INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
21–0585/2021/26–5–617–624
DOI: 10.17957/IJAB/15.1874
http://www.fspublishers.org

*Full Length Article*

# Bioactivity of Hexane Plant Extracts against Maize Weevil (*Sitophilus zeamais* Motschulsky) (Coleoptera: Curculionidae) on Stored Maize

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*Received 17 May 2021; Accepted 30 August 2021; Publishers 15 November 2021*

## Abstract

The maize weevil (*Sitophilus zeamais* Motschulsky) causes considerable post-harvest damage to stored grains, which leads to severe qualitative and quantitative losses. The control of maize weevil has mainly relied on the repeated use of chemical insecticides, which pose serious threats to human and environmental health. Plant products can be used as safe alternatives to traditional chemical insecticides; therefore, this study investigated the biological activities of crude hexane extracts of plant materials *viz.* seeds of neem tree (*Azadirachta indica*), succulent fruits of Bitter cress (*Caralluma turberculata*) and Tumha (*Citrullus colocynthis*), rhizomes of Garlic (*Allium sativum*) and Turmeric (*Curcuma longa*) and leaves of Ak plant (*Calotropis procera)* against maize weevil. The hexane plant extracts (HPE) were tested at six concentrations of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% (v /w), respectively, under constant laboratory conditions of 27 ± 2°C, 65 ± 2% R.H. The experiment was arranged in a completely randomized design in five replicates. Parameters such as days to adult emergence, total $F_1$ adult emergence, percentage infestation and grain weight loss, sex ratio and life span of $F_1$ adults were recorded during experimentation. The results revealed that all the tested hexane plant extracts had significant effect on the biology of maize weevil. However, hexane extracts of *A. indica* and *C. longa* at the maximum concentration of 3% performed significantly better showing the least percent infestation (1.74 and 2.22%), minimum weight loss (0.72 and 1.03%), less adult emergence (7.00 and 9.80) and maximum duration to $F_1$ emergence (59.40 and 54.40 days). It is, therefore, concluded that the hexane extracts of *A. indica* and *C. longa* may be used for the timely management of maize weevil. 

**Keywords:** Botanicals; Hexane plant extracts; *Sitophilus zeamais*; Biological effects

## Introduction

Maize (*Zea mays* L.) being one of the world's leading cereal crops after wheat and rice; is the only crop that is consumed from flower to flour (Boutard 2012). It is an important source of carbohydrates, vitamins, iron, proteins and minerals for human being, poultry feed and livestock fodder and is a source of raw material for many vital food industries in developed countries (Shiferaw *et al.* 2011; Kumar and Jhariya 2013). According to an estimate by FAO, the maize crop will become the biggest cereal crop in the world by 2050 (Rosegrant *et al.* 2009). Post-harvest storage insect pests cause heavy losses to cereal grains and in most cases also encourage the development of fungal and bacterial diseases (Dubey *et al*. 2010; Phillips and Throne 2010; Prusky 2011; Tefera *et al.* 2011; Rajashekar *et al.* 2012).

The maize crop is attacked by many insect pests during storage. Among the insect pests, the maize weevil (*Sitophilus zeamais* Motschulsky) is the most destructive pest of stored maize (Lopez *et al*. 2008). Being a primary pest, it attacks and destructs intact grains. The female lays eggs inside the grains and then conceals it with a gelatin material. The larvae of maize weevil feed and develop inside the grain kernels (Ojo and Omoloye 2012). The pupae develop inside the grains and an adult emerges by making a hole in the damaged grain, thus rendering the damaged grains unfit for human consumption or planting purposes (Lopez *et al.* 2008; Ojo and Omoloye 2016). The damage caused by maize weevil ranges from 20–30% in the tropical regions (Yigezu *et al.* 2010; Sharma *et al.* 2016). In previous studies, the maize weevil (*Sitophilus zeamais*) was found as the most abundant species infesting stored maize in Pakistan. The post-harvest storage insect pests caused

37.51% grain damage and 33.23% weight losses (Mamoon-ur-Rashid *et al.* 2016). It is a highly polyphagous pest of stored cereal grains due to its potential of cross infestation, higher biotic potential, power of invading big masses of stored grains, high number of host cereal grains, and the fact that both larvae and adult can damage the grains (Gallo *et al.* 2002; Nwosu 2018). Currently, its control mainly relies on the repeated use of synthetic insecticides such as fumigation with phosphine gas (Olakojo and Akinlosotu 2004; Nwosu *et al.* 2016). However, continuous application of phosphine has caused resistance in insects; resurgence of the pests and residual toxicity in stored grains (Shaaya and Kostyukovsky 2006; Isman 2006; Koul *et al.* 2008). Realizing the negative impacts of chemical insecticides, the scientists are therefore, working on the use of plant products which are cheaper, sustainable and environmentally friendly for saving stored grains from infestation by these obnoxious insect pests (Yohannes *et al.* 2014; Tilahun and Daniel 2016).

Bio-pesticides have considerable advantages over synthetic insecticides in terms of their high selectivity, lesser toxicity, rapid natural degradation and environmental friendliness for ensuring food safety, human and environmental health (Ukeh *et al.* 2009; Huang *et al.* 2011; Zibaee and Stoytcheva 2011). In plant kingdom, variety of botanical insecticides have been successfully synthesized and commercialized, however neem and turmeric are considered most versatile carrying strong repellent, toxic and growth inhibition properties against variety of insect pests (Tripathi *et al.* 2002; Wagner *et al.* 2013; Ali *et al.* 2014; Mobolade and Ewete 2014; Castillo-Sánchez *et al.* 2015; Mariano *et al.* 2017).

The extraction quality and quantity of different phytochemicals present in different parts of botanicals depends on the type of plant material and solvent used. It has been documented in various studies that organic solvents having high polarity yield higher quantity of phytochemicals compared to low-polarity solvents (Dai *et al*. 2016; Khaw *et al*. 2017). Similarly, the level of toxicity of these phytochemicals also depends on the part of the plant used, chemical nature of the extracts, the extraction technique and conditions (Suteu *et al*. 2020).

The current studies were conducted with the objectives to find out the effectiveness of six crude plant extracts using hexane as an extraction solvent carrying potential biological effects and to compare their efficacy against maize weevil.

## Materials and Methods

The studies were conducted to investigate the bio-efficacy of crude hexane plant extracts against maize weevil.

### Insect culture

The stock colonies of maize weevil, *S. zeamais* were obtained from the laboratory of Entomology section, Agricultural Research Institute, Dera Ismail Khan, Pakistan. The mixture of 200 female and male adults were cultured on 500g of maize grains at the moisture content of 12–14%. The jars were shifted to an incubator (Versatile Environment test Chamber, Sanyo Japan, Model-MLR-350 H) for 10 days at 28°C, 65 ± 5% R.H. and a photoperiod of 12:12 (L:D) h. After 10 days, the parent insects were removed via sieving and shifted to new jars for further multiplication. After 20 days, jars containing the infested grains and emerged adult weevils were collected in separate jars according to their age. The adult weevils that emerged on the same day were considered of the same age and were used for the subsequent investigations.

### Plant materials collection, preparation and extraction

All the six plant materials such as seeds of neem tree (*Azadirachta indica* L.), succulent fruits of Bitter cress (*Caralluma turberculata* Ait.) and Tumha (*Citrullus colocynthis* L.), rhizomes of Garlic (*Allium sativum* L.) and Turmeric (*Curcuma longa* L.) and leaves of Ak plant (*Calotropis procera* Ait.*)* were obtained from the local market. The collected plants were thoroughly washed, dried at room temperature (28°C) under shade conditions and ground to make uniform size powder by sieving through a 0.2 mm mesh sieve.

The hexane extracts of selected plant powders were prepared by following Okoye and Osadebe (2009). The powdered material (300 g) of each plant product was dissolved in the hexane at the ratio of (1:1). The stirring process of the solution was done on hourly basis in the laboratory of the Entomology Department, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan. The maceration process was continued for seven days for the solvent (hexane). All the extracts were filtered through a muslin cloth and then passing through a Whatmen No. 1 filter paper. The collected filtrate was concentrated near to dryness using a rotary evaporator. The obtained crude extracts were then stored in a refrigerator until used for subsequent experimentation. The extracts were accurately weighed using a digital balance. The crude extracts were then further added into 3 mL of hexane and mixed in maize seeds in transparent jars. All the treated samples were then kept for 5 h to ensure the complete evaporation of hexane solvent before introducing the adult maize weevils in the plastic jars.

### Experimental protocol

The experiment was laid out in a completely randomized design (CRD) with five replications. The hexane plant extracts (HPE) were tested at six concentrations of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0%. The hexane plant extracts were mixed with maize seeds (Cultivar: Azam white) in transparent plastic jars. The contents of jars were strongly shaken prior to the introduction of weevils. After one hour of the treatment, maize grains (20 grams) with HPE, 20 adult weevils (ten pairs) were introduced in each jar. Adult maize weevils were sexed by their dimorphic rostrum characteristics and by the distinctive shapes and lengths of their abdomens (Halstead 1963). The weevils were starved for an hour before releasing on the treated maize grains. After 20 days, each jar having infested grains were carefully monitored on daily basis to record data regarding days to emergence of adult weevils. The newly emerged weevils were removed from the jars on daily basis. At 45 days, after release of parent insects, the data was recorded on the total number of weevils emerged.

The percent-infested grains were calculated after 45 days of the treatment by counting the infested and sound grains using the following formula (Enbakhare and Law-Ogbomo 2002):

$$\text{Infestation \%} = \frac{Nb}{Tn} \times 100$$

Where, $N_b$ = Number of infested seeds, $T_n$ = Total number of seeds

The grain weight loss (GWL) was calculated using the formula (Zunjare *et al*. 2015):

$$\text{\% weight loss} = \frac{\text{Initial grain weight} - \text{final grain weight}}{\text{Initial weight of grains}} \times 100$$

For adult longevity, the newly emerged adult maize weevil (♂: ♀) were cultured in separate plastic jars. The newly emerged adult weevil, 40 insects (20 pairs) for each treatment along with fresh grains for feeding and oviposition purposes were shifted into separate jars. After every 15 days, the maize grains were changed to prevent the emergence of $F_2$ generation. The mortality of weevils was recorded and dead insects were removed on daily basis until the 100% mortality. The adult sex ratio was calculated as number of males emerged per 50 females during the investigation period.

### Statistical Analysis

The collected data were subjected to one-way analysis of variance (ANOVA) and Least Significance Difference (LSD) Test was applied to compare the differences between treatment means at 5% level of significance. All the statistical analysis was carried out by using computer software (STATISTIX version 8.1).

## Results

### Days to emergence of $F_1$ adults

All the tested hexane plant extracts (HPE) had a significant effect ($P < 0.05$) on the developmental period of *S. zeamais* as compared to control. The tested plant materials prolonged the developmental duration of maize weevil (Table 1). The plant extracts of *A. indica* and *C. longa* were found most effective compared to other treatments. The maximum developmental duration of 59.40 and 54.40 days was recorded in the maize grains treated with the maximum concentration (3%). The plant extracts of *C. procera* and *C. colocynthis* were found minimum effective showing 44.40 and 47.40 days, respectively developmental duration at the same concentration. Among the tested concentrations, the maximum concentration of 3% was the most effective whereas; the lowest concentration of 0.5% was found least effective. The minimum developmental duration of 25.80 days was recorded when maize weevil was reared on untreated maize grains (control).

### Total number of $F_1$ adults emerged

The data on the effect of HPE on the $F_1$ adult emergence of *S. zeamais* revealed significant differences among the treatments as compared to control (Table 2). All the evaluated extracts caused a significant reduction in the progeny emergence compared with control treatment, which was dose-dependent. The extracts of *A. indica* and *C. longa* were found most effective at the maximum concentration (3%) and significantly reduced the total number of $F_1$ adult's emergence (7.00 and 9.80) from treated maize grains. A gradual decrease in the adult emergence of *S. zeamais* was noted by increasing the concentration of tested plant materials. Among the treatments, the extracts of *C. procera* and *C. colocynthis* were found least effective showing 24.60 and 20.20 number of adult emergences as compared to control (89.00) at the maximum concentration of 3%.

### Percent infestation

All the tested HPE significantly inhibited the grain damage caused by *S. zeamais*, with the treated grains showing a smaller number of damaged grains than the control. The total number of infested/damaged grains in different treatments decreased significantly by increasing the concentration of different treatments. Among the treatments, the effect of *A. indica* and *C. longa* extracts on reducing the number of damaged maize grains was more pronounced showing 1.74 and 2.22% infested grains at the maximum concentration of 3% compared to other treatments and control. The lowest concentration of 0.5% of *A. indica* and *C. longa* hexane extracts resulted in 3.97 and 5.80% damaged grains. The comparison between the different treatments depicted that the extracts of *C. procera* and *C. colocynthis* were found least effective in reducing the number of damaged maize grains showing 7.62 and 8.52% infested grains at the maximum concentration (3%). Comparing the different concentrations with one another, the maximum concentration of 3% was more effective in reducing the number of damaged maize grains compared to other tested concentrations (0.5, 1.0, 1.5. 2.0 and 2.5%).

**Table 1:** Days to F1 (± SD) adult emergence of maize weevil cultured on maize grains treated with different concentrations of hexane plant extracts

| Treatments | Concentrations (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| *Azadirachta indica* | 20.00 ± 0.70 g | 18.40 ± 0.89 g | 11.40 ± 1.34 f | 9.40 ± 1.34 g | 8.80 ± 1.09 g | 7.00 ± 0.70 g |
| *Caralluma turberculata* | 33.40 ± 0.89 e | 25.40 ± 1.14 e | 22.40 ± 0.89 d | 17.40 ± 0.89 e | 13.20 ± 0.44 e | 11.40 ± 0.54 e |
| *Allium sativum* | 37.40 ± 1.51 d | 28.20 ± 0.83 d | 24.40 ± 1.51 d | 19.00 ± 0.70 d | 16.40 ± 0.89 d | 14.20 ± 0.44 d |
| *Curcuma longa* | 22.40 ± 0.89 f | 20.40 ± 0.89 f | 16.40 ± 0.89 e | 12.40 ± 0.89 f | 11.20 ± 0.83 f | 9.80 ± 0.83 f |
| *Citrullus colocynthis* | 40.40 ± 0.89 c | 30.40 ± 1.51 c | 31.20 ± 0.44 c | 24.60 ± 0.54 c | 21.40 ± 0.89 c | 20.20 ± 0.44 c |
| *Calotropis procera* | 50.00 ± 1.41 b | 55.40 ± 0.89 b | 41.80 ± 1.48 b | 32.40 ± 0.54 b | 25.00 ± 1.22 b | 24.60 ± 0.54 b |
| Control | 89.00 ± 1.00 a | 89.00 ± 1.00 a | 89.00 ± 1.00a | 89.00 ± 1.00 a | 89.00 ± 1.00 a | 89.00 ± 1.00 a |
| LSD Value | 1.26 | 1.16 | 2.22 | 1.03 | 1.12 | 0.87 |

Mean ± standard deviation. Column means having different letters are significantly different at 5% level of significance.

**Table 2:** Mean total number (± SD) of $F_1$ adults emerged from maize grains treated with different concentrations of hexane plant extracts

| Treatments | Concentrations (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| *Azadirachta indica* | 54.40 ± 0.89 a | 55.40 ± 0.89 a | 56.40 ± 0.89 a | 57.40 ± 0.83 a | 58.40 ± 0.89 a | 59.40 ± 0.89 a |
| *Caralluma turberculata* | 45.40 ± 0.89 c | 46.40 ± 0.89 c | 47.40 ± 0.89 c | 48.40 ± 0.89 c | 49.40 ± 0.89 c | 50.40 ± 1.51 c |
| *Allium sativum* | 44.40 ± 0.89 c | 45.40 ± 1.34 c | 46.00 ± 0.70 d | 47.40 ± 1.34 c | 48.40 ± 0.89 c | 49.40 ± 1.14 c |
| *Curcuma longa* | 49.40 ± 0.89 b | 50.40 ± 0.89 b | 51.40 ± 0.74 b | 52.40 ± 0.89 b | 53.40 ± 0.89 b | 54.40 ± 0.89 b |
| *Citrullus colocynthis* | 42.40 ± 0.89 d | 43.40 ± 1.14 d | 44.40 ± 0.89 e | 45.20 ± 0.83 d | 46.40 ± 1.51 d | 47.40 ± 1.51 d |
| *Calotropis procera* | 39.40 ± 1.14 e | 40.40 ± 0.83 e | 41.40 ± 1.51 f | 42.40 ± 0.89 e | 43.40 ± 1.14 e | 44.40 ± 0.89 e |
| Control | 25.80 ± 1.89 f | 25.80 ± 1.89 f | 25.80 ± 1.89 g | 25.80 ± 1.89 f | 25.80 ± 1.89 f | 25.80 ± 1.89 f |
| LSD Value | 1.11 | 1.14 | 1.11 | 1.13 | 1.14 | 1.14 |

Mean ± standard deviation. Column means having different letters are significantly different at 5% level of significance

**Table 3:** Effect of different concentrations of hexane plants extracts on percent infestation (±SD) of maize grains by maize weevil, *S. zeamais*

| Treatments | Concentrations (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| *Azadirachta indica* | 3.97 ± 1.37 f | 4.42 ± 0.02 f | 2.85 ± 0.03 g | 2.60 ± 0.01 g | 1.89 ± 0.04 g | 1.74 ± 0.01 g |
| *Caralluma turberculata* | 6.50 ± 0.03 d | 5.05 ± 0.04 e | 4.81 ± 0.01 d | 3.95 ± 0.01 d | 3.48 ± 0.03 d | 3.15 ± 0.01 d |
| *Allium sativum* | 6.28 ± 0.01 de | 5.18 ± 0.03 d | 4.46 ± 0.01 e | 3.52 ± 0.02 e | 3.09 ± 0.01 e | 2.74 ± 0.01 e |
| *Curcuma longa* | 5.80 ± 0.01 e | 5.08 ± 0.02 e | 3.99 ± 0.02 f | 3.23 ± 0.02 f | 2.61 ± 0.02 f | 2.22 ± 0.01 f |
| *Citrullus colocynthis* | 10.03 ± 0.06 c | 9.13 ± 0.01 c | 8.80 ± 0.05 c | 8.44 ± 0.03 c | 7.96 ± 0.02 c | 7.62 ± 0.18 c |
| *Calotropis procera* | 12.45 ± 0.04 b | 11.93 ± 0.03 b | 11.64 ± 0.03 b | 9.96 ± 0.02 b | 9.32 ± 0.04 b | 8.52 ± 0.68 b |
| Control | 56.72 ± 1.11 a | 58.72 ± 0.73 a | 60.66 ± 1.82 a | 56.34 ± 1.14 a | 54.72 ± 0.03 a | 62.32 ± 1.99 a |
| LSD Value | 0.67 | 0.36 | 0.40 | 0.03 | 0.03 | 0.34 |

Mean ± standard deviation. Column means having different letters are significantly different at 5% level of significance.

**Table 4:** Mean percent (± SD) weight loss of maize grains treated with different concentrations of hexane extracts from plant powders

| Treatments | Concentrations (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| *Azadirachta indica* | 2.31 ± 0.04 g | 2.23 ± 0.03 g | 1.87 ± 0.01 g | 1.29 ± 0.01 g | 0.89 ± 0.06 g | 0.72 ± 0.04 g |
| *Caralluma turberculata* | 3.24 ± 0.01 d | 2.94 ± 0.03 d | 2.40 ± 0.03 d | 1.98 ± 0.03 d | 1.70 ± 0.05 d | 1.54 ± 0.03 d |
| *Allium sativum* | 3.12 ± 0.02 e | 2.55 ± 0.01 e | 2.19 ± 0.01 e | 1.70 ± 0.01 e | 1.49 ± 0.06 e | 1.35 ± 0.03 e |
| *Curcuma longa* | 2.87 ± 0.01 f | 2.48 ± 0.01 f | 1.96 ± 0.01 f | 1.57 ± 0.02 f | 1.23 ± 0.03 f | 1.03 ± 0.03 f |
| *Citrullus colocynthis* | 5.00 ± 0.01 c | 4.56 ± 0.03 c | 4.44 ± 0.01 c | 4.22 ± 0.02 c | 3.95 ± 0.02 c | 3.62 ± 0.03 c |
| *Calotropis procera* | 6.17 ± 0.01 b | 5.95 ± 0.01 b | 5.79 ± 0.02 b | 4.95 ± 0.01 b | 4.55 ± 0.20 b | 4.25 ± 0.32 b |
| Control | 29.36 ± 3.97 a | 27.46 ± 0.17 a | 30.31 ± 3.97 a | 28.36 ± 3.97 a | 27.11 ± 3.97 a | 31.32 ± 0.29 a |
| LSD Value | 0.04 | 0.04 | 0.04 | 0.03 | 0.02 | 0.18 |

Mean ± standard deviation. Column means having different letters are significantly different at 5% level of significance

The efficacy of the plant products declined significantly and linearly by declining the concentrations of the plant materials. The maximum damage of grains (62.32%) was recorded in untreated maize grains.

## Weight loss

The grain weight loss varied significantly among different treatments from 0.72% in maize grains treated with 3% *A. indica* hexane extracts to 6.17% in grains treated with 0.5% concentration of *C. procera* caused by *S. zeamais*. Among the treatments, the effect of *A. indica* and *C. longa* extracts was more pronounced in reducing weight loss at all the tested concentrations. The extracts of *A. sativum* also showed comparatively better results at all the evaluated concentrations in comparison with the control treatment. Among the tested hexane plant extracts, the maximum weight loss of 6.17% was observed in maize grains treated

**Table 5:** Effect of different concentrations of hexane plant extracts on the life span of adult maize weevil cultured on maize grains

| Treatments | Concentrations (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| *Azadirachta indica* | 22.60 ± 0.89 g | 21.60 ± 0.89 g | 19.00 ± 0.70 g | 18.00 ± 0.70 f | 17.00 ± 0.70 g | 16.00 ± 0.70 g |
| *Caralluma turberculata* | 27.40 ±0.89 d | 27.00 ± 0.70 d | 26.00 ± 0.70 d | 24.60 ± 0.89 d | 24.00 ± 0.70 d | 23.00 ± 0.70 d |
| *Allium sativum* | 26.00 ± 0.70 e | 25.00 ± 0.70 e | 24.00 ± 0.70 e | 23.60 ± 0.89 d | 22.60 ± 0.89 e | 21.60 ± 0.89 e |
| *Curcuma longa* | 24.00 ± 0.70 f | 23.00 ± 0.70 f | 21.80 ± 0.83 f | 21.00 ± 0.70 e | 19.40 ± 0.89 f | 18.40 ± 0.89 f |
| *Citrullus colocynthis* | 31.00 ± 0.70 c | 30.00 ± 0.70 c | 28.80 ± 0.83 c | 28.00 ± 0.70 c | 27.00 ± 0.70 c | 25.80 ± 0.83 c |
| *Calotropis procera* | 34.40 ± 0.89 b | 34.00 ± 0.70 b | 33.00 ± 0.70 b | 32.00 ± 0.70 b | 31.00 ± 0.70 b | 30.00 ± 0.70 b |
| Control | 45.40 ± 0.89 a | 45.40 ± 0.89 a | 45.40 ± 0.89 a | 45.40 ± 0.89 a | 45.40 ± 0.89 a | 45.40 ± 0.89 a |
| LSD Value | 1.06 | 0.99 | 1.003 | 1.02 | 1.02 | 1.05 |

Mean ± standard deviation. Column means having different letters are significantly different at 5% level of significance

**Table 6:** Sex ratio (males/50 females) of maize weevil cultured on maize grains treated with different concentrations of hexane plant extracts

| Treatments | Concentrations (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| *Azadirachta indica* | 47.20 ± 1.53 NS | 46.16 ± 1.88 NS | 45.94 ± 2.07 NS | 44.63 ± 1.78 NS | 44.89 ± 1.39 NS | 45.25 ± 1.85 NS |
| *Caralluma turberculata* | 45.70 ± 0.86 | 46.63 ± 1.25 | 45.31 ± 2.27 | 46.21 ± 0.90 | 46.26 ± 2.06 | 45.39 ± 1.00 |
| *Allium sativum* | 45.34 ±1.98 | 45.17 ± 2.18 | 45.23 ± 1.24 | 46.53 ± 1.69 | 45.06 ± 2.56 | 43.86 ± 2.92 |
| *Curcuma longa* | 45.69 ± 1.79 | 46.48 ± 1.81 | 46.24 ± 1.17 | 45.34 ± 1.51 | 46.19 ± 1.57 | 46.05 ± 2.44 |
| *Citrullus colocynthis* | 45.23 ± 1.70 | 45.38 ± 2.92 | 45.96 ± 2.74 | 45.90 ± 2.18 | 45.00 ± 2.11 | 45.38 ± 1.92 |
| *Calotropis procera* | 45.39 ± 2.32 | 45.21 ± 3.12 | 45.65 ± 0.93 | 45.70 ± 0.17 | 45.67 ± 1.22 | 44.84 ± 1.19 |
| Control | 46.22 ± 0.21 | 46.22 ± 0.21 | 46.22 ± 0.21 | 46.22 ± 0.21 | 46.22 ± 0.21 | 46.22 ± 0.21 |
| LSD Value | 2.11 | 2.75 | 2.23 | 1.83 | 2.26 | 2.40 |

Mean ± standard deviation. Column means having no letters are statistically similar at 5% level of significance: N.S = Non Significant

with 0.5% concentration of *C. procera* extracts whereas; minimum weight loss of 0.72% was noted in grains treated with 3% concentration of *A. indica* hexane extracts followed by 1.03% grain damage in *C. longa* extracts treated maize grains. Among the different concentrations, the maximum concentration of 3% yielded the best results. Among the treatments, *C. procera* and *C. colocynthis* were found least effective in reducing weight loss of maize grains showing 6.17 and 5.00% weight loss in grains treated with 0.5% concentration. Overall, the maximum weight loss of 31.32% was noted in untreated maize grains.

### Adult life span

The life span of *S. zeamais* adults differed significantly on treated maize grains relative to control. The hexane extracts of *A. indica* at the highest concentration of 3% were found most effective compared to other treatments and control. The minimum life span (16.00 days) of adult weevils was recorded on maize grains treated with 3% *A. indica* extracts followed by 18.40 days recorded with *C. longa* treated grains at the same concentration. The maximum (45.40 days) life span of adult weevils was registered when the weevils were reared on untreated maize grains. The extracts of *A. sativum* and *C. tuberculata* also had maximum effects on the adult life span of weevils registering 21.60- and 23.00-days adult life span at 3% concentration treated grains. The hexane extracts of *C. procera* and *C. colocynthis* had a minimum effect on the longevity of adult weevils (30.00 and 25.80 days) of *S. zeamais* at 3% concentration. The lowest concentration of all the evaluated plant materials was found least effective regarding their effect on the life span of adult weevils (Table 5).

### Adult sex ratio

The hexane extracts of all the tested plant materials had no significant effect on the adult sex ratio of *S. zeamais*. It is clear from the obtained results that all the tested plants had no significant effect on the number of males/50 females (Table 6). Likewise, the plant materials, the tested concentrations did not affect the sex ratio of maize weevil; however, the number of females was always more compared to the number of males in all the tested plant materials (Table 6).

## Discussion

Botanical insecticides are natural plant-based chemicals that are extracted from plants and are used as safe alternative to traditional chemical insecticides. The excessive use of chemical insecticides causes many problems including ozone depletion, have negative impacts on the non-target organisms and the environment (Regnault-Roger *et al.* 2012). In the present study, the maximum time for the development of maize weevil was recorded on maize grains having maximum concentration of *A. indica* and *C. longa* hexane extracts. In previous studies, the treatment of maize grains with *Gloriosa superba* and *Lippia nodiflora* extracts resulted in lower progeny buildup of rice weevil, *S. oryzae* which could be attributed to lower fecundity, fertility of adults and pupal mortality (Nalini *et al.* 2009). The crude hexane plant extracts of *A. indica* and *C. longa* were found most effective showing the least percent infestation (1.74 and 2.22%), at higher concentrations of 2.5 and 3%, respectively. The obtained results prove that hexane extracts of *A. indica* and *C. longa* contain toxic and inhibitory effects on the growth and reproduction of maize weevil. Our findings are in line with the results of Lalla *et al.* (2013), who reported similar toxicity trends against *C. maculatus*. Ibrahim and Garba (2011) reported that garlic (*A. sativum*) powder is effective against maize weevil, however, in our study, it was relatively less effective which may be due to the difference in concentrations used in their experiments. Mobki *et al.* (2014) stated the higher fumigant toxicities of garlic extracts against red flour beetle. This disparity in efficacy of garlic extracts may be due to the variation in solvents of extractions, extract's concentration and susceptibility of the *S. zeamais* to garlic extracts compared to red flour beetle. Moreover, the efficacy of the tested extracts was clearly dependent on the concentration as the higher infestation was noted in the least concentration and the least infestation was witnessed with the highest concentration. It also coincides with the reports of Chaubey (2014) who also reported a positive relationship between the concentrations of *A. sativum* oils and mortality of pulse beetle. Our results presented that the minimum weight loss and less adult emergence were recorded at the maximum concentration of 3% of *A. indica* and *C. longa* hexane extracts. Similar findings were reported by Opiyo (2020), the n-hexane extracts prepared from the stem bark of *Elaeodendron schweinfurthianum* strongly inhibited the emergence of adult maize weevil. The hexane extracts of *C. procera* and *C. colocyngthis* were found minimum effective and had no significant toxicity against maize weevil; this may be featured to the presence of toxic compounds in low concentrations. These results are in accordance with those reported by Ouko *et al.* (2017).

The minimum life span of adult weevils was noted when maize grains were treated with *A. indica* and *C. longa* hexane extracts at 3% concentration. A decrease in the adult life span of weevils was noted by increasing the concentration of evaluated plant materials. These results are in complete conformity with the findings of Adeleye and Soyelu (2020), fewer eggs of cowpea weevil, *C. maculatus* and the minimum adult life span were noted on cowpea seeds treated with 3% n-hexane leaf extracts prepared from neem leaves. Souza *et al.* (2013) found that *C. longa* extracts carry repellent and highly toxic activities against maize weevil., In previous studies *C. longa* extracts have been found to carry strong repellent and toxic activities against insect pests (Sukari *et al.* 2010; Damalas 2011). The minimum longevity of weevils in the treated grains means that the adult weevils have less chance of seed damage and reproduction. The minimum infestation of weevils and weight losses were recorded when maize grains were treated with the maximum concentration of *A. indica* and *C. longa* hexane extracts is an indication of this phenomenon. All the tested hexane plant extracts did not have any effect on the sex ratio of the adult weevils. Similar findings were also reported by Adeleye and Soyelu (2020), they investigated the effect of aqueous and n-hexane extracts prepared from neem leaves and reported that both extracts did not affect the sex ratio of cowpea weevil. Further studies focusing on the effect of botanicals on the $F_2$ generation of weevils are needed.

## Conclusion

The results obtained from these studies confirmed that the crude hexane extracts of *A. indica* and *C. longa* plants carry strong growth inhibition properties and could serve as alternative measures for synthetic chemicals and may be used for the timely management of maize weevil.


## Acknowledgment

The first author thanks Pakistan Science Foundation (PSF), Islamabad, Pakistan for providing financial support for this study under Grant No. PSF/NSLP/KP-GU (424).


## Author Contributions

Muhammad Mamoon-ur-Rashid and Muhammad Tariq conceived and designed the experiments, Riaz-ud-Din conducted the experiments, Asghar Ali Khan and Asif Latif analyzed the data, Muhammad Naeem and Imran Khan helped in manuscript writing.

## Conflict of Interest

The authors have no conflicts to declare.

## Data Availability

The data presented in this study will be made available on request to the corresponding author.

## Ethics Approval

Not Applicable to this paper.

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