Caraka Tani
Journal of Sustainable Agriculture
ISSN 2613-9456 (Print) 2599-2570 (Online)

Caraka Tani: Journal of Sustainable Agriculture, 37(1), 185-196, 2022
URL: https://jurnal.uns.ac.id/carakatani/article/view/54213
DOI: http://dx.doi.org/10.20961/carakatani.v37i1.54213

Evaluation of Toxicity of Some Tropical Flora, Clay and Permethrin against *Sitophilus zeamais* Motsch. on Stored Maize Grains

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Abstract

Weevil (*Sitophilus zeamais* Motsch.) is a vital arthropod pest of maize (*Zea mays* L.) grains and flours in traditional storage systems. The pest bore holes into stored grains reducing their nutrient contents germination potentials and contaminating produce with frass. Its control using synthetic insecticides such as permethrin is being downplayed due to eco-mammalian toxicity from pesticide residues. Therefore, this study evaluates the toxicities of some indigenous plants *Ageratum conyzoides* L., *Cymbopogon nardus* L., clay and permethrin, under laboratory conditions to the insect pest. Maize grains weighing 50 g were treated with the plant powders and the synthetic insecticide at five different levels 0.00; 1.25; 2.50; 3.75 and 5.00 g. Subsequently, 10 adult weevils in each vial were used to infest the 50 g maize grains. Each plant powder and permethrin's effectiveness was assessed by recording weevil mortality at 5, 7, 14, 21 and 28 days post-treatment. The damage indices recorded by the weevil perforation index (WPI), percentage of perforated and unperforated grains, and weight loss percentage were also considered. Permethrin proved most toxic, followed by clay at 5.00 g among all the treatments. *A. conyzoides* and *C. nardus* were less effective in controlling *S. zeamais*. In conclusion, clay can be used in the integrated management of *S. zeamais* to minimize synthetic insecticides.

Keywords: bio-insecticide; insect mortality; perforation index; postharvest grain protection; *Zea mays*

Cite this as: Emeasor, K. C., Nwakanma, V. N., & Enyiukwu, D. N. (2022). Evaluation of Toxicity of Some Tropical Flora, Clay and Permethrin against *Sitophilus zeamais* Motsch. on Stored Maize Grains. *Caraka Tani: Journal of Sustainable Agriculture*, *37*(1), 185-196. doi: http://dx.doi.org/10.20961/carakatani.v37i1.54213

INTRODUCTION

Maize (*Zea mays* L.) (Poaceae) is an essential cereal in Sub-Saharan Africa (SSA). It originated from Mexico and is cultivated globally on 160 million ha of farmland across 166 countries, 94 consisting of developing economies (Demeke et al., 2009; Samuel et al., 2011). Globally, maize contributes to the cereal-food needs of 4.5 billion people and serves as a staple for 1.2 billion others in SSA (Shiferaw et al., 2011; Suleiman and Rosentrater, 2015). Nigeria produces 10.2 million metric tonnes of maize per annum (Demeke et al., 2009; Nwosu et al., 2015; Ononuju et al., 2016; Nwosu, 2018) used in formulating livestock feed and for brewing beer (Ononuju et al., 2016). About 100 g of raw maize grains contain carbohydrate (19.0 g), protein (3.7 g), lipid (1.0 g), crude fiber (2.0 g), B-vitamins, Vitamin C (6.8 mg), potassium (270 mg), magnesium (37 mg) and phosphorus (89 mg) (USDA, 2019).

The production is constrained by environmental and biotic pressures from pathogens and insect pests in the field and storage. For example, in SSA, 40% of agro-produce estimated at USD 1.6 billion are lost due to pest attacks (Suleiman and Rosentrater, 2015) and *Sitophilus zeamais* is a major postharvest weevil of maize in the tropics

* *Received for publication August 6, 2021*
Accepted after corrections March 3, 2022

(de Araújo et al., 2019; Gitahi et al., 2021a). Both larvae and the adult weevils are very destructive since they bore into the endosperm, causing loss of weight and nutrients, reduced seed viability, contaminating stored produce with frass, thereby reducing their market value (Nwosu et al., 2015). Under traditional storage systems, quantitative and qualitative losses from attacks of the weevil in tropical countries vary from 18% to 100% and 30% to 52% within a few weeks to 6 months (Kumar and Kalita, 2017; Nwosu, 2018; Gariba et al., 2021; Gitahi et al., 2021a).

Several control strategies used to control the weevil population and damage on stored grains include good agronomic practices (harvesting before the onset of rains, maintaining store hygiene) and entomopathogens (*Beaveria bassiana* and *Bacillus thuringiensis*). However, chemical treatments with permethrin, pirimiphos-methyl, methyl bromide or phosphine can kill the weevils (Bonjour, 2018; Bionet-Eafrinet, 2021). Excessive and continuous application of synthetic pesticides resulted in the development of insect resistance. Meanwhile, the killing of non-target species and pesticide residues in treated grains heightened the concerns about food and consumer safety (Nguemtchouin et al., 2013; Soujanya et al., 2016; Enyiukwu et al., 2021).

Methyl bromide used to treat large grains has been banned due to its ozone depletion and attention deficiency effects (Soujanya et al., 2016). Consequently, botanicals and clays are considered cheap, ecologically degradable alternatives for sustainable control of weevils in low-input pest management (Emeasor and Ukwuoma-Eke, 2015; Gvozdenac et al., 2018; Hiruy and Getu, 2018).

Ageratum conyzoides and *Cymbopogon citratus* are commonly used herbs for treating boils and malaria in Trado-Medicare (Soujanya et al., 2016; Enyiukwu et al., 2021). Studies showed that *C. citratus* and *A. conyzoides* inhibited *Alternaria bataticola* and *Botrydiplodia theobromae* (Kwembe et al., 2020; Enyiukwu et al., 2021). In Africa, formulations of *Hyptis suaveolus* and *Mangifera indica* inhibited oviposition, while the progeny emergence of *Prostephanus truncatum* and *S. zeamais* can protect treated maize grains (90%) for 5 months (Ngamo et al., 2007; Gariba et al., 2021). In Kenya, organic extracts of *Tithonia diversifolia*, *Vernonia lasiopus* and *Jatropha curcas* demonstrated significant toxicities against *S. zeamais* (Oyedeji et al., 2020; Gitahi et al., 2021a; Gitahi et al., 2021b). Furthermore, de Araújo et al. (2019) reported strong insecticidal activities of *C. citratus* essential oils (Eos) against *S. zeamais* in Brazil.

Clays are common constituents of soils and sediments used in drugs and pesticide formulations (Nguemtchouin et al., 2013). They have long been used for grain protection against insect infestation in many places, including the USA and Cameroun (Ngamo et al., 2007; Bonjour, 2018). Meanwhile, diatomaceous earth and kaoline killed 100% of *S. zeamais* and *Plodia interpunctella* within 7 days (Gvozdenac et al., 2018). Bonjour (2018) reported that diatomaceous earth (Dryacide 100) effectively protected grains against storage weevils. Unmodified and modified clays demonstrated insecticidal activity (26% to 59%) against *S. zeamais* to increase the stability and action of test flora (Nguemtchouin et al., 2013; Mbouga et al., 2014; Noudem et al., 2021).

Even though preparations of *A. conyzoides*, *Cymbopogon* species and clays have been used effectively to control storage weevil in many African countries, their use for grain protection in Umudike, Abia state Nigeria has not been widely reported. However, they are widely available in Umudike, cheap, easy to use and ecologically non-disruptive. Therefore, this study aims to evaluate the toxicity of powder preparations of *Cymbopogon nardus*, *A. conyzoides*, clay and permethrin to control *S. zeamais* on stored maize grains.

MATERIALS AND METHOD

Experimental site

This experiment was conducted at the Crop Science Teaching and Research Laboratory of the Michael Okpara University of Agriculture, Umudike, Nigeria, during the 2020 cropping season. The laboratory's mean ambient temperature and relative humidity were 28±2℃ and 75±20%, respectively.

Insect rearing

The *S. zeamais* were obtained from naturally infested maize grains, reared and kept in transparent plastic buckets. Subsequently, the lids were covered with muslin cloth and placed inside cupboards in the laboratory.

Source and preparation of plant and clay materials

Leaves of *A. conyzoides*, *C. nardus* and clay were obtained from the University Neighborhood. They were sun-dried for three days, pulverized with a macro-hammer mill, then sieved using a muslin cloth (150 µm) to obtain a fine powder. Meanwhile, the dry clay was crushed into powder and packed separately in an air-tight container until required. Permethrin was obtained from an agrochemical store in Umuahia.

Clay analysis

The clay material was analyzed for potassium, phosphorus, phosphate, magnesium, calcium and sodium cations using standard protocols adopted from AOAC (2000).

Application of treatments and experimental design

Fifty grams each of maize (Var. Bende White) grains obtained from Ndoru Market in Ikwuano Local Government Area, Abia State, was kept in a deep freezer (72h), sun-dried (2h) and placed in transparent vials. Meanwhile, 1.25 g, 2.50 g, 3.75 g and 5.00 g of *C. nardus*, *A. conyzoides*, clay and permethrin were separately added. The treated grains were thoroughly admixed for effective sticking on the maize seeds. Then the control experiments were set up with no plant extract or permethrin added. The experimental design was 4 × 4 × 3 factorial in a Completely Randomized Design (CRD) with three replicates. Furthermore, ten adult *S. zeamais* were introduced into each vial and placed on the laboratory bench.

Data collection

Data on the mortality count of *S. zeamais* at 5, 7, 14, 21 and 28 days after treatment (DAT) showed the damage to maize grains, and percentage loss in grain weight was taken. Subsequently, the weight of maize grains in each vial was taken pre-and post-experiment and the weight loss due to *S. zeamais* infestation was noted. The weevil perforation index (WPI) assessed by counting the number of damaged seeds in all the experimental units at 60 DAT was determined using the formula adopted by Ileke et al. (2020) as in Equation 1.

$$\text{WPI} = \frac{\text{\% treated maize grains perforated}}{(\text{\% control maize grains perforated}) + (\text{\% treated grains perforated})} \times 100 \qquad (1)$$

Statistical analysis

Data obtained were transformed using the Arcsine Method and analyzed by ANOVA, and their means were separated and compared using F-LSD at α 5% level of probability.

RESULTS AND DISCUSSION

Mortality of adult insects

Results of the mortality profile of the treated maize seeds at 5 DAT (Table 1) indicated significant ($P \leq 0.05$) percentage adult mortality of *S. zeamais* among the treatments. Only seeds treated with permethrin recorded mean adult mortality of *S. zeamais* (72%) at all concentrations at 5 g dosage exposure.

The botanicals recorded no mortality at 7 DAT. Clay recorded 23.90% to 26.60% kills for dosage levels of 1.25 g 50 g^{-1} to 5.0 g 50 g^{-1} seeds. In contrast, the mortality rate for permethrin remained slightly lower at all concentrations (Table 2).

Table 3 shows the percentage mortality profile of the target pest at 14 DAT, and permethrin recorded 90% mortality at all levels of treatments. *A. conyzoides* and *C. nardus* had the same mortality count (6.14% to 18.26%) at all application levels, while clay had 28.78% mortality of the maize weevils.

Botanicals are cheap and sustainable management approach to weevil decimation of stored grains (Adedire and Ajayi, 1996; Mbouga et al., 2014; Brügger et al., 2019). Brügger et al. (2019) found that *C. citratus* demonstrated repellency to *Podisus nigripinus* and substantial toxicity against 1^{st} to 5^{th} instar of the insect. Similarly, Paranagama et al. (2003) reported that *C. nardus* reduced the population of *Sitotroga cerealella* on a rough rice paddy. In Nigeria, extracts of *C. citratus* sufficiently protected stored maize grains, recording *S. zeamais* mortality comparable to those of Coprex (0.25 g l^{-1}) (Oboho et al., 2017). Repellency and toxicity activities of citronella and *Ocimum gratissimum* extracts against rice and maize weevils are also reported (de Araújo et al., 2019; Telaumbanua et al., 2021).

Table 1. Effect of plant powder, clay and permethrin on adult mortality of *S. zeamais* at 5 days post-treatment

Treatments	Mean percentage mortality (Dosages g 50 g^{-1} seed)					
	0.00	1.25	2.50	3.75	5.00	Mean
A. conyzoides	1.00	1.00	1.00	1.00	1.00	1.00
C. nardus	1.00	1.00	1.00	1.00	1.00	1.00
Clay	1.00	1.00	1.00	1.00	12.29	2.46
Permethrin	1.00	37.22	57.00	54.99	72.29	44.30

Note: LSD = 0.05; Treatment (T) = 3.517; Dosages (D) = 3.932; T × D = 7.864

Table 2. Effect of plant powder, clay and permethrin on adult mortality of *S. zeamais* at 7 days post-treatment

Treatments	Mean percentage mortality (Dosages g 50 g^{-1} seed)					
	0.00	1.25	2.50	3.75	5.00	Mean
A. conyzoides	1.00	1.00	1.00	1.00	1.00	1.00
C. nardus	1.00	1.00	1.00	1.00	1.00	1.00
Clay	1.00	23.90	26.10	23.90	26.60	20.10
Permethrin	1.00	35.20	28.30	37.20	71.10	34.40

Note: LSD = 0.05; Treatment (T) = 5.88; Dosages (D) = 6.58; T × D = 13.15

Table 3. Effect of plant powder, clay and permethrin on adult mortality of *S. zeamais* at 14 days post-treatment

Treatments	Mean percentage mortality (Dosages g 50 g^{-1} seed)					
	0.00	1.25	2.50	3.75	5.00	Mean
A. conyzoides	1.00	6.14	6.14	18.43	18.43	9.83
C. nardus	1.00	6.14	6.14	18.43	18.43	9.83
Clay	1.00	28.78	26.57	26.07	28.78	22.04
Permethrin	1.00	90.00	90.00	90.00	90.00	72.00

Note: LSD = 0.05; Treatment (T) = 3.825; Dosages (D) = 4.277; T × D = 8.544

Moreira et al. (2007) reported the insecticidal activities of *A. conyzoides* against *Rhizopertha dominica*, *Periplaneta america*, *Musca domesticus* and *Diaphania hyalinata.* Furthermore, exposure of *Zonocerus variegatus* to 10 mg ml^{-1} to 300 mg ml^{-1} of *A. conyzoides* for 4 days to 5 days induced 100% mortality of the insect pest (Ingrid et al., 2020). Similar trials by Pintong et al. (2020) indicated significant mortality of *Aedes aegypti* (dengue fever vector) to *A. conyzoides*. The sensitivity of *Callosobruchus maculatus*, *Sitophilus oryzae* and *S. zeamais* to *A. conyzoides* was also documented (Rioba and Stevenson, 2017). Fumigation of wheat grains with *H. suaveolus* and *A. conyzoides* essential oil killed 100% of *Tribolium castaneum* adult weevil associated with the grains (Jaya et al., 2014).

The plant's high presence of terpenoids, including nerol, geranyl acetate, geraniol, limonene, citronellal and citral, underscored this insecticidal activity (Wifek et al., 2016; Brügger et al., 2019). However, the evaluation of individual lemongrass terpenes against *Sitophilus granarius* pointed to geranyl and neral as the most toxic active principles killing 75% and 43% of the weevil, respectively (Plata-rueda et al., 2020). Additionally, muscular damage, epithelial necrosis, as well as ovarian and compound eye degradation affected treated insects (Pintong et al., 2020).

A. conyzoides is associated with antimicrobial, antiprotozoal and insecticidal activities (Yadav et al., 2019; Kotta et al., 2020; Chahal et al., 2021). Pyrollizoline alkaloids, polyoxygenated flavones, glucosides, chromenes (conyzorigum), precocene I and II, coumarin and eugenol underscored the activities of *A. conyzoides*. The precocenes and coumarin have strong insecticidal potentials (Moreira et al., 2007; Soujanya et al., 2016; Faqueti et al., 2017; Kouame et al., 2017; Yadav et al., 2019; Kotta et al., 2020; Pintong et al., 2020). The results suggest that *A. conyzoides* and *C. nardus*, compared to permethrin, were less effective in protecting the maize grains from *S. zeamais* at 21 and 28 DAT since 5.00 g 50 g^{-1} maize caused 26.57% mortality of the insect pest. This was inconsistent with the report of Gariba et al. (2021), where formulations of *Lantana camara*, *Hyptis suaveolus* and *Mangifera indica* can effectively protect stored maize grains from *S. zeamais* and *Prostephanus truncatus*.

The study conducted by Gitahi et al. (2021a) and Gitahi et al. (2021b) reported that extracts of *T. diversifolia* and *V. lasiopus* have substantial insecticidal activities against *S. zeamais*. Furthermore, *C. maculatus* and *S. zeamais* were sensitive to extracts of *Lavandula alba*, *Lavandula stoechas* and *Citrus sinensis* (Oyedeji et al., 2020; Patiño-Bayona et al., 2021). Data obtained showed incongruences with reports on strong sensitivity of *S. zeamais* to powder formulations of *Jatropha curcus*, *Euphobia basalmifer* and *Lawsonia infermis* (Suleiman et al., 2012; Suleiman and Suleiman, 2014; Ishaya et al., 2021). However, these results agree with the submission of Vilarinho et al. (2016) that extracts from *Azadirachta indica* and *Cymbopogon winterianus* presented low insect killing potential compared to deltamethrin or chlorpyrifos.

The efficacy of botanical pesticides is influenced by the type and concentration of the active ingredient(s), exposure to thermo or UV radiation and duration of exposure to the target pests (Ofuya and Dawodu, 2002; Ononuju et al., 2016). The insecticidal constituents of most flora are terpenes and EOs (Oyedeji et al., 2020; Gitahi et al., 2021b). For example, Terpeol and 3-carvene demonstrated high contact toxicity to *C. maculatus* and *S. zeamais*. At the same time, citral showed high fumigant toxicity to both insect pests (Oyedeji et al., 2020) and these active principles have acetylcholine impeding activities (Oyedeji et al., 2020; Gitahi et al., 2021b).

The poor performance of *A. conyzoides* and *C. nardus* powders against the weevils is associated with the volatilization of the active principle from sun-drying. The data from Table 1 to 3 are contrary to reports of an increase in insecticidal activities of plant extracts against target insects with concentration and contact time (Gitahi et al., 2021a; Gitahi et al., 2021b). Therefore, the active principle(s) may have lost efficacy due to denaturation by high heat or light intensity from exposure to sunlight.

The active ingredients of most plants are terpenoids and their formulation remains a challenge. Nguemtchouin et al. (2013), Mbouga et al. (2014) and Noudem et al. (2021) reported that the toxicity, stability, and persistence of volatile active principles of *O. gratissimum* extracts were significantly improved by adsorption on modified and unmodified clays. Therefore, the observations do not agree with the submissions of Otitodun et al. (2017), where ash of rice husk killed (91.1%) adult insects and suppressed (63.4%) F1 progeny of *Rhyzopertha dominica* and *S. oryzae*. The insecticidal efficacy of rice husk was ascribed to the high silica contents of its ash. The absence or low presence of silica in the test plants may explain the poor insecticidal action against *S. zeamais* in this evaluation, and permethrin is a persistent, contact-stomach-acting poison (Gitahi et al., 2021b). The inferior insect killing potential of *C. nardus* and *A. conyzoides* compared to permethrin may be due to their active principles' shallow persistence, poor repellence or low antienzyme action.

The percentage mortality counts at 21 DAT showed that *A. conyzoides* and *C. nardus* still had the same mean mortality of 12.14%, being the lowest percentage mortality among all treatments (Table 4). The cumulative mortality profile for seeds exposed to permethrin (90.00%) remained virtually unchanged from the previous levels at 14 DAT. However, clay material recorded 21.14% to 39.15% kills of *S. zeamais* at dosages of 1.25 g to 5.00 g. Results presented in Table 5 showed the mortality counts at 28 DAT. The result shows that clay and permethrin had 90% cumulative mortality apiece at all levels of application of treatment aside from the control while *A. conyzoides* had the least mean cumulative mortality count of *S. zeamais* (Table 5).

The study showed that clay demonstrated higher toxicity against *S. zeamais* at 21 and 28 DAT at 5.00 g 50 g^{-1} maize, causing 90% mortality of the target weevils. The smoothness of seed surface and color affect the level of adherence, attack and damage on stored grains. Fine clay particles effectively block insects' spiracles and trachea, resulting in higher mortality of weevils (Chukwu, 2020). The fineness may have dissuaded insect adherence to the treated seeds caused asphyxiation and mortality of weevils leading to reduced attacks and damage of the treated seeds.

The findings are consistent with Mahmoud et al. (2010), who found kaolin powder effectively (100%) protects broad bean against *C. maculatus* and *Callosobruchus chinensis* within 1 to 3 months. It also corroborated the report where kaolin admixture caused significant mortality of adult and F1 progeny of *C. maculatus* in cowpea (Kpoviessi et al., 2017).

Table 4. Effect of plant powder, clay and permethrin on adult mortality of *S. zeamais* at 21 days post-treatment

Treatments	Mean percentage mortality (Dosages g 50 g^{-1} seed)					
	0.00	1.25	2.50	3.75	5.00	Mean
A. conyzoides	1.00	12.29	12.29	12.29	23.86	12.14
C. nardus	1.00	6.14	12.29	18.43	23.86	12.14
Clay	1.00	21.14	35.22	35.22	39.15	26.15
Permethrin	1.00	90.00	90.00	90.00	90.00	72.00

Note: LSD = 0.05; Treatment (T) = 4.339; Dosages (D) = 4.851; T × D = 9.703

Table 5. Effect of plant powder, clay and permethrin on adult mortality of *S. zeamais* at 28 days post-treatment

Treatments	Mean percentage mortality (Dosages g 50 g^{-1} seed)					
	0.00	1.25	2.50	3.75	5.00	Mean
A. conyzoides	1.00	1.00	6.14	18.43	26.57	10.23
C. nardus	1.00	18.43	21.14	23.86	26.57	18.00
Clay	1.00	90.00	90.00	90.00	90.00	72.00
Permethrin	1.00	90.00	90.00	90.00	90.00	72.00

Note: LSD = 0.05; Treatment (T) = 2.517; Dosages (D) = 3.035; T × D = 6.070

The results are presented in Table 6, where clay comprised potassium, sodium, phosphate, magnesium and calcium ions. Calcium ion has the highest percentage composition of 0.321%, followed by phosphate, while phosphorus was the least, recording 0.045%. These ions may form weak organic acids or bases on clay-treated seed surfaces from moisture from respiring insects and seeds. These may contribute to the higher kills of target insects observed in clay treated maize seeds than in botanicals.

Table 6. Metallic ions (cations) composition of clay used in the study

Cations	Percentage composition (%)
Potassium (K^+)	0.124
Sodium (Na^+)	0.129
Phosphate (PO_4^{3+})	0.138
Phosphorous (P)	0.045
Magnesium ($Mg^{2+)}$	0.129
Calcium ($Ca^{2+)}$	0.321

Note: Data are means of 3 determinations

The trend of kills exhibited by the treatments over time is shown in Figure 1. Permethrin effected massive kills of *S. zeamais* beginning from 5 DAT, whereas effects of clay on the target pest were recorded from the 21 to 28 DAT. The botanicals performed poorly, as shown by the mean mortality progress curve (Figure 1). This study also revealed that permethrin, a persistent, neurotoxic, sodium channel activator, (Adesuyi, 1982) demonstrated superior insect-killing activity compared to the botanicals. The higher toxicity of permethrin may be attributed to its longer persistence on treated materials and the environment, unlike the botanicals easily degraded by heat or UV-light (Ononuju et al., 2016). Even though permethrin is a contact therapeutic insecticide, clay can be used effectively as a prophylactic contact application.

Results presented in Table 7 showed the damage caused by *S. zeamais* on maize grains 60 DAT. Permethrin and *C. nardus* recorded the lowest and highest grain perforation with a mean value of 16.83% and 68.95%, respectively. The effect of *A. conyzoides*, *C. nardus* and clay was similar at all the concentration levels in controlling *S. zeamais*. Permethrin had the highest potency and recording percentage grain imperforation of 83.11%, while *C. nardus* had the least (Table 7). The mean WPI recorded for *C. nardus* was the poorest, followed by clay, while *A. conyzoides* had 42.62%. According to Suleiman et al. (2012) and Ileke et al. (2020), the WPI greater than 50 indicates negative grain protection or encouragement of infestation from a treatment.

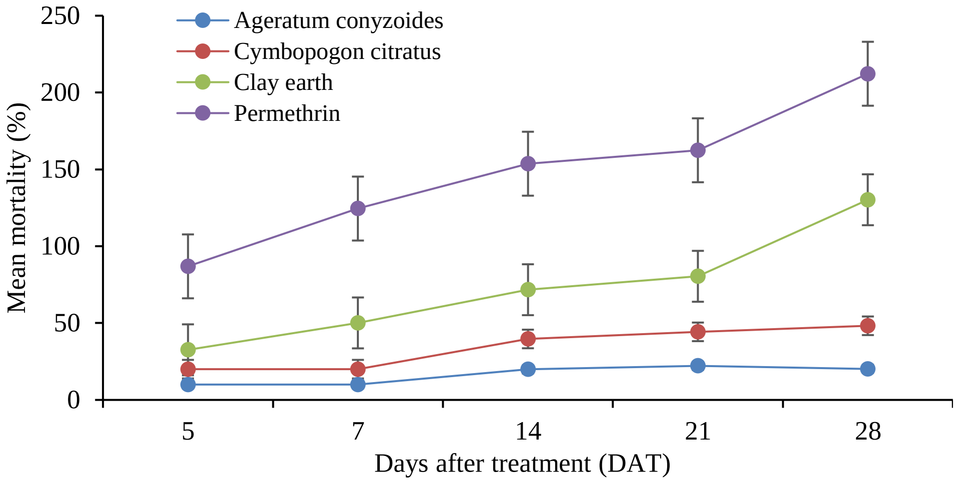

Figure 1. Progress curve showing cumulative mean mortality of *S. zeamais* on the treated maize grains

Table 7. Damage caused by *S. zeamais* to treated maize grains 60 days post-infection

Treatment (g) on 50 g of maize seeds	Grain perforation (%)	Grain unperforated (%)	WPI	Percentage weight loss
A. conyzoides				
1.25	66.50	33.50	42.80	53.00
2.50	56.80	43.20	38.78	51.27
3.75	77.80	22.20	46.07	50.87
5.00	68.30	31.70	42.81	43.13
Mean	67.35	32.65	42.62	49.57
C. nardus				
1.25	74.30	25.70	45.48	34.01
2.50	72.50	38.60	40.63	43.50
3.75	76.10	33.00	42.67	41.27
5.00	52.90	28.80	46.56	43.00
Mean	68.95	31.53	43.84	40.45
Clay				
1.25	70.90	29.10	45.76	35.53
2.50	61.40	38.60	44.97	37.53
3.75	66.50	33.50	46.14	32.40
5.00	70.20	29.80	37.32	11.33
Mean	67.25	32.75	43.55	29.20
Permethrin				
1.25	23.60	76.40	20.97	13.73
2.50	17.00	83.00	16.06	11.80
3.75	18.11	81.90	16.93	9.13
5.00	8.60	91.14	8.85	3.87
Mean	16.83	83.11	15.70	9.63
Control				
No treatment	88.70	11.30	50.00	85.73

Note: WPI = Weevil perforation index value above 50 is indicative of negative grain protection or enhancement of weevil infestation (Suleiman et al., 2012; Ileke et al., 2020)

Clay, *C. nardus*, *A. conyzoides* were inferior to permethrin (15.70), recording respective mean WPI values (43.55, 43.84, 42.62). Since the WPI values were less than 50, both clay and the botanicals can protect maize grains from attacks of *S. zeamais* (Suleiman et al., 2012; Ileke et al., 2020). The grains treated with *A. conyzoides* had the highest percentage weight loss, while the plot with a 5 g concentration of treatments had the lowest percentage. Permethrin and clay reduced the percentage of weight loss from 85.73% to 9.63% and 29.20%, showing high potency against *S. zeamais*.

All the treatments were superior to the observed protection indices on the maize grain over the control experiment, as indicated by the weevil protection index, greater and equal to 50 (Table 7). Superior clay and moderate insecticidal potential of the test botanicals to reduce weevil attack on maize grains and cause mortality translated to lower percentage weight loss of the treated grains over the untreated control.

CONCLUSIONS

This study demonstrated 10.23, 18.00 and 72.00% mean contact toxicity against *S. zeamais* within 28 DAT for *A. conyzoides*, *C. nardus* and clay. Permethrin was more effective and achieved a more significant mean cumulative mortality (90.00%) against the weevil in less exposure (14 DAT) than clay and the botanicals. Therefore, this study reveals that farmers can use powder formulations of leaves of *A. conyzoides*, *C. nardus* and clay as protectants rather than therapeutic agents against *S. zeamais*. However, further research is warranted on formulating and improving their activity or stability for longer persistence.

ACKNOWLEDGEMENT

The authors are very grateful to the staff of the Department of Plant Health Management, Laboratory of Plant Health Management and Unit of Research and Training of the College of Crop and Soil Sciences of the Michael Okpara University of Agriculture, Umudike, Nigeria.

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