Annals of West University of Timişoara, ser. Biology, 2019, vol. 22 (1), pp.3-14

RESISTANCE OF FOUR MAIZE VARIETIES TO *SITOPHILUS ZEAMAIS* (COLEOPTERA: CURCULIONIDAE) INFESTATION

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Received 20 December 2018; accepted 17 June 2019

ABSTRACT

Sitophilus zeamais causes severe damage to stored maize grains in Nigeria. Synthetic insecticides commonly used for its management could result in environmental pollution and development of resistant-insect strains. Information is scanty on the management of S. zeamais with resistant varieties. This study was conducted to screen four maize varieties against S. zeamais and to identify the sources of resistance against the insect pest. Grain samples (100 g) from four open-pollinated maize varieties: DMR ESR-Y, SUWAN ESR-Y, TZE COMP 3-W and TZPB SR–W (susceptible) were evaluated for resistance to S. zeamais, in the laboratory. The number of F_1 progeny, Grain Weight Loss and Dobie Index (0-3: resistant, 4-7: moderately resistant, 8-10: susceptible, ≥11: highly susceptible) were measured. Biophysical factors of resistance: Grain Thickness (mm) and Grain Weight (g) and biochemical factors: Nitrogen Free Extract, Crude Protein, Phenolic Acid and Trypsin Inhibitor were assessed. The number of F_1 progeny (38.5±1.44), Grain Weight Loss (2.4±0.30 g) and Dobie Index (4.6) were lowest on DMR ESR-Y maize variety and highest on TZPB SR-W (72.8±3.8, 8.14±0.5g and 11.6, respectively). The Grain Thickness ranged from 4.34±0.52 mm (TZPB SR-W) to 4.94±0.42 mm (SUWAN ESR-Y). SUWAN ESR-Y had the highest Grain Weight (0.28±0.2 g), while DMR ESR-Y had the least (0.21±0.2 g). DMR ESR-Y had the highest Phenolic Acid (0.4±0.1%), Trypsin Inhibitor (9.3±0.1%) and Crude Protein (14.9±0.3%), while the least were found on TZE COMP-3 (0.3±0.0%), TZPB SR-W (6.7±0.1%) and TZE COMP 3-W (11.8±1.2%), respectively. The Nitrogen Free Extract ranged from 70.4±1.2 (DMR ESR–Y) to 74.9±0.9% (TZPB SR-W). The use of maize variety such as DMR ESR-Y may reduce Sitophilus zeamais infestation and damage to maize grains. Mechanisms of maize resistance to S. zeamais infestation could be useful in successful breeding programs against post-harvest grain damage.

KEY WORDS: *Sitophilus zeamais, maize varieties, Dobie Index, Trypsin Inhibitor, Food security*

INTRODUCTION

The maize weevil, *Sitophilus zeamais* Motschulsky is a worldwide key pest of stored products especially maize. It has been established by several workers that it causes severe quantitative and qualitative losses in stored maize grain in Africa

(Nwosu, 2018). It is capable of penetrating and infesting intact kernels of grain in which immature stages develop (Lale *et al.*, 2001) leaving the maize emptied of its nutritional and seed value. This culminates in outright rejection of the product at the local and international markets (Nwosu *et al*., 2015). Infestation by *S. zeamais* begins in the field and is carried into the store where population builds up rapidly (Akinbuluma *et al.,* 2017). Damaged grains have reduced nutritional value, low percentage germination, reduced weight and market value and worldwide seed losses ranging from 20 to 90% have been reported for untreated maize due to the maize weevil *S. zemais* (Abebe *et al.,* 2009). The control of storage insects like *S. zeamais* is mainly centred on the use of synthetic insecticides (Adedire, 2003) with attendant problems such as development of resistant insect strains and high cost of procurement, thus necessitating alternative management methods that would protect the crop and environment. Also, since the food production in sub-Saharan Africa (SSA) is left in the hands of resource-poor smallholder farmers that cannot afford these chemicals, it is crucial to develop a more suitable and cheaper method to control this pest, such as the use of resistant varieties. Derera *et al*. (2001 a and b) and Dari *et al.* (2010) reported that weevil-resistant maize varieties would offer an affordable and sustainable control option especially suited to resource poor farmers. To this effect, this study evaluated four maize varieties in order to elucidate the mechanism of resistance to the maize weevil infestation and determine specific maize grain characteristics (biophysical and biochemical) that conferred resistance or susceptibility to *S. zeamais* infestation. Mechanisms of maize resistance to the maize weevil, *S. zeamais* infestation could be useful in successful breeding programs against post-harvest grain damage. The use of maize varieties with a low reproductive and population build-up potential for *S. zeamais* in conjunction with other control strategies in an integrated pest management package, would keep the weevil populations in stored maize at sub-economic levels (Akob *et al.,* 2007; Ciobanu & Ianovici, 2018). Therefore, the objective of this study was to determine the mechanism of resistance in four maize varieties to *Sitophilus zeamais*.

MATERIALS AND METHODS

Study locations and conditions. This study was conducted at the Entomology Research Laboratory, Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria under ambient temperature of 27±2°C, and relative humidity of 65±5%.

Maize varieties and Insects used. Clean and healthy seeds of four open pollinated maize varieties (TZPB-SR-W; TZE COMP 3-W; DMR ESR-Y and SUWAN ESR-Y) from the Institute of Agricultural Research and Training, Moor Plantation, Ibadan were used for the studies. Prior to the experiments, the grains were stored in a deep freezer for three weeks to kill any insects resulting from field infestation and were later air-dried in the laboratory before use to prevent mouldiness (Adedire *et al.,* 1999). Fresh colony of adult *S. zeamais* was established in the laboratory from an initial colony obtained from infested maize purchased from Bodija market, Ibadan. One hundred weevils (1male:1female) were introduced into two hundred and fifty grammes (250 g) maize grains in each of eight Kilner jars covered with mesh lids and these were arranged on a table whose stands were dipped in plastic bowls containing industrial oil to prevent ants from contaminating the cultures. After two weeks of mating and oviposition, old weevils were removed and jars observed daily for emergence of teneral adults. They were removed from the culture and sexed using the rostrum as the character for sex differentiation in *S. zeamais* and *S. oryzae* (Odeyemi *et al.,* 2000). Culture was maintained as source of weevils for experiments.

Assessment of egg laying ability and oviposition period of *S. zeamais.* Twenty grains from each of the four maize varieties were placed in each of four Petri dishes and one pair (1 male: 1 female) of day-old *S. zeamais* introduced. With the four maize varieties as treatments, the experiment was arranged in a completely randomised design (CRD) in six replications. The weevils were allowed to mate and oviposit on the grains. Grains were removed after seven days and the number of eggs laid was determined using the egg-plug staining/detection technique (Pederson, 1979). Maize grains from the Petri dishes above were replaced weekly with new batch until all the weevils died. Data on oviposition period was recorded and analyzed and means separated using the Least Significant Difference (LSD). A regression analysis was used to compare the egg laying ability and oviposition period of *Sitophilus zeamais* on the four maize varieties.

Evaluation of fecundity and sex ratio of maize weevil on four maize varieties. One hundred grammes (100 g) of maize grains of each of the four maize varieties was weighed and kept in separate Kilner jars and ten pairs (1:1) of 1-2 day-old maize weevils were introduced into the jars per maize variety and left for seven days. The grains were left undisturbed until the emergence of the F_1 generation. With the four maize varieties as treatments, the experiment was laid out in a CRD with six replications. The number of adult *S. zeamais* that emerged was counted and recorded. The grains were later sieved to remove the dust produced from adult feeding and re-weighed at eight weeks after infestation using a Digital Pocket Weighing balance and the percentage loss in weight determined as follows:

$$\text{Percentage (\%) weight loss} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Data on the total number of emerged F1 progeny and sex ratio of emerged F_1 progeny (from the time of emergence, till 49 days) as well as percentage grain weight loss were analyzed using the analysis of variance (ANOVA) and means separated using the LSD. The median development time was calculated as the time (days) from the middle of the oviposition period to the emergence of 50% of the F_1 progeny

(Dobie, 1977; Abebe *et al.*, 2009). The index of susceptibility was calculated using the method of Dobie (1974) as follows:

$$\text{Susceptibility index} = \frac{[\text{Log(total number of } F_1 \text{ progeny)}]}{\text{Median developmental time}} \times 100$$

The susceptibility index used to classify the maize varieties using the following scales: 0–4.0 = resistant, 4.1–6.0 = moderately resistant, 6.1–8.0 = moderately susceptible, 8.1–10.0 = susceptible and ≥ 10.1 = highly susceptible (Dobie, 1974; Siwale *et al*., 2009). The number of emerged adult male and female weevils on each maize variety was compared with a *t*-test. Susceptibility index was correlated with median developmental time, number of F_1 progeny and grain weight loss using the Pearson's correlation analysis at 5% level of significance.

Basis of resistance of four maize varieties to *Sitophilus zeamais* infestation

- **Biophysical basis of resistance of four maize varieties to *Sitophilus zeamais.*** Ten grains from each of the maize varieties were randomly hand-picked and carefully examined for morphological characteristics. Descriptions of varieties were based on visual observation of colour, appearance, shape, face-type and texture (Dobie, 1974; Adedire *et al*., 2011). The texture was felt with hand to supplement visual observation. Similarly, ten grains from each of the varieties were examined for physical characteristics. The length and width of the maize varieties were measured using a vernier calliper and the weight per ten grains was determined using a Metler weighing balance, 0.0001 mg. Morphological data on the four maize varieties were analyzed using one way ANOVA and LSD was used to determine significant differences between the varieties.
- **Biochemical basis of resistance of four maize varieties to *Sitophilus zeamais*.** Fifty grammes (50 g) of grains from each variety was milled and sieved through 0.4 mm sieve. The milled samples were subjected to chemical analysis at the central laboratory of Institute of Agricultural Research and Training, Moor Plantation, Ibadan, Nigeria. The maize kernels were milled using a laboratory mill and milled samples stored at 4°C prior to analysis. Biochemical factors of the grains (that is, determination of moisture, crude protein, soluble protein, soluble sugar, crude fat, crude fibre, ash, nitrogen–free extract, phenolic acid and trypsin inhibitor) were later determined in accordance with the standard method of Association of Official Analytical Chemists Washington, DC, USA632 A.O.A.C. (1990). Moisture content was determined by Farmex MT-PRO grain moisture meter. Crude protein content was determined using the Kjeldahl procedure. The protein content was estimated by 'N' percent x 6.25 considering that the protein contains 16% nitrogen (Amoo, 1998). The nitrogen–free extract was determined by calculating the difference of the total of percentages of crude protein, crude fat and ash from 100. Nitrogen–free extract = 100 – Σ (Ash % + Protein % + Fat %). Results from percentages of ash, protein and fat were calculated in the dry material

of kernels. Crude fibre was determined by subsequent acid base digestion. Crude fat was determined by ether extract method using Soxhlet apparatus. Ash content was determined using muffle furnace and the value expressed in percentage (Ianovici *et al*, 2017). Phenol was determined using the Prussian blue spectrophotometric method (Price & Bulter, 1977) and the percentage total polyphenol was determined using the formula:

$$\%\ \text{Total polyphenol} = \frac{\text{Absorbance xAverage gradient x Dilution factor}}{\text{Weight of Sample}} \text{ x } 10000$$

Trypsin inhibitor activity in the maize varieties was determined using the method developed and described by Kakade *et al.* (1974) and calculated as follows:

$$\text{Trypsin inhibitor (mg/g)} = \frac{\text{Standard} - \text{Sample x Dilution factor}}{0.19 \text{ x Sample weight(g)x Sample size}}$$

The data on chemical characteristics of the four maize varieties were analyzed using one way ANOVA and means were separated using LSD (DSAASTAT version 1.101) at 5% level of significance. Pearson's correlation analysis was also performed on the biochemical factors at 5% significant level using the Statistical Package for Social Sciences (SPSS) Version 10.0.

RESULTS AND DISCUSSIONS

Egg-laying ability and oviposition period of *S. zeamais.* Trends in the egg-laying ability and mean oviposition period of female *S. zeamais* on the four maize varieties were compared with a regression analysis (Fig. 1). The number of eggs laid by adult *S. zeamais* and oviposition period varied among maize varieties. Adult female *S. zeamais* laid the highest number of eggs (127±5.89) on the TZPB SR-W variety and with a prolonged number of days (141±6.38 days) compared to the least number of eggs (96±3.56) on variety DMR ESR-Y over a 114±3.46 day-period. Similar trend of egg laying ability by *S. zeamais* as well as the period oviposition was observed on the TZE COMP 3-W and SUWAN ESR–Y maize varieties (Fig. 1).

Fecundity and sex ratio of maize weevil and grain weight loss. Table 1 showed the number of F_1 emergence of *S. zeamais* on the four maize varieties. Significantly higher mean number of F_1 progeny was observed in the TZPB SR-W (72.75±3.77) relative to other maize varieties. SUWAN ESR-Y maize variety had the least adult emergence (27.00±2.94) which was not significantly ($p > 0.05$) different from 38.50±1.44 in DMR ESR-Y variety. The highest weight loss in grains (8.14±0.48 g) was obtained in the TZPB SR-W maize variety and was significantly ($p < 0.05$) higher than those of other varieties (Table 1). Significant differences ($p < 0.05$) among maize varieties were also recorded with regards to the median developmental time (MDT) of *S. zeamais*. The MDT ranged from 16±2.45 days in TZPB SR-W to 33±2.94 days in DMR ESR-Y. *Sitophilus zeamais* reared on maize varieties, TZE COMP 3-W and TZPB SR-W had relatively lower MDT than the highest DMR ESR-Y (Table 1). The number of male and female *S. zeamais* observed on the four maize varieties as well as the sex ratio is presented in Table 2. The highest number of emerged female (51.75±0.48) was found on the susceptible TZPB SR-W, which was significantly ($p < 0.05$) higher than that of DMR ESR–Y (30.0±1.41) and SUWAN ESR-Y (19.75±5.49). Table 3 shows the relationship between susceptibility index and MDT, number of F_1 progeny and grain weight loss. Susceptibility index was inversely related to MDT ($r = -0.97$) but showed a positive relationship with the number of F_1 progeny ($r = 0.96$) and grain weight loss ($r = 0.95$).

Sources of resistance to *Sitophilus zeamais* infestation

Biophysical characteristics. Significant differences ($p < 0.05$) were observed among the grain physical characteristics measured (Table 4). Sampled varieties differed in colour and shape but not in texture. Two colour types were differentiated: white in TZE COMP 3 and TZPB SR, but yellow in DMR ESR and SUWAN ESR varieties. SUWAN ESR-Y had the longest grains (9.08±0.54 mm) and was significantly longer than the shortest TZE COMP 3–W (7.53±0.52 mm). Whereas grain length of the former variety (SUWAN ESR-Y) was not significantly different ($p > 0.05$) from grain length of the susceptible TZPB SR–W (8.86±0.49 mm), that of the latter TZE COMP 3-W was significantly shorter. DMR ESR–Y variety had grains that were significantly shorter than the longest SUWAN ESR-Y grains but not different from the other two varieties tested (Table 4). The susceptible TZPB SR-W, with the biggest width (7.85±0.22 mm) was significantly different from TZE COMP 3-W which had the smallest width (7.24±0.22 mm). TZPB SR–W however had the thinnest grain (4.34±0.52 mm) while SUWAN ESR-Y had the thickest grain (4.94±0.42 mm). Similarly, grain weight of the susceptible check (0.26±0.08 g) did not significantly differ from that of the heaviest SUWAN ESR-Y, (0.28±0.17 g) but was significantly ($p < 0.05$) higher than those of TZE COMP 3-W (0.22±0.22 g) and DMR ESR–Y (0.21±0.24 g).

Biochemical composition of the four maize varieties in susceptibility test with *Sitophilus zeamais*. Proximate composition and secondary metabolites of the maize varieties are presented in Tables 5a and 5b, respectively. Significant differences ($p < 0.05$) were observed in the chemical constituents of the grains. The highest moisture content and nitrogen–free extract (8.9±0.3% and 74.9±0.9%) were obtained in the TZPB SR-W variety which differed significantly ($p < 0.05$) from (6.9±0.5% and 70.4±1.2%) in DMR ESR-Y maize varieties, respectively. The highest sugar content, crude protein, trypsin inhibitor and phenolic acid (16.4±0.4%, 14.9±0.3, 9.3±0.1 and 0.4±0.04%) were recorded in the DMR ESR–Y variety and followed by 14.2±1.3%, 12.4±1.3%, 8.0±0.6% and 0.3±0.03%, respectively in SUWAN ESR–Y variety. The susceptibility index was highest in TZPB SR–W (11.64) while DMR ESR–Y had the least susceptibility index (4.80) (Fig. 2). Maize varieties; DMR ESR-Y and SUWAN ESR–Y were rated as moderately resistant, TZE COMP 3-W as susceptible and TZPB SR–W as highly susceptible. The phenolic acid, trypsin inhibitor and protein content were negatively correlated with Dobie's susceptibility index (r= -0.70, -0.89 and -0.75), respectively, while nitrogen–free extract was positively correlated (r=0.86) (Table 6).

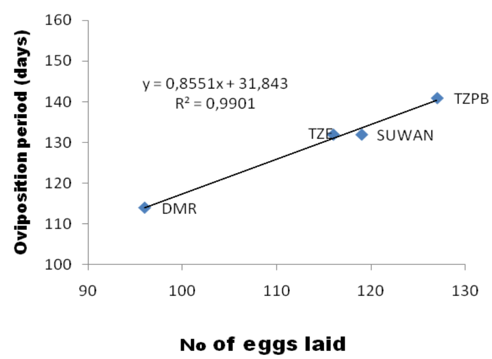

FIG. 1: Regression between the oviposition period and egg-laying ability of S*itophilus zeamais* on four maize varieties

TABLE 1: Number of F_1 progeny and median developmental time of *S. zeamais* and grain weight loss

Maize varieties	Mean no. of F_1 progeny (±S.D)	Grain weight Loss (±S.D)	Median developmental time (±S.D)
DMR ESR–Y	38.50±1.44	2.44±0.30	33±2.94
SUWAN ESR–Y	27.00±2.94	3.23±0.21	28±1.83
TZE COMP 3–W	55.50±6.59	4.30±0.42	19±3.56
TZPB SR–W	72.75±3.77	8.14±0.48	16±2.45
LSD $_{(0.05)}$	12.74	1.14	4.27

Differences in mean values in the same column greater than LSD shows that mean is significant at 5% LSD

TABLE 2: Sex ratio of F_1 progeny of *Sitophilus zeamais* reared on four maize varieties

Maize varieties	Male	Female	Sex ratio	t-value	p-value
DMR ESR–Y	8.50^a±0.65	30.00^a±1.41	1: 3.5	-12.97	0.001
SUWAN ESR–Y	7.25^a±0.75	19.75^a±5.49	1:2.7	-6.60	0.004
TZE COMP 3–W	11.50^b±1.26	44.00^b±5.49	1: 3.3	-7.25	0.003
TZPB SR–W	21.25^c±0.85	51.75^b±0.48	1:2.4	-8.54	0.003
LSD $_{(0.05)}$	2.80	10.99			(df 3, 5%)

df = degree of freedom; Differences in mean values in the same column greater than LSD shows that mean is significant at 5% LSD

TABLE 3: Correlation between susceptibility index and median developmental time, number of f_1 progeny and percentage weight loss

Parameters	Statistics	Susceptibilty index	Median Development Time	Number of F_1 progeny	% Weight Loss
Susceptibility Index	Pearson Correlation	1	-.965*	.960*	.950
	Sig.(2-tailed)	-	.035	.040	.050
Median Development Time	Pearson Correlation	-.965*	1	-.858	-.838
	Sig.(2-tailed)	.035	-	.1420	.162
Number of F_1 progeny	Pearson Correlation	.960*	-.858	1	.981*
	Sig.(2-tailed)	.040	.142	-	.019
% Weight Loss	Pearson Correlation	.950	-.838	.981*	1
	Sig.(2-tailed)	.050	.162	.019	-

* Correlation is significant at the 0.05 level (2-tailed).

TABLE 4: Biophysical basis of resistance of four maize varieties to *Sitophilus zeamais*

Maize varieties	Length (mm)	Width (mm)	Thickness (mm)	Weight (g/10 grains)
DMR ESR–Y	8.10±0.55	7.64±0.35	4.63±0.31	0.21±0.24
SUWAN ESR–Y	9.08±0.54	7.43±0.58	4.94±0. 42	0.28±0.17
TZE COMP 3–W	7.53±0.52	7.24±0.22	4.45±0.25	0.22 ± 0.22
TZPB SR–W	8.86±0.49	7.85±0.22	4.34±0.52	0.26±0.08
LSD $_{(0.05)}$	0.81	0.57	0.58	0.02

Differences in mean values in the same column greater than LSD shows that mean is significant at 5% LSD

TABLE 5A: Proximate composition of four maize varieties evaluated for resistance to *Sitophilus zeamais*

Maize varieties	% Crude fibre	% Ash	% Crude Fat	% Moisture	% Nitrogen–free Extract	% Protein
DMR ESR–Y	2.68±0.18	3.15±0.08	4.69±0.52	6.89±0.52	70.40±1.17	14.87±0.26
SUWAN ESR–Y	2.84±0.12	3.10±0.23	4.03±0.22	7.52±0.61	72.92±0.89	12.43±1.29
TZECOMP 3–W	2.75±0.79	2.92±0.07	3.87±0.17	8.64±0.34	73.89±1.03	10.68±0.79
TZPB SR–W	2.81±0.23	2.81±0.15	3.92±0.21	8.86±0.34	74.93±0.91	11.68±0.11
LSD $_{(0.05)}$	ns	0.23	0.49	0.72	1.55	1.19

ns = not significant at 5% level

Differences in mean values in the same column greater than LSD shows that mean is significant at 5% LSD

TABLE 5B: Sugar content and secondary metabolites composition of four maize varieties evaluated for resistance to *Sitophilus zeamais.*

Maize varieties	% Sugar content	% Trypsin inhibitor	% Phenolic Acid
DMR ESR–Y	16.37±0.35	9.29±0.11	0.36±0.04
SUWAN ESR–Y	14.15±1.28	8.02±0.58	0.27±0.03
TZE COMP 3–W	11.78±1.19	6.97±0.33	0.25±0.01
TZPB SR–W	13.67±1.06	6.71±0.06	0.26±0.03
LSD $_{(0.05)}$	1.60	0.53	0.05

Differences in mean values in the same column greater than LSD shows that mean is significant at 5% LSD

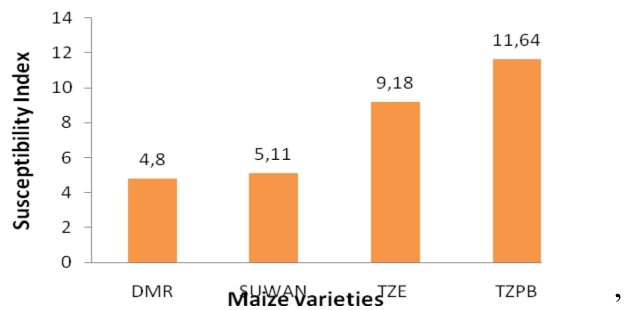

FIG. 2. Susceptibility index of maize varieties. Scales: 0–4.0 = resistant, 4.1–6.0 = moderately resistant, 6.1–8.0 = moderately susceptible, 8.1–10.0 = susceptible and ≥ 10.1 = highly susceptible.

TABLE 6. Correlation between susceptibility index and phenolic acid, trypsin inhibitor, protein content and nitrogen–free extract

Parameters	Statistics	Susceptibilty Index	% Phenolic Acid	% Trypsin Inhibitor	% Protein content	% Nitrogen–Free extract
Susceptibilty Index	Pearson Correlation	1	-.703	-.894	-.712	.866
	Sig.(2-tailed)	-	.297	.106	.288	.134
% Phenolic Acid	Pearson Correlation	-.703	1.	.938	.932	-.962*
	Sig.(2-tailed)	.297	-	.062	.068	.038
% Trypsin Inhibitor	Pearson Correlation	-.894	.938	1	.938	-.985*
	Sig.(2-tailed)	.106	.062	-	.062	.015
% Protein Content	Pearson Correlation	-.712	.932	.938	1	-.899
	Sig.(2-tailed)	.288	.068	.062	-	.101
% Nitrogen– free extract	Pearson Correlation	.866	-.962*	-.985*	-.899	1
	Sig.(2-tailed)	.134	.038	.015	.101	-

*. Correlation is significant at the 0.05 level (2-tailed).

In this study, considerable variations were observed among the four maize varieties with respect to number of F_1 progeny, median developmental time and sex ratio of *Sitophilus zeamais*. The lowest number of eggs laid, shortest oviposition period and least grain weight loss recorded on DMR ESR–Y variety indicate that this variety is the least favourable host to *S. zeamais*. TZPB SR–W variety with the highest number of F_1 progeny also recorded highest grain weight loss. Significantly higher number of female *S. zeamais* on the TZE COMP 3–W and TZPB SR–W maize variety is indicative of higher reproductive potential of the weevils on the maize varieties relative to others. The range of susceptibility index (4.80 to 11.64) obtained in this study suggests that DMR ESR–Y and SUWAN ESR–Y maize varieties are moderately resistant while TZPB SR-W is highly susceptible to *S. zeamais*. TZPB SR–W variety had the highest susceptibility index, least median developmental time and also the least developmental period. Abebe *et al*. (2009) earlier reported that weevils on maize varieties with a high index of susceptibility displayed reduced periods for the completion of development. The occurrence of significant differences in the physical factors of the sampled varieties in this study agree with the findings of earlier authors (Makanjuola *et al*., 2009; Tongjura *et al*., 2010; Nwosu *et al*., 2015). Comparatively smaller grain length, width and weight conferred certain level of resistance to weevil infestation thus agreeing with the findings of Tongjura *et al*. (2010) that smaller seeds which must be hard and compact, with less moisture were more resistant to the maize weevil attack. The control maize variety in this study, TZPB SR–W, with the highest moisture content also had the highest number of F_1 progeny and susceptibility index, suggesting that moisture plays an important role in maize susceptibility to insect pest. This agrees with the reports of CIMMYT (2001) and Tongjura *et al*. (2010) that high moisture content makes grains susceptible to weevil damage. *Sitophilus zeamais* also performed best on grains with the highest percent nitrogen–free extract in this study which agrees with Osipitan *et al.* (2007) who identified the nutritive factor of starch as a basis for susceptibility to maize weevil infestation. Similarly, Ichiro *et al*. (2009) reported that insects consume starch and proteins in grains to grow and to lay eggs. Increase in the amount of phenolic acid and trypsin inhibitor contents of the maize varieties increased resistance of the sampled maize varieties. Ashamo (2001) and Arnason *et al*. (1993; 2004) also reported that increase in phenolic and ferulic acid contents were responsible for the resistance of *S. zeamais* to maize grains. These substances might have impeded the nutritional metabolism of insects by inhibiting their digestive enzymes (Ichiro *et al*., 2009; Nwosu *et al.*, 2015).

CONCLUSIONS

Sitophilus zeamais completed its development on the four open-pollinated maize varieties with DMR ESR–Y being the most resistant with respect to oviposition, number of F_1 progeny and Dobie's susceptibility index. Biophysical characteristics of grains such as grain length, grain thickness and biochemical factors like nitrogen–free extract, crude protein, phenolic acid and trypsin inhibitor are attributes of resistance of maize varieties to *S. zeamais* infestation. Desirable characters from resistant varieties can be transferred to other varieties to improve their resistance to *Sitophilus zeamais.*

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