Resistance of Some Hybrid Maize (*Zea mays* L.) to Damage by Maize Weevil *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae) and Larger Grain Borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae)

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Abstract

Damage to stored maize grains by *Sitophilus zeamais* and *Prostephanus truncatus* is enormous and could be total if the insects are not controlled timely and appropriately. Control of the insects with host plant resistance has advantages over other control measures because of its lasting effect, friendliness to the environment and safety to natural enemies among others. This study assessed host resistance of 11 maize varieties to infestation and damage by *S. zeamais* and *P. truncatus*. One hundred gram maize grains each of the maize varieties were weighed into 250 cm³ glass jars and separately infested with twenty, 1-5 days old *S. zeamais* or *P. truncatus*. Percentage grain damage, weight loss, adult mortality, grain dust and number of insects were determined and integrated to define the resistance of the maize varieties to the insects. Eight of the 11 maize varieties were either resistant or moderately resistant to damage by *S. zeamais* and *P. truncatus*, while three were susceptible. The basis of resistance is antibiosis conferred by the ash, carbohydrate and fat content of the maize grains. The resistance varieties could be planted to mitigate infestation and damage by the insects. The factors conferring resistance can be used as environmentally friendly source of resistance to breed maize grains for resistance to the insects.

Keywords: *Prostephanus truncatus*, *Sitophilus zeamais*, host plant resistance, proximate composition, resistant.

INTRODUCTION

Maize, *Zea mays* L., is an important crop

ranked second in world grain production after wheat. The crop is versatile in its uses and environmental adaptation, and is an important component of agriculture and food

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systems all over the world (Makate, 2010). Storage of maize is crucial in order to maintain constant supply throughout the year for industries and household food supplies as well as to provide seeds for planting (Adetunji, 2007). However, stored grains may suffer severe infestation and damage from insect pests when not properly stored and or protected. The insects cause direct destruction of infested grains through feeding and also pre-disposes the stored grains to secondary attack by disease-causing pathogens such as mycotoxin-producing fungi; which could lead to increase in respiration and consequent loss in quantity and quality of the grains (Odogola, 1994).

The larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) cause considerable economic losses to smallholder farmers in Africa by reducing the quality, market and nutritional values of infested grains (Demissie *et al.*, 2008; Gueye *et al.*, 2008). *Prostephanus truncatus* is a pest of farm stored maize and a serious pest of dried cassava chips from Central America that infest and damage maize grains and the cob both before and after harvest (Gilman, 1984). The insect is now endemic in many parts of sub-Saharan Africa (Gueye *et al.*, 2008) and have been reported in Togo, Benin, Burkina Faso, Burundi, Ghana, Kenya, Malawi, Mozambique, Zambia, Nigeria and some Africa countries (Pike *et al.*, 1992; Borgemeister *et al.*, 2003). Adult LGB bore into cassava, maize husks, cob and grains making neat round holes and tunnels producing large quantities of grain dust (Boxall, 2002).

Losses due to infestation by *P. truncatus* and *Sitophilus zeamais* are enormous. In fermented cassava root, *P. truncatus* was reported to cause weight loss of 75% within 4 months of storage and 34%

in maize stored for a period of 3-6 months in Tanzania (Hodges *et al.*, 1985; Markham *et al.*, 1994). Similarly, *S. zeamais* have been recognized as an increasingly important problem in Africa (Markham *et al.*, 1994). The insect is responsible for heavy losses every year and worldwide grain losses of 20 to 90% have been reported for untreated maize due to infestation by *S. zeamais* (Giga *et al.*, 1991; Giga and Mazarura, 1991).

Synthetic insecticides are mostly used to control *P. truncatus* and *S. Zeamais* due to their availability and rapid action. However, their widespread use for the control of stored-product insect pests is of global concern (Cherry *et al.*, 2005). The increasing costs of synthetic insecticide is unaffordable by poor farmers and their widespread use causes environmental hazards, development of resistance, accumulation of residue in food and feed as well as their negative effects on non-target organisms (Otto, 1992). Today, there is increased public awareness and concern for the broader environmental safety with focus on the development of alternative management strategies such as the use of resistant maize varieties against insect pests of maize. Maize varieties have been reported to respond differently to insect infestation due to their morphological and biochemical constituents that confer resistance and reduced the successful utilization by insect pests (Temesgen and Waktole, 2013). A No-choice studied that screened 20 maize varieties to infestation and damage by Angoumois grain moth, *Sitotroga cerealla* on the basis of moth emergence, developmental period, insect weight, weight flour, grain weight loss, grain damage and nutritional indices indicated that Pratap makka-5 was the most resistant variety having the longest developmental, minimum grain damage and lowest susceptibility index (Demissie *et al.*, 2015).

Resistance breeding is a promising alternative that provides economical means to minimize post-harvest losses (Mwololo *et al.*, 2013). The use of host plant resistance for the control of insect pest is effective and may reduce the severity of infestation. The method is technically easy, economically feasible, environmentally benign and viable for the management of insect pests, especially among resource-constrained farmers (Giga *et al.*, 1991; Pereira *et al.*, 2009). However, the strategy of host plant resistance has been under-utilized in maize; particularly on storage pests (Pingali and Pandey, 2001). This study therefore assessed the resistance of some hybrid maize to infestation and damage by *S. zeamais* and *P. truncatus* during storage.

MATERIALS AND METHODS

Location of experiment and source of maize

The study was conducted in the Research Laboratory of the Department of Crop Protection, College of Plant Science and Crop Production, Federal University of Agriculture, Abeokuta (FUNAAB) at ambient temperature of 30-32°C and 68-70% relative humidity. The maize varieties used in this study were sourced from the International Institute of Tropical Agriculture (IITA), Ibadan (10) and FUNAAB (1) (Table 1).

Culture of *Prostephanus truncatus* and *Sitophilus zeamais*

The larger grain borer, *P. truncatus* and maize weevil, *S. zeamais* used for the study were obtained from stocks maintained in the Laboratory of Department of Crop Protection, College of Plant Science and Crop Production, FUNAAB and cultured in the laboratory. One hundred grams LGB-susceptible whole maize grains were

weighed into 250ml glass bottles and separately infested with several adults of *P. truncatus* and *S. zeamais* for seven days to lay eggs; the insects were thereafter sieved out of the grains. The insects that emerged thereafter were monitored and those between the age of 1-5 days were used for the study.

Evaluation of the maize genotypes for resistance to LGB in a no-choice test

One hundred (100) g maize grains were weighed into 250ml Kilner glass jars and infested with 20 unsexed 1-5 day old LGB. The treatments were arranged on the experimental table using Completely Randomized Design (CRD). The introduced insects were confined in the grains for 90 days and then sieved-out to separate insects, grains and maize flour. The grains were separated into damaged and undamaged. Data were collected on the following parameters:

Weight of dust(g) – the grain dust was sieved from the grains and weighed with a Mettler weighing balance.

Weight of damaged or undamaged grains – grain dust was sieved-out of the grains and the grains were separated into damaged and undamaged. The weight of damaged or undamaged grains were taken separately with a Mettler® weighing balance.

Number of adult larger grain borer – Living and dead adults of larger grain borer were counted to determine their number.

Percentage grain damage – Percentage grain damage was computed using the formulae:

$$\begin{aligned} \% \text{ grain damage} \\ &= \frac{\text{Weight of damaged grains}}{\text{Total weight of grains}} \times 100 \end{aligned}$$

Percentage weight loss – Percentage weight loss was calculated using the formulae:

$$\% \text{ Weight loss} = \frac{\text{Weight of control sample} - \text{Final weight of grains}}{\text{Weight of control sample}} \times 100$$

One hundred (100) g un-infested maize grains were weighed into 250ml Kilner glass jars and kept on work table in the laboratory throughout the experimental period. At the end of the experiment, they were weighed and the mean change in weight was used to correct for weight gain or loss due to sorption or loss in the test materials (Hurlock, 1967).

Evaluation of the maize varieties for resistance to *Sitophilus zeamais* in a no-choice test

One hundred (100) g maize grains were weighed into 250ml Kilner glass jars and infested with twenty 20 unsexed 1-5 day old *S. zeamais*. The glass jars were arranged on the experimental table using Completely Randomized Design (CRD). The introduced insects were left on the grains for 90 days. At 90 days' post-infestation, the insects were sieved-out to separate insects, grains and maize flour. The grains were separated into damaged and undamaged. Data on weight of dust, weight of damaged and undamaged grains, number of adult maize weevil were taken as indicated for *P. truncatus*. Percentage grain damage and percentage weight loss were also calculated as earlier indicated.

Determination of proximate composition of maize grains

The proximate composition of the maize varieties was determined prior to infestation by *S. zeamais* and *P. truncatus* to determine the variation in the composition of

proximate of the maize varieties (Demissie *et al.*, 2015). The grains were analyzed for moisture, ash, total protein, crude fat and crude fibre following the standard procedure of AOAC (1990).

Rating scale and resistance rating of maize genotypes to damage by *Prostephanus truncatus* and *Sitophilus zeamais*

A rating scale on a score of 1-5 based on five damage indices (adult mortality, grain damage, number of adult *P. truncatus*, weight of grain dust, grain weight) according to Osipitan and Odebiyi (2007) was used to score and rate the maize varieties for resistance to damage by *P. Truncates* and *S. zeamais* (Table 2). Five groups were determined according to Sturges (1926) formula for determination of class interval using $n=1+3.332 \text{ Log}N$, where N is the total number of treatments which is 11 and n is the number of groups. The number of groups (n) is therefore $1+3.332(1.042) = 1+3.472$, $n=4.472$. The group of 5 was used as rating scales incen is greater than 4. The weighted average score was generated and used for rating the maize varieties into one of the four widely recognized classes of resistance: highly resistant, resistant, moderately resistant and susceptible (Osipitan and Odebiyi, 2007).

Statistical Analysis

Statistical analysis of data was based on SAS general statistical linear models procedure (SAS, 2001). Analysis of variance (ANOVA) table was generated for all the variable treatments at $P \leq 0.05$ and Duncan Multiple Range Test (DMRT) was used to separate significant means. Data on all insect counts were transformed using square root transformation and all data in percentages were arcs in transformed before subjection to ANOVA. Indices of grain damage such as percentage weight loss, percentage damage

and weight of dust generated were correlated with population of adult LGB and adult *S. zeamais* (Demissie *et al.*, 2015).

RESULTS

Number of Adult LGB and *Sitophilus zeamais*

Number of adult *P. truncatus* differ significantly ($P < 0.05$) between the varieties (Table 3). SUWAN-1-SR has the highest number (152.67) of adult while 2000SYNEE-WSTR and TZEE-YPOPSTRQPM CO has the lowest number (38.33 and 38.33 respectively) of adult *P. truncatus*. There were no significant ($P < 0.05$) difference in the percentage mortality of all the maize varieties except 2000SYNEE-W QPMCO and 2009TZEE-W-STR (Table 3). The percentage mortality of adult *P. truncatus* was highest in the variety 2000SYNEE-WQPMCO (31.19%) and lowest (5.54%) in the variety 2009TZEE-W-STR. The number of adult *S. zeamais* on the maize varieties differed significantly ($P < 0.05$). The number of the insect (152.67) in variety SUWAN 1-SR was significantly higher, the number of the insect in the other maize varieties except the number (132.67) in TZEE-W POP STR C₅. The percentage mortality of adult *S. zeamais* were however, not ($P > 0.05$) significantly different irrespective of the maize variety except SUWAN-1-SR (Table 3).

Damage assessment in maize grains infested with LGB and *Sitophilus zeamais*

The percentage grain damage of 16.23 by *P. truncatus* in TZEE-W-POP-STRC₅ was significantly higher ($P < 0.05$) than the percentage grain damage in other maize genotypes, while SUWAN-1-SR has a significantly ($P < 0.05$) lower percentage grain damage of 7.15 (Table 4). The percentage grain damage in “2008TZEE Y-STR” and “SUWAN-1-SR” were not significantly

($P > 0.05$) different from each other (Table 4). Similarly, the weight (1.63g) of grain dust in SUWAN-1-SR infested with *P. truncatus* was significantly ($P < 0.05$) lower than the weight of grain dust in all other maize varieties (Table 4). The percentage grain weight loss of 1.7 in the maize variety “SUWAN-1-SR” was significantly ($P < 0.05$) lower than the weight losses in all other maize varieties (Table 4). The grain weight losses in the maize genotypes “2004 TZEE-YPOPSTR C₄,” “2009TZEE-W-STR C₄,” “99TZEE-Y STR” and “2000SYNEE-WQPMCO” damaged by *P. truncatus* were not ($P > 0.05$) significantly different from each other (Table 4).

The percentage grain damage due to the feeding activities of *S. zeamais* differed significantly ($P < 0.05$) among all the maize varieties except “2009TZEE-W-STR” and “2000SYNEE-WQPM CO” (Table 4). The grain damage in “TZEE-W-POP-STRC₅” was significantly ($P < 0.05$) lower than the damage in other maize varieties, while the damage was significantly ($P < 0.05$) higher in “2000SYNEE-WSTR”. The weight of grain dust in “TZEE-WPOPSTRC₅,” and “2008TZEEY-STR”, 2004 were not ($P > 0.05$) significantly different from each other (Table 4). Similarly, weight of grain dust in TZEE-YPOPSTRC₄, 2009TZEE-WSTR, 2004 TZEE-WPOPSTRC₄, 2000SYNEE-WQPM CO, 2008SYNEE-YDTSTR and TZEE-YPOPSTRQPMCO were not significantly ($P > 0.05$) different from each other (Table 4). The percentage weight loss was significantly ($P < 0.05$) higher in the maize varieties “2008TZEE Y-STR” and significantly ($P < 0.05$) lower in the maize varieties “2000 SYNEE-W STR” (Table 4).

Proximate composition of maize grains

The proximate composition of the eleven maize genotypes shows that the moisture

content of the maize varied between 10.08 and 13.01 (Table 5). The moisture content of SUWAN-1-SR was significantly ($P<0.05$) higher than the moisture content of others. The protein content varied between 9.63 and 17.51. The maize variety 2004TZEE-W POP STR C4 has a significantly lower protein content of 9.63, while 2009TZEE-WSTR and 2000SYNEE-W QPMCO has a significantly ($P<0.05$) higher protein content of 17.51 (Table 5). The fat content (1.52) in the variety “2009 TZEE-WSTR” was significantly ($P<0.05$) higher than the fat content in other maize varieties. The crude fibre varied between 3.40 and 8.18, with the maize variety “SUWAN-1-SR” and TZEE-YPOPSTRQPMCO possessing significantly ($P<0.05$) higher and lower content of 3.40 and 8.18 respectively (Table 5). The maize variety 2004TZEE-YPOPSTRC4 has significantly higher ash content of 9.92, while 2000SYNEE-WQPMCO and TZEE-YPOPSTRQPMCO has significantly lower ash content of 1.65. The carbohydrate content of 68.60 in the maize variety “2008SYNEE-YDTSTR” and 68.41 in “2000SYNEE-QPMCO” were not significantly ($P>0.05$) different from each other, but were significantly ($P<0.05$) higher than the carbohydrate contents of other maize varieties (Table 5).

Correlation of grain damage index and number of *P. truncatus* and *Sitophilus zeamais*

The correlation ($r=0.67699$) between weight of damaged grains and number of living *P. truncatus*, number of living *P. truncatus* and weight of dust ($r=0.93074$), number of living *P. truncatus* and % weight loss ($r=0.53487$), weight of damaged grains and weight of grain dust ($r=0.57591$) were positive and highly significant (Table 6). The correlation of weight of grain dust and %

weight loss in maize grains damaged by *P. truncatus* ($r=0.49493$), and weight of maize grains damaged by *P. truncatus* and grain weight loss were positive and significant ($r=0.51024$) (Table 6). In maize grains infested with *S. zeamais*, the correlation ($r=0.40771$) between weight of damaged grains and number of living insects, weight of dust and number of living insects, ($r=0.4393$), % weight loss and number of living insects ($r=0.41400$), weight of damaged grains and weight of grain dust ($r=0.33608$), weight of dust and % weight loss ($r=0.40074$), weight of damaged grains and grain weight loss ($r=0.70258$) were positive and significant (Table 6).

Correlation of proximate composition of maize grains with grain damage by *Prostephanus truncatus* and *Sitophilus zeamais*

The correlation of ash, carbohydrate and fat contents of maize grains with grain damage by *P. truncatus* was positive and significant ($r=0.3575, 0.6134$ and 0.50696 respectively) (Table 7). The correlations of protein, crude fibre and moisture contents with damage by *P. truncatus* were not significant ($r=0.228, -0.01000$ and -0.03318 respectively). The correlation of carbohydrate content of maize grains with damage caused by *S. zeamais* was positive and significant ($r=0.1985$). The correlation of ash, protein, crude fibre, moisture and fat contents were insignificant ($r=-0.2967, 0.2686, -0.2927, -0.01327$ and 0.04470 respectively) (Table 7).

Eight of the eleven maize varieties were resistance or moderate resistance to damage by *P. truncatus* and *S. zeamais*, while three were susceptible based on the resistance index. The three maize varieties TZEE-WPOPSTRC5, 2004TZEE-YPOPSTRC4 and 2009TZEE-WSTR were susceptible to damage by *P. truncatus*, while eight other ones were either resistance or moderately

resistance to the insect (Table 8). The eight maize varieties that were resistance or moderately resistance to *S. zeamais* are 2004TZEE-YPOPSTRC4, 2009TZEE-WSTR, 2004TZEE-WPOP STR C4, 99TZEE-YSTR, 2000 SYNEE-WQPMCO, 2008 SYNEE-YDT STR, 2000 SYNEE-WSTR and SUWAN-1-SR. The susceptible ones are TZEE-WPOPSTR C5, 2008TZEE-YSTR and TZEE-YPOPSTR QPMCO (Table 9). The maize variety “TZEE-Y-

POPSTRQPMCO” was resistant to damage by *P. truncatus*, but was susceptible to damage by *S. zeamais*, while the variety 2009TZEE-W-STR was susceptible to damage by *P. truncatus* but was moderately resistant to damage by *S. zeamais*. SUWAN 1-SR and 2000 SYNEE-W-STR were resistant to both insects, while 2004TZEE-WPOPSTRC4 and 99TZEE-YSTR were moderately resistant to both insects (Tables 8 and 9).

Table 1: Names and description of maize varieties used for the study

Variety	Source	Colour
TZEE-W POP STR C ₅	IITA, Ibadan	White
2004 TZEE-Y POP STR C ₄	IITA, Ibadan	Yellow
2009 TZEE-W STR	IITA, Ibadan	White
2004 TZEE-W POP STR C ₄	IITA, Ibadan	White
99 TZEE-Y STR	IITA, Ibadan	Yellow
2008 TZEE Y-STR	IITA, Ibadan	Yellow
2000 SYNEE-W QPM CO	IITA, Ibadan	White
2008 SYNEE-Y DT STR	IITA, Ibadan	Yellow
2000 SYNEE-W STR	IITA, Ibadan	White
TZEE-Y POP STR QPM CO	IITA, Ibadan	Yellow
SUWAN-1-SR	FUNAAB	Yellow

Table 2: Rating scale for indices of parameters used in determining resistance to damage by *Prostephanus truncatus* and *Sitophilus zeamais*

<i>Prostephanus truncatus</i>					
Score	Adult mortality	% Grain damage	Number of adult <i>P. truncatus</i>	Weight of grain dust	% Grain weight loss
1	25.64 -32.04	0.00 - 3.50	0.00 - 26.80	0.00 - 2.10	0.00 - 1.21
2	19.23 -25.63	3.51 - 7.01	26.81- 53.61	2.11 - 4.21	1.22- 2.43
3	12.82 -19.22	7.02 -10.52	53.62- 80.42	4.22 - 6.32	2.44 - 3.65
4	6.41 - 12.81	10.53 -14.03	80.43-107.23	6.33 - 8.43	3.66 - 4.87
5	0.00 - 6.40	14.04- 17.54	107.24-134.04	8.44 -10.54	4.88 - 6.09
<i>Sitophilus zeamais</i>					
Score	Adult mortality	% Grain damage	Number of adult <i>S. zeamais</i>	Weight of grain dust	% Grain weight loss
1	2.84 – 3.54	0.00 – 15.00	0.00 - 87.50	0.00 - 0.70	0.00 - 5.40
2	2.13 – 2.83	15.01 – 30.01	87.51 - 175.01	0.71 - 1.41	5.42-10.81
3	1.42 – 2.12	30.02 – 45.02	175.02 - 262.52	1.42 - 2.12	10.82 - 16.22
4	0.71 – 1.41	45.03 – 60.00	262.53 - 350.03	2.13 - 2.83	16.23 - 21.63
5	0.00 – 0.70	60.04 – 75.04	350.04 - 437.54	2.84 - 3.54	21.64 - 27.04

Table 3: Number of *Prostephanus truncatus* and *Sitophilus zeamais* in infested maize grains

Varieties	<i>Prostephanus truncatus</i>		<i>Sitophilus zeamais</i>	
	Number of adult	% Mortality	Number of adult	% Mortality
TZEE-W POP STR C ₅	132.67±63.23ab	12.14±7.66ab	389.67±48.66a	2.37±0.35a
2004 TZEE-Y POP STR C ₄	94.33±29.68b	10.84±6.00ab	435.67±46.63b	2.68±1.03a
2009 TZEE-W STR	91.33±17.62b	5.54±1.21b	422.00±61.58b	2.41±0.80a
2004 TZEE-W POP STR C ₄	65.33±8.08bc	13.56±4.62ab	423.67±50.27b	1.83±0.49a
99 TZEE-Y STR	64.33±22.51bc	17.46±11.30ab	437.33±21.45b	2.83±0.96a
2008 TZEE Y-STR	50.00±29.14bc	18.23±7.74ab	326.00±24.00a	2.60±0.31a
2000 SYNEE-W QPM CO	46.33±23.39bc	31.19±9.11a	367.67±36.67a	2.93±0.58a
2008 SYNEE-Y DT STR	42.67±13.01bc	15.80±6.38ab	374.67±10.10a	3.07±1.24a
2000 SYNEE-W STR	38.33±3.38c	15.90±3.88ab	379.33±63.80a	2.84±0.38a
TZEE-Y POP STR QPM CO	38.33±6.43c	13.80±2.08ab	394.00±35.10ab	1.82±0.32a
SUWAN-1-SR	152.67±8.33a	17.32±8.52ab	415.00±2.51a	3.37±0.39c

Means with the same letters along the column are not significantly different at P<0.05 using DMRT.

Table 4: Assessment of damage in maize grains infested with *Prostephanus truncatus* and *Sitophilus zeamais*

Varieties	<i>Prostephanus truncatus</i>			<i>Sitophilus zeamais</i>		
	% Grain Damage	Weight of grain dust (g)	% Weight loss	% Grain Damage	Weight of grain dust (g)	% Weight loss
TZEE-W POP STR C ₅	16.23±5.24a	10.22±3.55a	2.47±1.21f	62.55±3.81i	3.30±1.04a	24.36±6.47c
2004 TZEE-YPOP STRC ₄	15.79±0.88b	9.79±1.62b	4.86±2.37b	68.56±1.45d	1.57±0.14de	15.36±0.32g
2009 TZEE-W STR	14.87±2.72c	9.63±2.13c	4.92±1.00b	69.06±8.95c	1.95±0.43cd	23.19±8.97d
2004 TZEE-WPOP STR C ₄	9.71±0.83e	6.80±1.26e	6.06±0.97a	64.20±7.29g	1.58±0.25cde	16.16±4.20f
99 TZEE-Y STR	10.20±2.50d	7.98±2.79d	4.95±1.32b	72.60±1.74b	2.48±0.30b	10.55±1.95h
2008 TZEE Y-STR	7.12±3.41g	6.06±2.40f	4.43±0.84c	62.95±6.03h	3.18±0.76a	26.53±9.05a
2000 SYNEE-W QPM CO	6.18±1.48i	3.86±1.57i	4.89±2.73b	68.92±2.08c	1.96±0.33cd	24.81±2.92b
2008 SYNEE-Y DT STR	6.36±2.32h	4.43±1.36h	3.62±0.42d	63.21±1.54h	1.91±0.45cd	21.69±4.43e
2000 SYNEE-W STR	9.56±2.16f	5.52±0.73g	2.93±1.00e	73.01±1.83a	2.07±0.33bc	5.06±3.36i
TZEE-Y POP STR QPM CO	4.35±1.44j	3.32±0.76j	3.18±0.27e	67.96±0.61e	1.94±0.50cd	16.02±3.95f
SUWAN-1-SR	7.15±2.33g	1.63±1.64k	1.70±0.55g	67.48±2.28f	1.22±1.11e	7.15±2.22j

Means with the same letters along the column are not significantly different at P<0.05 using DMRT.

Table 5: Proximate composition of maize grains infested with *Prostephanus truncatus* and *Sitophilus zeamais*

Varieties	Proximate Composition Of Maize Grains (%)					
	Moisture	Crude Protein	Fat	Crude Fibre	Ash	Carbohydrate
TZEE-W POP STR C ₅	10.66f	16.46b	0.95b	5.40e	7.60d	58.93j
2004 TZEE-Y POP STR C ₄	10.69e	14.71d	0.00d	4.63g	8.92a	61.05i
2009 TZEE-W STR	10.43h	17.51a	1.52a	4.50h	2.07h	63.97f
2004 TZEE-W POP STR C ₄	11.61c	9.63i	0.00d	4.90f	7.66c	66.20c
99 TZEE-Y STR	10.99d	15.59c	0.00d	4.00i	8.33b	61.09i
2008 TZEE Y-STR	10.53g	14.71d	0.00d	6.00d	4.98f	63.78g
2000 SYNEE-W QPM CO	10.19j	17.51a	0.00d	8.00b	1.65j	62.65h
2008 SYNEE-Y DT STR	10.08k	12.37g	0.00d	7.02c	5.65e	64.88d
2000 SYNEE-W STR	10.23i	14.01f	0.48c	4.90f	1.78i	68.60a
TZEE-Y POP STR QPM CO	12.21b	14.33e	0.00d	3.40j	1.65j	68.41a
SUWAN-1-SR	13.01a	10.21h	0.00d	8.18a	4.13g	64.47e
Mean	10.97b	13.24b	0.27a	5.54b	4.94b	64.01b

Means with the same letters along the column are not significantly different at $P < 0.05$ using DMRT.

Table 6: Correlation of index of grain damage with number of *Prostephanus truncatus* and *Sitophilus zeamais*

<i>Prostephanus Truncatus</i>	Number of living insect	Weight of damaged grains	Weight of grain dust	% Grain weight loss
Number of living <i>P. truncatus</i>	1.000	0.67699**	0.93074**	0.53487**
Weight of damaged grains		1.000	0.57591**	0.51024*
Weight of grain dust			1.000	0.49493*
% Grain weight loss				1.000
<i>Sitophilus zeamais</i>				
Number of living <i>S. zeamais</i>	1.00	0.40771*	0.4393*	0.41400*
Weight of damaged grains		1.00	0.33608*	0.70258*
Weight of grain dust			1.00	0.40074*
% Grain weight loss				1.00

** Significant at $p \leq 0.01$

* Significant at $p \leq 0.05$

Table 7: Correlation of proximate composition of maize grains with grain damage of *Prostephanus truncatus* and *Sitophilus zeamais*

Insect	Proximate Composition						
	Damage	Ash	Protein	Carbohydrate	Crude fibre	Moisture Content	Fat
<i>P. truncatus</i>	Grain	0.3575*	0.228	0.6134**	-0.01000	-0.03318	0.50696*
<i>S. zeamais</i>	Grain	-0.2967	0.2686	0.1985*	-0.2927	-0.01327	0.04470

** Significant at $p \leq 0.01$ * Significant at $p \leq 0.05$ **Table 8:** Resistance rating of eleven maize varieties to damage by *Prostephanus truncatus*

Maize Variety	Insect mortality	% grain damage	Number of adult LGB	Weight of grain dust	% grain weight loss	Weighted average	Resistance rating
TZEE-W POP STR C ₅	4	5	5	5	3	4.4	Susceptible
2004 TZEE-Y POP STR C ₄	4	5	4	5	5	4.6	Susceptible
2009 TZEE-W STR	5	5	4	5	5	4.8	Susceptible
2004 TZEE-W POP STR C ₄	3	3	3	4	5	3.6	Moderately resistant
99 TZEE-Y STR	3	3	3	4	5	3.6	Moderately resistant
2008 TZEE Y-STR	3	3	2	4	4	3.2	Moderately resistant
2000 SYNEE-W QPM CO	1	2	2	2	5	2.4	resistant
2008 SYNEE-Y DT STR	3	2	2	3	3	2.6	resistant
2000 SYNEE-W STR	3	3	2	3	3	2.8	resistant
TZEE-Y POP STR QPM CO	3	2	2	2	3	2.4	resistant
SUWAN-1-SR	2	3	4	1	2	2.4	resistant

Table 9: Resistance rating of eleven maize varieties to damage by *Sitophilus zeamais*

Maize Variety	Insect mortality	% grain damage	Number of adult LGB	Weight of grain dust	% grain weight loss	Weighted average	Resistance rating
TZEE-W POP STR C ₅	2	5	5	5	5	4.4	Susceptible
2004 TZEE-Y POP STR C ₄	2	5	5	3	3	3.6	Moderately resistant
2009 TZEE-W STR	2	5	4	3	5	3.8	Moderately resistant
2004 TZEE-W POP STR C ₄	3	5	4	3	4	3.8	Moderately resistant
99 TZEE-Y STR	1	5	5	3	5	3.8	Moderately resistant
2008 TZEE Y-STR	2	5	4	5	5	4.2	Susceptible
2000 SYNEE-W QPM CO	1	5	5	3	5	3.8	Moderately resistant
2008 SYNEE-Y DT STR	1	5	5	3	5	3.8	Moderately resistant
2000 SYNEE-W STR	1	5	4	3	1	2.8	Resistant
TZEE-Y POP STR QPM CO	3	5	5	3	4	4.0	Susceptible
SUWAN-1-SR	1	5	4	2	2	2.8	resistant

DISCUSSION

In this study, eight of the eleven maize varieties were either resistance or moderately resistance to damage by *P. truncatus* and *S. zeamais*, while three were susceptible based on the resistance index. The result is inconsonance with that of Kumar (2002) which indicated that 19 landraces from the Caribbean showed resistance to *P. truncatus*. In a similar study, Kasambala (2009) screened some maize varieties for susceptibility to *P. truncatus* and reported that nine commercial maize hybrids, namely SC403, SC407, SC513, SC627, SC717, DK8033, DK8053, DK8073, MH18 were susceptible to the insect, and a local variety “Kanjerenjere” was resistant. Derera *et al.* (2000) and Abebe *et al.* (2009) have also reported existence of variation for resistance to damage by stored product insects among maize genotypes. Nhamucho *et al.* (2014) reported the existence of resistance to infestation and damage by *P. truncatus* among maize genotypes in Mozambique.

The variation in the damage by *P. truncatus* and *S. zeamais* to the maize grains suggest differences in the genetic make up of the maize varieties. This substantiate the results of earlier study by Osipitan and Odebiyi (2007) which indicated that ICW5BC2-B(KU1414) was not damaged by *P. truncatus* and did not have grain dust nor lost weight among twenty maize genotypes screened for damage by the insect. Luke *et al.* (2015) similarly reported highest weevil mortality, reduced percent grain damage, no weight loss, no powdering and no oviposition in two maize genotypes “2000SYNEE-WSTR” and “TZBRELD3C5”. Adedire *et al.* (2011) reported that TZBRELD3C was highly resistant to *S. zeamais*. Dhliwayo and Pixley (2003) reported that the existence of resistance to maize weevil in maize genotypes materials

will make improvement of resistance against maize weevil possible. The maize genotype “2000SYNEE-WSTR” classified as resistant in this study was also classified as resistant in a separate study by Nwosu *et al.* (2015) and Luke *et al.* (2015). Ewedairo *et al.* (2014) also reported relative resistance of the maize genotype “SUWAN-1-SR” to damage by *P. truncatus* among nine maize genotypes screened for resistance to damage by the insect. The results of this study show that some of the maize varieties such as SUWAN-1-SR-Y and 2000SYNEE-W-STR were resistant to both insects, while 2004TZEE-WPOPSTRC4 and 99 TZEE-YSTR were moderately resistant to the insects. This suggests that maize could demonstrate dual resistance to damage by *P. truncates* and *S. zeamais*. This possibility could be explored by seed breeders to breed maize varieties that have multiple resistance to infestation and damage by the insects. The maize genotypes SUWAN 1-SR and 2009TZEE-W-STR that were resistance to damage by *P. truncatus* and *S. zeamais* notably had relative lower grain damage, grain weight loss, weight of grain dust, final number of adult insects and higher mortality compared to the susceptible ones. In a similar study, Nwankwo *et al.* (2014) reported relatively low number of adult, low weight loss and damaged seeds in five maize varieties that were resistance to damage by *P. truncatus*.

The weight loss (1.70-6.06%), grain damage (4.35-16.23%) and grain dust (1.63-10.22 g) in the maize genotypes infested with *P. truncatus*, and weight loss (5.06-26.53%), grain damage (62.55-73.01%) and grain dust (1.22-3.30g) in the maize genotypes infested with *S. zeamais*. This is similar to earlier reports by McFarlane (1989), Denning *et al.* (2009) and APHLIS (2015) on the ability of *P. truncatus* to damage maize. Delima (1987) and Giga *et al.* (1991) indicated that

maize grains damaged by *S. zeamais* have reduced nutritional values, low percent germination, reduced weight and market values and reported worldwide seed losses of 20 to 90% for untreated maize due to *S. zeamais* infestation. In this study, higher number of *P. truncatus* and *S. zeamais* stimulated higher grain damage, grain dust and weight loss. In a similar study, Dushyant *et al.* (2009) reported positive correlation between weight loss and adult emergence of *S. oryzae*, while Tefera *et al.* (2011) indicated that the level of damage and weight loss during storage is strongly correlated with the number of adult insects.

The proximate composition of the maize genotypes indicated variation in the ash, protein, fat, crude fibre, carbohydrate and moisture contents. This is in agreement with the result of Nwankwo *et al.* (2014) which indicated that ten maize varieties differed in their overall chemical and physical parameters and their responses to *P. truncatus*. Similarly, Nwankwo *et al.* (2015) and Luke *et al.* (2015) reported differences in the chemical composition of maize grain screened for infestation and damage by *S. zeamais* and *P. truncatus*. The variation in the damage to the maize genotypes by the insects suggest that the chemical composition of the maize grains may likely influence damage by the insects and their population. The results suggest supportive influence of carbohydrate content on damage by *P. truncatus* and *S. zeamais*. In a similar study, Pamidi *et al.* (2016) reported positive correlation of starch to susceptibility parameters and concluded that *S. zeamais* showed preference to maize with high starch content. Similarly, Osipitan and Odebiyi (2007) and Chijindu and Boateng (2008) reported the role of starch content of maize grains as a susceptible factor to storage pests. Chalfant and Gaines (1973) reported that *P. truncatus* responded in general to odours

from starchy commodities and Scholz *et al.* (2009) reported that breeding by adults of *P. truncatus* was dependent on the high starch content of the wood of *Manihot esculenta*. Similarly, Ichiro *et al.* (2009) reported that insects consume starch and protein from grains to grow and for laying eggs.

The influence of fat and ash content on damage by *P. truncatus* was supportive. However, the influence of ash content on damage by *S. zeamais* was suppressive, though not significant and the effect of fat was also insignificant. This suggests that the influence of some bio-chemical composition of maize grains on *P. truncatus* and *S. zeamais* differed. The influence of protein content of the maize grains on damage by the insects was positive and insignificant. Siwale *et al.* (2009) and Luke *et al.* (2015) however reported significant positive correlation between protein and insect damage suggesting protein as a basis of susceptibility. The results are however at variance with the reports of Dobie (1977) and Arnason *et al.* (2004) which reported negative relationship between protein content and susceptibility index. From the results of the study, it could be concluded that some of the maize varieties are resistance to damage by *P. truncatus* and *S. zeamais*. The basis of resistance is antibiosis conferred by the ash, carbohydrate and fat content of maize grains. The factors conferring resistance can be used to breed maize grains that are resistant to *P. truncatus* and *S. zeamais*.

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