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Integration of Pyrethroid Insecticides Combined With Host Plant Resistance in the Management of the Larger Grain Borer, *Prostephanus Truncatus* (Horn) (Coleoptera: Bostrichidae), On Stored Maize, *Zea Mays* L.

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Abstract
Eight maize varieties from International Institute for Tropical Agriculture (IITA) Ibadan and two from local market were analyzed for their chemical and physical compositions. Thereafter,
They were evaluated in no-choice test at 29-36ºC and 51-85% R.H against four populations of adult *Prostepanus. truncatus* originating from three geographical locations in Nigeria and one from Ghana. The varieties exhibited varying degrees of susceptibility and loss to *P. truncatus* attack with Yellow Mangu Jos recording the largest insect population (12.78±1.2) and suffered highest weight loss (8.73±3.1%) and damage (17.58±3.1%). The maize varieties differed in their chemical and physical parameters and their responses to *P. truncatus* attack were significantly different ($P < 0.05$). There were positive and significant correlations between total adult population and carbohydrate level ($r = 0.506$, $P < 0.05$), weight loss and carbohydrate ($r = 0.503$, $P < 0.05$). Results obtained from the treatment of susceptible varieties with the pyrethroid demonstrate the attractive potentials of Bifenthrin and Deltamethrin against the larger grain borer.

Keywords: Susceptibility, Integration, *Prostephanus truncatus*, Deltamethrin, Bifenthrin, Plant

1. Introduction
The Larger Grain Borer (LGB), *Prostephanus truncatus* (Horn) (Coleoptera; Bostrichidae) poses the most serious threat to stored maize and dried cassava in the tropics [1, 2]. The insect was accidentally introduced from Central America to Africa between late 1970s and early 1980 [3].
In West Africa, it was reported in Togo in 1984 [4], Ghana [5], Nigeria [6, 7] and more than 16 African countries have been affected so far [8].
In fermented cassava root, 75% weight loss was reported within 4 months [9]. The pest has been reported to occur in natural wooded habitats remote from maize and cassava cultivation [10]. Hence, it remains a major threat to food security and building industry in Nigeria.
Attempts to control this pest have relied heavily on the use of synthetic pesticides [11]. resulting in several problems including environmental pollution among others. However, science has recognized the need to reduce pesticide usage to achieve a cleaner environment, but this would certainly result in reduced agricultural production. Thus, the conflict between the goals of reduced pesticide usage and production of sufficient food and fiber for the ever increasing human populations provides a strong impetus for the development of cost-effective and ecologically friendly alternatives which are major components of integrated pest management (IPM).
Integrated Pest Management (IPM) attempts to integrate available pest control methods to achieve economical and sustainable combination for a particular local situation. Often, emphasis is placed on the use of resistant host varieties, biological control, cultural methods and other non-polluting methods. In IPM, chemical pesticides are used only when necessary, especially when they can be integrated with other control methods [12]. It is also a widely accepted fact that insecticides will continue to play an important role in suppressing severe insect populations and minimizing storage losses, provided they are properly used and integrated in pest management system.

Successful control of *P. truncatus* in shelled maize grain with pyrethroid dust formulation of permethrin and deltamethrin has been reported [13]. Therefore, selective synthetic pesticides with a low mammalian toxicity and are environmentally friendly, have the potential to be used in combination with resistant cultivars in the development of an integrated pest management system for *P. truncatus*. A basic principle of insect problems depends on several harmonious tactics. Plant resistance can serve as an excellent component tactic, because it is usually compatible with pesticides and sometimes with biological control [14]. Quite often, levels of plant resistance alone are not sufficient to avoid economic losses from insect pests. Also, insect populations are able to develop biotypes that can attack formerly resistant varieties. Hence, combining plant resistance with well-timed low dosages of insecticides sometimes can achieve adequate suppression while reducing otherwise high insecticide inputs [14]. This was the case with using resistant sweet corn (471-U6 x 81-1) and insecticides against the corn earworm in Georgia [14]. Here, the resistant cultivar plus insecticide resulted in about 93% protection, compared with 86% for an insecticide-treated susceptible cultivar and 78% for the untreated resistant cultivar.

Resistant varieties are known to affect a cumulative reduction in pest numbers compared to susceptible varieties [15]. And form a key component in any pest management programme. The basis for resistance could be biochemical or physical factors that interrupt the normal host-selection process [14]. Varietal resistance is, therefore, a potentially useful technique for the long term management of LGB.

Two control strategies each of which provides moderate levels of control when both are applied together may provide control of a pest at a level that keeps the population below a treatment threshold [16]. Host plant resistance generally considered to be compatible with other management strategies can be a key component of an integrated pest management programme [15].

Thus it is possible that combining the use of less toxic pesticides of synthetic origin with the use of resistant maize cultivars might provide a higher level of control of insect pests of stored maize than either method used alone. However, the two control strategies when used together as adjunct might result in economically acceptable levels of control.

In the light of these, the present study was conducted to investigate the possibility of using synthetic pyrethroids in addition to seed resistance as alternative control techniques, with the vision of developing an integrated pest management system for LGB in Nigeria. The pest has been chosen for the study because it is a prolific pest of both dried maize and cassava chips.

2. Materials and Methods

Study Area: The entire study was carried out from June 2010-July 2012.

The investigations on insect maize screening were conducted under ambient temperature range of 29-36ºC and relative humidity of 51-85% at the Research Laboratory, General Biology Laboratory, Nnamdi Azikiwe University Awka. The chemical composition of maize were analysed at the Department of Biochemistry, Nnamdi Azikiwe University, Awka. The grain hardness was conducted at Mechanical Engineering Laboratory, Standards Organization of Nigeria (SON), Emene Enugu.

2.1. Collection and culturing of *P. truncatus* from three geographical locations in Nigeria and a strain from Ghana:

The initial culture of *P. truncatus* adults were acquired from market infested cassava in three geographical locations of the country namely, Enugu, Benue and Ibadan, representing, South-East, North- East and South- Western geographical zones of Nigeria and a strain collected from market infested cassava from Legon, Accra, Ghana. These strains of the insect were reared on a standard maize variety, White Mangu Jos (preferred substrate) obtained from open market in Enugu. The maize was initially cold sterilized in a deep freezer at -4ºC for two weeks.

Thereafter, the maize was transferred to an oven set at 50ºC and heat sterilized for two hours to kill further any existing infestation. When cooled, 500g of the maize were measured into one-liter capacity Kilner jars and fifty adult insects were introduced into each jar. The insects were then allowed to reproduce inside transparent plastic buckets. The culture was allowed to stand under ambient conditions to obtain enough F1 progeny. The new adults that emerged were kept in separate jars according to their age until when required [17].

2.2. Experimental maize crop

Ten maize varieties including eight improved varieties namely; Oba Super I, Oba Super II, Western yellow, Acr.89- DMR-ESR-W, Acr.97- TZL Comp 4^{C}, TZESR-W, Acr.91 SUWAN-1SRC1 and BR 9928-DWR-SR identified as varieties 1-10 respectively were collected from International Institute for Tropical Agriculture (IITA), Ibadan and two local varieties; Yellow popcorn and Yellow Mangu Jos obtained from the open markets in Enugu were used for the studies. The maize samples from market were subjected to heat sterilization at 50ºC for three hours before use. This was to ensure that any existing infestation was cleared.

2.3. The synthetic chemical treatments

The pyrethroid formulations, deltamethrin (12.5g/L EC) (Deltaforce) was purchased from Agrotech Chemical Company, Ibadan and bifenthrin (10%, 62.5g WP) (Bistar) was procured from Dizengoff Chemical Company, Enugu.

Ten grams each of the ten maize varieties were weighed into wide-mouth 60cm^3 plastic vials covered with nylon netting materials to ensure ventilation. They were artificially infested with twenty unsexed, 1day- 2 weeks old F1 adults of the insects. The experiment was laid out in a completely randomized design (CRD) with each treatment including control replicated three times. Measurement of adult mortality started from the first day of introduction of the adult insects and continued for 7 days. All insects were eventually removed. However, the number of parent insects that bored inside the grains were noted (they were not removed because of the difficulty in retrieving them without damaging the eggs laid). The samples were monitored from 25th day until the emergence of the F1 adults

2.4. Highly susceptible maize variety and variety with low level of resistance admixed with the lethal dose of insecticides

Twenty grams of the highly susceptible maize (Yellow Mangu Jos) and maize with low level of resistance (Oba Super 1) were admixed with lethal dose of Deltamethrin (3.19µg/ml) and Bifenthrin (10.19µg/ml) insecticides. Subsequently, they were artificially infested with twenty untreated maize samples of the two varieties served as a control. The treatments were carried out using 60cm^3 plastic jars covered with a nylon netting material. Each treatment was repeated three times and allowed to stand on the laboratory bench at random. Mortality counts were taken 7 days after treatment. At the end of the mortality counts, the samples were left to stand to allow the eggs laid by LGB to hatch and develop into adults. Weight loss and percentage damage assessments were also taken after 3 months in storage.

3. Data collection

At the end of all experiments, all insects, both dead and moribund (those that did not respond to a gentle probes with a pin) and those alive were removed and counted. The moribund insects were counted as dead. The dust produced by the insect was sieved through a mesh of 0.25mm size and each weighed separately. Damage assessment was carried out on the treated maize varieties by sorting the grains damaged (grains with characteristic emergence holes) and undamaged categories. The percentage grain damage was calculated using the formula:

$$\%Damage = \frac{A}{B} \times 100;$$

where A = number of undamaged grains, B = total number of grains.

The percentage gain weight loss was measured as the percentage of the difference between the initial weight of the grains and their final weight as described by [18].

$$PGWL = \frac{A-(B+C)}{A} \times 100.$$

Where PGWL = Percentage gain weight loss

A= the initial weight of the sample, B= weight of damaged grains

C= weight of undamaged grains. Where A= the initial weight of the sample, B= weight of damaged grains, C= weight of undamaged grains.

Six indices were used to measure grain resistance of the ten varieties. These were % adult mortality of *P. truncatus*, % grain damage, % weight loss, weight of dust/frass produced, number of F1 emergence and population density transformed into scores 1-5 (Table 1). The five scores were determined as class interval [19]. using the formula n= 1+3.332logN, where N is total number of samples which in the present study is 10 and n is the number of groups. Therefore, n= 1+3.332log10= 1+3.332(1); n=4.332. Since n is more than 4, the group of 5 was used as the rating scale. The weighted average score was used to classify the varieties into one of four classes of resistance namely, highly resistance, low level of resistance, susceptible and highly susceptible. In addition, cluster analysis was done on the rated parameters using the Centroid Hierarchical System [20]. To separate the different classes of resistance and the result obtained was compared with that of the weighted average score.

Table 1: Rating scale for indices of parameters used in determining the resistance of 10 maize varieties to *P. truncatus.*

Score	Adult Mortality	F1 Progeny	Population density	%Weight loss	% Damage	Frass
1	80.1-100	0.0-0.9	0.0-2.9	0.0-0.9	0.0-4.0	0.08-0.09
2	60.1-80.0	2.0-2.9	3.0-5.9	1.1-3.0	4.1-8.0	0.18-0.23
3	40.1-60.0	3.0-3.9	6.0-8.9	3.1-5.0	8.1-12.0	0.32-0.37
4	20.1-40.0	4.0-4.9	9.0-11.9	5.1-7.0	12.1-16.0	0.38-0.43
5	0.0-20.0	5.0-5.9	12.0-13.9	7.1-8.0	16.1-20.0	0.44-0.49

3.1. Identification of Basis for Resistance

Chemical factors such as moisture content, protein, ash, fat, fiber, carbohydrate content and soluble phenolics of the grain and the Physical Factors such as grain hardness, grain size and seed coat thickness that could confer resistance to infestation by *P. truncatus* were investigated.

3.2. Chemical Factors

Representative samples of the ten maize varieties were milled into powder and the chemical factors (proximate compositions of the maize) determined using standard analytical methods. Percentage crude protein was determined by micro-Kjeldal method multiplied by a factor of 6.25 to determine the nitrogen content of the grain [21, 22]. The ash content and crude fiber were determined using the method by [23]. while crude fat content was determined using method by [24]. The nitrogen free extract or the carbohydrate content of the samples was determined by subtracting the sum of the ash content, protein content, crude fiber and crude fat content from 100 on dry matter basis. Thus % carbohydrate= 100- (% ash + % protein + %crude fat + %crude fiber). The soluble phenolics were determined using Colorimetric Assay based on procedures described by [25]. The absorbance was read using Ultrospec 31000 Pw UV/ visible Spectrometer

3.3. Physical Factors

The physical factors of the maize were determined for the ten maize varieties. The grain hardness was determined by the Rockwell hardness test using ESEWAY Hardness Testing Machine. Four seeds were randomly selected from each cultivar and their compression strength determined. A grain was placed on the beam at a time and the lever was rolled down gradually until the grain produced a cracking sound. The bearing ratio (strength) value was read off. The seed coat thickness and grain size were determined using digital vernier calipers. The seed coat was determined by soaking four randomly selected seeds of the ten varieties for 48 hours in order to soften the seed coat. The seed coats were peeled out using a blade. For seed size, ten seeds were randomly picked from each variety and subsequently measured using digital vernier calipers (adapted from the method by [26].

3.4. Statistical Analysis.

Count of dead insects was taken to determine mortality rate after 7 days. The data collected on insect number, damage and percentage weight loss were analyzed using simple factorial ANOVA model in SPSS version 17 for Windows statistical package [27]. and Minitab version 15 Means were separated after accessing level of significance by Multiple Comparison Test using the LSD values at ($P < 0.05$). Correlation analysis was performed on the relationship between the chemical and physical composition of maize varieties and insect infestation.

5. Results and Discussion

The present study has shown that the resistant varieties were found to confer some level of protection to maize grains against *P. truncatus* from different geographical locations. This was observed in the relatively low numbers of adults recorded, low weight loss and damaged seeds. A critical examination of the data shows that low adult mortality was recorded on Yellow Mangu Jos, (28.3%) Oba Super I (29%) and Oba Super II (29%) and highest mortality on Br.9928-DWR-SR-Y (87.7%), Acr.89-DMR- ESR-W (81.5%), Acr. 97-TZL (82.5%) and TZESR-W (67.2%) (Table 3). No dust was sieved from variety, Br.9928-DWR-SR-Y as it was not damaged by LGB. Also, A careful examination of the indices used in determining the general performance of *P. truncatus* from different locations shows there were differences between the strains of *P. truncatus* from Ghana and those from Nigeria. Comparing the strains from the three geographical locations in Nigeria, *P. truncatus* from Ibadan appears to be more damaging to the maize grains than those from Enugu and Benue. The developmental period for the Ibadan strain was relatively shorter, 30.5±0.3 days (Table 2) when compared with the other strains (35.5±0.3, 38.6±0.3 and 34.4±0.2 days for Enugu, Benue and Ghanaian strain, respectively. Also, the F1 body weight and body size of the Ibadan strain were relatively higher than those of the other strains. However, statistical analysis indicates that these observations in these strains of *P truncatus* from different geographical locations were not significantly different (P> 0.05) Out of the ten maize varieties screened for resistance to *P. truncatus*, five were rated highly resistant based on [28]. indices of susceptibility. The effectiveness of some resistant varieties in suppressing the population of *P. truncatus* was also seen on the high adult mortality recorded on the resistant varieties. The weight loss caused by *P. truncatus* in this study confirmed several reports that *P. truncatus* adults generate high losses in stored maize and cassava [29], with relatively reduced loss in shelled maize than maize in cobs [30]. Unlike in cob where weight loss as high as 34% have been observed in some East African maize cribs after only 3- 6 months storage [30], weight loss as low as 0.3% was reported in some resistant maize and up to 17.6% in the susceptible variety in the present study after 2 months storage. The present study therefore, has confirmed that some improved varieties collected from IITA used in the study were relatively resistant to *P. truncatus* damage. The varieties, BR.9928-DWR- SR, Acr.89-DMR-ESR-W and Acr.97-TZL comp 4^C were less attacked and damaged by the pest. These suggest that in these varieties conditions are less favourable for higher oviposition, larval development and survival of the adults. It is well established that the development of *P. truncatus* is affected mainly by chemical factors in the maize [31], [32], [33] and [34]. In the studies on correlation between chemical composition of the southern pea and varietal resistance, [35]. reported a positive significant correlation between concentrations of total carbohydrates in the pea. In the present study, there were positive and significant correlations between total adult population and carbohydrate level (r =0.506, P< 0.05), weight loss and carbohydrate (r = 0.503, P< 0.05). These results may suggest that the level of carbohydrate content in the maize grain could influence the damage and survival of *P. truncatus*. The observation by [36]. that *P. truncatus* responded in general to odours from starchy commodities verifies this findings. Also, the possibility of breeding by adults of *P. truncatus* was dependent on the high starch content of the wood of *Manihot esculenta* as reported by [37]. There was very low phenolic content in the susceptible Yellow Mangu Jos (365.6mg/100g) and Western Yellow (309.4mg/100g) compared with some resistant varieties including BR.9928-DWR-SR and Acr.89-DMR-ESR-W which have phenolic contents ranging from 712.5 to 796.9mg/100g. Also, there was negative association between the phenolics, protein and most indices of susceptibility. A negative relationship between protein and susceptibility in terms of F1 progeny was reported by [38]. Also, in a study to unravel the biochemical nature of resistance to *P. truncatus* and *S. zeamais*, [39]. reported strong and negative correlation between weight loss and phenolic content of maize infested by *P. truncatus*. This finding was supported further by the fact that the phenolics and plant tannins have been considered as insect growth inhibitors for several years owing to their presumed action in binding with proteins to form insoluble digestion-inhibiting complexes [40]. On the contrary, [33]. believes that the character conferring resistance comprises both the physical factors such as hardness of the endosperm, seed coat thickness and consistency. He reported that these factors exerted a considerable influence on the development of beetles and weevils on cereal cultivars. The hardness of the cereal endosperm, according to him, may interfere with the ease with which larval weevils and adults obtain nutrients in the required amount for development. In addition, [41]. and [42]. recorded reduced oviposition rate when *P. truncatus* was maintained on flinty and popcorn maize varieties. It was further explained by [42]. that this was due to the higher energy cost of tunneling the harder maize since the female had to lay eggs in blind-ending tunnels, thereby leading to reduced fecundity and consequently the population size is reduced on the harder maize variety. The popcorn maize variety in this study was rated highly resistant owing to the low number of *P. truncatus* adults, low weight loss and damage The observed high mortality of F1 generation of *P. truncatus* on the highly susceptible maize and maize variety with low level of resistance treated with Bifenthrin and Deltamethrin could be due to toxic effects of the toxicants. However, these products were effective in outright killing of the adults, but Deltamethrin showed more efficacy than Bifenthrin [43]. As pointed out by [44]. and [31], resistant varieties may improve the effectiveness of insecticides and make it possible to omit or reduce treatments, and thus escape or lessen undesirable residues or side effects. The observed low weight loss caused by the larger grain borer in control samples (untreated grains) might be as a result of fact that maize was shelled and not on cob. It has been suggested that in locations where *P. truncatus* is likely to cause significant damage to stored maize, farmers are advised to shell their uninfested cobs and admix a suitable insecticidal dust with the grain [30]. According to them, shelling facilitates the efficient admixture of the insecticides and may also reduce the extent of damage since the *P. truncatus* develops poorer on shelled grain than on maize on cob. In the present study, the shelled susceptible maize (Yellow Mangu Jos) and maize with low level of resistance (Oba Super I) admixed with Bifenthrin dust and Deltamethrin gave 100% control respectively, of adult *P. truncatus* from Ibadan with the lowest LD50 value and most susceptible strain. This was comparatively different from the control sample without insecticide where the mortality of adult beetle was 28% for Yellow Mangu Jos and 58% for Oba Super I. The cost-benefit analysis determined in this study suggests that the use of pyrethroid insecticides is truly justifiable. The study, therefore, recommends its use since the farmer could prevent up to 88.2% and 92.9% damage, respectively in both local maize and improved maize varieties by spending only 11.82 Naira on bifenthrin and 1.92 Naira on deltamethrin in treating 1kg of maize. The analysis also showed that the grains treated with insecticides would store longer and the farmer might decide to sell at higher price when the demand is high. There are also good returns on investments with minimal cost of insecticides. In the untreated control, the grains have short storage duration; farmers would be forced to sell off the grains at low price in order to avoid damage and loss of revenue due to insect attack and weight reduction in the grains. The present study demonstrated a total protection of maize with the two pyrethroid treatments causing 100% mortality of *P. truncatus* adults. This result was comparable to the control treatment where there was 29% mortality of *P. truncatus* adults on the susceptible varieties and 58% mortality of the insect on maize with low level of resistance. Comparable suppression of the *P. truncatus* F1 progeny reduced by 96.5% and 63.5% were observed between the susceptible maize and maize with low level of resistance, respectively. Also, there was dramatic reduction in percentage weight loss from 1.3% in the control sample with low level of resistance to 98.7% after treatment with insecticides. However, there was arrest of further development of the insect explained by the fact that resistant maize increased the developmental time for *P. truncatus*. Compatibility between diverse control measures like host-plant resistance and the use of insecticides is a major issue in IPM. In this study, it has been established that there is a positive synergism between insect resistant varieties and the synthetic Pyrethroids. This study therefore provides evidence that partial resistance combined with Pyrethroids may be useful in an integrated pest management of LGB. Comparative long term data from large scale experiment in stores is needed.

Table 2: Performance of *P. truncatus* in no-choice test

Geographical Zone	Mortality (%)	F_1 progeny	Population density	F_1body weight(mg)	F_1body size(mm)	Developmental Period(days)
Enugu	39.5±1.1	2.7±0.3	8.8±1.4	2.8±0.03	0.33±0.1	35.5±0.3
Ibadan	60.0±3.9	2.8±0.3	7.0±1.8	3.4±0.03	0.35±0.1	30.5±0.3
Benue	53.0±1.0	2.0±0.4	6.7±1.2	2.5±0.02	0.28±0.1	38.6±0.3
Ghana	59.0±1.3	1.5±0.3	5.6±1.1	1.4±0.02	0.23±0.06	34.4±0.2
Mean	52.88±1.8	2.25±0.3	7.03±1.4	2.53±0.03	0.32±0.09	34.75±0.27

Means of three replicates (±S.E), F= 0.025; df= 3/20; P> 0.05 (Not significant)

Table 3: Mean values of performance and grain damage by *P. truncatus* on ten maize varieties screened for resistance or susceptibility to *P. truncatus* using the susceptibility indices.

S/No	Variety	Adult Mortality (%)	F_1 progeny	Population Density	Weight loss (%)	Grain damage (%)	Frass(g)
1	Oba super I	29.0±1.1	2.7±0.6	9.8±0.6	3.2±0.4	7.4±0.7	0.2±0.03
2	Oba Super II	29.0±0.8	2.8±0.6	10.8±1.5	3.5±1.2	10.3±2.7	0.3±0.04
3	Western Yellow	37.5±1.2	3.3±0.4	8.9±1.4	4.5±1.5	7.6±1.9	0.3±0.04
4	Acr.89-DMR-ESR-W	81.5±0.6	0.9±0.1	2.9±1.0	0.3±0.0	3.1±0.2	0.03±0.03
5	Acr.97-TZL	82.5±0.6	0.9±0.1	2.7±1.0	1.6±0.6	2.6±0.8	0.03±0.01
6	TZESR- W	67.2±1.0	0.8±0.0	4.0±1.6	0.7±0.2	2.2±0.7	0.03±0.04
7	Acr.91-SUWAN-1SRC1	42.3±1.3	4.7±0.4	10.5±1.4	6.8±2.9	12.9±3.3	0.3±0.07
8	BR.9928-DWR-SR-Y	87.7±0.8	0.0±0.0	1.3±0.6	0.0±0.0	0.0±0.0	0.0±0.0
9	Yellow Pop Corn	42.5±1.5	0.8±0.2	6.6±0.9	1.9±0.2	2.3±0.5	0.04±0.006
10	Yellow Mangu Jos	28.3±0.7	5.6±1.1	12.8±1.2	8.7±3.1	17.5±3.1	0.6±0.2
	Mean (± S.E	52.75±7.7	2.25±0.6	7.03±1.3	3.02±0.8	6.59±1.8	0.18±0.06

Table 4: Performance of 10 maize varieties screened for post-harvest resistance against *P. truncates*

Maize variety	Adult Mortality (%)	F_1 progeny	Population Density	Weight Loss (%)	Damage (%)	Frass (g)	Weighted average	Resistance rating
1.Oba Super I	4.0	2.0	4.0	2.0	2.0	2.0	2.7	Low level Of resistance
2.Oba Super II	4.0	2.0	4.0	2.0	3.0	3.0	3.0	Susceptible
3.Western Yellow	4.0	3.0	3.0	3.0	2.0	3.0	3.0	Susceptible
4.Acr.89- DMR-ESR-W	1.0	1.0	1.0	1.0	1.0	1.0	1.0	Highly resistant
5.Acr.97-TZL comp 4^C	1.0	1.0	1.0	1.0	1.0	1.0	1.0	Highly resistant
6.TZESR- W	3.0	1.0	2.0	1.0	1.0	1.0	1.5	Highly resistant
7.Acr.91- SUWAN-1SRC1	3.0	4.0	4.0	4.0	4.0	3.0	3.7	Susceptible
8.BR.9928- DWR-SR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	Highly resistant
9.Yellow Pop Corn	3.0	1.0	3.0	1.0	1.0	1.0	1.7	Highly resistant
10.Yellow Mangu Jos	4.0	5.0	5.0	5.0	5.0	5.0	4.8	Highly susceptible

Resistance rating

Highly resistant	1.0- 1.99 average score
Low level of resistance	2.0- 2.99
Susceptible	3.0- 3.99
Highly susceptible	4.0-5.00

Table 5: Chemical composition and physical parameters of the ten maize varieties

Variety	Moisture (%)	Protein	Carbohydrate	Fat	Ash	Fiber	Phenolics Mg/100g	Seed coat thickness (mm)	Grain hardness	Seed Size (mm)
1.Oba Super I	8.5	10.5	76.7	3.9	0.5	1.8	796.9	0.09	646.5	4.5
2.Oba Super II	9.0	9.6	79.0	2.9	0.3	2.2	731.3	0.14	761.8	6.2
3.Western yellow	9.5	12.3	75.3	2.6	0.5	1.0	309.4	0.14	772.0	4.4
4.Acr.8 9-DMR- ESR- W	10.5	10.5	69.3	3.2	0.5	1.8	796.9	0.16	747.0	4.6
5.Acr.97-TZL comp $_4$C	8.5	12.3	75.6	1.6	0.5	0.8	787.5	0.10	571.0	4.6
6.TZE SR- W	9.0	12.3	76.2	1.3	1.0	1.0	375.0	0.07	902.8	4.6
7.Acr.91-UWAN-ISRC1	10.5	7.6	77.5	3.4	0.3	2.2	712.5	0.08	399.8	5.1
8.BR.9928-DWR-SR	9.0	9.0	78.4	2.8	0.5	2.5	721.9	0.07	572.5	4.2
9.Yellow Pop Corn	8.0	10.5	75.7	2.1	1.0	2.9	562.5	0.11	561.3	3.9
10.Yellow Mangu	9.5	8.8	79.7	2.0	0.5	2.5	365.6	0.06	865.3	4.6
Jos Mean $\pm$.E	9.2$\pm$0.3	10.3$\pm$0.5	76.3$\pm$0.9	2.6$\pm$0.3	0.6$\pm$0.08	1.9$\pm$0.2	615.9$\pm$62.0	0.1$\pm$0.01	680.0$\pm$49.5	4.7$\pm$0.2

Table 6: Relationship between insect infestation level and chemical and physical parameters of maize varieties

Chemical composition	Adult Mortality (%)	F1 progeny	Total Adult population	F_1 body weight (mg)	Weight Loss (%)	Grainm damage (%)	Frass (g)
Moisture (%)	0.082	0.413	0.134	0.387	0.325	0.386	0.295
Protein (mg/100g)	0.261	-0.475	-0.412	-0.103	-0.484	**-0.530	-0.429
Carbohydrate (g/100g)	-0.470	0.441	**0.506	0.008	**0.503	0.481	**0.525
Fat (g/100g)	-0.282	0.244	0.295	0.333	0.170	0.218	0.136
Ash(g/100g)	0.166	-0.493	-0.353	**-0.587	-0.437	**-0.511	-0.453
Fiber (g/100g)	-0.294	0.167	0.290	-0.199	0.214	0.246	0.222
Phenolics (ug/100g)	0.322	-0.322	-0.291	-0.009	-0.342	-0.261	-0.412
Seed coat thickness (um)	0.001	-0.185	-0.072	0.303	-0.242	-0.175	-0.171
Grain hardness	-0.140	0.079	0.117	0.097	-0.029	0.134	0.268
Seed size (mm)	-0.329	0.359	0.428	0.514**	0.292	0.461	0.363

Correlation coefficient (r): ** = significant and strongly correlated at a level 5%. Mean of three replicates

Table 8: Infestation level of the highly susceptible maize (Yellow Mangu Jos) and the variety with low level of resistance (Oba super I) treated with the LD50.

INSECTICIDES	Yellow Mangu Jos (Highly susceptible variety)	Oba Super I(Low level of resistance)
Deltamethrin	100	100
Bifenthrin	100	100
CONTROL		
Mortality (%)	28	58
F1 progeny	7.3	0.7
(Final opulation)	(12.6)	(3.7)
Weight loss (%)	8.7	1.3
Damage (%)	11.8	7.1
Frass(g)	0.9	0.2

Economics of Control

Calculation of Cost-Benefit Analysis

Cost of maize varieties

Local varieties

The prices of maize at different periods are shown as follow: Improved yellow maize- 3.7kg@N350= N94.6/kg= (peak price) (April –Sept.) Local white maize- 3.7kg@N300=N81.0/kg (peak price) (April-Sept.) Improved yellow maize- 3.7kg@N300= N81.0/kg (off peak) (Jan.- Feb.) Local white maize- 3.7kg@ N250= N67.6/kg= (off peak) (January- February) It should be noted that these prices were determined by the level of demand and grain availability at both harvest and sales period. Duration in storage for yellow maize= 9 months and that of white maize= 3 months. Also, % damage for untreated yellow maize= 7.1% and that of untreated white maize= 11.8%. The costs of investments in the chemicals used in the preservation of grains are as follows: **Bifenthrin** @ N1450/62.5g of active ingredient (a.i) or N23.2/g of a.i and

Deltamethrin @ N1500/12.5g of a.i or N12/g of a.i

The cost of actual amount of active ingredients used in treating yellow maize grain (i.e the experimentally derived LD50 values adopted from [39]. were as follows;

1 LD50 of bifenthrin for treating 20g of maize=10.19 µg/ml at a cost of N11.82/kg of maize. 2. LD50 of deltamethrin for treating 20g of maize=3.19 µg/ml at a cost of N1.92/kg of maize. Thus, deriving from the above, supposing two farmers (A and B) represent the treated maize and untreated (control) yellow maize variety shown earlier in Table 8, the major factors applied in determining the cost/benefit for both are shown in Table 9.

Table 9: Calculation of cost-benefit for treated and untreated yellow maize grains.

TreatedGrain Farmer A)	Untreatedcontrol(Farmer B)
Cost of 1kg of grain= N81	Cost of 1kg of grain=
Cost of bifenthrin = N11.8	N81 Cost of bifenthrin =
Cost of deltamethrin =	Nil Cost of deltamethrin
N1.92 % damage= 0%	= Nil % damage= 7.1
Duration in storage- 9 months or	Duration- 3 months or less
More Selling price = N94.6/kg	Selling price = N83.6/kg
Profit= Sales- Cost=N13.6	Profit= Sales- Cost=N2.6

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