

Efficacy of *Anacardium occidentale*, *Citrus sinensis*, and *Croton zambesicus* as Natural Maize Seed Protectants against Maize Weevil, *Sitophilus zeamais* (Motschulsky) [Coleoptera: Curculionidae]

¹Kayode David Ileke, ¹Sheriffdeen Alabi Busari, ¹Richard Olajide Owaseye and ²Olaniyi Charles Ogungbite

¹Department of Biology, Federal University of Technology Akure, Akure, Nigeria

²NatureVantage Health Resources Nigeria Limited, Nigeria

Corresponding Author: Richard Olajide Owaseye (owasrichard@gmail.com)

ABSTRACT

Background and Objective: Maize (*Zea mays*) is a primary cereal crop across West Africa, particularly Nigeria. Despite its high production, maize weevil (*Sitophilus zeamais*) infestation threatens both field and storage integrity. Conventional chemical insecticides, while widely used, pose environmental hazards, health risks, and mammalian toxicity. This study evaluated the insecticidal potential of three botanical species (*Anacardium occidentale*, *Croton zambesicus*, and *Citrus sinensis*) as natural maize seed protectants against *S. zeamais* during storage. **Materials and Methods:** Botanical powders were applied at 0.2-1.0 /20 g of maize, and extracts at 0.2-1.0 mL/20 g. Parameters measured included adult mortality, emergence inhibition, grain weight reduction, damage percentages, and weevil perforation index (WPI). All statistical analyses were performed at a 5% level of significance ($p < 0.05$). Statistical analysis was carried out using IBM SPSS Statistics. **Results:** After 48 hrs, *C. sinensis* powder caused the highest adult mortality (66.66%), followed by *A. occidentale* (46.66%) and *C. zambesicus* (40%). Extracts were more toxic than powders, with *A. occidentale* extract achieving 80% mortality within 24 hrs, *C. sinensis* 70%, and *C. zambesicus* 53.5%. All extracts completely suppressed oviposition, prevented adult emergence, and significantly reduced weight loss and seed deterioration. **Conclusion:** These botanical materials effectively controlled *S. zeamais*, offering safe, economically viable alternatives for stored maize protection. Their integration into Integrated Pest Management (IPM) strategies can reduce grain losses, ensure seed viability, and enhance food security in maize-dependent regions.

KEYWORDS

Anacardium occidentale, *Croton zambesicus*, *Citrus sinensis*, maize weevil, natural, food security and integrated pest management

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INTRODUCTION

Throughout West Africa, particularly Nigeria, maize represents a primary cereal crop extensively grown during rainy seasons. Global production statistics position it as the world's leading cereal grain¹. The terms "maize" and "corn" both reference *Zea mays* within the Gramineae family; characterized by tall stature, extensive fibrous root networks, and cross-pollination between spatially separated male and female flowers. Cultivation spans all continents excluding Antarctica. Approximately 50 species exist, displaying diversity in coloration, texture, and grain morphology. African maize cultivation reached 40 mL hectares according to FAO², with Nigeria contributing 16% of continental production, followed by Tanzania. Annual global consumption exceeds 116 mL tons, with 30% and 21% occurring in specific major markets.

The maize weevil (*S. zeamais*) affects grain wholesomeness from field-to-storage phases worldwide. Insect activity constitutes the primary cause of maize grain deterioration in both environments³. Estimates attribute 10-40% of total stored grain damage to this species globally. Traditional tropical storage structures experience 12-80% grain weight reduction from maize weevil activity when grains remain untreated⁴. Consequences include diminished nutritional content, weight reduction, compromised germination capacity, and decreased market valuation. Both larval and adult maize weevils inflict severe damage similar to other Coleoptera order storage pests⁵. Post-harvest *S. zeamais* losses represent an escalating food security challenge across Africa. Infestation compromises quality, quantity, commercial viability, and agricultural utility of stored maize⁶. Due to the environmental and health concerns of chemical insecticides, there is growing interest in botanical alternatives. This study evaluates the insecticidal potential of *Anacardium occidentale*, *Citrus sinensis*, and *Croton zambesicus* as natural maize seed protectants against *S. zeamais* during storage.

MATERIALS AND METHODS

Study area: The study was carried out in the Department of Biology, Federal University of Technology Akure, Ondo State, Nigeria, Between April to September, 2024.

Rearing of insects: Maize weevils were collected from infested maize seeds stored in the Storage Entomology Postgraduate Research Laboratory, Department of Biology, Federal University of Technology, Akure (FUTA), Nigeria. One hundred pairs (100♂ and 100♀) of newly emerged adult weevils were introduced into 1 L glass Kilner jars containing 700 g of clean, uninfested maize grains obtained from a grain merchant within Akure metropolis, Ondo State, Nigeria. The number of 100 pairs was selected to ensure rapid establishment of a stable and sufficiently large culture population, as commonly adopted in stored-product insect rearing protocols and confirmed in preliminary trials to provide adequate progeny for subsequent bioassays.

The introduced weevils were allowed to oviposit and establish for 7 days, after which the parent adults were removed to obtain a uniform F1 generation. Newly emerged adults from the F1 generation were used for the experiments.

The cultures were maintained under ambient laboratory conditions of $28\pm 2^{\circ}\text{C}$ and $75\pm 5\%$ relative humidity. Temperature and relative humidity were continuously monitored using a digital thermometer and hygrometer placed within the insect-rearing enclosure throughout the culture period.

Collection and preparation of plant materials: Fresh leaves of *Anacardium occidentale* L., *Croton zambesicus* Baker, and *Citrus sinensis* (L.) Osbeck were collected from FUTA Northgate, Akure, Ondo State, Nigeria. The plant species were identified and authenticated by a plant taxonomist in the Department of Crop, Soil and Pest Management, Federal University of Technology, Akure (FUTA). However, no voucher specimen number was assigned.

The leaves were washed to remove debris and air-dried under shade at room temperature until constant weight was obtained to preserve phytochemical constituents. The dried leaves were pulverized using an electric blender, and the resulting powders were sieved through a 1 mm mesh sieve to obtain uniform particle size. The powders were stored in airtight containers and kept in a refrigerator at 4°C until use.

Collection of maize seeds: The maize seeds used for this study were collected from Oja-Oba market, Akure, Ondo State. After the wholesome seeds were carefully separated from the infested ones, they were cleaned from debris and dirt. It was then sterilized by keeping it in a deep freezer and maintained at -5°C for 7 days to ensure that all existing insect eggs, larvae, and pupae are killed. This process was carried out because all the life stages of insects are sensitive to cold. The disinfested maize seeds were oven-dried at 40°C for 4 hrs and allowed to cool for 2 hrs before measuring 20 g of the seeds into 250 mL plastic containers for insect bioassay.

Extraction of plant materials: Ethanol extracts of *A. occidentale*, *C. zambesicus* and *C. sinensis* leaves were carried out using a cold extraction method. Three hundred grams (300 g) of each of the plant powders were soaked in a bottle containing 600 mL of 100% ethanol separately. Each of the mixture was stirred intermittently and extraction was successful after 3 days. The mixture was filtered using a double layer of Whatman No. 1 filter paper and the solvent evaporated⁷. A rotary evaporator vacuum was used to recover excess solvent.

Insect bioassay: Effects of plant powders on adult mortality and adult emergence of *S. zeamais* were determined. Twenty grams (20 g) of sterilized maize seeds were measured into a 250 mL plastic container. 0.2, 0.4, 0.6, 0.8 g and 1.0 g dosage of the seed powders of *A. occidentale*, *C. zambesicus* and *C. sinensis* were carefully measured and mixed with the 20 g of the sterilized maize seeds separately. Newly emerged (three days old) ten pairs of adults of maize weevil were introduced into each of the treatments in three replicates. A control experiment was also set up. The mortality of adult weevils was counted and recorded every day for 5 days. The mortality of adult weevils was corrected using Abbott formula⁸:

$$PT = \frac{P_o - P_c}{100 - P_o} \times 100 \quad (1)$$

Where:

P_T = Corrected mortality (%)

P_o = Observed mortality (%)

P_c = Control mortality (%)

The weevil bioassay experiment was kept inside the insect culturing cage until the first filial generation emergence, counted, and documented. Percentage weight loss and seeds damaged were calculated using standard methods.

$$\text{Weigh loss (\%)} = \frac{\text{Change in weight}}{\text{Initial weight}} \times 100 \quad (2)$$

$$\text{Seed damage (\%)} = \frac{\text{Number of seeds damaged}}{\text{Total number of seeds}} \times 100 \quad (3)$$

The Perforation Index was also determined using the method of Fatope *et al.*⁹

Effects of plant ethanol extracts on adult mortality and adult emergence of *S. zeamais*: Twenty grams (20 g) of sterilized maize seeds were measured into a 250 mL plastic container. 0.2, 0.5, 1.0, and 2.0 mL concentration of the seed extracts of the three botanicals was carefully measured and mixed with 20 g of the cleaned maize seeds separately. Newly emerged (three-days old) ten pairs of adults of maize weevil was introduced into each of the treatments in three replicates. A control experiment was also set up. The mortality of adult weevils was counted and recorded every day for 5 days. The mortality of adult weevils was corrected using Abbott formula (Eq. 1). The weevil bioassay experiment was kept inside the insect culturing cage until the first filial generation emergence, counted and documented. Percentage weight loss (Eq. 2) and seeds damaged (Eq. 3) were calculated using standard methods. The Perforation Index was also determined using the method of Fatope *et al.*⁹.

Data analysis: The mortality percentages were calculated and corrected relative to the associated controls using Abbotts formula. Data collected from the laboratory tests were subjected to One-way Analysis of Variance (ANOVA) at 5% significance level and treatment means were separated using Duncans Multiple Range Test. Probit analysis was carried out on percentage mortality of the adult *S. zeamais* to determine the 50% lethal dose/concentration (LD₅₀/LC₅₀) and 90% lethal dose/concentration (LD₉₀/LC₉₀).

RESULTS

Phytochemical compositions (quantitative) of the experimental plants: Table 1 shows that there are four different types (alkaloid, saponin, tannin and flavonoid) of phytochemicals responsible for the bio-pesticidal ability of the plants. Although, the phytochemical composition varies in quantity in each plant. *Anacardium occidentale* powder contains the highest composition of alkaloid (3.92 mg/g). Followed by *C. sinensis* (3.40 mg/g) and *C. zambesicus* (3.11 mg/g). *Citrus sinensis* contains higher saponin and tannin (2.33 and 2.22 mg/g) followed by *A. occidentale* (2.28 and 2.12 mg/g) and *C. zambesicus* (2.18 and 2.08 mg/g). Overall, *A. occidentale* and *C. sinensis* are competitive in phytochemical composition while *C. zambesicus* contains lesser composition.

Mortality response of adult *S. zeamais* treated with some plant powders: Adult *S. zeamais* mortality exhibited dose-dependency when exposed to leaf powders from the three plant species as shown in Table 2. Higher dosages of the powders resulted in higher mortality rates. The toxicity of the three plant powders was significantly different ($p < 0.05$) compared to the control. *Citrus sinensis* leaf powder was the most toxic to the maize weevil. It caused 13.3, 20.0, 26.6, 30.0% and 40.0% mortality of *S. zeamais* at dosages of 0.2, 0.4, 0.6, 0.8 and 1.0 g per 20 g of maize grains after the first day of exposure, respectively. The second most toxic was *A. occidentale* leaf powder, which evoked 10.0, 10.0, 16.6, 23.3 and 26.6% mortality at dosages of 0.2, 0.4, 0.6, 0.8 and 1.0 g per 20 g of maize grains after the first day of exposure, respectively. The least toxic was *C. zambesicus* leaf powder, causing 3.3, 6.6, 13.3, 16.6 and 20.0% mortality at dosages of 0.2, 0.4, 0.6, 0.8 and 1.0 g per 20 g of maize grains after the first day of exposure, respectively. *C. sinensis* powder induced the highest mortality of maize weevils at 80% and 93% rates of 0.8 and 1.0 g per 20 g of maize grains after the fifth day of exposure, respectively. The toxicity level of the 3 plant powders was dependent on both dosage and exposure time.

Table 1: Phytochemical compositions (quantitative) of the experimental plants

Phytochemicals	Composition (mg/g)			
	Alkaloids	Saponins	Tannins	Flavonoids
<i>Anacardium occidentale</i>	3.92±0.03 ^a	2.28±0.04 ^a	2.12±0.02 ^a	3.60±0.02 ^a
<i>Citrus sinensis</i>	3.40±0.02 ^a	2.33±0.02 ^a	2.22±0.01 ^a	3.37±0.02 ^a
<i>Croton zambesicus</i>	3.11±0.01 ^a	2.18±0.01 ^a	2.08±0.02 ^a	2.97±0.02 ^a

Mean followed by the same alphabet in column are not significantly different from one another ($p > 0.05$) using Duncan Multiple Range Test (DMRT) and However, means followed by different alphabet in the column are significantly different ($p < 0.05$) from one another

Table 2: Mortality response of adult *S. zeamais* treated with some plant powders

Plant powders	Dosage (g)	Mortality (Mean±S.E) (%)				
		Day 1	Day 2	Day 3	Day 4	Day 5
<i>Citrus sinensis</i>	0.2	13.33±3.33 ^b	20.00±0.00 ^b	26.66±3.33 ^b	30.00±5.77 ^b	40.00±0.00 ^b
<i>Anacardium occidentale</i>		10.00±0.00 ^b	0.00±0.00 ^b	16.66±3.33 ^b	23.33±3.33 ^b	26.66±3.33 ^b
<i>Croton zambesicus</i>		3.33±3.33 ^b	6.66±3.33 ^b	13.33±3.33 ^b	16.66±3.33 ^b	20.00±0.00 ^b
<i>Citrus sinensis</i>	0.4	16.66±3.33 ^b	26.66±0.00 ^b	40.00±0.00 ^c	46.66±3.33 ^c	53.33±3.33 ^c
<i>Anacardium occidentale</i>		10.00±0.00 ^b	16.66±3.33 ^b	30.00±0.00 ^c	36.66±3.33 ^{bc}	43.33±3.33 ^c
<i>Croton zambesicus</i>		6.66±3.33 ^b	10.00±0.00 ^b	20.00±0.00 ^{bc}	23.33±3.33 ^{bc}	30.00±0.00 ^c
<i>Citrus sinensis</i>	0.6	30.00±0.00 ^c	40.00±0.00 ^c	46.66±3.33 ^c	56.66±3.33 ^{cd}	63.33±3.33 ^c
<i>Anacardium occidentale</i>		20.00±0.00 ^c	30.00±0.00 ^c	36.66±3.33 ^{cd}	46.33±3.33 ^{cd}	50.00±0.00 ^c
<i>Croton zambesicus</i>		10.00±0.00 ^c	20.00±0.00 ^c	26.66±3.33 ^{cd}	33.33±3.33 ^{cd}	40.00±0.00 ^c
<i>Citrus sinensis</i>	0.8	40.00±0.00 ^d	50.00±0.00 ^d	60.00±0.00 ^d	70.00±0.00 ^{de}	80.00±0.00 ^d
<i>Anacardium occidentale</i>		30.00±0.00 ^d	40.00±0.00 ^d	46.66±3.33 ^d	56.66±3.33 ^{de}	63.33±3.33 ^d
<i>Croton zambesicus</i>		23.00±3.33 ^d	30.00±0.00 ^d	36.66±3.33 ^{de}	46.66±3.33 ^{de}	53.33±3.33 ^d
<i>Citrus sinensis</i>	1.0	50.00±0.00 ^e	66.66±3.33 ^e	70.00±0.00 ^e	80.00±0.00 ^e	93.33±3.33 ^e
<i>Anacardium occidentale</i>		36.66±3.33 ^e	46.66±3.33 ^d	60.00±0.00 ^e	66.66±3.33 ^e	80.00±0.00 ^e
<i>Croton zambesicus</i>		36.66±3.33 ^e	40.00±0.00 ^d	50.00±0.00 ^e	50.00±0.00 ^e	60.00±0.00 ^e
Control	0.0	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a

Mean followed by the same alphabet in column are not significantly different from one another ($p>0.05$) using Duncan Multiple Range Test (DMRT) and However, means followed by different alphabet in the column are significantly different ($p<0.05$) from one another

Table 3: Lethal dosage (LD) of some plants powders against adult *S. zeamais*

Plant powder	Exposure period	Intercept± S.E.	Slope±S.E.	R ²	LD50 (LCL - UCL)	LD90 (LCL -UCL)	p-value
<i>Citrus sinensis</i>	DAY1	0.09±0.09	1.69±0.27	0.91	1.14 (0.92-1.63)	6.50 (3.6019.74)	3.64
	DAY2	0.24±0.09	1.80 ±0.25	0.90	0.73 (0.62-0.89)	3.87 (2.48-8.35)	5.67
	DAY3	0.40±0.09	1.57 ±0.24	0.95	0.56 (0.47-0.66)	3.63 (2.28-8.45)	2.71
	DAY4	0.70±0.10	1.86 ±0.24	0.96	0.42 (0.35-0.48)	2.04 (1.50-3.37)	2.61
	DAY5	1.06±0.10	2.10 ±0.25	0.85	0.31 (0.07-0.48)	1.28 (0.7526.18)	11.76
<i>Anacardium occidentale</i>	DAY1	0.42±0.09	1.52±0.29	0.84	1.89 (1.32-3.94)	13.14 (5.5685.49)	4.47
	DAY2	0.10±0.09	1.83±0.28	0.97	1.14 (0.93-1.60)	5.73 (3.34-15.41)	1.26
	DAY3	0.13±0.09	1.66±0.25	0.96	0.83 (0.70-1.07)	4.94 (2.93-12.81)	1.93
	DAY4	0.34±0.09	1.62±0.24	0.98	0.61 (0.52-0.74)	3.80 (2.38-8.79)	1.05
	DAY5	0.60±0.09	1.88±0.24	0.91	0.48 (0.41-0.55)	2.30 (1.66-3.92)	5.78
<i>Croton zambesicus</i>	DAY1	0.48±0.10	2.39±0.38	0.89	1.59 (1.25-2.45)	5.48 (3.27-14.59)	5.73
	DAY2	0.34±0.09	1.94±0.31	0.93	1.49 (1.16-2.33)	6.84 (3.78-21.01)	2.75
	DAY3	0.14±0.09	1.57±0.27	0.92	1.24 (0.97-1.91)	8.13 (4.12-31.30)	3.34
	DAY4	0.02±0.09	1.49±0.26	0.91	1.03 (0.52-0.74)	7.47 (3.83-28.10)	1.91
	DAY5	0.20±0.09	1.61±0.25	0.97	0.76 (0.64-0.95)	4.74 (2.82-12.32)	1.56

R²: Statistical measure of mortality proportion in regression model, S. E.: Standard error, S. D.: Standard deviation, LD₅₀: Lethal dosage at which 50% population response, LD₉₀: Lethal dosage at which 90% population response, LCL: Lower confidence limit, UCL: Upper confidence limit and P-value = Chi -square (χ^2) significant

Lethal dosage (LD) of some plants powders against adult *S. zeamais*: Table 3 shows the lethal doses of the three plant leaf powders needed to cause 50% (LD₅₀) and 90% (LD₉₀) mortality in *S. zeamais* after the first day of exposure. The LD₅₀ and LD₉₀ values were 1.14 and 6.50 g for *C. sinensis*, 1.89 and 13.14 g for *A. occidentale*, and 1.59 and 5.48 g for *C. zambesicus*, respectively. These lethal dose values continued decreasing over the second, third, fourth and fifth day of exposure. *C. sinensis* leaf powder had the lowest lethal doses across all exposure periods. Though the calculated values are shown, the actual effective doses may fall within the different confidence limits.

Number of adult emergence of *S. zeamais* in maize treated with some plant leaf powders: Table 4 illustrates the efficacy of *C. sinensis*, *A. occidentale*, and *C. zambesicus* powders in preventing adult *S. zeamais* emergence in treated maize. The protection effective provided by the plant powders was significantly different ($p<0.05$) from the control. The highest seed protection was seen with 1.0 g of *C. sinensis* which completely prevented adult weevil emergence (0.0). The protection of 1.0 g *C. sinensis* was not significantly different from 1.0 g *A. occidentale*, *C. zambesicus* (0.6 and 1.3% adult emergence recorded, respectively). *Citrus sinensis* and *A. occidentale* at 0.2 g (6.3 and 7.0% adult emergence, respectively) offered significantly greater protection ($p<0.05$) than 0.2 g of *C. zambesicus* (10.3%).

Table 4: Number of adult emergence of *S. zeamais* in maize treated with some plant leaf powders

Plant powder	Dosage (g)	Adult emergence
<i>Citrus sinensis</i>	0.2	6.33±1.20 ^c
<i>Anacardium occidentale</i>		7.00±1.52 ^c
<i>Croton zambesicus</i>		10.33±3.33 ^d
<i>Citrus sinensis</i>	0.4	4.00±0.57 ^{bc}
<i>Anacardium occidentale</i>		6.00±0.57 ^{bc}
<i>Croton zambesicus</i>		7.66±0.33 ^c
<i>Citrus sinensis</i>	0.6	2.33±0.33 ^b
<i>Anacardium occidentale</i>		3.33±0.33 ^b
<i>Croton zambesicus</i>		5.33±0.33 ^b
<i>Citrus sinensis</i>	0.8	0.33±0.33 ^a
<i>Anacardium occidentale</i>		1.66±0.57 ^a
<i>Croton zambesicus</i>		2.66±0.33 ^a
<i>Citrus sinensis</i>	1.0	0.00±0.00 ^a
<i>Anacardium occidentale</i>		0.66±0.33 ^a
<i>Croton zambesicus</i>		1.33±0.33 ^a
Control	0.0	34.33±0.00 ^a

Table 5: Protectant effect of some spices powders on maize seed damage, weight loss, and weevil perforation index against maize weevil

Plant powder	Dosage (g)	Total no of seeds	Seed damage (%)	Weight loss (%)	Weevil perforation index
<i>Anacardium occidentale</i>	0.2	71.00±0.57 ^b	4.69±0.47 ^a	0.20±0.06 ^a	0.08±0.01 ^a
	0.4	73.00±1.57 ^{ab}	2.73±0.79 ^a	0.08±0.02 ^a	0.04±0.01 ^a
	0.6	76.66±0.88 ^{ab}	2.31±1.66 ^a	0.06±0.04 ^a	0.03±0.02 ^a
	0.8	72.00±0.57 ^a	2.24±1.18 ^a	0.06±0.03 ^a	0.04±0.02 ^a
	1.0	76.33±0.33 ^a	1.36±0.79 ^a	0.04±0.02 ^a	0.02±0.01 ^a
<i>Citrus sinensis</i>	0.2	71.33±0.88 ^c	6.55±0.54 ^c	0.18±0.13 ^c	0.11±0.10 ^c
	0.4	73.66±0.33 ^{bc}	4.51±1.18 ^{bc}	0.13±0.03 ^{bc}	0.08±0.02 ^{bc}
	0.6	72.66±0.88 ^{ab}	2.32±0.95 ^{ab}	0.06±0.02 ^{ab}	0.03±0.02 ^{ab}
	0.8	71.33±0.33 ^a	0.90±0.45 ^a	0.02±0.01 ^a	0.01±0.01 ^a
	1.0	74.00±1.73 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
<i>Croton zambesicus</i>	0.2	73.66±0.88 ^a	7.36±2.58 ^a	0.18±0.07 ^a	0.11±0.04 ^a
	0.4	72.00±0.57 ^a	4.14±1.37 ^a	0.12±0.04 ^a	0.06±0.02 ^a
	0.6	73.33±0.88 ^a	3.14±0.12 ^a	0.09±0.01 ^a	0.05±0.01 ^a
	0.8	76.00±0.57 ^a	1.82±0.57 ^a	0.05±0.01 ^a	0.02±0.01 ^a
	1.0	74.00±1.73 ^a	0.45±0.45 ^a	0.01±0.01 ^a	0.01±0.01 ^a
Control	0.00	75.00±0.57 ^a	30.34±2.62 ^a	0.69±0.10 ^a	0.35±0.05 ^a

Mean follow by the same alphabet in column are not significantly different from one another ($p > 0.05$) using Duncan Multiple Range Test and However, means followed by different alphabet in the column are significantly different ($p < 0.05$) from one another

Protectant effect of some plants powders on maize seed damage, weight loss, and weevil perforation index against maize weevil: Table 5 depicts the percentage seed damage, weight loss, and weevil perforation index. Maize treated with 0.2 g *C. sinensis* and 0.2 g *A. occidentale* powders had 4.69% and 6.55% seed damage, respectively, with significant difference ($p < 0.05$) between them. However, these were significantly lower ($p < 0.05$) than the 7.36% damage caused by 0.2 g *C. zambesicus* powder. The highest percentage damage (7.36%) occurred with 0.2 g *C. zambesicus* significantly less ($p < 0.05$) than the control (30.34%). The lowest damage (0.0%) was seen with 1.0 g *C. sinensis* and 1.0 g *C. zambesicus* (0.45%), which did not differ significantly ($p > 0.05$). The highest weight loss (30.34%) was in the control, significantly more ($p < 0.05$) than the 7.36% with 0.2 g *C. zambesicus*. The highest weevil perforation index (0.11) occurred with 0.2 g *C. sinensis*, and *C. zambesicus* having the same value of perforation index.

Mortality response of adult *S. zeamais* treated with some plants extracts: Table 6 shows adult *S. zeamais* mortality increased with higher concentrations and longer exposure to *C. sinensis*, *A. occidentale*, and *C. zambesicus* extracts, differing significantly ($p < 0.05$) from controls. *A. occidentale* was most toxic, causing 36.6, 50.0, 60.0, 66.6 and 80.0% mortality at concentration of 0.2, 0.4, 0.6, 0.8, and 1.0 mL per 20 g maize over 1 day. *C. sinensis* caused 23.3, 36.6, 46.6, 56.6 and 70.0% mortality

Table 6: Mortality response of adult *S. zeamais* treated with some plant extracts

Plant powders	Dosage (g)	Mortality (Mean±S.E) (%)				
		Day 1	Day 2	Day 3	Day 4	Day 5
<i>Anacardium occidentale</i>	0.2	36.66±3.33 ^b	50.00±0.00 ^b	60.00±0.00 ^b	76.66±3.33 ^b	80.00±0.00 ^b
<i>Citrus sinensis</i>		23.33±3.33 ^b	33.33±3.33 ^b	50.00±0.00 ^b	56.66±3.33 ^b	63.33±3.33 ^b
<i>Croton zambesicus</i>		13.33±3.33 ^b	23.33±3.33 ^b	33.33±3.33 ^b	43.33±3.33 ^b	46.66±3.33 ^b
<i>Anacardium occidentale</i>	0.4	50.00±0.00 ^c	60.00±0.00 ^c	70.00±0.00 ^c	83.33±3.33 ^{bc}	93.33±3.33 ^c
<i>Citrus sinensis</i>		36.66±3.33 ^c	50.00±0.00 ^c	56.66±3.33 ^b	63.33±3.33 ^b	73.33±3.33 ^b
<i>Croton zambesicus</i>		26.66±3.33 ^c	36.66±3.33 ^c	50.00±0.00 ^c	56.66±3.33 ^c	63.33±3.33 ^c
<i>Anacardium occidentale</i>	0.6	60.00±0.00 ^d	70.00±0.00 ^d	80.00±0.00 ^d	90.00±0.00 ^c	100.00±0.0 ^d
<i>Citrus sinensis</i>		46.66±3.33 ^{cd}	56.66±3.33 ^{cd}	70.00±0.00 ^c	76.66±3.33 ^c	86.66±3.33 ^c
<i>Croton zambesicus</i>		36.66±3.33 ^{cd}	46.66±3.33 ^{cd}	56.66±3.33 ^c	63.33±3.33 ^{cd}	76.66±3.33 ^d
<i>Anacardium occidentale</i>	0.8	66.66±3.33 ^d	76.66±3.33 ^e	90.00±0.00 ^d	100.00±0.00 ^d	100.00±0.00 ^d
<i>Citrus sinensis</i>		56.66±3.33 ^d	63.33±3.33 ^d	76.66±3.33 ^{cd}	86.66±3.33 ^c	100.00±0.00 ^d
<i>Croton zambesicus</i>		40.00±0.00 ^d	50.00±0.00 ^d	60.00±0.00 ^c	70.00±0.00 ^d	80.00±0.00 ^d
<i>Anacardium occidentale</i>	1.0	80.00±0.00 ^e	90.00±0.00 ^f	100.00±0.0 ^d	100.00±0.00 ^d	100.00±0.00 ^d
<i>Citrus sinensis</i>		70.00±0.00 ^e	80.00±0.00 ^e	86.66±3.33 ^d	100.00±0.00 ^d	100.00±0.00 ^d
<i>Croton zambesicus</i>		53.33±3.33 ^e	63.33±3.33 ^e	73.33±3.33 ^d	86.66±3.33 ^e	100.00±0.00 ^e
Control	0.0	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a

Mean followed by the same alphabet in column are not significantly different from one another ($p>0.05$) using Duncan Multiple Range Test (DMRT) and However, means followed by different alphabet in the column are significantly different ($p<0.05$) from one another.

Table 7: Lethal concentration (LC) of some plants extracts against adult *S. zeamais*

Plant extracts	Exposure period	Intercept± S.E.	Slope±S.E.	R ²	LC ₅₀ (LCL - UCL)	LC ₉₀ (LCL -UCL)	p value
<i>Anacardium occidentale</i>	DAY1	0.67±0.91	1.54±0.24	0.94	0.37 (0.29-0.44)	2.51 (1.68-5.18)	2.71
	DAY2	0.98±0.98	1.55 ±0.24	0.90	0.23 (0.16-0.30)	1.57 (1.14-2.78)	5.67
	DAY3	1.53±0.12	2.04 ±0.27	0.91	0.18 (0.00-0.32)	0.76 (0.45-137.79)	13.28
	DAY4	2.07±0.17	2.13 ±0.34	0.95	0.42 (0.35-0.48)	2.04 (1.50-3.37)	13.26
	DAY5	3.09±0.34	3.29 ±0.57	1.00	0.12 (0.07-0.15)	0.28 (0.24-0.33)	3.75
<i>Citrus sinensis</i>	DAY1	0.39±0.89	1.70±0.24	0.96	0.40 (0.33-0.48)	3.36 (2.20-7.02)	2.26
	DAY2	0.62±0.09	1.58±0.24	0.91	1.14 (0.93-1.60)	2.60 (1.75-5.29)	4.16
	DAY3	0.91±1.00	1.46±0.24	0.9	0.24 (0.16-0.30)	1.80 (1.26-3.48)	4.31
	DAY4	0.39±0.11	2.02±0.27	0.88	0.21 (0.00-0.00)	0.88 (0.00-0.00)	17.92
	DAY5	1.96±0.15	2.59±0.31	0.91	0.17 (0.00-0.31)	0.54 (0.31-27.88)	18.49
<i>Croton zambesicus</i>	DAY1	0.01±0.09	1.61±0.26	0.98	0.99 (0.81-1.37)	6.19 (3.42-19.07)	1.06
	DAY2	0.24±0.09	1.43±0.24	0.97	0.68 (0.57-0.86)	0.90 (2.97-17.29)	1.33
	DAY3	0.43±0.09	1.29±0.24	0.84	0.46 (0.36-0.57)	4.55 (2.51-15.54)	6.05
	DAY4	0.81±0.09	1.51±0.24	0.85	0.29 (0.21-0.36)	2.06 (1.42-4.03)	6.20
	DAY5	1.33±0.11	2.20±0.26	0.99	0.25 (0.00-0.41)	0.95 (0.56-395.69)	16.66

R²: Statistical measure of mortality proportion in regression model, S. E.: Standard error, S. D.: Standard deviation, LC₅₀: Lethal dosage at which 50% population response, LC₉₀: Lethal dosage at which 90% population response, LCL: Lower confidence limit, UCL: Upper confidence limit and P-value = Chi -square (χ^2) significant

at 0.2, 0.4, 0.6, 0.8, and 1.0 mL per 20 g maize over 1 day, while *C. zambesicus* was least toxic at 13.3, 26.6, 36.6, 40.0 and 53.3% mortality at 0.2, 0.4, 0.6, 0.8, and 1.0 mL per 20 g maize over 1 day. By day 5, 100% mortality occurred at 0.6 ml of *A. occidentale*, 100% mortality occurred at 0.8 ml of *C. sinensis* and 100% mortality occurred at 1.0 mL of *C. zambesicus*. Toxicity correlated with concentration and exposure time.

Lethal concentration (LC) of some plants extracts against adult *S. zeamais*: Table 7 shows the lethal doses of the three plant extracts needed to cause 50% (LD₅₀) and 90% (LD₉₀) mortality in *S. zeamais* after the first day of exposure. The LD₅₀ and LD₉₀ values were 0.37 and 2.51 mL for *A. occidentale*, 0.40 and 3.36 mL for *C. sinensis*, and 0.99 and 6.19 mL for *C. zambesicus*, respectively. These lethal concentration values continued decreasing over the second, third, fourth and fifth day of exposure. *Anacardium. occidentale* leaf extracts had the lowest lethal doses across all exposure periods. Though, the calculated values are shown, the actual effective doses may fall within the different confidence limits.

Table 8: Number of adult emergence of *S. zeamais* in maize treated with some plants extract

Plant powder	Concentration (mL)	Adult emergence
<i>Anacardium occidentale</i>	0.2	3.33±0.33 ^c
<i>Citrus sinensis</i>		4.66±0.33 ^c
<i>Croton zambesicus</i>		6.66±3.33 ^d
<i>Anacardium occidentale</i>	0.4	1.33±0.33 ^b
<i>Citrus sinensis</i>		2.33±0.66 ^b
<i>Croton zambesicus</i>		4.33±0.33 ^c
<i>Anacardium occidentale</i>	0.6	0.33±0.33 ^{bc}
<i>Citrus sinensis</i>		2.33±0.33 ^b
<i>Croton zambesicus</i>		1.33±0.33 ^{bc}
<i>Anacardium occidentale</i>	0.8	0.00±0.00 ^a
<i>Citrus sinensis</i>		0.33±0.33 ^{bc}
<i>Croton zambesicus</i>		1.33±0.33 ^{bc}
<i>Anacardium occidentale</i>	1.0	0.00±0.00 ^a
<i>Citrus sinensis</i>		0.00±0.00 ^a
<i>Croton zambesicus</i>		0.33±0.33 ^a
Control	0.0	34.33±0.00 ^a

Table 9: Correlations between phytochemicals in *Anacardium occidentale* powder and *Sitophilus zeamais* adult emergence, grain damage and weight loss

Variables	Alkaloids	Saponins	Tanins	Flavonoids	Adult emergence	Seed damage (%)	Weight loss (%)
Alkaloids	1	-0.610	0.240	0.569	-0.882	-0.866	0.982
Saponins		1	0.623	-0.999*	0.164	0.132	-0.749
Tanins			1	-0.661	-0.670	-0.693	0.052
Flavonoids				1	-0.114	-0.082	0.715
Adult emergence					1	0.999*	-0.777
Seed damage (%)						1	-0.756
Weight loss (%)							1

*Correlation is significant at the 0.05 level (2-tailed) and **Correlation is significant at the 0.01 level (2-tailed)

Number of adult emergence of *S. zeamais* in maize treated with some plants extract: Table 8 shows the efficacy provided by the plant powders which was significantly different ($p < 0.05$) from the control. The highest grain protection was seen with 0.8 and 1.0 mL of *A. occidentale* which completely prevented adult weevil emergence (0.0). The protection of 1.0 mL *C. sinensis* was not significantly different from 1.0 mL of *A. occidentale*, *C. zambesicus* (0.00 and 0.33% adult emergence recorded, respectively). *Citrus sinensis* and *A. occidentale* at 0.2 mL (4.66 and 3.33 % adult emergence, respectively) offered significantly greater protection ($p < 0.05$) than 0.2 mL of *C. zambesicus* (6.66%).

Correlations between phytochemicals in *Anacardium occidentale* powder and *Sitophilus zeamais* adult emergence, grain damage and weight loss: Table 9 presents the correlation matrix among phytochemical constituents and infestation parameters, with correlation coefficients ranging from -1 to 1, indicating the strength and direction of relationships among variables. Alkaloids showed a strong negative correlation with adult emergence (-0.882) and percentage seed damage (-0.866), but a strong positive correlation with percentage weight loss (0.982). Saponins exhibited a strong negative and significant correlation with flavonoids (-0.999*), while tannins were negatively correlated with adult emergence (-0.670) and percentage seed damage (-0.693). A strong positive and significant correlation was observed between adult emergence and percentage seed damage (0.999*). Percentage weight loss was negatively correlated with adult emergence (-0.777) and percentage seed damage (-0.756).

Correlations between phytochemicals in *Citrus sinensis* powder and *Sitophilus zeamais* adult emergence, grain damage and weight loss: The correlation analysis between phytochemical constituents of *Citrus sinensis* powder and *Sitophilus zeamais* adult emergence, grain damage, and weight loss is presented in Table 10. Alkaloids showed strong positive correlations with saponins (0.982), tannins (0.891), and percentage weight loss (0.982), but a negative correlation with flavonoids (-0.655). Saponins

Table 10: Correlations between phytochemicals in *Citrus sinensis* powder and *Sitophilus zeamais* adult emergence, grain damage and weight loss

Variables	Alkaloids	Saponins	Tanins	Flavonoids	Adult emergence	Seed damage (%)	Weight loss (%)
Alkaloids	1	0.982	0.891	-0.655	0.330	0.000	0.982
Saponins		1	0.961	-0.500	0.502	0.189	1.000**
Tanins			1	-0.240	0.722	0.454	0.961
Flavonoids				1	0.498	0.756	-0.500
Adult emergence					1	0.944	0.502
Seed damage (%)						1	0.189
Weight loss (%)							1

*Correlation is significant at the 0.05 level (2-tailed) and**Correlation is significant at the 0.01 level (2-tailed)

Table 11: Correlations between phytochemicals in *Croton zambesicus* powder and *Sitophilus zeamais* adult emergence, grain damage and weight loss

Variables	Alkaloids	Saponins	Tanins	Flavonoids	Adult emergence	Seed damage (%)	Weight loss (%)
Alkaloids	1	0.954	-0.017	-0.795	-0.962	-0.962	-0.115
Saponins		1	-0.317	-0.577	-0.835	-0.836	0.189
Tanins			1	-0.592	-0.257	-0.256	-0.991
Flavonoids				1	0.931	0.931	0.693
Adult emergence					1	1.000**	0.382
Seed damage (%)						1	0.381
Weight loss (%)							1

*Correlation is significant at the 0.05 level (2-tailed) and **Correlation is significant at the 0.01 level (2-tailed)

exhibited a very strong positive and significant correlation with percentage weight loss (1.000**), and a strong positive relationship with tannins (0.961). Tannins were positively correlated with adult emergence (0.722) and percentage weight loss (0.961). Flavonoids showed a positive correlation with percentage seed damage (0.756) but a negative relationship with percentage weight loss (-0.500). Adult emergence was strongly positively correlated with percentage seed damage (0.944).

Correlations between phytochemicals in *Croton zambesicus* powder and *Sitophilus zeamais* adult emergence, grain damage and weight loss: The correlation analysis between phytochemical constituents of *Croton zambesicus* powder and *Sitophilus zeamais* adult emergence, grain damage, and weight loss is presented in Table 11. Alkaloids showed strong negative correlations with flavonoids (-0.795), adult emergence (-0.962), and percentage seed damage (-0.962). Saponins were also negatively correlated with adult emergence (-0.835) and percentage seed damage (-0.836). Tannins exhibited a very strong negative correlation with percentage weight loss (-0.991). Flavonoids showed strong positive correlations with adult emergence (0.931) and percentage seed damage (0.931). A perfect positive and significant correlation was observed between adult emergence and percentage seed damage (1.000**), while both variables showed weak positive correlations with percentage weight loss.

DISCUSSION

Study findings validate *C. sinensis*, *A. occidentale*, and *C. zambesicus* powders and extracts as viable maize seed preservation agents against storage insect degradation. Treatment applications drastically reduced weevil oviposition capacity on protected grain, minimizing damage levels. Botanical product effectiveness against *S. zeamais* in storage likely results from direct contact toxicity mechanisms when powders interact with weevils. Evidence demonstrated complete reproductive suppression in maize weevil populations for one-month periods following treatment. Repellent characteristics may constitute an additional action mechanism¹⁰.

Analytical results confirmed that botanical treatments significantly reduced or eliminated seed damage, weight loss percentages, and weevil perforation index. Contact application methodology produced substantial *S. zeamais* mortality, confirming contact toxicity properties within the oils¹¹. Both powdered and extracted forms exhibited insecticidal characteristics far exceeding control treatments. Among

powders, *C. sinensis* achieved lowest LD₅₀ and LD₅₀ values, indicating superior toxicity, with *A. occidentale* ranking second and *C. zambesicus* demonstrating weakest potency. Conversely, extract toxicity rankings differed: *A. occidentale* exhibited lowest LD₅₀ and LD₅₀ values, followed by *C. sinensis*, while *C. zambesicus* maintained its position as least toxic across both formulations. Mortality rates increased proportionally with dosage, concentration, and exposure duration¹².

Following 24 hrs exposure across all powder dosages, *C. sinensis* proved most effective against adult *S. zeamais*. Higher insecticidal compound concentrations in *C. sinensis* powder likely account for observed contact toxicity. However, *A. occidentale* extracts demonstrated superior toxicity compared to alternatives. The mechanism underlying this phenomenon requires confirmation. Possibly, *A. occidentale* compounds achieve better reactivity with ethanol compared to *C. sinensis*. Additional research should examine this relationship further. Previous reports have documented plant powder and extract efficacy in *S. zeamais* control through adult mortality induction¹³.

Toxicity patterns varied among plant species and exposure intervals¹⁴. Extract formulations generally exhibited higher toxicity, likely attributable to active component concentration during extraction processes. Appropriate solvent selection during extraction can amplify insecticidal plant powder potency. Insecticidal activity depends on active constituents including saponins, alkaloids, terpenes, and flavonoids. Four phytochemical compounds showed consistent presence (alkaloid, saponin, tannin, flavonoid) across experimental plants, though additional compounds may exist. These constituents likely inhibit acetylcholinesterase function, disrupt octopamine pathways, and cause mortality. Elevated mortality rates could also result from powder and extract coatings on grains that poison weevils upon contact¹⁵. Nutritional deprivation preventing growth support may contribute to mortality. Results align with previous leaf powder toxicity findings against *S. zeamais*.

CONCLUSION

Protecting grains from insect activity remains essential for ensuring food security. This research demonstrated plant material efficacy in controlling *S. zeamais* infestation of maize. Evidence supports the conclusion that natural botanical products; *A. occidentale*, *C. sinensis*, and *C. zambesicus*; derived from different plant species effectively controlled or reduced maize weevil impact on stored maize grains. These natural alternatives pose negligible mammalian toxicity while offering cost-effectiveness. In developing countries where maize represents a primary food source, safeguarding grain stores from insect damage constitutes a priority for reducing excessive food loss.

SIGNIFICANCE STATEMENT

This study demonstrates the practical potential of plant-based insecticides derived from *Anacardium occidentale*, *Citrus sinensis*, and *Croton zambesicus* in managing *Sitophilus zeamais* infestations in stored maize. The findings are significant as they provide effective, eco-friendly, and low-toxicity alternatives to synthetic chemical pesticides, which are associated with environmental pollution, health risks, and pest resistance. The strong insecticidal, oviposition-inhibiting, and grain-protective effects observed highlight their applicability within Integrated Pest Management (IPM) strategies. Adoption of these botanical protectants can substantially reduce post-harvest losses, preserve grain quality, and enhance food security, particularly in maize-dependent regions of sub-Saharan Africa where storage pest damage remains a persistent agricultural challenge.

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