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/caraka.tani.v3i1.54213

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
ils are very destructive, clay, in Africa, formulations of o control, demonstrated insecticidal activity (26 hs Beaveria). However, weevil logically degradable to. Furthermore, weevil logically degradable to. Consequently, infestation in many places, including (Ngamo et al., 2007; Gariba et al., 2021). Protect treated maize grains (90%) for 5 mont Prostephanus truncatum 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 (Oyedoji 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°C 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.

\[
WPI = \frac{\% \text{ treated maize grains perforated}}{(\% \text{ control maize grains perforated} + (\% \text{ treated grains perforated}) \times 100} \quad (1)
\]

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 ≤ 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 nigrispinus and substantial toxicity against 1st to 5th 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 Araujo 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) | Mean | 0.00 | 1.25 | 2.50 | 3.75 | 5.00 |
|------------|-----------------------------------------------|------|------|------|------|------|------|
| *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) | Mean | 0.00 | 1.25 | 2.50 | 3.75 | 5.00 |
|------------|-----------------------------------------------|------|------|------|------|------|------|
| *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) | Mean | 0.00 | 1.25 | 2.50 | 3.75 | 5.00 |
|------------|-----------------------------------------------|------|------|------|------|------|------|
| *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 americana*, *Musca domestica*, 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 (Witek 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 (conyzorignum), 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 et al., 2021). Data obtained showed incongruences with reports on strong sensitivity of *S. zeamais* to powder formulations of *Jatropha curcus*, *Euphorbia basalminfer* 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 Otiodun et al. (2017), where ash of rice husk killed (91.1%) adult insects and suppressed (63.4%) F1 progeny of *Rhysopertha 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 anti-enzyme 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 (PO₄³⁻) | 0.138                 |
| Phosphorous (P) | 0.045                     |
| Magnesium (Mg²⁺) | 0.129                   |
| Calcium (Ca²⁺) | 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](image)

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; Ikele 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.

**REFERENCES**

Adedire, C. O., & Ajayi, T. S. (1996). Assessment of the insecticidal properties of some plant extracts as grain protectants against the maize weevil, *Sitophilus zeamais* Motschulsky. *Nigerian Journal of Entomology*, 13(1), 93–101. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Adedire%2C%20C.%20%2C%20Ajayi%2C%20T.%20%2C%20S.%20+%281996%29+Assessment+of+the+insecticidal+properties+of+some+plant+extracts+as+protectants+against+the+maize+weevil+S.+%2C+S.+Sitophilus+zeamais+Motschulsky&as_nld=0&as_sdt=2005&scid=0,5

Adesuyi, S. A. (1982). Field trials with permethrin dust for the control of insect infestation on stored maize in southern Nigeria. *Journal of Stored Products Research*, 18(3), 125–130. https://doi.org/10.1016/0022-474X(82)90012-1

AOAC. (2000). *Official methods of analysis International* (17th ed.). Washington DC, USA: Association of organic and Analytical Chemists. Retrieved from https://scholar.google.co.id/scholar?cluster=17584172751477997691&hl=id&as_sdt=2005&sciodt=0,5

Bionet-Eafrinet. (2021). *Sitophilus zeamais* Motschulsky, 1885 - Maize weevil. Retrieved from https://keys.lucidcentral.org/keys/v3/eafrinet/maize_pests/key/maize_pests/Media/Html/Sitophilus_zeamais_Motschulsky_1885_-_Maize_Weevil.htm

Bonjour, E. L. (2018). Grain protectant and top-dress for stored grains. *Oklahoma Cooperative Extension Service*, EPP-7098. Retrieved from https://shareok.org/bitstream/handle/11244/334672/oksa_EPP-7098_2018-12.pdf?sequence=1

Brügger, B. P., Martínez, L. C., Plata-Rueda, A., de Castro e Castro, B. M., Soares, M. A., Wilcken, C. F., Carvalho, A. G., Serrão, J. E., & Zanuncio, J. C. (2019). Bioactivity of the *Cymbopogon citratus* (Poaceae) essential oil and its terpenoid constituents on the predatory bug, *Podisus nigrispinus* (Heteroptera: Pentatomidae). *Scientific Reports*, 9, 8358. https://doi.org/10.1038/s41598-019-44709-y

Chahal, R., Nanda, A., Akkol, E. K., Sobarzo-sánchez, E., Arya, A., Kaushik, D., Dutt, R., Bhardwaj, R., Rahman, M. H., & Mittal, V. (2021). *Ageratum conyzoides* L. and its secondary metabolites in the management of different fungal pathogens. *Molecules*, 26(10),
Chukwu, L. A. (2020). Insecticidal activity of some plant powders, clay and permethrin against *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) in Umudike, Nigeria [Unpublished doctoral dissertation]. Umuahia, Nigeria: Michael Okpara University of Agriculture.

de Araújo, A. M. N., de Oliveira, J. V., França, S. M., Navarro, D. M. d. A. F., Barbosa, D. R. e. S., & Dutra, K. de A. (2019). Toxicity and repellency of essential oils in the management of *Sitophilus zeamais*. Revista Brasileira de Engenharia Agrícola e Ambiental, 23(5), 372–377. https://doi.org/10.1590/1807-1929/agriambi.v23n5p372-377

Demeke, M., Pangrazio, G., & Maetz, M. (2009). Country responses to the food security crisis: Nature and preliminary implications of the policies pursued. Rome, Italy: Food and Agriculture Organization of the United Nations. Retrieved from http://www.globalbioenergy.org/uploads/media/0812_FAO_-_Country_responses_to_the_crisis.pdf

Emeasor, K. C., & Ukwuoma-Eke, O. (2015). Evaluation of insecticidal activity of some oils and clay against *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae) on stored cowpea. Journal of Sustainable Agriculture and the Environment (JSAE), 16(2), 252–262. Retrieved from https://ojs.mouau.edu.ng/index.php/jsae/article/view/71

Enyiukwu, D. N., Chukwu, L. A., Nwaogu, A. G., Bassey, I. N., & Nwaneri, J. A. (2021). Antifungal potentials of aqueous extracts of selected indigenous flora against leaf and stem blight (*Alternaria bataticola*) disease of sweet potato. Tropical Journal of Natural Product Research, 5(8), 1493–1499. https://doi.org/10.26538/tjnpr/v5i8.27

Faqueti, L. G., Sandjo, L. P., & Biavatti, M. W. (2017). Simultaneous identification and quantification of polymethoxyflavones, coumarin and phenolic acids in *Ageratum conyzoides* by UPLC-ESI-QToF-MS and UPLC-PDA. Journal of Pharmaceutical and Biomedical Analysis, 145(25), 621–628. https://doi.org/10.1016/j.jpba.2017.07.034

Gariba, S. Y., Dzidzienyio, D. K., & Eziah, V. Y. (2021). Assessment of four plant extracts as maize seed protectants against *Sitophilus zeamais* and *Prostephanus truncatus* in Ghana. Cogent Food and Agriculture, 7(1), 1918426. https://doi.org/10.1080/23311932.2021.1918426

Gitahi, S. M., Ngugi, M. P., Mburu, D. N., & Machocho, A. K. (2021a). Contact toxicity effects of selected organic leaf extracts of *Tithonia diversifolia* (Hemsl.) A. Gray and *Vernonia lasiopus* (O. Hoffman) against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). International Journal of Zoology, 2021, 8814504. https://doi.org/10.1155/2021/8814504

Gitahi, S. M., Ngugi, M. P., Mburu, D. N., & Machocho, A. K. (2021b). Repellent effects of selected organic leaf extracts of *Tithonia diversifolia* (Hemsl.) A. Gray and *Vernonia lasiopus* (O. Hoffman) against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). The Scientific World Journal, 2021, 2718629. https://doi.org/10.1155/2021/2718629

Gvozdenac, S., Tanasković, S., Krnjajić, S., Prvulović, D., Ovuka, J., & Sedlar, A. (2018). Effects of different inert dusts on *Sitophilus oryzae* and *Plodia interpunctella* during contact exposure. Proceedings of the 12th International Working Conference on Stored Product Protection (IWCSPP). https://doi.org/10.5073/jka.2018.463.179

Hiruy, B., & Getu, E. (2018). Efficacy of two locally available inert dusts against *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) of stored maize in Ethiopia. Journal of Stored Products and Postharvest Research, 9(1), 1–7. Retrieved from http://academicjournals.org/journal/ISPPR/article-full-text-pdf/72B7D9256403

Ileke, K. D., Adesina, J. M., Nwosu, L. C., & Olagunju, A. (2020). Perforation index assessment of cowpea seeds against cowpea bruchid, *Callosobruchus maculatus* (Fabricius) [Coleoptera: Chrysomelidae], infestation using *Piper guineense*. The Journal of Basic and Applied Zoology, 81, 60. https://doi.org/10.1186/s41936-020-00195-7
Ingrid, D. T., Akwanjoh, S. R., & Yacouba, M. (2020). Insecticidal activity of Ageratum conyzoides (Asteraceae) Aqueous Extracts against the Grasshopper Zonocerus variegatus (Orthoptera: Pyrgomorphidae). Journal of Agriculture and Ecology Research International, 21(8), 29–36. https://doi.org/10.9734/jaeri/2020/v21i830159

Ishaya, M., John, W. C., Oke, O., Chomini, M. S., Oladejo, A. O., Ihum, T. A., Olorundare, O. O., UkanyiRioha, C. J., Ayorinde, J. O., & Sikiru, G. K. (2021). Comparative effects of garlic (Allium sativum) bulb and bulb coat powder on maize weevils (Sitophilus zeamais). Russian Journal of Agricultural and Socio-Economic Sciences, 8(116), 91–95. https://doi.org/10.18551/rjosa.2021-08.10

Jaya, Singh, P., Prakash, B., & Dubey, N. K. (2014). Insecticidal activity of Ageratum conyzoides L., Coleus aromaticus benth. and Hypis suaveolens (L.) poit essential oils as fumigant against storage grain insect Tribolium castaneum Herbst. Journal of Food Science and Technology, 51, 2210–2215. https://doi.org/10.1007/s13197-012-0698-8

Kotta, J. C., Lestari, A. B. S., Candrasari, D. S., & Hariono, M. (2020). Medicinal effect, in silico bioactivity prediction, and pharmaceutical formulation of Ageratum conyzoides L.: A review. Scientifica, 2020, 6420909. https://doi.org/10.1155/2020/6420909

Kouame, B. K. F. P., Toure, D., Kablan, L., Bedi, G., Tea, I., Robins, R., Chalchat, J. C., & Tonzibo, F. (2017). Chemical constituents and antibacterial activity of essential oils from flowers and stems of Ageratum conyzoides from ivory coast. Records of Natural Products, 12(2), 160–168. https://doi.org/10.25135/rnp.22.17.06.040

Kpoviessi, D. A., Chougourou, D. C., Bokononganta, A. H., Fassinou-Hotegni, N. V., & Dossoj, J. (2017). Bioefficacy of powdery formulations based on kaolin powder and cashew (Anacardium occidentale L.) balms to control Callosobruchus maculatus F. (Coleoptera, Chrysomelidae: Bruchidae) in stored cowpea (Vigna unguiculata L.). International Journal of Biological and Chemical Sciences, 11(4), 1424–1436. https://doi.org/10.4314/ijbcs.v11i4.3

Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods, 6(1), 8. https://doi.org/10.3390/foods6010008

Kwembe, J. T. K., Mbula, J. P., Onantshu, O., Mpiana, P. T., & Haesaert, G. (2020). Antifungal activity of the strain of Lasiodiplodia theobromae and phytochemical study of Ageratum conyzoides and Newbodia laevis from Kasinger Region / DR Congo. International Journal of Pathogen Research, 5(4), 1–10. Retrieved from https://www.journalijpr.com/index.php/IJPR/article/download/30138/56554

Mahmoud, A. G., El-Sebai, O. A., Shahen, A. A., & Marzouk, A. A. (2010). Impact of kaolin-based particle film dusts on Callosobruchus maculatus (F.) and C. chinensis (L.) after different storage periods of treated broad bean seeds. Proceedings of the 10th International Working Conference on Stored Product Protection, 425. Retrieved from https://doi.org/10.5073/jka.2010.425.167.186

Mbouga, M. G. N., Ngassoum, M. B., Kamga, R., Cretin, M., & Chalier, P. (2014). Insecticidal formulation based on Ocimum gratissimum essential oil and montmorillonite clays for maize protection. IOBC-WPRS Bulletin, 98, 113–121. Retrieved from https://www.researchgate.net/publication/266004975_Insecticidal_formulation_based_on_Ocimum_gratissimum_essential_oil_and_montmorillonite_clays_for_maze_protection

Moreira, M. D., Picanço, M. C., Barbosa, L. C., A., Guedes, R. N. C., Barros, E. C., & Campos, M. R. (2007). Compounds from Ageratum conyzoides: isolation, structural elucidation and insecticidal activity. Pest Management Science, 63(6), 615–621. https://doi.org/10.1002/ps.1376

Ngamo, T. L. S., Goudoum, A., Ngassoum, M. B., Mapongmetsem, Logнay, G., Malaisse, F., & Hance, T. (2007). Chronic toxicity of essential oils of 3 local aromatic plants towards Sitophilus zeamais Motsch (Coleoptera: Curculionidae). African Journal of Agricultural Research, 2(4), 164–167.
Nguenmtchouin, M. G. M., Ngassoum, M. B., Chalier, P., Kamga, R., Ngamo, L. S. T., & Crépin, M. (2013). Ocimum gratissimum essential oil and modified montmorillonite clay, a means of controlling insect pests in stored products. Journal of Stored Products Research, 52, 57–62. https://doi.org/10.1016/j.jspr.2012.09.006

Noudem, J. A., Mbouga, M. G. N., Ngassoum, M. B., & Tsague, R. K. T. (2021). Insecticidal activities of essential oil of Ocimum gratissimum in composite of modified saponins-clay montmorillonite and mango seed starch bioplastic. SSRN, 3949250. https://doi.org/10.2139/ssrn.3949250

Nwosu, C. L., Adedire, C. O., & Ogunwolu, E. O. (2015). Screening for new sources of resistance to Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae) infestation in stored maize genotypes. Journal of Crop Protection, 4(3), 277–290. Retrieved from http://jcp.modares.ac.ir/article -3-10469-en.html

Nwosu, L. C. (2018). Maize and the maize weevil: Advances and innovations in postharvest control of the pest. Food Quality and Safety, 2(3), 145–152. https://doi.org/10.1093/fqsafe/ fyy011

Oboho, D., Eyo, J., Ekeh, F., & Okweche, S. (2017). Efficacy of Cymbopogon citratus Stapf leaf extract as seed protectant against Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae) on stored maize (Zea mays L.). Journal of Biological Control, 30(4), 220–225. https://doi.org/10.18311/jbc/2016/15540

Ofuya, T. I., & Dawodu, E. O. (2002). Aspects of insecticidal action of Piper guineense (Shum and Thonn) fruit powders against Callosobruchus maculatus (F) Coleoptera: Bruchidae. Nigerian Journal of Entomology, 19, 40–50. Retrieved from http://esnjournal.com.ng/download/Vol_19/Vol_19_d5.pdf

Ononuju, D. E. C., Awurum, A. N., & Nwaneri, J. A. (2016). Modes of action of potential phyto-pesticides from tropical plants in plant health management. IOSR Journal of Pharmacy, 6(7), 1–17. https://doi.org/10.9790/ 3013-06710117

Otitodun, G. O., Opit, G. P., Nwaubani, S. I., & Okonkwo, E. U. (2017). Efficacy of rice husk ash against rice weevil and lesser grain borer on stored wheat. African Crop Science Journal, 25(2), 145–155. https://doi.org/10.4314/acsj.v25i2.2

Oyedeji, A. O., Okunowo, W. O., Osuntoki, A. A., Olabode, T. B., & Ayo-folorunso, F. (2020). Insecticidal and biochemical activity of essential oil from Citrus sinensis peel and constituents on Callosobruchus maculatus and Sitophilus zeamais. Pesticide Biochemistry and Physiology, 168, 104643. https://doi.org/10.1016/j.pestbp.2020.104643

Paranagama, P., Abeysekera, T., Ngaliyadde, L., & Abewickrama, K. (2003). Effect of the essential oils of Cymbopogoncitrus, Cymbopogon nardus and Cinnamomum zeylanicum pest incidence and grain quality of rough rice (paddy) stored in an enclosed seed box. Journal of Food Agriculture and Environment, 1(2), 134–136. Retrieved from https://www.researchgate.net/publication/266390555_Effect_of_the_essential_oils_of_Cymbopogoncitrus_Cymbopogon_nardus_and_Cinnamomum_zeylanicum_pest_incidence_and_grain_quality_of_rough_rice_paddy_stored_in_an_enclosed_seed_box

Patiño-Bayona, W. R., Galeano, L. J. N., Cortes, J. J. B., Ávila, W. A. D., Daza, E. H., Suárez, L. E. C., Prieto-Rodríguez, J. A., & Patiño-Ladino, O. J. (2021). Effects of essential oils from 24 plant species on Sitophilus zeamais Motsch (Coleoptera, Curculionidae). Insects, 12(6), 532. https://doi.org/10.3390/insects12060532

Pintong, A., Ampawong, S., Komalamisra, N., Sriwichai, P., Popruck, S., & Ruangsittichai, J. (2020). Insecticidal and histopathological effects of Agaratum conyzoides weed extracts against dengue. Insects, 11(4), 224. https://doi.org/10.3390/insects11040224

Plata-rueda, A., da Silva Rolim, G., Wilcken, C. F., Zanuncio, J. C., Serrao, E. J., & Martinez, L. C. (2020). Acute toxicity and sublethal effects of lemongrass essential oil and their components against the granary weevil, Sitophilus granarius. Insects, 11(6), 379.
Retrieved from https://www.mdpi.com/2075-4450/11/6/379

Rioba, N. B., & Stevenson, P. C. (2017). *Ageratum conyzoides* L. for the management of pests and diseases by small holder farmers. *Industrial Crops and Products, 110*, 22–29. https://doi.org/10.1016/j.indcrop.2017.06.068

Samuel, A., Saburi, A., Usanga, O. E., Ikotun, I., & Isong, I. U. (2011). Post-harvest food losses reduction in maize production in Nigeria. *African Journal of Agricultural Research, 6*(21), 4833–4839. Retrieved from https://www.researchgate.net/publication/228759281_Post-harvest_food_losses_reduction_in_maize_production_in_Nigeria

Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security, 3*, 307. https://doi.org/10.1007/s12571-011-0140-5

Soujanya, P. L., Sekhar, J. C., Kumar, P., Sunil, N., Prasad, C. V., & Mallavadhani, U. V. (2016). Potentiality of botanical agents for the management of post harvest insects of maize: A review. *Journal of Food Science and Technology, 53*(5), 2169–2184. https://doi.org/10.1007/s13197-015-2161-0

Suleiman, M., & Suleiman, H. Y. (2014). Control of *Callosobruchus maculatus* (Coleoptera: Bruchidae) using leaf powders of *Euphobia balsamifera* and *Lawsonia infernalis*. *International Journal of Science, Environment, and Technology, 36*(1), 100–109. Retrieved from https://www.academia.edu/download/47602758/Control_of_Callosobruchus_maculatus_F.20160728-23992-1bapx02.pdf

Suleiman, M., Ibrahim, N. D., & Majeed, Q. (2012). Control of *Sitophilus zeamais* (Motsch.) [Coleoptera: Curculionidae] on sorghum using some plant powders. *International Journal of Agriculture and Forestry, 2*(1), 53–57. https://doi.org/10.5923/j.ijaf.20120201.09

Suleiman, R., & Rosentrater, K. (2015). Current maize production, postharvest losses and the risk of *Mycotoxins contamination* in Tanzania. *American Society of Agricultural and Biological Engineers Annual International Meeting*, 152189434. https://doi.org/10.13031/aim.20152189434

Telaumbanua, M., Savitri, E. A., Shofi, A. B., Suharyatun, S., Wisnu, F. K., & Haryanto, A. (2021). Plant-based pesticide using citronella (*Cymbopogon nardus* L.) extract to control insect pests on rice plants. *IOP Conference Series: Earth and Environmental Science, 739*, 012071. https://doi.org/10.1088/1755-1315/739/1/012071

USDA. (2019). *USDA (United States Department of Agriculture) Nutritional composition of maize (corn)*. Retrieved from https://fdc.nal.usda.gov/fdc-app.html#/food-details/169998/nutrients

Vilarinho, M. K. C., da Silva, T. J. A., Caneppele, C., & Rozado, A. F. (2016). Chemical pesticides and vegetal extracts on *Sitophilus zeamais* control in stored corn grains. *Bioscience Journal, 32*(2), 288–297. https://doi.org/10.14393/BJ-v32n2a2016-26160

Wifek, M., Saeed, A., Rehman, R., & Nisar, S. (2016). Lemongrass: a review on its botany, properties, applications and active components. *International Journal of Chemical and Biochemical Sciences, 9*(2016), 79–84. Retrieved from https://www.researchgate.net/publication/336134806_Lemongrass_a_review_on_its_botany_properties_applications_and_active_components

Yadav, N., Ganie, S. A., Singh, B., Chhillar, A. K., & Yadav, S. S. (2019). Phytochemical constituents and ethnopharmacological properties of *Ageratum conyzoides* L. *Phytotherapy Research, 33*(9), 2163–2178. https://doi.org/10.1002/ptr.6405