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Varietal Resistance of Maize to *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and its Management with *Petiveria alliacea* L. Extract

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Abstract

Prostephanus truncatus is a major maize pest in Africa, typically managed with synthetic insecticides and fumigants, but their use has been widely criticized. Therefore, screening for maize varietal resistance and use of botanical were investigated to proffer alternatives in the management of *P. truncatus*. Nine maize varieties were evaluated for resistance to *P. truncatus* in the laboratory. Number of emerged *P. truncatus*, median development time, susceptibility index, and grain weight loss were assessed. Grains morphological characteristics: length, weight, width of grains, and proximate composition: Moisture, percentage Ash, Fat, Carbohydrate, Protein, Fibre were also evaluated. *Petiveria alliacea* leaves were extracted using three solvents: n-Hexane, ethyl acetate and methanol and evaluated at a concentration of 10%, 20% and 30%, against *P. truncatus* to determine its toxicity. Number of emerged *P. truncatus* (66.25±2.95), grain weight loss (0.00±0.00 g) and susceptibility index (3.8) were lowest on LNTP-Y and highest on ART-98-SW6 (161.75±29.54, 5.50±1.44, 5.1) respectively. ART-98-SW6 had the least percentage ash (1.11±0.01%), fat (0.06±0.01%), and highest moisture content (12.88±0.24%). The percentage carbohydrate ranged from 78.42±1.58 (SUWAN-Y) to 71.37±0.22 (BR9928). The n-hexane extract of *P. alliacea* had the highest mortality at a concentration of 30 % (v/v) while ethanol had lowest mortality at both 24 h and 48 h of exposure. LNTP–Y exhibited the highest resistance to *P. truncatus*, showing the longest developmental period, lesser grain damage together with the lowest susceptibility rating. Solvent extracts of *P. alliacea* were active against *P. truncatus* with n-Hexane extract seemed to be more potent.

Keywords: Maize, *Prostephanus truncatus,* mortality, *Petiveria alliacea,* Solvent extracts, Median Developmental Time

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INTRODUCTION

The larger grain borer, *Prostephanus truncatus* (Horn) is one of the major and economically important insect pests of maize. The insect infestation starts in the field and continues in the store. Adult *P. truncatus* infests both already damaged grains and whole grains (Muatinte *et al*., 2019), resulting in reduced grain weight, quality and nutritional content, and also increase costs incurred by farmers and traders in controlling this insect pest (Tadesse, 2020). It is polyphagous in nature, as it feeds and causes substantial damage to some other agricultural produce like roots and tubers, cereals, cocoa, coffee, groundnut and wooden structures (Quellhorst *et al*., 2021). In West Africa, yields of maize and cassava chips, due to *P. truncatus,* have been reported to decrease by 45% and 100%, respectively, depending on storage duration (Ejiro *et al*., 2018). Currently, 20 African countries are affected by this pest, and if preventive measures are not taken, the insect pest has the potential to spread to all countries in sub-Saharan Africa (Muatinte *et al*., 2019).

Chemical pesticides are currently used in controlling *P. truncatus* (Muatinte, *et al*., 2019) as their use has proven successful in the past decades, however, their effectiveness is fading due to negative impacts (Ogbonna *et al*., 2014), including toxicity to end users and environmental pollution. Furthermore, many insects have become resistant to man-made pesticides, leading to increasing pest populations (Ali *et al*., 2023).

Varietal resistance is one of the promising ways of managing post-harvest losses of maize due to insect pests in developing countries, including *P. truncatus*. This method is safe, affordable and does not require any technical know-how (Nwosu, 2018). Varietal resistance has been attributed to physical or biochemical properties, which alter either the behaviour (xenobiosis) or negatively affect the development of insect pest (antibiosis). Majority of the research on varietal resistance, particularly on cereals, has been conducted with no-choice bioassays whereby adult insects are being introduced to each of the tested varieties. Recently, chemical composition of grains also exhibited a significant role in determining the relative resistance to *P. truncatus* attacks (Ngom and Sembene*,* 2020).

Additionally, certain herbs have shown to possess numerous compounds with insecticidal effects. These plants are abundant in our environment, and interest in their potential application in insect control has increased (Ukoroije and Abdulkadir*,* 2020). Many plant based materials have been reported to lower the chances of survival of insect life stages such as larvae. In addition, plant extracts and essential oils from various plants and their powders have been found to repel stored products pests (Moshrefi *et al*., 2022). Among the tropical plants whose powders and extracts have been used as biopesticides include *Azadirachta indica, Calotropis gigantia, Eucalyptus globulus, Ocimum basillum* and *Piper nigrum* (Kathirvelu and Raja, 2015).

The Guinea henweed, *Petiveria alliacea* L., is a shrub found widely in the hot humid and subtropical countries. It is also commonly found in southern Nigeria where it is also known as "Awogbarun" meaning "cure many diseases" and "Arunyanyan" meaning "smelling good" (Lawal *et al*., 2024). *Petiveria alliacea* has greatly received enormous attention recently (Conceição *et al*., 2023). Although some studies have been carried out on its insecticidal effects (Rasado-Aguilar *et al*., 2010; Neves *et al*., 2011; Akintan and Akinneye, 2020), but they are not yet fully understood in this regard. Thus, *P. alliacea* is a plant of great importance in the search for new biologically active phytochemicals to combat pests and pathogens.

By using appropriate solvents, it is possible to concentrate the active ingredients of plant extracts and increase their insecticidal activity (Khan *et al*., 2017; Akinbuluma *et al.,* 2017). Extracts of several aromatic and herbal plants, prepared using solvents of different polarity, have insecticidal properties against a wide range of insect species (Boussaada *et al*, 2008; Ukoroije and Abdulkadir, 2020).

Therefore, to select maize that are resistant to *P. truncatus*, there is need to check its infestation on different maize varieties. In addition, since botanicals have proven effective in reducing losses caused by insect pests in storage (Bezabih *et al*., 2022), there is lack of adequate information on the toxicity of *Petiveria alliacea* to *P. truncatus*. Therefore, we assessed the resistance of nine maize varieties to *P. truncatus* and identified which morphological characters and proximate composition of these maize varieties constituted resistance to *P. truncatus*. Additionally, we conducted study to determine the toxicity of three solvent extracts of *Petiveria alliacea* on adult *P. truncatus.* Our study may offer sustainable management to *P. truncatus* in Nigeria.

MATERIALS AND METHODS

Experimental Site

All experiments were conducted at the Entomology Laboratory of the Nigerian Stored Products Research Institute, Onireke, Ibadan, under ideal environmental conditions (30±2˚C temperature and 75±5% relative humidity).

Insect culture

Culture of *P. truncatus* was established from infested maize seeds purchased from Bodija market (latitude 7°26'14" and longitude 3°54'57"), Ibadan, Oyo State, Nigeria. From this initial stock, two jars each containing 250 g maize seeds were infested with adults of eighty (1 male:1 female) *P. truncatus*. The insects were allowed to mate and oviposit and were removed after 14 days. Adults were sexed using external morphological characteristics in identification (Shires and McCarthy, 1976), and newly emerged (1-2 day-old adults) were used for all experiments.

Maize varieties

The open pollinated maize seeds used for the experiment were; SUWAN-Y, ART-98-SW1, LNTP, ART-98SW6, BR9943, BR9928, PRO-VITA and DMR-LSR, obtained from the Institute of Agricultural Research and Training (IAR&T), located in Ibadan, Oyo State, while the local grains (Solo) was bought from Bodija market, Ibadan, Oyo State. Prior to use, the maize seeds were first sorted by picking out already damaged seeds before placing the cleaned ones in a cold freezer (-18°C) for three weeks for disinfestation. Before the commencement of our experiments, the maize varieties stored in the deep freezer were taken out and air-dried for three hours to prevent mouldiness and to acclimatise with the laboratory conditions.

Fecundity and Median Developmental Time of *P. truncatus*

Eighty grammes (80 g) of each maize variety were weighed into four Kilner jars and infested with ten pairs (1 male: 1 female) of teneral adult *P. truncatus.* The insects were allowed for mating and oviposition and were removed after two weeks. The jars were left alone until the emergence of F_1 progeny of adult *P. truncatus*. The experiment was laid out in a Completely Randomised Design (CRD) with nine treatments and four replications.

Daily data on F_1 progeny were taken from the beginning of emergence till emergence was completed. In each case, emerged adults were removed, counted, sexed and recorded by sieving out newly emerged adults in a holding pan. The grains were retained by the sieve while the *P. truncatus* and flour dust were retained in the holding pan. Grains in each Kilner jar were re-weighed and the percentage seed weight loss per jar was also calculated at the termination of the experiment as:

$$\%\ weight\ loss\ of\ grains = \frac{Initial\ weight\text{-}final\ weight}{\text{inital weight}} \times 100$$

Median developmental period (in days) was estimated as the interval from the middle of egg laying period to 50% emergence of adult *P. truncatus*. Susceptible index of Dobie was also adopted to categorize the maize varieties of maize into groups (Dobie, 1974; Akinbuluma and Ewete*,* 2019) using the following:

$$\text{Susceptibility index} = \frac{[\log(total\ number\ of\ F1\ progeny)]}{\text{Median development time}} \times 100$$

0-4 = Resistance; 4.1-6.0 = Moderately Resistance; 6.1-8.0 = Moderately Susceptible; 8.1-10 = Susceptible; ≥ 10.1 = Highly Susceptible

Morphological characteristics and proximate composition of maize

To determine whether morphological characteristics of maize grains have influence on the resistance of *P. truncatus,* we used the visual observation, a Mettler weighing balance (Mettler Toledo, ME204TE/00) and the digital Vernier calliper (Starrett, USA). Ten clean kernels from each variety were picked randomly and were carefully examined to determine their colours, length, width and weight. Furthermore, clean grains (15 g) from each variety were milled using a milling machine (Manger, 32060967) and analyzed for proximate composition.

Preparation of *Petiveria alliacea* leaves for insecticidal activity

Petiveria alliacea leaves were freshly harvested near the Department of Veterinary Medicine, Botanical Garden, at the University of Ibadan (UI), Ibadan, Nigeria. The leaves were air-dried at the roof-top screen house of the Department of Crop Protection and Environmental Biology, (UI), for two weeks. The leaves were crushed into powder using a Thomas milling machine at 1425Hz revolutions per minute in the Department of Chemistry, UI and then stored in the laboratory shelf until use.

Samples were extracted using the cold extraction process according to the procedures described by Okoduwa *et al*. (2016) with slight modifications. Briefly, one thousand grammes (1000 g) of powdered *P. alliacea* leaves was soaked in methanol for 72 hours The methanol crude extract was first filtered and then concentrated using a rotary evaporator (lab scale, REV-2000AX). Sample was further fractionated using different solvents; n-Hexane, a non-polar solvent and followed by ethyl acetate, a moderately polar solvent, in a separatory funnel (Sigma-Aldrich, Darmstadt, Germany) to obtain individual solvent extract. All solvent extracts were further concentrated with a rotary evaporator (lab scale, REV-2000AX) before use. Each solvent extract of *P. alliacea* at dosages of 0.1 g, 0.2 g and 0.3 g was added to diluted 1 mL ethanol (70 %) to obtain concentrations of 10% vol/vol, 20% v/v and 30% v/v. Since ethanol was used in diluting the extracts, ethanol only (0.00%) was used as the negative control. A synthetic chemical, cyperforce (Cypermethrin 10% EC), was prepared by diluting 0.5 mL into 10 mL of water and taken as the positive control. Consequently, there were eleven concentrations.

Toxicity test of *Petiveria alliacea* solvent extracts on adult *P. truncatus*

Five teneral adult of *P. truncatus* were placed per Petri-dish and provided with five grammes (5 g) of Solo variety being the local variety planted mostly by farmers within the study area while contact toxicity test was carried out by applying 0.1 µL of each concentration (10, 20, and 30% v/v) of *P. alliacea* extract, ethanol and cyperforce) individually on each of the insect with the aid of micro syringe (1mL 20). Adult *P. truncatus* in the control Petri-dish were treated with ethanol-control. To aid ventilation, each Petri-dish was later covered with a fine mesh lid. Five (5) adult *P. truncatus* were treated per Petri-dish. The experiment was laid in a CRD, with eleven treatments and four replications. Insects were classified as dead whenever any of the tested insect did not make a move when disturbed using the camel brush and the number of mortality was taken at both 24 and 48 hours.

Statistical analyses

Morphological characteristics and proximate composition analysis data on the nine maize varieties were analyzed using one way ANOVA and Duncan Multiple Range Test in R software (R Core 2020) to determine significant differences between the varieties. Susceptibility index was correlated with median developmental time, number of F_1 emergence of *P. truncatus* and grain weight loss using the Pearson's correlation analysis at 5% level of significance (Statistical Package for Social Sciences (SPSS), Version 20.0). The number of emerged adult male and female *P. truncatus* on the tested maize varieties was compared with a t-test to determine the significant difference between the adult male and female *P. truncatus*. The data on contact toxicity were analyzed using one way ANOVA and means were separated using Duncan Multiple Range Test at 5% level of significance.

RESULTS

Number of F_1 emergence of *P. truncatus*, median development time (MDT) and grain weight loss of maize varieties infested with *P. truncatus*

The number of F_1 progeny of adult *P. truncatus* on each of the maize varieties was significant. ART-98-SW6 had the highest mean population (161.75±29.54) of F_1 progeny which was not significantly ($p > 0.05$) different from that of SUWAN-Y (119.50±10.18), DMR-LSR (117.25±13.02) and BR9928 (117.25±20.25) but was significantly ($p < 0.05$) different from the other maize varieties (Table 1). Significant ($p < 0.05$) differences were also recorded with regards to the MDT of *P. truncatus*. The MDT varied from 55.00 to 58.50 among the maize varieties. The MDT of *P. truncatus* on variety LNTP-Y was the highest (58.50±0.86), and was not significantly different from SUWAN-Y (57.00±0.00) and BR9943 (56.25±1.49) but was significantly ($p < 0.05$) higher than the MDT of other samples. Similarly, variety LNTP-Y had the least grain weight loss (0.0±0.00 g), with no significant ($p > 0.05$) difference between the Solo (0.25±0.25 g), DMR-LSR (1.0±0.70 g), BR9928 (1.50±0.50 g) and PROVITA (2.0±0.57 g). Additionally, among the nine varieties used, variety ART-98-SW6 (5.50±1.44 g) had the highest grain weight loss, showing no significant ($p > 0.05$) difference with ART-98-SW1 (4.00±0.40 g) but significantly ($p < 0.05$) different from all other varieties (Table 1).

Table 1: Number of F_1 emergence of *P. truncatus*, median development time and grain weight loss of nine maize varieties infested with *P. truncatus*

Maize varieties	No. of F_1 emergence (± S.E)	MDT (d) (± S.E)	Grain Weight loss (%) (± S.E)
ART-98-SW1	111.75ab±16.47	55.50a±0.50	4.00de±0.40
ART-98-SW6	161.75c±29.54	55.00a±0.81	5.50e±1.44
BR9928	117.25bc±20.25	55.00a±0.00	1.50abc±0.50
BR9943	108.00ab±11.05	56.25ab±1.49	2.50bcd±0.86
DMR-LSR	117.25bc±13.02	56.00a±0.57	1.00ab±0.70
LNTP-Y	66.25a±2.95	58.50b±0.86	0.00a±0.00
SUWAN-Y	119.50bc±10.18	57.00ab±0.00	3.25cd±0.25
PRO-VITA	101.75ab±3.17	55.50a±0.50	2.00abcd±0.57
Solo (Control)	103.25ab±10.45	56.00a±0.57	0.25a±0.25

Means with the same alphabet(s) along the column are not significantly different from one another at 5% using Duncan Multiple Range test.
MDT = Median developmental time

Susceptibility indices of nine maize varieties to *P. truncatus*

Variety LNTP-Y (3.8) had the lowest susceptibility index among the varieties tested, followed by SUWAN-Y (4.0) and BR9943 (4.0). Solo had the susceptibility index of 4.6, ART-98-SW1 (4.7), PRO-VITA (4.7), DMR-LSR (4.7), BR9928 (4.8) and ART-98-SW6 (5.1) (Figure 1).

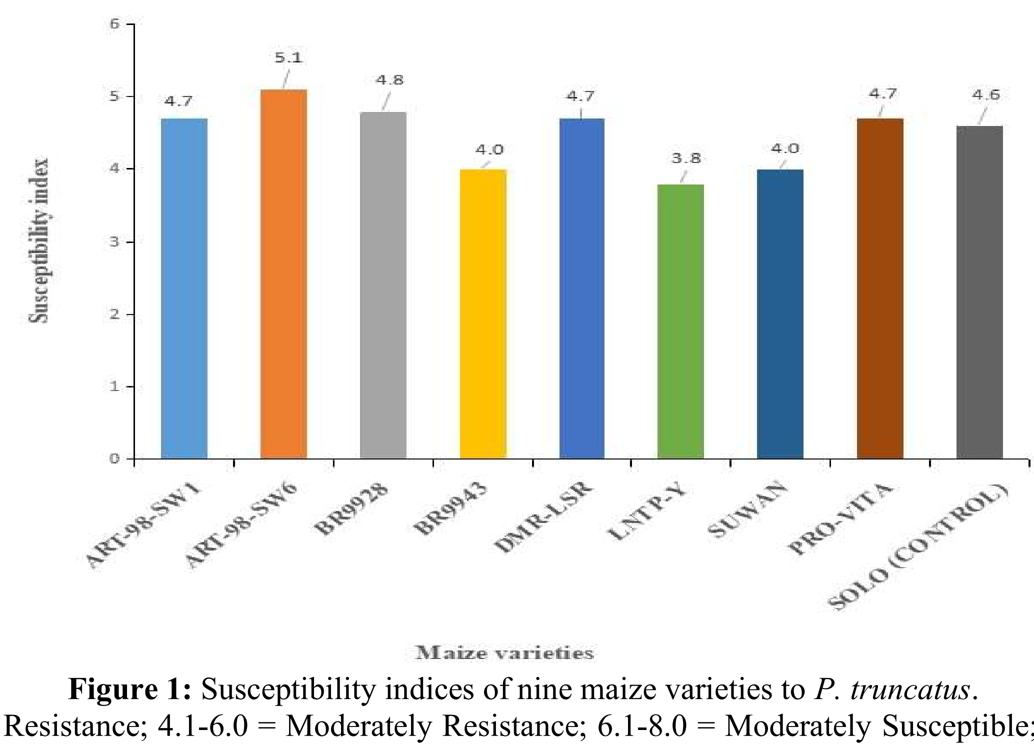

Figure 1: Susceptibility indices of nine maize varieties to *P. truncatus*.
0-4 = Resistance; 4.1-6.0 = Moderately Resistance; 6.1-8.0 = Moderately Susceptible; 8.1-10 = Susceptible; ≥ 10.1 = Highly Susceptible

Correlation between number of F_1 emergence of *P. truncatus*, median developmental time, percentage weight loss and susceptibility index

The correlation among the number of F_1 emergence of *P. truncatus*, median developmental time, percentage weight loss and susceptibility index were presented in Table 2. There was a positive relationship between the number of emergence and percentage weight loss as well as number of emergence and susceptibility indices (r=0.788 and r=0.683, respectively). However, correlation of MDT with number of F_1 emergence was negative (r=-0.722) (Table S2). Similarly, the correlation between F_1 emergence and susceptibility indices with MDT was negative and significant (r-0.722 and r=-0.886, respectively) while the correlation of percentage weight loss with MDT was negative and insignificant (r =-0.490). We also found a positive relationship between the number of F_1 progeny positively correlated with percentage weight loss (r=0.788) while MDT and SI with percentage weight loss indicated no significant correlation (r=-0.490 and r=0.395) respectively. The correlation between F_1 emergence and MDT with SI were significant (r=0.683 and r=-0.886, respectively) while the correlation of percentage weight loss (r=0.292) with SI was not significant (Table 2).

Male to female ratio of F_1 emergence of *Prostephanus truncatus*

Among the maize samples tested, ART-98-SW6 had the highest number (75.25±13.89) of male *P. truncatus,* which was not significantly ($p > 0.05$) different from DMR-LSR (54.25±5.79) and SUWAN-Y (56.50±4.09) but significantly ($p < 0.05$) different from other varieties (Table 3). Additionally, variety LNTP-Y had the lowest number (30.50±1.31) of male *P. truncatus* emergence, with no significant ($p > 0.05$) difference from ART-98-SW1 (50.75±7.66), BR9928 (52.50±9.04), BR9943 (48.50±7.85), DMR-LSR (54.25±5.79), PRO-VITA (46.25±1.79) and Solo (47.00±4.24).. ART-98-SW6 (88.00±15.81) had the highest mean count of female *P. truncatus,* with no significant ($p > 0.05$) differences from DMR-LSR (62.50±7.41) and SUWAN-Y (63.25±5.79).

Table 2: Correlation between number of F_1 emergence, median developmental time, percentage weight loss and susceptibility index

Parameters	Statistics	Number of F_1 emergence	Median development time	% Weight Loss	Susceptibility Index
Number of F_1 emergence	Pearson Correlation	1	-.722*	.788*	.683*
	Sig. (2-tailed)		.028	.012	.043
Median development time	Pearson Correlation	-.722*	1	-.490	-.886*
	Sig. (2-tailed)	.028		.181	.001
% Weight Loss	Pearson Correlation	.788*	-.490	1	.395
	Sig. (2-tailed)	.012	.181		.292
Susceptibility Index	Pearson Correlation	.683*	-.886**	.395	1
	Sig. (2-tailed)	.043	.001	.292	

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

Table 3: Male to female ratio of F_1 emergence of *Prostephanus truncatus* raised on nine maize samples

Maize varieties	Male (± S.E)	Female (± S.E)	Sex ratio (M:F)	t-value	p-value
ART-98-SW1	50.75ab±7.66	61.25ab±8.77	1:1.2	-0.901	0.402
ART-98-SW6	75.25c±13.89	88.00c±15.81	1:1.1	-0.606	0.567
BR9928	52.50ab±9.04	65.25bc±11.13	1:1.2	-0.889	0.408
BR9943	48.50ab±7.85	54.00ab±4.43	1:1.1	-0.610	0.565
DMR-LSR	54.25abc±5.79	62.50abc±7.41	1:1.1	-0.877	0.414
LNTP-Y	30.50a±1.32	35.75a±1.88	1:1.1	-2.278	0.063
SUWAN-Y	56.50bc±4.09	63.25bc±5.79	1:1.1	-0.952	0.378
PRO-VITA	46.25ab±1.79	53.50ab±2.53	1:1.1	-2.334	0.058
Solo (CONTROL)	47.00ab±4.24	56.25ab±6.32	1:1.1	1.214	0.270

Means with the same alphabet(s) along the column are not significantly different from one another at 5% using Duncan Multiple Range test.

Morphological characteristics and Proximate composition of maize varieties

Morphological characteristics of nine maize varieties in relation to their resistance or susceptibility to larger grain borer are presented in Table 4. Among the varieties, BR9943 (9.68±1.11 mm) was the longest grain, with no significant ($p > 0.05$) difference from ART-98-SW1 (8.98±1.4 mm), DMR-LSR (9.03±0.9 mm), PRO-VITA (8.60±1.3 mm) and Solo (8.64±1.2 mm), while LNTP-Y (7.72±1.2 mm) had the shortest length. LNTP-Y (7.54±0.6 mm) had the lowest grain width which was not significantly ($p > 0.05$) different from ART-98-SW1 (8.22±0.9 mm), ART-98-SW6 (8.38±0.9 mm), BR9928 (8.17±0.7 mm), BR9943 (8.11±1.0 mm) and PRO-VITA (8.09±1.0 mm). Similarly, LNTP-Y (1.74±0.1 g) had the lowest grain weight per ten grains. Among the maize seeds, only variety ART-98-SW6 and BR9943 were white in colour while others were yellow (Table 4).

In Table 5, it was observed that variety ART-98-SW6 (12.88±0.24%) had the highest percentage moisture content, which was not significantly ($p > 0.05$) different from ART-98-SW1 (12.38±0.13%) (Table 5). In addition, LNTP-Y had the least percentage ash (1.15±0.06%), with no significant ($p > 0.05$) difference between BR9943 (1.15±0.02%), ART-98-SW6 (1.11±0.01%), DMR-LSR (1.37±0.10%) and PRO-VITA (1.42±0.20%). The control maize variety, Solo, had the highest percentage fat content (0.97±0.07%), followed by SUWAN-Y (0.43±0.07%), while variety ART-98-SW6 had the least percentage fat (0.06±0.01%). SUWAN-Y (78.42±1.58%) had the highest percentage carbohydrate which was not significantly ($p > 0.05$) different from those of variety ART-98-SW1 (76.39±0.57%) and PRO-VITA (76.44±0.10%). The lowest percentage carbohydrate was recorded in variety BR9928 (71.37±0.22%).

BR9943 (10.90±0.34%) was found to have the highest percentage of protein, with no difference from DMR-LSR (10.70±0.15%) and Solo (10.16±0.31%) (Table 5). SUWAN-Y (7.11±0.91%) had the lowest percentage protein, and showed no significant ($p > 0.05$) difference from ART-98-SW1 (8.04±0.40%). ART-98-SW1 (1.45±0.06%) had the least percentage fibre, with no significant ($p > 0.05$) difference from Solo (1.66±0.04%) and LNTP-Y (1.72±0.10%), while the BR9928 (2.85±0.13%) had the highest percentage fibre.

Effects of *P. alliacea* extracts and cypermethrin on the mortality of *Prostephanus truncatus*

The mortality rate of adult *P. truncatus* being exposed to different concentration of *Petiveria alliacea* extracts and the synthetic insecticide (cypermethrin) was compared in Table 6. After 24 h of treatment, there was no significant ($P > 0.05$) difference between the mortality caused by n-hexane fraction of *P. alliacea* (100.00±0.00) at a concentration of 30 %v/v, and those caused by the synthetic insecticide (cyperforce) (90.00±10.00).

Similarly, at 48 hr of exposure of adult *P. truncatus* to extract of *P. alliacea,* n-hexane had the highest morality at 30%v/v (100.00±0.00), with no significant ($p > 0.05$) difference from the mortality on ethyl acetate extract (70.00±5.77), methanol extract (95.00±5.00) and cypermethrin (100.00±0.00) treated *P. truncatus* during the observation period but significantly different ($p < 0.05$) from ethanol (0.00±0.00).

Table 4: Morphological characteristics of nine maize varieties as basis of resistance to *P. truncatus*

Maize varieties	Length (mm) (± S.E)	Width (mm) (± S.E)	Weight(g/10 grains) (± S.E)	Grains colour
ART-98-SW1	8.98bc±1.4	8.22ab±0.9	2.57ab±0.1	Yellow
ART-98-SW6	8.47ab±0.3	8.38ab±0.9	2.48ab±0.2	White
BR9928	7.92ab± 0.9	8.17ab±0.7	2.33ab±0.0	Yellow
BR9943	9.68c±1.1	8.11ab±1.0	2.52ab±0.0	White
DMR-LSR	9.03bc±0.9	8.73b±0.5	2.41ab±0.2	Yellow
LNTP-Y	7.72a±1.2	7.54a±0.6	1.74c±0.1	Yellow
SUWAN-Y	8.44ab±1.2	8.65b±0.7	2.26b±0.0.3	Yellow
PRO-VITA	8.60abc±1.3	8.09ab±1.0	2.40ab±0.0	Yellow
Solo	8.64abc±1.2	8.62b±0.7	2.78a±0.1	Yellow

Means with the same alphabet(s) along the column are not significantly different from one another at 5% using Duncan Multiple Range test.

Table 5: Proximate composition of resistance of nine maize varieties tested for resistance to *Prostephanus truncatus*

Maize varieties	% Moisture (± S.E)	% Ash (± S.E)	% Fat (± S.E)	% Carbohydrate (± S.E)	% Protein (± S.E)	% Fibre (± S.E)
ART-98-SW1	12.38cd±0.13	1.57b±0.13	0.15abc±0.00	76.39cd±0.57	8.04ab±0.40	1.45a±0.06
ART-98-SW6	12.88d±0.24	1.11a±0.01	0.06a±0.01	74.69bc±0.07	8.93bc±0.19	2.32b±0.10
BR9928	11.71bc±0.13	2.07c±0.04	0.21bc±0.03	71.37a±0.22	9.09bc±0.21	2.85d±0.13
BR9943	11.66bc±0.30	1.15a±0.02	0.11ab±0.01	72.73ab±0.56	10.90d±0.34	2.42bc±0.06
DMR-LSR	10.49ab±0.12	1.37ab±0.10	0.12ab±0.01	74.67bc±0.56	10.70d±0.15	2.63bcd±0.24
LNTP-Y	10.95b±0.31	1.15a±0.06	0.16abc±0.02	73.76b±0.50	8.90bc±0.31	1.72a±0.10
SUWAN-Y	9.73a±0.78	1.55b±0.05	0.43d±0.07	78.42d±1.58	7.11a±0.91	2.74cd±0.02
PRO-VITA	10.93b±0.72	1.42ab±0.20	0.25c±0.00	76.44cd±0.10	8.52b±0.28	2.42bc±0.04
Solo(CONTROL)	11.51bc±0.25	2.77d±0.21	0.97e±0.07	72.92ab±0.54	10.16cd±0.31	1.66a±0.04

Means with the same alphabet(s) along the column are not significantly different from one another at 5% using Duncan Multiple Range test.

Table 6: Effects of Leaf extract of *P. alliacea* on mortality of *P. truncatus*

P. alliacea fractions	Concentration (%v/v)	24 h	48 h
n-Hexane	10	45.00bc±17.07	80.00bc±14.14
	20	80.00cd±11.54	100.00c±0.00
	30	100.00d±0.00	100.00c ±0.00
Ethyl-acetate	10	45.00bc±9.57	75.00bc±12.58
	20	45.00bc±9.57	75.00bc±15.00
	30	35.00ab±5.00	70.00bc±5.77
Methanol	10	45.00bc±18.92	50.00b±17.32
	20	40.00bc±23.09	55.00b±26.29
	30	70.00bcd±12.90	95.00c±5.00
Control (Ethanol)	0.000	0.00a±0.00	0.00a±0.00
Cypermethrin (Cyperforce)	5	90.00d±10.00	100c±0.00

Means with the same alphabet(s) along the column are not significantly different from one another at 5% using Duncan Multiple Range test.

DISCUSSION

Insect pest infestations are perhaps one of the most important constraints to stored maize, particularly in developing countries, and one of the primary causes of low quality and quantity of the produce (Gobena, 2012; Dhillon *et al*., 2013; Hiruy *et al*., 2018). They significantly reduce the amount of stored maize and other grain products. As a result, controlling storage insect pests has been crucial in minimizing the damaged content of stored maize by promptly implementing the proper management techniques, such as integrating pest management, in order to minimize losses and preserve high nutritional status (Guru *et al*., 2022).

In this study, F_1 emergence of *P. truncatus* showed that all the maize varieties tested are favourable to the development of the insect pest. The fact that adult *P. truncatus* was most abundant on ART-98-SW6, indicate that this variety was the most preferred, while LNTP-Y, was the least preferred. Furthermore, the fact that LNTP-Y variety had the least number of emergence and grain weight loss may be due to reduced oviposition by female *P. truncatus* on this variety. Earlier reports revealed that the feeding activities of stored product insects caused variations in grain weight losses among maize varieties and categorized these varieties into levels of resistance (Osipitan *et al*., 2011; Akinbuluma and Ewete, 2019; Ngom and Sembene, 2020). Interestingly, maize variety, ART-98-SW6 with significantly higher F_1 progeny also had higher weight loss. The attack and reduction in grain weight, resulting from the feeding activities of *P. truncatus* were enormous in this particular variety. Thus, our study is in agreement with the report of Nwankwo *et al*. (2014) that number of emergence of insects is positively related to attacks and percentage weight loss of grains. Notably, maize varieties, ART-98-SW6, BR9928 and PRO-VITA, with significantly lower MDTs had higher susceptibility indices, indicating that these varieties were more preferred to *P. truncatus* than others.

When checking for variation in the number of male and female *P. truncatus,* we found no significant difference in the emergence of male and female *P. truncatus*, however, based on their mean sex ratio, we observed that more female than male *P. truncatus* emerged in the maize varieties checked. The lack of significant variation in sex ratio of *P. truncatus* among the maize varieties we tested may suggest that varietal traits do not differentially affect the development or survival of male and female *P. truncatus*. Consequently, population dynamics of the pest are unlikely to be influenced through sex ratio modification by host genotype. Earlier work also revealed equal number of male and female *Sitophilus zeamais* and *Sitotroga cerealella* on some maize varieties tested (Ashamo and Khanna, 2006; Derera, *et al*., 2010). Possibly, the more females that we observed may only reflect biological variation and not due to bias in sex differentiation.

When we examined the morphological characteristics of maize grains from the varieties, our study revealed variation in some parameters and these might have impacted attraction and repulsion of maize by *P. truncatus*. Previous studies on susceptibility of maize grains to *P. truncatus* have found that the physicochemical properties of the maize grains have a decisive influence on *P. truncatus* (Altunç *et al*., 2023). For example, shorter grain length, shorter width and lighter weight might have conferred certain level of resistance to *P. truncatus* infestation such as in LNTP-Y, agreeing with Tongjura *et al*. (2010) that compact small seeds are more resistant to attack by stored insect pest. Apparently, female *P. truncatus* lay eggs in large grains, thereby providing food for the larvae until their emergence (Ashamo and Khanna, 2006; Morey, 2023).

The correlations between the number of F_1 progeny, median developmental time, and susceptibility index indicate that the tested maize varieties with lower median development time tend to have more F_1 emergence of *P. truncatus* and higher susceptibility. Similarly, more F_1 emergence of *P. truncatus* is linked to more weight loss, and that susceptibility index is greatly influenced by F_1 emergence and median development time. These findings corroborate the work of Abebe *et al.* (2009) who found that weevils on maize kernels that are very easy to infest took longer time to complete their development.

We also observed differential content in the proximate composition of maize varieties. The maize variety ART-98-SW6 with the higher moisture content had the highest susceptibility index and number of *P. truncatus* emergence, indicating that moisture content had a major role to play in maize susceptibility to insect pest. This is in line with the work of Atanda *et al*. (2016) who indicated that grains with high moisture content are susceptible to insect attack due to high respiration rate. Differences in damage caused by the insect on different maize varieties suggest that the maize chemical composition could affect insect damage and population size (Suleiman *et al*., 2013). Additionally, biochemical bases of resistance (Sugar content, phenolic acid, and amylose) and even paddy of rice also contributed to resistance of insects (Ashamo and Khanna, 2006; Osipitan and Odebiyi, 2007; Ngom *et al*., 2020). However, investigating these factors was beyond the scope of this research. Solvent fractions including n-hexane, ethyl-acetate and methanol of *P. alliacea* elicited significant mortality of adult *P. truncatus*, which were comparable to mortality caused by synthetic chemical. Our study is consistent with previous reports that partitioned extracts of botanicals were toxic to stored insect pests (Akinbuluma *et al*., 2017; Khan *et al*., 2017; Muhammed *et al*., 2022). The detrimental effects of phytochemicals of the studied plant species may be responsible for the mortality of *P. truncatus* found in this study. One mechanism for the potency of the solvent fractions of *Petiveria alliacea* could be that the extracts blocked the insect spiracle, thereby leading to lack of oxygen for respiration and eventually leading to suffocation and death of the insect pest (Ukoroije and Abdulkadir, 2020). Although the *Petiveria alliacea* extracts showed potential as insecticides, their toxicity towards *P. truncatus* varied, probably due to the many phytochemical components they contained. The specific phytochemicals within *Petiveria alliacea* extracts which are responsible for potency against *P. truncatus* remain to be isolated.

CONCLUSION

This study confirmed the development of *P. truncatus* on the tested nine maize varieties with the variety LNTP-Y being the most resistant variety in respect to number of F_1 emergence, and susceptibility index. Morphological characteristics and proximate composition such as grain length, minimum weight loss, and moisture content are attributes of resistance of the maize variety to *P. truncatus* infestation. These traits could be utilized by breeders to reproduce maize kernels that can withstand damage caused by *Prostephanus truncatus.* In addition, the solvent extracts of *Petivera alliacea* were active against *Prostephanus truncatus*. However, n-hexane extract showed superior efficacy to methanol and ethyl-acetate extracts against the insect pest. This suggests that *P. alliacea* contains bioactive compounds with insecticidal properties that could be harnessed for eco-friendly pest management. The active compounds in this extract may be isolated and synthesized for usage in the management of *Prostephanus. truncatus*.

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