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Laboratory Evaluation of Spice Powders and Extracts for Biocontrol of Maize Weevil (*Sitophilus zeamais*) in Stored Maize Seeds

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ABSTRACT

Background and Objective: Maize (*Zea mays*) is a versatile grain with high genetic yield potential, originally domesticated in Central America. It thrives across diverse seasons and ecological zones, making it a globally significant crop. The study investigated the toxicity of seed powders and extracts derived from *Curcuma longa* (turmeric) and *Piper guineense* (African black pepper) for their potential to control maize weevils (*Sitophilus zeamais*) in stored maize grains under laboratory conditions. **Materials and Methods:** Powders were applied at doses of 0.2, 0.4, 0.6, 0.8, and 1.0 g/20 g of maize, while extracts were evaluated at concentrations of 0.2, 0.4, 0.6, 0.8, and 1.0 mL/20 g of maize. Key parameters assessed included insect mortality, oviposition rates, adult emergence, weight loss, seed damage, and the weevil perforation index (WPI). The laboratory experimental data were analyzed using Analysis of Variance (ANOVA) with a significance level of 5%. **Results:** The results revealed that *P. guineense* powder was the most effective, causing 81.7% adult mortality at 1.0 g/20 g within 24 hrs. This was followed by *C. longa* powder, which achieved 70% mortality at the same dose. Remarkably, the extracts were more toxic than the powders, with *P. guineense* extract achieving 96.7% mortality at 1.0 mL/20 g within 24 hrs. Similarly, *C. longa* extract induced 80% mortality under comparable conditions. Additionally, powders and extracts from the two botanicals completely inhibited oviposition, adult emergence, weight loss, and seed damage, demonstrating their effectiveness in suppressing the reproductive and developmental processes of the weevils. **Conclusion:** These findings underscore the potential of *C. longa* and *P. guineense* as viable alternatives to synthetic pesticides in managing *S. zeamais* infestations in stored maize grains. Their use as botanical insecticides offers an eco-friendly, cost-effective, and sustainable approach to reducing post-harvest losses and preserving seed quality. This could significantly enhance food security in developing countries, where maize is a staple food crop and post-harvest pest infestations often lead to substantial losses.

KEYWORDS

Toxicity, botanicals, *Sitophilus zeamais*, *Curcuma longa*, *Piper guineense*

INTRODUCTION

Maize (*Zea mays*) is one of the world's most significant crops, widely cultivated as a cereal grain that originated from domestication in Central America. Renowned for its versatility, maize is recognized globally as the "queen of cereals" due to its exceptional genetic yield potential. It is the only cereal crop

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capable of thriving across various seasons, ecological zones, and applications[1]. Additionally, maize is among the most vital cereal crops globally which serves a staple food for millions of people. It is of the grass family Poaceae and is the third largest plant-based food source in the world[2]. Its cultivation and consumption are integral to the economy and food security of many regions. It is a rich source of carbohydrates, dietary fiber, vitamins, and minerals. Its nutritional composition makes it a vital component of diets, particularly in regions where food diversity is limited. Maize is cultivated in diverse agroecological zones, with production practices varying according to local climatic conditions and farming systems. It is valued for its nutritional source of carbohydrates, dietary fiber, vitamins, and minerals[3]. This composition makes it a vital component of diets, particularly in regions where food diversity is limited. Additionally, maize serves as feed for livestock and is a raw material for various industrial products, further emphasizing its economic significance.

Sitophilus zeamais (Motschulsky) is a globally prevalent insect that infests stored grains, particularly maize. The insect significantly threatens stored maize grains across tropical and temperate regions[4]. Infestation by this insect causes significant post-harvest losses of staple food crops in Nigeria, leading to notable economic challenges[5,6]. Adult weevils feed on maize kernels and lay eggs inside them. Upon hatching, the larvae consume the internal contents of the grains, leading to quality deterioration and economic losses. The lifecycle of the maize weevil is affected by factors like temperature, humidity, and grain moisture content, with favorable conditions accelerating population growth and infestation. Chemical pesticides have traditionally been used to control maize weevils and other stored grain pests. However, their widespread use has raised concerns regarding environmental pollution, negative impacts on non-target organisms, and the development of pesticide resistance among target pests. Additionally, residues of chemical pesticides in food grains pose risks to human health, prompting the search for safer, more suitable alternatives. Growing concerns over health and environmental risks, alongside challenges such as genetic resistance in insect species, pest resurgence, and the residual toxicity of chemical pesticides, have led many societies to advocate for safer and more sustainable pest control alternatives[6,7]. The utilization of plant-derived products, such as botanical extracts and powders, has gained attention as alternative protectants against maize weevils. These products contain bioactive compounds with insecticidal properties that disrupt the development and reproduction of weevils, thereby reducing grain damage and preserving grain quality. Recently, there has been a growing interest in using plant-based products as cost-effective and environmentally friendly alternatives for managing insect pest infestations in stored cereals and grains, particularly in tropical regions[8]. There is a growing focus on utilizing edible plant materials as protectants for stored grains[7,9]. The tropics, in particular, are rich in diverse plant species, many of which also have medicinal uses. Common plant sources of such protectants include neem (*Azadirachta indica*), tobacco (*Nicotiana tabacum*), and chilli (*Capsicum* spp.) have shown insecticidal properties against maize pests, while being environmentally friendly and non-toxic to humans. The objective of the study was to investigate the toxicity of seed powders and extracts derived from *Curcuma longa* (turmeric) and *Piper guineense* (African black pepper) in controlling maize weevils (*Sitophilus zeamais*) in stored maize grains under laboratory conditions.

MATERIALS AND METHODS

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

Insect rearing: Adult maize weevils (*Sitophilus zeamais*) were obtained from the Entomology Research Laboratory, in the Biology Department at the Federal University of Technology Akure (FUTA), Nigeria. A total of 100 pairs of weevils were placed in a one-liter glass jar containing 600 g of maize grains obtained from a local supplier in Akure, Ondo State, Nigeria. The insect colony was kept under controlled laboratory conditions at a temperature of 28±2°C and relative humidity of 75±5%.

Identification and sex determination of adults of *S. zeamais*: The cultured weevils were identified to the species level based on the morphological characteristics of their genitalia[10]. The adult maize weevils are characterized by a rostrum, which is a forward snout-like extension of the head and carries the mouthparts in a position that is ideal for penetrating commodities. The female *Sitophilus zeamais* is distinguished by its relatively longer rostrum compared to the male. The antennae are elbow-shaped when at rest, consisting of eight segments, and extend outward when the insect is in motion. Additionally, the elytra features four pale reddish-brown or orange-brown oval markings, although these may often be faint. The metathoracic flight wings are well-developed, and the prothorax is characterized by circular punctures.

Collection of plant material: *Curcuma longa* rhizomes and *Piper guineense* seeds were procured from Oja-Oba in Akure, Ondo State. The plant materials were allowed to dry naturally by air in the Biology Laboratory and pulverized using an electric blender. The resulting powders were sieved through 1 mm^2 perforation to achieve uniform particle size. The fine powders were subsequently stored in airtight plastic containers and kept in a refrigerator at 4°C to maintain their quality before application.

Collection of maize grains: The maize grains used in this study were sourced from a newly harvested stock free of insecticides at the Ministry of Agriculture, Agricultural Development Programme, Akure, Ondo State, Nigeria. To eliminate any potential insect eggs and larvae, the grains were first sterilized by placing them in a deep freezer at -5°C for three days[11]. After sterilization, the grains were naturally air-dried in the laboratory for 3 days to inhibit mold growth[7].

Extractions of plant material: *Curcuma longa* and *Piper guineense* were processed with absolute ethanol as the extracting solvent. For each extraction, 300 g of the powdered material was submerged in 600 mL of absolute ethanol in individual extraction containers. The mixtures were stirred with a glass rod every 6 hrs, and the extraction process was carried out over three days. The mixtures obtained were passed through a double layer of Whatman No. 1 filter paper, and the solvent was recovered by redistillation using a rotary evaporator at a temperature of 30-40°C, with a rotation speed of 3-6 rpm for 8 hrs[12]. Afterward, the extracts were air-dried to remove any residual ethanol. The crude extracts were stored in labelled dark bottles and refrigerated to preserve their quality. A 3% concentration was subsequently prepared by mixing 0.3 mL of the extract with 9.7 mL of the solvent[13].

Insect bioassay: Toxicity of *C. longa* and *P. guineense* on the mortality and emergence of adult *S. zeamais* A quantity of 20 g of pure, pest-free maize grains was weighed using an electronic balance (Model JTC 2101N) and placed in 250 mL plastic cups. *Curcuma longa* and *Piper guineense* powders were then mixed with the maize grains at concentrations of 0.2, 0.4, 0.6, 0.8, and 1.0 g per 20 g of maize. The cups were thoroughly shaken to ensure proper mixing of the powders with the grains. Next, one hundred copulating pairs (50 males and 50 females) of newly emerged *S. zeamais* adults were introduced into each cup with the treated maize grains, which were then sealed. The experiment was arranged in a complete randomized block design with five replicates for the treated groups and untreated controls. The control treatment consisted of 20 g of maize grains and fifty mating pairs of *S. zeamais*, with no plant powder added. Insect mortality was monitored daily for 120 hrs. Weevils that did not react to pin probing (a sharp pin touch) were considered dead. After the 5th day, all insects, both alive and dead, were removed from the containers before the grains were returned to their respective cups. The percentage of adult mortality was calculated at the end of 120 hrs using the formula[13,14]:

$$PT = \frac{PO - PC}{100 - PO} \times 100$$

Where:
PT = Corrected mortality (%)
PO = Observed mortality (%)
PC = Control mortality (%)

The weight loss of the maize grains was calculated as the percentage loss in weight using the following formula[13]:

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

The number of damaged maize grains was assessed by calculating the percentage of seed damage using the following formula[13]:

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

The weevil perforation index (WPI) was calculated using the formula:

$$\text{WPI (\%)} = \frac{\text{Number of seeds damaged}}{\text{Control maize grains perforated}} \times 100$$

A weevil perforation index (WPI) value exceeding 50 was considered indicative of an increased level of infestation by the weevil, or a lack of protective efficacy of the powders and extracts tested.

Toxicity of *C. longa* and *P. guineense* extracts on the mortality and emergence of adult *S. zeamais*: Twenty grams of clean, un-infested maize grains were weighed into 250 mL plastic cups. Extracts of *Curcuma longa* and *Piper guineense* were separately mixed with the maize grains at concentrations of 0.2, 0.4, 0.6, 0.8, and 1.0 mL, measured using a graduated syringe. The extracts were added to the maize grains inside the plastic containers and thoroughly stirred with a glass rod. The plastic containers were left uncovered for 40 min to enable the evaporation of the ethanol solvent. Subsequently, ten mating pairs (10 females: 10 males) of less than 4 days old adult *Sitophilus zeamais* were introduced into each cup and covered. The control setup contained only 20 g of maize grains and 50 mating pairs of *S. zeamais*, without any plant extract.

Data analysis: The data from the laboratory experiments were subjected to Analysis of Variance (ANOVA) with a significance threshold set at 5%. Treatment means were compared and separated using New Duncan's Multiple Range Test (NDMRT). Additionally, a log-probit analysis was conducted on the percentage mortality of adult *Sitophilus zeamais* to estimate the lethal dose and concentrations[15].

RESULTS

Mortality response of adult *S. zeamais* treated with some *C. longa* and *P. guineense* powder: The mortality response of adult *S. zeamais* is presented in Table 1. The toxicity of the two plant-derived powders was significantly ($p<0.05$) different from the control. *Piper guineense* powder was the most toxic to maize weevil, the powder caused 16.67, 28.33, 46.67, 58.33 and 81.67% mortality of *S. zeamais* at concentration 0.2, 0.4, 0.6, 0.8 and 1.0/20 g of maize grains after the first day of exposure, respectively. Next, *C. longa* powder resulted in 6.67, 28.33, 30.0, 40.0, and 70.0% mortality of maize weevils at concentrations of 0.2, 0.4, 0.6, 0.8, and 1.0/20 g of maize grains, exhibiting the least toxic effects on the weevils. *Curcuma longa* evoked 81.67 and 100% mortality of maize weevil at the rate of 0.8 and 1.0/20 g of maize grains after the fifth day of exposure while *P. guineense* had 100% mortality of maize weevils at the rates of 0.8 and 1.0 g/20 g of maize grains after the fifth day of exposure, respectively.

Table 1: Mortality response of adult *Sitophilus zeamais* treated with plant powders

		Mortality (%)±SE (days)				
Plant powder	Dosage (g)	Day 1	Day 2	Day 3	Day 4	Day 5
Curcuma longa	0.2	6.67 ± 1.67^{a}	10.00 ± 0.00^{b}	16.67 ± 3.33^{b}	21.67 ± 3.33^{b}	26.67 ± 3.33^{b}
	0.4	28.33 ± 1.67^{c}	36.67 ± 3.33^{d}	38.33 ± 1.67^{d}	38.33 ± 1.67^{c}	41.67 ± 4.41^{c}
	0.6	30.00 ± 0.00^{c}	38.33 ± 1.67^{de}	45.00 ± 2.89^{d}	51.67 ± 4.41^{d}	55.00 ± 2.89^{d}
	0.8	40.00 ± 2.89^{d}	45.00 ± 2.89^{e}	58.33 ± 1.67^{e}	68.33 ± 1.67^{e}	81.67 ± 1.67^{e}
	1.0	70.00 ± 2.89^{f}	80.00 ± 0.00^{h}	93.33 ± 3.33^{g}	100.00 ± 0.00^{g}	100.00 ± 0.00^{f}
Piper guineense	0.2	16.67 ± 3.33^{b}	23.33 ± 3.33^{c}	28.33 ± 1.67^{c}	33.33 ± 1.67^{c}	40.00 ± 0.00^{c}
	0.4	28.33 ± 1.67^{c}	45.00 ± 0.00^{e}	45.00 ± 2.89^{d}	51.67 ± 1.67^{d}	58.33 ± 1.67^{d}
	0.6	46.67 ± 1.67^{d}	56.67 ± 1.67^{f}	61.67 ± 1.67^{e}	70.00 ± 0.00^{e}	76.67 ± 1.67^{e}
	0.8	58.33 ± 4.41^{e}	66.67 ± 3.33^{g}	80.00 ± 5.00^{f}	86.67 ± 3.33^{f}	100.00 ± 0.00^{f}
	1.0	81.67 ± 1.67^{g}	93.33 ± 3.33^{i}	100.00 ± 0.00^{g}	100.00 ± 0.00^{g}	100.00 ± 0.00^{f}
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}

Means sharing the same letter within a column are not significantly different ($p > 0.05$) and according to Duncan's New Multiple Range Test (DNMRT)

Table 2: Lethal concentration (LC_{50} and LC_{90}) of *C. longa* and *P. guineense* powder against adult *Sitophilus zeamais*

Plant powder	Period of exposure (days)	LC_{50} (LCL-UCL)	LC_{90} (LCL-UCL)	R^2	p-value
Curcuma longa	1	0.80 (0.56-1.15)	2.69 (1.88-3.83)	0.88	0.17
	2	0.66 (0.47-0.93)	2.26 (1.49-3.43)	0.83	0.19
	3	0.52 (0.34-0.79)	2.19 (1.55-3.08)	0.79	0.28
	4	0.51 (0.38-0.69)	1.56 (1.08-2.25)	0.97	0.17
	5	0.42 (0.29-0.61)	1.51 (1.12-2.03)	0.87	0.29
Piper guineense	1	0.58 (0.41-0.81)	1.94 (1.37-2.73)	0.91	0.46
	2	0.43 (0.31-0.59)	1.49 (1.02-2.18)	0.84	0.59
	3	0.40 (0.27-0.58)	1.34 (0.97-1.85)	0.94	0.48
	4	0.33 (0.23-0.48)	1.23 (0.79-1.89)	0.94	0.94
	5	0.28 (0.18-0.43)	1.12 (0.78-1.60)	0.97	0.29

Table 3: Number of adult emergence of *Sitophilus zeamais* in maize treated with *Curcuma longa* and *Piper guineense* powder

Plant powder	Dosage (g)	Number of adult emergence
Curcuma longa	0.2	9.67 ± 0.33^{e}
	0.4	8.00 ± 0.57^{de}
	0.6	6.33 ± 0.33^{cd}
	0.8	4.33 ± 0.33^{bc}
	1.0	2.00 ± 0.58^{ab}
Piper guineense	0.2	1.67 ± 0.33^{ab}
	0.4	1.00 ± 0.00^{a}
	0.6	0.33 ± 0.33^{a}
	0.8	0.00 ± 0.00^{a}
	1.0	0.00 ± 0.00^{a}
Control	0.0	25.33 ± 2.73^{f}

Means sharing the same letter within a column is not significantly different ($p > 0.05$) and according to Duncan's New Multiple Range Test (DNMRT)

Lethal dosage (LD) of *C. longa* and *P. guineense* powders against adult *S. zeamais*: The lethal dose of *C. longa* and *P. guineense* powder against *S. zeamais* is shown in Table 2. The dosage calculated for the turmeric powder and African black pepper to result in 50% (LD_{50}) and 90% (LD_{90}) mortality against *S. zeamais* calculated after the first day were 0.80, 2.69, 0.58 and 1.94 g, respectively. However, it was observed that these values continued to decrease after the second, third, fourth, and fifth days of exposure.

Number of adult emergences of *S. zeamais* in maize treated *with C. longa* and *P. guineense* powders: Table 3 illustrates the effectiveness of *C. longa* and *P. guineense* powder against maize weevil adult emergency. The protection effectiveness of *C. longa* and *P. guineense* powder against infestation of *S. zeamais* is significantly different ($p < 0.05$) from the control. The highest seed protection was recorded from 0.8 and 1.0 g of *P. guineense* powder (0.0 adult emergence of *S. zeamais* was recorded). The seed protection ability of 0.8 and 1.0 g of *P. guineense* powder are significantly different from 0.8 and 1.0 g of *C. longa* powder (4.33 and 2.00 adult emergence was recorded, respectively). The protection strength of 0.6 g of *P. guineense* powders (0.33) is significantly different ($p<0.05$) from the 0.6 g powder of *C. longa* where 6.33 was recorded, respectively on maize seeds in respect to maize weevil adult emergence. There is a significant difference ($p<0.05$) in the seed protection ability against adult emergence of maize weevil when comparing 0.2 and 0.4 g of *P. guineense* (1.67 and 1.00 were recorded, respectively) and 0.2 and 0.4 g of *C. longa* powder (9.67 and 8.00 weevil emergence were recorded, respectively).

Protectant effect *of C. longa* and *P. guineense* powder on maize seed damage, weight loss, and weevil perforation index against maize weevil: Percentage seed damage, weight loss, and weevil perforation index were presented in Table 4. Maize seeds treated with 0.2 g of *P. guineense* and *C. longa* gave 4.02 and 5.91, respectively. There was no significant difference between these two plant powders at 0.2 g. The highest percentage of seed damage was recorded from maize treated with 0.6 g of *C. longa* powder which caused 7.47% seed damage, this was significantly different ($p<0.05$) from the control (44.14%). The lowest percentage of seed damage was recorded from those treated with 1.0 g of *P. guineense* (0.42 damage was recorded), their protective effects were not significantly different from 0.8 g of *P. guineense* and 1.0 g of *C. longa* (1.19 and 1.25, respectively). The highest weight loss was recorded with maize treated with 0.6 and 0.8 g of *P. guineense* powder (0.67) and those treated with 0.2 g of *C. longa* powder (0.67). The weevil perforation index recorded from the seeds treated with 0.6 g of *C. longa* powder (16.89) was the highest, followed by 0.2 g of the same powder with 13.50.

Mortality response of adult *S. zeamais* treated with *C. longa* and *P. guineense* extracts: The mortality response of adult *S. zeamais* treated with *C. longa* and *P. guineense* extracts is summarized in Table 5. The results indicate that the mortality of *S. zeamais* is dependent on both concentration and exposure time; higher concentrations result in increased mortality rates. The toxicity of the two plant powders was significantly ($p<0.05$) different from the control. *Piper guineense* extract was the most toxic to maize weevil, the extract caused 38.33, 55.00, 70.00, 83.33, and 96.67% mortality of *S. zeamais* at concentrations 0.2, 0.4, 0.6, 0.8, and 1.0 mL/20 g of maize grains after the first day of exposure, respectively. The least toxic plant extract of the two was *C. longa* which causes 16.67, 36.67, 50.00, 70.00, and 80.00%. Mortality of *S. zeamais* at concentrations 0.2, 0.4, 0.6, 0.8, and 1.0 mL/20 g of maize grains after the first day of exposure, respectively. *Curcuma longa* evoked 100% mortality of maize weevils at concentrations 0.6, 0.8, 1.0 mL/20 g of maize grains after the fifth day of exposure while *P. guineense* evoked 100% mortality of maize weevils at concentrations 0.4, 0.6, 0.8, and 1.0 mL/20 g of maize grains after the fifth day of exposure.

Table 4: Protectant effect of *Curcuma longa* and *Piper guineense* powder on maize seed damage, weight loss, and weevil perforation index against maize weevil

Plant powder	Dosage (g)	Total number of seeds	Number of seeds with holes	Seed damage (%)	WL (%)	WPI
Curcuma longa	0.2	79.00±0.58	4.67±0.33	5.91 ± 0.46^{d}	0.67 ± 0.33^{a}	13.50 ± 1.47^{d}
	0.4	79.33±0.88	4.33±0.33	5.47 ± 0.47^{d}	0.00 ± 0.00^{a}	12.40 ± 1.03^{cd}
	0.6	80.33±0.33	6.00±0.58	7.47 ± 0.72^{e}	0.33 ± 0.33^{a}	16.89 ± 1.35^{e}
	0.8	87.33±1.20	2.67±0.67	3.19 ± 0.66^{bc}	0.00 ± 0.00^{a}	7.19 ± 1.42^{b}
	1.0	80.33±1.86	1.00±0.00	1.25 ± 0.03^{ab}	0.00 ± 0.00^{a}	2.84 ± 0.15^{a}
Piper guineense	0.2	83.00±1.16	3.33±0.33	4.02 ± 0.41^{cd}	0.17 ± 0.17^{a}	9.19 ± 1.29^{bc}
	0.4	80.00±1.53	3.33±0.33	4.17 ± 0.45^{cd}	0.00 ± 0.00^{a}	9.56 ± 1.42^{bc}
	0.6	81.67±2.03	3.33±0.33	4.11 ± 0.51^{cd}	0.67 ± 0.33^{a}	9.31 ± 1.11^{bc}
	0.8	84.00±3.06	1.00±0.00	1.19 ± 0.04^{ab}	0.67 ± 0.44^{a}	2.71 ± 0.06^{a}
	1.0	80.33±1.45	0.33±0.33	0.42 ± 0.42^{a}	0.00 ± 0.00^{a}	0.89 ± 0.80^{a}
Control	0.0	81.67±2.30	35.33±1.76	44.14 ± 1.69^{f}	0.00 ± 0.00^{a}	$>50.00^{f}$

Means sharing the same letter within a column is not significantly different ($p>0.05$), according to Duncan's New Multiple Range Test (DNMRT), WL: Weight loss and WPI: Weevil perforation index

Table 5: Mortality response of adult *Sitophilus zeamais* treated *Curcuma longa* and *Piper guineense* extracts

		Period of exposure				
Plant extract	Concentration (mL)	Day 1	Day 2	Day 3	Day 4	Day 5
Curcuma longa	0.2	16.67±3.33^{b}	35.00±2.89^{b}	43.33±3.33^{b}	53.33±1.67^{b}	60.00±0.00^{b}
	0.4	36.67±3.33^{c}	51.67±1.67^{c}	60.00±0.00^{c}	70.00±0.00^{c}	85.00±2.89^{d}
	0.6	50.00±0.00^{d}	66.67±1.67^{d}	81.67±1.67^{d}	100.00±0.00^{d}	100.00±0.00^{e}
	0.8	70.00±0.00^{e}	80.00±0.00^{e}	91.67±1.67^{e}	100.00±0.00^{d}	100.00±0.00^{e}
	1.0	80.00±0.00^{f}	91.67±1.67^{f}	98.33±1.67^{f}	100.00±0.00^{d}	100.00±0.00^{d}
Piper *guineense*	0.2	38.33±1.67^{c}	51.67±1.67^{c}	60.00±0.00^{c}	68.33±1.67^{c}	73.33±1.67^{c}
	0.4	55.00±2.89^{d}	70.00±0.00^{d}	80.00±0.00^{d}	100.00±0.00^{d}	100.00±0.00^{d}
	0.6	70.00±0.00^{e}	83.33±1.67^{e}	100.00±0.00^{f}	100.00±0.00^{d}	100.00±0.00^{d}
	0.8	83.33±3.33^{f}	96.67±1.67^{g}	100.00±0.00^{f}	100.00±0.00^{d}	100.00±0.00^{d}
Control	1.0	96.67±3.33^{g}	100.00±0.00^{g}	100.00±0.00^{f}	100.00±0.00^{d}	100.00±0.00^{d}
	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}

Means sharing the same letter within a column is not significantly different ($p>0.05$) and according to Duncan's New Multiple Range Test (DNMRT)

Table 6: Lethal concentration (LC_{50} and LC_{90}) of *Curcuma longa* and *Piper guineense* extract against *Sitophilus zeamais*

Plant extract	Period of exposure (days)	LC_{50} (LCL-UCL)	LC_{90} (LCL-UCL)	R^2	p-value
Curcuma longa	1	0.52 (0.37-0.72)	1.65 (1.18-2.30)	0.98	0.88
	2	0.33 (0.23-0.48)	1.17 (0.81-1.69)	0.93	0.78
	3	0.26 (0.18-0.38)	0.83 (0.57-1.20)	0.94	0.71
	4	0.18 (0.09-0.32)	0.79 (0.46-1.44)	1.00	-
	5	0.16 (0.10-0.25)	0.46 (0.32-0.77)	1.00	-
Piper guineense	1	0.31 (0.22-0.43)	0.95 (0.68-1.32)	0.86	0.56
	2	0.22 (0.15-0.32)	0.66 (0.46-0.96)	0.89	0.75
	3	0.15 (0.09-0.25)	0.63 (0.38-1.05)	1.00	-

Lethal concentration (LC) of *C. longa* and *P. guineense* extracts against adult *S. zeamais*: The lethal dose of *C. longa* and *P. guineense* extracts against *S. zeamais* is given in Table 6. The dosage calculated for the *C. longa* and *P. guineense* plant extracts to cause 50% (LD_{50}) and 90% (LD_{90}) mortality against maize weevil calculated after the first day were 0.52 and 1.65, 0.31 and 0.95 mL, respectively. However, it was observed that these values continued to reduce after the second, third, fourth, and fifth days of exposure. From the calculation, *P. guineense* extract was observed to have the lowest lethal dose across all periods of exposure. All these values have different confidence limits that might be effective aside from the calculated values.

Number of adult emergences of *S. zeamais* in maize treated with *C. longa* and *P. guineense* extracts: Table 7 illustrates the effectiveness of *C. longa* and *P. guineense* extracts against maize weevil adult emergency. The protection effectiveness of *C. longa* and *P. guineense* against infestation of *S. zeamais* is significantly different ($p<0.05$) from the control (27.67). The highest seed protection was recorded from 0.8 and 1.0 mL of *C. longa* and 0.4, 0.6, 0.8, and 1.0 mL of *P. guineense*; (0 adult emergence was recorded). The seed protection ability of 0.2, 0.4, and 0.6 mL of *C. longa* extracts are not significantly different from 0.2 mL of *P. guineense* extracts (1.33, 0.67, 0.33, and 0.33 adult emergence are recorded, respectively).

Phytochemicals screening of ethanolic extracts of *C. longa and P. guineense* powder: The phytochemical screening of ethanolic extracts from *C. longa* and *P. guineense* plant powders is presented in Table 8. The results reveal that the phytochemicals present in the ethanolic extracts of both *C. longa* and *P. guineense* powders were identical. The quantity of Flavonoid Alkaloid, Tannin, and Saponin was higher in *P. guineense* with values of 5.19, 6.03, 3.27, and 2.63 mg/g, respectively. *Curcuma longa* had the least among the two, flavonoid (4.27 mg/g), alkaloid (5.18 mg/g), tannin (3.13 mg/g), and saponin (1.83 mg/g) contents. The presence of flavonoids and alkaloids in plant parts signifies their potential toxicity to arthropod pests, including insects.

Table 7: Number of adult emergences of *Sitophilus zeamais* in maize treated with *Curcuma longa* and *Piper guineense* extracts

Plant extract	Concentration (mL)	Number of adult emergence
Curcuma longa	0.2	1.33±0.33^a
	0.4	0.67±0.33^a
	0.6	0.33±0.33^a
	0.8	0.00±0.00^a
	1.0	0.00±0.00^a
Piper guineense	0.2	0.33±0.33^a
	0.4	0.00±0.00^a
	0.6	0.00±0.00^a
	0.8	0.00±0.00^a
	1.0	0.00±0.00^a
Control	0.0	27.67±1.20^b

Means sharing the same letter within a column is not significantly different ($p>0.05$) and according to Duncan's New Multiple Range Test (DNMRT)

Table 8: Quantitative analysis of phytochemicals in *Curcuma longa* and *Piper guineense*

	Plant (mg/g)				df = 1
Phytochemicals	*C. longa*	*P. guineense*	Sum of squares	F-value	p-value
Flavonoid	4.27±0.05	5.19±1.13	1.260	45.557	0.003
Alkaloid	5.18±0.03	6.03±0.05	1.084	207.086	0.000
Tannin	3.13±0.04	3.27±0.04	0.032	7.446	0.053
Saponin	1.83±0.02	2.63±0.05	0.960	223.256	0.000

DISCUSSION

The results of this study support the use of *Curcuma longa* and *Piper guineense* powders and extracts as effective protectants for maize grains against degradation by storage insect pests. The treatments significantly reduced the ability of maize weevils to lay eggs on the protected grains, leading to a reduction in the level of damage. The efficacy of these plant products against *S. zeamais* can be ascribed to the toxic effects of the powders upon contact, which disrupt the weevil's reproductive capacity. The results show that the treatments controlled maize weevil reproduction by almost 100% for up to two and a half months. This could be due to the antifeedant or repellent nature of the plant materials. Antifeedants are chemicals that deter feeding by making the treated materials unpalatable or unattractive to insects[16].

Insecticidal screening tests demonstrated that all plant powders and extracts evaluated for their insecticidal properties were highly toxic to *S. zeamais*, particularly in comparison to the control. The lowest values of LD_{50} and LD_{90} for *P. guineense* indicated its high toxicity, while *C. longa* showed comparatively lower toxicity. The adult insect mortality increased with both the exposure time and concentration gradient, with *P. guineense* proving to be the most effective at all concentrations after 24 hrs of exposure. These findings align with Ileke *et al.*[17], who reported that 0.4 g of powdered *P. guineense* mixed with 5 g of maize caused 50% mortality in adult *S. zeamais*. This study demonstrates that *P. guineense* (both in powder and extract form) is highly toxic to *S. zeamais*, followed by *C. longa*. It also revealed that the plant extracts were generally more toxic than the leaf powders. This difference may be due to the concentration of active components during the extraction process. As suggested by Makanjuola[18], the effectiveness of insecticidal plant powders can be improved through extraction with suitable solvents. According to Soujanya *et al.*[19], plant extracts, being lipophilic, can penetrate the insect cuticle. Additionally, Shiberu and Negeri[20] highlighted that the insecticidal activity of plant extracts is influenced by their active compounds. These compounds, including monoterpenes, sesquiterpenes, and related phenols, inhibit acetylcholinesterase (AChE) activity and interfere with the neuromodulator octopamine, ultimately leading to insect mortality[21,22].

This study further confirms the effectiveness of plant powders and extracts as crop protectants, demonstrating their ability to prevent adult *S. zeamais* emergence, seed damage, and weight loss in maize. The decrease in adult emergence observed in the treated maize grains can be attributed to the high mortality rate, which likely prevented the weevils from laying eggs, thus reducing subsequent seed damage. The plant extracts, in particular, appeared to be more effective than the leaf powders, as evidenced by the lower number of adult emergence and the significantly lower LD_{50} and LD_{90} values. This suggests that the extraction process concentrated the active compounds, enhancing their toxicity. The ability of these plant products to completely prevent seed damage and weight loss may also stem from their action in inhibiting egg-laying, which prevents larval feeding and thus mitigates the damage caused by the weevils, as also suggested by Alabi and Adewole[23]. Phytochemical analysis of the ethanolic extracts revealed the presence of bioactive compounds such as alkaloids, saponins, tannins, and flavonoids, which have been shown to demonstrate strong activities against various pathogens and insect pests[24]. *Piper guineense* was found to be more toxic than *Curcuma longa*, likely due to its higher composition of these bioactive compounds. For instance, saponins possess anti-inflammatory, antiviral, antifungal, insecticidal, and antibacterial properties[25], while alkaloids are known for their toxicity and antifeedant effects against stored product insect pests. Flavonoids also exhibit insecticidal activity[26]. The insecticidal activity observed in the plant extracts is likely a result of these compounds interfering with the neuromodulator octopamine, leading to insect death[22,27].

This research underscores the potential of plant-derived insecticides in the control of *S. zeamais* and provides scientific support for the use of these botanicals as alternatives to synthetic insecticides for post-harvest protection. The negative environmental impact of broad-spectrum synthetic pesticides has created a demand for biodegradable alternatives with higher selectivity[28]. The findings of this study show that the plant extracts tested may serve as effective alternatives to synthetic pesticides. Unlike synthetic insecticides, which contribute to environmental pollution and accelerate resistance development in pests[1], botanical products have a lower likelihood of inducing resistance. As a result, they are gaining increased attention as a sustainable solution for pest control, and further refinement through conventional scientific procedures could enhance their effectiveness.

CONCLUSION

Keeping the food safe from insects is crucial for food security. This research study explored the use of plant materials to manage *S. zeamais*. It can be concluded that natural products from *C. longa* and *P. guineense* effectively controlled maize damage from *S. zeamais* insects. *Piper guineense* was the most toxic to *S. zeamais* in terms of effectiveness in the management of these pests. Unlike chemical insecticides, these plant-derived products are highly effective and should be developed further. They break down quickly, they are easily available, less harmful to beneficial insects, and does not linger in the environment. Using these natural products can help reduce our reliance on chemical insecticides and ensure safer food for everyone.

SIGNIFICANCE STATEMENT

This study highlights the potential of *Curcuma longa* and *Piper guineense* as eco-friendly and cost-effective alternatives to synthetic pesticides for controlling maize weevils in stored grains. The findings show their effectiveness in reducing insect mortality, inhibiting reproduction, and minimizing seed damage, contributing to reduced post-harvest losses and improved seed quality. Their use aligns with sustainable agricultural practices, offering a safer approach to pest management while mitigating the adverse effects of chemical pesticides on human health and the environment. This can significantly enhance food security, particularly in developing countries where maize is a vital staple crop.

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