Vol. 22(11), pp.273-285, November 2023
DOI: 10.5897/AJB2023.17612
Article Number: 4CF11D071403
ISSN: 1684-5315

http://www.academicjournals.org/AJB

African Journal of Biotechnology

Full Length Research Paper

Efficacy of organic extracts of *Nicotiana tabacum* (Solanaceae) leaf and *Jatropha curcas* (Euphorbiaceae) seed against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) under laboratory conditions

Tsegab Temesgen[1]* and Emana Getu[2]

[1]Department of Biology, College of Natural and Computational Sciences, Oda Bultum University, Addis Ababa, Ethiopia.
[2]Insect Sciences Stream, Department of Zoological Sciences, Addis Ababa University, P. O. Box, Addis Ababa, Ethiopia.

Received 31 August, 2023; Accepted 12 October, 2023

The maize weevil is a pest of stored maize controlled with synthetic insecticides. The widespread use of these insecticides, however, is harmful to the environment and human health. In this study, solvent extracts (SEs) and powder treatments (PTs) of *Nicotiana tabacum* leaves and *Jatropha curcas* seeds were tested for their efficacy against *Sitophilus zeamais* Motschulsky. The experiment was designed in a completely randomized design with three replications. For extraction, ethyl acetate and dichloromethane were used. Extract concentrations of 25, 50, 75 and 100% were evaluated at dosages of 4, 8, and 12 ml. PT of botanicals was evaluated at dosages of 4, 8, and 12 g. Mortality was calculated at 1, 3, 5, 7, and 14 days after treatment. At the end of the experiment, the percentage of grain damage, weight loss, and germination percentage was calculated. Dichloromethane SEs of *N. tabacum* leaves and *J. curcas* seeds at 50, 75, and 100% levels of extract concentrations (LEC) in all doses caused 100% mortality. The *J. curcas* seed PTs at 12 g and its SEs of ethyl acetate and dichloromethane in 100% LEC at 12 ml experienced the least grain weight loss of 1.36, 0.79 and 0.64%, respectively. The results suggest that these plant-based products are very promising, generally available, cost-effective, non-toxic to non-target organisms, and simple to produce. Thus, dichloromethane SEs of *N. tabacum* leaves and *J. curcas* seeds at 50% LEC and above in all doses can be recommended for the management of *S. zeamais*.

Key words: Adult emergence, dichloromethane, ethyl acetate, insecticidal activity, maize weevil.

INTRODUCTION

Maize (*Zea mays* L.) is a member of the grass family (Poaceae). It is one of the world's most significant annual cereal crops, serving as staple food and a source of income for many people in developing countries (Tandzi

and Mutengwa, 2019). Maize grain is damaged by insects, reducing its benefits (Hiruy and Getu, 2020). *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) is one of the most damaging insects to stored grain, particularly in tropical areas (Bhusal and Khanal, 2019).

To protect their maize from insect pests, farmers and maize traders use a variety of pest control methods. Synthetic insecticides are the most commonly used grain protection option (Njoroge et al., 2014). On the other hand, insecticide exposure has been linked to several human acute and chronic diseases (Kandel et al., 2021). Hence, it is critical to develop more effective alternatives that control pest populations while minimizing the negative impact of synthetic insecticides (Goldel et al., 2020). Plants and plant-derived products have long been used to control pests in underdeveloped countries (Grzywacz et al., 2014) because they are a more environmentally friendly and cost-effective pest control method than synthetic insecticides (George et al., 2014; Tavares et al., 2021). They are non-toxic to non-target organisms and have a specific mode of action. Furthermore, farmers can easily develop these (Iqbal et al., 2021).

Tobacco, *Nicotiana tabacum* (Solanaceae), is an herbaceous annual or perennial plant in the Solanaceae family (Rao et al., 2016). It has been known for a long time that tobacco leaves are used as insecticides and pesticides (Weber et al., 2019; Kanmani et al., 2021; Prommaban et al., 2022). *Jatropha curcas* belongs to the family Euphorbiaceae (Abdelgadir and Staden, 2013). It is rich in phytochemicals and studied for toxic effects (Oseni and Akindahunsi, 2011). Its extract has a wide range of biological effects, including molluscicidal, acaricidal, and insecticidal effects (Cordova-Albores et al., 2016). Organic extracts of *J. curcas* seeds are shown to be toxic to a wide range of insect orders (Lepidoptera, Coleoptera, Diptera, and Hemiptera) and can be used to protect field crops and stored grains (Temitope, 2014; Eisa et al., 2020). The current study aimed to determine the efficacy of organic extracts of *N. tabacum* leaves and *J. curcas* seeds on maize weevil (*S. zeamais s*) mortality, adult emergence, and grain loss.

MATERIALS AND METHODS

Experimental site and laboratory condition

The study was carried out between July and November, 2022 in the crop protection laboratory of the Bako National Maize Research Centre (BNMRC). Bako is located at 9°6' North and 37°9' East at an elevation of 1650 m above sea level. The experiments were carried out in a laboratory at 25 to 28°C, 65 to 70% relative humidity, and a12:12 (light:dark) photoperiod. The artificial climate chamber controlled the indoor air temperature and relative humidity with errors of ±0.3°C and ±2% throughout the experiment. The experiment was designed in a completely randomized design (CRD) with three replications. As indicated in Table 2, there were 24 treatments (2 botanicals × 4 LECs × 3 doses) for solvent extracts (SEs) and 6 treatments (2 botanicals × 3 doses) for powder treatments (PTs), as indicated in Table 7.

Plant samples collection

Tobacco, *N. tabacum* leaves, and *J. curcas* seeds were collected from gardens near Bako town and dried in shade for 3 to 4 weeks. It was ground into a fine powder using a mortar and pestle. To prevent quality loss, the powder was sealed in polythene bags and kept in the refrigerator (Khan et al., 2014). The botanicals were chosen because they were easily accessible in the area, and their powder tests showed a promising result for storage and insect pest control (Prommaban et al., 2022).

Preparation of dry extracts

To prepare the dry extracts, the solvents ethyl acetate (ETOAc) and dichloromethane (DCM) were used to extract the powdered leaves and/or seeds. For ETOAc extraction, 500 g of powdered leaves and/or seeds were put separately in conical flasks. 1000 mL of ETOAc were added to each flask and corked. The mixture was left for 12 h. After 12 h, the extract filtrates were filtered into separate, labeled bottles using a funnel and Whatman filter paper No. 1. Again 500 mL of solvent was added to each flask (decanted extract), which was then kept for 24 h. After 24 h, the filtration process was repeated. Once more, 500 mL of ETOAc was added to each decanted extract and left for 48 h; the final extract filtrates were collected. Spinning was sometimes done to ensure extraction was complete. To keep solvent from escaping, cotton wool, and aluminium foil were always used to cover the flasks. Dry extracts were created after vacuum-concentrating extract filtrates with a Heidolph rotary evaporator. Dry extracts were formed by drying the concentrates further and removing any remaining solvents (Khan et al., 2014; Gitahi et al., 2021). For DCM extractions, a similar procedure was used. Both organic extracts were then stored in bottles in a refrigerator at 4°C until use.

Preparation of different levels of extract concentrations (LECs) from dry extract

Various plant extract concentrations were prepared, mostly according to Gitahi et al. (2021). The dry extracts were diluted with ETOAc and DCM at a concentration of 1 g/ml, and this was called the "stock solution" (100% w/v concentration). The plant extract concentrations used were 25, 50, 75, and 100% (w/v), which were prepared differently. For the 25% (w/v) plant extract concentration, 1 mL of the stock solution was diluted with 3 mL of solvent to produce 4 mL; for the 50% (w/v) plant extract concentration, 2 mL of the stock solution was mixed with 2 mL of solvent to make 4 mL; and for the 75% (w/v) plant extract concentration, 1 mL of solvent was added to 3 mL of the stock solution to make 4 mL (Table 1)

*Corresponding author. E-mail: tsegab.temesgen@aau.edu.et. ORCID ID: 0000-0003-2882-3108.

Table 1. Preparation of solvent extracts (SEs) protocols for determination of the toxicity activities of *N. tabacum* leaf and *J. curcas* seed on *S. zeamais.*

Treated area	Stock solution (ml)	Solvent (ml)
25% PE (w/v)	1	3
50% PE (w/v)	2	2
75% PE (w/v)	3	1
100% PE (w/v)	4	0
Malathion dust 5%	Pc	

Pc=Positive control, PE= plant extract (w/v).
Source: Authors.

Mass rearing of the test insects

The maize grain used in the experiment (BH-661 hybrid maize) was obtained from the Bako National Maize Research Centre and was cleaned and disinfested by being placed in a deep freezer for two weeks at temperatures ranging from 0 to -20°C to remove internal infestations. It was kept for two more weeks in experimental settings for acclimatization by Hiruy and Getu (2020). Initial stock (weevils) was obtained from infested maize purchased from the local market. They were cultured on clean and disinfested maize grain stored in eight 1.5-kg-capacity plastic jars covered with muslin cloth. This was to allow for aeration and prevent weevil escape. After two weeks, all weevils, both alive and dead, were removed from each jar, and the jars were kept in the same laboratory setting. Then, after 30 days, 0 to 3-day-old *S. zeamais* progeny were sieved out and used for the experiment.

Toxicity bioassay of the plants' solvent extracts (SEs)

Following Danga et al. (2015) methods, 100 g of disinfected maize grains were added to 250 cm^3 capacity glass jars with brass screen lids that allow ventilation. Three different rates of each extract (4, 8, and 12 ml) were added to each jar from the four levels of extract concentrations (LECs): 25, 50, 75, and 100%. The jar contents were shaken thoroughly for 5 min to ensure uniform distribution of the solution over the grain surface. The treated grains were then left for 36 h for ETOAc and 24 h for DCM to allow the solvents to completely evaporate before the bioassay. The effect of the solvents (ETOAc and DCM) without a bioassay (the untreated control) was compared to Malathion 5% dust at a recommended rate of 0.05 g/100 g of maize grains (standard check).

Toxicity bioassay of the plants' powder treatments (PTs)

Disinfested maize grains (100 g) were added to 250 cm^3 capacity glass jars with brass screen lids that allow ventilation, and three different rates of each botanical (4, 8, and 12 g) were weighed and added to the grain in each glass jar and shaken well to ensure even distribution (Danga et al., 2015). Following that for both OEs and PTs, 25 pairs of unsexed, laboratory-reared (0–3-day-old) *S. zeamais* were introduced into each jar at the rate of one weevil per 2 g of maize seeds (1:2 g; 50 weevils per 100 g of maize). The jars were kept in the laboratory. When the insects did not respond to a sharp pin inserted into the abdomen, it was determined that they were dead (Ileke and Bulus, 2012).

The effect of SEs and PTs on adult mortality

The mortality data of SEs or PTs-treated jars were collected at 1, 3, 5, and 7 days after treatment application, based on Kidane (2011). Dead adults (*S. zeamais*) were removed and counted during each assessment from each jar. During each assessment day, alive *S. zeamais* returned to their respective colonies.

$$\% \text{ Mortality} = \frac{\text{Number of dead weevils}}{\text{Total number of weevils}} \times 100$$

The effects of SEs and PTs on the emergence of *S. zamias*

On the 14th day of treatment, all the dead and alive *S. zamias* were sieved, counted, and discarded. After that, the grains were placed back in their respective jars and kept under the same experimental conditions for progenies' emergence. F_1 progenies were monitored, counted, and removed every two days for 28 days. Percentage reductions in *S. zamias* emergence or inhibition rate (% IR) were determined using the following formula as adopted by previous researchers (Aboalola et al., 2020).

$$\% \text{ IR} = \frac{(C_n - T_n)}{C_n} \times 100$$

where C_n is the number of newly emerged insects in the untreated check (control) jars and T_n is the number of newly emerged insects in the treatments.

The effects of SEs and PTs on grain weight loss

At the end of the experiment, after 42 days, the percentages of grain damage, weight loss, and germination percentage were calculated. To estimate the percentage of weight loss, 100 maize grains were randomly taken from each jar. Based on the count and weigh method described by Hiruy and Getu (2020), the percentage of weight loss was calculated by counting and weighing the damaged and undamaged grains.

$$\% \text{ Weight loss} = \frac{(W_u \times N_d) - (W_d \times N_u)}{W_u \times (N_d + N_u)} \times 100$$

Table 2. Adult mortality of *S. zeamais* on exposure to *N. tabacum* leaf and *J. curcas* seed SEs of ETOAc.

Botanicals	LEC (%)	Dose (ml)	Mean					
			1day	3days	5days	7 days	14 days	Total
N. tabacum	25	4	16±0^{b}	8±0^{b}	22±0^{fg}	12±0^{bcd}	5.3±1^{ab}	63.3±1^{b}
		8	16±0^{b}	10±0^{bc}	22±0^{fg}	14±0^{bcd}	4±0^{ab}	66±0^{bc}
		12	18±0^{cd}	12±0^{cd}	20±0^{def}	10.7±2^{bcd}	7.3±2^{ab}	68±0^{cd}
	50	4	18±0^{cd}	14±0de	20±0^{def}	12±0^{bcd}	6±2^{ab}	70±0de
		8	18±0^{cd}	14±0de	20±0^{def}	12.7±1^{bcd}	7.3±1^{ab}	72±0^{fgh}
		12	18±0^{cd}	15.3±1^{e}	20.7±1^{ef}	12±1^{bcd}	7.3±1^{ab}	73.3±1^{fgh}
	75	4	18.7±1de	16.7±1^{ef}	19.3±1^{def}	10±1^{bc}	10±1^{b}	74.7±1^{hi}
		8	20±0^{ef}	20.7±1^{gh}	18±0^{cde}	10.7±1^{bcd}	9.3±1^{ab}	78.7±1^{jk}
		12	20±0^{ef}	22±0^{hi}	18±0^{cde}	11.3±1^{bcd}	9.3±1^{ab}	80.7±1^{kl}
	100	4	20.7±1^{fg}	24±1^{ij}	17.3±1^{bcd}	17.3±2^{d}	4.7±2^{ab}	84±1^{lm}
		8	22±0^{gh}	27.3±1^{k}	16±0^{bc}	18±2^{cd}	4±2^{ab}	87.3±1^{mn}
		12	22.7±1^{h}	30.7±1^{l}	15.3±1^{bc}	19.3±1^{d}	2.7±1^{ab}	90.7±1no
J. curcas	25	4	16±0^{b}	8.7±1^{b}	22±0^{fg}	12.7±1^{bcd}	5.3±1^{ab}	64.7±1^{bc}
		8	16.7±1^{bc}	10±1^{bc}	21.3±1^{fg}	10.7±2^{bcd}	7.3±2^{ab}	66±1^{bc}
		12	18±0^{cd}	12±0^{cd}	18±0^{cde}	16±1^{cd}	4±1^{ab}	68±0^{cd}
	50	4	18±0^{cd}	14±0de	20±0^{def}	10±0^{bc}	8.7±1^{ab}	70.7±1^{def}
		8	18±0^{cd}	14±0de	20±0^{def}	12.7±1^{bcd}	7.3±1^{ab}	72±0^{fgh}
		12	18±0^{cd}	16±0^{ef}	20±0^{def}	14±2^{bcd}	6±2^{ab}	74±0^{ghi}
	75	4	20±0^{ef}	18.7±1^{fg}	18±0^{cde}	13.3±2^{bcd}	6.7±2^{ab}	76.7±1^{ij}
		8	20±0^{ef}	22±0^{hi}	18±0^{cde}	17.3±2^{cd}	3.3±2^{ab}	80.7±1^{kl}
		12	20±0^{ef}	22±0^{hi}	18±0^{cde}	15.3±3^{cd}	6±3^{ab}	81.3±1^{kl}
	100	4	22±0^{gh}	26±0^{jk}	16±0^{bc}	16.7±2^{cd}	6.7±1^{ab}	87.3±1^{mn}
		8	22±0^{gh}	28.7±1^{kl}	16±0^{bc}	19.3±1^{d}	2.7±1^{ab}	88.7±1no
		12	23.3±1^{h}	31.3±1^{l}	14.7±1^{b}	17.3±1^{d}	5.3±1^{ab}	92±1^{n}
UC		0	0±0.0^{a}	4.7±0^{a}	5.3±0.0^{g}	6±0.0^{ab}	14±0.0^{b}	30±0^{a}
M5%		0.05	100±0^{g}	0±0^{a}	0±0.0^{a}	0±0.0^{a}	0±0.0^{a}	100^{o}±0
Total			21.6±2	17.1±1	17.5±1	13.3±1	5.87±0	75.2±2
p≤values			0.001	0.001	0.001	0.001	0.001	0.001
LSD0.05			26.1	14.25	7.33	3.64	2.8	13.60
CV%			3.85	5.0	3.41	8.13	39.7	1.79

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA (P ≤ 0.05) followed by Tukey`s test. LEC= Level of extraction concentration, UC= untreated control (ETOAc).
Source: Authors

where Wu = Weight of undamaged grains, Nu = Number of undamaged grains, Wd = Weight of damaged grains, and Nd = Number of damaged grains.

The effects of SEs and PTs on grain damage

Counting methods were used to calculate the grain damage percentage. One hundred grains were randomly selected from each maize sample. The number of damaged grains and undamaged grains was counted for holes or insect burrows using a hand lens. The percentage of grain damage was then calculated as follows (Shiferaw, 2011):

$$\% \text{ damaged grains} = \frac{\text{No. of damaged grains}}{\text{Total No. of grains}} \times 100$$

The effects of PTs on grain germination

The experiment was completed with a germination test after data on many factors were collected. Twenty grains were randomly chosen from both the treatment and control groups for the germination test. These grains were then placed one by one in each sterilized Petri dish containing moistened filter paper (Whatman No. 1) and kept at room temperature around 20 to 22°C (68-72°F). Each treatment was repeated three times. Untreated seeds served as the control. After seven days, the number of seedlings that emerged from each Petri dish was counted and recorded. The percentage of germination was calculated using the formula (Talská et al., 2020).

$$\text{Viability index (\%)} = \frac{N_G}{T_G} \times 100$$

where N_G = number of grains germinated and T_G = total number of grains tested in each Petri dish.

Statistical analysis

Data on percentage of adult mortality, grain weight loss, and grain damage were angularly transformed (arcsine √proportion) to reduce variance heterogeneity, but data on F_1 progeny emergence and percentage of seed germination were square root transformed. The transformed data were examined using the Statistical Package for Social Sciences (SPSS, 2016). A one-way ANOVA was used to perform inferential statistics on this data, followed by Tukey's post hoc test for separation and pairwise mean comparisons. $P < 0.005$ was used to indicate that there was a significant difference between the treatment groups. Back transformed data are shown in the tables

RESULTS

Effects of *N. tabacum* leaf and *J. curcas* seed SEs on the mortality of *S. zeamais*

Tables 2 and 3 show the mortality of *S. zeamais* caused by *N. tabacum* leaf and *J. curcas* seed organic extracts at different concentration levels (LECs) and application dosages for 14 days of exposure. The treatments used in these trials resulted in *S. zeamais* mortality beginning on the first day of treatment. *J. curcas* seed organic extracts of ethyl acetate (ETOAc) in 100% LEC at a dosage of 12 ml showed 92% mean mortality on the 14th day of exposure, while the lowest mortality of 63.3% was recorded from *N. tabacum* leaf extract of ETOAc in 25% LEC at a dose of 4 ml (Table 2). Moreover, all dosages of *J. curcas* seed and *N. tabacum* leaf SEs of ETOAc at different LECs applied were significantly ($p<0.05$) different in *S. zeamais* mortality from the untreated control. Only the chemical insecticide Malathion (5% dust) at a rate of 2 g caused 100% weevil mortality on the first day of treatment application (Tables 2 and 3).

N. tabacum leaf and *J. curcas* seed of DCM SEs in 50, 75, and 100% LECs at all dosages were the most effective, causing 100% mean mortality (Table 3). All LECs were effective insecticides. *S. zeamais* mortality was closely related to each extract concentration level; increases in treatment dose and exposure time were linked to a significant increase in cumulative insect mortality.

Following the 14-day powder treatment, a different mortality percentage was recorded. The least toxic dose of *N. tabacum* leaf powder resulted in only 38% mortality in *S. zeamais* (Table 7). Comparing the toxicity of leaf/seed PTs and SEs from the same plant revealed that SEs were substantially more harmful to test insects than the former (Tables 2, 3, and 5). In the untreated control, test insects were alive for the duration of the study, with only 30% mortality (Tables 2 and 3).

Tables 4 and 5 show the mean emergence of *S. zeamais* after 28 days of exposure to *N. tabacum* leaf and *J. curcas* seed SEs at different LECs. There was no emergence of *S. zeamais* in maize grains treated with Malathion 5% dust at 2 g. *N. tabacum* leaf SEs of ETOAc had the highest emergence (62±0.0) of *S. zeamais,* in 25% LEC at a dose of 4 ml, while it had the lowest emergence (18.3±0.7) of *S. zeamais* in 100% LEC at a dose of 12 ml. *N. tabacum* leaf SEs of DCM caused the highest emergence (60.3±0.3) of *S. zeamais* in 25% LEC at the dose of 4 ml, but it induced the lowest emergence (16±0.0) of *S. zeamais* in 100% LEC at the dose of 12 ml (Table 5). The results of this study showed that *N. tobacco* leaf SEs of ETOAc had comparatively higher emergence of *S. zeamais*, since about 62% of *S. zeamais* emergence was recorded in 25% LEC at a dose of 4 ml after 28 days of treatment (Tables 4 and 5).

On the other hand, the number of emerging *S. zeamais* in untreated grains was far too high (134). *J. curcas* seed SEs of ETOAc in 100% LEC at a dose of 12 ml inhibited 88.56% of the emergence of *S. zeamais*, *N. tabacum* leaf SEs of DCM, and *J. curcas* seed SEs of ETOAc in 100% LEC at a rate of 12 ml suppressed 87.3% of the emergence of *S. zeamais*. Malathion 5% dust at 2 g inhibited 100% of *S. zeamais* adult emergence (Table 5). Table 6 shows the mean percentage of weight loss and grain damage to maize grains due to *S. zeamais.* This is influenced by *N. tabacum* leaf and *J. curcas* seed SEs at various LECs and application dosages at the end of the 42-day experiment. The grain weight loss treated with *J. curcas* seed SEs of DCM was lower than that of grains treated with *N. tabacum* leaf SEs of ETOAc and the untreated control. *N. tabacum* leaf SEs of ETOAc in 25% LEC at a dose of 4 ml caused the most grain damage, followed by *J. curcas* seed SEs of ETOAc in 25% LEC at a dose of 4 ml, then *N. tabacum* leaf SEs of ETOAc in 25% LEC at a dose of 8 ml, and *N. tabacum* leaf SEs of ETOAc in 25% LEC at a dose of 12 ml (30.0, 29.2, 28.4, and 26.93%, respectively) (Table 6). Similarly, *J. curcas* seed SEs of DCM in 100% LEC gave pronounced antifeedant effects with significantly lower grain damage of 12.4% at a dose of 4 ml, 9.73% at a dose of 8 ml, and 6.8% at a dose of 12 ml when compared with untreated

Table 3. Percent adult mortality of *S. zeamais* on exposure to *N. tabacum* leaf and *J. curcas* seed SEs of DCM.

Botanicals	LEC (%)	Dose (ml)	Mean					
			1 day	3 days	5 days	7 days	14 days	Total
N. tabacum	25	4	13.3±1^{b}	14.7±1^{c}	16.7±1^{c}	14±0^{c}	11.3±3^{c}	68.7±1^{b}
		8	13.3±3^{b}	14±0^{c}	18±0^{cd}	19.3±1^{bc}	18.7±1^{d}	82±0^{c}
		12	19.3±1^{cd}	14±0^{c}	18±0^{cd}	22±0^{c}	20±0^{d}	93.3±1^{d}
	50	4	20±2^{d}	18.7±1^{c}	22.7±1^{d}	20±0^{bc}	18.7±1^{d}	100±0^{f}
		8	18±0^{bcd}	20±0^{c}	18±0^{cd}	22±0^{c}	22±0^{d}	100±0^{f}
		12	22±0^{d}	18±0^{c}	18±0^{cd}	20±0^{bc}	22±0^{d}	100±0^{f}
	75	4	22±0^{d}	18±0^{c}	22±0^{d}	20±0^{bc}	18±0^{d}	100±0^{f}
		8	20±0^{d}	18±0^{c}	18±0^{cd}	22±0^{c}	22±0^{d}	100±0^{f}
		12	20.7±1^{d}	18.7±1^{c}	19.3±1^{cd}	20.7±1^{c}	20.7±1^{d}	100±0^{f}
	100	4	18.7±1^{bcd}	18±0^{c}	20.7±1^{cd}	20.7±1^{c}	22±0^{d}	100±0^{f}
		8	19±1^{bcd}	18±0^{c}	20±1^{cd}	21±1^{c}	22±0^{d}	100±0^{f}
		12	21±1^{d}	16±1^{c}	19±1^{cd}	22±0^{c}	22±0^{d}	100±0^{f}
J. curcas	25	4	14±1^{bc}	14±1^{c}	18±1^{c}	18±1^{bc}	18±0^{d}	82±1^{c}
		8	17.3±0^{bcd}	14±0^{c}	18±0^{cd}	20.7±1^{bc}	18±0^{d}	88±0^{c}
		12	19.3±1^{cd}	18.7±3^{c}	16.7±1^{cd}	20.7±1^{c}	21.3±1	96.7±0^{e}
	50	4	19±1^{bcd}	21±1^{c}	18±0^{cd}	21±1^{c}	21±1^{d}	100±0^{f}
		8	18±0^{bcd}	21±1^{c}	18±0^{cd}	21±1^{c}	22±0^{d}	100±0^{f}
		12	20.7±1^{d}	19.3±1^{c}	20.7±1^{cd}	20±0^{bc}	19.3±1^{d}	100±0^{f}
	75	4	19.3±1^{cd}	18.7±1^{c}	22±0^{d}	19.3±1^{bc}	20.7±1^{d}	100±0^{f}
		8	22±0^{d}	19.3±1^{c}	20.7±1^{cd}	19.3±1^{bc}	18.7±1^{d}	100±0^{f}
		12	21±1^{d}	19±1^{c}	20±1^{cd}	21±2^{c}	19±1^{d}	100±0^{f}
	100	4	21±1^{d}	19±1^{c}	20±1^{cd}	20±1^{bc}	20±1^{d}	100±0^{f}
		8	22±0^{d}	14±4^{c}	22±0^{d}	22±2^{c}	20±1^{d}	100±0^{f}
		12	21.3±1^{d}	16±2^{c}	19.3±1^{cd}	21.3±1^{c}	22±0^{d}	100±0^{f}
UC		0	0±0^{a}	4.7±0^{b}	5.3±0^{b}	6±0^{b}	14±0^{b}	30±0^{a}
M5%		0.05	100±0^{a}	0±0^{a}	0±0^{a}	0±0^{c}	0±0^{d}	100^{f}±0
Total			21.9±2	16.3±1	18.3±1	19.2±1	18.8±1	94.4±2
p <values			0.08	0.08	0.06	0.02	0.06	0.08
LSD0.05			22.68	8.43	8.7	12.73	9.25	24.1
CV%			4.15	4.43	2.84	3.18	2.94	0.21

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA (P ≤ 0.05) followed by Tukey's test. LEC= Level of extraction concentration, UC= Untreated Control (DCM).
Source: Authors.

controls (66.27%). In conclusion, *J. curcas* seed powder at 12 g and its SEs with ETOAc and DCM in 100% LEC at a dose of 12 ml experienced the least grain weight loss (1.36, 0.79 and 0.64%, respectively) (Tables 6 and 9). Untreated controls had the greatest grain weight loss (5.88%).

The efficacy of *N. tabacum* leaf and *J. curcas* seed PTs against *S. zeamais*

Table 7 shows the mean percent mortality of *S. zeamais* on maize grains treated with *N. tabacum* leaf and *J. curcas* seed PTs. The results indicated that the PTs of

Table 4. Mean number of adult *S. zeamais* emerging and percent protection in *N. tabacum* leaf and *J. curcas* seed SEs of ETOAc.

Botanicals	LEC (%)	Dose (ml)	Mean number of F_1 progeny emerged			% IR
			14 days	28 days	Total	
N. tabacum	25	4	32 ± 0.0^{q}	30 ± 0.0^{p}	62 ± 0.0^{p}	54.73 ± 0.25^{b}
		8	30 ± 0.0^{p}	28 ± 0.0^{op}	58 ± 0.0^{no}	56.97 ± 0.25^{c}
		12	28 ± 0.0^{no}	27 ± 0.0^{no}	55 ± 0.0^{mn}	59.7 ± 0.00^{d}
	50	4	27.7 ± 0.3^{mn}	26 ± 0.0^{mn}	53.7 ± 0.3^{lm}	62.19 ± 0.5^{de}
		8	25 ± 0.0^{kl}	24 ± 0.0^{kl}	49 ± 0.0^{jk}	64.18 ± 0.00^{ef}
		12	24 ± 0.0^{kl}	23 ± 0.0^{jk}	47 ± 0.0^{ij}	65.67 ± 0.00^{gh}
	75	4	23 ± 0.0^{ij}	22±0.0ij	45 ± 0.0^{hi}	68.16 ± 0.25^{ij}
		8	20 ± 0.0^{gh}	19 ± 0.0^{gh}	39 ± 0.0^{g}	73.13 ± 0.43^{k}
		12	18 ± 0.0^{f}	17 ± 0.0^{f}	35 ± 0.0^{f}	75.12 ± 0.25^{l}
	100	4	15.7 ± 0.7^{e}	14.7 ± 0.7^{e}	30.3 ± 0.0^{e}	78.61 ± 0.66^{m}
		8	13.5 ± 0.3^{d}	12.5 ± 0.3^{d}	26 ± 0.0^{d}	82.84 ± 0.43^{n}
		12	10.5 ± 0.3^{bc}	9.5 ± 0.3^{bc}	20 ± 0.0^{bc}	86.82 ± 0.5^{p}
J. curcas	25	4	31 ± 0.0^{pq}	29.5 ± 0.3^{pq}	60.5 ± 0.3^{op}	$55.47\pm0.25_{bc}$
		8	29.7 ± 0.3^{op}	27 ± 0.0^{no}	56.7 ± 0.3^{mn}	58.21 ± 0.43^{c}
		12	28 ± 0.0^{no}	27 ± 0.0^{no}	55 ± 0.0^{mn}	60.45 ± 0.43^{c}
	50	4	26 ± 0.0^{lm}	25 ± 0.0^{lm}	51 ± 0.0^{kl}	63.43 ± 0.43^{e}
		8	25 ± 0.0^{kl}	24 ± 0.0^{kl}	49 ± 0.7^{jk}	65.17 ± 0.25^{ef}
		12	23.7 ± 0.3^{kl}	22.7 ± 0.3^{jk}	46.3 ± 0.7^{ij}	66.67 ± 0.5^{fg}
	75	4	21.7 ± 0.3^{hi}	20.7 ± 0.3^{hi}	42.3 ± 0.7^{h}	70.4 ± 0.66^{hi}
		8	18.7 ± 0.3^{fg}	17.7 ± 0.3^{fg}	36.3 ± 0.7^{fg}	74.38 ± 0.25^{j}
		12	17.5 ± 0.3^{f}	16.5 ± 0.3^{f}	34 ± 0.6^{f}	76.87 ± 0.43^{l}
	100	4	14.5 ± 0.3^{de}	13.5 ± 0.3^{de}	28 ± 0.6^{de}	80.85 ± 0.25^{lm}
		8	11.5 ± 0.3^{c}	10.5 ± 0.3^{c}	22 ± 0.6^{c}	85.07 ± 0.43^{n}
		12	9.7 ± 0.3^{b}	8.7 ± 0.3^{b}	18.3 ± 0.7^{b}	88.56 ± 0.5^{o}
UC		0	79.3 ± 3^{e}	54.7 ± 2^{f}	134 ± 2^{g}	0 ± 1.14^{p}
M5%		0.05	0 ± 0.0^{a}	0 ± 0.0^{a}	0 ± 0.6^{a}	100 ± 0.00^{a}
Total			20.7±0.9	19.8±1.0	40.5±0.6	68.22±2.02
p ≤values			0.001	0.001	0.001	0.001
LSD0.05			22.88	22.19	25.63	7.41
CV%			3.53	3.72	3.43	4.3

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA (P ≤ 0.05) followed by Tukey`s test. LEC= Level of extraction concentration, UC= Untreated Control (ETOAc).
Source: Authors.

the two different plant species significantly (P<0.05) reduced the number of *S. zeamais*. The lowest concentration of the PTs used in this study (4 g) induced only 38% mortality within 14 days after *S. zeamais* were exposed to the powder. When the powder concentration was increased to 8 g, mortality increased to 53% within 14 days of the mortality study. This percentage of mortality gradually increased to 62% when the powder

Table 5. The mean number of *S. zeamais* emerged and the percent protection in *N. tabacum* leaf and *J. curcas* seed SEs of DCM.

Botanicals	LEC (%)	Dose (ml)	Mean number of F_1 progeny emerged			% IR
			14 days	28 days	Total	
	25	4	31 ± 0.0^{r}	29.3 ± 0.3^{r}	60.3 ± 0.3^{q}	53.7 ± 0.00^{b}
		8	29 ± 0.0^{pqr}	28.3 ± 0.3^{qr}	57.3 ± 0.3^{op}	56.2 ± 0.5^{cd}
		12	27.7 ± 0.3^{op}	26.3 ± 0.3^{opq}	54 ± 0.0^{mn}	58.7 ± 0.25^{ef}
	50	4	26.7 ± 0.3^{mn}	24.7 ± 0.3^{no}	51.3 ± 0.7^{l}	60.2 ± 0.5^{g}
		8	24 ± 0.0^{klm}	24 ± 0.0^{mn}	48 ± 0.0^{k}	62.4 ± 0.5^{h}
		12	23 ± 0.0^{jk}	23 ± 0.0^{lm}	46 ± 0.0^{jk}	64.4 ± 0.00^{hi}
N. tabacum						
	75	4	$2^{2}\pm0.0^{ij}$	21 ± 0.0^{k}	43 ± 0.0^{i}	66.9 ± 0.43^{j}
		8	19 ± 0.0^{gh}	17.3 ± 0.3^{ij}	36.3 ± 0.3^{g}	71.4 ± 0.43^{l}
		12	17 ± 0.0^{f}	16.3 ± 0.3^{hi}	33.3 ± 0.3^{f}	73.9 ± 0.00^{m}
	100	4	14.7 ± 0.7^{de}	13.3 ± 0.3^{fg}	28 ± 1.0^{e}	76.9 ± 0.5^{n}
		8	12.5 ± 0.3^{c}	11 ± 0.0^{de}	23.5 ± 0.3^{d}	80.9 ± 0.5^{o}
		12	9.5 ± 0.3^{b}	8.5 ± 0.3^{bc}	18 ± 0.6^{bc}	85.3 ± 0.5^{pq}
	25	4	30.5 ± 0.3^{qr}	29 ± 0.0^{r}	59.5 ± 0.3^{pq}	54.5 ± 0.25^{bc}
		8	28.7 ± 0.3^{opq}	27 ± 0.0^{pq}	55.7 ± 0.3^{no}	57.5 ± 0.5^{de}
		12	27 ± 0.0^{no}	25.7 ± 0.3^{nop}	52.7 ± 0.3^{lm}	59.0 ± 0.5^{fg}
	50	4	25 ± 0.0^{lm}	23.5 ± 0.5^{mn}	48.5 ± 0.5^{k}	61 ± 0.86^{h}
		8	24 ± 0.0^{lm}	23 ± 0.0^{mn}	47 ± 0.0^{jk}	63 ± 0.5^{hi}
		12	23.3 ± 0.7^{kl}	22 ± 0.0^{kl}	45.3 ± 0.7^{ij}	64 ± 0.5^{ij}
J. curcas						
	75	4	20.7 ± 0.3^{hi}	18.7 ± 0.3^{j}	39.3 ± 0.7^{h}	64 ± 0.5^{k}
		8	17.3 ± 0.3^{fg}	16.7 ± 0.3^{hi}	34 ± 0.0^{fg}	73 ± 0.00^{lm}
		12	16.5 ± 0.3^{ef}	15 ± 0.0^{gh}	31.5 ± 0.3^{f}	75 ± 0.5^{m}
	100	4	13.5 ± 0.3^{cd}	12 ± 0.0^{ef}	25.5 ± 0.3^{de}	79 ± 0.5^{no}
		8	10.5 ± 0.3^{b}	9.5 ± 0.3^{cd}	20 ± 0.6^{c}	83.3 ± 0.5^{p}
		12	8.7 ± 0.3^{b}	7.3 ± 0.3^{b}	16 ± 0.0^{b}	87.3 ± 0.86^{q}
UC		0	79.3 ± 3^{e}	54.7 ± 2^{f}	134 ± 2^{g}	0 ± 1.14^{a}
M5%		0.05	0 ± 0.0^{a}	0 ± 0.0^{a}	0 ± 0.0^{a}	100 ± 0^{a}
Total			19.9±1.0	18.8±1.0	38.5±1.9	66.9±2
p ≤values			0.001	0.001	0.001	0.001
LSD0.05			9.94	10.35	19.65	29.96
CV%			3.99	4.02	3.71	6.00

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA (P ≤ 0.05) followed by Tukey`s test., M5%= Malathion 5% dust, LEC= Level of extraction concentration, UC= Untreated Control (DCM).
Source: Authors.

concentration increased to 12 g. Only 47.3% of the *S. zeamais* mortality was recorded when the insects were exposed to the *J. curcas* seed powder at the study's lowest concentration (4 g) perished within 14 days. The 12 g powder concentration showed a mortality of 65.3% within 14 days of insects' exposure to the powder, while the 8 g powder concentration killed 56.7% of *S. zeamais* within the same 14 days (Table 7).

The percentage mortality recorded at 4, 8, and 12 g powder concentrations was significantly different for the

Table 6. The mean number of grain damage and grain weight loss caused by *S. zeamais* on maize grains treated with *N. tabacum* leaf and *J. curcas* seed SEs of ETOAc/DCM.

Botanicals	LEC (%)	Dose (ml)	Mean			
			ETOAc		DCM	
			% GD	% WL	% GD	% WL
		4	30±0.13^{u}	2.8±0.01^{t}	30±0.23^{t}	2.81±0.02^{t}
	25	8	28.4±0.00st	2.66±0.00^{rs}	28.4±0.23^{rs}	2.66±0.02^{rs}
		12	26.93±0.13^{qr}	2.52±0.01^{pqr}	26.67±0.27^{pq}	2.5±0.02^{pq}
		4	25.87±0.13^{opq}	2.43±0.00^{nop}	25.33±0.13^{op}	2.37±0.01^{op}
	50	8	24.53±0.13^{mno}	2.3±0.02^{lmk}	23.73±0.13^{mn}	2.22±0.01^{mn}
		12	23.2±23^{lm}	2.18±0.01^{kl}	22.4±0.23^{lm}	2.1±0.02^{lm}
N. tabacum						
		4	21.73±27^{jk}	2.04±0.01^{j}	20.8±0.23^{jk}	1.95±0.02^{jk}
	75	8	19.33±35^{i}	1.81±0.01^{i}	17.87±0.35^{i}	1.68±0.04^{i}
		12	17.2±23^{gh}	1.61±0.02^{gh}	16±0.23^{gh}	1.5±0.02^{gh}
		4	15.2±46^{f}	1.43±0.01^{f}	14±0.46^{f}	1.31±0.04^{f}
	100	8	12.53±0.13^{de}	1.17±0.00^{de}	11.07±0.27^{de}	1.04±0.03^{de}
		12	10±46^{c}	0.94±0.02^{c}	8.4±0.46^{c}	0.79±0.04^{c}
		4	29.2±0.00^{ty}	2.74±0.02st	29.2±0.23st	2.74±0.02st
	25	8	27.6±23^{rs}	2.59±0.04^{qr}	27.6±0.23^{rq}	2.59±0.02^{qr}
		12	26.27±013^{pqr}	2.47±0.02^{opq}	25.87±0.13^{op}	2.43^{op}±0.01^{op}
		4	25.07±0.13^{nop}	2.35±0.03^{mno}	24.4±0.23^{no}	2.29±0.02^{no}
	50	8	24±0.00^{mn}	2.25±0.01^{lm}	23.2±0.00^{mn}	2.18±0.00^{mn}
		12	22.4±0.23^{kl}	2.1±0.01^{jk}	21.6±0.23^{kl}	2.03±0.02^{kl}
J. curcas						
		4	20.93±0.27^{j}	1.96±0.04^{j}	19.6±0.23^{j}	1.84±0.04^{ij}
	75	8	18.27±0.13^{hi}	1.72±0.01^{hi}	16.8±0.23^{hi}	1.58±0.02^{hi}
		12	16.53±0.13^{fg}	1.55±0.04^{fg}	15.2±0.46^{fg}	1.43±0.02^{fg}
		4	13.73±0.48^{e}	1.29±0.04^{fg}	12.4±0.237^{e}	1.16±0.04^{e}
	100	8	11.33±0.27^{cd}	1.06±0.03^{cd}	9.73±0.46^{cd}	0.91±0.03^{cd}
		12	8.4±0.46^{b}	0.79±0.04^{b}	6.8±0.23^{b}	0.64±0.04^{b}
UC		0	66.27±0.00^{v}	5.88±0.00^{u}	66.27±0.00^{u}	5.88±0.00^{u}
M5%		0.05	0±0.00^{a}	0±0.00^{a}	0±0.00^{a}	0±0.00^{a}
Total			20.55±0.89	1.93±08	19.59±0.91	1.84±0.09
p ≤values			0.001	0.001	0.001	0.001
LSD0.05			24.89	24.77	23.85	23.94
CV%			3.78	3.8	4.45	4.49

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA (P ≤ 0.05) followed by Tukey`s test. LEC= Level of extraction concentration, GD= grain damage, WL= weight loss, UC= Untreated Control (ETOAc/DCM), M5%= Malathion 5% dust.
Source: Authors

duration of 1, 3, 5, 7, and 14 days following *S. zeamais'* introduction into the jars ($p<0.05$) (Table 7). Both *N. tabacum* leaf powder and *J. curcas* seed PTs were found to be very effective in insect mortality and adult

Table 7. The mean number of mortality of *S. zeamais* on maize grains treated with *N. tabacum* leaf and *J. curcas* seed PTs.

Botanicals	Dose (g)	Means					
		1 day	3 days	5 days	7 days	14 days	Total
N. tabacum	4	2±0^{ab}	4.7±1^{ab}	6.7±1^{ab}	8±1^{ab}	16.7±1^{ab}	38±1^{b}
	8	2±0^{ba}	12.7±3^{bc}	9.3±3^{c}	13.3±4^{c}	16±3^{ab}	53.3±1^{cd}
	12	0.7±1^{c}	16.7±2^{c}	12.7±4^{c}	15.3±2^{c}	16.7±6^{c}	62±2^{ef}
J. curcas	4	1.3±1^{abc}	7.3±1^{abc}	11.3±1^{c}	12.7±2^{c}	14.7±3^{c}	47.3±3^{c}
	8	0.7±1^{c}	15.3±5^{c}	8±2^{ab}	12.7±5^{c}	20±4^{c}	56.7±1de
	12	2±0^{c}	16.7±1^{c}	9.3±1^{c}	18±5^{c}	19.3±5^{c}	65.3±1^{f}
UC	0	0±0^{ab}	4.7±1^{ab}	5.3±1^{ab}	6±0^{ab}	14±2^{ab}	30±0^{a}
M5%	0.05	100±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}	100±0^{g}
Total		13.6±7	9.8±1	7.8±1	10.8±1	14.7±2	56.6±4
p ≤values		0.001	0.001	0.006	0.003	0.019	0.001
LSD0.05		41.6	11.4	8.8	12	16.8	25.7
CV%		84.8	34.1	35.8	32.5	36.3	6.9

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA (P ≤ 0.05) followed by Tukey`s test. UC= Untreated Control, M5%= Malathion 5% dust
Source: Authors

Table 8. The mean number of F_1 progeny of *S. zeamais* produced and the percent protection of *N. tabacum* leaf and *J. curcas* seed PTs of maize grains.

Botanicals	Dose (g)	Mean number of F_1 progeny emerged			
		14 days	28 days	Total	% IR
N. tabacum	4	53.3±1^{d}	52.7±3^{ef}	106±2^{f}	20.9±2^{b}
	8	50±4^{cd}	36.7±3^{cd}	86.7±6de	35.32±5^{cd}
	12	35±3^{b}	32±1^{bc}	67±2^{bc}	50±2^{ef}
J. curcas	4	50.7±1^{cd}	44±2de	94.7±2^{ef}	29.35±2^{bc}
	8	41.3±2^{bc}	35±1^{bcd}	76.3±1^{cd}	43.03±1de
	12	30.7±2^{b}	27±2^{b}	57.7±1^{b}	56.97±1^{f}
UC	0	79.3±3^{e}	54.7±2^{f}	134±2^{g}	0±1^{a}
M%	0.05	0±0^{a}	0±0^{a}	0±0^{a}	100±0^{g}
Total		42.5±5	35.3±3	77.8±8	41.95±6
LSD0.05		9.69	8.8	12.	12.
p ≤values		0.001	0.001	0.001	0.001
CV%		14.01	13	3.8	67.43

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA (P ≤ 0.05) followed by Tukey`s test. UC= Untreated Control, M5%= Malathion 5% dust.
Source: Authors.

emergence. The toxicity of these plant powders increased as the dosage and duration of exposure increased. *J. curcas* seed PTs were more toxic than *N. tabacum* leaf PTs to insects (Table 7).

Table 8 shows the mean number of F_1 progeny of *S. zeamais* that emerged from *N. tabacum* leaf and *J. curcas* seed PTs at different concentration doses. When maize was treated with *N. tabacum* leaf PTs at doses of 4 to 12 g, 106 to 67 adult *S. zeamais* were produced. Conversely, when maize was treated with *J. curcas* seed

Table 9. Mean numbers of percent grain damage, weight loss, and germination caused by *S. zeamais* on maize grains treated with *N. tabacum* leaf and *J. curcas* seed powders.

Botanicals	Dose (g)	Mean		
		% GD	% WL	% Germination
N. tabacum	4	42.67±0.67^{d}	4.35±4.11^{f}	57.6±0.8^{b}
	8	24.53±4.21^{c}	2.71±0.11^{f}	75.87±4.2^{c}
	12	14.4±2.27^{bc}	1.67±0.01^{bc}	85.87±2.2^{cd}
J. curcas	4	27.47±4.5^{c}	3.36±0.41^{c}	72.8±4.2^{c}
	8	24.53±4.39^{c}	2.31±0.3^{c}	75.9±4.4^{c}
	12	9.6±1.4^{ab}	1.36±0.27^{ab}	90.8±1.4^{de}
UC	0	66.27±0^{e}	5.88±0.1^{e}	34.13±0.27^{a}
M5%	0.05	0±0.27^{e}	0±0.00^{a}	100±0.0^{e}
Total		26.18±00	2.71±0.36	74.12±4.1
p≤values		0.001	0.001	0.001
LSD0.05		6.88	8.78	6.82
CV%		27.78	17.49	7.57

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA **(P ≤** 0.05) followed by Tukey`s test. GD= grain damage, WL= weight loss, UC= Untreated Control. M5%= Malathion 5% dust.
Source: Authors.

PTs, 94.7 to 57.7 adult *S. zeamais* were produced using *N. tabacum* leaf PTs (Table 8). At high doses, both *N. tabacum* leaf and *J. curcas* seed PTs significantly reduced *S*. *zeamais* emergence.

Compared to grains treated with *J. curcas* seed powder, grains treated with *N. tabacum* leaf powder had the highest number of F_1 progeny on the 14th day. At a dose of 4 to 12 g, 53.3 to 35 adults of *S. zeamais* were recorded. At the same dose, however, 50.7 to 30.7 adults of *S. zeamais* were found. For the next 28 days, the outcome followed the same pattern. The untried (control) group produced the most F_1 *S. zeamais* (134), followed by *N. tabacum* leaf powder at a dose of 4 g (106) adults (Table 8).

When the efficacy of the two plants was compared after 28 days, the maize grains treated with *J. curcas* seed powder produced the fewest F_1 *S. zeamais*. In general, *N. tabacum* leaf powder was less effective than *J. curcas* seed powder.

Table 9 shows the mean percentage of grain damage, weight loss, and germination caused by *S. zeamais* on maize grains treated with *N. tabacum* leaf and *J. curcas* seed powders at different concentration doses. The assessment of grain damage showed that grains treated with *N. tabacum* leaf powder were most damaged (14.4-42.67%), whereas the least damaged grains were those treated with *J. curcas* seed powder (9.6-27.47%).

After the untreated control, the percentage of seed weight loss of maize grain treated with *N. tabacum* leaf powder (4.35% at 4 g treatment and 1.67% at 12 g treatment) was the second highest number of weight losses. On the other hand, this result significantly differed from the grain weight loss recorded on grains treated with *J. curcas* seed powder (3.36% at 4 g treatment and 1.36% at 12 g treatment). Both results were statistically different from untreated seeds (the control), which recorded a weight loss of 5.88%.

The percentage germination of maize grains treated with *J. curcas* seed powder (72.8% at 4 g, 75.9 at 8 g, and 90.8% at 12 g) was significantly higher than seeds treated with *N. tabacum* leaf powder at all dose rates (57.6% at 4 g, 75.87 at 8 g, and 85.87% at 12 g). *N. tabacum* leaf and *J. curcas* seed powders had a significant effect on maize seeds germination compared with the control group (Table 9).

DISCUSSION

The current study showed that both leaf and seed solvent extracts of DCM and ETOAc had the strongest protective capacity against insects. They caused mortality and a complete reduction of *S. zeamais* F_1 progeny. These results agree with Kavallieratos et al. (2023), who reported that in grains treated with *J. curcas* L. oil (Euphorbiaceae), there was a lower emergence of *S. oryzae* and *Ephestia küehniella* Zeller (Lepidoptera: Pyralidae) compared with untreated grains. The high

concentration of phenol ester in the seeds may explain the superior biocidal activity of *J. curcas* oil extracts (Saosoong et al., 2016). Application of the extracts directly was more efficient since extract molecules are absorbed by insects' integuments, affecting their central nervous system and leading to their death (Ubulom et al., 2021).

Nicotine quickly kills insects, causing intense tremors, convulsions, and paralysis. It competes with the major neurotransmitter, acetylcholine, by binding to acetylcholine receptors at nerve synapses and causing uncontrolled nerve firing (Kanmani et al., 2021). Nicotine, as an alkaloid, disrupts biological membranes, malfunctions internal organs and metabolism, redox imbalance, disruptions in insect development and reproduction, and inhibition of food intake (El-Wakeil, 2013; Akbar et al., 2022).

Grain weight loss is an indicator of insect pest damage during storage (Ngom et al., 2020). A small weight loss of grains was observed when maize was treated with *J. curcas* seed and *N. tobacum* leaf SEs and powder formulations. The plant materials demonstrated excellent protection against maize damage caused by *S. zeamais*. Temitope (2014) found seed SEs of *J. curcas* exhibited antifeedant and grain protectant effects, producing excellent results against *S. zeamais.* Likewise, Viteri-Jumbo et al. (2018) and Idoko and Ileke (2020) showed that sub-lethal doses of essential oil significantly reduced grain damage since oviposition rates were reduced.

This study revealed that the number of *S. zeamais* present was related to maize grain weight losses. This means that because the majority of weevils died shortly after introduction, there was less adult emergence in seeds treated with SEs and powder formulations. In addition, feeding activities were reduced, and thus fewer weight losses were recorded. The present results are in agreement with Gariba et al. (2021) findings in which less progeny and grain weight loss were recorded in maize grains treated with 0.05 and 0.1 g/mL organic extracts of *Lantana camara*, *Hyptis suaveolens, Citrus sinensis*, and *Moringa oleifera*. In addition to their toxicity, the botanicals' chemical constituents may have inhibited weevil feeding on the treated maize grains, thereby protecting the grains from damage (Oboho et al., 2016).

Overall, the results showed that treating maize with *N. tabacum* leaf and *J. curcas* seed powders and SEs at the majority of the investigated dosages reduced the emergence of *S. zeamais*, decreased weight loss, and reduced seed damage. So, because these plant resources are inexpensive, readily available, simple and safe to use, farmers should be encouraged to use them to control *S. zeamais.* They should also protect stored maize.

Conclusion

For a long time, plant materials, crude organic plant extracts, and essential oils have been used to protect crops from insect pests. This is due to the fact that these plant-based products are very promising, generally available, economical, and simple to produce and apply to grains. They are non-toxic to non-target organisms and have a specific mode of action. Based on the findings of the present study, it can be concluded that *N. tabacum* leaves and *J. curcas* seeds SEs of ETOAc and DCM could be used for the control of *S. zeamais* under farmers' storage conditions. Hence, farmers are advised to utilize native plant organic extracts to control *S. zeamais* and safeguard stored maize. Further studies to isolate pure compounds from *N. tabacum* leaf and *J. curcas* seed organic extracts and determine the mode of action are suggested.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors appreciate the contribution of the Bako National Maize Research Centre and the facilities offered for the experiment's success.

REFERENCES

Abdelgadir HA, Staden JV (2013). Ethnobotany, ethnopharmacology and toxicity of *Jatropha curcas* L. (Euphorbiaceae): A review. South African Journal of Botany 88:204-218.

Aboalola DM, Weli AM, Hossain MA,Touby SA (2020). Toxicological study of various crude extracts of Hyoscyamus gallagheri native to Oman. Toxicology Reports 29:680-684. doi: 10.1016/j.toxrep.2020.05.004.

Akbar R, Khan IA, Alajmi RA, Ali A, Faheem B, Usman A, Ahmed AM, El-Shazly M, Farid A, Giesy JP (2022). Evaluation of insecticidal potentials of five plant extracts against the stored grain pest, *Callosobruchus maculatus* (Coleoptera:Bruchidae). Insects 13(11):1047. https://doi.org/10.3390/ insects13111047

Bhusal K, Khanal D (2019). Role of maize weevil, *Sitophilus zeamais* on spread of Aspergillus section flavi in different Nepalese maize varieties. Advances in Agriculture pp. 1-5.

Cordova-Albores LC, Bautista-Banos S, Barrera-Necha LL, Salvador-Figueroa M, Adriano-Anaya L, Ovando-Medina I (2016). Physic nut (*Jatropha curcas*) extracts and active compounds with biological activity against pest insects and pathogenic fungi. In: The Promising Future *of Jatropha curcas*. Ed: Maira R. Segura-Campos et al., Nova Science Publishers, Inc.

Danga SPY, Nukenine EN, Fotso GT, Adler C (2015). Use of NeemPro®, a neem product to control maize weevil *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae) on three maize varieties in Cameroon. Agriculture and Food Security 4:1-7. DOI 10.1186/s40066-015-0039-z

Eisa SMA, Hamid HA, Ishag AES (2020). Jatropha (*Jatropha curcas*) and Argel (*Solenostemma argel*) extracts as an oviposition inhibitor to Spiny Bollworm [*Earias insulan*a (Lepidoptera: Noctuidae)]. International Journal of Life Sciences Research 8(1):5-11.

El-Wakeil NE (2013). Retracted article: Botanical pesticides and their mode of action. Gesunde Pflanzen 70(2):115-115. https://doi.org/10.1007/s10343-013-0308-3

Gariba SG, Dzidzienyo DK, Eziah VY (2021). Assessment of four plant

extracts as maize seed protectants against *Sitophilus zeamais* and *Prostephanus truncatus* in Ghana. Cogent Food and Agriculture 7(1):1918426.

George DR, Finn RD, Graham KM, Olivier AE (2014). Present and future potential of plant-derived products to control arthropods of veterinary and medical significance. Parasites and Vectors 7(1):1-12.

Gitahi SM, Piero MN, Mburu DN, Machocho AK (2021). Repellent effects of selected organic leaf extracts of *Tithonia diversifolia* (Hemsl.) A. Gray and *Vernonia lasiopus* (O. Hoffman) against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). Scientific World Journal 2021:1-13 https://doi.org/10.1155/2021/2718629

Goldel B, Lemic D, Bazok R (2020). Alternatives to synthetic insecticides in the control of the Colorado potato beetle (*Leptinotarsa decemlineata* Say) and their environmental benefits. Agriculture 10(12):611.

Grzywacz D, Stevenson PC, Mushobozi WL, Belmain S, Wilson K (2014). The use of indigenous ecological resources for pest control in Africa. Food Security 6:71-86.

Hiruy B, Getu E (2020). *Militia feruginaea* solvent extracts on maize weevils and red flour beetles repellency; an implication to use them in storage pest management in Ethiopia, Cogent Food and Agriculture 6(1):1-16: DOI: 10.1080/23311932.2020.1860562

Idoko JE, Ileke KD (2020). Comparative evaluation of insecticidal properties of essential oils of some selected botanicals as bio-pesticides against Cowpea bruchid, *Callosobruchus maculatus* (Fabricius) [Coleoptera: Chrysomelidae]. Bulletin of the National Research Centre 44(1):119 https://doi.org/10.1186/s42269-020-00380-2

Ileke KD, Bulus DS (2012). Response of lesser grain borer, *Rhizopertha dominica* (Fabr.) (Coleoptera: Bostrichidae) to powders and extracts of *Azadirachta indica* and *Piper guineense* seeds. Jordan Journal of Biological Sciences 5(4):315-320.

Iqbal T, Ahmed N, Shahjeer K, Ahmed S, Al-Mutairi KA, Khater HF, Ali RF (2021). Botanical insecticides and their potential as anti-insect/pests: Are they successful against insects and pests? In (ed.), Global decline of insects. Intech Open. doi.org/10.5772/intechopen.100418y

Kandel P, Khare K, Njoroge A, Smith BW, Diaz-Valderrama JR, Timilsina RH, Paudel GP, Baributsa D (2021). On-farm grain storage and challenges in Bagmati Province, Nepal. Sustainability 13(14):7959. https://doi.org/10.3390/su13147959

Kanmani S, Kumar L, Raveen R, Tennyson S, Arivoli S, Jayakumar M (2021). Toxicity of tobacco *Nicotiana tabacum* Linnaeus (Solanaceae) leaf extracts to the rice weevil *Sitophilus oryzae* Linnaeus 1763 (Coleoptera: Curculionidae). The Journal of Basic and Applied Zoology 82(2):10. https://doi.org/10.1186/s41936-021-00207-0

Kavallieratos NG, Bonacucina G, Nika EP, Skourti A, Georgakopoulou SKC, Filintas CS, Panariti AME, Maggi F, Petrelli R, Ferrati M (2023). The type of grain counts: effectiveness of three essential oil-based Nanoemulsions against *Sitophilus oryzae*. Plants 12(4):813. https://doi.org/10.3390/ plants12040813

Khan A, Islam Md S, Rahman M, Zaman T, Haque Md E (2014). Pesticidal and pest repellency activities of a plant derived triterpenoid 2α,3β,21β,23,28-penta hydroxyl 12-oleanene against *Tribolium ca*staneum. Biological Research 47(1):68. doi: 10.1186/0717-6287-47-68

Kidane D (2011). The Potential of Orange (*Citrus sinensis* L.) peel oil as a fumigant and repellent to control maize weevil (*Sitophillus zeamais* Motsch). Journal of Biologically Active Products from Nature 1(3):193-199. DOI: 10.1080/22311866.2011.10719086

Ngom D, Fauconnier ML, Malumba P, Dia CAKM, Thiaw C, Sembène M (2020). Varietal susceptibility of maize to larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera; Bostrichidae), based on grain physicochemical parameters. PLoS One 15(4):e0232164. https:// doi.org/10.1371/journal.pone.0232164

Njoroge AW, Affognon HD, Mutungi CM, Manono, Lamuka PO, Murdock LL (2014). Triple bag hermetic storage delivers a lethal punch to *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in stored maize. Journal of Stored Products Research 58:12-19. http://dx.doi.org/10.1016/j.jspr.2014.02.005

Oboho D, Eyo J, Ekeh F, Okweche S (2016). Efficacy of *Cymbopogon citratus* Stapf leaf extract as seeds protectant against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) on stored maize (*Zea mays*). Journal of Biological Control 30(4):220-225. DOI: 10.18311/jbc/0/15540

Oseni OA, Akindahunsi AA (2011). Some phytochemical properties and the effect of fermentation on the seeds of *Jatropha curcas*. American Journal of Food Technology 6(2):158-165. DOI: 10.3923/ajft.2011.158.165

Prommaban A, Kheawfu K, Chittasupho C, Sirilun S, Hemsuwimon K, Chaiyana W (2022). Phytochemical, antioxidant, antihyaluronidase, antityrosinase, and antimicrobial Properties of *Nicotiana tabacum* L. leaf extracts. Hindawi Evident Based Complement Alternate Medicine Article ID 5761764. doi: 10.1155/2022/5761764.

Rao NS, Marwaha S, Ravisankar H, Sivaraju K, Saha A, Deb CK (2016). Expert system for the identification of diseases in tobacco (*Nicotiana tabacum*). Journal of Basic and Applied Engineering Research 3(6):561-563.

Saosoong K, Litthanapongsatorn I, Ruangviriyachai C (2016). Antioxidant activity of the extracts from *Jatropha curcas* fruit and its correlation with total phenolic content. Oriental Journal of Chemistry 32(2):1121-1127. DOI: 10.13005/ojc/320237

Shiferaw B, Prasanna BM, Hellin J, Banziger M (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Journal of Food Security 3(3**)**:307-327. DOI: 10.1007/s12571-011-0140-5

SPSS (2016). SPSS Statistics for Windows, Version 26.0 (IBM Corp.). New York, United States.

Talská R, Machalová J, Smýkal P, Hron K (2020). A comparison of seed germination coefficients using functional regression. Applications in Plant Sciences 8(8):e11366. doi: 10.1002/aps3.11366.

Tandzi LN, Mutengwa CS (2019). Review: estimation of maize (*Zea mays L*.) yield in the harvest area: Appropriate methods. Agronomy 10(1):29. https://doi.org/10.3390/agronomy10010029

Tavares WR, Barreto MDC, Seca AML (2021). Aqueous and ethanolic plant extracts as bio-insecticides establishing a bridge between raw scientific data and practical reality. Plants 10(5):920. https://doi.org/10.3390/ plants10050920

Temitope OO (2014). Evaluation of the powder of three medicinal botanicals in the control of maize weevil, *Sitophilus zeamais* Motschulsky. Nature and Science 12(11):184-190.

Ubulom PME, Yaro CA, Udoh UAP (2021). Repellency and insecticidal properties of seed oil of *Jatropha curcas* L. against American cockroach, *Periplaneta Americana*. The Journal of Basic and Applied Zoology 82:1-8. https://doi.org/10.1186/s41936-021-00208-z

Viteri-Jumbo LO, Haddi K, Faroni LRD, Heleno FF, Pinto FG, Oliveira EE (2018). Toxicity to, oviposition and population growth impairments of *Callosobruchus maculatus* exposed to clove and cinnamon essential oils. PLoS One 13(11):e0207618. doi: 10.1371/journal.pone.0207618.

Weber S, Kaminski KP, Perret JL, Leroy P, Mazurov A, Peitsch MC, Hoeng J (2019). Anti-parasitic properties of leaf extracts derived from selected Nicotiana species and *Nicotiana tabacum* varieties. Food and Chemical Toxicology 132:110660. doi:10.1016/j.fct.2019.110660