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New sources of resistance to spotted stem borer, *Chilo partellus* in sorghum

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Abstract

The lepidopteran *Chilo partellus* Crambid, an introduced pest in East and southern Africa from Asia, is the most economically important stem borer species infesting cereals in Africa. *Chilo partellus* causes more than 40% yield loss in sorghum in East Africa. Cultural strategies, biological control using parasitoids, as well as pesticides are being employed, but are either ineffective or uneconomic for resource constrained farmers in cereal production. Thus host resistance remains the most economic viable strategy. Sorghum is an African crop and has thus co-evolved with several pests, inherently developing resistance to them as well as *C. partellus*. Moreover, *C. partellus* is exotic with limited sources of resistance in local sorghum. Sorghum from other ecologies with a long history of *C. partellus* infestation could thus provide additional and new sources of resistance. The objective of this study was to evaluate a panel of local and exotic sorghum genotypes for resistance to *C. partellus*. Seven genotypes from East Africa and twenty from India were evaluated at Kiboko, Kenya, for tolerance/resistance to *C. partellus* during long- and short-rainy seasons of 2010. Test plants were artificially infested with five stem borer neonates, and data were recorded on leaf feeding, deadhearts, stem tunneling and exit holes as well as agronomic parameters. Based on selection index generated, genotypes ICSA 472, ICSA 473, ICSV 700 and ICSA 464 were resistant owing to antibiosis and antixenosis mechanisms of resistance. These genotypes can be used in sorghum improvement to develop cultivars with high grain yield and resistance to *C. partellus*..

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Introduction

Sorghum production especially in tropical Africa is curtailed by a number of important anthropod pests, with the stem borers belonging to Lepidoptera playing the most significant role. There are two groups of stem borers that infest sorghum, indigenous species such as African stem borer *Busseola fusca* (Fuller) and *Sesamia calamistis* Lepidoptera Noctuids and exotic ones such as the spotted stem borer *Chilo partellus* (Swinhoe) Lepidoptera Crambid introduced from Asia (Sharma *et al.,* 2005). *Chilo partellus* is reported the most important pest in East Africa and many countries of sub-Saharan Africa accounting over 49% yield losses (Seshu Reddy, 1998; Songa *et al.,* 2001). *Chilo partellus* is highly invasive, and has partially displaced some indigenous stem borers in Kenya attacking all cereals (Kfir *et al.,* 2002). Damage symptoms of *C. partellus* in sorghum include leaf feeding, deadhearts, exit holes, stem tunneling and chaffy grain in case of extensive stem tunneling and peduncle damage (Jose *et al.,* 2001; Kfir *et al.,* 2002; Kishore *et al.,* 2007; Sally *et al.,* 2007).

Cultural pest management practices such as early planting, destruction of stover, biological control, developing insect-resistant cultivars, and the use of chemical insecticides are being used (Ofomata *et al.,* 2000; Rwomushana, 2005; Sharma *et al.,* 2006). Push and pull technology is a relatively new cultural technique of managing stem borers where by a repellent crop, in this case desmodium *spp* (Fabaceae) is planted around the cereal crop while Napier Grass (*Pennisetum Purpureum*) is utilized as a trap plant to the borers (Zeyaur *et al.,* 2007).

The efficacy of pesticides is however limited especially when the larvae are feeding inside the stalks (Kfir *et al.,* 2002). Thus host plant resistance to insects remains the most viable option to manage the pest. Several sorghum accessions have been screened for resistance to *C. partellus*, and several sources of resistance identified, but the resistance levels range from low to moderate (Sharma *et al.,* 2003, 2006; Singh, 2011). Therefore, it is important to identify sorghum genotypes with higher levels of resistance with diverse mechanisms of resistance to diversify the bases of resistance to this pest. Progress in breeding for resistance to this pest has been slow due to the complex inheritance of the trait and the strong influence of environmental factors on expression of resistance to stem borers.

Screening for resistance to stem borer under natural conditions is ineffective because of non-uniform pest pressure over time and space, and thus, it is necessary to employ artificial infestation to identify sources of resistance to this pest (Songa *et al.,* 2001). Marulasiddesha *et al.* (2007) evaluated 20 sweet sorghum and three grain sorghum genotypes under artificial infestation in the field, and found SSV 7073 to be the most resistant with respect to leaf feeding, deadheart formation, and peduncle and stem tunneling. Several other authors have screened sorghum under artificial infestation and genotypes with varying levels of resistance identified (Sharma *et al.,* 2005, 2006: Dhillon *et al.,* 2006; Kishore *et al.,* 2007; Singh, 2011). Improvement for resistance to *C. partellus* requires identification of new sources of resistance to diversify the bases of resistance to this pest (Songa *et al.,* 2001; Kishore *et al.,* 2007). Therefore, the present studies were undertaken to identify new sources with diverse mechanisms of resistance to *C. partellus*.

Materials and methods

Experimental site

Experiments to evaluate sorghum genotypes against *C. partellus* damage were conducted at the Kenya Agricultural Research Institute (KARI), Kiboko, Kenya. Kiboko is located at an elevation of 975 m above sea level with average minimum and maximum daily temperatures of 14.3°C and 35.1°C, respectively, with an overall annual mean temperature of 24°C (Franzel *et al.,* 1999). The long rains are received from March to June with a seasonal mean of 233 mm, while the short rains are more reliable and are received between October to January, with a seasonal mean of 328 mm (Franzel *et al.,* 1999). Spotted stem borer is known to result in severe damage to the crop thus the basis upon which this site was selected for the study (Sharma *et al.,* 2007).

Experimental material and design

Seven East African popular commercial cultivars and 20 introductions from India were evaluated during the long and short rainy seasons in 2010 (Table 1). The reason for including local sorghum materials was to assess if they possess some level of resistance to this borer. MACIA, GADAM E1 HAMAM and KARI-MTAMA 1 have good processing qualities, and are utilized for making beer by the 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 are breeding materials at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

The test material was planted in α lattice design, consisting of nine genotypes by three blocks per replication, using single-row plots replicated twice. The rows were 2 m long, and 0.75 m apart, and the interspacing within the plants was 0.25 m. Genotypes IS 1044 and SWARNA were included as resistant and susceptible checks, respectively. All the recommended production practices were followed to raise a healthy crop. At 16 days after planting, (two weeks before borer infestation), the crop was sprayed with cypermethrin (synthetic pyrethroid) to minimize shoot fly infestation, since this insect interferes with screening for resistance to stem borers.

The stem borer neonates used in this study were obtained from International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya.

At 30 days after planting, five plants in each row were artificially infested in the whorl 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 or late in the evening to encourage larval survival.

Observations

The observations were recorded on per plant basis at two and four weeks after artificial infestation. Leaf damage was expressed as the number of plants showing pinhole damage as a percentage of the total number of plants sampled. Deadheart incidence was computed by expressing the number of plants showing deadheart damage as a percentage of the total number of plants sampled.

At harvest, number of stem borer exit holes on the stem were counted on each sampled plant. The main stem of plants infested with *C. partellus* larvae were split open from the base to the apex, and the cumulative tunnel length measured in centimeters. Numbers of larvae recovered alive or dead after cutting the stems longitudinally were also recorded. Morphological parameters: Waxy bloom was recorded on a scale of 1 - 9, where 1= no visible bloom, 3 = slightly present, 5 = medium, 7 = mostly bloomy, 9 = completely bloomy at the 50% flowering stage. At physiological maturity, plant height was measured from the base of the plant to the tip of the panicle. At the same time, plant color based on leaf sheath coloration was visually assessed on a scale of 1-2 where 1=tan and 2=pigmented. Days to panicle emergence was recorded as the number of days from the date of planting to the date of panicle emergence in 50% of plants in a plot. Days to 50% flowering was recorded as the number of days from planting to anthesis of 50% of the plants in a plot. The number of tillers with harvestable panicles was recorded on each plant.

Brix is a measure of the level of soluble solids in the sorghum juice (Nibouche and Tebere, 2008). All genotypes were harvested at the same time and sugar brix was measured using a hand held refractometer (Reichert Inc, 3362 Walden Avenue Depew NY 14043 made in Japan). The cane was squeezed by hand and the juice dispensed on the sample area of the refractometer. Samples were tested each at a time and the sample dip area was cleansed using methylated spirit to avert sample contamination. After harvest, sorghum panicles were sun-dried and threshed. Grain yield and hundred grain mass were measured for each of the 5 plants sampled using an electronic balance (Mettler PM 6000, CH- 8606 GREIFENSEE-ZURICH, made in Switzerland).

Statistical analysis

Data on percentages was angular transformed while that of counts was log transformed before analysis of variance. The mean values of all the traits for each replicate were used to compute the analysis of variance using Genstat (10th version). Treatment means were compared using a protected Fishers' least significant difference (LSD) test at P=0.05. A borer 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 from the overall mean for each parameter, and dividing by 4 (number of damage parameters considered). Genotypes were grouped into four categories namely resistant, moderately resistant, moderately susceptible and susceptible (Tadele *et al.,* 2011). Pearson's correlation coefficients were computed to determine the association of morphological characteristics with traits measuring stem borer damage.

Results

Relative susceptibility of different sorghum genotypes to C. partellus damage

Susceptibility parameters mainly deadhearts, exit holes, stem tunneling damage, number of larvae recovered alive or dead, number of tillers per plant and selection index based on the four damage parameters all varied significantly (P≤ 0.01) among genotypes (Table 2).

Dead heart damage differed highly significant among genotypes. Low deadheart damage was recorded in ICSA 473, ICSA 467, IESV 93042 SH and KARI-MTAMA 1 (< 20 %) as compared to IESV91104 DL, DJ 6514, IS 27329 and SWARNA (susceptible check) (Table 2). The resistant check, IS 1044 suffered four times less deadhearts as compaired to susceptible check, Swarna. Leaf damage did not vary differently among genotypes. KARI-MTAMA 1, IESV 930 SH, ICSA 464 and its maintainer line exhibited low leaf damage (<30 %), while IESV 91131 DL, IS 8193, ICSB 474, SWARNA (S), TAM 2566 and IS 2205 suffered high leaf damage (≥ 50%) (Table 2).

The numbers of exit holes per plant in ICSA 472, ICSA 464, IS 21879, ICSA 473 and ICSV 700 were much lower than that of resistant check, IS 1044 (Table 2). Genotype IS 8193 suffered three times more damage compared to the resistant check IS 1044. Stem tunneling damage per plant was low in genotypes ICSA 472, ICSV 700, ICSA 464, ICSB 473, ICSB 472 and IESV 91131 DL (< 10 cm) as compared to GADAM E1 HAMAM, SEREDO, and IS 8193 that suffered more than 24 cm long tunnels (Table 2). IS 8193 suffered eight times more stem tunneling than the identified most resistant genotype ICSA 472.

Among the 27 genotypes evaluated, the stem borer damage index based on leaf damage, dead heart formation, exit holes and stem tunneling varied significantly (Table 2). The susceptibility index developed categorized genotypes into four groups namely resistant (26 %), moderately resistant (37 %), moderately susceptible (26 %) and 11 % as susceptible. In this scheme, some genotype were better than the resistant check and it is noteworthy that some genotypes succumbed to *C partellus* damage distinctly more than the susceptible check.

There were significant (P≤0.01) differences in the numbers of larvae recovered either alive or dead among different genotypes (Table 2). Dead stem borer larvae were recovered from ICSV 700, ICSB 474 and GADAM E1 HAMAM. The least number of larvae recovered alive were recorded on KARI-MTAMA 1, ICSA 474, IS 1044 (R), ICSB 464 and ICSB 464 (Table 2). Genotypes that produced harvestable tillers were ICSB 473, IS 2205 and ICSA 464 produced highest number of productive tillers.

Table 1. List of sorghum genotypes evaluated for resistance to *C. partellus* at Kiboko, Kenya (2010 long and short rain seasons).

IS No.	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	(IS18432 X ICSB 6)11-1-1-2-2	India
10	ICSB 474	(IS18432 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

Variation in morphological traits among different sorghum genotypes evaluated for resistance to C. partellus

Sugar brix level, plant height, days to 50 % flowering, waxy bloom, days to panicle emergence, agronomic score, panicle length, dry panicle weight, grain mass and a hundred grain mass varied significantly among the genotypes tested (Table 3). Sugar brix levels ranged from 11.2 on IESV 91131 DL to 22.6 on ICSB 464, with an average of 17. 2 (Table 3). The susceptible check, Swarna had a brix value of 19.1 while the resistant check, IS 1044 scored 16.7 brix. The tallest genotype, IS 27329 recorded 253.5 cm while the most dwarf, TAM 2566 reached 79 cm (Table 3). Days to 50 % flowering ranged from 87 to 65 days on ICSV 700 and GADAM E1 HAMAM respectively. Bloom waxiness ranged from 2.8 (slightly present) to 6.5 (mostly bloomy), with an average mean of 4.6 (Table 3). Genotypes with highest bloomy wax included Swarna (susceptible check), MACIA and GADAM E1 HAMAM in decreasing order while little bloom was recorded on the resistant check IS 1044 and IS 27329 in the same order (Table 3). Days to panicle emergence was longest for ICSV 700 with 87 days while GADAM E1 HAMAM took 58 days for the panicle to emerge.

Table 2. Response of 27 sorghum genotypes to spotted stem borer, *C. partellus* damage during 2010 rain seasons at KARI Kiboko, Kenya.

Genotype	Dead heart (%) DH	Leaf damage (%) (LD)	No. of exit holes (EH)	Stem tunneling (%) (cm) (ST)	larvae recovered alive	No. of larvae recovered dead	No. of tillers /plant	[1]Selection index	Category	Plant colour
ICSA 473	6.6	35.5	2.8	10	0.8	0	0.1	0.6	R	T
ICSA 464	32.3	29.1	2.2	7.5	0.5	0	2.3	0.67	R	T
ICSV 700	23.1	48.2	2.3	6.6	1.3	0.3	0.1	0.7	R	T
ICSA 472	32.9	39.2	1.9	4.3	0.5	0	0.3	0.71	R	T
IESV930 SH	6.6	23.1	3.5	22.3	1.8	0	0.3	0.72	R	T
ICSB 473	23.1	32	3.4	8.6	1.0	0	1.3	0.72	R	T
ICSB 472	26.6	39.2	3	8.6	1.3	0	0.4	0.78	R	T
IS 21879	26.3	54.8	2.4	11.2	1.0	0	1.0	0.79	MR	P
IS 1044 (R)	19.9	32.3	3.4	16.9	0.3	0	0.3	0.79	MR	P
KARI-MTAMA 1	16.4	19.9	5	17.8	0	0	0.4	0.8	MR	T
ICSA 467	6.6	38.9	4.5	16.9	4.0	0	0.1	0.81	MR	T
ICSA 474	35.2	35.8	3.4	12.6	0	0	0.1	0.82	MR	P
MACIA	22.5	41.2	3.4	13.7	2.0	0	0.4	0.84	MR	T
IESV9113 1 DL	32	51.1	2.4	9.9	0.8	0	0.7	0.85	MR	T
ICSB 464	42.1	29.7	3.1	11.3	0.3	0	0.1	0.87	MR	T
ICSB 467	26	35.8	3.9	13.8	1.0	0	0.2	0.87	MR	T
IS 2205	29.1	60.9	4.5	14.1	0.5	0	1.7	1.07	MR	P
ICSB 474	29.1	57.7	6.3	20.4	0.2	0.5	0.3	1.23	MS	P
IS 21881	26.3	38.9	6.3	20.2	0.8	0	0.5	1.24	MS	P
IESV9110 4 DL	54.8	38.9	5.8	14.9	1.5	0	0	1.27	MS	T
SEREDO	42.1	38.9	6.3	24.8	1.8	0	0.7	1.3	MS	P
TAM 2566	32.3	58	7.1	18.8	2.8	0	1.9	1.3	MS	P
GADAM E1 HAMAM	35.8	42.1	6.5	24.3	1.5	0.5	0.6	1.3	MS	P
IS 27329	67.5	48.2	4.7	15.8	0.5	0	0.8	1.34	MS	P
SWARNA (S)	73.6	58	4.8	18.8	2.3	0	0.2	1.48	S	T
DJ 6514	67.5	47.9	5.9	24	0	0	1.0	1.53	S	T
IS 8193	22.5	54.8	9.5	34	2.8	0	1.1	1.62	S	P
Mean	31.8	41.9	4.4	15.6	1.1	0	0.6	1		
LSD	29.01	30.61	2.508	8.041	1.726	0.4	0.819	0.402		
P	<.001	0.435	<.001	<.001	0.002	<.001	<.001	<.001		

R= Resistant, Ms=Moderately Resistant, Ms=Moderately Susceptible, S=Susceptible T=Tan, P=Pigmented

[1]Selection index was based on dead heart formation, leaf damage, exit holes and stem tunnels damage.

Agronomic score determined from a scale of 1-5 where 1 was poor while 5 excellent ranged from 3.6 - 2.5 on ICSA 474 and SEREDO correspondingly (Table 3). The longest (37 cm) and shortest (16 cm) panicles were recorded on genotypes IS 27329 and ICSA 472 respectively. The heaviest dry panicle on IESV 91131 DL weighed 4 times more than ICSA 472 which weighed the least. Grain weight ranged from

45.3 grams on IESV 91131 DL to 2.1 grams on ICSA 472 with an average of 20 grams (Table 3). Highest hundred grain mass was recorded in KARI-MTAMA 1, IESV 93042 SH, IS 27329 and SEREDO in decreasing order. Despite the fact that SWARNA was used as a susceptible check, it yielded one and a half times much as the resistant check, IS 1044 (Table 3).

Table 3. Agronomic traits of 27 sorghum genotypes evaluated for response to *C. partellus* damage during 2010 rain seasons at KARI Kiboko, Kenya.

Genotype	Sugar Brix	Plant height (cm)	Days to 50% flowering	Waxy bloom (1-9 scale)	Days to panicle emergence	Agronomic score (1-5)	Panicle length	Dry panicle weight	Grain mass	100 Grain mass
DJ 6514	16.4	164.5	78.0	5.0	66.3	2.9	19.4	28.2	18.0	0.8
GADAM E1 HAMAM	16.4	110.2	65.0	5.5	57.8	3.0	19.9	28.9	17.9	1.8
ICSA 464	20.5	151.8	79.0	3.5	68.0	3.5	26.7	15.8	3.8	0.1
ICSA 467	15.0	138.7	76.5	3.5	66.3	3.3	26.0	19.7	5.9	1.0
ICSA 472	16.2	193.2	81.0	5.0	68.3	3.5	16.1	13.6	1.8	0.2
ICSA 473	16.4	131.2	74.3	5.0	65.0	3.3	19.2	17.6	5.3	0.7
ICSA 474	17.0	189.5	74.0	4.5	64.0	3.6	22.9	21.3	3.8	1.0
ICSB 464	22.6	136.0	78.8	4.0	69.3	2.6	24.7	45.8	31.0	1.7
ICSB 467	17.8	145.9	74.0	4.0	64.8	3.0	26.0	36.5	23.7	2.1
ICSB 472	17.2	179.2	80.0	4.5	68.3	2.5	16.2	32.0	18.6	2.0
ICSB 473	17.8	132.9	79.5	4.5	67.5	2.5	20.9	33.6	22.2	1.7
ICSB 474	18.3	188.0	74.8	4.5	65.0	2.5	21.5	38.2	19.8	2.4
ICSV 700	16.3	218.1	87.0	3.5	76.8	3.1	17.9	33.5	21.1	1.7
IESV 91104 DL	20.0	169.0	73.8	3.5	65.3	2.8	20.1	29.1	17.2	2.0
IESV 91131 DL	11.7	101.9	74.3	5.5	63.8	2.6	23.2	58.6	45.3	2.1
IESV 930 SH	20.1	151.4	76.8	4.5	67.5	3.0	21.3	41.9	30.0	2.9
IS 1044 (R)	16.7	159.6	68.3	3.0	59.8	3.0	22.0	25.0	12.3	2.0
IS 21879	13.4	97.4	86.0	6.5	75.5	2.5	22.6	40.7	30.2	1.5
IS 21881	13.5	87.8	75.8	6.0	63.0	2.8	23.8	42.0	28.6	2.0
IS 2205	18.6	211.2	80.0	4.0	68.8	3.1	16.1	16.2	5.7	1.0
IS 27329	18.9	253.5	72.8	2.8	63.3	3.6	37.2	29.2	12.9	2.7
IS 8193	15.0	132.4	73.8	4.5	63.0	3.3	19.2	34.5	27.0	1.9
KARI-MTAMA 1	18.8	137.9	73.8	4.5	64.3	2.9	22.2	40.3	25.9	3.6
MACIA	16.8	122.2	76.5	6.0	66.5	2.8	23.1	50.0	34.6	2.1
SEREDO	18.5	129.4	73.5	5.5	62.8	2.5	22.2	41.7	28.6	2.6
SWARNA (S)	19.1	104.1	69.8	6.5	61.5	3.3	22.5	32.2	16.6	2.2
TAM 2566	15.3	79.0	75.8	3.5	65.5	2.8	16.7	44.3	33.2	1.6
Mean	17.2	148.7	76.0	4.6	65.8	3.0	21.8	33.0	20.0	1.8
LSD	3.44	11.93	6.19	1.56	4.57	0.54	2.36	12.96	9.58	0.74
P	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Association of morphological parameters with resistance/susceptibility to C. partellus damage

Correlations were done to determine the extent of relationship between various parameters (Table 4). A significant negative correlation existed between bloom waxiness and sugar brix (r = -0.37, P = 0.05) (Table 4). Considerable relationship was observed between sugar brix and plant height (r = 0.37, P = 0.05). A weak association existed between exit holes and live larvae (r = 0.36, P= 0.06). The positive relationship between exit holes and live larvae recovered from the stems imply that leaf damage would indicate stem damage and presence of living larvae inside the stem (Table 4).

Table 4. Correlation analysis among different characters in 27 sorghum genotypes grown at KARI Kiboko, Kenya.

Days to 50% flowering	1	-														
Days to panicle emergence	2	0.97**	-													
Dead heart %	3	-0.21	-0.21	-												
Dry panicle weight	4	-0.02	0	-0.01	-											
Grain mass	5	0.03	0.04	-0.05	0.98**	-										
Leaf damage %	6	0.09	0.08	0.37*	0.07	0.1	-									
No of exit holes	7	-0.47	-0.52**	0.22	0.15	0.2	0.35	-								
Larvae recovered alive	8	-0.09	-0.06	-0.18	0.12	0.17	0.24	0.36	-							
No of tillers	9	0.2	0.11	0.07	-0.07	0.03	0.27	0.17	0.02	-						
Panicle length	10	-0.24	-0.21	0.26	0.11	0.01	-0.18	-0.07	-0.08	-0.06	-					
Plant height	11	0.22	0.24	0.18	-0.50**	-0.55**	0.01	-0.22	-0.38*	-0.15	0.14					
Selection index	12	-0.43*	-0.47*	0.65**	0.14	0.17	0.56**	0.86**	0.23	0.17	0.05	-0.11	-			
Stem tunneling	13	-0.54**	-0.55**	0.13	0.21	0.26	0.2	0.88**	0.34	0.05	0.02	-0.26	0.77	-		
Sugar level	14	-0.08	0.01	0.26	-0.19	-0.25	-0.40*	-0.07	-0.22	-0.06	0.18	0.37*	-0.03	-0.05	-	
Waxy bloom	15	-0.01	-0.06	0.08	0.35	0.36*	0.19	0.02	0.04	-0.11	-0.21	-0.58**	0.14	0.14	-0.37*	-
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

**, * Significant at P = 0.01, and 0.05, respectively

Discussion

This study identified sources of resistance to *C. partellus* based on leaf damage, deadheart formation, exit holes and stem tunneling. The reason for considering several parameters is due to the fact that resistance to *C. partellus* is a multi-mechanism, low-heritability quantitative trait, and thus, selecting for resistance based on a single parameter would not be effective (Singh *et al.,* 2011).

Three plant defence mechanisms namely antibiosis, tolerance and antixenosis responsible for this resistance were also established. Antibiosis mechanism measured in terms of reduced leaf and stem feeding was observed on resistant genotypes ICSA 473, ICSA 464, ICSA 472 and their maintainer lines, ICSV 700 and IESV 930 SH. Reduced larval development was recorded on ICSV 700. The least number of larvae recovered alive was observed on resistant and moderately resistant genotypes ICSA 472, ICSA 464, ICSB 464, IS 1044 (R) and IS 2205.

Since tillering serve as a component of recover resistance, it was employed to determine tolerance. Resistant and moderately resistant genotypes ICSA 464, ICSB 473, ICSA 472, ICSB 472, IS 2205 and IS 21879 displayed tolerance through tillering. Plants with ability to tolerate insect damage may produce more yield than the non tolerant susceptible cultivar at the same level of insect infestation. High grain mass was recorded on resistant genotypes KARI-MTAMA 1, IESV 930 SH, ICSB 472, IESV 91131 DL, ICSB 467, MACIA and ICSB 472.

Bloom waxiness on the stem and leaves of the plant was used to measure antixenosis since bloom waxiness curtails the movement of borer on the plant. Resistant and moderately resistant genotypes ICSA 472, ICSA 473, IS 21879, MACIA and IESV 91131 DL were mostly bloomy. It is worth noting that majority of the resistant and moderately resistant genotypes possessed a combination of the three mechanisms of resistance.

The significant and positive association between sugar brix and plant height suggested that high sugar levels could indirectly contribute to grain yield since taller plants mature late, and have significantly high yields. Harvesting was done at the same time for all genotypes, in which case and the later maturing varieties showed less senescence, greener leaves and juicier stems than the early maturing varieties. Current results suggest that low sugar brix was associated with susceptibility to leaf damage (r = -0.40, P = 0.03). Leaf damage observed may not have been severe to disrupt photosynthesis thus the insignificant association between the leaf damage and grain yield. This observation agrees with studies on other stem borers reported by Odiyi (2007) who suggested that leaf damage due to *Eldana saccharina* (Walker) and *Sesamia calamistis* (Hampson) did not result in a significant grain yield reduction in maize. Nibouche and Tibere, (2008) also who found that there was no significant genetic relationship between resistance and sugar content on sugarcane stalk damage by *Chilo sacchariphagus*.

Non pigmented genotypes suffered significantly lower deadheart incidence, stem tunneling and exit holes and had high sugar levels as compared to the pigmented ones (Table 2). Tanning possibly had an adverse effect (antibiosis) on larvae inside the stem. Interestingly, tanned genotypes suffered higher leaf damage than the pigmented ones. Possibly, resistance displayed by leaves was different from that exhibited by the stems. The significant positive relationship between dead hearts and leaf damage (r =0.37, P= 0.05) indicates a close relationship between the two damage parameters. The association between dead hearts and selection index based on the four damage parameters was strongly significant (r = 0.65, P<0.001).

Stem tunneling and exit holes correlated negatively with days to 50% flowering (r = -0.54, P= 0.003 and r = -0.47, P= 0.01) respectively indicating poor tolerance to stem tunneling by early flowering plants since the plants only have a relatively short period for growth. This observation agrees with observation made on other stalk borers by Odiyi 2007 on maize with *Eldana saccharina* and *Sesamia calamistis*. Schulz *et al.* (1997) too observed that late silking plants suffered less stem tunneling owing to antibiosis against European corn borer in maize.

Information on relationship between stem borer damage and grain yield loss is important in developing an efficient improvement program for resistance to stem borers. The positive correlation between grain yield and plant height (r = -0.55, P= 0.002) indicated that dwarf genotypes were better grain yielders than late maturing. A positive but weak association was observed between bloom waxiness and grain mass (r = 0.36, P= 0.06) suggesting that completely bloomy genotypes would give significantly higher yields.

Conclusions

This study demonstrated that there are genotypic differences in resistance and/or susceptibility to damage by *C. partellus*. Resistance to *C. partellus* is polygenic, and thus, use of numerous traits facilitates identification of superior genotypes. Mechanisms of resistance in the majority of resistant genotypes were found to be antibiosis, tolerance and antixenosis. Stem borer resistant genotypes identified in this study could be used as sources of resistance to improve local susceptible, but popular varieties. These genotypes could also be grown by farmers in areas where *C. partellus* is a major constraint in sorghum production. There is a need to study the mode of inheritance of resistance traits to this insect. The most susceptible genotype, IS 8193 could be utilized as a susceptible check in screening for resistance to *C. partellus*.

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