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Insecticidal activities of indigenous plants from Volta Region, Ghana in managing *Sitophilus zeamais* and *Prostephanus truncatus* in stored maize

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Abstract. *Ankutse DK, Eziah VY, Afreh-Nuamah K. 2021. Insecticidal activities of indigenous plants from Volta Region, Ghana in managing* Sitophilus zeamais *and* Prostephanus truncatus *in stored maize. Intl J Trop Drylands 5: 48-60.* The rising rate of pest resistance, and the high expense and health risks associated with insecticide use, have become a source of public concern. This study aimed to discover and evaluate plant species used by farmers in the Volta Region to control *Sitophilus zeamais* (Motschulsky, 1855) and *Prostephanus truncatus* (Horn, 1878) in stored maize grains. In a survey, *Azadirachta indica, Clausena anisata, Phyllanthus amarus, Picralima nitida, Vernonia amygdalina, Nauclea latifolia,* and *Momordica charantia* were discovered to be grain protectants against stored insect pests. All of the plants indicated above were employed in the experiment, except for *A. indica*, which has a long history of being used to combat grain storage pests. The insecticidal activity of dried powders (5 and 10%) and aqueous extracts (0.1 and 0.2 g/mL) of plants against *P. truncatus* and *S. zeamais* was examined. Plant species and dose rate influenced repellency. In the *V. amygdalina* treatment, plant powders and methanol extracts were the most poisonous to insects. The toxicity of *V. amygdalina* to *P. truncatus* and *S. zeamais* was 83.3 and 86.7%, respectively, at higher concentrations of 0.2 g/mL. At 0.2 g/mL, all plant extracts exhibited a significant difference in Actellic repellent (P0.05); nevertheless, *C. anisata* had the highest repellent action against *P. truncatus* and *S. zeamais*, with 80.0 and 66.7%, respectively. As grains were treated with plant extracts, oviposition and egg emergence were reduced compared to the control. When embryonic stages of insects were treated with methanol extracts of botanicals, the number of adult insects decreased. These findings show that the studied plants have the potential to aid in the development of post-harvest protection technology against the principal pests of stored grains, *P. truncatus* and *S. zeamais*. As a result, farmers should use it to control *P. truncatus* and *S. zeamais* in stored maize grains.

Keywords: Indigenous plants, insecticidal, *Prostephanus truncatus*, *Sitophilus zeamai*s, *Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) is a member of the Gramineae family and is one of the most significant cereal crops grown in various agro-ecological environments around the world (Owusu-Sekyere et al. 2011). Maize is produced in greater quantities than any other grains, and statistics reveal that maize accounts for 37% of total cereal consumption in Sub-Saharan Africa (Quandzie 2011). In Ghana, it is grown in all ten regions of the country with the Eastern Region being the most prolific producer. Maize is only third in production after roots & tubers and plantain (MOFA 2008). Maize farming takes up less space than wheat or rice, but produces a higher average output per unit area of roughly 5.5 tons per hectare (Obeng-Ofori and Dankwah 2004).

Maize is used for three main purposes: human food, industrial raw materials, and livestock feed. According to IITA (2003), globally, 66% of all maize is utilized for livestock feed, 25% for human consumption, and 9% for industrial purposes. However, in poor countries such as Ghana, around half of all maize is consumed as food, while the remaining 43% is given to livestock and the rest is used for industrial purposes. Whole grains are either mature or immature (fresh corn) or various processed forms, depending on the location or ethnic group. It can also be processed into a wide range of intermediate goods, including different-sized maize grits, maize meal, maize flour, and flaking grits.

Despite maize's importance, storage losses are still relatively substantial. According to FAO (2008), global grain losses amount to about 10% of all stored grain, i.e., 13 million tons of grain are lost owing to insect pest damage and 100 million tons are lost due to improper storage. According to Cornelius et al. (2008) estimates, losses in developing countries might be as high as 50% of what is produced. In contrast to perishable crops, maize can be stored for extended periods of time; however, preservation quality during long-term storage is an issue in many regions of the world, as quality decreases with storage duration. Losses in storage might occur as a result of over-drying of grains, weight loss owing to respiration, or the incorrect application of synthetic pesticides. In addition, infestation by rodents and insects, as well as feeding damage, contamination with mycotoxins caused by molds and bacteria, and dead insect parts, can all lead to storage loss (Boxall 2001).

The most common insect pests on maize are *Prostephanus truncatus* (Horn, 1878) (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Motschulsky, 1855) (Coleopteran Curculionidae). The larvae and adults of both insects feed on the grain, reducing its viability, quality, and value, as well as its weight and nutrients (Cornelius et al. 2008). Food insecurity and poverty levels among farmers have increased as a result of this predicament, particularly in developing nations like Ghana.

Synthetic pesticides are currently commonly utilized to control insect pests of stored foodstuffs in most developing countries, such as Ghana. However, indiscriminate use of synthetic pesticides has resulted in food poisoning, the extinction of natural enemies and non-target species, pest resistance, the transformation of harmless species into pests, food contamination and air pollution all, of which pose a health risk to humans and animals (Gill and Garg 2014).

As a result, most academics are now focusing on non-chemical grain storage systems in order to limit the usage of synthetic insecticides. Plants have significant economic and health benefits for users, consumers, and the environment (Elhag 2000; Talukder and Howse 2000). The usage of plant extracts has a variety of impacts on insects. They are non-toxic to warm-blooded animals and act as antifeedants, growth regulators, sterilants, oviposition deterrents, repellents, and impair insect fitness (Saxena et al. 1989; Schmutterer 1990). According to Obeng-Ofori (2007), the application of plants as grain protectants from insect damage is gaining traction and yielding favorable results in recent years.

Under these conditions, laboratory and field bioassays were undertaken to determine the efficiency of six indigenous Ghanaian plant powders and extracts against *S. zeamais* and *P. truncatus* in the Volta Region's Jasikan, Afadjato, and South Dayi Districts. The objectives of this research were (i) To identify the various plant species used to preserve corn in the selected districts. (ii) To determine the antimicrobial efficacy of six potential plant powders against *S. zeamais* and *P. truncatus* in preserved maize. (iii) To determine the toxicity and repellency of the best plant's methanol extract against *S. zeamais* and *P. truncatus* in stored maize. (iv) To determine the optimal concentration of the most effective plant methanol extract against *S. zeamais* and *P. truncatus* in stored maize. (v) To determine the effective concentration of potential plant extract against *S. zeamais* and *P. truncatus* in a bioassay.

MATERIALS AND METHODS

The study area

A survey was done in three districts of Ghana's Volta Region (Jasikan, Afadjato, and South Dayi) to ascertain the plants used by farmers to protect maize grains from insect pests. The Jasikan District is one of the Volta Region's twenty-five (25) municipalities and districts. Jasikan serves as the administrative capital. The district is bounded on the east by the Republic of Togo, on the west by the Volta River, on the north by Biakoye District, and on the south by Afadjato District and Kpandu Municipal. It has an area of 1355 km^2 and comprises 33 villages and 33 sub-towns. The primary activity of their inhabitants is farming, with the majority of them being women engaged in small-scale production (Ghanaditricts.com 2013).

In 2012, the Afadjato District was carved out of Hohoe Municipality. Ve-Golokwati serves as the administrative capital of the District. The District is bounded on the north by Hohoe Municipality, on the west by Kpando Municipality, on the east by the Republic of Togo, and on the south by Ho West District and South Dayi District. It comprises around 238,533 km^2 and the majority of its inhabitants are peasant farmers who cultivate corn primarily on subsistence scales (ghanaditricts.com 2013).

South Dayi District is located between latitudes 3.020'N and 3.5005'N, with longitude 0017'E. It is bordered on the north by Kpando and Afadjato South, east by Ho West, and south by Asougyaman District, with the Volta Lake forming the western boundary. The District has a total size of 1,000 km^2, with the Volta Lake submerging around 20% of it. The yearly rainfall averages between 900 and 1300 millimeters. The District's vegetation is dominated by Guinea woodland and deciduous forests. The human population of South Dayi District in September 2010 was 46,661, according to the 2010 Population and Housing Census. Farming and fishing activities employ approximately 62% of the economically active population (Ghanaditricts.com 2013).

The laboratory and final field trials were done at the University of Ghana Farm and the Entomology Laboratory at the Crop Science Department. A ventilated crib of 3 x 1.5 x 1.5 m was built with a wooden framework at the University farm of Ghana-Legon. The efficacy of plant extracts against *S. zeamais* and *P. truncatus* in bioassay was determined by storing grains treated with four extracts at two concentration levels in the crib.

Field survey

The Volta Region's field survey was done in three districts: Jasikan, Afadjato, and South Dayi. Three villages were chosen at random in each district to represent villages, and ten maize farmers in each village were picked with the help of extension officers. Ninety (90) farmers from the three districts were asked open-ended and closed-ended questions. Farmers' demographics, storage methods, maize varieties and effectiveness, and customer acceptability of grain treated with plant extracts were all covered in the questionnaires. The data was examined using the SPSS storage method.

Culturing of insects

Sitophilus zeamais

Sitophilus zeamais was isolated from contaminated maize grains collected from a maize farmer in the Volta Region's Kpeve. In the Crop Science Laboratory, one hundred adult insects of mixed sexes were infested in 500 g of sterilized grains in a glass jar covered with muslin cloth. The culture was stored on the laboratory shelf for one week to allow for oviposition. Adult insects were removed, and emerging generations were used to establish the experimental cultures. To get enough insects for the studies, the culturing of *S. zeamais* was repeated four times.

Prostephanus truncatus

Prostephanus truncatus samples were collected from infested maize grain stock at Baika in the Jasikan District of the Volta Region and from old stock at the Crop Science Laboratory. First, whole maize grains were sterilized for 3 hours at 60°C and then allowed to cool for 12 hours before being utilized in the culture. Then, in a glass jar, one hundred insects of mixed sexes were injected into 500 g of sterilized maize grains using an aspirator in a controlled room at 28 ± 2°C and 65% relative humidity (Osafo 1998; Weaver et at. 1998; Udo et al. 2009). Adult insects have sieved away after one week of oviposition and the culture was left to stand for emerging progeny employed to establish the experimental cultures (Udo et al. 2009).

Selection of plants

The plant species employed in grain storage in this study were chosen based on the following parameters by farmers during a field survey. These considerations include the efficiency of the plant against stored insects, its availability, how frequently it is employed in the area, and whether or not the plant has been utilized or properly researched in the country to store grains.

Seven plants were detected in total (*Azadirachta indica, Clausena anisata, Phyllanthus amarus, Picralima nitida, Vernonia amygdalina, Nauclea latifolia,* and *Momordica charantia*), although *A. indica* was not picked due to its considerable research in the country. The synthetic reference pesticide Actellic was chosen since it is one of Ghana's most frequently utilized synthetic chemicals for grain storage. The names of the plants, their local names in the location where they were collected, and the portions used to prepare the plant powders and extracts are listed in Table 1.

Preparation of plant powders

The components of the six plant species were gathered from Baika in the Volta Region's Jasikan District. They were brought to the Crop Science Laboratory of the University of Ghana-Legon, where they were prepared for identification at the university's herbarium in the Botany Department. After washing the plant specimens with tap water to remove sand and other undesirable particles, they were air-dried for 15 days at room temperature. Next, the specimens of the chosen plants were beaten using a mortar and pestle before being processed into a fine powder. To achieve homogeneous size particles, the powders were sieved with an Impact Test Sieve with a mesh size of 70. A day before being employed for grain treatment, the crushed powders were kept in six distinct airtight containers.

Preparation of methanol extract of plants

Six conical flasks containing 430 mL each of 100% methanol were filled with approximately 100 g of the plant powders. For 48 hours, the flasks were covered with Parafilm and shaken. The solution was filtered through a 2.5-mesh filter and concentrated at 60°C using a rotary evaporator, following which the residues were dissolved in acetone to obtain concentrations of 0.1 g/mL and 0.2 g/mL for the various bioassays.

Screening of the six plant powders

Effect of plant powders on adult insects

Four kg of whole grains was placed on a metal tray and sterilized in a 60°C oven for 3 hours. For 24 hours, the sterilized grains were equilibrated at 28 ± 2°C and 65% relative humidity in a controlled atmosphere. Sterilized whole maize grains (100 g) were placed in glass jars, and two sets of plant powders (5% and 10%) were combined in with the grains. Actellic 25 EC was administered in acetone at a concentration of 2 mL/L, while the control treatment included no botanical powder. Before introducing 20 adult *S. zeamais* and *P. truncatus* (5-10 days old) into the treated and untreated maize grains, the setups were let to stand for one hour. Under a randomized design, the treatments were replicated four times. For seven days, the daily mortality of insects was recorded. It was declared dead if an insect did not respond to poking with a blunt probe.

Effect of methanol extracts on adult insect in treated grains

Sterilized maize grains (50 g) were placed in Kilner glass jars, and four botanicals (*C. anisata, P. amarus, P. nitida,* and *V. amygdalina*) were administered to each jar in two concentrations (0.1 g/mL and 0.2 g/mL). In addition, grain was treated with Actellic (2 mL/L) and control-treated with acetone. The treated grains were air-dried for one hour to evaporate the solvent. After introducing twenty adult *S. zeamais* and *P. truncatus* (5-10 days old) into the treated and untreated maize grains, the jars were covered with muslin cloth held in place with rubber bands. The treatments were repeated four times and kept for one week in a controlled chamber at 28 ± 2°C and 65% relative humidity. Insects were declared dead if they did not respond to three probes with a blunt probe.

Table 1. Plant species used for the experiment

Plant species	Local name	Common name	Parts use	Stage of collection
Clausena anisata	Ayira	Horsewood	Leaves	Before flowering
Phyllanthus amarus	Kpavideme	Phyllantus	Leaves	During flowering
Picralima nitida	Quinine	Akuamma plant	Seed	Matured seed
Vernonia amygdalina	Gbɔti	Bitter Leaf	Leaves	Before flowering
Nauclea latifolia	Nyimɔke	African peach	Root	Maturity
Momordica charantia	Kakle	Bitter gourd	Leaves	During flowering

Contact toxicity by topical application

The procedure described by Obeng-Ofori and Reichmuth (1997) was used in this test. Ten adults of each *S. zeamais* and *P. truncatus* (5-10 days old) were placed in a separate petri dish lined with damp filter paper for three minutes. Using a micro-pipette, one microlitre of four plant extracts, Actellic, and a control (water) were applied to the dorsal surface of the thorax of insects. The experiment was carried out four times in all. The mortality of insects was measured during five days.

Effect of methanol extracts on oviposition

50 g maize grains were weighed into glass jars and given four different herbal treatments. Another jar was given Actelic at a concentration of 2 mL/L, whereas the control received no treatment. The treated grains were infested with mixed sexes of 20 adults of *S. zeamais* and *P. truncatus* (5-10 days old) after being left for one hour. To allow for oviposition, the jars were covered with muslin cloth kept in place with rubber bands and put in a controlled atmosphere at 28 ± 2°C and 65% relative humidity for seven days. The experiment was set up in a completely randomized design with three repetitions. The adult insects were sieved on the eighth day, and the number of eggs laid was calculated using egg plug staining procedures (acid fuchsin method) FAO (2008).

Effect of methanol extracts of plants on eggs and immature stages

Effect on eggs

Six glass jars were filled with sterilized maize grains (100 g) with a moisture content of 12%. To allow for egg laying, the grains were infested with 20 adult *S. zeamais* and *P. truncatus* (5-10 days old) of mixed sexes in each set of jars. After seven days of oviposition, the adult insects were collected and the percentage of oviposition was calculated before grains were treated with methanol extracts of *C. anisata, P. amarus, P. nitida,* and *V. amygdalina* at 0.1 g/mL and 0.2 g/mL, respectively. Water and Actellic were used to treat the control and reference groups, and each treatment was repeated three times. In addition, the number of newly emerged adults was counted and recorded.

Toxicity of methanol extracts to larva.

Twenty adults of *S. zeamais* and *P. truncatus* (5-10 days old) of mixed sexes were infested with 100 g of sterilized maize in each glass jar, and oviposition was allowed for seven days. On the seventh day, the adult insects have sieved away, and the grains were permitted to stay for another seven days to allow the eggs to develop into larva. The grains were subsequently treated with two concentrations of plant extracts and Actellic (0.1 g/mL and 0.2 g/mL), with the control being treated with acetone. Under a completely randomized design, the experiment was repeated four times. The number of newly emerged adults was counted and recorded.

Effect of methanol extracts on the pupa

In this experiment, 100 g of sterilized maize grains was placed in twelve glass jars, with twenty adults of *S. zeamais* (5-10 days old) of mixed sexes delivered into six jars and twenty adults of *P. truncatus* introduced into the remaining six jars. On the seventh day following oviposition, the mature insects have sieved. The grains were treated with four different botanical extracts and Actellic at two concentrations (0.1 g/mL and 0.2 g/mL) on the 22nd day, whereas the control was given water. The emerged adults were numbered and documented after each treatment was reproduced three times in a completely randomized method.

Repellency assay

The repellency of methanol extracts of plants on *S. zeamais* and *P. truncatus* was determined in the laboratory using Obeng-Ofori and Reichmuth's (1997) approach carried out at 28 ± 2°C and 68-73% relative humidity. Full disc filter sheets were separated into two halves, with one half being treated with the test solutions (0.1 g/mL and 0.2 g/mL) and the other half being treated with water using a micropipette. The modified filter sheets were air-dried for three hours in the laboratory. The treated and untreated filter papers of the same dimension were joined together to produce a whole disc using sellotape. Each filter paper was placed in a petri dish, and 10 adults (5-10 days old) mixed sexed *S. zeamais* and *P. truncatus* were placed in the center of each filter paper and covered. Three times the experiment was carried out. The number of insects present on the treated (Nt) and control (Nc) groups were counted and recorded 30 minutes after the insects were introduced. $PR = [(Nc - Nt)/ [(Nc + Nt)] \times 100$ was used to calculate the percentage repellency (PR) values.

Damage assessment

An approach of Cornelius et al. (2008) for assessing grain damage was used. Methanol extracts of four plants treated sterile whole maize grains (2 kg) each. The control group received simply methanol treatment. The treated grains were then air-dried for three hours before being placed in 30 x 40 cm sacks. One hundred *S. zeamais* and *P. truncatus* adults (5-10 days old) of mixed sexes were discharged into two separate bags. Three times each therapy was carried out. The bags were then placed in a crib at the University of Ghana farm for ten weeks, following which the amount of weight lost was calculated using the count and weigh method. 1000 grain samples were taken from each of the treatments, and 500 grains were counted from each sample. Damaged and undamaged grains were isolated from the 500 grains. They were all weighed and counted. The percentage weight loss was calculated using the FAO approach, as updated by Cornelius et al. (2008):

$$\text{Percent Weight Loss} = (UNd)-(DNu)/ U(Nd + Nu) \times 100$$

Where: *Nu* is the number of undamaged grains; *Nd* is the number of damaged grains; *U* is the weight of undamaged grains; and *D* is weight of damaged grains.

Separate sieves were used to separate the grains, and the frass from each treatment was weighed and the means compared.

RESULTS AND DISCUSSION

Survey

A summary of survey results from the three districts of the Volta Region

Respondent profile: this section covers the respondent's gender, age group, marital status, educational level, dependents, and farming experience. The study discovered that both men and women were active in utilizing plants to manage pests of stored products, albeit the demographics indicated a higher proportion of female respondents (72%). Farmers' ages and educational levels did not differ significantly across the three districts. While all respondents were adults, 60% were between the ages of 40-60, 94% of farmers had some level of schooling, and 85% were married with dependents (Table 2). At least 70% of respondents reported had 10-20 years of expertise growing and utilizing botanicals to conserve their produce.

Type of crops grown and storage method by farmers in Volta Region

Although a variety of crops were planted, 90% of respondents cultivated maize for subsistence farming, primarily during the minor season for storing. Farmers harvest and store their crops manually in the majority of cases. For example, 50% of farmers stored their corn in cribs, while the other half stored grains in 15 L oil gallon (hermetic) containers with plant parts, barns, and sacks (Figure 1).

Table 2. A summary of survey results from the three districts of the Volta Region, Ghana

	Frequency	Percentage
Sex		
Male	25	28
Female	65	72
Age of farmers (range)		
Under 21	0	0
21-40	22	25
41-60	54	60
Above 60	14	15
Educational level		
None	5	6
Basic	49	54
Secondary	27	30
Tertiary	9	10
Method of storage		
Crib	45	50
Barn	15	17
Hermetic	30	33
Total	60	100

Figure 1. Methods of maize storage with plant parts in Jasikan, Afadjato and South Dayi Districts, Volta Region, Ghana. A. Integrated storage method, B. Crib, C. Barn, D. Integrated Storage Method

The use of plant elements, effectiveness and marketing of grains treated with botanicals

According to the survey, 90% of respondents utilized just plant elements, while 10% used plant elements and synthetic chemicals (Actellic). Farmers utilized a total of seven plant species to prevent their wheat from insect pest infestation (Table 3). From 73.5% respondents agreed that *A. indica, C. anisata, P. nitida,* and *V. amygdalina* were more effective at managing stored insect pests than the other plant species. All respondents agreed that there were no issues with the sale of grains preserved with plant elements.

Effect of plant powder on *Sitophilus zeamais and Prostephanus truncatus* in treated maize

Figure 2 illustrates the reaction of all six plant powders at 5% and 10% against adult *P. truncatus* and *S. zeamais* after seven days. After seven days of treatment with all six plant powders at 5% and 10%, *S. zeamais* survival ranged between 54-86% and 41-64%, respectively, while *P. truncatus* survival ranged between 55-86% and 42-71%. All of the readings were significantly (P and < 0.05) less than what Actellic induced.

Contact toxicity by topical application

Table 4 shows the adult mortality of *P. truncatus* and *S. zeamais* after contact toxicity with methanol extracts of *C. anisata, P. amarus, P. nitida,* and *V. amygdalina* at concentrations of 0.1 g/mL and 0.2 g/mL. The results revealed that the type of plant and the concentration of extract applied had a substantial (P < 0.05) impact on the toxicity of methanol extracts of various plants. In the lower (0.1g/mL) concentration, mortality in *P. truncatus* and *S. zeamais* was 36.7-60% and 50-70%, respectively, whereas, in the higher (0.2/mL) concentration, mortality was 50-83% and 56.7-86.7% in *P. truncatus* and *S. zeamais*, respectively. Insect mortality was higher in the higher concentration than in the lower concentration.

Toxicity of extracts to *Sitophilus zeamais* and *Prostephanus truncatus* in treated grain.

Figure 3 shows the effects of methanol extracts of *C. anisata, P. amarus, P. nitida,* and *V. amygdalina* at concentrations of 0.1 g/mL and 0.2 g/mL on adult insects in treated grains. In both treatments, the survival of both insects rose as the concentration increased. However, at 0.1 g/mL, *P. truncatus* and *S. zeamais* had the lowest survival rates of 35% and 38%, respectively, while at 0.2 g/mL, they had even worse survival rates of 28% and 23%. In almost all of the treatments, the reference product had zero survival.

Table 3. Botanicals used by farmers in Volta Region, Ghana to store maize grains.

Botanicals	Local name	Common name
Azadirachta indica	*Liliti*	Neem
Clausena anisata	*Ayira*	Horsewood
Phyllanthus amarus	*Kpavideme*	Phyllantus
Picralima nitida	*Quinine*	Akuamma plant
Vernonia amygdalina	*Gbɔti*	Bitter Leaf
Nauclea latifolia	*Nyimɔke*	African peach
Momordica charantia	*Kakle*	Bitter gourd

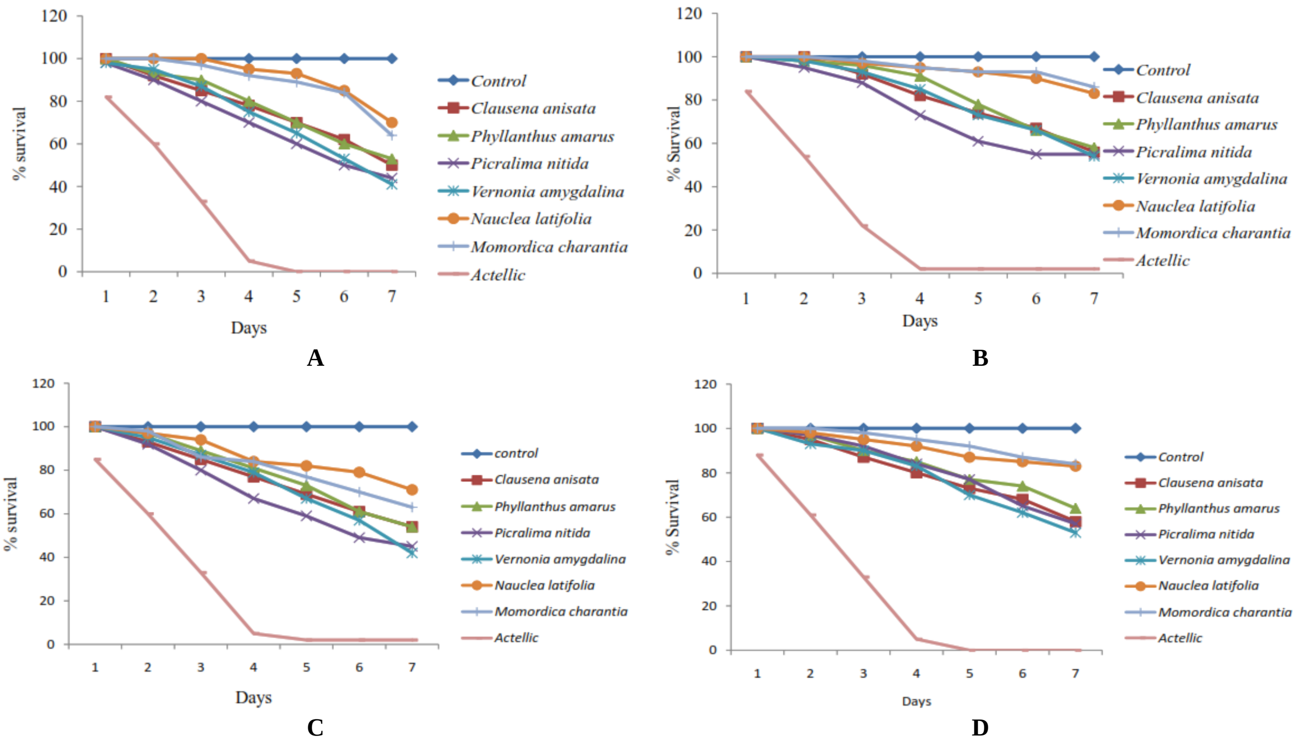


Figure 2. Effect of the powders of six plant species at: A. 10% on the survival of adult *Sitophilus zeamais*, B. 5% on the survival of adult *S. zeamais*, C. 10% on the survival of adult *Prostephanus truncatus*. D. 5% on the survival of adult *P. truncatus*

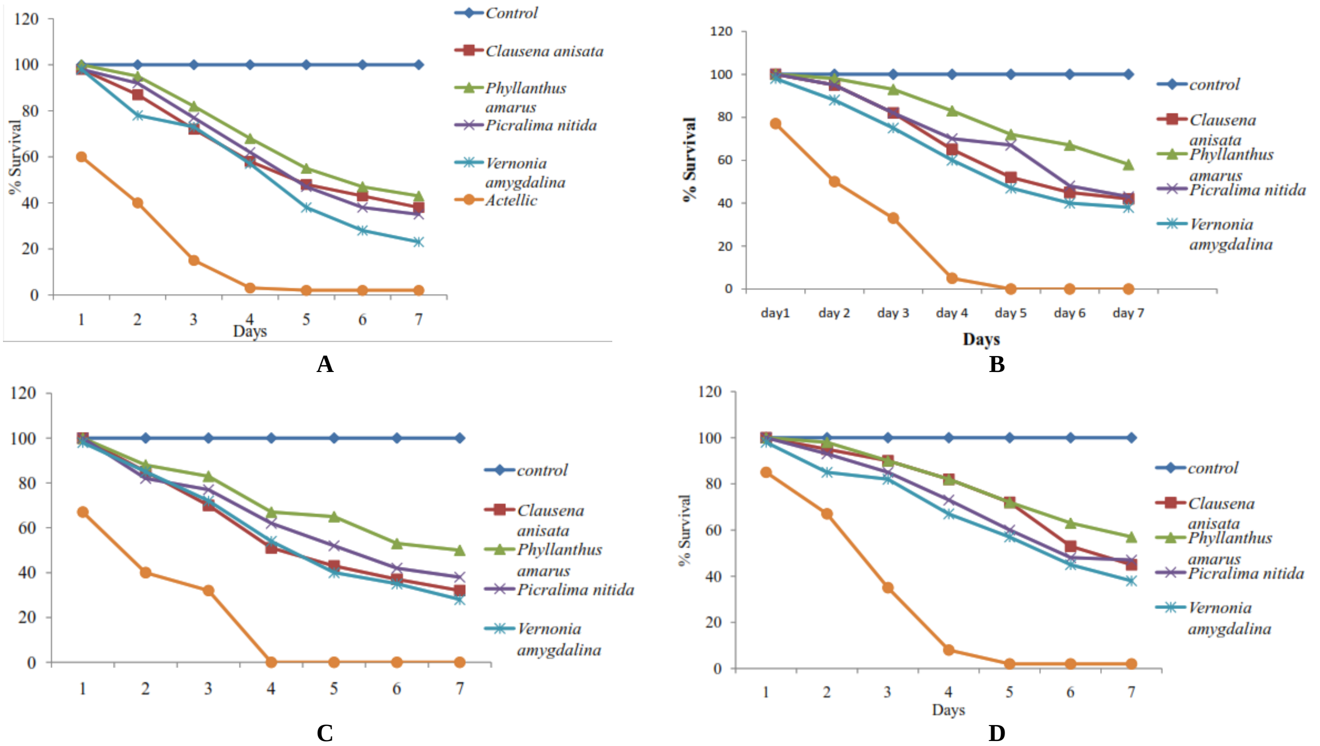


Figure 3. Effect of methanol extract of four plant species at: A. 0.2 g/mL on the survival of adult *Sitophilus zeamais* in treated grain, B. 0.1 g/mL on the survival of adult *S. zeamais* in treated grain, C. 0.2 g/mL on the survival of adult *Prostephanus truncatus* in treated grain, D. 0.1 g/mL on the mortality of adult *P. truncatus* in treated grain

Effect of methanol extract of plants on oviposition of Prostephanus truncatus *and* Sitophilus zeamais

In Figure 4, the number of eggs laid by *P. truncatus* and *S. zeamais* on grains (50 g) treated with *C. anisata, P. amarus, P. nitida, V. amygdalina* at concentrations of 0.1 g/mL and 0.2 g/mL, and Actellic (2 mL/L) are shown. When compared to the lower concentration, the higher concentration had the fewest eggs (3.0 and 4.0) laid by *P. truncatus* and *S. zeamais*, respectively (4.5 and 5.3). The difference between the eggs placed on the treated grains and the control was significant ($P < 0.5$). The reference product (Actellic) was found to be more effective than other treatments in reducing the quantity of eggs laid on grains.

Effect of methanol extract of four botanicals on eggs and immature stages

Effect of methanol extracts of four botanicals on eggs of Prostephanus truncatus *and* Sitophilus zeamais

The emergence of *P. truncatus* and *S. zeamais* in treated grain was reduced by methanol extracts of *C. anisata, P. amarus, P. nitida,* and *V. amygdalina* (0.1 g/mL and 0.2 g/mL) (Table 5). The difference between the extract-treated grains and the control grains was significant ($P<0.05$). Insects did not emerge from grains treated with Actellic, *C. anisata*, or *V. amygdalina* at a higher concentration (0.2 g/L).

Effect of methanol extract of four botanicals on the larvae of Prostephanus truncatus *and* Sitophilus zeamais

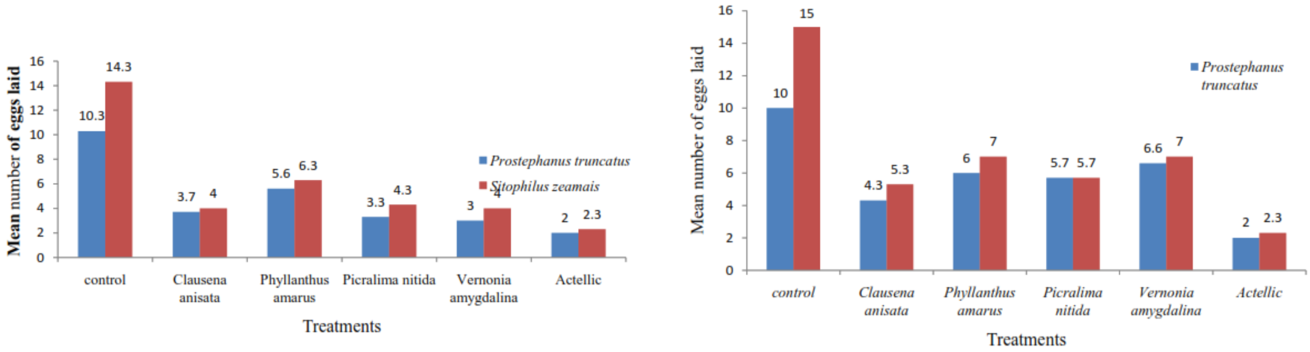
The effect of leaf extracts from *C. anisata, P. amarus, P. nitida, V. amygdalina,* and Actellic on grains containing *P. truncatus* and *S. zeamais* larvae was shown in Table 6. There was a significant difference ($P<0.05$) between the emergence of insects in grains treated with extract and the control at both concentrations. Insect emergence was lowest at the highest concentration (0.2 g/mL), and in some cases none at all.

Effect of methanol extract of four plants on the pupae Prostephanus truncatus *and* Sitophilus zeamais

When grains were treated with plants, the extracts of *C. anisata, P. amarus, P. nitida,* and *V. amygdalina* were considerably ($P<0.05$) harmful to pupae of *P. truncatus* and *S. zeamais* when compared to the control (Table 7). At both concentrations, there was no significant ($P<0.05$) difference between botanicals and Actellic. The botanical extracts with the highest concentration (0.2 g/mL) had the lowest survival on both insects and no pupae survival after 35 days of storage in *V. amygdalina* and *C. anisata.*

Repellency

Table 8 illustrates the repellent activity of *C. anisata, P. amarus, P. nitida,* and *V. amygdalina* against *P. truncatus* and *S. zeamais* in stored maize grains at concentrations of 0.1 g/mL and 0.2 g/mL. Compared to Actellic, all plant extracts were more repellant to *P. truncatus* and *S. zeamais.* However, *P. truncatus* was more resistant to the plant extracts than *S. zeamais* in general. Furthermore, all treatments had a greater repellent effect on both insects at higher concentrations (0.2 g/mL) than at lower concentrations (0.1 g/mL).



A B

Figure 4. Effect of methanol extract of four plant species at: A. 0.2 g/mL and B. 0.1 g/mL on oviposition *Postephanus truncatus* and *Sitophilus zeamais*

Table 4. Contact toxicity of methanol extract of four plant species by topical application to *Sitophilus zeamais* and *Prostephanus truncatus* after 96 hrs

Treatment	Percentage mean mortality (±SE) after 96 hrs	
	P. truncatus	***S. zeamais***
0.1 g/mL		
Clausena anisata	53.3±0.67	63.3 ± 0.67
Phyllanthus amarus	36.7±0.33	50.0 ± 0.57
Picralima nitida	50.0±1.00	56.7 ± 1.20
Vernonia amygdalina	60.0±0.58	70.0 ± 0.16
Actellic	100±0.00	100 ± 0.00
Control	00.0±0.00	00.0 ±0.00
LSD(P<0.05)	19.66	19.66
0.2 g/mL		
Clausena anisata	70.0 ±1.16	80.0±1.16
Phyllanthus amarus	50.0 ±0.16	56.7±1.20
Picralima nitida	73.3±1.90	73.3±1.80
Veroniaamydalima	83.3 ±0.89	86.7±0.33
Actellic	96.7±0.33	100 ±0.00
Control	00.0 ± 0.00	00.0±0.00
LSD(P<0.05)	20.64	20.6

Table 6. Effect of methanol extract of four plant species on the larvae of *Prostephanus truncatus* and *Sitophilus zeamais*

Treatment	Mean number of adults that emerged (±SE)	
	P. truncatus	***S. zeamais***
0.1 g/mL		
Clausena anisata	2.00±0.89	1.00±0.33
Phyllanthus amarus	2.00±1.20	2.00±0.88
Picralima nitida	1.00±0.88	2.00±0.58
Vernonia amygdalina	1.00±0.33	0.00±0.33
Actellic	0.00±0.00	0.00±0.00
Control	6.00 ±0.89	4.00±0.33
LSD(P<0.05)	1.12	1.12
0.2 g/mL		
Clausena anisata	0.00±0.00	0.00±0.00
Phyllanthus amarus	1.00±0.66	1.00±0.33
Picralima nitida	1.00±1.33	1.00±0.00
Vernonia amydalina	0.00±0.00	0.00±0.00
Actellic	0.00±0.00	0.00±0.00
Control	6.00±1.20	4.00±0.88
LSD(P<0.05)	1.61	1.61

Table 5. Effect of methanol extract of four plant species on eggs of *Prostephanus truncatus* and *Sitophilus zeamais*

Treatment	Mean number of adults emerged (±SE)	
	P. truncatus	***S. zeamais***
0.1 g/mL		
Clausena anisata	2.0±0.33	2.0±0.00
Phyllanthus amarus	3.0±0.33	2.0±0.33
Picralima nitida	2.0±0.00	1.0±0.33
Vernonia amygdalina	1.0±0.33	0.0±0.00
Actellic	0.0±0.00	0.0±0.00
Control	8.0±1.15	5.0±0.33
LSD(P<0.05)	1.22	1.22
0.2 g/mL		
Clausena anisata	0.0±0.00	0.0±0.00
Phyllanthus amarus	1.0±1.16	1.0±0.33
Picralima nitida	1.0±0.58	1.0±0.33
Vernonia amydalina	0.0±0.00	0.0±0.00
Actellic	0.0±0.00	0.0±0.00
Control	7.0±1.15	8.0±0.33
LSD(P<0.05)	1.12	1.12

Table 7. Effect of methanol extracts of four plant species on pupae of *Prostephanus truncatus* and *Sitophilus zeamais*

Treatment	Percentage mean mortality (±SE) after 96 hrs	
	P. truncatus	***S. zeamais***
0.1 g/mL		
Clausena anisata	1.00±0.00	1.00±0.33
Phyllanthus amarus	2.00±0.00	1.00±0.67
Picralima nitida	1.00±0.58	1.00±0.66
Vernonia amygdalina	0.00±0.00	0.00±0.00
Actellic	0.00±0.00	0.00±0.00
Control	7.00±0.88	6.00±0.33
LSD(P<0.05)	1.46	1.46
0.2 g/mL		
Clausena anisata	0.00±0.33	0.00±0.00
Phyllanthus amarus	2.00±0.33	2.00±0.33
Picralima nitida	1.00±0.66	1.00±0.33
Vernonia amygdalina	0.00±0.00	0.00±0.00
Actellic	0.00±0.00	0.00±0.00
Control	6.00±0.88	6.00±0.60
LSD(P<0.05)	1.22	1.22

Table 8. Percentage mean repellency of methanol extract of four plant species on *Prostephanus truncatus* and *Sitophilu zeamais*

Treatment	Percentage mean repellency (PR) ± SE	
	P. truncatus	*S. zeamais*
0.1 g/mL		
Clausena anisata	60.0 ±1.56	53.3 ±1.33
Phyllanthus amarus	33.3 ± 0.65	26.7 ±0.65
Picralima nitida	46.7 ± 1.76	40.0 ±1.55
Vernonia amygdalina	53.3 ± 1.33	46.7 ±1.76
Actellic	33.3 ±1.33	6.7 ± 0.67
LSD(P<0.05)	20.63	20.63
0.2 g/mL		
Clausena anisata	80.0± 1.56	66.7 ±2.40
Phyllanthus amarus	53.3± 0.67	46.7 ±1.76
Picralima nitida	60.0± 1.56	46.7 ±0.67
Vernonia amygdalina	73.3± 0.56	66.7 ±1.76
Actellic	33.3± 1.33	26.7±0.67
LSD(P<0.05)	20.63	20.63

Table 9. Effect of methanol extract of four plant species on grain loss (powder) caused by *Prostephanus truncatus* and *Sitophilus zeamais* after 10 weeks of treatment

Treatment	Percentage mean weight loss (±SE) after 10 weeks	
	P. truncatus	*S. zeamais*
0.1 g/mL		
Clausena anisata	18.6±2.37	18.0±1.60
Phyllanthus amarus	24.2±2.23	22.8±1.42
Picralima nitida	14.5±1.66	12.4±1.84
Vernonia amygdalina	11.5±1.53	8.0±0.52
Actellic	1.4±0.06	1.4±0.07
Control	30.0±0.58	31.0±0.86
LSD(P<0.05)	4.22	4.22
0.2 g/mL		
Clausena anisata	13.5±1.52	11.9±0.54
Phyllanthus amarus	22.0±0.99	23.0±1.94
Picralima nitida	13.4±0.58	11.4±1.16
Vernonia amydalina	10.5±0.33	7.2±0.69
Actellic	1.4± 0.12	1.4±0.07
Control	30.0±0.58	31.0±0.86
LSD(P<0.05)	2.75	2.75

Loss assessment

When grains were treated with methanol extract of plants after 10 weeks of infestation, there was a significant (P<0.05) difference in the weight of powder produced by *S. zeamais* and *P. truncatus.* When applied to the grains at a 0.2 g/mL concentration of plant extract, the least mean weight of powder was reported in *V. amygdalina*, with a mean value of 10.5 and 7.2 g in *P. truncatus* and *S. zeamais*, respectively. At a 0.1 g/mL concentration, *P. amarus* lost the most weight (24.2 g) (Table 9). Compared to the lower concentration, the greater concentration created very little powder.

Damage assessment

In general, all grains treated with plant extracts provided better pest protection than untreated grains. However, there was no statistically significant difference (P>0.05) between all four plants and Actellic (Table 10). In terms of lowering weight loss, all of the plant extracts examined were more effective at higher (0.2 g/mL) dosages than at lower (0.1 g/mL) dosages. Compared to *S. zeamais, P. Truncatus* produced higher weight loss in grains treated with botanical extracts.

Damage assessment

In general, all grains treated with botanicals provided better pest protection than untreated grains. However, there was no statistically significant difference (P>0.05) between all four plant extracts and Actellic (Table 10). In terms of lowering weight loss, all of the botanicals examined were more effective at higher (0.2 g/mL) dosages than at lower (0.1 g/mL) dosages. Compared to *S. zeamais, P. Truncatus* produced higher weight loss in grains treated with botanical extracts.

Table 10. Effect of methanol extract of botanicals on damage caused by *Prostephanus truncatus* and *Sitophilus zeamais* after 10 weeks of treatment

Treatment	Percentage mean weight loss (±SE) after 10 weeks	
	P. truncatus	*S. zeamais*
0.1 g/mL		
Clausena anisata	1.41±2.28	2.1±0.14
Phyllanthus amarus	5.28±1.32	4.18±0.59
Picralima nitida	2.60±2.25	3.34±0.83
Vernonia amygdalina	1.14±0.69	0.59±0.12
Actellic	0.69±0.27	0.52±0.09
Control	13.33±2.99	11.02±4.19
LSD(P<0.05)	6.46	6.46
0.2 g/mL		
Clausena anisata	0.69±0.45	0.49±0.23
Phyllanthus amarus	3.66±1.45	3.47±1.19
Picralima nitida	1.89±0.45	1.88±0.60
Veronica amygdalina	0.66±0.96	0.39±0.18
Actellic	0.32±0.23	0.41±0.27
Control	11.56±2.07	9.91±1.68
LSD(P<0.05)	3.64	3.64

Discussion

Survey

The survey revealed that both men and women are involved in farming and mostly employ plants to protect stored maize grains from insect pests. However, most respondents were female, confirming previous research by Cornelius et al. (2008) indicating approximately 70% of women generated 80% of household food in Africa. Matobola (2014) also noted that while more women were engaged in rural agricultural economic sub-sectors, they lacked access to assets, limiting their ability to acquire inputs. As a result, such households were forced to rely on indigenous materials to produce and preserve crops on a big scale.

The seven plant species used were *A. indica*, *V. amygdalina*, *P. nitida*, *C. anisata*, *P. amarus*, *N. latifolia*, and *M. charantia*, decreasing order of efficiency in pest control. *A. indica* was not chosen for the research since its efficacy against grain storage pests has been well known for an extended time.

Effect of plant powders on Prostephanus truncatus *and* Sitophilus zeamais

After seven days of treatment, the crushed powders of *C. anisata*, *P. amarus*, *P. nitida*, *V. amygdalina*, *N. latifolia*, and *M. charantia* showed varying efficiency degrees against *P. truncatus* and *S. zeamais* in treated grains. Insect survival decreased when the powder concentration increased from 5% to 10%.

The survival of *P. truncatus* and *S. zeamais* in grains treated with 10% *V. amygdalina* powder demonstrated that the plant is a promising control agent against the two insects due to its alkaloid content, which included caffeine, cocaine, morphine, and nicotine Irvine (1961). However, these chemicals are harmful to both insects and may have contributed to the insects' low survival rates in the treated grains. This finding confirms Irvine's (1961) earlier finding that the biter principle, vernonine, in *V. amygdalina* is toxic to mites. Similarly, Bouda et al. (2001) and Asawalam and Hassanali (2006) previously stated that the toxicity of *V. amygdalina* essential oil against *S. zeamais* was ascribed to the primary component terpenoids, which act as neurotoxins in insects.

The results of this study showed that *P. nitida* powder had a protective effect against two insect species that feed on stored maize grains (Ojo and Ogunleye 2013). The high lethality of the aqueous leaf and seed extract of *P. nitida* against *Anopheline* larvae and several kinds of fungi may be due to the presence of bioactive substances such as alkaloids, cardiac glycosides, saponins, tannins, flavonoids, terpenes, and steroids in the studied plant (Mujeeb et al. 2014). These chemicals may have contributed to the decreased survival of *P. truncatus* and *S. zeamais* in treated grains, explaining the efficacy of *P. nitida* in our investigation.

When *P. amarus* powder was administered at a 5% concentration, it was found to be effective in reducing *S. zeamais* and *P. truncatus* survival to 56%. The survival rate of insects was further reduced to 52% when the powder dosage was increased to 10%. Jayakumar (2010) previously demonstrated that greater concentrations of plant extracts were more efficient at reducing oviposition and increasing the death of target insect pests than lower concentrations.

Clausena anisata leaf powder's efficacy against the two insects suggested a possible contact action. This could be because the leaf oil contains the highly poisonous chemical component "estragole" (Sentilkumar and Venkatesalu 2009). The leaf powder of *C. anisata* may have contained additional chemical components that inhibited insects from eating on grains treated with the powder.

The use of *N. latifolia* and *M. charantia* powder as grain protectants against *S. zeamais* and *P. truncatus* resulted in a much greater survival rate than the other four plant species discussed previously.

While, *N. latifolia* and *M. charantia* contain alkaloids, terpenoid, morphine, and phenol, their concentrations may be lower in the plant portions utilized in the experiment than in the other four plant species (Akinkurolere 2012). This could explain why *P. truncatus* and *S. zeamais* survived so well in the treated grains. This observation contradicts Akinkurolere's (2012) conclusion that *M. charantia* is extremely poisonous to *S. zeamais* and *C. maculatus*. The difference in efficacy of these plants could also be attributed to changes in meteorological and soil variables, as well as the parts used and harvesting time (Jorge et al. 2009; Ndomo et al. 2009).

Toxicity of extracts applied topically to insects

After 96 hours of topical application, all plant extracts were harmful to insects at varying concentrations compared to the control. The greater concentration (0.2 g/mL) was more effective against both insects than the lower concentration (0.1 g/mL) in all treatments. Due to the presence of chemical substances such as alkaloids, flavonoids, lignans, and vernonine in *V. amygdalina*, it was very harmful to both insects (Irvine 1961). At 0.2 g/mL, *V. amygdalina* was 83.3 percent lethal to *P. truncatus* and 86.7% lethal to *S. zeamais*. This confirms previous studies undertaken by Asawalam and Hassanali (2006), who discovered that essential oil of *V. amygdalina* contained a variety of terpenoids and triggered 82 percent mortality in *S. zeamais* after 7 days of treatment with 750 mg/250 g of essential oil. *Prostephanus truncatus* was more resistant to methanol extract than *S. zeamais*, which may be explained by its more robust character, high feeding ability, and heavily sclerotized cuticle, which may have limited the active component of the extract's physical absorption through the cuticle.

Toxicity of extracts to Sitophilus zeamais *and* Prostephanus truncatus *in treated grain*

After seven days, the methanol extracts at both concentrations were applied to adult insects in treated grain, causing a substantial ($P<0.05$) reduction in survival for both insects compared to the control. The species of plant, the dose administered, and the time of contact all had an effect on the toxicity of the extract applied to adult insects in treated grain (days). *Vernonia amygdalina* was the most effective plant species, whereas *P. amarus* was the least effective. Although *P. amarus* includes similar chemical elements such as lignans, flavonoids, and phyllanthin, they may not have been as effective as *V. amygdalina* at killing insect pests. They can, however, be employed to prevent fungus from attacking stored grains (Oudhia 2008). The higher concentration of the herb resulted in a reduction in insect survival. Due to the continual buildup of the botanical's chemical component in the insects, the period of contact (days) had a substantial effect on the percentage survivability of adult *P. truncatus* and *S. zeamais*. While the standard (Actellic) caused 100% death or no survivorship after five days of contact, *V. amygdalina* at 0.2 g/mL caused 62% mortality or 38% survival in *P. truncatus* after five days off treatment. As a result, the extracts killed insects more slowly than the manufactured toxin (Actellic). This finding corroborates an earlier observation by Obeng-Ofori and Dankwah (2004) that Actellic had a quick knockdown effect, instantly killing adult insects on contact.

Effect of methanol extract of plants on oviposition of Prostephanus truncates *and* Sitophilus zeamais

After seven days of treatment, all plant extracts successfully lowered the quantity of eggs laid by both insects compared to the control. At a 0.2 g/mL dosage, *C. anisata* was the most efficient of all the plant extracts against both insects. This suggests that *C. anisata* may have repellant and/or oviposition deterrent properties, resulting in alterations in the adult insects' physiology and behavior, as indicated in their egg laying capacity. This supports the findings of Schmuttere (1990) and Ndomo et al. (2009) that plant extracts and essential oils reduce oviposition and fecundity in a variety of insects. *Sitophilus zeamais* lay more eggs than *P. truncatus* in all of the treatments. This could be due to *S. zeamais* having a higher fecundity level than *P. truncatus.*

Effect of methanol extract of plants on eggs and immature stages of Prostephanus truncatus *and* Sitophilus zeamais

In comparison to the control, the methanol extracts of all plants were effective against the eggs, larvae, and pupae of *P. truncatus* and *S. zeamais* at both doses. This supports the findings of Jayakumar et al. (2003), who found that plant extracts had a clear effect on postembryonic survival of the insect, resulting in a reduction in adult emergence when different plants are used. Because of the toxicity of extracts to eggs, larvae, and pupae, the number of adults emerging from treated seeds was significantly reduced. The potency could be owing to the extract's bitter antinutritive secondary metabolites acting as a barrier on the seed coat, preventing the eggs from developing into adults (Tchinda 2011). After 35 days of treatment, a 0.2 g/mL methanol extract of *V. amygdalina* and *C. anisata* completely blocked the development of eggs, larvae, and pupae of both insects into adults. This is on par with the gold standard (Actellic), which also completely inhibited adults.

When compared to the juvenile stages developing inside cowpea seed, the eggs of *P. truncatus* and *S. sitophilus* in treated grains were more vulnerable to the extracts of *V. amygdalina*. This could be due to the extract's reduced action to pupae compared to larvae due to relative inactivity, reduced metabolism, and superior exoskeleton growth in both insects. This supports Law-Ogbomo and Enobakhare's (2007) findings that 1 to 5 g of *V. amygdalina* dry leaf powder suppressed the growth of *S. zeamais* and *S. oryzae* on stored maize grains and rice. The total prevention of the development of eggs and immature stages within the treated grain increases the ability of *V. amygdalina* and *C. anisata* to protect stored grains from insect damage.

Repellency

All four plant extracts were found to resist *P. truncatus* and *S. zeamais* better than the synthetic commercial pesticide (Actellic). *C. anisata*, on the other hand, was found to be very repellent to the two insects tested, with overall mean repellency of 80.0% and 66.7% for *P. truncatus* and *S. zeamais*, respectively, at 0.2 g/mL. Tchinda (2011) discovered that dried leaves of *C. anisata* were utilized as insect repellents throughout tropical Africa, and that the leaves were used as mattress filling in Kenya, because they were scented and repelled insects. Carbazole alkaloids, peptide derivatives, and phytosterol are the main chemical components of *C. anisata*, which may explain the strong insect repellent properties of the plant (Songue et al. 2012).

Damaged assessment

The greater concentration (0.2 g/mL) of evaluated plants resulted in lower mean weight loss in the treated grains than the lower concentration (0.1 g/mL). The number of damaged seeds in maize treated with plant extracts was significantly lower than control. Law-Ogbomo and Enobakhare (2007) concurred that the proportion of pierced grain in the treated grain with *V. amygdalina* was lower than the untreated control grain. *Vernonia amygdalina* is also an efficient grain protestant against *S. zeamais*, according to Enobakhare and Law-Ogbomo (2002). *Sitophilus zeamais* was able to inflict greater damage to grains than *P. truncatus*. Due to the high humidity in the bioassay, some of the plant extract-treated grains, excluding *V. amygdalina*, were attacked by *Aspergillus flavus*. According to Ogbebor et al. (2007), inhibitory activity of *V. amygdalina* is due to secondary metabolites that are resistant to fungus

In terms of plant and bug kind, the powder generated after ten weeks of storage varies. *Prostephanus truncatus* produced more powder than *S. Sitophilus*, according to the findings. This could be attributed to its hardy nature, exploratory nature, and capacity to feed and breed in dry environments, including maize with a moisture level of 9% (Cornelius et al. 2008).

In conclusion, the bioactivity of six indigenous plants in the management of *S. zeamais* and *P. truncatus* in stored maize was identified and analyzed in this study. *Azadirachta indica, C. anisata, P. amarus, P. nitida, V. amygdalina, N. latifolia,* and *M. charantia* were identified as plant species utilized by farmers in the Volta Region to manage insect pests in maize. *Azadirachta indica*, on the other hand, was not chosen because it has already undergone significant research. When applied at 5% and 10% concentrations, the powders of the other six botanicals were poisonous to *P. truncatus* and *S. zeamais*, lowering insect survival. The botanical *V. amygdalina* was shown to be the most promising in terms of safeguarding maize grains from the two insects. Insecticides, antifeedants, anti-ovipositant, ovicidal, and repellent activities are all present in the methanol extract of *V. amygdalina*. After 96 hours, contact treatment of a methanol extract of *V. amygdalina* at 0.2 g/mL eradicated 83.3% of *P. truncatus* and 86.7% of *S. zeamais*, respectively. This did not differ significantly ($P<0.05$) from the standard (Actellic). In comparison to the control, insect mortality in maize grains treated with *V. amygdalina* methanol extract was extremely high. After 10 weeks, insect damage to maize grains treated with *V. amygdalina* in a crib was minor, and it did not differ much from Actellic. Both insects laid a few eggs in maize grains treated with *C. anisata* extract. When grains were treated with extract of *V. amygdalina* and the standard, adult emergence from eggs, larvae, and pupa was completely inhibited (Actellic). The repellency of *C. anisata* extract (0.2 g/mL) to insects was significantly significant in comparison to the standard. The presence of toxicants and growth inhibitors in *V. amygdalina* when applied to *P. truncatus* and *S. zeamais* suggests that they have a lot of promise for storage pest management, particularly in farm stored grains of peasant farmers. The investigation also confirmed the scientific reality that farmers utilize *V. amygdalina* as a grain protectant.

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