https://dx.doi.org/10.4314/gjas.v58i2.12

Efficacy of some plant extracts as a safe and sustainable management option for *Sitophilus zeamais* (Motschulsky) in stored maize

V. SACKEY*, Y.V. EZIAH, E.O. OWUSU, M. BILLAH & S. ADDAE

(V.S. & E.O.O.: Council for Scientific and Industrial Research – Plant Genetic Resources Research Institute (CSIR-PGRRI), P. O. Box 7, Bunso, Ghana; Y.V.E.: Department of Crop Science, School of Agriculture, University of Ghana, P. O. Box 25, Legon, Accra, Ghana; M.B. & S.A.: Africa Regional Postgraduate Programme in Insect Science, University of Ghana, Legon, Accra, Ghana)

**Corresponding author's email: nanaekuasackey@gmail.com*

ABSTRACT

The use of synthetic chemical insecticides has proven effective in controlling insects. However, indiscriminate use is associated with a variety of health and environmental problems. Plant-based products could be an alternative for pest control because of their natural originality, low/non mammalian toxicity, biodegradability, zero residual effect and accessibility. A survey conducted in the Southern part of Volta region in Ghana collected data on plant species used as maize protectants. A total of eleven plant species were obtained. Seven out of the eleven were selected based on their availability and accessibility including lemon grass (*Cymbopogon citratus*), basil (*Ocimum basilicum*), Acheampong leaves (*Chromolaena odorata*), garlic (*Allium sativum*), Africa scent leaf (*Ocimum gratissimum*), guava leaves (*Psidium guajava*), onion (*Allium cepa*) for preliminary screening. Four most efficacious species (*Cymbopogon citratus*, *Psidium guajava*, *Ocimum basilicum* and *Ocimum gratissimum*) were selected for further work in the laboratory at 28±2°C, 65% RH and 12D:12L against *S. zeamais*. The assays were conducted by treating 50 g of maize with methanol extracts at the rates of 0.2, 0.3, 0.4 and 0.5 g/mL. Contact toxicity, repellency, effects on oviposition, development, seed damage, and weight loss were assessed. The extracts significantly ($p \geq 0.05$) reduced emergence of progeny from adult weevil, eggs and immature stages. The extracts had a reproduction inhibition rate of 81–100%. The extracts protected maize against damage by *S. zeamais* for 12 weeks. Maximum weight loss and seed damage of 11.3% and 8.7%, were recorded compared to control with 21.4% and 24.7%, respectively. The extracts could therefore be used as alternatives for synthetic insecticides.

Key words: Plant extracts; seed maize; *Sitophilus zeamais*; insecticides; toxicity

Original scientific paper. Received 17 Jul 2023; revised 20 Oct 2023

Introduction

One of the most important global challenges of our time is meeting future food needs and tackling hunger and malnutrition in a context of climate change and growing populations. Maize has become the second most produced crop in the world. Specifically, in Sub-Saharan Africa, more and more land is used for maize production (Romy, 2020). In Ghana, production is dominated by smallholder farmers accounting for more than 70%, cultivating on area of land less than 2 hectares and contributing about 80% output (Prah *et al*., 2023).

Despite the intervention at the production level of maize, there is evidence of seed and food insecurity arising from storage losses. One of the elements contributing to high storage losses is the problem of storage insect pests such as the maize weevil, *Sitophilus zeamais* (Motschulsky); rice weevil, *Sitophilus oryzae* (L.); Angoumois grain moth, *Sitotroga cerealella* (Olivier); and the larger grain borer, *Prostephanus truncatus* (Horn) (Tefera *et al*., 2011). Substantial amount of maize produced is lost to insect pests attack in storage particularly among smallholder farmers (Rifath, *et al*., 2022). The most destructive primary storage pest of seed maize is *Sitophilus* spp. (Coleoptera: Curculionidae) (Vijay *et al*., 2015). In the tropical and sub-tropical regions, *Sitophilus. zeamais* cause about 80% seed maize damage (Ndomo *et al*., 2009; Archibong *et al*., 2022). According CABI (2005) and Ngongang *et al.* (2022), both the adult *Sitophilus* spp. and the larvae feed on undamaged grains and reduce them to powder, causing loss of viability and market value. Stored grains accounts for almost 80% of the seeds used by small-scale farmers for planting (Louwaars & De Boef, 2012).

The commonest method of controlling insects by smallholder farmers is the use of synthetic chemicals. However, indiscriminate use of many synthetic insecticides is associated with manifold health and environmental problems, such as development of resistance in insect pests, high residues in food products, pest resurgence and the destruction of non-target organisms (Kumar *et al*., 2008). Long term exposure of people to these chemicals could cause acute poisoning and long-term health implications, which may include cancer and reproductive anomalies (WHO, 2018). Plant based products are potential alternatives to synthetic insecticides for pests' control because of their low/non mammalian toxicity, biodegradability, zero residual effect and easy accessibility.

There are a number of medicinal plants with insecticidal properties (Holst *et al*., 2000, Gariba *et al*., 2021). Some plant extracts have growth inhibitory effects on insect and cause the reduction of larval, pupal and adult weight, extended larval and pupal duration, reduced pupal retrieval and reduced rate of adult emergence (Koul *et al*., 2008). More importantly smallholder farmers can easily and cheaply produce these plant extracts for their use. From the survey, plants that are currently used by farmers for the management of weevils include Africa scent leaf powder, lemon grass powder, basil powder, guava powder, "Acheampong" leaf powder, and shallot powder. Keeping in view the current problems of chemical insecticides, this research was designed to evaluate the efficacy of lemon grass (*Cymbopogon citratus*), guava leaves (*Psidium guajava*), basil (*Ocimum basilicum*) and Africa scent leaves (*Ocimum gratissimum*) extracts against maize weevil (*Sitophilus zeamais*). Extensive work has been on neem plant hence excluded from the current study.

Materials and Methods

The experimental sites

The study was conducted at the Entomology Laboratory of the Department of Crop Science of University of Ghana, Legon, Accra.

Field survey

Structured questionnaires were purposively administered to collect information from 150 maize growers to ascertain the different kinds of plants used as seed/grain protectants in storage in three districts (Akatsi, Keta and Ketu) in the southern part of Volta region of Ghana. A close-ended questionnaire was administered. This is a part of an ongoing project to document all plants species with insecticidal effects in the Volta region of Ghana.

Collection and culturing of adult Sitophilus zeamais

Maize seeds, without infestation or defect were obtained from the University of Ghana farm, sterilized at 60°C for three hours and allowed to establish equilibrium at 28±2°C and 65% relative humidity for 24 hours. Jars and muslin cloth for the experiment were also sterilized at same conditions. Adult maize weevils were obtained from an existing culture maintained in the Entomology Laboratory. A culture was set by infesting the sterilized maize at 12% moisture content (400 g) with the 50 unsexed weevils in a litre glass kilner jar covered with muslin cloth to allow for air passage and fastened with rubber. Initial stock of *S. zeamais* was sieved out after a week of oviposition. The culture was kept to allow for progeny emergence. The culture was replicated six times in completely randomised design.

Collection and preparation of plant powders

The method of Handa *et al.* (2008) was used for the extraction of active compounds in the plant materials. The method included collection and authentication of plant material, drying, size reduction, extraction, filtration, concentration, drying and reconstitution. The leaves of *Cymbopogon citratus*, *P. guajava*, *O. basilicum* and *O. gratissimum* collected at the Nursery field of Plant Genetic Resources Research Institute, Bunso, put in untied white polythene bags and brought to the Crop Science Laboratory of the University of Ghana and washed with distilled water. The specimen was put in strainers to drain off excess water. Samples of each plant was put in brown envelope and sent to the Botany Department of the University of Ghana for authentication of their identity at the Herbarium. Plant materials for the experiment were then air dried under room temperature for two weeks and ground into fine powder using Fritsch electric mill (manufacturer: Fritsch, Germany) and further sieved through 0.5 mm sieve. They were then put into air tight plastic containers, well labelled and stored at 4°C in the cold room of the West Africa Centre for Crop Improvement (WACCI), University of Ghana prior to use.

Preparation of crude methanol extracts of plants

The methodology for the methanol extraction of the plant powders was adopted from Derbalah (2012). Approximately 100 g of each of the plant powders were weighed into four conical flasks containing 430 mL of 100% methanol. The flasks were covered with parafilm and placed in a shaker for 48 hours. The extracts were filtered using muslin cloth. The filtrates were concentrated to dryness using warm water basin rotary at 40°C (Derbalah, 2012). The residues were dissolved in acetone to give concentrations of 0.2 g/mL, 0.3 g/mL, 0.4 g/mL and 0.5 g/mL for the various bioassays.

Effect of methanol extracts on oviposition

With moisture content at 12.0%, 50 g of infestation free sterilized seed maize (Obaatanpa) was weighed and put into 51 kilner glass jars. The four botanicals (*O. gratissimum, P. guajava, C. citratus* and *O. basilicum)* with four levels (0.2 g/mL, 0.3 g/mL, 0.4 g/mL and 0.5 g/mL) were admixed to the seed maize in each of the glass jars. The set-up was allowed to stand for 24 hours after which they were infested with 20 adult weevils. The glass jars were covered with muslin cloth and held tight with rubber bands to prevent insects escape and allow for ventilation. There were three replications for each treatment arranged in a completely randomized design and allowed to oviposit for 7 days. Adult weevils were sieved out on the eighth day, percentage oviposition was determined using Acid-fuchsin method, (Boateng & Obeng-Ofori, 2008). The Percentage oviposition was calculated according to Eman & Abbass (2010).

$$Oviposition(\%) = \frac{Number\ of grains with egg\ plugs}{Total\ number\ of\ grains counted} x100$$

Contact toxicity of methanol extracts on adult weevil

Sterilized seed maize (50 g) was put into 51 kilner glass jars and treated with 0.2 g/mL, 0.3 g/mL, 0.4 g/mL, 0.5 g/mL and 0.0 g/mL methanol extract of *O. gratissimum, P. guajava, C. citratus* and *O. basilicum*. The set-up was allowed to stand for one hour after which they were infested with 20 unsexed *S. zeamais*. The glass jars were then covered with muslin cloth and fastened with rubber bands to prevent the escape of the insects and also allow for ventilation. The treatments were replicated three times in a completely randomised design and kept under room conditions at 28±2°C and 65±5% relative humidity for seven days. Insect mortality was taken 24 hours after treatment application for seven days.

$$Mortality(\%) = \frac{Number\ of\ Responded\ Insects}{Total\ Number\ of\ Insects\ Introduced} X100$$

(Ileke *et al*., 2011).

Effect of methanol extracts on F1 progeny emergence

The set-up for testing the contact toxicity of methanol extracts against the adult weevils were used for this bioassay. Dead and live insects were sieved from the glass jar on the eighth day of set-up. The experiment was carried out under unaltered conditions. Progeny counting began 32 days after the set-up. The adults which emerged were counted and recorded every three days for five weeks. All the emerged adults were removed from the jars on each assessment day. Percentage index reduction was computed using the formula (Tefera *et al*., 2008)

$$IR(\%) = \frac{Number\ of\ F1\ progeny \in control - Number\ of\ F1\ progeny \in treatment}{Number\ of\ F1\ progeny \in control} x100$$

Effect of methanol extracts on eggs of S. zeamais

Seed maize was infested with 20 adult *S. zeamais* of mixed sex and allowed to oviposit for seven days. Adult insects were sieved out on the eighth day. Percentage oviposition was determined. Seeds were then treated with four botanicals (*Ocimum gratissimum, P. guajava, C. citratus* and *O. basilicum)* at 0.2 g/mL, 0.3 g/mL, 0.4 g/mL and 0.5 g/mL. The set-ups were replicated three times in completely randomized design and allowed to stand for three weeks. Adult insects emerged were counted and recorded every three days for five weeks. Percentage index reduction was computed using the formula by (Tefera *et al*., 2008) described above.

Effect of methanol extracts on the immature stages of S. zeamais

In this experiment, 50 g of sterilised seed maize was infested with 20 adult *S. zeamais* and allowed to oviposit for seven days. Adult insects were sieved after a week of oviposition. The seed maize was allowed to stay for extra seven, fourteen and 21 days. Seed maize were then treated with *Ocimum gratissimum*, *P. guajava*, *C. citratus* and *O. basilicum* at 0.2 g/mL, 0.3 g/mL, 0.4 g/mL, 0.5 g/mL and 0.0 g/mL (control) for one week, two weeks and three weeks after oviposition to evaluate the efficacies on eggs, larvae and pupae, respectively. The treatments were replicated three times in completely randomised design. The adult weevils that emerged were counted and recorded. Percentage index of reduction was computed using the formula (Tefera *et al*., 2008) described above.

Bioassay on repellency

Seeds were treated with four botanicals (*Ocimum gratissimum, P. guajava, C. citratus* and *O. basilicum*) at 0.5g/mL and no treatment (control). The glass jars containing the treated and untreated seeds (control) were attached to olfactometer (two arm, T-olfactometer). The set-ups were allowed to stand for one hour. Unsexed 20 adult insects were introduced into the olfactometer. The number of insects present on the control (including dead ones in the tube towards the control) was recorded and number of insects found on treated seed maize was also recorded after 24 hours. Percentage repellency was computed using formula of Uzakah *et al.* (2015).

$$Repellency(\%) = \frac{[Nc - Nt]}{[Nc + Nt]} x\,100$$

Where;

Nc: number of insects present on untreated seed maize (control)

N: number of insects present in treated seed maize

Weight loss assessment

At six weeks (42 days) of treatment, the weight loss of the seed maize was evaluated for each of the treatments. Seeds were classified into damaged and undamaged. Weight of the damaged and undamaged seeds was taken. The percentage loss in weight was determined according to Boateng & Obeng-Ofori (2008) formula.

$$Weight\,loss(\%) = \frac{(UNd) - (DNu)}{U(Nd + Nu)} x\,100$$

Where;

Nu: number of undamaged seeds

Nd: number of damaged seeds

U: weight of undamaged seeds

D: weight of damaged seeds

Seed damage evaluation

Using a diphanoscope, seeds for this experiment were carefully sorted out into whole seeds; seeds without any evidence of insect emergent holes. Percentage grain damage was evaluated by randomly selecting 100 seeds from each of the treatments, separated into two groups (seeds with emergent holes and seeds without emergent holes). The number of seeds with emergent holes was counted and the percentage grain damage computed as follows (Ileke, 2011):

$$Seed\,damage(\%) = \frac{Number\ of\ seed\ maize\ with\ emergent\ holes}{Total\ number\ of\ seed\ maize\ counted} x\,100$$

Qualitative analysis of phytochemical compounds

Qualitative analysis was conducted on the botanicals to ascertain the presence of the different compounds in the leaves of the plant species. The method used and their resultant inferences are shown below. The following reagents were used; ferric chloride, chloroform, distilled water, glacial acetic acid, sulphuric (aqueous and concentrated) acid, hydrochloric acid.

Test for phenols and tannins
Extract (1 g) was mixed with 2 mL of 2% solution of ferric chloride ($FeCl_3$). A blue-green or black colouration indicated the presence of phenols and tannins (Harbome, 1973).

Test for saponins
About 0.5 g of each extract was placed in a test tube and shaken vigorously with water. The formation of stable foam was an indication for the presence of saponins (Ngbede *et al*., 2008).

Test for terpenoids (Salkowski test)
About 1 mL of each extract was mixed with 2 mL of chloroform and treated with 2 mL of concentrated sulfuric acid and carefully shaken gently. A reddish-brown colouration of the interphase formed showed positive results for the presence of terpenoids.

Test for Flavonoids **(**Shinoda Test**)**
Extracts (0.5 mL) each was mixed with magnesium ribbon fragments. Concentrated hydrochloric acid was added drop wise. Orange, red, pink, or purple colouration indicates the presence of flavonoids.

Test for Glycoside
Keller-Killani test was used. About 0.5 mL of each plant extract was treated with 2mL of glacial acetic acid containing 2 drops of 2% ferric chloride ($FeCl_3$). The mixture was poured into another tube containing 2 mL of concentrated sulfuric acid (H_2SO_4). A brown ring at the interphase indicates the presence of glycosides.

Data analysis
Data in the form of percentages were subjected to arcsine transformation whilst data on counts subjected to square root transformation to stabilize the variance. General Analysis of Variance was conducted using GenStat Statistical Package 12th Edition. Fisher's protected LSD was used to separate means at 5% significant level.

Results and Discussion

Chemical composition of the plant extracts
The results of the qualitative photochemical screening of plant leaves powders showed the presence/absence of the compounds listed in the table.

TABLE 1
Phytochemical screening of botanicals

Compounds	***P. guajava***	***O. basilicum***	***C. citratus***	***O. gratissimum***
Phenols	+	+	+	-
Tannins	+	+	+	+
Saponins	-	+	+	-
Terpenoids	+	+	-	+
Flavonoids	+	+	+	+
Glycosides	+	-	-	+
Alkanoids	+	+	+	+
Steroids	-	+	+	+
Resins	-	-	+	-
Anthraqui-nones	-	-	+	

(+) = present; (-) = absent

Effect of methanolic extracts on insect survival
Methanolic extracts applied at 0.2 g/mL 0.3 g/mL 0.4 g/mL 0.5 g/mL greatly affected the survival of the insects on seed maize ($p < 0.05$). Mortalities in some of the treatments (*Ocimum basilicum*, *O. gratissimum* and *P. guajava*) were not dependent on the concentrations. However, mortality of insects in seed maize treated with *Cymbopogon citratus* increased with increasing concentration. All the insects in the control survived after seven days. Extracts of *Cymbopogon citratus*, *O. gratissimum and P. guajava* recorded the highest insect mortality with percentage mean mortality of 65% at concentrations of 0.5 g/mL (fig.4), 0.4 g/mL (fig.3) and 0.2 g/mL (fig.1), respectively, followed by *O. basilicum* with 60% percentage mean mortality at 0.2 g/mL (fig.1).

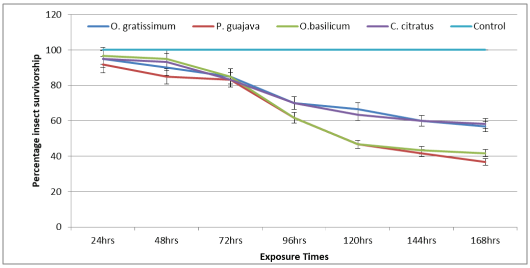

Fig. 1: Effect of methanol extracts on insect survival applied at 0.2 g/mL[1]

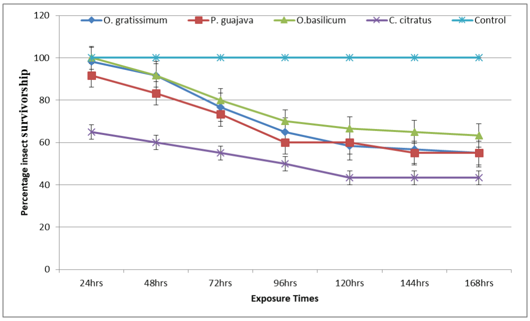

Fig. 2. Influence of methanol extracts on insect survival in maize treated with four botanicals at 0.3 g/mL[2]

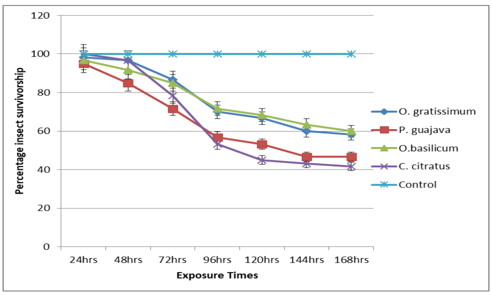

Fig.3: Effect of methanol extracts of four botanicals on insect survival in treated maize at 0.4 g/mL[3]

[1] *Ocimum gratissimum, Psidium guajava, Ocimum basilicum, Cymbopogon citratus* Data points on line graphs are means +/- mean bars

[2] *Ocimum gratissimum, Psidium guajava, Ocimum basilicum, Cymbopogon citratus* Data points on line graphs are means with mean bars

[3] *Ocimum gratissimum, Psidium guajava, Ocimum basilicum, Cymbopogon citratus* Data points on line graphs are mean with mean bars

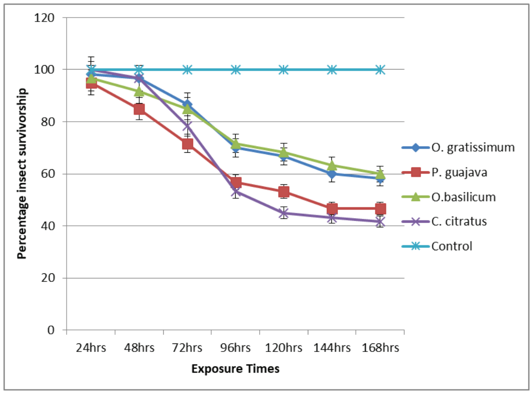

Fig. 4: Effect of methanol extracts of four botanicals on insect survival in treated maize at 0.5 g/mL[4]

Effect of extracts on weevil oviposition

The mean oviposition percentage in table 2 indicates that the extracts inhibited the normal oviposition activity of the weevils. There was significant difference between the botanicals and the control with *Psidium guajava* and *C. citratus* recording the lowest percentage mean oviposition (26.7%) both at 0.3 g/mL.

TABLE 2

Effect of different concentrations of different plant extracts on insect oviposition

Conc.(g/mL)	Botanicals	%Oviposition
0.2	*O. gratissimum*	36.7±6.6a
	P. guajava	30.0±0.0a
	O. basilicum	40.0±10.0a
	C. citratus	33.3±3.3a
0.3	*O. gratissimum*	33.3±3.3a

[4] *Ocimum gratissimum, Psidium guajava, Ocimum basilicum, Cymbopogon citratus* Data points on line graphs are mea with mean bars

	P. guajava	26.7±3.3a
	O. basilicum	30.0±0.0a
	C. citratus	26.7±3.3a
0.4	*O. gratissimum*	36.7±3.3a
	P. guajava	36.7±3.3a
	O. basilicum	30.0±5.8a
	C. citratus	30.0±5.8a
0.5	*O. gratissimum*	33.3±8.8a
	P. guajava	30.0±5.8a
	O. basilicum	33.3±3.3a
	C. citratus	30.0±5.8a
0.0	Control	63.3±3.3b

Effects of methanol extracts on eggs, eclosion and immature stages of S. zeamais

Tables 3, 4, 5, 6 and 7detail the effect of methanol extracts on the emergence of progeny from adult and the different stages of growth. The result showed that the extracts significantly influenced progeny emergence at all the different life cycles of the insect. It was observed that *Cymbopogon citratus* and *O. basilicum* exerted maximum (100%) reproduction inhibition at rates of 0.5 g/mL and 0.3 g/mL respectively at the egg stage of development. The results gave an indication that the extracts were promising controlling agents against *S. zeamais*.

[5] Means followed by the same letter in a column are not significantly different at 5% probability. Data are means +/- standard error of means

Ocimum gratissimum, Psidium guajava, Ocimum basilicum Cymbopogon citratus

TABLE 3

Effect of different concentrations of extract on progeny emergence from adult weevil

Botanicals	Conc.	% IR/F1
O. gratissimum	0.2 g/mL	89.7±2.9bc
	0.3 g/mL	91.2±3.6bc
	0.4 g/mL	93.5±2.7bc
	0.5 g/mL	88.1±4.7bc
P. guajava	0.2 g/mL	95.8±1.4bc
	0.3 g/mL	95.4±2.3bc
	0.4 g/mL	86.6±5.4b
	0.5 g/mL	95.4±0.7bc
O. basilicum	0.2 g/mL	95.4±2.0bc
	0.3 g/mL	87.4±4.1bc
	0.4 g/mL	90.0±4.6bc
	0.5 g/mL	92.7±1.7bc
C. citratus	0.2 g/mL	89.7±1.1bc
	0.3 g/mL	90.4±5.6bc
	0.4 g/mL	96.2±2.8c
	0.5 g/mL	92.0±2.4bc
Control	0.00 g	0.0±0.00a

TABLE 5

Effect of extracts on progeny emergence from eggs of adult weevils

Botanicals	**Conc.**	**%IR/Egg**
O. gratissimum	0.2 g/mL	97.5±1.1bc
	0.3 g/mL	98.1±1.9bc
	0.4 g/mL	97.8±1.1bc
	0.5 g/mL	96.6±3.0bc
P. guajava	0.2 g/mL	95.0±2.3b
	0.3 g/mL	95.3±2.0b
	0.4 g/mL	98.4±0.8bc
	0.5 g/mL	94.7±1.7b
O. basilicum	0.2 g/mL	97.5±1.4bc
	0.3 g/mL	100.0±0.0c
	0.4 g/mL	97.8±1.4bc
	0.5 g/mL	98.1±1.1bc
C. citratus	0.2 g/mL	98.4±0.8bc
	0.3 g/mL	97.8±1.1bc
	0.4 g/mL	97.8±2.2bc
	0.5 g/mL	100.0±0.0c
Control	0.00 g	0.0±0.0a

Means with the same letters in the column are not significantly different ($p \leq 0.05$)

TABLE 6

Effect of extracts on progeny emergence from larvae of adult weevil

Botanicals	**Conc.**	**%IR/Larvae**
O. gratissimum	0.2 g/mL	92.2±2.7bc
	0.3 g/mL	97.4±1.4c
	0.4 g/mL	96.9±2.4c
	0.5 g/mL	94.8±1.0bc
P. guajava	0.2 g/mL	88.0±0.5bc
	0.3 g/mL	95.3±0.9bc
	0.4 g/mL	89.5±7.5bc
	0.5 g/mL	90.1±9.9bc
O. basilicum	0.2 g/mL	85.9±1.8bc
	0.3 g/mL	85.4±10.0bc
	0.4 g/mL	93.7±0.9bc
	0.5 g/mL	96.9±1.8c
C. citratus	0.2 g/mL	92.2±2.4c
	0.3 g/mL	82.7±8.3b
	0.4 g/mL	95.8±1.0bc
	0.5 g/mL	93.2±1.0bc
Control	0.00 g	0.0±0.0a

TABLE 7

Effect of extracts on progeny emergence from pupae of adult weevil

Botanicals	**Conc.**	**%IR/Pupa**
O. gratissimum	0.2 g/mL	97.4±1.3e
	0.3 g/mL	97.8±1.6e
	0.4 g/mL	97.8±0.4e
	0.5 g/mL	96.09±3.9e
P. guajava	0.2 g/mL	94.8±2.6de
	0.3 g/mL	90.9±4.0cde
	0.4 g/mL	91.31±3.8cde
	0.5 g/mL	91.3±2.8cde
O. basilicum	0.2 g/mL	93.5±3.4cde
	0.3 g/mL	86.1±1.9bc
	0.4 g/mL	92.6±1.1cde
	0.5 g/mL	97.4±0.8e
C. citratus	0.2 g/mL	87.0±3.5bcd
	0.3 g/mL	81.3±2.4b
	0.4 g/mL	90.0±4.3cde
	0.5 g/mL	91.7±4.6cde
Control	0.00 g	0.0±0.0a

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TABLE 8

Effect of extracts on weight loss caused by adult weevil

Botanicals	**Conc.**	**%Weight loss**
O. gratissimum	0.2 g/mL	9.3±2.5ab
	0.3 g/mL	6.7±2.0ab
	0.4 g/mL	3.0±0.5a
	0.5 g/mL	3.4±0.7ab
P. guajava	0.2 g/mL	9.1±3.2ab
	0.3 g/mL	9.1±2.5ab
	0.4 g/mL	9.5±5.8ab
	0.5 g/mL	7.7±2.2ab
O. basilicum	0.2 g/mL	11.3±3.3b
	0.3 g/mL	8.7±5.3ab

6 Means followed by the same letter in a column are not significantly different at 5% probability. Data are means +/- standard error of means

Ocimum gratissimum, Psidium guajava, Ocimum basilicum. Cymbopogon citratus

IR-Reproduction inhibition

	0.4 g/mL	4.0±0.4ab
	0.5 g/mL	4.1±0.7ab
C. citratus	0.2 g/mL	11.2±3.3ab
	0.3 g/mL	10.6±4.1ab
	0.4 g/mL	7.9±0.5ab
	0.5 g/mL	5.3±2.4ab
Control	0.00 g	21.4±1.0c

TABLE 9

Effect of extracts on damage caused by adult weevil

Botanicals	**Conc.**	**%Damage**
O. gratissimum	0.2 g/mL	8.7±2.4c
	0.3 g/mL	8.0±1.2bc
	0.4 g/mL	6.0±1.2abc
	0.5 g/mL	6.7±2.4abc
P. guajava	0.2 g/mL	9.3±3.5c
	0.3 g/mL	9.3±3.3c
	0.4 g/mL	6.7±3.5abc
	0.5 g/mL	0.7±0.7a
O. basilicum	0.2 g/mL	8.7±1.8c
	0.3 g/mL	8.0±3.1bc
	0.4 g/mL	4.0±2.0abc
	0.5 g/mL	1.3±1.3a
C. citratus	0.2 g/mL	5.3±1.8abc
	0.3 g/mL	5.3±2.9abc
	0.4 g/mL	4.0±2.3abc
	0.5 g/mL	2.0±1.1ab
Control	0.00 g	24.7±0.7d

Effect of plant extracts on damage and weigh loss of maize caused by S. zeamais

Insect survival in seed maize treated with methanol extracts was affected by the type of botanical and the concentration. There were significant differences among all the treatments at the various dosage after seven days compared to control. However, it was observed that mortality did not depend on concentrations, except that of *C. citratus*. This is contrary to earlier studies (Uwamose Okolugbo, 2017; Gariba, *et al.*, 2021; Halder *et* al., 2021), who reported that insect pest mortality was dependent on the levels of concentration of extracts. The methanolic extract of the plant products was able to cause up to 66.7% mean mortality. The effectiveness of the extracts (*O. gratissimum*, *C. citratus*, *P. guajava*, *and O. basilicum*) in causing mortality was probably due to the presence of active compounds such as terpenoids, alkaloids, steroids, glycosides and flavonoids as reported by Dibua *et al.* (2013). These phytochemical compounds are known for various protective effects (Umar *et al*., 2016). Triterpenoids of various plant extracts have been proven to have toxic effect against coleopterans (Dzubak, *et al*., 2006).

The present study revealed that all the four botanicals i.e. *O. gratissimum*, *P. guajava*, *O. basilicum*, and *C. citratus*, were potent in reducing the survival of *S. zeamais* (100.0%) to 33.3% at 0.4 g/mL, 36.7% at 0.2 g/mL, and 41.7% at 0.2 g/mL and 0.5 g/mL, respectively. Michael *et al*. (2023) recorded the highest mortality (73.4%) in *T. granarium* adults exposed to groundnut seed treated with 0.4 ml oils of *Psidium guajava*. Also, work done by other scientists previously, reported that *C. citratus* plant powders and extracts are toxic to storage insect pests at different concentrations (Maitra *et al*., 2023). Furthermore, Dike & Mbah, (1992), reported on the efficacy of lemongrass extracts in the control of *C. maculatus* on stored cowpea. In another research conducted by Okparaeke & Dike (2005) to compare the products of *A. sativum* and *C. citratus* in the control of *C. maculatus* on stored cowpea grains, they found that both plant powders caused 100% mortality of the beetles within seven days after treatment.

Effect of methanol extracts on oviposition of S. zeamais

All the botanicals were efficacious at the various concentrations. The extract *C. citratus* and *P. guajava* recorded the lowest (26.7%) mean oviposition percentage at 0.3 g/mL compared to control (63.3%). This may be attributed to the presence of oviposition deterrent compounds which might have altered the physiological behaviours of the adult insects and egg laying. Gariba, *et al.* (2021) attributed suppression of oviposition in *Callosobruchus maculatus* to bioactive compounds such as caryophyllene and germacrene.

The effect of plant extracts on eggs and immature stages of S. zeamais

The botanical extracts affected the different life stages of the insect in this study. The results did not show concentration sensitive effects. The extracts of *C. citratus and O. basilicum* recorded the highest (100.0%) reproduction inhibition (IR) at the egg stage. It can therefore be deduced that *C. citratus and O. basilicum* are the most potent botanicals on eggs of *S. zeamais*. Reproduction inhibition percentages showed that these botanicals have potential in controlling *S. zeamais* (from progeny emergence from adult to pupa stage). The study showed that the extracts were all efficacious on the different developmental stages (eggs, larvae and pupae) of *S. zeamais* at all the concentrations compared to control. This was evident in the mean reproduction inhibition percentages computed at all the concentrations.

Ileke *et al*. (2020) attributed the high inhibition percentage to the pungent nature of the botanicals which might have prevented the insects from normal feeding and hence affecting the normal breeding activity. However, Raveen *et al.* (2017) attributed it to the fact that some plant extracts have effect on the various life cycles of insects' survival resulting in the reduction in adult population. This study also reports high reproduction inhibition of 80.0% to 100.0% at all the concentrations of the four botanicals on the various life cycles of the insect. This confirmed the findings of (Islam, 2017) that seed treated with botanicals are injurious to insects at different growth stages. The toxicity of the extracts on eggs, larvae and pupae resulted in reduced progeny emergency compared to control. Tchinda *et al.* (2017) also confirmed that the efficacy of the extracts on the different life cycles may be as a result of the bitter anti-nutritive secondary metabolites of the extracts on the seed coat which acts as barriers.

Damage and weight loss assessment

The qualitative and quantitative analysis carried out showed that the extracts greatly influenced the normal feeding habit of the insect in that high weight loss (21.4%) and damage (24.7%) was recorded in the control while the extracts recorded the highest percentage weight loss (11.3%) and percentage damage (9.3%) at concentration of 0.2 g/mL by *C. citratus and O. basilicum.* All extracts applied were potent in protecting seed from damage and weight loss.

Conclusion and Recommendation

The high efficacy level of the extracts against the adults and immature stages of *S. zeamais* evident in the results obtained is an indication that the plant species are promising agents against the maize weevil and can be used as substitutes to synthetic chemicals. *Psidium gaujava* and *O. basilicum* at 0.2 g/mL was able to inhibit the emergence of progeny from adult weevil. *Cymbopogon citratus* was most effective on egg and larvae of the weevil at 0.2 g/mL. On the other hand, O. gratissimum performed best on the larvae and pupae stages of growth of the weevil at 0.2 and 0.3

g/mL. The botanicals proved potent against the weevil and can used as seed and grain protectants and incorporated in the Integrated Pest Management (IPM) programs to reduce the overall effect of the conventional chemicals and mitigate the development of insects' strain resistance.

Acknowledgement

I want to extend my profound gratitude to the West Africa Centre for Crop Improvement (WACCI) under the sponsorship of the World Bank Africa Centre of Excellence for sponsoring this work.

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