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A study on the susceptibility of maize genotypes against the maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae)

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Several maize varieties with high-yield potential have recently been created; however, their resistance to storage pests is unknown. This study compares the resistance ability to *Sitophilus zeamais* of four open-pollinated varieties (OPVs) and thirteen hybrid maize varieties using Dobie's susceptibility index (SI). The genotypes were tested in a completely randomized design with three replications at a temperature of 28°C and a humidity of 65 to 70%. A resistant OP maize variety (Melkassa 6Q) had SI of less than 3.5 (3.43). OPVs evaluated (Gambela, Gibe 2, and Gibe 3) had SI of 4.60, 5.32, and 6.77, respectively, while most hybrid varieties had SI of 3.82, 4.15, 4.22, 4.65, 4.74, 4.92, 5.17, 5.74, 6.00, 6.50, and 7.37 respectively. These include BH547, AMH851, P3812W, HB30G19, MHQ138, SC627, BH546, P3506W, BH549, P2859W, and AMH850. Among the thirteen hybrids, AMH853 had a SI of 8.13. This susceptible variety produced a high number of F_1 progenies (2.19), had a low median developmental time (27 days), a high percentage of seed damage (75.00%), a high production of grain dust (0.92 g), a high percentage of seed weight loss (1.1%), and a low percentage of weevil mortality (0.16%). Subsistence farming in developing countries should encourage resistant varieties.

Key words: Maize varieties, progeny emergence, susceptibility index, weight loss.

INTRODUCTION

After wheat and rice, maize (*Zea mays* L.) is the third-largest cereal crop grown worldwide (Wang et al., 2018). According to Ranum et al. (2014), it is widely accessible and consumed by both people and domestic animals. Insect pests' damage 20 to 30% of maize stored worldwide (Midega et al., 2016). Although pest infestations can happen in the field, the majority of damage happens during storage (Manu et al., 2018). The maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae), which is a significant pest of maize in the tropics and causes significant losses to many impoverished farmers who store grains on their farms for use as food and seeds, is primarily responsible for the damage (Rashid et al., 2021).

Sub-Saharan Africa grows 80% of dry food crops by smallholders (Dijkink et al., 2022). Sub-Saharan African

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*Corresponding author. E-mail: tsegab.temesgen@aau.edu.et farmers sell their maize grains after two months of storage to avoid losses from insect invasion and thus miss the chance of getting the highest price during the starving period (World Bank, 2011). To reduce such problems, synthetic insecticides have been extensively used to control storage pests. This strategy typically comes with its own set of disadvantages, such as the development of resistant strains, harmful residues, and higher expenses (Stejskal et al., 2021). Users, on the other hand, are growing increasingly concerned about insect-related food quality issues as they become more aware of chemical pesticide hazards.

Farmers employ botanicals or plant-based products; smoke and ash with insecticidal properties are a few local pest management strategies farmers employ (Ngegba et al., 2022). Traditional pest management strategies are often unrealistic for large-scale farmers. Chemical pesticides are often used instead, leading to environmental degradation and other risks. Furthermore, pesticide-related issues, pesticide misuse, and further unintended consequences require a vigorous search for active, low-cost, and long-term pest management alternatives (Mengistie et al., 2017; Andersson and Isgren, 2021). Insect pest-resistant maize varieties are one such control option (Nwosu, 2018). In such circumstances, searching for effective and resistant varieties is useful at no cost to farmers. Several maize varieties with high yield potential have recently been created; however, it is unknown whether they are tolerant of pests that affect stored goods (Lopez-Castillo et al., 2018). Effective, resistant varieties against storage insect pests would have significant advantages over alternative control methods, particularly pesticide use, which has several drawbacks (Kumari et al., 2022). Therefore, this study assessed the resistance varieties of seventeen maize genotypes to *S. zeamais* using the susceptibility index.

MATERIALS AND METHODS

Experimental design

This research was conducted from December 2021 to August 2022 in the Bako National Maize Research Center (BNMRC) crop protection laboratory. The treatments were set up in a completely randomized design (CRD) with three replications for each maize variety in this study, which was carried out in a laboratory at 25°C–28°C, 65–70% relative humidity, and a 12:12 (light: dark) photoperiod.

Maize variety collection

A total of seventeen (17) currently available maize varieties were collected from Melkassa, Ambo, and the Bako National Maize Research Centers. Four open-pollinated varieties (Melkassa-6Q, Gambela, Gibe 2, and Gibe 3), and thirteen F_1 hybrid maize varieties (MHQ138, MH140, AMH850 (Wenchi), AMH851, AMH853 (Kolba), P2859W, BH546, BH547, BH549, HB30G19, SC627, P3812W, and P3506W) were collected. These varieties were used for screening resistance varieties against maize weevils in the Bako National Maize Research Center's crop protection laboratory.

Mass rearing of the test insect

S. zeamais was reared in a laboratory at temperatures ranging from 25 to 28°C and relative humidity levels ranging from 68.5 to 74.5%. The maize grain used in the experiment (BH-661 hybrid maize) was cleaned and disinfested by being placed in a deep freezer for two weeks at temperatures ranging from -20 to 0°C to remove internal parasites. To adapt it, it was kept under experimental conditions for two more weeks (Hiruy and Getu, 2020). The maize weevils were obtained from BARC's maize store and grown in the lab. Weevils were reared in eight plastic jars with muslin cloth coverings to allow aeration while preventing escape. Each jar, which held 1.5 kg of grain, was contaminated with at least 300 adults of *S. zeamais*.

All *S. zeamais* dead and alive parents were removed after two weeks. F_1 emergent progeny (0–3 days old) were sieved out and used for experimentation after 30 days.Forty grams of each maize grain variety were weighed and inserted into a 250-cm^3 glass jar with brass screen lids. This allows for ventilation and prevents weevil escape. These were then infested with 20 pairs of *S. zeamais* adult insects, which were introduced to each seed sample. Similarly, seeds from each variety that did not contain *S. zeamais* were kept under similar conditions and served as a control.

Data collection and analysis

To reduce variation, data on adult mortality, grain damage, and weight loss were angular-transformed (arcsin √ proportion), which equals the inverse sine of the square root of the proportion, whereas F1 progeny numbers were log-transformed. The Statistical Package for Social Sciences (SPSS, 2016) was used to analyze the transformed data. The Tukey test ($P<0.05$) was applied to distinguish significant differences between the means. Kidane (2011) used the number of parental insects alive and dead after 13 days of oviposition to determine mortality:

$$\% \text{ Mortality} = \frac{\text{Number of dead weevils}}{\text{Total number of weevils}} \times 100$$

All dead and alive adult insects were removed from each jar during adult mortality data analysis. The seeds of each test variety were stored under the same experimental conditions to measure F1 progeny emergence for consecutive periods. Every day from the moment the new imago phase was visible from outside the maize grains until no new F1 insects emerged for roughly 56 days, the number of new adult insects was counted (Barre and Jenber, 2022). Daily checks were required, especially after 25 days, to collect and record the number of developing progeny in each jar. Collecting continued on for more than two weeks until no more adults showed up. Adult insects that had just emerged were counted.

A total of all the F1 progenies of each test insect were added together per genotype to calculate the number of F1 insect progenies that emerged from each genotype. Seventy days after the weevils were introduced, 100 seeds were randomly selected from each jar.

The number of seeds injured by weevil feeding was counted. The amount of seed damage was calculated as a percentage of the total number of seeds sampled. The count and weight method was used to determine seed weight reduction.

After the trial, the feed preference was determined by calculating the percentage of weight loss.

Table 1. Adult mortality, F_1 progeny, and median development time (MDT).

Variety	Adult mortality %	F_1 progeny	MDT
P2859W	0.24 ± 0.02^{bc}	2.14 ± 0.01^{jkl}	32.67 ± 0.67^{cd}
BH547	0.65 ± 0.01^{j}	1.85 ± 0.01^{cd}	46.7 ± 0.33^{h}
MH140	0.61 ± 0.02^{ij}	1.83 ± 0.00^{bc}	45.3 ± 0.67^{h}
Gambela	0.35 ± 0.01^{de}	2.04 ± 0.00^{gh}	38.0 ± 0.58^{ef}
AMH851	0.61 ± 0.01^{hi}	1.88 ± 0.00^{d}	44.0 ± 0.00^{gh}
BH549	0.31 ± 0.01^{cd}	2.09 ± 0.01^{ij}	35.0 ± 0.33^{cd}
P3812W	0.55 ± 0.00^{ghi}	1.94 ± 0.01^{e}	44 ± 0.00^{gh}
P3506W	0.32 ± 0.00^{cd}	2.05 ± 0.01^{hi}	35.0 ± 0.33^{de}
SC627	0.43 ± 0.02^{ef}	1.99 ± 0.01^{fg}	40.0 ± 0.00^{f}
MHQ138	0.46 ± 0.00^{f}	1.79 ± 0.02^{b}	41.0 ± 0.00^{fg}
Gibe-2	0.20 ± 0.02^{ab}	2.13 ± 0.01^{jk}	32.0 ± 0.00^{bc}
AMH850	0.18 ± 0.02^{ab}	2.15 ± 0.01^{kl}	29.3 ± 1.33^{ab}
Melkassa-6Q	0.73 ± 0.04^{k}	1.72 ± 0.01^{a}	50.3 ± 1.33^{i}
Gibe-3	0.51 ± 0.01^{fgh}	1.97 ± 0.00^{ef}	41.0 ± 0.00^{fg}
BH546	0.37 ± 0.01^{de}	1.88 ± 0.01^{d}	38.7 ± 0.33^{ef}
AMH853	0.16 ± 0.02^{a}	2.19 ± 0.01^{l}	27.00 ± 1.00^{a}
HB30G19	0.47 ± 0.01^{fg}	1.85 ± 0.01^{cd}	44.0 ± 0.00^{efg}
Mean ±SE	0.42±0.02	1.97±0.02	38.9±0.88
LSD(0.005)	10.07	12.90	9.60
CV%	40.51	7.07	16.18

Mean values in a column with the same letter are not significantly different at $P < 0.05$; angular-transformed values were presented here; CV=Coefficient of Variation; LSD=Least significant difference.

This was estimated using the count and weigh method according to Boxall (1986) and determined using the formula:

$$\% \text{ Weight loss} = \frac{(W_u \times N_d) - (W_d \times N_u)}{W_u \times (N_d + N_u)} \times 100$$

where W_u = Weight of undamaged grains, N_u = Number of undamaged grains, W_d = Weight of damaged grains, and N_d = Number of damaged grains.

The Dobie method was used to calculate the susceptibility index (Dobie and Kilminster, 1997). The number of F_1 progeny and the median developmental time are both factors to consider.

$$\text{Index of Susceptibility} = \frac{\text{Log (Total number of } F_1 \text{ progeny emerged)}}{\text{Median developmental time}} \times 100$$

The Dobie's index was then used to categorize the maize varieties as modified by Nhamucho et al*.* (2017). The susceptibility index values ranged from 0 to 11, with the following categories: 0–3 = resistant (R); 4–7 = moderately resistant; 8-10 = vulnerable (S); and 11 denote high susceptibility (HS).

RESULTS AND DISCUSSION

Mortality in *S. zeamais*, F_1 progeny emergence, and median developmental time

The percentages of adult mortality, F_1 progeny emergence, and median developmental days among maize varieties were significantly different ($p<0.05$) (Table 1). The study's findings demonstrate that resistance to the maize weevil varies greatly among the maize varieties tested. Adult weevil mortality, the number of weevils produced, the median development time, seed weight loss, the weight of grains damaged, and the weight of powder produced at the end of the screening period were all related. Accordingly, the aforementioned variables can be integrated to calculate susceptibility using Dobie's index and then used to categorize maize varieties as modified by Nhamucho et al. (2017). The Melkassa-6Q maize variety had the highest and significantly higher adult weevil mortality (0.73%), followed by BH547 (0.65), MH140 (0.61), AMH851 (0.61), P3812W (0.55), Gibe-3 (0.51), HB30G19 (0.47), MHQ138 (0.46), SC627 (0.43), BH546 (0.37), Gambela (0.35), P3506W (0.32), BH549 (0.31), P2859W (0.24), Gibe-2 (0.20), and AMH850 (0.18), with the AMH853 maize variety having the lowest parent weevil mortality (0.16%). Parent weevil mortality ranged from 0.16 to 0.73% (Table 1). The variability, namely: Melkassa-6Q (0.73%), followed by BH547%, MH140%, AMH851%, P3812W%, Gibe-3, HB30G19%, MHQ138%, SC627%, BH546%, Gambela, P3506W%, BH549%, P2859W%, Gibe-2, and AMH850%, could be due to physical properties of the seeds, such as colour, kernel hardness, shell thickness, and the size of the seeds, or failure to

Table 2. The mean grain damage (GD), % WL, and WPP by *S. zeamais* infestations on seventeen maize varieties for 70 days.

Variety	Mean GD (g)	% GD	Mean WL %	Mean WPP (g)
P2859W	0.19±0.00^{bc}	73.3±0.3^{f}	0.61±0.01^{ab}	0.61±0.05^{efg}
BH547	0.20±0.00^{i}	69.0±0.0^{b}	0.38±0.01^{a}	0.26±0.03^{ab}
MH140	0.20±0.00^{kl}	69.0±0.0^{b}	0.47±0.04^{ab}	0.33±0.02^{abc}
Gambela	0.19±0.00^{e}	72.0±0.0^{e}	0.5±0.04^{ab}	0.50±0.03^{def}
AMH851	0.19±0.00^{jk}	69.0±0.0^{b}	0.43±0.00^{ab}	0.43±0.04^{cd}
BH549	0.19±0.00^{cd}	72.0±0.6^{e}	0.57±0.01^{ab}	0.66±0.0^{g}
P3812W	0.19±0.00^{ij}	70.0±0.0^{c}	0.44±0.01^{ab}	0.46±0.1^{cde}
P3506W	0.19±0.00^{d}	72.0±1.5^{e}	0.56±0.00^{ab}	0.62±0.04^{fg}
SC627	0.19±0.00^{fg}	71.0±0.0^{d}	0.5±0.00^{ab}	0.50±0.03^{def}
MHQ138	0.19±0.00^{gh}	71.0±0.7^{d}	0.48±0.01^{ab}	0.59±0.03^{def}
Gibe 2	0.19±0.00^{ab}	74.0±0.0^{f}	0.65±0.02^{ab}	0.84±0.02^{h}
AMH850	0.19±0.00^{ab}	74.0±0.0^{f}	0.72±0.02^{b}	0.86±0.0^{h}
Melkassa-6Q	0.20±0.00^{l}	68.0±0.0^{a}	0.36±0.01^{a}	0.21±0.01^{a}
Gibe 3	0.19±0.00^{hi}	70.0±0.0^{c}	0.46±0.00^{ab}	0.41±0.01^{bcd}
BH546	0.19±0.00^{ef}	72.0±0.0^{e}	0.53±0.00^{ab}	0.46±0.03^{cdef}
AMH853	0.19±0.00^{a}	75.0±0.6^{g}	1.1±0.23^{c}	0.92±0.02^{h}
HB30G19	0.19±0.00^{hi}	71.0±0.0^{d}	0.47±0.00^{ab}	0.50±0.04^{def}
Mean± SE	0.19±0.00	0.19	0.54±0.03	0.53±0.03
LSD(0.005)	14.20	2.67	4.50	0.29
CV%	1.41	2.84	15.94	37.85

*Mean values in a column with the same letter are not significantly different at $P < 0.05$; angular-transformed values were presented here. GD=Grain Damaged; WL= weight loss; WPP= weight of powder produced; CV=Coefficient of Variation; LSD=Least significant difference.

provide stimuli that are attractive to the pest (antixenosis), or the adverse effect of maize grains on the development and reproduction of insect pests, which led to the subsequent death of the maize weevils. This showed that these sixteen maize varieties have resistant factors in or on their grain that inhibit weevil attacks (Rahardjo et al., 2017).

High parental weevil mortality may also be due to biochemical and biophysical factors that are toxic to insects (antibiosis); that is, resistance mechanisms that deter colonization by insects. The plant contains chemicals toxic to insects in the form of alkaloids, terpenoids, phenol compounds, or benzoate compounds (War et al., 2012). Even if adult weevils can survive without food for more than ten days (Khakata et al., 2018), high parental weevil mortality might also be recognized as an absence of nutritional factors such as starchy amylose content, antifeedant compounds such as phenolic, and the presence of toxic alkaloids in the grain, which might be important for insect development (Suleiman et al., 2015).

The AMH853% maize variety had the lowest parent weevil mortality, indicating high susceptibility to weevil attack (Table 2). Variations and significant differences ($p<0.05$) were observed among the varieties in the number of weevils that emerged. AMH853 (2.19), AMH850 (2.15), P2859W (2.14), and Gibe-2 (2.13) produced the most weevils, while Melkassa-6Q (1.72), BH547 (1.85), and AMH851 (1.88) produced significantly fewer F_1 progenies. The mean number of weevils that emerged ranged from 1.72 to 2.19 (Table 2). The Melkassa-6Q maize variety had the highest and significantly higher adult emergence (1.72), followed by MHQ138 (1.79), MH140 (1.83), BH547 (1.85), HB30G19 (1.85), AMH851 (1.88), BH546 (1.88), P3812W (1.94), Gibe-3 (1.97), SC627 (1.99), Gambela (2.04), P3506W (2.05), BH549 (2.09), Gibe-2 (2.13), P2859W (2.14), AMH850 (2.15), and AMH853 (2.19).Previous research has found that the susceptible genotypes have a higher number of F_1 progeny emergences than the resistant genotypes, implying that antibiosis is the mechanism promoting high parental mortality and lower progeny emergence (Siamey et al., 2021).

Furthermore, the shortest MDT was recorded on the AMH853 variety at 27.00 days.

The differences in the number of F_1 weevils developed showed that maize weevil attack susceptibility varied among the varieties. Varieties with the highest number of F_1-progeny had the greatest susceptibility to maize weevil attack, and this may have been due to a lack of resistance mechanisms in the maize grain (Sserumaga et al., 2021).

The low weevil emergence in Melkassa-6Q can be attributed to high parent weevil mortality. As a result, F_1 offspring were produced. The few F_1-weevil emergencies in these varieties are perhaps recognized as the absence of key nutrients and an uneven proportion of nutrients, leading to larval mortality (Kasozi et al., 2018). F_1 maize weevil development may have been significantly affected by antibiosis effects in resistant maize varieties, which stunted growth in maize weevil progeny and sometimes led to the death of the weevils before they laid eggs (Jiménez-Galindo et al., 2023). The median developmental period ranges from 27 days for AMH853 maize varieties to 51 days for the Melkassa-6Q maize variety. The resistant variety required longer developmental times (Jallow and Pitan, 2022). A shorter MDT increases the number of generations produced within a given period. Hence, progeny size increases compared to a variety that delays pest growth. The larger the F_1 progeny, the heavier the infestation, and the more susceptible a variety is. In general, as the median developmental period decreases, the F_1 progeny increases as the percentage of adult weevil mortality decreases (Table 1). The degree of damage during grain storage is closely related to two key elements. Higher degrees of adult emergence and the number of emerging adults during each generation are two factors. In line with this, varieties of maize with higher adult *S. zeamais* emergence and lower mortality rates suffered greater harm than those with lower progeny emergence and higher mortality rates (Medugu et al., 2020).

Mean grain damage (%) and mean seed weight loss (SWL) percentage

The results showed that the percentage of grain damage was highly significant ($p<0.005$) among the experimental varieties (Table 2). AMH853 (75.0%), AMH850 (74.0%), Gibe 2 (74.0%), P2859W (73.3%), Gambela (72.0%), BH549 (72.0%), P3506W (72.0%), and BH546 (72.0%) had significantly greater mean grain damage means (%) than the other varieties, while Melkassa-6Q (68.00%), BH547 (69.00%), MH140 (69.00%), and AMH851 (69.00%) had significantly lower mean seed damage (%). These are consistent with the high number of F1 progeny emergences. These results agree with Ahmad et al. (2022), who showed that the extent of damage during storage depends on the number of emerging adults during each generation and the length of each life cycle. Varieties allowing more rapid and higher levels of adult emergence are more severely harmed. Some of the varieties, namely Melkassa-6Q, MHQ138, and MH140, had small kernel sizes and were too rigid and compact to be exploited by the weevils. According to Mwenda et al. (2019), small kernels are dense and compact, thus more resistant to weevil attack. The results showed that time (days) had a large influence on GWL% among the experimental varieties; the outcomes indicated that maize grain weight loss and damage were highly significant ($p<0.005$) among the experimental varieties (Table 2).

At 70 days of storage, AMH853 (1.1%), AMH850 (0.72%), Gibe 2 (0.65%), and P2859W (0.61%) had the highest weight loss, whereas Melkassa-6Q (0.36%), BH547 (0.38%), AMH851 (0.43%), and P3812W (0.44), had the lowest weight loss (Table 2). AMH853 had the most damaged grains (1.1%) after 70 days of maize weevil exposure, followed by AMH850 (0.72%), Gibe 2 (0.65%), and P2859W (0.61%). The average percentage of weight loss was 0.54%, with a range of 0.36 to 1.1% (Table 2). The researcher considered the weight of the data. Low weight loss occurred in Melkassa-6Q (0.36%) and BH547 (0.38 %); whereas, AMH853 (1.1%) had the greatest weight loss and thus could be said to be more susceptible to weevil attack than other varieties collected from different research centers for this experiment. Overall, there were significant differences between seed WL% and kernel damage in maize varieties ($P < 0.05$); the results showed time (days) had a larger influence on seed WL%. The highest seed WL% was observed on AMH853 and AMH850 at 70 days of storage (Table 1).

In general, seed WL% results were related to kernel weight damage; these could be due to resistance mechanisms in, or on, the grain that prevent weevil attack. Resistance to insect attack in stored maize has been attributed to physical factors such as grain hardness and pericarp surface texture, as well as nutritional factors such as amylose, lipids, and protein content (Rahardjo et al., 2017). Secondary plant metabolites such as phenolic acids and hexanoic acid, produced by the maize crop, may cause antixenosis. Secondary plant chemicals are toxic to insects at both deadly and sub-lethal concentrations, with repellence being the most pronounced effect (Chowanski et al., 2016). Phenolic compounds poison insects, according to numerous artificial feeding studies (Wu et al., 2015).

Weight of powder production

The lowest powder weight was observed on Melkassa-6Q (OP) (0.21 g), BH547 (H) (0.26 g), MH140 (H) (0.33 g), Gibe 3 (OP) (0.41 g), AMH851 (H) (0.43 g), P3812W (H) (0.46 g), and BH546 (H) (0.46 g) maize varieties. This finding is consistent with the percentages of parental and adult mortality and seed weight loss. The highest powder weight was observed on AMH853 (H) (0.92 g), AMH850 (H) (0.86 g), Gibe 2 (OP) (0.84 g), BH549 (H) (0.66 g), P3506W (H) (0.62 g), and P2859W (H) (0.61 g) maize varieties. This result is consistent with the number of F1 progeny emerging and the percentage of damaged seed (Table 3). The powder weight produced a significant difference ($P <0.05$). This is similar to previous studies that reported significant variation in powder weight among different maize varieties when infested with the

Table 3. Index of susceptibility (IS) of maize varieties to maize weevil.

Variety	Dobie's IS	Classification
P2859W	6.50 ± 0.14^{i}	MR
BH547	3.82 ± 0.07^{ab}	MR
MH140	4.03 ± 0.07^{abc}	MR
Gambela	5.32 ± 0.09^{fg}	MR
AMH851	4.15 ± 0.00^{bcd}	MR
BH549	6.0 ± 0.09^{hi}	MR
P3812W	4.22 ± 0.0^{bcd}	MR
P3506W	5.74 ± 0.07^{gh}	MR
SC627	4.92 ± 0.0^{ef}	MR
MHQ138	4.74 ± 0.0^{def}	MR
Gibe 2	6.77 ± 0.0^{i}	MR
AMH850	7.37 ± 0.32^{j}	MR
Melkassa-6Q	3.43 ± 0.11^{a}	R
Gibe 3	4.60 ± 0.01^{cde}	MR
BH546	5.17 ± 0.8^{efg}	MR
AMH853	8.13 ± 0.33^{k}	S
HB30G19	4.65 ± 0.0^{cdf}	MR
Means ±SE	5.27	
$LSD_{(0.005)}$	8.21	
CV%	24.63	

MR = Moderately resistant; S = susceptible; OP = open-pollinated varieties, and H = hybrids; CV=coefficient of variation; LSD=least significant difference. Means followed by the same letter within the column are not significantly different at $p < 0.05$.

maize weevil, *S. zeamais* (Taulu et al., 2020).

The index of susceptibility

Significant differences ($p<0.05$) were observed in the tested against *S. zeamais* for resistance, only one maize variety had a < 3.5 index of susceptibility. It was considered resistant to a weevil attack. A variety's resistance to *S. zeamais* is inversely correlated with its susceptibility index (Tefera et al., 2013).

However, most of the varieties, namely BH547, MH140, AMH851, P3812W, Gibe 3, SC627, MHQ138, HB30G19, BH546, Gambela, P3506W, BH549, Gibe 2, P2859W, Gibe 2, and AMH850, had an index of susceptibility of 3.82, 4.03, 4.15, 4.22, 4.60, 4.65, 4.74, 4.92, 5.17, 5.32, 5.74, 6.00, 6.50, 6.77, and 7.37, respectively, and are viewed as moderately resistant to weevil attack.

Only one variety, called AMH853, had an index of susceptibility of 8.13 and was regarded as a susceptible variety to maize weevil attack.

One OP maize variety (Melkassa-6Q) had less than a 3.5 (3.43) index of susceptibility to maize weevil attack and was called resistant. However, three of the OPVs evaluated (Gambela, Gibe-2, and Gibe-3) had an index of susceptibility of 4.60, 5.32, and 6.77, respectively, and most of the hybrid evaluated (BH547, AMH851, P3812W, HB30G19, MHQ138, SC627, BH546, P3506W, BH549, P2859W, and AMH850) had an index of susceptibility of 3.82, 4.15, 4.22, 4.65, 4.74, 4.92, 5.17, 5.74, 6.00, 6.50, and 7.37, respectively, and are viewed as moderately resistant to weevil attack. One of the thirteen hybrids, AMH853 (Kolba), had an index of susceptibility of 8.13 and was regarded as a susceptible variety to maize weevil attack.The susceptible variety AMH853 (Kolba) produced a high number of F_1 progeny (154.00), had a low median developmental time (27 days), a high percentage of seed damage (75.00%), a high production of grain dust (0.92 g), a high percentage of seed weight loss (1.1%), and a low percentage of weevil mortality (0.16%). These results agree with Acheampong et al. (2019).

The index of susceptibility is based on the assumption that the more F_1 progeny and the shorter the development duration, the more susceptible the seeds would be. Similarly, Jiménez-Galindo et al. (2023) indicated that progeny emergencies were higher in susceptible genotypes than in resistant ones. In general, maize-resistant genotypes were indicated by low weight loss, low seed damage, and a decline in adult insects. In addition, according to Ngom et al. (2020) variety-resistant maize is distinguished by high levels of amylose and moisture content, as well as high grain hardness; increasing amylose content might damage insect

Table 4. Pearson correlation coefficient of *S. zeamais* infestation on maize varieties.

Correlation	SI	% AM	F_1P	MDT	WUG	WDG	% SWL	PP
SI	1.00							
PAM	-0.90**	1.00						
F_1P	0.98**	-0.94**	1.00					
MDT	-0.97**	0.95**	-0.98**	1.00				
WUG	-0.96**	0.95**	-0.98*	0.97*	1.00			
WDG	0.96**	-0.95**	0.99**	-0.97**	-0.99**	1.00		
SWL	0.90*	-0.93**	0.92**	-0.93**	-0.92**	0.91**	1.00	
PP	0.92**	-0.87**	0.92**	-0.92**	-0.94**	-0.94**	0.89**	1.00

IS: Susceptibility Index, % AM: percentage of Adult Weevil Mortality, F_1P: Number of Weevils Produced, MDT: Median Development Time, WGD: Weight of Grain Damaged (g), WGU: Weight of Grain Undamaged (g), SWL (%) percentage Seed weight loss, PP: weight of powder produced (g). **Correlation is significant at the 0.05 level.

reproduction by interfering with digestion mechanisms (antibiosis mechanisms). It has also been demonstrated that resistant types had reduced grain damage and weight loss, which could be attributable to antixenosis resistance mechanisms that prevent the insect from laying eggs and feeding (Astuti et al., 2019). Several biochemical properties have been described to have an effect on maize resistance to *S. zamias*, and maize breeders have been successful in developing varieties with resistance to the maize weevil, but it is difficult to say that these efforts have reached their intended heights since some improved varieties of maize are broken down by the weevil under storage conditions (Nwosu, 2018). This confirms that there may be no specific biochemical factor associated with maize resistance to *S. zeamais* and that maize resistance to *S. zeamais* is the result of a collection of related biochemical and physical elements in maize grain (Ngom et al., 2020). Subsistence farming in developing countries should encourage resistant varieties. As a result, to prevent farmers from suffering significant losses due to maize weevil attacks, breeders should work to create varieties with effective post-harvest insect pest resistance (Berhe et al., 2022).

Simple correlation coefficient of the variables

The susceptibility index, number of weevils produced, median development time, percentage of seed weight loss, weight of damaged grains, weight of undamaged grains, and weight of powder produced (g) were all determined, and their simple linear correlation coefficients are listed in Table 4. It is obvious from the Pearson correlation coefficients (r) that an opposite relationship occurred between the susceptibility index (SI), percentage of adult mortality (% AM), median development time (MDT), and weight of undamaged grains (WUG). On the other hand, the number of F_1 progeny emergence (F_1P) was strongly correlated with the weight of grain damaged (WDG), the weight of powder produced (PP), the percentage seed weight loss (% SWL), and the Index of susceptibility (IS).

The median development time was negatively associated with F_1 progeny emergence (r =-0.98) and positively associated with adult weevil mortality (r =0.95). In general, seed damage, dust production, and seed weight loss were all significantly and positively connected with the high number of F_1 progeny's emergence, but inversely related to median development time and adult mortality.

Conclusion

Among the maize varieties, F_1 progeny emerged; median developing time, seed damage, seed weight loss, and susceptibility index were all significantly varying. These variations in susceptibility among maize varieties reflect a variety's inherent ability to *resist S. zeamais* assault. The research revealed that different types of maize had different reactions to maize weevil attacks, ranging from vulnerable to resistant.

The AMH853 maize variety was extremely sensitive, as evidenced by weight loss, grain damage, a high number of weevils emerging, and a low proportion of weevil deaths. Most of the varieties, namely Melkassa-6Q, MHQ138, MH140, BH547, HB30G19, BH546, AMH851, P3812W, Gibe 3, SC627, Gambela, P3506W, BH549, Gibe 2, P2859W, and AMH850, exhibited minimum seed damage and minimum percentage seed weight loss, high insect mortality, and low number of F_1 *S. zeamais* emergences.

Some of the varieties, namely Melkassa-6Q, MHQ138, and MH140, had small kernel sizes and were too hard and compact. Small kernels are hard and compact, thus more resistant to the weevil attack.

Under the circumstances of subsistence farming in developing countries, the use of resistant varieties should be encouraged. Breeding programs should aim at searching for resistant maize varieties and ensuring food security at the family household level in Ethiopia.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Acheampong A, Ayertey JN, Eziah VY, Ifie BE (2019). Susceptibility of selected maize seed genotypes to *Sitophilus zeamais* (Coleoptera: Curculionidae). Journal of Stored Products Research 81:62-68. https://doi.org/10.1016/j.jspr.2019.01.003

Ahmad R, Hassan S, Ahmad S, Nighat SK, Devi Y, Javeed K, Hussain B (2022). Stored grain pests and current advances for their management. IntechOpen doi: 10.5772/intechopen.101503

Andersson E, Isgren E (2021). Gambling in the garden: pesticide use and risk exposure in Ugandan smallholder farming. Journal of Rural Studies 82:76-86. doi:10.1016/j.jrurstud.2021.01.013

Astuti LP, Yahya SM, Hadi MS (2019). Susceptibility of six corn varieties (*Zea mays* L.) to *S. zeamais* Motschulsky (Coleoptera: Curculionidae). Journal of Plant Protection Research 10:7441. https://doi.org/10.4081/pb.2019.7441.

Barre J, Jenber AJ (2022). Evaluation of selected botanicals for the management of maize weevil (*Sitophilus zeamais*) on maize (*Zea mays* L.) grain under laboratory conditions in Gabilay district, Somaliland. Heliyon 8:e11859. https://doi.org/10.1016/j.heliyon.

Berhe M, Subramanyam B, Chichaybelu M, Demissie G, Abay F, Harvey J (2022). Post-harvest insect pests and their management practices for major food and export crops in East Africa: an Ethiopian case study. Insects 13:1068. https://doi.org/10.3390/insects13111068

Boxall RA (1986). A critical review of the methodology for assessing farm-level grain losses after harvest, Tropical Development and Research Institute, U.K.

Chowanski S, Adamski Z, Marciniak P, Rosinsk G, Buyukguzel E, Buyukguze K, Falabella P, Scrano L, Ventrella E, Lelario L, Bufo SA (2016). A review of the bioinsecticidal activity of Solanaceae alkaloids. Toxins 8(3):60. doi:10.3390/toxins 803060.

Dijkink B, Broeze J, Vollebregt M (2022). Hermetic bags for the storage of maize: Perspectives on economics, food security and greenhouse gas emissions in different Sub-Saharan African countries. Front. Sustain. Food System 6:767089. https://doi.org/10.3389/fsufs.2022.767089

Dobie P, Kilminster AM (1997). The susceptibility of triticale to post-harvest infestation by *S. zeamais* Motschulsky, *Sitophilus oryzae* (L.), and *S. granarius* (L.). Journal of Stored Products Research 14:87-93. http://doi.org/10.1016/0022-474X(78)90003-6.

Hiruy B, Getu E (2020). *Militia feruginaea* solvent extracts on maize weevils and red flour beetles repellency; an implication to use them in storage pest management in Ethiopia, Cogent Food and Agriculture 6:1860562. DOI: 10.1080/23311932.2020.1860562

Jallow M, Pitan OOR (2022). Screening for sources of resistance to the maize weevil on stored maize varieties obtained in the Gambia Current Science International 11:342-348. DOI: 10.36632/csi/2022.11.3.25

Jiménez-Galindo JC, Castillo-Rosales A, Castellanos-Pérez G, Orozco-González F, Ortega-Ortega A, Padilla-Chacón D, Butrón A, Revilla P, Malvar RA (2023). Identification of resistance to the corn weevil (*Sitophilus zeamais* M.) in Mexican maize races (*Zea mays* L.). Agronomy 13:312. https://doi.org/ 10.3390/agronomy13020312

Kasozi LC, Derera J, Tongoona P, Zziwa S, Muwonge A, Gasura E, Bergvinson D (2018). Comparing the effectiveness of the “weevil warehouse” and “laboratory bioassay” as techniques for screening maize genotypes for weevil resistance. Food Security 6:170-177. DOI:10.12691/jfs-6-4-5

Khakata S, Mbute FN, Chemining’wa GN, Mwimali M, Karanja J, Harvey J, Mwololo JK (2018). Post-harvest evaluation of selected in inbred lines to maize weevil *Sitophilus zeamais* resistance. Journal of Plant Breeding and Crop Science 10(5):105-114 DOI: 10.5897/JPBCS2017.0646

Kidane D (2011). The Potential of orange (*Citrus sinensis* L.) peel oil as a fumigant and repellent to control maize Weevil (*Sitophillus zeamais* Motsch). Journal of Biologically Active Products from Nature 1(3):193-199. DOI: 10.1080/22311866.2011.10719086

Kumari P, Jasrotia P, Kumar D, Kashyap PL, Kumar S, Mishra CN, Kumar S, Singh GP (2022). Biotechnological approaches for host plant resistance to insect pests. Frontiers in Genetics 13:914029. doi: 10.3389/fgene.2022.914029.

Lopez-Castillo LM, Silva-Fernandez SE, Winkler R, Bergvinson DJ, Arnason JT, García-Lara S (2018). Postharvest insect resistance in maize. Journal of Stored Products Research 77:66-76. https://doi.org/10.1016/j.jspr.2018.03.004

Manu N, Osekre EA, Opit GP, Campbell JF, Arthur FH, Mbata G, Armstrong PR, Danso JK (2018). Population dynamics of stored maize insect pests in warehouses in two districts of Ghana. Journal of Stored Products Research 76:102-110. doi:10.1016/j.jspr.2018.01.001

Medugu MA, Okrikat AE, Dunuwel DM (2020). Management of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) using Nigerian raw diatomite. Journal of Applied Sciences and Environmental Management 24(9):1663-1669.

Mengistie BT, Mol APJ, Oosterveer P (2017). Pesticide use practices among smallholder vegetable farmers in Ethiopian central rift valley. Environ. Environment, Development and Sustainability 19:301-324. https://doi.org/10.1007/s10668-015-9728-9

Midega CAO, Murage AW, Pittchar JO, Khan ZR (2016). Managing storage pests of maize: farmers’ knowledge, perceptions, and practices in western Kenya. Crop Protection 90:142-149.

Mwenda ET, Ringo JH, Mbega ER (2019). The implication of kernel phenology in convening resistance to storage weevil and varietal development in sorghum. Journal of Stored Products Research 83:176-184. doi:10.1016/j.jspr.2019.06.010

Ngegba PM, Cui G, Khalid MZ, Zhong G (2022). Use of botanical pesticides in agriculture as an alternative to synthetic pesticides. Agriculture 12:600. https://doi.org/10.3390/ agriculture12050600

Ngom D, Fauconnier ML, Malumba P, Dia CAM, Thiaw C, Sembène M (2020). Varietal susceptibility of maize to larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera; Bostrichidae), based on grain physicochemical parameters. PloS One 15:e0232164. doi.org/10.1371/journal.pone.0232164.

Nhamucho E, Mugo S, Gohole L, Tefera T, Kinyua M, Mulima E (2017). Resistance of selected Mozambican local and improved maize genotypes to weevil *S. zeamais* (Motschulsky). Journal of Stored Products Research 73:115-124. doi.org /10.1016/j.jspr.2017.07.0 03.

Nwosu LC (2018). Maize and the maize weevil: advances and innovations in postharvest control of the pest. Journal of Food Safety 2(3):145-152. doi:10.1093/fqsafe/fyy011

Rahardjo BT, Astuti LP, Sugiarto AN, Rizali A (2017). Susceptibility of maize genotypes to weevil *S. zeamais* Motsch. (Coleoptera: Curculionidae). GRIVITA The Journal of Agricultural Science 39:329-334. https://doi.org/10.17503/agrivita.v39i3.1278.

Ranum P, Pena-Rosas JP, Garcia-Casal MN (2014). Technical considerations for maize flour and corn meal fortification in public health global maize production, utilization, and consumption. Annals of the New York Academy of Sciences Journal 1312:105-112. doi: 10.1111/nyas.12396

Rashid MM, Din R, Naeem M, Khan MA, Ashfaq M (2021). Relative resistance of maize varieties against maize weevil, *Sitophilus zeamais* (Motschulsky), (Coleoptera: Curcolionidae). Pakistan Journal of Agricultural Sciences 58:1169-1176. DOI: 10.21162/PAKJAS/21.45

Siamey J, Ansah KD, Kotey DA (2021). Evaluation of maize genotypes for resistance to *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) infestation. Asian Journal of Agriculture and Biology 3:202010549. DOI: https://doi.org/10.35495/ajab.2020.10.549

SPSS (2016). Statistics for Windows, Version 26.0. IBM Corporation, Armonk, NY.

Sserumaga JP, Makumbi D, Oikeh SO, Otim M, Machida L, Anani BY, Nhamucho E, Beyene Y, Mugo S (2021). Evaluation of early-generation tropical maize testcrosses for grain-yield potential and weevil (*Sitophilus zeamais* Motschulsky) resistance. Crop Protection 139:105384. doi: 10.1016/j.cropro.2020.105384.

Stejskal V, Vendl T, Aulicky R, Athanassiou C (2021). Synthetic and natural insecticides: Gas, liquid, gel and solid formulations for stored-product and food-industry pest control. Insects 12:590. https://doi.org/10.3390/ insects12070590

Suleiman R, Williams D, Nissen A, Bern CJ, Rosentrater KA (2015). Is flint corn naturally resistant to *S. zeamais* infestation? Journal of Stored Products Research 60:19-24. https://doi.org/10.1016/j.jspr.2014.10.007

Taulu S, Lungu DM, Sohati PH (2020). Breeding for weevil (*Sitophilus Zeamais* Motschulsky) resistance in maize (*Zea maysL*). International Journal of Sustainable Agricultural Research 7:255-266. DOI: 10.18488/journal.70.2020.74.255.266

Tefera T, Demissie G, Mugo S, Beyene Y (2013). Yield and agronomic performance of maize hybrids resistant to the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). Crop Protection. 46:94-99. doi:10.1016/j.cropro.2012.12.010

Wang J, Vanga SK, Saxena R, Orsat V, Raghavan V (2018). Effect of climate change on the yield of cereal crops: a review. Climate 6:41. https://doi.org/10.3390/cli6020041

War AR, Paulraj MG, Ahmad T, Buhroo AA, Hussain B, Ignacimuthu S, Sharma HC (2012). Mechanisms of plant defense against insect herbivores. Plant Signaling and Behavior 7:1306-1320. doi:10.4161/psb.21663

World Bank (2011). Missing food: the case of postharvest grain losses in Sub-Saharan Africa. © Washington, DC.

Wu K, Zhang J, Zhang Q, Zhu S, Shao Q, Clark KD, Liu Y, Ling E (2015). Plant phenolics are detoxified by prophenoloxidase in the insect gut. Scientific Reports 5:16823. https://doi.org/10.1038/srep16823.