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Susceptibility of selected maize seed genotypes to *Sitophilus zeamais* (Coleoptera: Curculionidae)

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ABSTRACT

Studies were carried out under laboratory conditions of 25 ± 2 °C and 70 ± 5% RH in an incubator to determine the relative susceptibility of eighteen maize genotypes to attack by the maize weevil, *Sitophilus zeamais* Motschulsky. The experiment was laid out in a Completely Randomized Design (CRD) with three replications. Adult mortality, number of F_1 progeny, weevil development time, susceptibility index, percentage seed damage, percentage weight loss, and weight of powder produced were determined after storage period of three months. The susceptibility index was determined using Dobie's formula and the genotypes were classified into different susceptibility groups. The genotypes exhibited varying degrees of susceptibility to *S. zeamais* attack. Only Aseda was regarded as resistant and TZE-Y POP STR as moderately resistant to *S. zeamais*. Kpari-Faako, Tintim, WACCI-M-1215, WACCI-M-1594 and Wang-Dataa were regarded as moderately susceptible to *S. zeamais*. However, Abontem, Bihilifa, Ewul-Boyu, Sanzal-Sima, TZE-I 17, WACCI-M-1205, WACCI-M-1508 and WACCI-M-1510 were regarded as susceptible genotypes. Furthermore, Aburohemaa, Obaatanpa and Omankwa were regarded as highly susceptible to *S. zeamais*. Number of F_1 progeny, seed damage, seed weight loss, weight of dust produced and seed moisture content had positive relationship with varietal susceptibility while adult weevil mortality, median development period and seed germination after infestation had an inverse relationship with susceptibility in maize. The use of insect resistant genotypes would offer a sustainable way of minimizing postharvest losses of seeds in storage especially for smallholder farmers who keep harvested grains for future use as food and seed.

1. Introduction

Maize (*Zea mays* L.) is an essential component of global food security. Maize serves as a valuable cereal crop in the world due to its diverse use as food for man, feed for livestock and raw material for several industries (Gupta *et al*., 2015). It is one of the most commonly grown crops and a major staple crop for many smallholder farmers in the world. The crop has diverse germplasm adapted to different ecological zones (Koutsika-Sotiriou, 1999). In Ghana, it is the principal staple crop produced and consumed by most farming households. Maize is the most cultivated crop in Ghana, and 2.6 metric tonnes of the crop is produced annually (OECD, 2016). Hence it is ranked first among cereal crops in the country in terms of area planted and value of sales (MoFA, 2014). Maize is grown in almost every region in Ghana. The five major maize growing areas in Ghana are the Eastern, Ashanti, Central, Brong-Ahafo and the Northern Regions (Adu *et al*., 2014).

Despite the efforts made in increasing production and productivity of maize through the development of high yielding stress tolerant genotypes in the country there is evidence of seed and food insecurity arising from storage losses. In Ghana, it is reported that most farmers experience very high storage losses of up to 50% if all quantity losses, quality losses, and income loss due to early sale are considered in the estimation (Kaminski and Christiaensen, 2014). One of the factors responsible for the high storage losses is the problem of stored grain insect pests some of which are field to store pests, include the maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae); rice weevil, *S. oryzae* (L.) (Coleoptera: Curculionidae); Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae); and the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) (Abebe *et al*., 2009; Tefera *et al*., 2011). Storage loss averages of 4–21% due to storage

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insects have been reported (Affognon, 2014). *Sitophilus zeamais* is a serious pest of maize in tropical regions, causing considerable losses to many small-scale farmers who keep grains on farm for future use as food and seed (Thanda and Kevin, 2003).

Existing control measures for stored product insect pests include sanitation, modification of the storage environment, chemical pesticides, biological control and host plant resistance (Golob, 2002). Of these existing control measures, the application of chemical pesticides is the most common insect pest management strategy among farmers in rural communities. These chemical pesticides are expensive and farmers lack requisite skills to handle and use them (Rugumamu, 2011). One alternative to the use of chemical pesticides for control of stored product insect pests is the use of resistant varieties (Throne *et al.*, 2000). The use of varietal resistance in Integrated Pest Management (IPM) of *S. zeamais*, particularly in tropical environment, where smallholder farmers produce and keep their harvested grains under conditions that favour insect pest colonization cannot be overemphasized. Resistant varieties are economical, easy to handle and use, and safe. A better understanding of host-plant resistance of stored maize to *S. zeamais* infestation will undoubtedly lead to the identification of suitable genotypes which may be incorporated in storage pests management programmes. This study was undertaken to determine the susceptibility of selected maize seed genotypes from the maize breeding programme of three institutes in Ghana, namely Crops Research Institute (CRI), Savanna Agricultural Research Institute (SARI) and West Africa Centre for Crop Improvement (WACCI) to attack by the maize weevil, *S. zeamais*.

2. Materials and methods

2.1. Plant material

A total of eighteen maize genotypes were collected from the maize breeding programmes of three institutes in Ghana (CRI in Kumasi, SARI in Tamale and WACCI, University of Ghana, Legon) comprising six advanced breeding materials and 12 cultivated varieties. The different genotypes of maize seeds received were cleaned and kept in a cold room at 4 °C for 1 week to kill any existing/hidden storage insect pests. The seeds were further dried in an oven at 60 °C for 3 h to a moisture content level of 12 ± 2%. This was followed by keeping the seeds for 1 week under the experimental conditions in an incubator for acclimatization.

2.2. Maize weevil (Sitophilus zeamais) culture

The maize weevils used to set up the culture were obtained from a two-month old culture in the Entomology Laboratory, University of Ghana. The weevils were sieved and 200 adults were introduced into sterilized 3 L glass jars containing sterilized (60 °C for 3 h to kill any insect eggs which might have been present in the grains) maize seeds (1.2 kg) of Obaatanpa, a variety widely adopted by Ghanaian farmers. The glass jars were covered with muslin cloth and held in place by rubber bands to prevent possible re-infestation. The jars were placed on inverted Petri dishes in industrial oil on shallow trays to keep out other arthropods. The insects were allowed to oviposit for 10 days after which they were sieved out and the culture left to develop. After 35 days from the mid-point of the oviposition period, the F_1 progeny was sieved out. The F_1 adult weevils that had emerged, which were 0–1 week old, were introduced into replicates of glass jars containing sterilized maize seeds for one week to obtain enough 1–2 weeks old weevils which were used for the experiments.

2.3. Experimental set up

Maize seeds (150 g) from each variety were placed in a 250 mL glass jar. Thirty unsexed adult weevils aged between 1 and 2 weeks were put into each of the glass jars and covered with muslin cloth held in place with rubber band. There were three replications laid out in a Completely Randomized Design (CRD). After 10 days oviposition period, grains from each experimental jar were sieved to discard adult weevils and the experimental set up was maintained at 25 ± 2 °C and 70 ± 5% RH and 12 h light: 12 h dark photoperiod in Rubarth Apparate GmbH RUMED laboratory test chamber. After 30 days, the F_1 progeny emergence was monitored and assessed daily for further 36 days.

3. Data collected

Moisture content of the seeds was measured prior to introduction of the adult weevils using Seedburo 1200D Digital Moisture Tester (Marlow Bucks, England). Assessment of adult weevil mortality was done 10 days after the introduction of the weevils by noting the number dead and alive. Adult weevil mortality was calculated by using the formula: Adult mortality $(\%) = \frac{Number\ of\ dead\ weevils}{Total\ number\ of\ all\ weevils} \times 100$.

F_1 Progeny Production was monitored through daily counts and removal of the F_1 progeny were done to prevent the F_1 progeny from laying eggs in the maize samples to produce the F_2 generation. This continued for 56 days to ensure that all expected developing immature stages had emerged (Abebe *et al.*, 2009).

Seed Damage, Weight Loss and Weight of Seed Powder: Seeds (200) were randomly selected from each glass jar to assess the number of damaged seeds. Seed damage was calculated using the formula: Seed damage $(\%) = \frac{Number\ of\ damaged\ seeds}{Total\ number\ of\ seeds} \times 100$. Seed weight loss was determined using the count and weigh method expressed as: $W\ (\%) = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu \times (Nd + Nu)} \times 100$; where, W = weight loss (%), Wu = weight of undamaged seed, Nu = number of undamaged seed, Wd = weight of damaged seed, and Nd = number of damaged seed (Boxall *et al.*, 1986). Seeds from each glass jar were sieved to collect the dust (frass) produced by the weevils. This was followed by weighing the dust using a KERN 870 electronic balance (Gottl, Kern & Sohn D-72458, Albstadt).

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

Dobie's (1974) index of susceptibility was used to determine susceptibility of the maize genotypes attacked by *S. zeamais* as follows: $IS = \frac{Ln \sum x}{MDP} \times 100$; where, IS = index of susceptibility, LnΣx = natural logarithm of the sum of the number of F_1 progeny emerged and MDP = median development period. Dobie's susceptibility index scores ranging from ≤4 to ≥10, was used to classify the maize genotypes, where ≤4 was classified as resistant; 4.1–6.0 as moderately resistant; 6.1–8.0 as moderately susceptible; 8.1–10 as susceptible and ≥10 as highly susceptible.

Seed Germination Test: Seed germination test was conducted by randomly picking 100 seeds from each maize variety before introducing the weevils and after the seeds were damaged by the weevils at the end of the assessment period in each glass jar. The test was conducted under ambient laboratory conditions of 28 ± 1 °C and 70 ± 5% RH with 4 replicates of 25 seeds per replicate of each maize variety. The selected seeds were placed on a wetted filter paper in Petri dishes. The number of seeds that germinated normally was counted and recorded after 7 days. The percentage germination (viability index) was calculated as follows: $GP\ (\%) = \frac{NSG}{TNS} \times 100$; where, GP = germination percentage, NSG = number of seeds germinated after 7 days and TNS = total number of seeds tested in each Petri dish (Ogendo *et al*., 2004).

4. Data analysis

Data on adult mortality, seed damage, and seed weight loss recorded in percentages were arcsine transformed whereas number of F_1 progeny was log transformed so as to stabilize the variance. These data together with percent seed germination were analyzed using a general Analysis Of Variance (ANOVA) using GenStat statistical package 12th Edition. Means were separated using Bonferroni all pairwise comparisons test or Tukey Standardized Test to compare the differences between the treatments at 5% level of probability where appropriate. Correlation analysis was used to determine the association between moisture content, adult mortality, F_1 progeny, seed damage, weight loss, dust produced, germination percentage, median development period and susceptibility index.

5. Results

The genotypes were highly significantly ($P < 0.001$) different from each other for moisture content and *S. zeamais* mortality among the 18 maize genotypes during 10 days of the oviposition period (Table 1). Seed moisture content ranged from 11.4% in Aseda to 13.8% in Abontem. The highest weevil mortality was observed in Abontem (60.0%) whereas Aburohemaa (1.1%) recorded the lowest mortality.

Highly significant ($P < 0.001$) differences were observed among the 18 maize genotypes for the time of first emergence of F_1 progeny of *S. zeamais* and the number of weevils which completed development and emerged as adults during the assessment period (Table 1). The first batches of weevils completed development and emerged as adults at 27 days after set up (DAS) and were from Obaatanpa and Omankwa. However, the first F_1 progeny emerged 41 DAS in Aseda, and varied from 32 to 36 DAS among the remaining genotypes. The highest number of F_1 progeny was recorded in Aburohemaa (128.0) whereas the lowest number was recorded in Aseda (5.3). There were variations in the pattern of weekly emergence of *S. zeamais* among the eighteen maize genotypes. The highest number of F_1 progeny per week was recorded in Aburohemaa, Obaatanpa and Omankwa while the lowest number was recorded in Aseda and TZE-Y POP STR.

Significant ($P < 0.010$) differences were observed among the 18 maize genotypes for the MDP (Table 1) and IS (Table 2). The MDP ranged from 37.7 days for Abontem to 47.3 days for Tintim. Using the Dobie's index of susceptibility score, three genotypes had values ≥ 10, eight fell within 8.1–10, five within 6.1–8.0, one within 4.1–6.0 and one was ≤ 4.

Highly significant ($P < 0.001$) differences were observed among the genotypes for seed damage, seed weight loss and weight of powder produced after the storage period (Table 3). The variety with the most seed damage was Aburohemaa (26.0%), followed by

Table 2
Mean ± SE of Susceptibility Index and degrees of resistance of Eighteen Maize Genotypes to *S. zeamais*.

Varieties	Index of Susceptibility	Susceptibility Status
Aseda	3.7 ± 0.2a	Resistant
TZE-Y POP STR	5.2 ± 0.1 ab	Moderately resistant
WACCI-M-1215	6.9 ± 2.0abc	Moderately susceptible
Tintim	7.0 ± 0.5abc	Moderately susceptible
Wang-Dataa	7.3 ± 0.7bc	Moderately susceptible
WACCI-M-1594	7.4 ± 0.1bc	Moderately susceptible
Kpari-Faako	7.9 ± 0.4bc	Moderately susceptible
Sanzal-Sima	8.2 ± 0.7bcd	Susceptible
WACCI-M-1508	8.2 ± 0.5bcd	Susceptible
Abontem	8.5 ± 1.9bcd	Susceptible
Bihilifa	8.5 ± 0.6bcd	Susceptible
Ewul-Boyu	8.5 ± 0.2bcd	Susceptible
TZE-I 17	8.7 ± 0.3cd	Susceptible
WACCI-M-1205	9.1 ± 0.7cde	Susceptible
WACCI-M-1510	10.1 ± 0.4cdef	Susceptible
Omankwa	11.3 ± 1.1def	Highly susceptible
Obaatanpa	12.2 ± 0.4ef	Highly susceptible
Aburohemaa	12.6 ± 0.9f	Highly susceptible
P value	0.001	
Tukey ($P < 0.05$)	1.86	
CV (%)	13.4	

Values followed by the same letter within the column are not significantly different at $P < 0.05$.

Table 1
Mean ± SE of moisture content, adult mortality, time of first emergence, number of F_1 progeny and median development period of eighteen maize genotypes to *S. zeamais*.

Varieties	SMC (%)	AM (%)	TFE (Days)	No. of F_1P	MDP (Days)
Abontem	13.8 ± 0.6d	60.0 ± 15.2c	29.7 ± 1.2abc	30.3 ± 14.7a	37.7 ± 1.1a
Aburohemaa	13.1 ± 0.2bcd	1.1 ± 1.4a	28.3 ± 0.4 ab	128.0 ± 31.7d	38.3 ± 1.7 ab
Aseda	11.4 ± 0.1a	59.8 ± 17.8c	41.0 ± 3.5e	5.3 ± 1.1a	43.7 ± 4.6 ab
Bihilifa	11.9 ± 0.4 ab	17.8 ± 12.4 ab	36.3 ± 0.4de	42.3 ± 10.6 ab	43.7 ± 0.4 ab
Ewul-Boyu	12.3 ± 0.0abcd	7.8 ± 3.8a	36.0 ± 0.0de	37.0 ± 4.0 ab	42.3 ± 0.4 ab
Kpari-Faako	12.1 ± 0.0abc	4.4 ± 1.4a	36.3 ± 0.4de	27.0 ± 4.0a	41.7 ± 0.9 ab
Obaatanpa	12.6 ± 0.2abcd	5.6 ± 3.8a	27.3 ± 0.4a	105.3 ± 4.8cd	38.3 ± 1.1 ab
Omankwa	13.3 ± 0.2bcd	14.4 ± 8.1a	27.3 ± 0.4a	93.7 ± 38.9bcd	39.0 ± 1.5 ab
Sanzal-Sima	12.4 ± 0.2abcd	12.2 ± 7.7a	36.0 ± 0.0de	34.7 ± 7.5 ab	43.3 ± 0.9 ab
Tintim	11.9 ± 0.3 ab	12.2 ± 1.4 ab	36.0 ± 0.0de	29.3 ± 9.2a	47.3 ± 3.7b
TZE-I 17	11.5 ± 0.3a	8.9 ± 1.4a	34.3 ± 0.4cd	36.7 ± 2.4 ab	41.3 ± 0.9 ab
TZE-Y POP STR	11.9 ± 0.2 ab	2.2 ± 1.4a	36.0 ± 0.0de	10.7 ± 1.1a	45.7 ± 3.0 ab
WACCI-M-1205	12.3 ± 0.7abcd	24.4 ± 7.7abc	33.0 ± 1.3bcd	47.7 ± 15.1abc	42.0 ± 2.3 ab
WACCI-M-1215	13.6 ± 0.4cd	53.3 ± 18.1bc	35.3 ± 2.7d	26.7 ± 16.5a	41.7 ± 1.1 ab
WACCI-M-1508	13.2 ± 0.6bcd	23.3 ± 7.5abc	32.7 ± 0.9bcd	33.7 ± 7.1 ab	42.7 ± 1.9 ab
WACCI-M-1510	12.8 ± 0.5abcd	7.8 ± 3.8a	32.3 ± 0.4abcd	54.0 ± 3.4abc	39.7 ± 1.1 ab
WACCI-M-1594	13.3 ± 0.7bcd	15.6 ± 3.8 ab	34.0 ± 2.0cd	23.7 ± 6.8a	42.3 ± 4.1 ab
Wang-Dataa	12.2 ± 0.5abcd	6.7 ± 2.5a	36.0 ± 0.0de	34.3 ± 15.9 ab	46.3 ± 3.0 ab
P value	0.001	0.001	0.001	0.001	0.010
Tukey ($P < 0.05$)	0.86	20.97	2.74	32.49	4.99
CV (%)	4.2	67.5	4.9	44.1	7.2

Values followed by the same letter within the column are not significantly different at $P < 0.05$.
SMC = Seed moisture content; AM = Adult mortality; TFE = Time of first emergence; F_1P = Number of F_1 progeny; MDP = Median development period; LSD = Least significance difference; and CV = Coefficient of variation.

Table 3
Mean ± SE of level of Damage, Weight Loss, Frass Weight and Viability for Eighteen Maize Genotypes s after Exposure to *S. zeamais*.

Variety	% Seed damage	% Seed weight loss	% Seed Germination before infestation	% Seed Germination after infestation
Abonten	18.3 abcd	5.8 ab	84.2 a	80.1 bc
Aburohemaa	30.5 e	8.5 b	83.0 a	57.1 ab
Aseda	6.9 a	2.0 a	84.2 a	83.0 c
Bihilifa	19.4 bcde	7.8 b	76.3 a	79.3 bc
Ewul-Boyu	17.0 abc	7.5 ab	79.2 a	69.9 abc
Kpari-Faako	16.5 abc	8.5 b	76.2 a	69.3 abc
Obaatanpa	27.0 cde	8.7 b	78.9 a	57.2 ab
Omankwa	29.0 de	8.7 b	81.8 a	53.6 a
Sanzal-Sima	21.0 bcde	8.1 b	80.1 a	69.0 abc
Tintim	17.8 abcd	6.7 ab	72.4 a	64.2 abc
TZE-I 17	19.9 bcde	8.3 b	79.8 a	67.3 abc
TZE-Y POP ST	13.3 ab	5.9 ab	85.9 a	72.0 abc
WACCI-M-1205	22.1 bcde	7.1 ab	74.1 a	61.8 abc
WACCI-M-1215	16.6 abc	5.1 ab	80.1 a	72.9 abc
WACCI-M-1508	17.4 abcd	6.7 ab	75.0 a	77.9 abc
WACCI-M-1510	22.7 bcde	6.7 ab	80.8 a	65.8 abc
WACCI-M-1594	15.1 abc	4.7 ab	78.9 a	67.9 abc
Wang-Dataa	20.4 bcde	7.2 ab	76.2 a	62.8 abc

Values followed by the same letter within the column are not significantly different at P < 0.05.
Experimentwise error rate = 0.0500.
Comparisonwise error rate = 0.0003.

Omankwa (23.8%) and Obaatanpa (20.8%). Seed damage for Aseda (1.5%) was significantly lower than the remaining genotypes. Seed weight loss among the genotypes ranged from 0.1% in Aseda to 2.4% in Obaatanpa after three months of storage. Seed weight loss recorded in the remaining maize genotypes varied from 0.7% to 2.3%. The highest weight of powder produced after three months period of storage was observed in Aburohemaa which was 138.5 mg whilst the lowest value recorded was 4.9 mg in Aseda.

Germination percentages before weevil infestation and after infestation were significantly different (Table 3). Germination of non-infested seeds ranged from 87.0% in Tintim and WACCI-M-1508 to 99.0% in Aseda and TZE-I 17 (Table 3). After infestation with *S. zeamais*, seed germination ranged from 52.0% in Omankwa to 98.0% in Aseda.

Simple linear relationship among variables such as moisture content, adult mortality, F_1 progeny, percentage seed damage, percentage seed weight loss, weight of dust produced, germination percentage, median development period and susceptibility index were determined and summarized (Table 4). It is clear from the correlation coefficient (r) that an inverse association existed between index of susceptibility and adult mortality, MDP and seed germination. However, the number of F_1 progeny, seed damage, seed weight loss, weight of dust produced and seed moisture content were positively correlated with the index of susceptibility. Seed damage ($r = 0.9$, $P < 0.001$), seed weight loss ($r = 0.6$, $P < 0.001$) and weight of seed powder ($r = 0.9$, $P < 0.001$) showed positive and highly significant correlations with index of susceptibility. Furthermore, the number of F_1 progeny showed highly significant and positive correlations between seed damage ($r = 0.9$, $P < 0.001$), seed weight loss ($r = 0.6$, $P < 0.001$) and weight of dust produced ($r = 0.9$, $P < 0.001$) from the genotypes. However, number of F_1 progeny was highly significant and negatively ($r = -0.7$, $P < 0.001$) associated with seed germination. Moreover, seed damage was negatively and highly significantly ($r = -0.8$, $P < 0.001$) correlated with seed germination.

6. Discussion

The significant differences and considerable variations observed among the maize genotypes for variables studied suggest that response to the weevil is genotype dependent (Keba and Sori, 2013; Kasozi *et al.*, 2016). These differences indicate that variability existed among the maize genotypes evaluated that would allow for the identification of resistant genotypes.

Most of the weevils completed development and emerged as adults in maize genotypes with higher moisture content which suggests that seed moisture content plays a significant role in susceptibility of maize to insect pests attack. This confirms the observation by Keba and Sori (2013) who reported a positive relationship between seed moisture content and weevils which completed development and emerged as adults. Birch (1944) also reported that the oviposition rates of *S. zeamais* are influenced by

Table 4
Correlation among variables for susceptibility to *S. zeamais*.

	IS	Mor	F_1P	SMC	MDP	SD	SWL	Dust	SG
IS	1								
Mor	−0.4**	1							
F_1P	0.9***	−0.4**	1						
SMC	0.3*	0.1	0.2	1					
MDP	−0.5***	−0.2	−0.3**	−0.5***	1				
SD	0.9***	−0.3**	0.9***	0.3	−0.3	1			
SWL	0.6***	−0.4***	0.6***	0.0	−0.1	0.6	1		
Dust	0.9***	−0.4**	0.9***	0.2	−0.4	0.9	0.6***	1	
SG	−0.7***	0.4**	−0.7***	−0.2	0.3	−0.8***	−0.5***	−0.7***	1

*, ** and *** designate significance at 0.05, 0.01, and 0.001 probability levels respectively.
IS = Index of susceptibility, Mor = Mortality, F_1P = F_1 progeny, SMC = Seed moisture content, MDP = Median development period, SD = Seed damage, SWL = Seed weight loss and SG = Seed germination.

both temperature and grain moisture content. The lower moisture contents in Aseda (11.4%) and TZE-Y POP STR (11.9%) might have deterred *S. zeamais* from colonizing, feeding and egg laying and could account for the low number of weevils which completed development and emerged as adults from these genotypes. The critical moisture content for *S. zeamais* development is 12% (Birch, 1944) compared to the low 11.4% recorded for Aseda in the present study. Possible mechanisms of resistance especially in the Aseda genotype may be a combination of antixenosis, antibiosis and tolerance. This also suggests that under normal conditions, *S. zeamais* will prefer maize genotypes with higher moisture content and will only attack genotypes with lower moisture content under conditions where their preferred variety is not available. This may be the case of TZE-117 which recorded a low seed moisture content of 11.5% and yet produced quite a high F1 progeny.

The high weevil mortality rate for Abontem, Aseda, WACCI-M-1508, WACCI-M-1205 and WACCI-M-1215 might be due to certain chemical compounds in them that hinder the development of this pest. Aburohemaa, TZE-Y POP STR, Kpari-Faako, Obaatanpa, Wang-Dataa, Ewul-Boyu, WACCI-M-1510, TZE-I 17, Sanzal-Sima, Tintim and Omankwa which recorded the least adult mortality rate provided a more favorable environment for egg laying, egg hatching and development of this pest. Maize weevils which completed development and emerged as adults were however high in Abontem, WACCI-M-1215, WACCI-M-1205 and WACCI-M-1508 despite their high mortality rates indicating that adult mortality may not contribute significantly to maize resistance to *S. zeamais*. Dobie (1974) and Abebe *et al.* (2009) reported significant differences among genotypes when tested against *S. zeamais*. However, there was no variation among genotypes for mortality of *S. zeamais*. Abraham and Firdissa (1991) found out in a laboratory test that adult *S. zeamais* survived for more than ten days on stored grains. These indicate that adult weevil mortality is not a good indicator for measuring resistance. Nevertheless, low adult weevil mortality gives an indication of the likelihood of high number of eggs laid by surviving adult weevils resulting in increase in number of weevils which complete development and emerge as adults.

The variations observed in the number of weevils which completed development and emerged as adults indicate the inherent ability of a particular variety to resist *S. zeamais* attack. It also revealed that response of the genotypes to *S. zeamais* is genotype dependent. Dobie (1986) reported that the quantity and quality of nutrient constituents had influence on the fecundity of the females and weevils which complete development and emerge as adults. Thus, weevil development and emergence is faster on a more susceptible host. Consequently, susceptible genotypes produced a higher number of F_1 progeny in a short period as compared to the resistant genotypes. This could explain why the first batch of F_1 progeny emerged early in Obaatanpa, Omankwa and Aburohemaa and consequently higher number of F_1 progeny during the first two weeks than the remaining genotypes. Higher numbers in such genotypes might also be attributed to the age group of adult *S. zeamais* used for the experiment. This is because earlier studies by Dobie (1974) indicated that the fecundity rate of weevils increase from week one reaching a peak at week three and thereafter decline.

The variations found in MDP indicate that the development of this pest is influenced by the maize variety on which it feeds. Both diet and varietal differences have been found to influence developmental time and reproductive ability of *Sitophilus* species in cereals (Keba and Sori, 2013; Muzemu *et al.*, 2013). The observed MDP of *S. zeamais* on the eighteen maize genotypes are within the range that has been reported by several authors. Howe (1952) reported that the total developmental periods of *S. zeamais* ranged from 35 days to 110 days depending on the conditions during storage. In addition, the prolonged developmental time observed in the resistant and moderately resistant genotypes contributed to the reduction in *S. zeamais* population. Abebe *et al.* (2009) stated that prolongation of developmental periods reduces the number of weevil generations. A longer median developmental period slowed down the developmental stages of *S. zeamais*.

The outcome of this study showed a high degree of variation in the response of Aburohemaa which produced twenty four (24) times as many F_1 progeny as Aseda. This observation is not surprising since variation in MDP and F_1 progeny emergence were observed among the eighteen maize genotypes. This finding is in conformity to the assumption of Horber (1988) that the higher the number of F_1 progeny as well as the shorter the length of the developmental period, the more susceptible the genotypes would be. The study revealed that only Aseda was found to be resistant to *S. zeamais* based on Dobie's index of susceptibility. The study also found TZE-Y POP STR to be moderately resistant to *S. zeamais*. Furthermore Kpari-Faako, Tintim, WACCI-M-1215, WACCI-M-1594 and Wang-Dataa were regarded as moderately susceptible to *S. zeamais*. Abontem, Bihilifa, Ewul-Boyu, Sanzal-Sima, TZE-I 17, WACCI-M-1205, WACCI-M-1508 and WACCI-M-1510 were classified as being susceptible to *S. zeamais*. The remaining three varieties, namely Aburohemaa, Obaatanpa and Omankwa were categorized as highly susceptible to *S. zeamais*.

In this study, *S. zeamais* caused considerable damage to susceptible and highly susceptible genotypes than moderately resistant and resistant genotypes. Tefera *et al.* (2011) and Abraham (1991) observed that the degree of damage in storage is influenced by the number of weevils which completed development and emerged as adults for each generation period as well as the length of each life cycle and genotypes allowing more rapid emergence of adults experience more damage. Generally, seed damage increased with increasing number of weevils which completed development and emerged as adults during the assessment period. Consequently, seed of maize genotypes with high number of weevils which completed development and emerged as adults showed the most seed damage. The highest weight loss occurred in the highly susceptible genotypes whereas the lowest occurred in the resistant genotypes. However, there appeared to be exceptions to this pattern.

Howe (1965) reported that the weight loss caused by storage insect pests is influenced by several factors including the insect species, environmental conditions, length of storage time and the product itself. This is not only true for *S. zeamais* in maize but for *P. truncatus* in dried chips of plantain, cocoyam, cassava and yam (Isa *et al.*, 2012), *Callosobruchus maculatus* in cowpea (Audi *et al.*, 2011), *C. maculatus* in Bambara groundnut (Danjuma *et al.*, 2008) and *P. truncatus* and *Araecerus fasciculatus* in dried yam chips (Danjuma *et al.*, 2008).

Generally, maize genotypes with higher number of F_1 progeny and higher index of susceptibility recorded the highest weight of seed powder. Thus, those genotypes with lower number of F_1 progeny and lower index of susceptibility recorded low weight of seed powder. The degree of infestation and feeding by this pest also determine the quantity of powder produced. Feeding activity by this pest was severe in highly susceptible and susceptible genotypes resulting in the high weight of seed powder produced. The relationship between the numbers of F_1 progeny emergence with the increase in the quantity of seed powder has also been observed in many studies (Keba and Sori, 2013; Nwosu *et al.*, 2015; Suleiman *et al.*, 2015). Weight of seed powder also followed similar trend as the seed damage and susceptibility of the different maize genotypes, though there appeared to be exceptions to this pattern. The variation in seed powder weight may be caused by physical characteristics of the seeds such as size and hardness as well as nutritional composition. This could contribute to the exceptional observation to the pattern of seed powder produced in some of the maize genotypes.

Percentage germination of the eighteen maize genotypes was higher in non-infested seeds (before *S. zeamais* introduction) when compared with damaged seeds (after *S. zeamais* introduction). In damaged seeds high germination was recorded for Aseda and TZE-Y POP STR when compared to the remaining genotypes. This may be because of low number of weevils which completed development and emerged as adults from these genotypes. On the other hand, germination in Aburohemaa, Obaatanpa and Omankwa after *S. zeamais* infestation was drastically reduced because of higher number of weevils which completed development and emerged as adults from these genotypes. These genotypes with low germination indicate their susceptibility to *S. zeamais*. This confirms the observations by Keba and Sori (2013) who stated that when the number of weevils which completed development and emerged as adults were high, the embryo was totally destroyed and for that reason seed germination was inhibited. However there appeared to be exceptions to the pattern of seed germination in damaged seeds among some genotypes. Some weevil damaged seeds germinated and this might be attributed to the fact that the weevils did not damage the embryo. This could account for the better germination of Aburohemaa than Obaatanpa and Omankwa despite the higher number of F_1 progeny and greater percentage seed damage it recorded. Similar trend was observed in Ewul-Boyu, Bihilifa and WACCI-M-1205 which performed better than other genotypes even though they produced higher number of F_1 progeny compared to the other genotypes.

The results obtained from this study have indicated that there were variations in the degree of susceptibility of the maize genotypes developed from the maize improvement programme of CRI and SARI of CSIR and WACCI in Ghana. Aseda and TZE-Y POP STR which demonstrated resistance to *S. zeamais* should be promoted or incorporated into breeding programmes to help minimize seed damage, weight loss and loss of viability incurred by farmers during storage. Also, Kpari-Faako, Tintim, WACCI-M-1215, WACCI-M-1594, Wang-Dataa, Abontem, Bihilifa, Ewul-Boyu, Sanzal-Sima, TZE-I 17, WACCI-M-1205, WACCI-M-1508, WACCI-M-1510, Aburohemaa, Obaatanpa and Omankwa will require more protection in storage so as to preserve seed quality. Maize farmers in the country should dry their seeds to safe moisture contents and ensure that an equilibrium relative humidity is maintained as well as concentrate their control on the management of *S. zeamais* at the beginning of seed storage if the seed is planned to be stored beyond three months.

Resistant genotypes used in stored product insect pests' management is environmentally sound and economically justifiable option which should be promoted for the management of insect pests in stored maize, particularly for resource-poor subsistence farmers who keep grains on farm for future use as food and seed. This would provide a sustainable way of reducing postharvest losses of seeds in storage and increase net grain yield among smallholder farmers in the country.

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