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Susceptibility of sorghum varieties to the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae)

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Sitophilus zeamais **Motsch. is one of the most important pests of sorghum in storage causing severe economic damage to the grain. Twenty-one sorghum varieties obtained from Haramaya University Sorghum Improvement Research Program were investigated for their relative resistance to *S. zeamais* attack. The Dobie index of susceptibility was used to group the varieties into different reaction categories. Among the twenty one sorghum varieties evaluated, only one variety, 'WB-77', was regarded as resistant to the weevil. All the remaining varieties were categorized as moderately resistant. Weevils reared on the resistant variety produced a few number of F_1 progeny (20.00), had a high median developmental time (42.00 days) and a low percentage of seed damage (2.67) and seed weight loss (0.30). Percentage seed damage and weight loss are significantly and positively correlated with the mean number of F_1 progeny emergence and are inversely associated with median developmental time. Consequently, those varieties with high number of F_1 progeny scored high percentage of seed damage and weight loss. These results indicated that high lysine content was found to be the predominant factor in sorghum resistance to *S. zeamais.***

Key words: Sorghum varieties, resistance, insect infestation, *Sitophilus zeamais*, susceptibility index.

INTRODUCTION

Sorghum, *Sorghum bicolor* L. Moench is an important crop ranking fifth in world cereal production with an annual production of 55.7 million tonnes (FAOSTAT, 2012). It is the main source of calories and protein in some regions of Africa and Asia (Waniska and Rooney, 2000). Sorghum accounts for an average 10% of daily caloric intake of households living in the eastern and northwest areas of Ethiopia (USDA, 2012). Ethiopia is the second largest producer of sorghum in eastern and southern Africa next to Sudan (Demeke and Marcantonio, 2013). In Ethiopia, one third of the cereal diet comes from sorghum, and it plays an important role in achieving food security at the household level (Dendy, 1995). In Ethiopia, both the production and productivity of sorghum have increased since the introduction and selections of high yielding sorghum varieties and landraces by the Ethiopian Institute of Agricultural Research and Haramaya University (EARO, 2000; Adugna, 2007). However, these varieties are reported to be highly susceptible to stored grain insect pests Mendesil et al.,

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(2007). As a result, farmers are hardly the beneficiaries of the high yield potential of these varieties.

The stored sorghum is attacked and damaged by a number of pests that lead to qualitative and quantitative deterioration. Among insect pests of sorghum in storage, the weevils are the most important pests, among them *Sitophilus zeamais* is the major one in Ethiopia (Bekele et al., 1997; Eticha and Tadesse, 1999; Abebe et al., 2009; Tefera et al., 2011; Temesgen and Waktole, 2013). Infestation by this weevil begins in the field (Caswell, 1962; Demissie et al., 2008), but significant damage happens during storage. Reports from other African countries also confirmed the field-to-store infestation of *S. zeamais* (Hill and Waller, 1990). Worldwide seed losses in the range of 15 to 77% have been reported for insecticide untreated sorghum due to the maize weevil (IDRC, 1976; Caswell, 1978; Kidane and Habteyes, 1989; Seifelnasr, 1992; Nyambo, 1993; Eticha and Tadesse, 1999; Ramputh et al., 1999). Losses are particularly pronounced in the tropical developing countries where environmental factors are conducive for the reproduction and development of weevils, and where storage facilities are inadequate (Shazali and Smith, 1985; Gwinner et al., 1996; Bekele et al., 1997). In a country, where production is much lower than the national demand and is characterized by the above stated level of post-harvest loss, a great effort is needed to reduce this loss.

In Ethiopia, Synthetic chemical insecticides are used by few farmers for the management of storage insect pests. The majority of farmers do not apply chemical insecticides against stored sorghum insect pests due to unavailability and high cost (Mendesil et al., 2007). Synthetic insecticides cause environmental pollution, adverse effect on non-target organisms, resistance development, and food contamination with toxic residues (Niber, 1994; Asawalam et al., 2006; Dhuyo and Ahmed, 2007; Kumar et al., 2007).

Thus, the search for easily available, eco-friendly, and cost effective insect pest management options are of paramount importance. One of the benign alternative management options is the use of resistant sorghum varieties against insect pests of sorghum including *S. zeamais*. In countries where storage facilities are inadequate, use of grains resistance to storage pests might be employed either alone or along with other management methods. The use of resistant varieties is economically feasible, technically easy and environmentally friendly alternative to minimize losses to storage insect pests. This study seeks to evaluate released and farmers' local sorghum varieties in Ethiopia for their resistance to *S. zeamais* based on a susceptibility index.

MATERIALS AND METHODS

The sorghum varieties used in this study were: Abshier; AL-70; Awash-1050; Chelenko; ETS-2750; Fendisha-5; Gubiye; IS-9302; Muyra-1; Red Sheferie-2; Red Sheferie-6; Yellow Wogere-6; White Wogere-8; Red Sheferie-1; Red Sheferie-5; Yellow Wogere-1; Yellow Wogere-2; Teshale; White Fendisha; WB-77; Wogere-3.

Culture of *S. zeamais*

S. zeamais was reared on sorghum to obtain similar aged weevils for the experiments. About 15 kg seed of the sorghum variety Muyra-1 was obtained from Haramaya University Sorghum Improvement Research Program. The seeds were cleaned to remove seeds with viable damage symptoms. The cleaned seeds were disinfested by keeping them in a deep freezer at -20 ± 2°C for two weeks to eliminate any potential field infestation. The seeds were then transferred to plastic bags and kept at rearing room conditions for two weeks (Abebe et al., 2009). Then, unsexed *S. zeamais* were collected from the infested sorghum grains and reared on the clean and disinfested sorghum seeds (Muyra-1) in 5 jars, each jar with 2 L capacity. To each jar containing 500 g of seeds, 100 adult weevils were introduced. Subsequently, the jars were covered with muslin cloth and fixed with rubber band to prevent escape of weevils and to allow aeration. The infested seeds were kept at room temperature (20 to 22°C). Eight days after oviposition, all parent weevils were removed from each jar and the seeds were kept at the same experimental conditions. The insect cultures used for the experiment were multiplied in jars of sorghum seeds for two generations to obtain uniform population for the experiment.

Sorghum varieties

The study was carried out in the Plant Protection Laboratory of Haramaya University, Ethiopia. For this experiment, a total of twenty one released and farmers' local sorghum varieties were used. The varieties are currently under production in different parts of Ethiopia. The varieties were collected from Haramaya University Sorghum Improvement Research Program, Ethiopia. Freshly harvested seeds of each variety were cleaned and disinfested by keeping them in a deep freezer at -20±2°C for two weeks before the commencement of the experiment to kill any mites and insect pests that might be present. The seeds were then kept for two weeks at the experimental conditions for acclimatization (Abebe et al., 2009). The moisture content of the seeds was adjusted to 12 to 13%.

Experimental design and procedure

One hundred (100) gram of seeds from each of the sorghum varieties were placed in a 250 ml glass jar covered with white muslin cloth and fixed with rubber band to allow aeration and to prevent escape of the weevils. No choice test method in which predetermined weevils were introduced to each jar was used for the study.

Thirty newly emerged unsexed adult weevils were introduced to each jar to infest 100 g seeds of each variety and were kept for ten days for oviposition. Seeds of each variety without *S. zeamais* were maintained under similar conditions and served as a control. The treatments were arranged in a Completely Randomized Design (CRD) with three replications. The treatments were placed in a laboratory at 25±2°C, 40 to 60% RH and 12:12 (light: dark) photoperiod. Mortality of *S. zeamais* was assessed eight days after introduction of weevils. All insects were removed and dead and alive insects were counted.

The treatments were kept under the same experimental conditions to assess the emergence of F_1 progeny. Seeds were inspected daily and the emerging progenies were removed and

Table 1. Adult mortality, progeny emergence and median developmental time (MDT) of *S. zeamais* on different sorghum varieties.

Variety	Adult mortality (%)	F_1 progeny emerged	MDT (days)
Abshier	3.14 ± 0.6[a]	100.67 ± 6.92[def]	37.10 ± 0.12[cdef]
AL-70	2.98 ± 0.3[a]	137.00 ± 5.51[ab]	34.00 ± 0.92[fgh]
Awash-1050	3.25 ± 0.4[a]	91.67 ± 4.04d[efg]	38.10 ± 1.30[bcde]
Chelenko	3.03 ± 0.1[a]	125.00 ± 5.51[bcd]	34.53 ± 1.17[fgh]
ETS- 2752	3.41 ± 0.2[a]	99.33 ± 4.62[def]	37.43 ± 1.46[bcde]
Fendisha- 5	3.22 ± 0.3[a]	155.00 ± 4.51[a]	31.40 ± 1.44[h]
Gubiye	3.37 ± 0.4[a]	60.33 ± 3.21[hi]	39.87 ± 1.60[abc]
IS-9302	3.19 ± 0.5[a]	122.33 ± 5.57[bcd]	35.10 ± 1.83[defg]
Muyra-1	3.27 ± 0.2[a]	138.00 ± 7.77[ab]	33.33 ± 1.26[gh]
Red Sheferie-2	3.26 ± 0.4[a]	69.33 ± 3.61[gh]	39.40 ± 1.22[abcd]
Red Sheferie-6	3.33 ± 0.2[a]	66.00 ± 3.0[ghi]	39.53 ± 1.60[abc]
Yellow Wogere-6	3.71 ± 0.3[a]	80.67 ± 7.21[fgh]	38.10 ± 1.39[bcde]
White Wogere-8	3.36 ± 0.4[a]	68.33 ± 4.00[ghi]	39.53 ± 1.60[abc]
Red Sheferie-1	4.12 ± 1.2[a]	118.00 ± 7.51[bcd]	35.13 ± 0.80[defg]
Red Sheferie-5	3.56 ± 0.5[a]	111.00 ± 5.29[cde]	36.83 ± 0.86[cdef]
Yellow Wogere-1	3.71 ± 0.2[a]	102.00 ± 5.29[def]	36.93 ± 1.69[cdef]
Yellow Wogere-2	4.02 ± 0.5[a]	117.00 ± 4.58[bcde]	34.67 ± 1.94[efg]
Teshale	3.51 ± 0.3[a]	42.67 ± 2.31[ij]	40.93 ± 1.55[ab]
White Fendisha	3.46 ± 0.4[a]	128.00 ± 5.29[bc]	34.00 ± 0.92[fgh]
WB-77	3.43 ± 0.3[a]	20.00 ± 1.53[j]	42.00 ± 1.42[a]
Wogere-3	3.37 ± 0.2[a]	77.00 ± 4.36[fgh]	38.50 ± 0.62[bcde]

Means followed by the same letter within the column are not significantly different at p < 0.01. Original (back-transformed) values are presented here; however, log and angular-transformed values were used for the analysis.

counted per jar on each assessment day. Observations were continued for two months (56 days) until all F_1 progenies were expected to have emerged.

Sixty-four days after introduction of the weevils, 100 seeds were randomly taken from each jar to assess the number of seed damage (seeds with hole) and grain weight loss. Seed damage was expressed as a proportion of the total number of seeds sampled. Grain weight loss was determined using the count and weight method of Gwinner et al. (1996) expressed as:

$$\text{Weight loss (\%)} = \frac{(Wu*Nd) - (Wd*Nu)}{Wu*(Nd + Nu)}*100;$$

Where Wu = Weight of undamaged seed, Nu = Number of undamaged seed, Wd = Weight of damaged seed, and Nd = Number of damaged seed.

The median development period was calculated as the time (days) from the middle of the oviposition period to the emergence of 50% of the F_1 adults (Dobie, 1977).

The index of susceptibility was calculated as given by the formula of Dobie (1974): Index of susceptibility = 100 x [$\log_e$ (total number of F_1 progeny emerged) / (median development time)]. The susceptibility range of 0 to 11 was used to classify the sorghum varieties; where; 0 to 3 = resistant, 4 to 7 = moderately resistant, 8 to 10 = susceptible and ≥ 11 = highly susceptible (Dobie, 1974).

Data analysis

Data were subjected to analysis of variance (ANOVA) using the statistical software PROC GLM; SAS Institute (2008) (version 9.2). Data on percent adult mortality, percent seed damage, and weight loss were subjected to angular-transformation, while numbers of F1 progenies were log transformed in order to stabilize the variance. Statistical analysis was performed using one-way analysis of variance. Differences among means were compared by Tukey's HSD test. Pearson correlation coefficients were obtained using the same statistical software.

RESULTS

Adult mortality, progeny emergence and developmental time

There were insignificant differences among the sorghum varieties in percentage adult mortality (Table 1). However, highest weevil mortality was recorded in the varieties Red Sheferie-1 and Yellow Wogere-2 whereas, least percent of mortality was noticed in AL-70 and Chelenko. Significant differences (P<0.01) were observed between the varieties in the number of F_1 progeny emergence (Table 1). Maximum numbers of F_1 progenies emerged from Fendisha-5 (155) followed by Muyra-1 (138) and AL-70 (137) while significantly the least number of F_1 progenies was counted from WB-77 (20). The median developmental time varied significantly (P <0.01) among the sorghum varieties (Table 1).

Table 2. Extent of seed damage and weight loss by *S. zeamais* on different sorghum varieties.

Variety	Seed damage (%)	Weight loss (%)
Abshier	13.00 + 3.67[bc]	3.13 + 0.59[d]
AL-70	21.00 + 3.46[ab]	7.10 + 0.54[b]
Awash-1050	11.00 + 2.36[c]	2.80 + 0.41[de]
Chelenko	15.66 + 4.56[bc]	5.67 + 0.74[bc]
ETS-2752	12.67 + 1.20[bc]	2.98 + 1.20[de]
Fendisha-5	29.33 + 4.23[a]	12.40 + 0.84[a]
Gubiye	4.00 + 1.00[e]	1.01 + 0.74[f]
IS-9302	15.00 + 4.35[bc]	5.50 + 1.10[bc]
Muyra-1	23.00 + 4.61[ab]	8.77 + 1.27[b]
Red Sheferie-2	9.00 + 2.81[dc]	2.26 + 0.30[e]
Red Sheferie -6	5.00 + 1.10[d]	1.98 + 0.43[ef]
Yellow Wogere- 6	10.67 + 1.15[c]	2.35 + 0.56[e]
Yellow Wogere-8	6.00 + 2.00[d]	2.14 + 0.28[e]
Red Sheferie- 1	14.00 + 3.31[bc]	3.90 + 0.16[c]
Red Sheferie- 5	13.00 + 4.20[bc]	3.50 + 0.93[cd]
Yellow Wogere-1	13.00 + 3.46[bc]	3.05 + 0.16[d]
Yellow Wogere-2	14.67 ± 3.78[bc]	4.10 ± 0.60[c]
Teshale	3.67 + 0.50[e]	0.85 + 0.10[f]
White Fendisha	19.00 + 3.43[ab]	6.22 + 0.50[b]
WB-77	2.67 ± 0.67[ef]	0.30 ± 0.26[g]
Wogere-3	10.66 + 2.43[c]	2.49+0.59[e]

Means followed by the same letter within the column are not significantly different at p<0.01. Original (back-transformed) values are presented here; however, angular-transformed values were used for the analysis.

Development from egg to adult ranged from 31.40 days for Fendisha-5 to 42.00 days for WB-77. Generally, as the median developmental period increases, the F_1 progeny emergence decreases. A shorter median developmental time gives rise to more generations a year, and the greater is the susceptibility of the variety.

Seed damage and weight loss

Significant variations (P<0.01) were recorded in the percentages of seeds damaged and weight loss between the sorghum varieties (Table 2). The results revealed that the highest seed damage and weight loss were observed in Fendisha-5, Muyra-1 and AL-70. The least percent of seed damage and seed weight loss were recorded inWB-77, Teshale and Gubiye varieties. Percentage seed damage and weight loss were directly related to the mean number of F_1 progeny emergence. Consequently, those varieties with high number of F_1 progeny scored high percentage of seed damage and weight loss.

Index of susceptibility

The index of susceptibility ranged from 3 for variety WB-77 to 7 for Fendihsa-5 (Figure 1). Out of the twenty-one sorghum varieties evaluated for their resistance to *S. zeamais*, only one variety WB-77, was rated as resistant, while all the remaining varieties were categorized as moderately resistant to weevil attack.

Simple correlation coefficient of the variables

The simple linear association between variables like number of F_1 progeny, median developmental time, susceptibility index (SI), weight loss, and seed damage are summarized in Table 3. SI was positively correlated with important genetic resistant factors such as progeny emergence, percent of seed damage and percent of weight loss. However, median development time was inversely correlated with the susceptibility index, and was negatively and significantly associated with F_1 progeny emergence (r = -0.93, P< 0.01) (Table 3). As can be expected, with the increasing number of F_1 progenies, there was an increasing and highly significant percentage of seed damage (r = 0.94, P< 0.01) and seed weight loss (r = 0.92, P< 0.01) from the varieties.

DISCUSSION

The difference in sorghum varieties were mainly due to

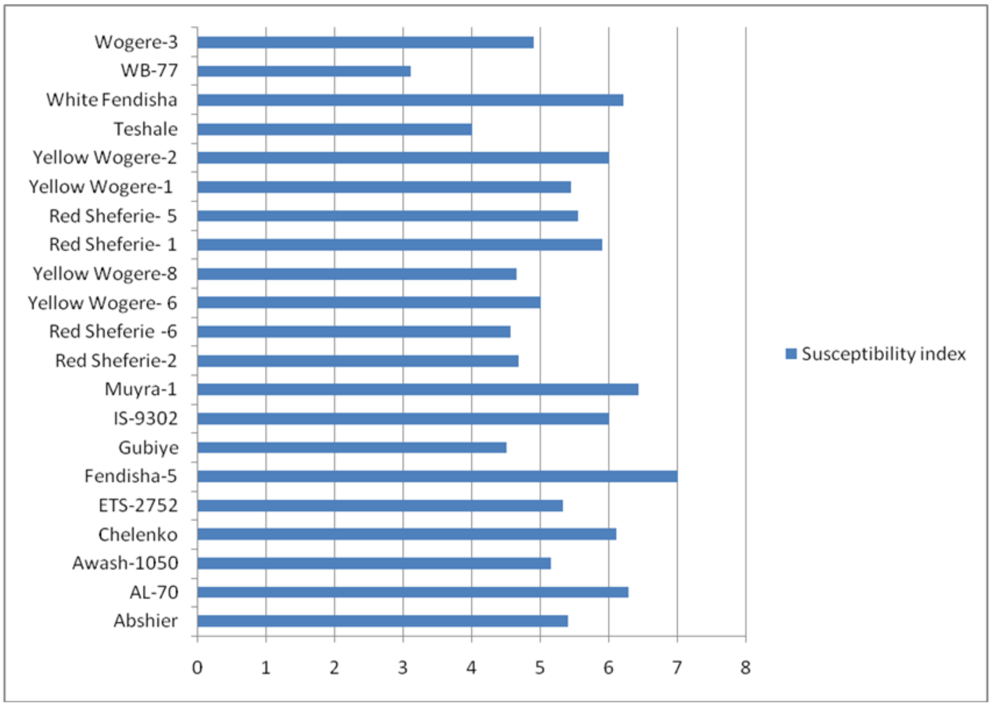

Figure 1. Susceptibility index of sorghum varieties to *S. Zeamais* infestation (0-11 scale), where; 0-3= resistant, 4-7= moderately resistant, 8-10= susceptible and $\geq$ 11= highly susceptible

the variation in seed damage level, the percent of grain weight loss, F_1 progeny emergence, median developmental time and susceptibility index. These variations in the differential susceptibility of the sorghum varieties show the innate capacity of a particular variety to resist *S. zeamais* attack. Resistant varieties exhibited minimum grain damage and weight loss, reduced multiplication of F_1 progeny, longer median developmental period and lower score of susceptibility index. A number of factors contribute to the differences in genetic resistance of sorghum varieties to stored grain insect attack through their influence on fecundity and development (Shazali, 1987; Adentuji, 1998). This indicates that presumably antibiosis and/or antixenosis (non-preference) mechanisms of resistance play a role in varietal resistance. Similarly, several authors reported that antibiosis and non-preference act together as mechanisms of resistance to *S. zeamais* in sorghum and maize grains (Santos and Foster, 1983; Torres et al., 1996; Chuck-Hernández et al., 2013; Temesgen and Waketole, 2013).

Resistance in stored sorghum to insect attack has been attributed to the presence of toxic alkaloids or amino acids, insect feeding deterrents, pericap surface texture, enzyme inhibitors, grain hardness, grain temperature and moisture content. These factors acting alone or in combination are responsible for the varying levels of resistance to certain species of storage insect pests (Baker, 1976; Wongo and Pedersen, 1990; Ramputh et al., 1999; Chandrashekar and Satyanarayana, 2006). Bamaiyi et al. (2007) also reported grain hardness as the main resistance parameter for *S. oryzae* in stored sorghum.

The resistant sorghum variety, WB-77, has high lysine content (ICRISAT, 1985). Higher levels of lysine and tryptophan decreased the rate of reproduction of *S. zeamais* (LeCato and Arbogast, 1974; Abebe et al., 2009). Further, Arnason et al. (2004) also reported that protein content was negatively correlated with the susceptibility of maize cultivars to *S. zeamais*. All the tasted sorghum varieties were not significantly different from each other with regard to weevil's mortality. Abebe et al. (2009) reported a similar result among thirteen maize varieties evaluated against *S. zeamais.* Similarly, Dobie (1974) found low mortality of adult maize weevils on different varieties of maize, and concluded that there was no evidence for variation among the varieties in their effect upon the mortality of *S. zeamais*. Abraham (1991) also stated that mortality of maize weevil was not a good parameter to quantify the susceptibility and/or resistance of varieties, because adult weevils were found to survive without food for more than ten days in a laboratory test.

Progeny emergence was highly correlated with the susceptibility of varieties to weevil infestation. Consequently, varieties which are susceptible to maize weevils produce more number of progeny as compared to the resistant varieties. A large difference in the number of F_1 progenies between the resistant and susceptible varieties

Table 3. Correlation coefficient of *S. zeamais* infestation on sorghum varieties.

Variable	F_1P	MDT	SI	SD	WL
F_1P	1				
MDT	-0.93**	1			
SI	0.95**	-0.92**	1		
SD	0.94**	-0.91**	0.83**	1	
WL	0.92**	-0.91**	0.81**	0.86**	1

F_1P: No. of F_1 progeny, MDP: median developmental period, SI: index of susceptibility, SD: seed damage, WL: weight loss, *: Correlation is significant at 0.05 level; **: Correlation is significant at 0.01 level.

is an important variable for the management of *S. zeamais* in stored sorghum. According to Davey (1965), the difference in the number of emerging progenies of *S. oryzae* is an adequate measure for comparing damage among sorghum varieties. *S. zeamais* required less developmental time on the susceptible variety, Fendisha-5 (31.40 days) while, longer developmental time was elapsed on the resistant variety, WB-77 (42.00 days). This indicates that one effect of increased resistance is prolongation of the developmental period. The susceptible sorghum variety, Fendisha-5, had approximately eleven day shorter developmental period for the number of F_1 emergence than the resistant variety, WB-77. Similarly, *S. zeamais* emerged from varieties having a high index of susceptibility exhibited reduced periods for the completion of developments. According to Horber (1988), the susceptibility index is based on the assumption that the higher F_1 progeny and the shorter the duration of the development, the more susceptible the varieties would be. According to Abraham (1991), the extent of damage during storage depends on the number of emerging adults during each generation and the duration of each developmental time. Thus, varieties allowing rapid and high levels of adult emergence will be more seriously damaged. Several sorghum varieties, especially local landraces have been characterized as sources of resistance to *Sitophilus* species (Anonymous, 1986; Tibebu and Tessema, 1986; Ramputh et al., 1999; Teshome et al., 1999; Chitio et al., 2004; Chandrashekar and Satyanarayana, 2006; Bamaiyi et al., 2007; Chuck-Hernández et al., 2013).

The information obtained from the present study will assist to devise the management strategies against this legendary pest of sorghum as well as other cereals. Based on the present investigation, the most resistant sorghum variety among the varieties tested is WB-77. The resistant variety WB-77 is a variety with reduced number of F_1 progenies, seed damage, weight loss, indices of susceptibility; and extended median developmental time. These indicate that the overall loss incurred to this variety during storage will be minimal. This variety deserves special consideration and can be stored for longer periods of time under traditional storage system of small scale farmers with inadequate storage facilities. Resistant varieties can reduce the cost of weevil's management and can also be utilized as an environmental friendly way to reduce damage by *S. zeamais.* In the past, a reasonable number of sorghum varieties have been evaluated for their resistance to maize weevil, but still more explorations are needed to achieve long-term and sustainable pest management strategies and to diversify the basis of resistance to this pest. Thus, the authors suggest the inclusion of this resistant sorghum variety in the integrated sorghum production system.

Conflict of interest

The authors have not declared any conflict of interest.

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