Hindawi
International Journal of Agronomy
Volume 2023, Article ID 5584859, 13 pages
https://doi.org/10.1155/2023/5584859

Research Article

Evaluating Plant Leaf Tinctures against Maize Weevils (*Sitophilus zeamais* Motsch.) in Stored Maize (*Zea mays* L.) under Laboratory Conditions

Shetie Gatew and Abrham Chalew

Environmental Science, Department of Biology, College of Natural Sciences, Arba Minch University, Arba Minch 21, Ethiopia

Correspondence should be addressed to Shetie Gatew; shetieg@yahoo.com

Received 28 December 2022; Revised 22 August 2023; Accepted 28 August 2023; Published 4 September 2023

Academic Editor: Othmane Merah

Maize weevils (*Sitophilus zeamais* Motschulsky) are commonly stored grain pests of economic importance in several parts of Africa. A huge amount of synthetic pesticides is being used for the management of crop pests, which have many negative effects on the biotic and abiotic components of the environment. Plant-derived pesticides, on the other hand, are safe for the environment, affect only target insects, have a low application cost, and are easily biodegradable. The purpose of this research was to determine the effectiveness of ethanol leaf tinctures of four selected botanicals against *S. zeamais: Brucea antidysenterica* (J.) (Waginos), *Croton macrostachyus* (Hochst.) (broad-leaved croton), *Nephrolepis exaltata* (L.) (Boston fern), and *Carica papaya* (L.) (papaya). The experiment was carried out in a completely randomized design (CRD) with four different concentrations (0 mL, 2.5 mL, 5 mL, and 7.5 mL) and four plant leaf tinctures in three replicates. A random sample of 300 g of clean maize seed was treated with the four selected botanicals in plastic jars covered with a muslin cloth. Twenty adult maize weevils were introduced into each disinfected, treated, and untreated maize grain. The mortality rate, grain damage, and F_1 progeny emergences were assessed and analyzed using SPSS software version 25. The highest (100%) mortality rate of *S. zeamais* was recorded for maize seeds treated with the leaf tincture of *B. antidysenterica*, followed by maize seeds treated with the leaf tincture of *C. papaya* (97.5%) at an application rate of 7.5 mL/300 g. The mean weight loss of the seeds showed a significant variation between the treatments. The mean weight loss of the seeds in the control (8.96%) was higher than the total mean weight loss treated by all plant leaf tinctures (3.66%). The emergence of F_1 progeny of *S. zeamais* on maize grains showed significant differences among the treatments. The highest emergence (100%) of F_1 progenies was recorded for the control treatment followed by *C. macrostachyus* (16.65%) at a rate of 2.5 mL/300 g maize grain treatment. The study concluded that *B. antidysenterica* and *C. papaya* tinctures had the potential to control the infestation of maize grains by *S. zeamais.*

1. Introduction

Maize (*Zea mays* L.) is one of the major cereal grains that are widely cultivated and consumed in Africa [1–3]. However, it is vulnerable to insect damage. *S. zeamais* is the most important maize storage pest [4, 5]. Maize damage by *S. zeamais* results in food loss, increased poverty, reduced nutritional values, increased malnutrition and weight loss, and reduced market values and seed germination [6]. In developing countries, maize production and consumption often fall below demand because of postharvest losses [7]. Furthermore, the main causes of crop losses in tropical developing nations include unfavourable climatic conditions, inadequate storage facilities, and pests [8].

Ethiopia is one of the major producers of cereal crops in Africa. Maize accounts for 27% of the total annual cereal production [9]. The annual grain loss in Ethiopia ranges from 20 to 30% [4]. The major loss is caused by storage pests such as maize weevil, *S. zeamais*, grain moth, *Sitotroga cerealella* (Olivier), rice weevil, *Sitophilus oryzae* (L), and flour beetle, *Tribolium confusum* (J.) [4]. These insect pests can cause 20–40% losses during cultivation and 30–90% during postharvest and storage [10].

Nowadays, huge amounts of synthetic pesticides are being used to control stored grain pests [11]. Regardless of their inherent hazards, they are intensively used in the agricultural sector in Ethiopia. A study in four regions of Ethiopia (Amhara, South Nations, Nationalities, and People (SNNP), Oromia, and Tigray) showed that more than 80% of the farmers used fumigant insecticides to control *S. zeamais* [12]. The use of synthetic chemicals to manage crop pests has many negative effects on biotic and abiotic components of the environment. Some of these effects include pesticide resistance in some pests, acute toxicity, a low rate of degradation, destruction of non-target organisms, and a carcinogenic effect [11]. Moreover, the cost of pesticides has increased due to pest resistance [13]. Therefore, identification of biodegradable, less toxic, and effective botanical insecticides is essential to overcome the aforementioned human and environmental hazards caused by the majority of synthetic pesticide chemicals [14–16].

Some plant species, such as *Annona muricata*, *Eucalyptus tereticornis*, *Tephrosia vogelii*, *Olax subscorpioidea*, *Aframomum melegueta*, *Euphorbia balsamifera,* and *Mentha piperita,* have secondary metabolites that can be tinctured with ethanol, methanol, or acetone [16–20]. These secondary metabolite tinctures have been reported to cause high mortality among storage crop pests [20, 21]. Mohammad et al. [16] reported that the methanol extract of *Annona muricata* L. showed the highest mortality (100%) of *S. zeamais* within 7 days with a minimum concentration. Erenso and Berhe [22] reported the toxicity effect of seed and leaf powder of the neem tree (*Azadirachta indica* L.) against *S. zeamais* and recorded 61–82% *S. zeamais* mortality. The efficacy of leaf and seed powder of *Azadirachta indica* L., *Lantana camara* L., and *Jatropha curcas* L. showed *S. zeamais* mortality, a decrease in F1 progeny, and low seed damage [1]. Application of the oil extract from *Ocimum kilimandscharicum* (Guerke) on maize grain also resulted in 100% mortality of *S. zeamais* at 105 μl/mL concentration [23].

Traditionally, farmers have used plants and plant products for centuries to control postharvest crop pests [24]. Farmers in the study area have traditionally used leaves of *B. antidysenterica* (J), *C. macrostachyus* (Hochst), *N. exaltata* (L), and *C. papaya* (L) to reduce storage pest infestations and repel insects. Therefore, this study aimed to evaluate the efficacy of selected plant extracts against *S. zeamais*.

2. Materials and Methods

2.1. Maize (Zea mays L.) Collections. Approximately, 15 kg (5 kg from each study site) of commonly grown hybrid maize grain (BH-660) was collected from the farmers at the three selected study sites Mankusa, Jiga, and Birsheleko of Jabi Tahinan district, west Gojjam zone (Figure 1). The maize grain used during the laboratory study was disinfected at −4°C in a deep freezer for 2 weeks to kill any live insects [13]. Similar-sized maize grains were selected for the experimental analysis following Muzemu et al. [13].

2.2. Collection and Rearing of S. zeamais. Adult *S. zeamais* was collected from maize grains stored in farmers' traditional storage facilities, such as *gumbi, gombisa*, *diya* (bamboo), and sack (Figure 2). The infected grains were brought to the Debre Markose University Plant Science Laboratory, and the insects were separated from the infected maize grains. Ten paired unsexed adult weevils were introduced into ten plastic jars (15 cm × 15 cm × 20 cm) containing 300 g of maize grains disinfested at −21°C in a deep freeze for 2 weeks for mass rearing [25]. These jars were covered with thin netting held in place by rubber bands to allow ventilation and prevent the escape of experimental insects. The insects were cultured at 27 ± 3°C and 55–70% relative humidity [26]. Parents of the experimental insects were sieved out after an oviposition time of 13 days. The seeds were then kept under laboratory conditions until the F_1 progeny emerged. The F_1 progenies of the insects that emerged after 30 days were sieved out and used for the experiment. Each experiment was conducted in triplicate.

2.3. Plant Material Collection. Medicinal plants used to prevent and kill insects were collected from *Jabi Tahinan* district, west Gojjam zone, Ethiopia. Three kebeles (the smallest administrative unit in Ethiopia), namely, Mankusa, Jiga, and Birsheleko, were purposively selected. A total of 45 key informants including medicinal plant practitioners were selected proportionally from each kebele. Medicinal plants were prioritized based on the results obtained from key informants and medicinal plant practitioners (Table 1). Plant species were identified based on published volumes of the flora of Ethiopia and Eritrea [27–31]. The most frequently used plant species and plant materials (leaves) were collected for tincture preparation.

2.4. Preparation of Tinctures of Plant Materials. The plant leaves collected from the study area were washed thoroughly with running tap water to remove the attached dirt and air-dried under shade at room temperature for one week to prevent denaturation of the chemical substances. The dried leaves of each plant species were powdered using a domestic electric grinder and sieved through a mesh sieve of 0.1 mm to obtain a uniform particle size (Figure 3). The resulting powders were labeled and kept separately in a plastic bottle with a screw cap and stored at room temperature in the dark until used in the experiment.

The tincture of the selected plants was prepared by mixing each plant's leaf powder in 70% ethanol in a 1 : 5 (w/v) ratio following Suleiman et al. [17]. The mixture was placed in a dark cool area for three weeks and shaken every day for complete homogenization. After three weeks, the tincture was filtered using cotton and clean gauze, and then, the filtrate was placed in plastic bottles, sealed, and kept in a cold dark place until it was used.

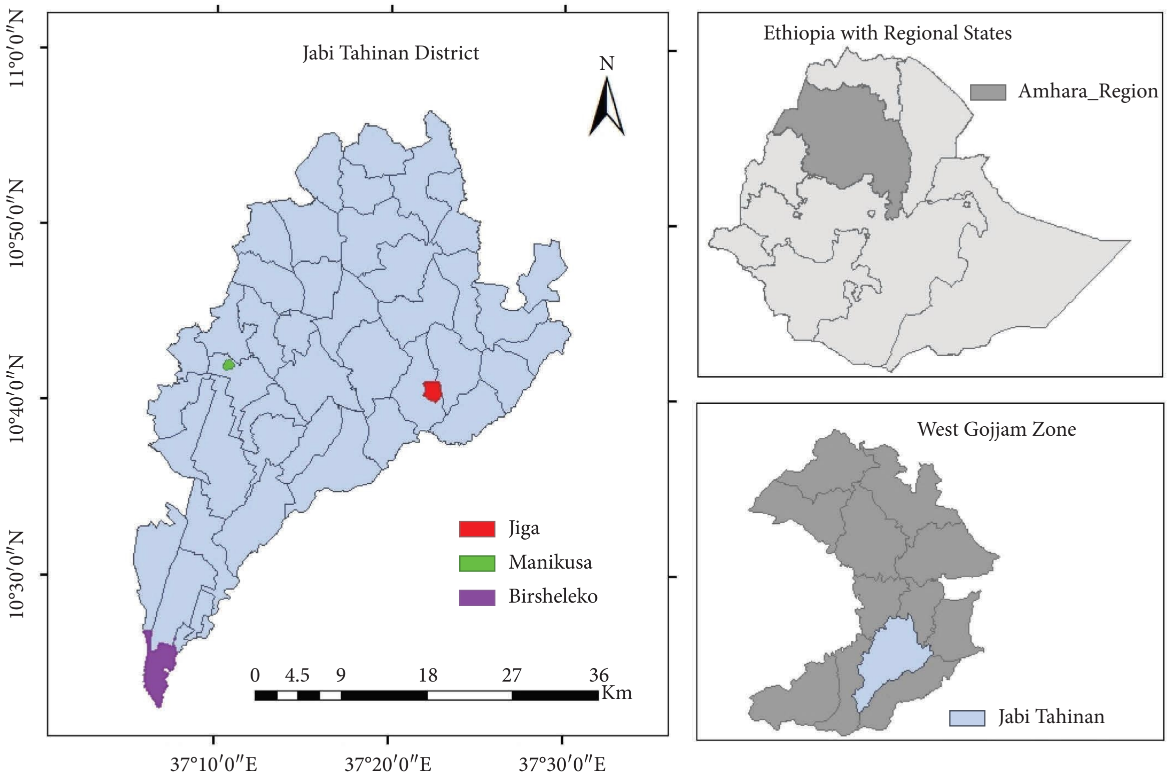

Figure 1: Map of maize grain collection areas.

2.5. Laboratory Bioassays

2.5.1. Effects of Plant Tincture on Maize Weevil Mortality. The experiment was carried out in a completely randomized design (CRD) with three different concentrations and one control of the four plant tincture concentrations (0 mL 2.5 mL, 5 mL, and 7.5 mL) with three replicates [32]. Grains in the control were treated with ethanol (70%) only. A random sample of 300 g of clean maize seed was taken, and the weight was recorded. The seeds were kept in one-liter plastic jars covered with a muslin cloth. Each of the three tincture concentration was poured on the seeds, and the jars were shaken thoroughly for 5 min to ensure uniform distribution of the solution over the grain surfaces. The treated grains were kept open for 36 hours to allow complete evaporation of the solvent before conducting the bioassay experiment. Twenty unsexed newly emerged weevils (3–5 days old) [33] were introduced into each jar, and the fate of the weevils was recorded on the 6th, 12th, 24th, 48th, and 72nd hours and weekly for four weeks after their introduction.

2.5.2. Effects of Plant Tincture on Grain Damage. A random sample of 300 g of clean undamaged and uninfected maize seeds was weighed and kept in 250 mL plastic jars, which were covered with a muslin cloth. The jars were kept on the laboratory bench for daily observation. Each of the three tincture concentrations was coated onto the seeds, and the jars were shaken to mix the plant tincture and the maize seeds. Soon after mixing, ten unsexed freshly emerged weevils (3–5 days old) [33] were introduced into each jar. After two months, a random sample of 20 seeds was taken from each jar to determine the number of seeds showing signs of weevil attack (holes), and for each jar, the weight of seeds was recorded; the percentage weight loss was calculated based on the original weight. Grains with holes were counted, and the percentage of grain damage caused by the weevils to the total grains was calculated using the following formula [4]:

$$\text{Grain damage (\%)} = \left[\frac{\text{TNDG}}{\text{TNG}}\right] \times 100, \quad (1)$$

where TNDG = total number of damaged grains and TNG = total number of grains.

2.5.3. Effects of Plant Tincture on the Emergence of F_1 Progeny. In the same experimental setup, after two months of the introduction of the parent adult weevils to the treated seeds, all the dead and alive weevils were sieved, counted, and discarded. The grains were placed back into the jars, covered with a nylon mesh, and kept under the same conditions to assess the F_1 progeny. The F_1 progeny weevils were counted and removed until two months, and adults were counted and removed from the jar on each assessment day to avoid overlapping emergencies [26].

In the samples, grain weight loss, damaged grains, weevil mortality, and F_1 progeny emergency were calculated as follows [13]:

Figure 2: Traditional grain storage in the study area. Grain storage structures: gombisa with mud (a) and gumbi (b), diya (bamboo) (c), and sack (d) [49].

(1) Weight Loss. The weight loss of maize seeds due to infestation with *S. zeamais* was determined two months after treatment. The dry weight loss was calculated as follows [13]:

$$\text{Weight loss (\%)} = \left(\frac{\text{IDWS} - \text{DWA3M}}{\text{IDWS}}\right) \times 100, \quad (2)$$

where IDWS = initial dry weight of seeds and DWA3M = dry weight after three months.

(2) Weevil Mortality. Weevil mortality was counted after the introduction of the tincture. The following formula was used to calculate the percentage of weevil mortality [13]:

$$\text{Weevil mortality (\%)} = \frac{\text{ND}}{\text{TN}} \times 100, \quad (3)$$

where ND = number of dead weevils and TN = total number of weevils initially.

Table 1: Medicinal and wild plants identified by key informants and medicinal practitioners.

Local names	Common names (English name)	Scientific names	Medicinal activities	Plant part	Frequency
Bisana	"Broad-leaved croton" or "rush foil"	*Croton macrostachyus* (Hochst)	Antimalarial and treating weevils	Leaf	45
Abalo	Waginos	*Brucea antidysenterica* (J.F.Mill.)	Against termites and weevils	Leaf	40
Neem	Neem	*Azadirachta indica* (A.Juss.)	Antimalarial	Leaf	33
Kulukual	Spurge	*Euphorbia ampliphylla* (Pax)	Against rabies	Fruit	14
Endode	Phytolaque	*Phytolacca dodecandra* (L'Herit)	Intestinal parasites	Leaf	21
Yeazohareg	Leather	*Clematis hirsuta* (Guill. & Perr.)	Kill weevils	Leaf	19
Mitmita	Bell pepper	*Capsicum annuum* (L)	Antimalarial	Leaf	12
Bahirzafe	"Fever tree" and "blue gum tree"	*Eucalyptus globules* (L)	Kill ants	Leaf	16
Koke	Peach	*Prunus persica* (L)	Antiallergic	Fruit	9
Nechshenkurt	Cultivated garlic	*Allium sativum* (L)	Antimalarial	Leaf	6
Tembelele	Forest Jasmine	*Jasminum abyssinicum* (Hochst)	Antifungus	Root	6
Keberecho	Kebericho Mesfin	*Echinops kebericho* (Mesfin)	Kill ants	Root	8
Fern	Sword fern or Boston fern	*Nephrolepis exaltata* (L)	Kill mosquitos	Leaf	36
Yeharegresa	Bryonia scabra L.f	*Zehneria scabra* (L.) Sond	Antimalarial and anemia	Leaf	8
Tejsar	Lemon grass	*Cymbopogon citratus* (Stapf)	Kill weevils	Leaf	11
Kitkita	Hopbush	*Dodonaea angustifolia* (L)	Antimalarial	Leaf	5
Papaya	Papaya pawpaw	*Carica papaya* (L)	Hepatitis and antimalarial	Leaf	41

Sources: key informants and traditional medicine practitioners.

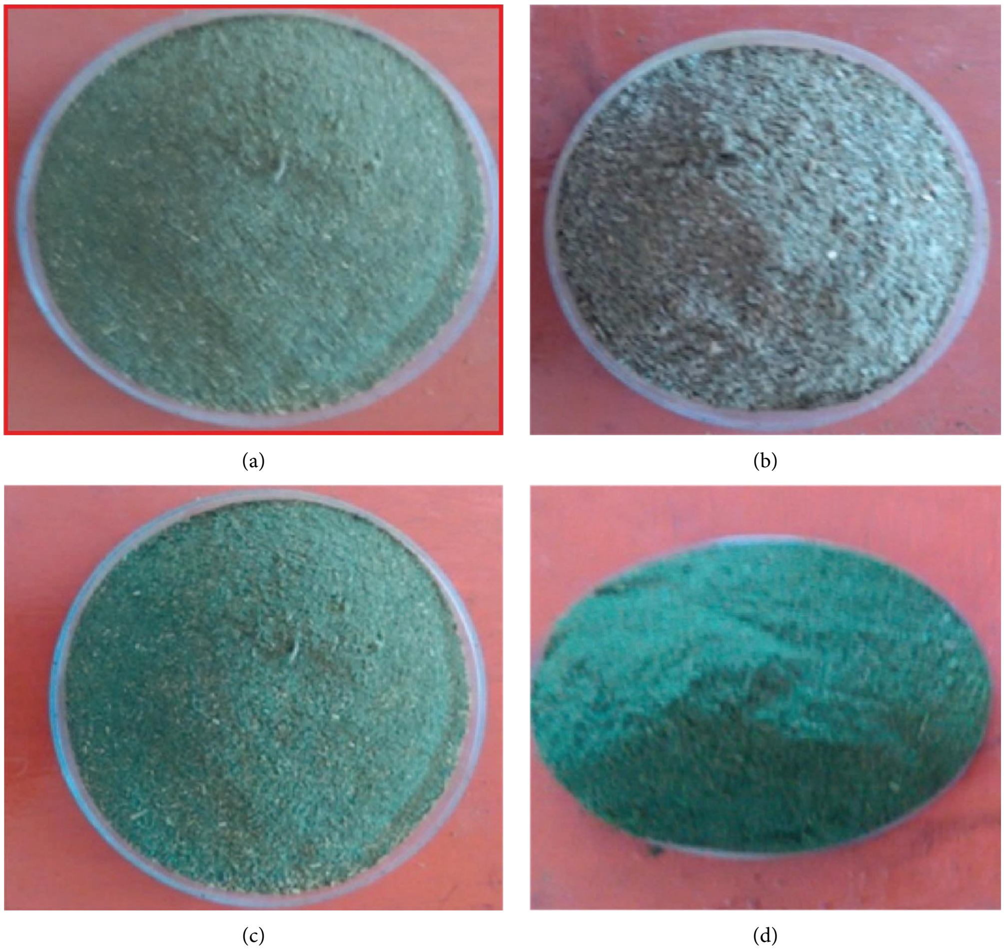

Figure 3: Plant leaves powder: (a) *B. antidysenterica* (J), (b) *C. macrostachyus* (Hochst), (c) *N. exaltata* (L), and (d) *C. papaya* (L).

(3) F_1 Progeny Emergence. The inhibition of F_1 progeny emergence (%IR) was calculated using the following formula [26]:

$$\text{IR}\ (\%) = \frac{\text{Total F1 progeny in control} - \text{Total F1progeny in treatment}}{\text{Total F1 progeny in control}} \times 100. \quad (4)$$

2.6. Data Analysis. Data on the number of weevil mortality, holed grains, and weight loss obtained were entered into Microsoft Excel (version 2010), and all data were transformed by the logarithmic function Log10 $(X+1)$ before the analysis with one-way ANOVA using SPSS version 25 software. The means were separated using Tukey's HSD test at a 5% level of significance.

3. Results

3.1. Plant Species Selection. The key informants and medicinal plant practitioners identified 19 plant species that have been used for medicinal purposes, especially for insecticidal activities in their locality (Table 1). The informants ranked these plant species according to their effectiveness and frequency of use. The first four plant species that were mentioned most frequently were *C. macrostachyus* (Hochst), *C. papaya* (L), *B. antidysenterica* (J), and *N. exaltata* (L) (Table 1).

3.2. Laboratory Bioassays

3.2.1. Effect of Plant Tincture on Maize Weevil Mortality

(1) Effect of Brucea antidysenterica (J.) Tincture on Maize Weevil Mortality. Weevil mortality at 6 and 12 hours was very low compared with other hours. Moreover, on the 24^{th} and 48^{th} hours after the treatment, the weevils' mortality declined because the weevils were acclimatized to the chemical effects of the plants (Figure 4). There was high weevil mortality after

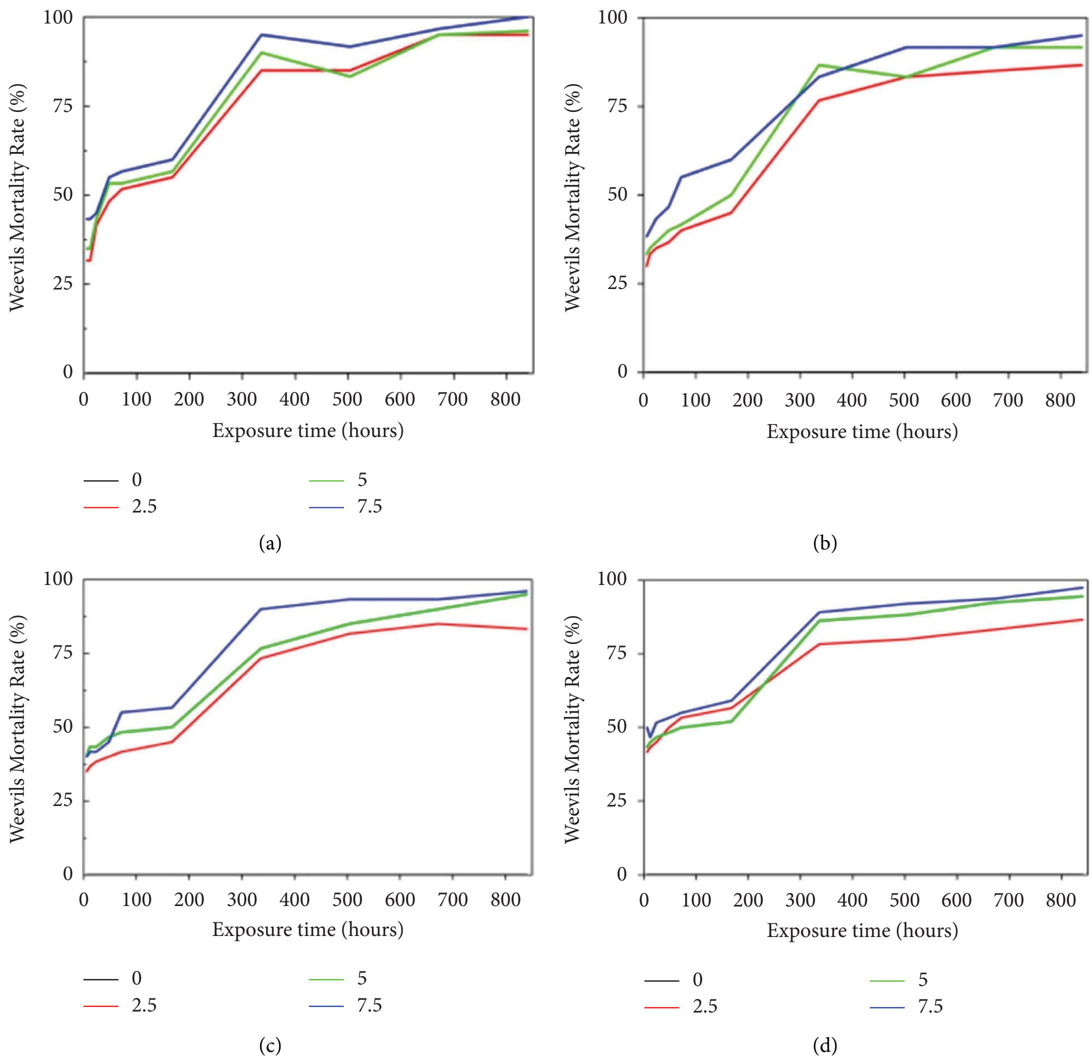

Figure 4: Effect of the different concentrations of the plant extracts at different time intervals against *S. zeamais*, (a) *B. antidysenterica*, (b) *C. macrostachyus*, (c) *N. exaltata*, and (d) *C. papaya*.

72 hours of treatment applications. Weevil mortality increased with an increased dosage of the tincture and exposure time (Figure 4). During the first week, 2.5 mL, 5 mL, and 7.5 mL concentrations of *B. antidysenterica* tincture treatment resulted in 55%, 56%, and 60% weevil mortality, respectively. At 7.5 mL of *B. antidysenterica*, tincture resulted in 100% mortality by the 4^{th} week (Figure 4(a), Table 2).

(2) Effect of Croton macrostachyus (Hochst) Tinctures on Maize Weevil Mortality. *S. zeamais* mortality generally increased with the time of exposure, especially starting from 72 hours after treatment. The maximum weevil mortality was observed by the end of the observation (4^{th} week) at the 7.5 mL tincture application followed by the 5 mL and 2.5 mL concentrations in decreasing order. Weevil mortality in this plant tincture was 95% at 7.5 mL in the 4^{th} week (Figure 4(b), Table 2).

(3) Effect of Nephrolepis exaltata L. Tinctures on Maize Weevil Mortality. The weevil mortality was observed starting at 72 hours of exposure time. By the end of the observation period (on the 4^{th} week), the maximum weevil death was observed at a 7.5 mL concentration of *N. exaltata* tincture (96%), followed by its 5 mL (95.00%) and 2.5 mL tincture concentration (83.3%) in descending order (Figure 4(c), Table 2).

(4) Effect of Carica papaya L. Tinctures on Maize Weevil Mortality. Weevil mortality increased after 72 hours of treatment. But weevil mortality was maximum (97%) by the end of the 4th week due to a 7.5 mL concentration of *C. papaya* L. leaf tincture followed by a 5 mL concentration of the same tincture which was higher than that of 2.5 mL in decreasing order (Figure 4(d), Table 2).

3.2.2. Effect of Plant Tincture on Maize Grain

(1) Weight Loss. The mean weight loss of the seeds showed a significant variation between the treatments ($P < 0.05$). The three concentrations of *B. antidysenterica*, *C. papaya*, *C. macrorostachyus*, *and N. exaltata* tinctures resulted in the 1.88%, 3.33%, 4.77%, and 4.88% mean weight loss,

Table 2: Mean mortality of *S. zeamais* at different hours of exposure to plant extracts under laboratory conditions (temp = 27 ± 3°C; relative humidity = 55–70%).

Plant species	Concentration (mL)	Mean ± Std, mean % adult mortality								
		6 hrs	12 hrs	24 hrs	48 hrs	72 hrs	1week	2 weeks	3 weeks	4 weeks
B. antidysenterica	2.5	6.33 ± 1.15^{a}	6.33 ± 1.52^{a}	8.33 ± 0.57^{a}	9.66 ± 0.57^{a}	10.33 ± 0.57^{a}	11.00 ± 0.00^{a}	17.00 ± 1.00^{a}	17.00 ± 2.64^{a}	19.00 ± 1.00^{a}
	5	7.00 ± 1.00^{a}	7.00 ± 1.00^{a}	8.66 ± 0.57^{a}	10.66 ± 0.57^{a}	10.66 ± 0.57^{a}	11.33 ± 0.57^{a}	18.00 ± 1.00^{a}	17.66 ± 0.57^{a}	19.00 ± 0.00^{a}
	7.5	8.66 ± 0.57^{a}	9.00 ± 1.00^{a}	9.00 ± 1.00^{a}	11.00 ± 0.00^{b}	11.33 ± 0.57^{a}	12.00 ± 1.00^{a}	19.00 ± 0.00^{a}	18.33 ± 0.57^{a}	20.00 ± 0.00^{a}
C. macrostachyus	2.5	6.00 ± 0.00^{a}	6.66 ± 0.57^{a}	7.00 ± 0.00^{a}	7.33 ± 0.57^{a}	8.00 ± 1.00^{a}	9.00 ± 1.00^{a}	15.33 ± 0.57^{a}	16.66 ± 1.15^{a}	17.00 ± 1.00^{a}
	5	6.66 ± 0.57^{a}	7.00 ± 0.00^{a}	7.33 ± 0.57^{a}	8.00 ± 1.00^{a}	8.33 ± 0.57^{a}	10.00 ± 1.00^{a}	17.33 ± 1.15^{a}	17.66 ± 0.57^{a}	18.33 ± 1.15^{a}
	7.5	7.66 ± 0.57^{b}	8.00 ± 0.00^{b}	8.66 ± 0.57^{b}	9.33 ± 0.57^{b}	11.00 ± 0.00^{b}	12.00 ± 1.00^{b}	17.66 ± 2.08^{a}	18.33 ± 1.52^{a}	18.33 ± 1.52^{a}
N. exaltata	2.5	7.00 ± 0.00^{a}	7.33 ± 0.57^{a}	7.66 ± 0.57^{a}	8.00 ± 0.00^{a}	8.33 ± 0.57^{a}	9.00 ± 1.00^{a}	14.66 ± 0.57^{a}	16.33 ± 1.15^{a}	17.00 ± 1.00^{a}
	5	8.00 ± 0.00^{a}	7.66 ± 0.57^{a}	7.66 ± 0.57^{a}	8.33 ± 0.57^{b}	9.66 ± 0.57^{ab}	10.00 ± 0.00^{a}	15.33 ± 1.15^{ab}	17.00 ± 0.00^{a}	18.00 ± 0.00^{a}
	7.5	8.00 ± 1.00^{a}	8.33 ± 0.57^{a}	8.33 ± 0.57^{a}	9.00 ± 0.00^{b}	11.00 ± 1.00^{b}	11.33 ± 1.52^{a}	18.00 ± 1.73^{b}	18.66 ± 1.52^{a}	18.66 ± 1.52^{a}
C. papaya L	2.5	8.33 ± 0.57^{a}	8.66 ± 0.57^{a}	9.00 ± 0.00^{a}	10.00 ± 1.00^{a}	10.67 ± 0.57^{ab}	11.33 ± 0.57^{a}	15.66 ± 1.52^{a}	16.00 ± 1.73^{a}	16.66 ± 2.30^{a}
	5	8.66 ± 0.57^{a}	9.00 ± 0.00^{a}	9.33 ± 0.57^{ab}	9.66 ± 0.57^{a}	10.00 ± 0.00^{a}	10.41 ± 0.79^{a}	17.25 ± 1.48^{a}	17.66 ± 0.65^{a}	18.50 ± 0.67^{a}
	7.5	10.00 ± 1.00^{a}	9.33 ± 0.57^{a}	10.33 ± 0.57^{b}	10.66 ± 0.57^{a}	11.00 ± 0.00^{b}	11.83 ± 1.02^{a}	17.83 ± 1.58^{a}	18.41 ± 1.16^{a}	18.75 ± 1.13^{a}
Control	0	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}	$0.000.00^{c}$	0.00 ± 0.00^{c}	0.00 ± 0.000^{c}	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}

Each value is the mean ± standard deviation. Means followed by the same letter in a column are not significantly different ($P < 0.05$) from the Tukey HSD test.

Table 3: Effect of different plant tinctures on grain weight loss caused by *S. zeamais*.

Plant species	Concentration (mL)	Mean dry weight ± Std (g) (after three months)	% weight loss (after three months)
Brucea antidysenterica	2.5	292.00 ± 2.00	2.66[b]
	5	294.00 ± 2.00	2.00[b]
	7.5	297.00 ± 1.73	1.00[b]
Carica papaya	2.5	285.00 ± 2.64	3.00[c]
	5	289.00 ± 3.00	3.66[c]
	7.5	290.00 ± 2.64	3.33[c]
Croton macrostachyus	2.5	283.00 ± 1.00	5.33[d]
	5	286.00 ± 0.00	5.00[d]
	7.5	287.00 ± 2.64	4.00[d]
Nephrolepis exaltata	2.5	284.00 ± 1.73	5.66[d]
	5	285.00 ± 1.73	4.66[d]
	7.5	288.00 ± 2.00	4.33[d]
Control	0	273.06 ± 0.00	8.98[a]

$n = 36$; Std = standard deviation; initial weight = 300 g; *mean weight loss % followed by the same letters is not significantly different ($P < 0.05$) from the Tukey HSD test.

respectively, while the control had a more mean weight loss (8.98%). The mean percent weight loss due to all the plant tinctures was 3.66% (Table 3).

(2) Grain Damage. The number of seeds with holes varied among different plant tincture treatments. However, the numbers of seeds with holes were lower on treated seeds than on the control treatment. The percentage of seeds with holes varied from 0.0% at 7.5 mL on *B. antidysenterica* to 6.65% at 2.5 mL on *N. exaltata* and *C. macrostachyus*. Therefore, *B. antidysenterica* had the most significant effect on reducing weevil attacks on maize grains, with a mean value of grains with holes of 0.33 per 20 maize grains. On the other hand, *C. macrostachyus and N. exaltata* had the least effect, with a mean value of 0.99 and 0.88 grains with holes per 20 maize grains, respectively. However, the control maize grain had a staggering percentage of seeds with holes of just 76.66% with a mean value of 14.33 holes per 20 maize grains. Seeds treated with the plant tinctures had significantly fewer seed holes than the control ($P < 0.05$) (Table 4).

3.2.3. Effect of Plant Tincture on the Emergence of F_1 Progeny. The experimental results showed that the F_1 progeny of the *S. zeamais* emergency status on maize grains treated with a tincture of *B. antidysenterica* at 2.5 mL, 5 mL, and 7.5 mL was 10.0%, 5.0%, and 0.0%, respectively, and that of *C. papaya* at 2.5 mL, 5 mL, and 7.5 mL was 6.65%, 5.0%, and 5.0%, respectively. The highest number of F_1 progeny emerged from the control group (100.0%). The F_1 emergencies on the treatments of *C. macrostachyus* at 2.5 mL, 5 mL, and 7.5 mL tincture were 16.65%, 13.30%, and 11.65%, respectively, and those of *N. exaltata* at 2.5 mL, 5 mL, and 7.5 mL were 6.65%, 5.0%, and 10.0%, respectively (Table 5). This showed that the highest concentration of the tincture gave the lowest F_1 progeny emergence. Therefore, the F_1 progeny's emergence significantly declined with an increasing concentration of application. The F_1 emergency of *S. zeamais* after the application of the tinctures was significantly different from that in the control group ($P < 0.05$).

4. Discussion

Starting from 6 to 48 hours of exposure time, the plant tinctures were less effective on maize weevils (*S. zeamais*), and all plant tinctures had similar effects. However, after 72 hours of exposure time, the rate of weevil mortality increased. The mortality of *S. zeamais* showed a progressive increase with treatments of *B. antidysenterica*, *C. macrostachyus*, *N. exaltata*, and *C. papaya* tinctures as the concentration and exposure time increased. *B. antidysenterica* was the most effective on weevil mortality at different concentrations and time exposures; this was in agreement with reports by Langsi et al. [34] and Esther Ojebode et al. [35], who stated that the effectiveness of different botanicals against adult weevil mortality increased with exposure time.

The maximum number of *S. zeamais* mortality was recorded at a 7.5 mL concentration of *B. antidysenterica* (100%), followed by *C. papaya* (97.50%), *N. exaltata* (96.05%), and *C. macrostachyus* (95%) tinctures in descending order. This may be due to the presence of terpenoids and phenolics in the tinctures of *B. antidysenterica* [36], *C. macrostachyus* [37], *C. papaya* [38], and *N. exaltata* [39]. Adeniyi et al. [40] revealed that these plants can act as antifeedants and growth disruptors that possess high toxicity toward insects. The *B. antidysenterica and C. papaya* tinctures had the highest mortality effect within four weeks of exposure time at 7.5 mL concentrations. Similarly, other studies indicated that *B. antidysenterica* is highly effective against mosquito larvae [41]. The aqueous tinctures of ferns showed acaricidal and insecticidal activity depending on the exposure time and concentration [42], and *C. macrostachyus* had molluskicidal activity [41].

The concentration affected the effectiveness of the tincture at the same time of exposure. The controlled grain had the least weevil mortality due to the absence of plant tinctures that contain secondary metabolites, which was also

Table 4: Percentage of grain damage treated with different plant tinctures at various concentrations.

Plant species	Concentration (mL)	Mean grain damage ± Std	% grain damage
B. antidysenterica	2.5	0.66 ± 0.57	3.33[b]
	5	0.33 ± 0.57	1.65[b]
	7.5	0.00 ± 0.00	0.00[d]
C. papaya	2.5	1.00 ± 0.00	5.00[C]
	5	0.66 ± 0.57	3.33[b]
	7.5	0.33 ± 0.57	1.65[b]
C. macrostachyus	2.5	1.33 ± 0.57	6.65[C]
	5	1.00 ± 0.00	5.00[C]
	7.5	0.66 ± 0.57	1.65[b]
N. exaltata	2.5	1.33 ± 0.57	6.65[C]
	5	1.00 ± 0.00	5.00[C]
	7.5	0.33 ± 0.57	3.33[b]
Control	0	14.33 ± 0.00	76.66[a]

Each value is the mean ± standard deviation of three replicates. Means followed by the same letter in a column are not significantly different ($P < 0.05$).

Table 5: F_1 progeny of *S. zeamais* on seeds treated with different plant tinctures.

Plant species	Concentration (mL)	Mean ± Std (F_1 progeny)	% inhibition rate
B. antidysenterica	2.5	2.00 ± 1.00	90.00[c]
	5	1.00 ± 0.00	95.00[b]
	7.5	0.00 ± 0.00	100.00[a]
C. macrostachyus	2.5	3.33 ± 1.52	83.35[c]
	5	2.66 ± 1.52	86.70[c]
	7.5	2.33 ± 0.57	88.35[c]
N. exaltata	2.5	1.33 ± 0.57	93.35[b]
	5	1.00 ± 0.00	95.00[b]
	7.5	2.00 ± 1.00	90.00[c]
C. papaya	2.5	1.33 ± 0.57	93.35[b]
	5	1.00 ± 0.00	95.00[b]
	7.5	1.00 ± 1.00	95.00[b]
Control	0	20.00 ± 0.00	0.00[d]

Each value is the mean ± standard deviation (Std) of three replicates. Means followed by the same letter in a column are not significantly different ($P < 0.05$) from the Tukey HSD test.

supported by the work of Udo [33] and Esther et al. [35]. The weevil mortality differences may be due to the proportion of active chemicals in each plant's tinctures [1, 43]. *C. macrostachyus* and *N. exaltata* had little effect on weevil mortality relative to *B. antidysenterica* and *C. papaya* tinctures.

The present study showed that *B. antidysenterica* tinctures resulted in a 1.88 mean percent of weight loss, and the highest weight loss was recorded from the controlled maize grain (8.98%). The weight loss recorded in untreated (control) maize grain was more likely caused by weevil attack and loss of moisture contents, and the least weight loss recorded in the treated maize grain by *B. antidysenterica* might be due to loss of moisture contents rather than *S. zeamais*. Similar results showed that the treated grains had fewer weight losses due to moisture loss than weevil damage [44]. The weight loss of controlled seeds was significantly higher than that of grains treated with plant tinctures ($P < 0.05$), and this result was in line with the findings of Ileke and Oni [45].

The controlled grain offered a free environment where the weevils suffered no developmental limitations. Hence, they had the highest feeding rate, and similar results were reported by Cosmas et al. [44]. As maize weight loss increased with increasing grain damage, the number of live weevils also increased. Therefore, weight loss and the amount of grain damage were directly related [44].

Hikal et al. [46] reported that botanical powder mixed with grains effectively protected against damage by different insect pests. The reduction in grain damage could be explained by the presence of chemical factors that can affect the feeding habits of insects. Seeds treated with *N. exaltata* tincture had a higher number of grain damage than the other four plant tincture treatments. However, the tinctures of *B. antidysenterica and C. papaya* have a high protective effect against infestation from *S. zeamais* with mean values of grain damage of 0.33 and 0.66 per 20 maize seeds, respectively. After two months of the application of the treatments, the control maize grains had 76.66% grain damage. The percentage of grain damage varied between 0.0% at 7.5 mL on *B. antidysenterica* and 6.65% at 2.5 mL on *N. exaltata* and C.papaya. Therefore, *B. antidysenterica* had the most significant effect on reducing weevil attacks on maize grain. On the other hand, C. macrostachyus and *N. exaltata* had the least effect. Maize seeds treated with any of the four plant tinctures had less grain damage than the control. The amount of grain damage on the control maize seeds was significantly higher than that on the treated maize seeds ($P < 0.05$). Similarly, Paranagama et al. [47] reported that the essential oil of lemongrass mixed with grains effectively protected against damage by different insect pests and that the presence of chemicals could affect the feeding habits of insects. In addition to causing adult insect mortality, insecticides either completely hindered or significantly reduced progeny emergence, indicating their potential for use in the management of the maize weevil. This also agrees with the findings of Selase and Emana [26].

The present study showed that F_1 progeny of *S. zeamais* emergence status on maize grains treated with a leaf powder tincture of *B. antidysenterica* at 7.5 mL was nil. The highest number of F_1 progeny emerged from the control group (100.0%). The F_1 values of the remaining two plants, *C. macrostachyus* and *N. elongata*, at 7.5 mL were 11.65% and 10%, respectively. Similarly, Chebet et al. [48] reported that crude powders of *Azadirachta indica, Lantana camara,* and *Tephrosia vogelii* were strong insect repellents and caused a reduction in maize grain damage and F_1 progeny. Chowański et al. [21] reported that pure metabolites and crude extracts obtained from Solanaceae plants had sublethal and lethal toxicity to insect pests. Langsi et al. [34] also tested two hydrogenated extract compounds from *Cupressus sempervirens* plants against *S. zeamais* in the laboratory to evaluate the contact and fumigation effects on the mortality of adult and immature weevils, progeny production, and grain damage. The results showed that insecticidal effects were concentration-dependent since mortality increased with the dosage and exposure period. *Lantana camara* seed powder at a rate of 10% w/w caused adult mortality, suppressed oviposition, and reduced F_1 progeny emergence of *Zabrotes subfasciatus* on haricot bean compared to the untreated control [48]. The F_1 emergency of *S. zeamais* after the application of ethanol tincture was significantly different from the control group ($P < 0.05$), and similar results were reported by Ileke and Oni [45].

5. Conclusions

The results of this study demonstrated that the mean percent mortality of *S. zeamais.* treated with *B. antidysenterica, C. papaya, N. exaltata and C. macrostachyus* tinctures was 100%, 97.5%, 96%, and 95%, respectively, at the end of the 4^{th} week with a 7.5 mL concentration. The treatment of the tested botanical tincture with different rates and concentrations reduced maize grain damage and weight loss by the maize weevil. The weevil mortality rate was significantly higher in seeds treated with plant tinctures than that in the control. However, the concentration and time of exposure affected mortality rates. The tested plants showed significant variation in reducing maize grain weight loss due to maize weevil attacks. Maize grain weight loss was significantly lower in seeds treated with plant tinctures than in the control. The highest number of F_1 progeny of the insect emerged from the control seeds than from the treated seeds, and the highest concentration of the tincture resulted in the lowest F_1 progeny emergence of the insect. *B. antidysenterica* had the most significant effect on reducing weevil attacks on maize grain. Thus, it is most promising among plant extracts in this study for the effective management of *S. zeamais*. However, further research is recommended on the isolation and formulation of the active compound of *B. antidysenterica.* Generally, the results of this study indicated that the natural environment is a rich source of a wide range of plant species with pesticidal effects.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical Approval

Our study was approved by the Arba Minch University Research Review Committee based on the university guidelines of the College of Natural Science, Ethiopia. Permission for the study was obtained from the district and woreda administration offices. The Arba Minch University Research Review Committee approved the proposed verbal consent procedure and confirmed that the study had no significant risks to the participants.

Consent

Respondents and discussants had well-known information about the study. We informed the objectives of the research with verbal consent and the expected duration of this particular research. Before the commencement of each questionnaire and group discussion, consent was obtained from all participants and discussants.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Shetie Gatew take care of project administration, conceptualization, methodology, formal analysis, investigation, data curation, software, review, and editing. Finally, both authors have read and approved the manuscript to be submitted. Abrham Chalew, who was responsible for writing the original draft, methodology, formal analysis, software, investigation, and data curation.

Acknowledgments

We would like to thank Ethio-Agreseft, Debre Markos University, and Arba Minch University for providing facilities, equipment, and financial support for this research. The study was supported by Arba Minch University.

References

[1] Y. Alemnew, "Studies on the management of maize weevil (sitophilus zeamais l.) using botanicals on maize grain in storage," MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 2017.

[2] B. Shiferaw, B. M. Prasanna, J. Hellin, and M. Bänziger, "Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security," *Food Security*, vol. 3, no. 3, pp. 307–327, 2011.

[3] T. Abate, B. Shiferaw, A. Menkir et al., "Factors that transformed maize productivity in Ethiopia," *Food Security*, vol. 7, no. 5, pp. 965–981, 2015.

[4] S. Waktole and A. Amsalu, "Storage pests of maize and their status in Jimma Zone, Ethiopia," *African J. Agric. Reseearch*, vol. 7, no. 28, pp. 4056–4060, 2012.

[5] D. N. Ifeanyi and F. A. Elechi, "Laboratory evaluation of freshly prepared juice from garlic (Allium sativum L.) Liliaceae as protectants against the maize weevil, Sitophilus zeamais (Motsch.) [Coleoptera: Curculionidae]," *African Journal of Biotechnology*, vol. 13, no. 10, pp. 1123–1130, 2014.

[6] R. Suleiman, K. A. Rosentrater, and C. J. Bern, "Evaluation of maize weevils Sitophilus zeamais Motschulsky infestation on seven varieties of maize," *Journal of Stored Products Research*, vol. 64, pp. 97–102, 2015.

[7] D. Kumar and P. Kalita, "Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries," *Foods*, vol. 6, no. 1, p. 8, 2017.

[8] E. Edelduok and E. Akpabio, "Bio-insecticidal potentials of testa powder of melon, citrullus vulgaris schrad for reducing infestation of maize grains by the maize weevil sitophilus zeamais motsch," *Journal of Biology, Agriculture and Healthcare*, vol. 2, no. 8, pp. 13–17, 2012.

[9] A. Seyoum, P. Dorosh, and S. A. Gemessa, "Crop production in Ethiopia: regional patterns and trends," *Food Agric. Ethiop. Prog. Policy Challenges*, University of Pennsylvania Press, Philadelphia, PA, USA, pp. 53–83, 2013.

[10] M. Odendo, H. De Groote, and O. M. Odongo, "Assessment of farmers' preferences and constraints to maize production in moist midaltitude zone of western kenya," in *Proceedings of the 5th International Conference of the African Crop Science Society*, pp. 21–26, Lagos, Nigeria, October 2001.

[11] C. A. Damalas and I. G. Eleftherohorinos, "Pesticide exposure, safety issues, and risk assessment indicators," *International Journal of Environmental Research and Public Health*, vol. 8, no. 5, pp. 1402–1419, 2011.

[12] N. Fufa, Z. Tekalign, M. Dawit, and D. Teshale, "Assessing storage insect pests and post-harvest loss of maize in major producing areas of Ethiopia," *International Journal of Agricultural Science and Food Technology*, vol. 7, pp. 193–198, 2021.

[13] S. Muzemu, J. Chitamba, and S. Goto, "Screening of stored maize (Zea mays L.) varieties grain for tolerance against maize weevil, Sitophilus zeamais (motsch.)," *International Journal of Plant Research*, vol. 3, no. 3, pp. 17–22, 2013.

[14] M. Suleiman, "Efficacy of some spices as sorghum grain protectants against Sitophilus zeamais Motschulsky [Coleoptera: Curculionidae]," *African Journal of Agricultural Research*, vol. 9, no. 9, pp. 841–845, 2014.

[15] W. Goudoungou Jean, N. Elias Nchiwan, N. Dieudonné, S. Christopher, C. Adler, and C. Nukenine Elias Nchiwan, "Efficacy of diatomaceous earth and wood ash for the control of Sitophilus zeamais in stored maize," *J. Entomol. Zool. Stud. JEZS*, vol. 3, no. 35, pp. 390–397, 2015.

[16] M. Y. Mohammad, H. M. Haniffa, and V. Sujarajiini, "Insecticidal effect of selected medicinal plants on Sitophilus zeamais Mostschulsky in stored maize," *Biocatalysis and Agricultural Biotechnology*, vol. 48, Article ID 102635, 2023.

[17] M. Suleiman, C. P. Rugumamu, and N. D. Ibrahim, "Insecticidal toxicity of some botanicals against Sitophilus zeamais Motsch," *Coleoptera:Curculionidae in stored sorghum grains in Nigeria*, vol. 6, no. 1, pp. 1280–1287, 2018.

[18] J. Kamanula, G. W. Sileshi, S. R. Belmain et al., "Farmers' insect pest management practices and pesticidal plant use in the protection of stored maize and beans in Southern Africa," *International Journal of Pest Management*, vol. 57, no. 1, pp. 41–49, 2010.

[19] A. Yohannes, G. Asayew, G. Melaku, M. Derbew, S. Kedir, and N. Raja, "Evaluation of certain plant leaf powders and aqueous extracts against maize weevil, sitophilus zeamais motsch.(-coleoptera: curculionidae)," *Asian Journal of Agricultural Sciences*, vol. 6, no. 3, pp. 83–88, 2014.

[20] P. Cosmas, "Use of botanical pesticides in controlling Sitophilus zeamais (maize weevil) on stored zea mays (maize) grain," *Modern Concepts & Developments in Agronomy*, vol. 1, no. 4, pp. 64–67, 2018.

[21] S. Chowański, Z. Adamski, P. Marciniak et al., "A review of bioinsecticidal activity of Solanaceae alkaloids," *Toxins*, vol. 8, no. 3, pp. 60–28, 2016.

[22] T. F. Erenso and D. H. Berhe, "Effect of neem leaf and seed powders against adult maize weevil (Sitophilus zeamais motschulsky) mortality," *International Journal of Agricultural Research*, vol. 11, no. 2, pp. 90–94, 2016.

[23] S. Kaguchia, S. Gitahi, C. Thoruwa, J. Birgen, and J. Birgen, "Bioefficacy of selected plant extracts against Sitophilus zeamais on post-harvest management of Zea mays," *The Journal of Phytopharmacology*, vol. 7, no. 4, pp. 384–391, 2018.

[24] T. Abate, M. Fisher, T. Abdoulaye et al., "Characteristics of maize cultivars in Africa: how modern are they and how many do smallholder farmers grow?" *Agriculture & Food Security*, vol. 6, no. 1, 2017.

[25] L. C. Nwosu, C. O. Adedire, and E. O. Ogunwolu, "Feeding site preference of Sitophilus zeamais (Coleoptera: Curculionidae) on maize grain," *International Journal of Tropical Insect Science*, vol. 35, no. 02, pp. 62–68, 2015.

[26] A. G. Selase and G. Emana, "Evaluation of botanical plants powders against Zabrotes subfasciatus (Boheman) (Coleoptera: bruchidae) in stored haricot beans under laboratory condition," *African Journal of Agricultural Research*, vol. 4, no. 10, pp. 1073–1079, 2009.

[27] I. Hedberg and S. Edwards, *Flora of Ethiopia. Pittosporaceae to Araliaceae*, The National Herbarium, Addis Ababa, Ethiopia, and Department of Systematic Botany, Uppsala, Sweden, 1989.

[28] S. Edwards, M. Tadesse, S. Demissew, and I. Hedberg, *Flora of Ethiopia & Eritrea. Magnoliaceae to flacourtiaceae*, The National Herbarium, Addis Ababa, Ethiopia, and Department of Systematic Botany, Uppsala, Sweden, 2000.

[29] T. Mesfin, *Flora of Ethiopia & Eritrea. Asteraceae (compositae)*, The national herbarium, addis ababa, Ethiopia, And Department of Systematic Botany, Uppsala, Sweden, 2004.

[30] I. Hedberg, E. Kelbessa, S. Edwards, S. Demissew, and E. Persson, *Flora of Ethiopia & Eritrea. Gentianaceae To Cyclocheilaceae*, The National Herbarium, Addis Ababa, Ethiopia, and Department of Systematic Botany, Uppsala, Sweden, 2006.

[31] A. Bekele-Tesemma, "Useful trees and shrubs of ethiopia: identification, propagation, and management for 17

agroclimatic zones," 2007, https://books.google.com.et/books/about/Useful_Trees_and_Shrubs_of_Ethiopia.html?id=15UfAQAAIAAJ&redir_esc=y.

[32] I. Y. Jnr, A. D. Abugri, and J. Afun, "Efficacy of ethanolic leaf extract of chromolaena odurata in controlling Sitophilus zeamais in stored maize," *Journal of Experimental Agriculture International*, vol. 14, no. 5, pp. 1–10, 2016.

[33] I. O. Udo, "Evaluation of the potential of some local spices as stored grain protectants against the maize weevil Sitophilus zeamais Mots (Coleoptera: Curculionidae)," *Journal of Applied Sciences & Environmental Management*, vol. 9, no. 1, pp. 165–168, 2005.

[34] J. D. Langsi, E. N. Nukenine, K. M. Oumarou, H. Moktar, C. N. Fokunang, and G. N. Mbata, "Evaluation of the insecticidal activities of α-pinene and 3-carene on Sitophilus zeamais motschulsky (Coleoptera: Curculionidae)," *Insects*, vol. 11, no. 8, pp. 540–611, 2020.

[35] M. Esther Ojebode, C. Ojo Olaiya, O. Charles Openiyi, and A. Adegoke Emmanuel, "Efficacy of some plant extracts as storage protectants against callosobruchus maculatus," *Journal of Biotechnology & Biomaterials*, vol. 06, no. 01, 2016.

[36] I. A. B. S. Alves, H. M. Miranda, L. A. L. Soares, and K. P. Randau, "Simaroubaceae family: botany, chemical composition and biological activities," *Revista Brasileira de Farmacognosia*, vol. 24, no. 4, pp. 481–501, 2014.

[37] L. B. Mekonnen, A. Solomon, T. Teklehaimanot, and L. B. Mekonnen, "In vivo antimalarial activity of the crude root and fruit extracts of Croton macrostachyus (Euphorbiaceae) against Plasmodium berghei in mice," *Journal of Traditional and Complementary Medicine*, vol. 5, no. 3, pp. 168–173, 2015.

[38] M. Saxena, J. Saxena, and S. Khare, "A brief review on: therapeutical values of Lantana camara plant," *Int. J Ournal P Harmacy L Ife S Ciences*, vol. 3, no. 3, pp. 1551–1554, 2012.

[39] S. Singh and R. Singh, "Ethnomedicinal use of pteridophytes in reproductive health of tribal women of Pachmarhi biosphere reserve, Madhya Pradesh, India," *International Journal of Pharma Sciences and Research*, vol. 3, no. 12, pp. 4780–4790, 2012.

[40] S. A. Adeniyi, C. L. Orjiekwe, J. E. Ehiagbonare, and B. D. Arimah, "Preliminary phytochemical analysis and insecticidal activity of ethanolic extracts of four tropical plants (Vernonia amygdalina, Sida acuta, Ocimum gratissimum and Telfaria occidentalis) against beans weevil (Acanthscelides obtectus)," *International Journal of the Physical Sciences*, vol. 5, no. 6, pp. 753–792, 2010.

[41] K. Karunamoorthi and K. Ilango, "Larvicidal activity of Cymbopogon citratus (DC) Stapf. and Croton macrostachyus Del. against Anopheles arabiensis Patton, a potent malaria vector," *European Review for Medical and Pharmacological Sciences*, vol. 14, no. 1, pp. 57–62, 2010.

[42] P. Prabhakaran, B. Radhakrishnan, K. K. Srikumar, and B. Suresh Kumar, "Efficacy of certain common ferns against red spider mite oligonychus coffeae and tea mosquito bug helopeltis theivora infesting tea," *Plant Protection Science*, vol. 53, no. 4, pp. 232–242, 2017.

[43] I. E. Edwin and I. E. Jacob, "Bio-insecticidal potency of five plant extracts against cowpea weevil, callosobruchus maculatus (F.), on stored cowpea, vigna unguiculata (L)," *Jordan Journal of Biological Sciences*, vol. 10, no. 4, pp. 317–322, 2017.

[44] P. Cosmas, G. Christopher, K. Charles, K. Friday, M. Ronald, and Z. M. Belta, "Tagetes minuta formulation effect Sitophilus zeamais (weevils) control in stored maize grain," *International Journal of Plant Research*, vol. 2, no. 3, pp. 65–68, 2012.

[45] K. D. Ileke and M. O. Oni, "Toxicity of some plant powders to maize weevil, Sitophilus zeamais (motschulsky) [Coleoptera: curculiondae] on stored wheat grains (Triticum aestivum)," *African Journal of Agricultural Research*, vol. 6, no. 13, pp. 3043–3048, 2011.

[46] W. M. Hikal, R. S. Baeshen, and H. A. H. Said-Al Ahl, "Botanical insecticide as simple extractives for pest control," *Cogent Biology*, vol. 3, no. 1, Article ID 1404274, 2017.

[47] P. A. Paranagama, K. H. T. Abeysekera, K. Abeywickrama, and L. Nugaliyadde, "Fungicidal and anti-aflatoxigenic effects of the essential oil of Cymbopogon citratus (DC.) Stapf. (lemongrass) against Aspergillus flavus Link. isolated from stored rice," *Letters in Applied Microbiology*, vol. 37, no. 1, pp. 86–90, 2003.

[48] F. Chebet, A. L. Deng, J. O. Ogendo, A. W. Kamau, and P. K. Bett, "Bioactivity of selected plant powders against prostephanus truncatus (Coleoptera: bostrichidae) in stored maize grains," *Plant Protection Science*, vol. 49, no. 1, pp. 34–43, 2013.

[49] T. D. Haile, "Indigenous knowledge of farmer on grain storage and management practice in Ethiopia," *Food Science & Nutrition Technology*, vol. 5, no. 4, pp. 1–14, 2020.