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Field Application of λ-cyhalothrin 2.5 EC on Maize Cobs for the Management of *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) Infestation in the Field and Store

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Abstract Maize is a major staple cereal crop in West Africa serving as one of the sources of energy for humans and feed for livestock. The crop is highly susceptible to depredation in storage by maize weevil, *Sitophilus zeamais* (Motschulsky) but commences infestation in the field. The combinations of varietal resistance, time of harvest at commencement of yellowing of cobs, at advanced yellowing and at complete drying, and field application of λ-cyhalothrin 2.5 EC at different doses (300ml/ha, 600ml/ha and 800ml/ha) for efficient protection of maize against S*itophilus zeamais* infestation in storage was evaluated in the Niger Delta region of Nigeria for two seasons. Three local maize cultivars (Akparike, Bende and Ogbia muno) and four hybrid maize (ACR.97 TZL COMP.1-W, TZL COMP.4C2, ADV.NCRE-STR and BG 97 TZE COMP.3XL) were used. The three factors were investigated in a Randomized Complete Block Design arranged in a split plot with cultivars as the main factors, chemical application rates as the sub plot factor and harvest time as the sub-sub plot factor. The study was carried out at the Faculty of Agriculture, University of Port Harcourt, Nigeria located in the Niger Delta Region. There were significant differences ($P \geq 0.05$) in mean number of teneral adults among harvest times in all the treatments; more maize weevils emerged in maize cultivars harvested late with a range of 13.19 observed in maize treated with λ-cyhalothrin 2.5 EC at 800ml/ha (TRT 3) to 22.81 in maize treated with λ-cyhalothrin 2.5 EC at 300ml/ha (TRT 1). Mean grain weight decreased with increase in time of harvest of the cobs. On average, the number of teneral adults that emerged from each maize variety treated with different doses of insecticide and harvested at different times increased as harvesting time increased but decreased with increase in concentration of insecticide. Overall, the susceptibility index increased with delay in harvest time and decreasing dosage of insecticide. Combining early harvest, application of λ-cyhalothrin and resistant variety could be an appropriate tactic to effectively manage *S. zeamais* infestation in the storage in the Niger Delta agro-ecological zone.

Keywords λ-cyhalothrin 2.5 EC, Varietal Resistance, *Sitophilus Zeamais*, Harvest time Hybrid and Teneral Adult

1. Introduction

Maize is one of the most important cereal crops grown on about 3.8 million ha in West Africa and Nigeria produces about 1.5 million metric tons annually from approximately 2 million ha of land[1]. It is well known for its food, feed value and as raw materials for many industrial products for breweries and pharmaceutical companies[2] and holds considerable promise as a weapon against poverty and food crises in the West African sub-region[3]. The major constraint to utilization of maize in the tropics and subtropics is the attack by maize weevil (*Sitophilus zeamais*)[4]. *S. zeamais* belongs to the family Curculionidae in the order Coleoptera and is a principal post-harvest pest and infestation commences in the field as soon as maize cobs begin to turn yellow[5]. Adult weevils and larvae feed on undamaged grains and frequently cause severe powdering, rendering the product unfit for human consumption[6].

The annual losses of grains due to weevils are estimated at an average of 25 to 40 % after 6 months of storage[7, 8] and depending on the crop variety, it can reach 50 %[9]. Enobakhare and Law-Ogbomo[10] and Lale and Kartay[11] have shown from their studies that some cultivars of maize were relatively resistant to *S. zeamais* attack. In addition, harvest time modification has also been shown to be an effective strategy for reducing field-infestation of crop produce by field-to-store insect pests[12]. In Africa

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harvested maize is usually left in the field for further drying and this undue delay in harvesting increases infestation rate by pests[13]. Semple *et al.*[14] concurred that maize more than any other cereal, is prone to field infestation by field-to-store pests and it is heavily attacked when standing in the field at the early stage of ripening by *S. zeamais* which may complete one or even two life cycles before harvest. Protection of stored produce by judicious application of insecticides in conjunction with the use of improved warehouse sanitation and other physical methods, host–plant resistance and biological methods invariably remain a vital factor in reducing losses during storage[15]. In this study therefore, the combination of varietal resistance with application of λ-cyhalothrin 2.5 EC directly on maize cobs with time of harvest was assessed as a possible strategy for the management of *S. zeamais* infestation in storage.

2. Materials and Methods

The experiment was conducted at the Teaching and Research Farm of the Faculty of Agriculture, University of Port Harcourt located at latitude 4.54°N and longitude 6.55°E with an elevation of approximately 20 m above sea level. Mean annual rainfall is variable and ranges from 2000 mm to 2680 mm. Annually, the mean monthly maximum temperature ranges from 28℃ to 33℃ while the mean monthly minimum temperature ranges from 20℃ to 23℃.

2.1. Experimental Procedures

Seven maize cultivars comprising four hybrids (ACR.97 TZL COMP.1-W, TZL COMP.4C2, ADV.NCRE-STR and BG 97 TZE COMP.3XL) developed by the International Institute of Tropical Agriculture, Ibadan, Nigeria obtained from their germplasm and three local cultivars (Akparike, Bende and Ogbia muno) obtained from the open markets in Elibrada Emuoha, Rivers State, Nigeria were sown on 17 October in 2008 and 2009 cropping seasons and sprayed with λ-cyhalothrin 2.5 EC at three levels of 300ml/ha (TRT 1), 600ml/ha(TRT 2) and 800ml/ha(TRT 3) and harvested at different times with the cultivars as the main factors, chemical application rates as the sub plot factor and harvest time as the sub-sub plot factor[16]. Each plot measured 3 m by 6.6 m. The experiment was laid out in a strip plot design in which the treatments were replicated three times. Each plot was sown with double 10 rows of each maize variety at a depth of 2-3 cm by placing 3-4 seeds/hole and the plants were thinned after 2 weeks to two plants per stand. Spacing between rows and plants were 0.75 and 0.3 m, respectively, and distance between treatments and replicates was 1.5 m. Fertilizer was applied 3 weeks after planting (WAP) and 6 WAP to give 60 kgN (119 g N/plot) and 60 kgP_2O_5 ha^{-1} (119 gP_2O_5/plot) as recommended for the area in two splits[17]. The fields were kept weed-free by hand weeding.

2.2. Harvest Time

Mature cobs were harvested at three different stages[at the commencement of yellowing (Harvest 1; HVT1), at advanced yellowing (Harvest 2; HVT2) and at complete drying (Harvest 3; HVT3)] to evaluate the effectiveness of the combination of the various techniques in mitigating the introduction of *S. zeamais* into the store. The cobs were left to dry for 35 days under an open shade with each harvest time kept in a cluster and kept one meter apart in order to minimize cross infestation. After drying, each cob was shelled by hand and the grains collected on a piece of white cloth.

2.3. Number of Teneral *S. Zeamais* Adults

Twenty grammes were weighed from each lot using a sensitive Mettler balance (Model A & D FX-6000), placed in a 1-L Kilner jars and left undisturbed under laboratory conditions (25-30℃ and 70-90% r.h)[18]. Record of the number of adults that emerged was taken daily by emptying the content of each jar carefully onto a white paper and adult insects counted and removed to determine their daily emergence pattern. The content of each jar was carefully placed back into the jar and the jar kept in its original position.

2.4. Moisture Content Determination

The percent moisture content was calculated as weight of moisture/weight of wet sample x 100[19].

Thus: $Mw = \frac{Wm}{Wo} \times 100\%$

Where Wm=water weight in grain at Mw
Wo= total grain weight at Mw
Since Wo=Wm+Wd
Where: Wd=dry matter weight at Mw moisture content

Therefore $Mw = \frac{Wm}{(Wm + Wd)} \times 100\%$

2.5. Grain Weight Loss

Grain weight loss was determined as described by[20]:

$$\%\text{weight loss} = \frac{[UaN - (U + D)]}{UaN} \times 100$$

Where U= weight of undamaged fraction (the seeds in the sample that were not damaged) in a sample
N=total number of grains in a sample
Ua=average weight of one undamaged kernel (kernels without weevil emergence hole)
D= weight of damaged fraction in a sample

This was confirmed by the modified gravimetric method of[21] by counting damaged grains and weighing the final samples using the formula:

$$\%\text{weight loss} = \frac{Pnd - Pfa}{Pnd}$$

Where: Pnd = weight of non damaged kernels
Pfa = final weight of sample

2.6. Susceptibility Index

Susceptibility index of[22] was determined for each maize variety or cultivar.

$$SI = \frac{LogY}{T} \times 100$$

Where: SI= Susceptibility index
Log Y= log number of F_1 emerged adults
T=Mean developmental periods (days)

2.7. Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) using the Statistical software package SAS 2000 version and according to the procedures reported by[23].

3. Results

Table 1 shows the adult progeny (F_1) of *S. zeamais* that emerged in the different maize seeds treated in the field at different doses of λ-cyhalothrin 2.5 EC and harvested at different times. There were significant differences ($P \leq 0.05$) in the mean number of teneral adults that emerged in both years among harvest times in all the treatments. More weevils emerged in maize cultivars harvested latest (HVT 3; where the cobs were allowed to dry completely on the field) with a range of 13.19 observed in TRT 3 to 22.81 in TRT 1. The least number of maize weevils were recorded in maize variety harvested early (HVT 1 where the maize cobs were harvested at the point where they just turned yellow) with a range of 7.57 observed in TRT 3 to 12.86 in the maize cultivars in the field treated with λ-cyhalothrin 2.5 EC at 300ml/ha (TRT 1). Progeny number with respect to dose of chemical applied was in the following order 300 ml/ha (TRT 1) > 600 ml/ha (TRT 2) > 800 ml/ha (TRT 3).

Table 2 shows that adult emergence was higher in the local varieties Ogbia muno and Akparike. The improved varieties TZL COMP.4C2, BG97 TZE COMP.3XL and ADV.NCRE-STR had the least number of emerged maize weevils. The cobs of maize treated with λ-cyhalothrin 2.5 EC at 800ml/ha (TRT 3), a rate above the recommended dosage, and harvested just as the cobs began to turn yellow (HVT 1) were significantly less infested with adult maize weevils than those treated with the same concentration of insecticide but harvested when the cobs were completely dry (HVT 3) in the field. On the whole, the number of teneral adults that emerged from each maize variety treated with different doses of insecticide and harvested at different times increased as harvesting time increased but decreased with increase in concentration of insecticide. It also shows that local cultivars of maize supported more adult weevils than the improved varieties (Table 3).

In 2009, the result shows that there were significant differences among the harvest periods and application rate of the λ-cyhalothrin 2.5 EC. There were no consistencies in grain weight loss in the harvest periods; however, HVT 1 had higher weight loss. Although application of λ-cyhalothrin at 300ml/ha had the highest weight loss, overall, grain weight loss decreased with increase in the concentration level of insecticide (Table 4).

Table 1. Mean number of adult *S. zeamais* that emerged at different harvest times under different doses of Attacke 2.5 EC (Lambdacyhalothrin 2.5 EC) chemical applied on maize cobs

Harvest time/treatment	300 ml/ha (TRT1)	600 ml/ha (TRT2)	800 ml/ha (TRT3)
	2008		
HVT1	12.86	8.43	7.57
HVT2	17.62	12.05	9.33
HVT3	22.81	15.81	13.19
	2009		
HVT1	14.19	9.57	8.00
HVT2	23.14	12.76	10.43
HVT3	26.81	20.14	17.76

LSD **(P≥0.05) 1.69 (2008); 4.21 (2009)** = harvest
1.12(2008); 1.59 (2009) = treatment.

Table 2. Teneral adult *S. zeamais* emerged in different maize varieties treated with Attacke 2.5 EC (λ-cyhalothrin 2.5 EC) as a management technique against infestation by *S. zeamais*

Variety	Field intervention techniques λ-cyhalothrin 2.5 EC	
	2008 cropping season	**2009 cropping season**
ACR.97 TZL COMP.1-W	11.33[d]	16.00[c]
ADV.NCRE-STR	13.00[c]	12.78[d]
Akparike	15.00[b]	19.81[b]
Bende	14.93[c]	18.63[b]
BG 97 TZE COMP.3XL	11.26[d]	12.89[d]
Ogbia muno	18.86[a]	21.15[a]
TZL COMP.4C2	8.93[e]	9.81[e]
SED	0.64	0.71
SNK (P≥0.05)	1.27	1.40

Table 3. Teneral adult *S. zeamais* emerged in different maize varieties under different harvest times and doses of Attacke 2.5 EC (λ-cyhalothrin 2.5 EC) chemical applied on maize cobs as a management technique against infestation by *S. zeamais*

	Treatment combination 2008 cropping season								
	Treatment 1 (300ml/ha)			Treatment 2 (600ml/ha)			Treatment 3 (800ml/ha)		
Variety	TRT1HVT1	TRT1HVT2	TRT1HVT3	TRT2HVT1	TRT2HVT2	TRT2HVT3	TRT3HVT1	TRT3HVT2	TRT3HVT3
ACR.97 TZL COMP.1-W	8.67c	12.33d	20.00cd	7.67b	9.33c	15.67b	6.33c	7.33cd	14.67b
ADV.NCRE-STR	13.00b	20.67bc	23.67b	7.33b	13.00b	12.67de	7.00bc	9.33b-d	10.33bc
AKPARIKE	17.67a	18.00c	25.00b	11.33a	12.67b	17.67bc	8.67abc	10.00abc	14.00b
BENDE	13.00b	22.00b	23.33bc	7.33b	17.67a	18.00ab	7.33abc	13.33a	12.33bc
BG 97 TZE COMP.3XL	12.00b	13.00d	18.67de	8.00ab	7.33c	14.67cd	7.33abc	8.33b-d	12.00bc
OGBIA MUNO	18.00a	26.33a	33.00a	11.33a	17.33a	21.00a	10.67a	10.67a-c	19.33a
TZL COMP.4C2	7.67c	11.00d	16.00e	6.00b	7.00c	11.00e	5.67c	6.33d	9.67c
2009 cropping season									
ACR.97 TZL COMP.1-W	14.00bc	21.67bc	26.00c	11.33a-c	14.33a	21.67b	9.33a	10.33a-c	15.33b
ADV.NCRE-STR	12.33c	21.33bc	25.00c	7.33bc	9.67b	13.33c	7.00a	8.00c	11.00c
AKPARIKE	17.00ab	30.00a	32.00ab	11.67a	17.67a	25.00b	8.67a	13.67a	22.67a
BENDE	18.67a	24.00b	30.67b	10.67a-c	15.67a	25.00b	9.33a	12.33ab	21.33a
BG 97 TZE COMP.3XL	12.00c	19.33c	20.00d	7.67a-c	9.33b	15.00c	6.33a	9.33bc	17.00b
OGBIA MUNO	17.67a	34.00a	35.67a	11.67a	15.67a	29.33a	9.00a	12.00ab	25.33a
TZL COMP.4C2	7.67d	11.67d	18.33d	6.67c	7.00b	11.67c	6.33a	7.33c	11.67c

Means with the same letters in the same column are not significantly ($P \leq 0.05$) different by Student-Newman-Keul test

Table 4. Mean weight loss (%) of grains due to *S. zeamais* infestation at different harvest times under different doses of Attacke 2.5 EC (λ-cyhalothrin 2.5 EC) applied on maize as a management technique against *S. zeamais*

Harvest time/treatment	300 ml/ha (TRT1)	600 ml/ha (TRT2)	800 ml/ha (TRT3)
	2008		
HVT1	1.75	1.64	1.73
HVT2	1.65	1.33	1.51
HVT3	1.84	1.43	1.31
	2009		
HVT1	2.48	2.51	2.61
HVT2	1.82	1.74	1.51
HVT3	2.24	1.89	2.12

LSD ($P \geq 0.05$) 2.27 (2008); 1.24 (2009) = harvest
0.86 (2008); 0.47 (2009) = treatment.

Table 5. Weight loss of maize grains due to *S. zeamais* infestation in different varieties treated with Attacke 2.5 EC (λ-cyhalothrin 2.5 EC) and harvested at different times as a management technique against *S. zeamais*

Variety	Field intervention technique Application of (λ-cyhalothrin 2.5 EC)	
	2008 cropping season	**2009 cropping season**
ACR.97 TZL COMP.1-W	1.66[b]	2.45[a]
ADV.NCRE-STR	1.77[b]	2.29[a]
Akparike	1.25[b]	2.14[a]
Bende	1.52[b]	2.57[a]
BG 97 TZE COMP.3XL	2.37[a]	2.22[a]
Ogbia muno	1.26[b]	2.32[a]
TZL COMP.4C2	1.20[b]	0.71[b]

Means with the same letters in the same column are not significantly (P≤0.05) different by Student-Newman-Keul test

Table 6. Mean weight loss (%) of maize grains due to *S. zeamais* infestation in different varieties under different harvest time and doses of Attacke 2.5 EC (λ-cyhalothrin 2.5 EC) applied on maize cobs as a management technique

Treatment combination (2008 cropping season)									
	Treatment 1 (30ml/ha)			Treatment 2 (600ml/ha)			Treatment 3 (800ml/ha)		
Variety	TRT1HVT1	TRT1HVT2	TRT1HVT3	TRT2HVT1	TRT2HVT2	TRT2HVT3	TRT3HVT1	TRT3HVT2	TRT3HVT3
ACR.97 TZL COMP.1-W	3.19a	1.49a	1.47ab	1.71a	1.28a	0.93b	2.63a	1.28ab	0.96a
ADV.NCRE-STR	1.90a	2.22a	2.29ab	1.95a	2.07a	1.34ab	1.81a	1.08ab	1.30a
AKPARIKE	1.25a	1.11a	1.23ab	1.61a	1.50a	0.94b	1.44a	1.25ab	0.91a
BENDE	1.64a	1.37a	3.03a	1.64a	1.02a	1.14ab	1.37a	1.52ab	0.92a
BG 97 TZE COMP.3XL	1.54a	3.20a	1.13ab	2.28a	1.37a	3.62a	1.56a	3.70a	2.89a
OGBIA MUNO	1.45a	1.14a	0.75b	1.02a	1.33a	1.23ab	2.52a	0.84b	1.09a
TZL COMP.4C2	1.26a	1.01a	2.94ab	1.27a	0.74a	0.82b	0.80a	0.87b	1.11a
2009 cropping season									
ACR.97 TZL COMP.1-W	3.33a	2.14a	2.87a	3.41ab	1.50ab	1.74ab	3.34a	1.66a	2.10ab
ADV.NCRE-STR	2.59a	1.45ab	2.43a	2.85ab	2.23a	1.81ab	2.77a	1.71a	2.81a
AKPARIKE	3.02a	1.75ab	1.94a	2.59ab	1.35ab	1.83ab	3.31a	1.34a	2.09ab
BENDE	2.96a	2.45a	3.07a	3.49a	2.66a	1.78ab	2.92a	1.49a	2.31a
BG 97 TZE COMP.3XL	1.93ab	2.06a	2.22a	2.12b	2.12a	2.92a	1.94b	2.01a	2.65a
OGBIA MUNO	2.66a	2.24a	2.54a	2.45ab	1.56ab	2.35a	3.33a	1.81a	1.94ab
TZL COMP.4C2	0.84b	0.65b	0.60b	0.64c	0.72b	0.83b	0.67c	0.55b	0.93b
Means with the same letters in the same column are not significantly (P≤0.05) different by Student-Newman-Keul test									

Table 7. Index of susceptibility of different maize varieties to *S. zeamais* infestation under different field treatment and Store intervention techniques

Variety	TRT1			TRT2			TRT3			TRT1			TRT 2			TRT 3		
	2008 Field Intervention									2009 Field intervention								
	HVT1	HVT2	HVT3	HVT1	HVT2	HVT3	HVT1	HVT2	HVT3	HVT1	HVT2	HVT3	HVT1	HVT2	HVT3	HVT1	HVT2	HVT3
ACR.97 TZL COMP.1-W	5.21	6.06	7.23	4.91	5.39	6.64	4.45	4.81	6.48	6.37	7.42	7.86	5.86	6.42	7.42	5.39	5.63	6.59
BG 97 TZE COMP.3XL	6.00	6.19	7.06	5.02	4.81	6.48	4.81	5.12	6.00	6.00	7.15	7.22	4.91	5.38	6.53	4.45	5.39	6.84
Bende	6.19	7.46	7.60	4.81	6.93	6.97	4.81	6.25	6.05	7.06	7.67	8.26	5.71	6.63	7.77	5.39	6.06	7.38
Akparike	6.93	6.97	7.77	5.86	6.13	6.93	5.21	5.56	6.37	6.84	8.21	8.36	5.93	6.93	7.76	5.21	6.31	7.53
Ogbia Muno	6.97	7.89	8.44	5.86	6.88	7.35	5.71	5.71	7.15	6.93	8.51	8.62	5.93	6.63	8.15	5.30	5.00	7.80
TZL COMP. 1SYN STR-Y	4.91	5.79	6.69	4.32	4.69	5.79	4.19	4.45	5.47	4.91	5.93	7.02	4.58	4.69	5.93	4.45	4.81	5.39
ADV.NCRE-STR	6.19	7.37	7.63	4.31	6.13	6.13	4.69	5.39	5.63	6.06	7.38	7.77	4.81	5.47	6.25	4.69	5.02	5.79

Table 8. Grain moisture content according to treatment combinations showing initial and final values for 2008 and 2009 cropping seasons

	2008 Moisture content (%)																	
	TRT1						TRT2						TRT 3					
	HVT1		HVT 2		HVT3		HVT1		HVT 2		HVT3		HVT1		HVT 2		HVT3	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
ACR.97 TZL COMP.1-W	13.92	10.06	13.97	10.42	13.80	10.24	13.21	9.06	12.07	10.02	11.10	9.14	12.22	10.06	12.07	9.26	11.09	9.41
BG 97 TZE COMP.3XL	13.61	10.02	13.92	10.73	13.62	10.11	12.61	9.03	10.90	9.37	11.66	9.17	11.69	9.32	12.86	9.35	12.29	9.14
Bende	15.38	12.61	14.31	13.73	15.01	10.32	13.31	11.01	12.11	11.32	13.09	9.21	13.31	10.18	12.10	10.31	13.05	9.21
Akparike	14.73	11.76	14.02	12.92	14.97	12.76	13.39	10.86	12.12	10.92	13.57	11.06	12.35	10.06	12.21	10.21	12.07	11.64
Ogbia Muno	15.21	12.92	14.35	13.02	14.49	13.00	13.26	11.02	13.31	11.12	13.29	10.13	13.15	10.21	13.30	11.21	13.09	11.01
TZL COMP.1SYN STR-Y	14.03	11.01	13.01	11.26	13.03	12.00	11.03	9.21	12.14	10.02	11.33	9.90	12.34	10.10	11.21	9.68	11.02	9.70
ADV. NCRE-STR	14.61	10.63	14.01	11.04	13.91	11.01	11.67	9.98	12.01	10.04	11.71	9.51	12.15	9.39	12.01	10.41	12.10	10.12
	2009 Moisture content (%)																	
ACR.97 TZL COMP.1-W	12.82	9.61	12.09	10.21	12.10	9.42	12.91	9.21	11.27	9.12	11.12	9.16	11.12	9.06	12.17	9.23	10.03	9.31
BG 97 TZE COMP.3XL	12.51	9.21	11.23	10.03	12.29	10.01	11.64	9.32	10.19	9.34	11.21	9.18	10.16	9.21	12.26	9.30	11.21	9.54
Bende	14.28	11.15	13.14	12.31	13.15	10.42	12.33	11.14	12.41	10.12	12.24	9.01	12.15	10.12	12.11	10.71	12.07	9.26
Akparike	13.53	10.62	13.28	12.21	13.78	11.61	12.30	10.62	12.32	10.32	12.17	10.26	12.25	10.16	11.91	10.61	11.06	10.64
Ogbia Muno	14.14	11.23	13.31	12.24	13.91	12.02	12.21	11.02	12.43	10.12	12.19	10.21	12.55	10.23	12.40	11.01	12.19	9.01
TZL COMP.1SYN STR-Y	13.32	10.12	12.16	11.61	12.31	11.40	11.34	9.23	11.14	9.12	10.03	9.91	10.34	9.10	10.11	9.63	10.32	9.07
ADV. NCRE-STR	13.52	9.31	13.14	11.41	12.14	10.01	11.70	9.08	11.31	9.24	10.11	9.52	11.74	9.13	11.21	9.41	11.11	9.32

The grain weight loss in each maize cultivar attributed to the maize weevil in 2008 cropping season was significantly higher in a hybrid variety BG 97 TZE COMP.3Xl and the least in TZL COMP.4C2 in both cropping seasons (Table 5).

in 2008, BG 97 TZE COMP.3Xl variety treated with λ-cyhalothrin 2.5 EC at 800ml/ha and harvested when the cobs reached an advanced stage of yellowing (HVT 2) suffered a significantly higher weight loss followed by same variety in a treatment combination (TRT3 and HVT3). In 2009 however, Bende (TRT2 and HVT1) followed by Akparike and Ogbia muno (TRT1 and HVT1; TRT3 and HVT1) (Table 6).

Dobie's index of susceptibility for maize treated in the field withλ-cyhalothrin 2.5 EC at different doses and varying planting dates in 2008 ranged from 4.19 in TZL Comp.1SYN STR-Y (TRT 3; HVT 1) to 8.66 in Bende (TRT 1; HVT 3). Overall, the susceptibility index increased with delay in both harvest time and increasing dosage of insecticide in the order H1 < H2 < H3 and TRT1 < TRT 2 < TRT3, respectively (Table 7). Similar results were obtained when the experiment was repeated in 2009.

Table 8 shows the initial and final values of gain moisture content according to treatment combinations for the 2008 and 2009 cropping seasons. The initial moisture content of maize grains treated with λ-cyhalothrin 2.5 EC in the field was highest (15.38%) in a local variety Bende and lowest (10.03%) in TZL COMP.1SYN STR-Y harvested when the cobs just reached yellowing stage (HVT 1) and when cobs were fully dried in the field (HVT 3) in 2008 and 2009 cropping seasons respectively. The final moisture content of the grains was highest (13.73%) in Bende and lowest (9.01%) in Ogbia muno harvested when the cobs were allowed to reach an advanced stage of yellowing (HVT 2) and when they were allowed to reached their full drying potentials in the field (HVT 3) in 2008 and 2009 respectively.

4. Discussion

4.1. Harvest Time as a Suitable Tool in Curbing the Introduction of *S. Zeamais* to Store and a Practical Management Technique in Maize Production

The length of time that maize and other cereals are left in the field before harvest plays a great role in determining the insect pest load especially in the case of field-to-store pests. The result that late harvest of maize, where the cobs were allowed to dry completely in the field (HVT 3), supported higher number of adult weevils confirms the work of[12] on *Callosobruchus maculatus* in cowpea who reported that cowpea seeds harvested very late supported more storage bruchids than cowpeas harvested early. It is evident from the result that late harvesting of maize would only increase the number of both teneral adults and/or immature stages that will further develop and reproduce in store. This assertion concurs with the findings of[24] that the higher the initial infestation at harvest the higher the subsequent infestation in the store and that the presence of adult maize weevil on stored ears after 30 days of storage is an indication that the maize weevils had mated and reproduced in the field on the ears before harvest. Early harvest might, therefore, offer the maize an opportunity to escape invasion and colonization by the weevils in the field as[25] stated in his work that early harvest of maize would probably reduce damage and losses attributed to insect pests. Staggered harvesting of maize as indicated in study will encourage an escape from weevil infestation as suggested by[26] for cowpea harvest as a mitigating measure against bruchids in Nigeria. However, harvesting as soon as the maize attains physiological maturity would mean repeated harvest and increased labour costs, but these would most probably be offset by the increased value of sound maize saved from infestation by weevils. This agrees with[27] who observed a steady increase of 33 % in maize production for a period of about 5 years in Brazil due to adoption of good harvest practices.

4.2. Field Application of Insecticide as a Strategy for Mitigating *S. Zeamais* Infestation and Ensuring Healthy Maize Grains in Store

The direct application of insecticide to the maize cobs in the field at an appropriate dosage served as an appropriate means of breaking the cycle of *S. zeamais* from building up in the store and also reduces the unnecessary injection of chemicals into farm produce such as maize. This finding concurs with[28,29] who reported that pre-harvest sprays of neem seed products and pirimiphos-methyl with harvest time modification of cowpea resulted in a significant reduction of bruchids in store. Bosque-Perez and Buddenhagen[30] reported that maize weevil is a serious field-to-store pest of maize in the tropics; the insect infests the ripening cob of maize before harvest and multiplies further during storage[31] and infestation builds up in store, a function of the number of eggs laid and developing stages initiated in the field[32]. Controlling the build-up of weevil number through application of chemical directly on the maize cobs or by modifying the harvest time to enhance escape and the use of resistant variety as reported in this study can significantly reduce the pest load to be encountered in the store. Similar observations were made by[33] by pre-harvest application of some synthetic insecticides in reducing field infestation of maize by *Sitotroga cerealella* (Olivier) and *S. oryzae* (L.); Ajayi and Lale[34] reported on pre-oviposition application of spice oils in stored bambaranut seeds against *C. maculatus* and[28] reported on pre-harvest application of spice oils and insecticides on cowpea and/or bambaranuts against bruchid infestation.

The result of the study in both years indicating TZLComp.4C2, ACR97TZL Comp.1-W and to some extent ADV.NCRE-STR as resistant varieties over the local varieties commonly cultivated in the study area suggests that these improved varieties possess some degrees of resistance as they supported fewer adult weevils in all the treatment combinations. The reasons for the poor performance of *S. zeamais* on these varieties could be attributed partly to what[35] reported as the presence of the secondary metabolites in them which were probably lacking in the local cultivars which improve defense against microbial attack and herbivore predation. Such metabolites have chronic effect rather than acute toxicity on insects. Therefore, the insects may attempt to breed on the field but will fail to maximize the substrates and will consequently affect the overall progeny development. Other possible reasons may be high kernel hardness and other seed coat characteristics exhibited by the improved varieties as deduced by Adesuyi[36] who reported that the presence of toxic alkaloids or amino acids in some products affects their susceptibility to pest infestation. Certain seed coat characteristics discourage oviposition and inhibit digestive enzyme. Throne *et al*.[37] in their work on resistance of tripsacorn to *S. zeamais* and *Oryzaephilus surinamensis* found out that whole tripsacorn kernels were immune to attack by maize weevils and suggested that such immunity may have been conferred by the hardness of the fruitcase which discouraged the weevils from laying eggs; immunity was also partly due to possible repellent chemicals in the fruitcase.

The result of the study also showed lack of consistency among the varieties with respect to all the parameters tested except for TZLComp.4C2. This lack of reproducibility in results was also reported by[16] that millet varieties identified to be resistant did not show this response for all parameters and[38] reported some degree of variation and inconsistency in levels of infestation by *Coniesta ignefusalis* in millet and sorghum grown under natural field conditions. Researchers have attributed such variations partly to the differences in maturity periods as well as to differences in stem and plant characteristics of the different millet cultivars studied and also by[39,16].

The high weevil numbers recorded in some of the hybrids-Bg 97 TZE Comp.3XL, ACR 97 TZL Comp.1-W and ADV.NCR-STR relative to number of weevils recorded in the local maize cultivars which suffered virtually the same levels of damage in some treatments may reduce the readiness of local farmers to adopt these new cultivars of maize in their cropping system. However, the levels of susceptibility observed in the local cultivars commonly cultivated in the study area imply that farmers must control grain weevils both in the field and in the store to guarantee good maize storage in this agroecology. Lale and Makoshi[40] opined that use of resistant variety for the management of storage pests in tropical agriculture has advantages: it is easy to use, economical, safe and effective.

The absence of a specific trend in response to concentrations of insecticide used in the field in relation to grain weight loss could mean that the loss in moisture content of the grains might have played a significant role. This was the case when harvest was made at the onset of maturity the grains had higher moisture content, and the implication therefore, is that moisture levels need to be reduced before grains are stored otherwise it will encourage weevil activity. As reported by[12] weight loss in the cowpea was largely due to moisture loss and to the feeding activity of the bruchids. Caneppele *et al*.[41] also reported a positive correlation between percentage moisture content and the number of insects and weight loss.

Puzzi[42] suggested that the increase in moisture with increase infestation may be due to the galleries that expose the endosperm allowing moisture absorption by hygroscopic carbohydrates. It is a known fact that low moisture level is the key to safe storage of farm produce and biological activity occurs only when it is present at a certain critical level; the elevation of moisture content and temperature of the grain mass is generally a result of the metabolic activity of insects[42]. High moisture content increases activities of biotic agents, thus increasing loss in storage[19]. Although early harvest encourages retention of high moisture content of the grains, early harvest is still a reasonable proposition because infestation levels are low at this point[43,8].

The ability of maize grains to support large weevil population and yet suffer insignificant weight loss could therefore be used in judging its quality of resistance or otherwise[44]. Olubayo and Port[12] recorded an average of 17.1% moisture content on cowpea harvested early, 13.7% for seeds harvested at the recommended time, 13.5% for late harvested cowpea seeds and 13.2 % for the seeds harvested very late.

The high SI value obtained in the study however concurs with the result of[45] who obtained 14 on susceptible varieties and[46] who in a similar study recorded an index of 11.1 on a most susceptible cultivar and an index of 7.9 as the lowest. Ashamo[44] recorded a suitability index of less than 5 which he attributed to the fact that the cultivars used were improved and all of them showed relative resistance to *S. zeamais* infestation with the lowest value being 3.23. Siwale *et al*.[47] gave some explanation as to why he obtained a lower value (0.77) as partly due to the resistant variety used and partly due to moisture content which was not the case in this study where susceptible cultivars were equally used in order to determine the effectiveness of the mitigating measure being tested. Ashamo[44] reported that a relatively lower SI index could partly be attributed to the grain hardness which is an estimate of the percentage of corneous endosperm in the grain and that it is most likely to be the most important factor in governing its susceptibility to insect attack[47]. Leuschner *et al*.[48] also observed a distribution of larger numbers of *S. oryzae* progenies among genotypes of pearl millet (*Pennisetum glaucum* L.) that had higher proportion of soft endosperm.

5. Conclusions

The study has shown that the local cultivars of maize supported higher populations of *S. zeamais* progeny than the improved varieties invested with thicker testae and harder kernels. Akparike, a local susceptible cultivar, had a thick testa, indicating that physical properties alone do not account for the observed resistance in the improved varieties.

The results have also shown that the length of time the maize is left on the field after physiological maturity plays significantly influences the intensity of infestation of field-to-store pests: maize harvested late when the cobs were completely dry supported the highest number of weevils and suffered greater grain weight loss.

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