date of anthesis of plants in a plot. Fifty percent flowering was considered since it is a distinct stage in flowering plants and in sorghum panicles flower from the top. The number of tillers with harvestable panicles was recorded on each plant sampled. After harvest, sorghum panicles were sun-dried and hand threshed. Total grain yield and hundred-grain mass were recorded for each of the sampled plants using a weighing balance (Mettler PM 6000, CH- 8606 GREIFENSEE-ZURICH, made in

Switzerland).

Statistical analysis

Data on percentages was arcsin transformed while that of counts was log transformed before analysis of variance. The computed mean values of all the traits for each replicate were used to compute the analysis of variance (ANOVA 1) using GenStat statistical soft ware (Genstat Release 12 Reference Manual, Part 1 Summary, 2009, VSN International, Hemel Hempstead HP1 1ES, United Kingdom).

Treatment means were compared using a protected Fishers' least significant difference test at P = 0.05. All parameters related to stem borer damage (leaf damage, deadhearts, stem tunneling and exit holes) were used to define reaction of sorghum genotypes to *B. fusca* damage. Selection index was calculated based on leaf damage, dead heart, stem tunneling and exit holes by adding the ratios between the values for each genotype and the overall mean for each parameter, and dividing by 4 (number of damage parameters considered) (Tadele et al., 2011). Pearson's correlation coefficients were computed to determine association between morphological characteristics with traits measuring plant reaction to *B. fusca* infestation.

RESULTS

Damages caused by *B. fusca* infestation

The analysis of variance indicated highly significant (P < 0.01) differences in leaf damage, dead heart formation, stem tunneling, exit holes, panicle length, dry panicle weight, total grain yield and hundred grain mass among the genotypes tested (Table 2). Genotypes observed to show low leaf damage were IS 27329, SWARNA, ICSA 474, IS 21879, ICSA 472, IS 2205 (in increasing order of leaf damage incidence). Genotypes ICSB 467 and ICSB 472 suffered the least dead heart damage (Table 2).

Genotypes that suffered low stem tunneling were ICSA 473, SEREDO, ICSB 464 and IESV 91131 DL (Table 2). The highest stem tunneling damage was observed in SWARNA, IS 8183 and IS 2205. Genotypes with fewer exit holes were SEREDO, ICSA 464 and ICSB 464 than TAM 2566, IS 8193 and SWARNA (Table 2). Plant height ranged from 181 to 78 cm on ICSV 700 and TAM 2566 with an average of 124 cm. Longer panicles were observed on IS 27329, KARI-MTAMA 1, ICSA 467 and IS 1044 while IS 2205, ICSA 474 and ICSA 472 had shorter panicles (Table 2). Highest and lowest dry panicle weight was recorded on ICSB 472 and GADAM respectively with an average of 46 g. High grain yield (> 49 g) were observed on IS 8193, ICSB 472, ICSB 474 and IS 1044 while lower grain yield was recorded on IESV 91131 DL, GADAM, MACIA and IS 27329 (< 20 g). Genotypes with high hundred grain mass were ICSB 474, KARI-MTAMA 1 and IS 1044 compared to IS 21879, ICSB 473 and DJ 6514 (Table 2). Based on the selection index, 26% of genotypes evaluated were categorized as resistant, 30% as moderately resistant, 33% moderately susceptible and 11% as susceptible (Table 2).

Morphological traits characterizing the sorghum genotypes during *B. fusca* infestation

Leaf glossiness, seedling vigour, leaf toughness, trichome density and tillering varied significantly (P ≤ 0.01) among the genotypes tested (Table 3). Leaf glossiness ranged from 1 to 4 (where 1 = highly glossy, 3= moderately glossy and 5 = non-glossy). Genotypes TAM 2566, SWARNA and KARI-MTAMA 1 were non-glossy, while ICSA 474, ICSA 464, ICSA 472, their respective maintainer lines, ICSV 700 and IS 1044 were highly glossy (Table 3).

Seedling vigor scores ranged from 2 to 4 [where 1 = low vigor (plants showing minimum growth, less leaf expansion and poor adaptation), 3=moderate vigor, and 5 = high vigor (plants showing maximum height, leaf expansion and robustness)]. Genotypes ICSA 467, IESV 93042 SH, IS 1044, KARI-MTAMA 1 and IS 8193 had greater vigor scores (this is, were more vigorous) than ICSA 472, ICSA 474 and DJ 6514 (Table 3). Greatest leaf toughness (≥0.1 kg) was recorded on ICSA 464, IS 2205, ICSB 464, DJ 6514, IESV 91104 DL, ICSV 700 while the least force (< 0.05 kg) was recorded on Seredo and IS 21881(Table 3). Genotypes ICSA 467, IESV 91104 DL, TAM 2566, ICSA 474 and ICSA 473, had high density of trichomes while ICSB 473, IS 2205, ICSB 464 and IS 27329 were essentially trichomeless. Bloom waxiness was not significantly different among genotypes evaluated (Table 3).

Correlations between morphological and damages parameters

Positive correlations between hundred grain mass and seedling vigor score (r = 0.6) (P= 0.002), hundred grain mass and grain yield per plant (r = 0.6) (P=0.002), hundred grain mass and dry panicle weight (r = 0.6) (P=0.004) and, hundred grain mass and dead heart damage (r = -0.5) (P=0.03) were highly significant (Table 4). Highly significant positive correlations was observed between grain yield and leaf damage (r = 0.5) (P= 0.03), grain yield and plant height (r = 0.6) (P= 0.007) and, grain yield and seedling vigor (r = 0.6) (P=0.002). Significant positive correlations were observed between bloom waxiness and grain yield (r = 0.4) (P= 0.09) and, bloom waxiness and leaf damage (r = 0.5) (P=0.03) (Table 4).

Negative correlations were observed between days to 50 % flowering and panicle length (r = -0.4) (P= 0.04). Negative relationship existed between leaf glossiness score and number of tiller (r = - 0.4) (P=0.04), and plant height (r = -0.6) (P=0.03) (Table 4). There was positive correlation between tillering and stem tunneling (r = 0.4) (P=0.05). Significant positive relationship was observed between seedling vigor score and stem tunneling (r = 0.4). A negative correlation was observed between dead heart damage and seedling vigor (r = -0.5) (P=0.01) and leaf damage (r = - 0.4) (P= 0.03) (Table 4). A significant

Table 2. Reaction of sorghum genotypes to *Busseola fusca* at Kabete, Kenya during 2010 rains.

Genotype	Dead heart (%)	Leaf damage (%)	stem tunneling (cm)	No. of exit hole	Selection index	Category	Plant height (cm)	Panicle length (cm)	Dry panicle weight (g)	Grain yield (g)	100 grain mass (g)
ICSB 467	16.4	67.5	0.0	0.0	0.4	R	113.4	20.9	35.5	24.8	2.0
ICSA 473	19.3	51.6	0.8	0.6	0.4	R	99.6	16.0	8.9	2.0	0.2
MACIA	21.6	54.5	1.7	0.0	0.5	R	101.1	17.9	32.8	18.0	2.9
IS 21881	45.0	53.7	0.0	0.0	0.5	R	91.3	20.9	40.7	25.2	2.5
ICSB 464	19.3	61.4	1.4	0.5	0.5	R	85.6	15.6	51.8	36.2	3.1
GADAM-E1 HAMAM	51.6	64.3	0.0	0.0	0.5	R	101.2	16.0	28.1	18.8	1.6
IESV91131 DL	16.4	57.7	1.4	1.2	0.5	R	86.6	19.5	32.4	19.2	2.4
IESV91104 DL	29.1	51.9	1.5	0.5	0.6	MR	136.7	18.2	62.6	47.4	3.4
ICSA 472	22.5	59.1	2.8	1.3	0.7	MR	151.7	14.0	7.2	3.8	1.7
ICSA 474	46.4	45.0	1.7	0.8	0.7	MR	114.7	14.3	24.2	9.4	1.2
IS 27329	70.4	13.3	0.0	0.0	0.7	MR	143.0	26.8	30.8	11.6	1.5
SEREDO	51.6	58.3	1.1	0.3	0.7	MR	117.9	20.1	46.2	28.1	3.4
ICSB 474	35.8	57.7	1.5	1.0	0.7	MR	168.9	17.9	76.1	50.2	4.7
ICSB 472	16.4	83.4	2.4	1.6	0.8	MR	164.1	15.9	93.3	59.7	3.5
ICSA 464	29.4	73.6	4.0	0.4	0.9	MR	104.2	20.0	15.1	5.4	0.8
KARI-MTAMA 1	29.1	64.6	6.4	1.4	1.0	MS	124.3	26.5	65.7	49.4	4.1
ICSA 467	22.5	67.5	6.9	2.4	1.1	MS	120.3	22.6	36.5	21.6	2.3
ICSB 473	45.0	73.6	4.1	1.7	1.1	MS	107.5	16.5	32.0	35.5	1.4
IESV930 SH	22.5	73.6	5.5	3.0	1.2	MS	138.5	18.9	57.4	42.0	3.9
IS 21879	45.0	45.0	4.5	2.5	1.2	MS	120.4	17.7	77.1	41.5	1.5
ICSV 700	45.0	61.4	5.4	2.8	1.2	MS	180.7	15.8	73.0	48.7	3.6
DJ 6514	73.6	58.3	4.1	2.1	1.4	MS	122.3	15.6	44.5	28.2	1.2
IS 1044 (R)	25.7	54.8	9.9	4.0	1.5	MS	153.2	21.4	76.3	49.4	4.1
IS 2205	22.5	45.6	11.2	4.3	1.6	MS	173.5	15.6	39.1	26.1	2.2
TAM 2566	51.6	64.3	7.6	4.3	1.6	S	77.6	17.7	32.9	21.8	2.7
SWARNA (S)	51.6	35.2	10.3	4.9	1.8	S	115.0	20.7	37.4	28.3	2.6
IS 8193	45.0	64.6	10.8	4.7	1.9	S	135.7	20.1	89.9	60.8	3.1
Mean	35.9	57.8	4.0	1.7	0.9		124.0	18.6	46.2	30.1	2.5
LSD (P=0.05)	24.70	19.27	5.02	2.56	0.92		34.65	4.91	21.18	16.76	0.90
P	<.001	<.001	<.001	<.001	0.04		<.001	<.001	<.001	<.001	<.001
CV	48.4	23.5	71	65.9	47.3		62	42.5	73.8	89.6	1.6

Selection index was calculated based on leaf damage, dead heart formation, exit holes and stem tunneling damage; R= Resistant, MR=moderately resistant, MS= Moderately susceptible, S=Susceptible

Table 3. Morphological traits governing resistance to *B. fusca* in 27 sorghum genotypes evaluated in 2010 rains at Kabete, Kenya.

Genotype	Leaf glossiness (1-5)	Seedling vigour score (1-5)	Leaf toughness (Kg force)	Trichome density (No./cm^2)	Bloom waxiness score (1-9)	Tillering
DJ 6514	4	2	0.10	0.2	6	0.4
ICSA 472	2	2	0.09	4.1	5	1.1
ICSA 473	3	2	0.08	6.7	7	1.4
ICSA 474	1	2	0.07	6.8	6	1.8
IS 27329	2	2	0.09	0.1	4	1.5
GADAM-1 El HAMAM	3	3	0.07	3.4	6	2.0
ICSA 464	2	3	0.15	0.6	7	1.0
ICSB 464	2	3	0.10	0.1	6	1.1
ICSB 467	3	3	0.07	2.1	7	0.8
ICSB 472	2	3	0.09	1.9	6	0.8
ICSB 473	4	3	0.10	0	6	1.0
ICSB 474	2	3	0.10	1.9	7	2.2
ICSV 700	2	3	0.10	2.1	6	1.8
IESV 91131 DL	4	3	0.07	1.4	7	0.3
IS 21879	2	3	0.08	0.2	7	0.2
IS 21881	4	3	0.05	1.7	6	1.0
IS 2205	2	3	0.10	0	5	3.6
MACIA	3	3	0.09	3.6	5	0.7
SEREDO	3	3	0.05	3.6	6	2.1
SWARNA	4	3	0.09	0.3	6	1.1
TAM 2566	4	3	0.09	7.2	6	0.8
ICSA 467	4	4	0.09	10.5	6	3.4
IESV 91104 DL	4	4	0.10	10.1	6	0.9
IESV 93042 SH	3	4	0.09	0.6	6	1.3
IS 1044	2	4	0.09	0.2	5	1.8
IS 8193	3	4	0.09	2.5	6	2.5
KARI- MTAMA 1	4	4	0.07	1.1	7	1.0
Mean	2.76	3.07	0.09	3.29	6	1.4
LSD (P=0.05)	1.366	1.346	0.077	1.517	2.463	1.1343
Significance	<.001	<.001	<.001	<.001	NS	<.001
CV (%)	24.1	3	4.7	5.5	5.2	6

Leaf glossiness scale of 1 – 5, where 1 = highly glossy, and 5 = non-glossy. Seedling vigor scale of 1 – 5, where 1 = low vigor and 5=high vigor. Waxy bloom scale of 1 – 9, where 1= no bloom, 3 = slightly present, 5 = medium, 7 = mostly bloomy, 9 = completely bloomy at 50% flowering.

correlation was observed between plant height and tillering (r = 0.4) (P=0.008). A positive relationship existed between leaf damage and seedling vigor (r = 0.4) (P= 0.06), leaf damage and panicle length (r = -0.5) (P=0.03). A highly significant relationship was observed between selection index and stem tunneling (r = 0.9) (P= <0.001) (Table 4). A remarkable significant correlation was observed between exit holes and selection index (P= <0.001) and exit holes and stem tunneling (P= <0.001).

DISCUSSION

This study identified sorghum genotypes with resistance to *B. fusca* based on leaf damage, deadheart formation, stem tunneling and exit holes following artificial infestation of seedling whorls with stem borer neonates. The mechanism of this resistance to stem borer damage was mainly tolerance since some genotype produced substancial grain yield after supporting high leaf damages, dead hearts and stem tunnelling damages. Genotype IS 2205, previously reported resistant based on antixenosis to *C. partellus* in India (Sharma et al., 2007) and to *B. fusca* in Zimbabwe (Chinwada et al., 2001), was found moderately susceptible to this pest at the test site in Kenya. This could be attributed to genotype by environment interactions that influenced expression of resistance to damage by *B. fusca*. For example, the lower temperatures at this relatively high elevation test site may have slowed the growth of this

Table 4. Correlations between *B. fusca* damage and agronomic traits in sorghum.

100 grain mass	1																	
50 % flowering	2	-0.1																
Bloom waxiness	3	0.2	0.2															
Dead heart	4	-0.5	-0.2	-0.2														
Dry panicle weight	5	0.6	0.3	0.3	-0.2													
Grain yield	6	0.6	0.2	0.4	-0.3	0.9												
Leaf damage	7	0.3	0.1	0.5	-0.4	0.3	0.5											
Leaf glossiness	8	-0.2	-0.3	0.3	0.2	-0.4	-0.3	0.1										
Leaf toughness	9	0.1	0.3	-0.3	-0.1	0.2	0.3	-0.1	-0.3									
No. of exit holes	10	0.1	0.1	0.0	0.1	0.3	0.3	0.0	0.0	0.4								
Panicle length	11	0.1	-0.4	-0.2	0.1	-0.1	-0.1	-0.5	0.2	-0.4	-0.1							
Plant height	12	0.4	0.3	-0.2	-0.1	0.6	0.6	-0.1	-0.6	0.5	0.3	0.0						
Seedling vigour	13	0.6	-0.2	0.3	-0.5	0.5	0.6	0.4	0.1	-0.1	0.3	0.2	0.1					
Selection index	14	0.0	0.0	-0.1	0.3	0.3	0.3	-0.1	0.0	0.4	1.0	-0.1	0.3	0.2				
Tillering	15	0.2	-0.3	-0.3	0.0	0.1	0.1	-0.1	-0.4	0.1	0.3	-0.1	0.5	0.2	0.3			
Trichome density	16	0.2	-0.1	0.1	0.0	0.0	0.0	0.1	0.3	-0.1	-0.2	-0.1	-0.2	0.3	-0.2	-0.1		
stem tunneling	17	0.2	-0.1	-0.1	0.0	0.3	0.4	0.0	0.0	0.3	1.0	0.0	0.3	0.4	0.9	0.4	-0.2	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

genotype, which in more favourable environments typically outgrows shoot pests.

Sorghum genotypes with highly glossy, non-vigorous seedlings suffered lower damage compaired to the non-glossy but highly vigorous ones. Similar observations have earlier been reported for sorghum shootfly, wherein highly glossy lines were resistant to shoot fly attack (Dhillon et al., 2005). The positive correlation observed between grain yield and plant height implied that tall genotypes yielded significantly more than short genotypes. Under the artificially-infested conditions of this trial, sorghum genotypes with poor seedling vigor (that is, low seedling vigor scores) tended to have lower grain yields than those with highly vigorous seedlings perhaps because the whorls of the less vigorous genotypes provided a better environment for the stem borer larvae.

Plants with high seedling vigor scores (that is, highly vigorous seedlings) suffered less dead heart damage and were high yielding. This implies that improving seedling vigor could lead to development of genotypes that are more tolerant to stem borer damage. This conforms to observations made by Odiyi (2007), who suggested that vigorous maize plants suffered less damage by *Eldana saccharina* and *Sesamia calamistis*, and were high yielding. Seedling vigor as a result of lack of damage to seedlings is highly correlated with shoot fly resistance in sorghum as reported by Dhillon et al. (2005). Sorghum genotypes with high leaf toughness suffered less deadhearts possibly because of poor palatability of such genotypes to the borer larvae. Leaf toughness is positively correlated with resistance to stem borer attack in maize (Bergvinson, 2002). An inverse correlation existed between deadheart incidence and hundred grain mass implying significant and direct negative relationship between these two direct measures of stem borer damage.

Trichomes are known to hinder movement of insect pests in many host plants. Most of the tolerant genotypes in this study possessed more trichomes, were highly glossy, and were more vigorous than the susceptible genotypes. High levels of resistance to shoot fly were identified when both glossy and trichome traits occurred together (Dhillon et al., 2005; Aruna and Padmaja, 2008). There were positive and significant correlations between grain yield, leaf damage and stem tunneling. Odiyi (2007) suggested that leaf feeding and deadheart formation did not lead to a significant reduction in maize yield due to stem borer damage. In the present study, deadheart formation significantly contributed to substantial grain yield loss. This could be explained by the fact that deadheart formation resulted in destruction in of apical shoot of the main stem thus production of unproductive tillers. Sorghum genotypes with high seedling vigour scores (that is, high vigor) had high grain yield per plant under the conditions of this artificially-infested trial. A similar observation has been made by Odiyi (2007). A positive and significant correlation between grain weight and plant height implied that tall genotypes yielded significant more than the dwarf genotypes.

Conclusion and recommendations

New sorghum genotypes tolerant to *B. fusca* infestation have been identified in this study based on parameters linked to pest damages. The utilization of multiple traits assists in identifying superior genotypes for resistance to *B. fusca*, which is a polygenic trait. These new tolerant genotypes can be useful in breeding for tolerance to this pest. The tolerant genotypes can be utilized to increase the levels of tolerance to stem borer damage in common sorghum varieties. Cultivation of genotypes with tolerance to stem borers would greatly improve food security and income of the resource poor farmers in areas prone to African corn stalk borer. There is need to investigate inheritance of tolerance traits to this pest in order to develop appropriate strategies to improve sorghums for stem borer tolerance and grain yield in future.

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