

Research Article

Evaluation of Crude Oil Extracts from Plants for Controlling Maize Infestations Caused by the Weevil *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae)

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Plant extracts have emerged as promising options for the controlling maize weevil due to their bio-insecticidal potential and reduced environmental impact in developing countries. The experiments were carried out to assess the effectiveness of crude plant oil from *Eucalyptus globulus*, neem (*Azadirachta indica*), marigold (*Tagetes minuta*), moringa (*Moringa stenopetala*), Ayobangira (*Ocimum basilicum*), custard apple (*Annona squamosa*), and *Chenopodium ambrosioides*. These extracts were evaluated at concentrations of 0.05, 0.1, and 0.15 g per gram, diluted with 10 ml of deionized water, and applied to 50 grams of maize against *Sitophilus zeamais*. The insects were reared in a plastic jar with one liter of capacity. For comparison, Actellic 2% dust at a dose of 0.05 g/50 gram maize was utilized as a standard check, with untreated seeds serving as the control. The experiment followed a completely randomized design with triple replications. Adult *S. zeamais* mortality was approximately 83% for maize seeds treated with *A. indica*, *T. minuta*, *A. squamosa*, and *E. globulus* within 96 hours of treatment at a rate of 0.10 g and 0.15 g/50 g of maize. Plant crude oil treatments with *A. indica* and *E. globulus* at all tested rates at higher concentrations (0.10 g and 0.15 g per 50 g) inhibited *S. zeamais* F1 progeny production with approximately $97.2 \pm 0.03\%$. The proportion of maize grain infection by *S. zeamais* was dramatically reduced after treating the plant with crude oil. Furthermore, the oil treatment for these plants had no effect on seed germination percentage. Overall, the findings suggest that these plant crude oil extracts can be utilized to control *S. zeamais*.

1. Introduction

Maize (*Zea mays*) is the most commonly used grain in many parts of the world, both for human consumption and as livestock feed [1]. It is a cereal grain that was first farmed by indigenous people in Mexico 10,000 years ago [2, 3]. It is one of the most significant cereal grains grown in Ethiopia [4] as a staple food and cash crop, providing calories to consumers while also earning money for merchants and farmers [4–6].

The productivity of maize is constrained by a variety of factors. Among the biotic limitations, postharvest insect pests are the most damaging, attacking grains during storage. Weevil infestation in agricultural storage causes significant grain weight loss as well as quality losses [7]. According to Birhanu and Emanu [8], one of the biggest hurdles to achieving food security in emerging and developing countries is large postharvest losses and deterioration in quality. The global estimate of grain and pulse

crop losses after harvest is about 15–20%, primarily due to insect pests, which is particularly significant in developing countries [9, 10].

The maize weevil, *S. zeamais* (Motschulsky) (Coleoptera: Curculionidae) [6], causes significant damage and limits maize storage [11]. In rural communities, issues in managing stored grain insects include the use of chemical insecticides, which can be costly, unavailable when needed, and subject to incorrect handling procedures [12]. Pesticide usage is widespread and regular, resulting in environmental contamination, resistance development, residue buildup in food, and negative effects on nontarget organisms in ecosystems. This is especially problematic for subsistence farmers who grow and store their harvested maize seed locally, typically in settings that promote insect colonization. It is more sensible and cost-effective to conserve the crop that has already been harvested than to compensate for losses by expanding output.

In view of these problems in controlling corn weevil, there has been an urgent push to look for alternative pest control tools, such as nonchemical technologies that can reduce the use of synthetic chemicals while providing economic and health benefits for users, customers, and the environment [4–9]. Botanical pesticides are frequently selective, do not impact nontarget species or natural enemies, are biodegradable and nontoxic compounds, and have a low persistence in the environment [13]. Furthermore, they can have the potential to be used as part of an integrated pest management strategy [14]. The use of botanical insecticides for crop pest protection during storage is becoming increasingly common in organic food production. The aim of this study is to assess the effectiveness of locally sourced plant species extracts for control stored grain (Maize) against the maize weevil, *S. zeamais*.

2. Materials and Methods

2.1. Weevils (*Sitophilus zeamais*) Rearing. Adult *S. zeamais* were reared at Addis Abeba University Department of Zoological Sciences, Entomology Research Laboratory. The experiment took place at a temperature of $27 \pm 5^\circ\text{C}$ and a relative humidity of 55–75%. The experiment used ten kg of Awash Q6 maize seed variety obtained from the Melkassa Agricultural Research Center. The seeds were cleaned to eliminate any obvious damage to the seeds and then disinfected by washing in deionized water, sterilizing in 70% ethanol, and freezing for two weeks at -20°C to 0°C to eradicate any internal infestation [9]. To acclimatize, the seed was placed in a plastic bag and maintained in experimental conditions for two or more weeks [15]. To provide equally aged weevils for the trials, a maize weevil culture was established. The plastic jars were covered by muslin cloth and secured with a rubber band to ensure ventilation while keeping insects from escaping [16]. After two weeks, all parent weevils, dead and alive, were counted and removed. The experiment involved newly emerging adult *S. zeamais* (7–10 days old). The sexes of *S. zeamais* were determined by examining the snout with a hand lens. Female snouts are longer and thinner, with smooth-textured bodies, whereas male snouts are shorter, thicker, and rougher-textured [6].

2.2. Collection and Preparation of Botanicals. Based on the researcher's recommendations and personal observation in the community, the majority of farmers used seven locally available plants, namely, *Eucalyptus globulus* (leaves), neem (*Azadirachta indica*) (seed), marigold (*Tagetes minuta*) (whole plant), moringa (*Moringa stenopetala*) (seed), *Ocimum basilicum* (Ayobangira) (whole plant), custard apple (*Annona squamosa*) (seed), and *Chenopodium ambrosioides* (whole plant). These plants were evaluated against *S. zeamais*. Plant parts were collected from different areas. *C. ambrosioides* was collected from Hawassa city and neem seeds from Dire Dawa city, while other botanicals were collected from the surrounding areas in Addis Ababa city, as well as Actellic 2% dust (0.05 g) [17] purchased from the local market in Merkato, Addis Ababa, and utilized as the standard check. Untreated grain was used as a control for comparison. The leaves of *E. globulus*, whole plants of *C. ambrosioides* and whole plants of *O. basilicum*, and seeds of *A. indica* and *A. squamosa*, whole plants of *T. minuta*, and seeds of *M. stenopetala* were dried in the shade. The dried leaves and seeds of the plants were ground into a fine powder using a mortar and pestle [11, 16].

2.3. Extraction of Plant Crude Oils. In this study, the maceration extraction method [19] was used to extract crude oil from the leaves and seeds of *E. globulus*, *A. indica*, *T. minuta*, *M. stenopetala*, *O. basilicum*, *A. squamosa*, and *C. ambrosioides* (Figure 1). Dry powders (100 g) of each of botanical plants were extracted separately with 300 ml of solvents: hexane, chloroform, and methanol, respectively. Each extraction was conducted within an 800 ml round-bottomed flask. The solvents were added in a 1 : 3 (w/w) ratio at room temperature (25°C). The mixture was macerated and soaked on a shaker bath in a chemistry laboratory for 48 hours for each solvent. The mixture was then filtered using Whatman (No. 9) filter paper. This process was repeated for each plant. Each plant was extracted separately in three solvents. The filtrates obtained with hexane, chloroform, and methanol were concentrated using vacuum rotary evaporator (Heidolph Rotavapor R-124; <https://www.heidolph.com>, Germany) at 70°C , 60°C , and 65°C , respectively, at 120 rpm [28] and weighed using an electronic balance. All samples were stored in airtight bottles at -5°C in the refrigerator and used for subsequent experiments [20].

2.4. Experimental Design. The study was designed using a completely randomized design (CRD) with three replications. Seven locally available plants, namely, *E. globulus*, *A. indica*, *T. minuta*, *M. stenopetala*, *O. basilicum*, *A. squamosa*, and *C. ambrosioides*, were evaluated against *S. zeamais*. The treatments were prepared using three types of solvents (hexane, chloroform, and methanol) (Actellic 2% dust) as a standard check [21], while untreated maize seeds served as a control.

2.5. Mortality Rate. Crude oils from seven different plant species were applied to the seeds at 0.05, 0.1, and 0.15 g (w/w), diluted in 10 ml of deionized water, and then added

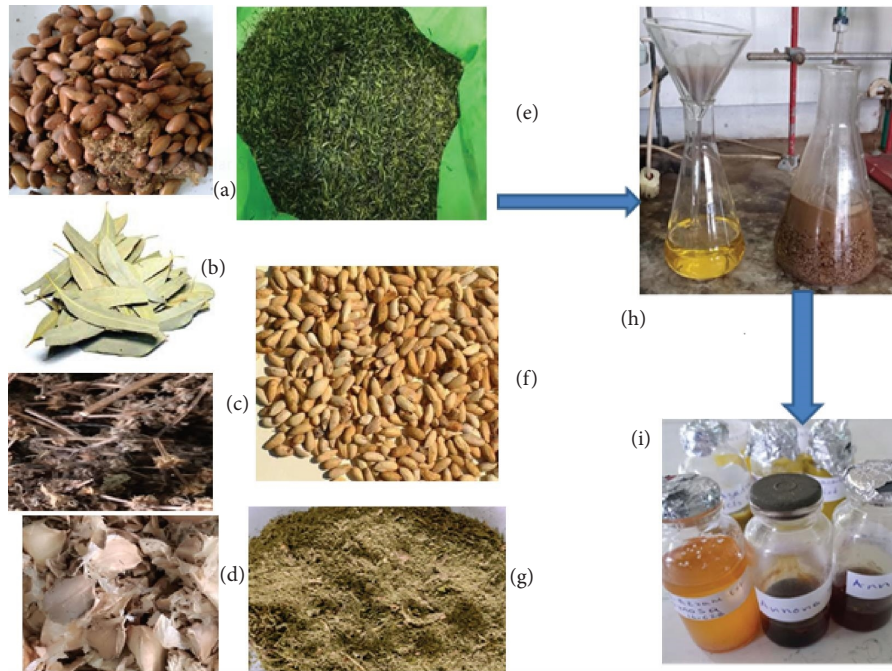


FIGURE 1: Plant species name and crude oil: (a) *A. squamosa*, (b) *E. globulus*, (c) *O. basilicum*, (d) *M. stenopetala*, (e) *T. minuta*, (f) *A. indica*, (g) *C. ambrosioides* of a dried sample, (h) filtration, (i) crude oil.

separately to 50 g of maize in 500 ml glass jars, which were manually stirred for 2 minutes. The containers were exposed to air in the laboratory for 45 minutes to allow the solvents to fully evaporate [15]. Seeds treated with Actellic 2% dust at a rate of 0.05 g per 50 g of maize seed were utilized as a standard control, with untreated seeds serving as the control group. After the solvents had completely evaporated, each plastic container was filled with two unsexed beetles aged 7–10 days [18]. All treatments were repeated three times. The number of dead insects in each jar was sieved and counted after 24, 48, and 96 hr. The percentage insect mortality was calculated using Abbott [22] formula as follows:

$$\% \text{ corrected mortality} = \frac{1 - n \text{ in } T \text{ after treatment}}{n \text{ in } Co \text{ after treatment}} * 100, \quad (1)$$

where n = insect number, T = treated, and Co = control.

2.6. F1 Progeny Test Assessment. After the mortality assessment, the treated jars were kept for additional 10 days to allow for the oviposition period [15]. Both living and dead insects were removed from plastic jars, which were then closed and kept under the same ambient conditions to assess F1 progeny. F1 progeny were monitored once a week for seven weeks after infestation [18]. The percentage reduction in adult emergence or inhibition rate (% IR) was used to determine which oil treatment inhibited the emergence of F1 progeny, following Tapondjou's formula [23]:

$$(\%IR) = \left(\frac{\text{Total F1 progeny in control} - \text{Total F1 progeny in treatment}}{\text{Total F1 progeny in control}} \right) * 100, \quad (2)$$

where IR is the inhibition rate.

2.7. Seed Damage (Weight Loss) Assessment. Seed damage loss assessment was conducted on the treated and untreated maize [19]. Hundred maize were taken randomly from each container, and the number of damaged (maize seed with

characteristic hole) and undamaged seeds was counted and weighed. Percentage weight loss was calculated using the formula cited in Adams and Schultzer [24] as follows:

$$\% \text{ Weight loss} = \frac{[UaN - (U + D)] * 100}{UaN}, \quad (3)$$

where U is the weight of undamaged seed in sample, N is the total number of grains in a sample, U_a is the average weight undamaged seed, and D is the weight of damaged seed in sample.

2.8. Percentage of Germination Test. Germination viability tests were carried out to determine whether the derived crude oils affected seed germination [19]. For this test, ten seeds were picked at random from each jar. Maize seeds from treated and control groups were placed separately in Petri dishes lined with moisturized Whatman No. 8 filter paper and kept at $25 \pm 2^\circ\text{C}$. After 7 days, the number of seedlings that emerged from each Petri dish was counted and recorded. The percentage of germination was estimated using a formula developed by Ogendo et al. [25].

$$\text{Germination percentage (\%)} = \frac{\text{NG}}{\text{TG}} * 100, \quad (4)$$

where NG is no. of seeds germinated and TG is total no. of seeds tested in Petri dish.

3. Methods of Data Analysis

Data entry and analysis were carried out using Microsoft Excel and SPSS Version 26. An arcsine transformation was used for analyzing percentage mortality. To evaluate the impact of treatments on percentage mortality, reduction in F1 progeny, weight loss, and maize seed germination, a two-way analysis of variance (ANOVA) was performed. When significant results emerged, means were compared using Tukey's studentized (HSD) test at a 5% significance level.

4. Results

4.1. The Effect of Crude Oil Extracts from Plants and Maize Treatments on the Mortality Rates of Adult *S. zeamais*. Table 1 shows the mortality of adult *S. zeamais* at 24, 48, and 96 hours following the application of various plant crude oils. The highest dose (0.15 g/50 g) of plant crude oil extracts significantly ($P < 0.05$) enhanced adult mortality insects within twenty-four hours after treatment applied. On seeds treated with Actellic 2% dust, the mortality rate of *S. zeamais* was 100%. Treatments of *A. indica*, *E. globulus*, *A. squamosa*, and *T. minuta* at a dose of 0.15 g/50 g of grain were capable of eliciting 100%, 100%, 90%, and 90% mortality after 96 hours of application, respectively. In contrast, seeds treated with *M. stenopetala* and *O. basilicum* had significantly lower mortality (Table 1).

4.2. Effect of Treatments on the F1 Progeny Production. Table 2 presents the F1 progeny produced by adult *S. zeamais*. Most treatments had significantly less F1 progeny than the untreated control ($P < 0.05$). However, seeds treated with hexane-extracted crude oils from *M. stenopetala* and *O. basilicum* at all tested rates (0.05, 0.10, and 0.15 g/50 g) yielded a higher number of F1 progeny and showed lower percent inhibition. The inhibition percentage for the treatments with *M. stenopetala* and *O. basilicum* was 54.58%

and 69.58%, respectively, with inhibition rates between 43.75% and 68.75%. All plant crude oils exhibited insecticidal effects that increased with dosage and time after treatment. At doses of 0.05, 0.10, and 0.15 g/gram, the inhibition rate for *A. indica*, *A. squamosa*, *T. minuta*, and *E. globulus* extracted with methanol ranged from 81% to 100% (Table 2). Among all treatments, neem oil extracted using methanol demonstrated the most insecticidal potential.

4.3. Effect of the Plant Crude Oil Extract on Various Solvent and Plant Species of % Weight Loss. Table 3 displays the findings on the percentage of weight loss in treated and untreated seeds due to *S. zeamais* infestation. Most plant crude oil extracts significantly ($P < 0.05$) decrease weight loss than untreated control in period of 56 days after infestation. However, the hexane-extracted oils from *O. basilicum* and *M. stenopetala* at lower doses (0.05 mg and 0.10 mg) were either significantly less or more effective in mitigating damage from *S. zeamais*. No weight loss was observed in maize treated with Actellic 2% dust. The mean percentage of weight loss in seeds treated with crude oil extracts from *A. squamosa*, *T. minuta*, and *E. globulus* at higher rates was comparable to that of the standard check and *A. indica*.

4.4. Effect of Plant Crude Oil on the Germination. Table 4 shows the mean percent seed germination of maize seeds treated with various plant crude oil extractions. The maize treated with *A. indica*, *E. globulus*, and Actellic 2% dust germinated almost completely. There was no significant difference in germination rates between maize treated with plant crude oils and those that were untreated ($P > 0.05$). The maize seeds treated with crude oils from *A. indica* and *E. globulus* (extracted with chloroform and methanol) at a rate of 0.15 g per 50 g of grain exhibited the highest germination rates at 95% and 100%, respectively.

5. Discussion

The findings of the current laboratory study indicate that the locally available plant materials have an insecticidal potential that can be used in the control of *S. zeamais*, similar to a synthetic insecticide (Actellic 2% dust) with previously studied by [8]. The method used to assess the mortality of *S. zeamais* through oil extract treatment on maize was consistent with several previous studies. All crude oils mixed with maize resulted in significant mortality rates for adult *S. zeamais*. Mortality rates of 100%, 100%, 100%, 100%, 90%, 80%, and 76% were recorded in seeds treated with the crude oils of *A. indica*, *E. globulus*, *T. minuta*, *A. squamosa*, *C. ambrosioides*, *M. stenopetala*, and *O. basilicum* at a dosage of 0.15g within 96 hours after treatment, respectively. The highest concentration applied at a dose of 0.15g was recorded 100% mortality of *S. zeamais* treated with neem extract within 96 hours after treatment application. Solvent extracts from neem seed, *E. globulus*, and *T. minuta* leaves with methanol resulted in a significantly better mortality rate of *C. ambrosioides* and *S. zeamais* at a dose of 0.5 g. However,

TABLE 1: Mortality Mean % $\pm$ SD adult *S. zeamais* due to the grain treated with crude oils extracted by different plant and solvents.

Plant species	Concentration%	Mortality after 24 Hrs			Mortality after 48 Hrs			Mortality after 96 Hrs		
		Chloroform	Hexane	Methane	Chloroform	Hexane	Methane	Chloroform	Hexane	Methane
<i>A. indica</i>	5	80 $\pm$ 0.5 ^e	66 $\pm$ 0.7 ^c	68 $\pm$ 0.9 ^c	78 $\pm$ 0.4 ^e	76 $\pm$ 1.2 ^{ef}	75 $\pm$ 0.2 ^d	100 $\pm$ 0.0 ^g	66 $\pm$ 0.1 ^a	100 $\pm$ 0.0 ^g
	10	83 $\pm$ 0.6 ^e	91 $\pm$ 0.4 ^f	91 $\pm$ 0.3 ^e	90 $\pm$ 0.2 ^f	86 $\pm$ 2.3 ^{fg}	86 $\pm$ 0.5 ^{ef}	100 $\pm$ 0.0 ^g	91 $\pm$ 0.3 ^{ef}	100 $\pm$ 0.0 ^g
	15	95 $\pm$ 0.7 ^f	98 $\pm$ 0.7 ^g	98 $\pm$ 0.3 ^g	93 $\pm$.69 ^g	91 $\pm$ 0.7 ^{fg}	91 $\pm$ 0.4 ^{ef}	100 $\pm$ 0.0 ^g	98 $\pm$.4 ^{fg}	100 $\pm$ 0.0 ^g
<i>E. globulus</i>	5	80 $\pm$ 3.6 ^e	71 $\pm$ 3.2 ^{cd}	75 $\pm$ 3.6 ^{de}	98 $\pm$ 1.5 ^g	86 $\pm$ 1.5 ^{fg}	83 $\pm$ 1.7 ^e	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g
	10	80 $\pm$ 4.6 ^e	95 $\pm$ 0.6 ^f	83 $\pm$ 4.6 ^{ef}	98 $\pm$.6 ^g	93 $\pm$ 0.6 ^g	85 $\pm$ 3.3 ^{ef}	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g
	15	88 $\pm$ 0.4 ^d	93 $\pm$ 1.7 ^f	83 $\pm$ 4.0 ^{ef}	71 $\pm$ 0.0 ^e	85 $\pm$ 2.1 ^{ef}	86 $\pm$ 1.5 ^{ef}	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g
<i>M. stenopetala</i>	5	63 $\pm$ 2.1 ^c	15 $\pm$ 1.7 ^a	21 $\pm$ 3.5 ^a	56 $\pm$ 4.6 ^d	58 $\pm$ 5.0 ^d	31 $\pm$ 1.3 ^{ab}	23 $\pm$ 3.5 ^a	71 $\pm$ 2.0 ^{bc}	63 $\pm$ 5.3 ^{bcd}
	10	61 $\pm$ 3.5 ^c	21 $\pm$ 5.0 ^a	25 $\pm$ 4.0 ^a	30 $\pm$ 1.7 ^b	38 $\pm$ 0.6 ^{ab}	46 $\pm$ 1.7 ^{bc}	26 $\pm$ 3.1 ^a	73 $\pm$ 3.05 ^c	63 $\pm$ 5.3 ^{bcd}
	15	43 $\pm$ 1.2 ^a	25 $\pm$ 2.4 ^{ab}	41 $\pm$ 4.0 ^b	28 $\pm$ 1.2 ^a	46 $\pm$ 1.2 ^c	38 $\pm$ 4.0 ^b	23 $\pm$ 0.6 ^a	98 $\pm$ 1.3 ^{fg}	63 $\pm$ 5.3 ^{bcd}
<i>A. squamosa</i>	5	80 $\pm$ 2.0 ^e	66 $\pm$ 1.5 ^{cd}	68 $\pm$ 4.7 ^c	78 $\pm$ 1.5 ^e	86 $\pm$ 0.6 ^f	85 $\pm$ 4.0 ^{ef}	81 $\pm$ 0.6 ^{de}	82 $\pm$ 0.0 ^{cd}	80 $\pm$ 0.0 ^{ef}
	10	80 $\pm$ 4.9 ^a	91 $\pm$ 2.0 ^f	91 $\pm$ 0.6 ^{fg}	80 $\pm$ 2.7 ^f	86 $\pm$ 1.5 ^{ef}	86 $\pm$ 0.6 ^{ef}	86 $\pm$ 2.3 ^{ef}	81 $\pm$ 0.5 ^{de}	90 $\pm$ 0.0 ^{fg}
	15	80 $\pm$ 4.9 ^a	98 $\pm$ 1.5 ^g	98 $\pm$ 0.6 ^g	83 $\pm$ 2.7 ^f	81 $\pm$ 0.6 ^{ef}	81 $\pm$ 0.6 ^e	88 $\pm$ 2.3 ^{de}	90 $\pm$ 0.04 ^{ef}	90 $\pm$ 1.5 ^{fg}
<i>O. basilicum</i>	5	60 $\pm$ 0.1 ^d	65 $\pm$ 5.3 ^c	68 $\pm$ 0.0 ^c	58 $\pm$ 5.3 ^d	63 $\pm$ 5.3 ^e	63 $\pm$ 2.1 ^{cd}	70 $\pm$ 0.0 ^{bc}	62 $\pm$ 4.16 ^a	55 $\pm$ 0.6 ^a
	10	70 $\pm$ 0.0 ^d	70 $\pm$ 1.6 ^c	74 $\pm$ 0.0 ^d	64 $\pm$ 5.3 ^c	75 $\pm$ 2.7 ^{ef}	74 $\pm$ 6.0 ^{ef}	90 $\pm$ 2.3 ^{def}	70 $\pm$ 1.5 ^b	90 $\pm$ 0.7 ^{fg}
	15	80 $\pm$ 0.6 ^e	85 $\pm$ 1.2 ^e	90 $\pm$ 4.4 ^{fg}	81 $\pm$ 0.6 ^f	86 $\pm$ 1.2 ^f	85 $\pm$ 1.2 ^{ef}	100 $\pm$ 0.0 ^g	80 $\pm$ 0.0 ^{cd}	80 $\pm$ 0.1 ^{ef}
<i>C. ambrosioidae</i>	5	80 $\pm$ 2.0 ^e	66 $\pm$ 1.5 ^c	68 $\pm$ 4.7 ^{cd}	18 $\pm$ 1.6 ^a	20 $\pm$ 0.6 ^{ab}	25 $\pm$ 4.0 ^a	61 $\pm$ 0.6 ^{bc}	85 $\pm$ 0.0 ^e	76 $\pm$ 1.5 ^{ef}
	10	83 $\pm$ 4.9 ^e	91 $\pm$ 2.0 ^f	91 $\pm$ 0.6 ^f	10 $\pm$ 2.7 ^a	6 $\pm$ 1.5 ^a	56 $\pm$ 0.6 ^c	76 $\pm$ 2.3 ^b	81 $\pm$ 0.6 ^d	81 $\pm$ 0.6 ^{fg}
	15	95 $\pm$ 4.9 ^f	98 $\pm$ 1.5 ^g	78 $\pm$ 0.6 ^{de}	53 $\pm$ 2.7 ^a	41 $\pm$ 0.6 ^c	41 $\pm$ 0.6 ^{bc}	81 $\pm$ 2.3 ^{de}	100 $\pm$ 0.0 ^g	65 $\pm$ 0.0 ^{def}
<i>T. minuta</i>	5	75 $\pm$ 0.6 ^d	80 $\pm$ 0.0 ^e	80 $\pm$ 0.0 ^{ef}	88 $\pm$ 1.4 ^g	65 $\pm$ 1.2 ^e	65 $\pm$ 1.3 ^{cd}	100 $\pm$ 0 ^g	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g
	10	81 $\pm$ 0.6 ^e	73 $\pm$ 0.6 ^{ce}	83 $\pm$ 0.6 ^{fg}	78 $\pm$ 1.5	75 $\pm$ 0.6 ^{ef}	85 $\pm$ 0.6 ^e	100 $\pm$ 0 ^g	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g
	15	81 $\pm$ 0.6 ^e	81 $\pm$ 0.6 ^{de}	83 $\pm$ 1.5 ^{ef}	82 $\pm$ 3.5 ^f	83 $\pm$ 0.4 ^{ef}	86 $\pm$ 1.6 ^{ef}	100 $\pm$ 0 ^g	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g
Standard Check	5	100 $\pm$ 0 ^g	100 $\pm$ 0 ^g	100 $\pm$ 0 ^g	100 $\pm$ 0 ^g	100 $\pm$ 0 ^g	100 $\pm$ 0 ^g	100 $\pm$ 0 ^g	100 $\pm$ 0.0 ^g	100 $\pm$ 0.0 ^g
Control		0.00 $\pm$ 0.0	0.00 $\pm$ 0.0	0.00 $\pm$ 0.0	0.00 $\pm$ 0.0	0.00 $\pm$ 0.0	0.00 $\pm$ 0.0	0.00 $\pm$ 0.0	0.00 $\pm$ 0.0	00 $\pm$ 0.00

Means within column followed by different letters are significantly different ($P < 0.05\%$), Tukey student test (HSD).

TABLE 2: Combined effect of plant extract, concentration rate, and different solvents on inhibition rate (IR) of F1 progeny of *S. zeamais*.

Treatment	Dose (g/kg)	% inhibition rate (mean $\pm$ SD)		
		Hexane	Chloroform	Methanol
<i>A. indica</i>	5	87.5 $\pm$ 16.54 ^{ih}	87.5 $\pm$ 6.5 ^{ih}	93.75 $\pm$ 6.25 ^{ih}
	10	100 $\pm$ 0.00 ⁱ	95.25 $\pm$ 21.65 ⁱ	95.83 $\pm$ 7.23 ⁱ
	15	100 $\pm$ 0.00 ⁱ	100 $\pm$ 0.00 ⁱ	100 $\pm$ 0.00 ⁱ
<i>C. ambrosioides</i>	5	68.75 $\pm$ 0.00 ^{efghi}	52.08 $\pm$ 0.16 ^{efgh}	70.83 $\pm$ 0.25 ^{efgh}
	10	68.75 $\pm$ 0.14 ^{dfigh}	72.92 $\pm$ 0.24 ^{dfigh}	81.25 $\pm$ 0.23 ^{dfigh}
	15	68.75 $\pm$ 0.15 ^{fghi}	85 $\pm$ 0.25 ^{fghi}	89.553 $\pm$ 0.18 ^{fghi}
<i>M. stenopetala</i>	5	54.58 $\pm$ 1.33 ^{ab}	56.67 $\pm$ 0.36 ^{ab}	51.25 $\pm$ 0.00 ^{ab}
	10	62.5 $\pm$ 0.33 ^{bc}	66.67 $\pm$ 0.23 ^{bc}	69.58 $\pm$ 0.69 ^{bc}
	15	63.33 $\pm$ 0.24 ^{bc}	62.91 $\pm$ 0.16 ^{bc}	69.58 $\pm$ 0.18 ^{bc}
<i>A. squamosa</i>	5	66.25 $\pm$ 0.13 ^{cde}	62.50 $\pm$ 0.09 ^{cde}	70.83 $\pm$ 0.16 ^{def}
	10	83.33 $\pm$ 0.07 ^{cdef}	81.25 $\pm$ 0.08 ^{cdef}	89.58 $\pm$ 0.03 ^{defgh}
	15	100 $\pm$ 0.00 ⁱ	95.58 $\pm$ 0.09 ^{hi}	100 $\pm$ 0.00 ⁱ
<i>E. globulus</i>	5	81.25 $\pm$ 0.08 ^{defg}	81.83 $\pm$ 0.09 ^{defg}	91.67 $\pm$ 0.03 ^{hi}
	10	93.75 $\pm$ 0.11 ^{fghi}	85.42 $\pm$ 0.25 ^{fghi}	100 $\pm$ 0.00 ⁱ
	15	97.2 $\pm$ 0.03 ^{hi}	100 $\pm$ 0.00 ⁱ	100 $\pm$ 0.00 ⁱ
<i>O. basilicum</i>	5	48.75 $\pm$ 0.35 ^{cdfg}	43.75 $\pm$ 0.06 ^{cdfg}	62.5 $\pm$ 0.16 ^{cdfg}
	10	59.17 $\pm$ 0.16 ^{cde}	56.25 $\pm$ 0.34 ^{abc}	69.17 $\pm$ 0.14 ^{bc}
	15	61.67 $\pm$ 0.07 ^a	68.75 $\pm$ 0.25 ^{ab}	62.1 $\pm$ 0.40 ^{ab}
<i>T. minuta</i>	5	62.08 $\pm$ 0.31 ^{efgh}	66.25 $\pm$ 0.93 ^{efg}	75.00 $\pm$ 12.50 ^{fg}
	10	82.25 $\pm$ 0.20 ^{ghi}	89.58 $\pm$ 0.44 ^{hi}	81.25 $\pm$ 0.07 ^{ghi}
	15	89.58 $\pm$ 0.03 ^{ghi}	89.50 $\pm$ 0.88 ^{hi}	95.42 $\pm$ 0.16 ^{hi}
Actellic 2% dust	5	100.00 $\pm$ 0.00 ⁱ	100.0 $\pm$ 0.00 ⁱ	100.0 $\pm$ 0.00 ⁱ
Untreated seed		00.00 $\pm$ 00 ^a	00.00 $\pm$ 00 ^a	00.00 $\pm$ 0.00 ^a

Means within a column followed by different letters are significantly different ($P < 0.05\%$), Tukey's student test (HSD).

TABLE 3: Mean $\pm$ SD weight loss affected by adult *S. zeamais* on seed treated with crude oil extracts from various plant materials and solvents.

Treatment	Dose (g/kg)	%mean $\pm$ SD weight loss		
		Hexane	Chloroform	Methanol
<i>A. squamosa</i>	5	0.16 $\pm$ 0.07 ^b	0.06 $\pm$ 0.06 ^b	0.23 $\pm$ 1.09 ^a
	10	0.03 $\pm$ 0.02 ^a	0.01 $\pm$ 00 ^a	0.13 $\pm$ 0.14 ^a
	15	0.01 $\pm$ 0.01 ^a	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a
<i>C. ambrosioides</i>	5	0.1 $\pm$ 0.17 ^{bc}	0.10 $\pm$ 0.13 ^b	0.10 $\pm$ 0.03 ^{bc}
	10	0.2 $\pm$ 0.09 ^{ab}	0.06 $\pm$ 0.10 ^b	0.14 $\pm$ 0.03 ^b
	15	0.66 $\pm$ 0.10 ^b	0.03 $\pm$ 0.05 ^b	0.03 $\pm$ 0.03 ^a
<i>E. globulus</i>	5	0.26 $\pm$ 0.21 ^c	0.14 $\pm$ 0.22 ^b	0.00 $\pm$ 0.00 ^a
	10	0.06 $\pm$ 0.10 ^a	0.1 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a
	15	0.00 $\pm$ 0.00 ^a	0.04 $\pm$ 0.00 ^b	0.00 $\pm$ 0.00 ^a
<i>M. stenopetala</i>	5	0.42 $\pm$ 0.28 ^b	0.03 $\pm$ 0.01 ^b	0.28 $\pm$ 0.00 ^{ab}
	10	0.36 $\pm$ 0.12 ^b	0.01 $\pm$ 0.02 ^{ab}	0.24 $\pm$ 0.21 ^{ab}
	15	0.16 $\pm$ 0.14 ^{bc}	0.01 $\pm$ 0.01 ^a	0.05 $\pm$ 0.08 ^b
<i>A. indica</i>	5	0.02 $\pm$ 0.02 ^a	0.00 $\pm$ 0.00 ^a	0.02 $\pm$ 0.03 ^b
	10	0.04 $\pm$ 0.05 ^{ab}	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a
	15	0.05 $\pm$ 0.09 ^{bc}	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a
<i>O. basilicum</i>	5	0.30 $\pm$ 0.06 ^b	0.16 $\pm$ 0.10 ^{ab}	0.31 $\pm$ 0.26 ^b
	10	0.28 $\pm$ 0.34 ^b	0.06 $\pm$ 0.08 ^b	0.02 $\pm$ 0.02 ^b
	15	0.11 $\pm$ 0.09 ^b	0.01 $\pm$ 0.01 ^a	0.01 $\pm$ 0.01 ^a
<i>T. minuta</i>	5	0.38 $\pm$ 0.13 ^b	0.17 $\pm$ 0.03 ^b	0.73 $\pm$ 0.82 ^c
	10	0.08 $\pm$ 0.07 ^{bc}	0.07 $\pm$ 0.00 ^b	0.00 $\pm$ 0.00 ^a
	15	0.06 $\pm$ 0.10 ^c	0.04 $\pm$ 0.06 ^{bc}	0.00 $\pm$ 0.00 ^a
Control		5.56 $\pm$ 0.06 ^c	4.54 $\pm$ 0.06 ^c	4.73 $\pm$ 0.82 ^c
Actellic 2% dust	5	0.00	0.00	0.00

Means within a column followed by different letters are significantly different ($P < 0.05\%$), Tukey's student test (HSD).

TABLE 4: Effect of crude oil extracts of plants and solvent on percent germination of maize seeds.

Treatment	Dose (g/kg)	%Mean $\pm$ SD germination		
		Hexane	Chloroform	Methanol
<i>A. squamosa</i>	5	93.33 $\pm$ 0.58 ^{ab}	86.66 $\pm$ 0.58 ^a	86.67 $\pm$ 0.58 ^a
	10	90.00 $\pm$ 1.00 ^{ab}	90.00 $\pm$ 0.00 ^{ab}	93.33 $\pm$ 0.58 ^{ab}
	15	88.5 $\pm$ 1.00 ^{ab}	90.00 $\pm$ 0.00 ^{ab}	96.67 $\pm$ 0.58 ^b
<i>C. ambrosioides</i>	5	83.33 $\pm$ 2.08 ^a	83.33 $\pm$ 1.15 ^a	83.33 $\pm$ 1.15 ^a
	10	85.00 $\pm$ 1.00 ^a	86.67 $\pm$ 0.58 ^a	93.33 $\pm$ 1.15 ^{ab}
	15	81.67 $\pm$ 0.58 ^a	90.00 $\pm$ 0.00 ^{ab}	90.00 $\pm$ 0.00 ^{ab}
<i>E. globulus</i>	5	90.00 $\pm$ 1.00 ^{ab}	93.33 $\pm$ 0.58 ^{ab}	93.33 $\pm$ 0.58 ^{ab}
	10	85.00 $\pm$ 2.00 ^a	83.33 $\pm$ 0.58 ^a	96.67 $\pm$ 0.58 ^b
	15	80.00 $\pm$ 1.73 ^a	100.00 $\pm$ 0.00 ^{ab}	100.00 $\pm$ 0.00 ^b
<i>M. stenopetala</i>	5	86.67 $\pm$ 2.08 ^a	86.67 $\pm$ 0.58 ^a	90.00 $\pm$ 1.00 ^{ab}
	10	86.67 $\pm$ 0.58 ^a	86.33 $\pm$ 0.58 ^a	90.00 $\pm$ 0.00 ^{ab}
	15	85.00 $\pm$ 0.00 ^a	86.66 $\pm$ 0.58 ^a	96.67 $\pm$ 0.58 ^b
<i>A. indica</i>	5	95.00 $\pm$ 0.00 ^b	93.33 $\pm$ 0.58 ^{ab}	93.33 $\pm$ 0.58 ^{ab}
	10	90.00 $\pm$ 0.00 ^{ab}	83.33 $\pm$ 0.58 ^a	86.67 $\pm$ 0.58 ^a
	15	80.00 $\pm$ 1.73 ^a	86.66 $\pm$ 0.58 ^a	90.00 $\pm$ 0.00 ^{ab}
<i>O. basilicum</i>	5	90.00 $\pm$ 0.00 ^{ab}	86.67 $\pm$ 1.52 ^a	86.67 $\pm$ 1.58 ^a
	10	78.33 $\pm$ 1.15 ^a	90.00 $\pm$ 1.00 ^{ab}	90.00 $\pm$ 1.00 ^{ab}
	15	83.33 $\pm$ 1.15 ^{ab}	93.33 $\pm$ 0.58 ^{ab}	96.67 $\pm$ 0.58 ^b
<i>T. minuta</i>	5	91.67 $\pm$ 0.58 ^{ab}	93.33 $\pm$ 0.58 ^{ab}	93.33 $\pm$ 0.58 ^{ab}
	10	76.67 $\pm$ 1.15 ^a	90.00 $\pm$ 1.00 ^{ab}	96.67 $\pm$ 0.58 ^b
	15	75.00 $\pm$ 0.00 ^a	86.67 $\pm$ 0.58 ^a	90.00 $\pm$ 1.00 ^{ab}
Actellic 2% dust	5	87.67 $\pm$ 1.15 ^{ab}	96.67 $\pm$ 0.58 ^b	96.67 $\pm$ 0.58 ^b
Control		96.00 $\pm$ 0.58 ^b	96.67 $\pm$ 0.58 ^b	96.67 $\pm$ 0.58 ^b

Means within a column followed by different letters are significantly different ($P < 0.05$), Tukey's studentized range test (HSD).

the solvent extracts of *M. stenopetala* and *O. basilicum* by hexane resulted in a significant mortality of insects at a dose of 0.5 g within 96 hours after treatment compared with neem crude oils. The plant crude oil treatments' mortality impact was dosage and time-dependent in line with a previous study [15, 27]. In general, the findings of this study indicated that *A. indica*, *E. globulus*, *A. squamosa*, and *T. minuta* crude oils were effective in controlling *S. zeamais* [28].

The outcomes of this study showed that the toxicity of the oil of the seven botanical treatments against *S. zeamais* is consistent with the results of previous researchers [21]. In the present study, the effectiveness of the tested oils in causing insect mortality varied significantly ($P \leq 0.05$) depending upon the solvent type used for extraction [28]. The highest mortality was observed with the hexane extracts, followed by the chloroform and methanol extracts. The result of the current experiment is in agreement with the findings by [26, 27], where the hexane extracts of *E. globulus* were the most effective. Similarly, Bezabih et al. [12] reported the superior efficacy of hexane extracts may be due to the broad solubility of the bioactive organic compounds in hexane. A combination of hexane solvent properties and its relatively benign toxicological profile make it a practical and preferred choice for preparing plant extracts for evaluating their potential as natural insecticides or pesticides [29].

Various scientists suggested that there are numerous plant extracts with insecticidal potential against various storage pests on filter paper and in admixture bioassays [7–10, 26]. In similar studies, all plant crude oil tested

showed an effect on mortality, percentage insect damage, and weight loss on different insect pests. Lelise et al. [12] supported these findings by demonstrating the effectiveness of two botanical powders, *E. globulus* and *C. ambrosioides* (whole plant), against storage pests affecting two maize varieties (BH-661 and LIMU) stored in polypropylene sacks. This is supported by a recent study [27] that the essential oil of basil (*O. basilicum*) has significant biological activity against insect pests.

Assefa [13] reported on the preparation and characterization of locally sourced custard apple seed extract for its potential use as a natural biopesticide. The findings suggest that custard apple seed extract could be a viable alternative for producing natural pesticides, aligning with the current study's results. Weaver [27] suggests that using crude extracts of *Tagetes* spp. may be the most effective approach for control programs.

In this laboratory study, all treatments significantly decreased the emergence of *S. zeamais* compared to the untreated control groups. Neem oil and *E. globulus* proved to be the most effective in decreasing the F1 progeny of *S. zeamais* at all concentrations tested. However, neem oil at a concentration of 0.5 g was comparatively less effective ($P \leq 0.05$) in providing protection against the F1 progeny than the other concentrations.

Wahedi [30] observed that oil derived from neem seeds and leaves significantly reduced the emergence of progeny in maize weevils (*S. zeamais*). Similar results showed that crude oil from neem seeds effectively lowered the assessment of F1 progeny. Additionally, the effectiveness of ethanol seed

extracts from *A. indica* and Piper guineense (Schum and Thonn) at concentrations of 10%, 20%, 30%, and 40% v/v was evaluated for controlling *S. zeamais*, comparing them to the conventional insecticide pirimiphos-methyl at a dosage of 0.5 ml per 50 g of Oba Super II maize grains [29].

The reduced incidence of F1 progeny may be attributed to the increased mortality of insects, as well as the ovicidal and larvicidal properties of the tested crude oils from the leaves and seeds of the plant [31]. Similarly, Tapondjou et al. [23] reported the powdered plant can kill larvae hatching from eggs laid on seed, thereby inhibiting feeding and damage. Additionally, Medugu et al. [14] found that botanical powders weaken insects, leading to a decrease in the number of eggs laid compared to their usual rate.

The addition of plant crude oils to the grain significantly reduced seed damage and weight loss compared to the untreated control. In this scenario, there was also a decrease in seed damage and weight loss as the application rate of treatments increased. Neem was found to be more effective at all concentrations in managing weight loss than *M. stenopetala* and *O. basilicum* [29]. This reduction may be attributed to the presence of a volatile compound that influences the feeding behavior of the insects [8].

In this investigation, germination bioassay results showed that all plant crude oils, regardless of the solvent used to treat maize infested with *S. zeamais* had no negative impact on seed germination at any concentration. Both untreated and botanically extracted seeds germinated at rates ranging from 83.33% to 100%. Maize grains treated with Actellic (2% dust) and untreated grains showed the same germination rate of 96.67%. However, certain treatments were affected by mold growth; unless the seed damage was severe, maize damage did not affect seed germination [16].

6. Conclusion

Crop protection has usually depended on synthetic chemicals, but their availability is declining due to increased regulations and the emergence of pest resistance. *A. indica*, *A. squamosa*, *T. minuta*, and *E. globulus* have promising bio-insecticidal potential for protecting stored grain from *S. zeamais* infestations. The crude oil extracts from these plants did not negatively affect seed germination viability. The findings of this study indicate a significant potential for these crude oil extracts as protectants against *S. zeamais*, while they can be utilized as an option or component of an integrated pest management strategy for maize.

Data Availability

Data will be made available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Fikadu Kifle, Melaku Girma, Araya G/Silase, and Yitbarek W/Hariat designed the study. Fikadu Kifle experimented

and analyzed the first draft. Melaku Girma, Araya G/Silase, Yitbarek W/Hariat, and Estifanos Ele revised, supervised, and edited the manuscript. All authors read and approved the final manuscript version.

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References

- [1] H. Gul, S. Rahman, A. Shahzad et al., "Maize (*Zea mays* L.) Productivity in response to nitrogen management in Pakistan," *American Journal of Plant Sciences*, vol. 12, no. 08, pp. 1173–1179, 2021.
- [2] P. Ranum, J. P. Peña-Rosas, and M. N. Garcia-Casal, "Global maize production, utilization, and consumption," *Annals of the New York Academy of Sciences*, vol. 1312, no. 1, pp. 105–112, 2014.
- [3] O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, "Global maize production, consumption and trade: trends and R and D implications," *Food Security*, vol. 14, no. 5, pp. 1295–1319, 2022.
- [4] M. Suleiman, N. D. Ibrahim, and C. P. Rugumamu, "Application of some botanicals in the protection of sorghum grains against the maize Weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae)," *Proceedings of the Zoological Society*, vol. 74, no. 2, pp. 219–226, 2021.
- [5] S. Waktole and A. Ayana, "Storage pests of maize and their status in Jimma Zone," *African Journal of Agricultural Research*, vol. 7, no. 28, pp. 4056–4060, 2012.
- [6] B. Chouangthavy, K. Bouttavong, J. Louangphan, P. Phewphanh, P. Sibounnavong, and D. Babendreier, "Diversity of beetle family Curculionidae and Bostrichidae (Coleoptera) in two national protected areas in Lao PDR," *Zoological Society*, vol. 76, no. 3, pp. 347–353, 2023.
- [7] T. Shiberu, "Determination of the appropriate doses of promising botanical powders against maize weevil, *Sitophilus zeamais* Mots (Coleoptera: Curculionidae) on maize grain," *Agricultural Research & Technology: Open Access Journal*, vol. 6, no. 5, pp. 104–108, 2017.
- [8] H. Birhanu and G. Emanu, "Efficacy of solvent extracts of *Calpurnia aurea* (Ait.) Benth and *Milletia ferruginea* (Hochest) Baker leaves against maize weevils, *Sitophilus zeamais* (Motsch.) of stored maize in Ethiopia," *Journal of Stored Products and Postharvest Research*, vol. 9, no. 3, pp. 27–35, 2018.
- [9] S. Waktole, "Effect of selected botanicals and local seed storage practices on maize insect pests and health of maize seeds in Jimma Zone," *Singapore Journal of Scientific Research*, vol. 4, no. 2, 2014.
- [10] G. Bezabih, N. Satheesh, F. S. Workneh, M. Wale, and M. Atlabachew, "Reducing postharvest loss of stored grains using plant-based biopesticides: a review of past research efforts," *Advances in Agriculture*, vol. 10, pp. 1–16, 2022.
- [11] T. Marid, "Post-harvest loss of stored grain, its causes and reduction strategies," *Food Science and Quality Management*, vol. 96, pp. 2224–6088, 2020.
- [12] T. Lelise, A. Tadesse, W. Gobena, and C. Kuyu, "On farm evaluation of *Eucalyptus globulus* Labill leaf and *Chenopodium*

- ambrosioides* L. whole plant powder against storage insect pests in stored maize at Sokoru District in Jimma Zone of Oromia Regional State, Ethiopia," *Psyche (London)*, vol. 2019, p. 7, 2019.
- [13] T. Assefa, "Production and characterization of custard apple seed extract for its possible application as bio-pesticide," *A Journal of Plant Growth Regulation*, vol. 37, pp. 1185–1194, 2019.
 - [14] M. A. Medugu, E. Okrikata, and D. M. Dunuwel, "Management of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) using Nigerian raw diatomite," *Journal of Applied Sciences & Environmental Management*, vol. 24, no. 9, pp. 1663–1669, 2020.
 - [15] T. Abraham, A. Amare, G. Emanu, and T. Tadele, "Review of research on post-harvest pests in Ethiopia," in *Increasing Crop Production through Improved Plant Protection- Volume II. Plant Protection Society of Ethiopia*, T. Abraham, Ed., pp. 475–562, PPSE and EIAR, Addis Ababa, Ethiopia, 2009.
 - [16] E. Adjalien, P. Sessou, F. T. D. Bothon et al., "Chemical composition and bioefficacy of *Dennettia tripetala* and *Uvariandron angustifolium* leaves essential oils against the Angoumois grain moth, *Sitotroga cerealella*," *International Journal of Biosciences*, vol. 5, no. 8, pp. 161–172, 2014.
 - [17] J. M. Omoyakhi and A. M. Orheruata, "Actellic 2% dust as pesticide in feed ingredients: post-weaning tolerance," *Growth Performance and Organ Weights of Growing Rabbits. Pakistan Journal of Nutrition*, vol. 8, no. 9, pp. 1368–1372, 2009.
 - [18] E. N. Nukenine, C. Adler, and C. Reichmuth, "Bioactivity of fenchone and *Plectranthus glandulosus* oil against *Prostephanus truncatus* and two strains of *Sitophilus zeamais*," *Journal of Applied Entomology*, vol. 134, no. 2, pp. 132–141, 2010.
 - [19] G. Adugna, M. Negeri, and B. Abdisa, "Phytochemical screening and insecticidal activities of some medicinal plants against the maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae)," *Scientific Report*, vol. 14, p. 8678, 2024.
 - [20] L. Wei, R. Hua, M. Li et al., "Chemical composition and biological activity of star anise *illicium verum* extracts against maize weevil, *sitophilus zeamais* adults," *Journal of Insect Science*, vol. 14, no. 80, pp. 1–13, 2014.
 - [21] A. Tesfaye, A. J. Jenber, and M. Mintesnot, "Survey of storage insect pests and management of rice weevil, *Sitophilus oryzae*, using botanicals on sorghum (*Sorghum bicolor* L.) at Jawi District, Northwestern Ethiopia," *Archives of Phytopathology and Plant Protection*, vol. 54, no. 19–20, pp. 2085–2100, 2021.
 - [22] W. W. Abbott, "A method of computing the effectiveness of insecticide," *Journal of Economic Entomology*, vol. 18, pp. 265–267, 1925.
 - [23] L. A. Tapondjou, C. Adlerb, H. Boudaa, and D. A. Fontemc, "Efficacy of powder and essential oil from *Chenopodium ambrosioides* leaves as post-harvest grain protectants against six-stored product beetles," *Journal of Stored Products Research*, vol. 38, pp. 395–402, 2002.
 - [24] J. M. Adams and G. M. Schultze, "53. Losses caused by insects, mites, and micro-organisms," in *Postharvest Grain Loss Assessment Methods*, K. L. Harris and C. G. Lindblad, Eds., pp. 83–95, American Association of Cereal Chemists, New York, NY, USA, 1978.
 - [25] J. Ogendo, A. Deng, S. Belmain, D. Walker, and A. Musandu, "Effect of insecticidal plant materials, *Lactana camara* L. and *Tephrosia vogelii* Hook, on the quality parameters of stored maize grains," *Journal of Food Technology in Africa*, vol. 9, pp. 29–36, 2004.
 - [26] B. Jembere, G. Daniel, N. Merid, and S. Emiru, "Toxicity of birbira (*Milletia ferruginea*) seed crude extracts to some insect pests as compared to other botanical and synthetic insecticides," *11th NAPRECA Symposium Book of Proceedings, Antananarivo, Madagascar*, pp. 88–96, University of Nairobi, Nairobi, Kenya, 2005.
 - [27] D. K. Weaver, J. L. Zettler, C. D. Wells, J. E. Baker, W. Bertsch, and J. E. Throne, "Toxicity of fractionated and degraded Mexican marigold floral extract to adult *Sitophilus zeamais* (Coleoptera: Curculionidae)," *Journal of Economic Entomology*, vol. 90, no. 6, pp. 1678–1683, 1997.
 - [28] D. J. Langsi, E. N. Nukenine, C. N. Fokunang et al., "Evaluation of the insecticidal properties of fractionated extracts of *Ocimum canum* and *Laggetera pterodonta* on stored maize against the infestation of *Sitophilus zeamais* (Coleoptera: Curculionidae)," *Journal of Agronomy and Agricultural Research*, vol. 10, no. 6, pp. 41–50, 2017.
 - [29] M. Dele Akinbuluma and F. Kolawole Ewete, "Comparative efficacy of extracts from *Azadirachta indica*, *Piper guineense* and pirimiphos-methyl against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in stored maize," *Journal of Biology, Agriculture and Healthcare*, vol. 4, no. 27, pp. 327–335, 2014.
 - [30] J. Wahedi, "Laboratory evaluation of neem (*Azadirachta indica* Linn (Meliaceae)) seed powder and seed oil for the control of *Sitophilus zeamais* (Coleoptera: bruchidae) on stored maize," *Adamawa State University Journal of Scientific Research*, vol. 2, no. 2, pp. 2251–0702, 2012.
 - [31] J. Barre and A. J. Jenber, "Evaluation of selected botanicals for the management of maize weevil (*Sitophilus zeamais*) on maize (*Zea mays* L.) grain under laboratory condition in Gabilay District, Somaliland," *Heliyon*, vol. 8, no. 12, Article ID e11859, 2022.