Bioprospecting of some indigenous plant bio-active materials for sustainable management of stored maize weevil Sitophilus zeamais Mostch. (Coleoptera: Curculionidae)

Tange Denis Achiri
achiritange@gmail.com

University of Buea

Mamudou Jallow
University of the Gambia

Oben Tom Tabi
University of Buea

Manju Evelyne Bi Tima
University of Bamenda, NWR

Lendzemo Eugene Tatah
University of Bamenda, NWR

Wirdzenyuy Susane Mensiy
University of Buea

Tanyi Clovis Bessong
Biaka University Institute of Buea, SWR

Njualem Dominic Khumbah
University of Bamenda, NWR

Research Article

Keywords: Maize weevil, botanicals, insecticides, siam weed, tithonia, eucalyptus, SDG

Posted Date: November 10th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-7554844/v1

Additional Declarations: No competing interests reported.

Bioprospecting of some indigenous plant bio-active materials for sustainable management of stored maize weevil *Sitophilus zeamais* Mostch. (Coleoptera: Curculionidae)

Authors: Tange Denis Achiri[1,2], Mamudou Jallow[3], Oben Tom Tabi[1], Manju Evelyne Bi Tima[4], Lendzemo Eugene Tatah[4], Wirdzenyuy Susane Mensiy[1], Tanyi Clovis Bessong[2,5] & Njualem Dominic Khumbah[4,6]

Addresses:

[1]Department of Agronomic and Applied Molecular Sciences, Faculty of Agriculture and Veterinary Medicine, University of Buea. P. O Box 63. Buea, Cameroon.
[2]Department of Agronomy, School of Agricultural Science, Biaka University Institute of Buea, P. O. Box 77. Buea, SWR, Cameroon.
[3]Department of Physical and Natural Sciences, School of Arts and Sciences, University of the Gambia, P. O. Box 3530 Serrekunda, The Gambia
[4]Department of Crop Production Technology, College of Technology, University of Bamenda, P. O Box 39. Bambili, NWR, Cameroon.
[5]Agricultural Research Institute for Development IRAD, Ekona, SWR, Cameroon
[6]School of Tropical Agriculture and Natural Resource, Catholic University of Cameroon, P. O Box 782. Bamenda, NWR, Cameroon.

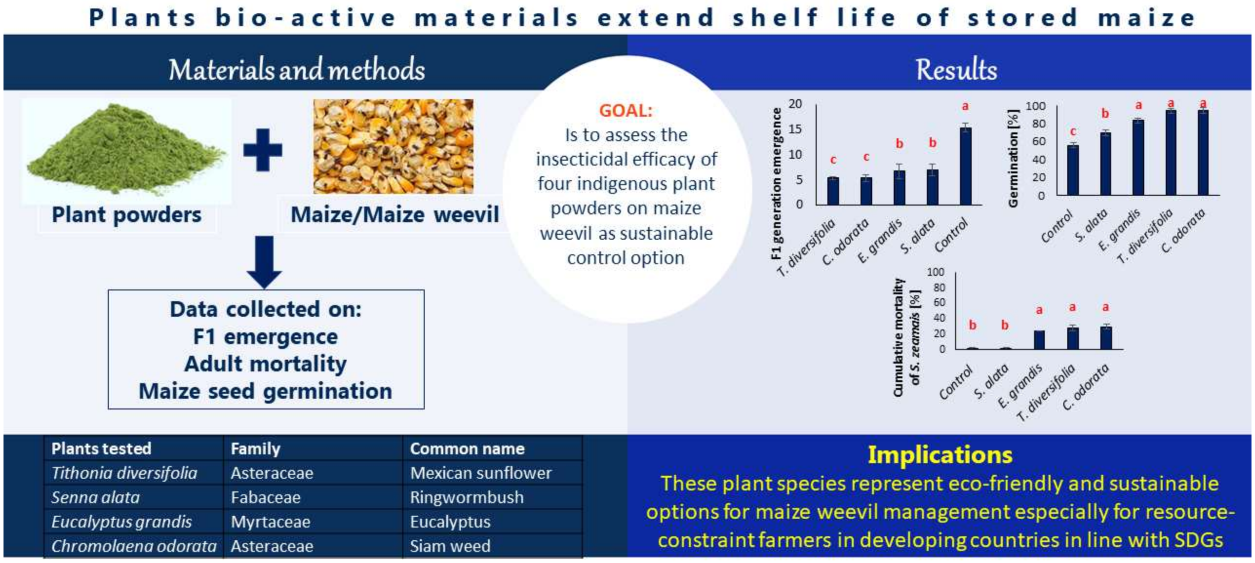
Corresponding author: achiritange@gmail.com, https://orcid.org/0000-0003-2791-6062

Abstract

Stored maize (*Zea mays*) is jeopardized by maize weevil *Sitophilus zeamais*, resulting to recorded losses between 20% - 90%. Botanicals have emerged as promising alternatives to synthetic pesticides for the control of maize weevil due to their bio-insecticidal properties and minimal to zero impact on humans and the environment.

In line with this, this research was conducted to evaluate the insecticidal properties of some botanicals (*Tithonia diversifolia*, *Senna alata*, *Chromolaena odorata*and *Eucalyptus grandis*) leaf powders on maize weevil. Uninfested maize grains where obtain from a local market in Buea, Southwest region of Cameroon and plant powders were obtained from ground leaves of these botanicals. In 2023, a laboratory study was conducted using completely randomized design with three replicates to evaluate the insecticidal activity of these botanicals with untreated control. All botanicals significantly reduced the number of F1 emerging when compared to the control. The number of F1 was 5, 5, 7, 7 and 15 for *T. diversifolia*, *C. odorata, E. grandis, S. alata* and control, respectively. Hatching reduction (%) followed a similar trend with 66.67%, 64.44%, 55.56% and 53.33% reported from *C. odorata, T. diversifolia, E. grandis* and *S.alata*, respectively. Cumulative mortality of maize weevil was 30.0%, 28.33%, 25.0% from *C. odorata, T. diversifolia*, and *E. grandis* respectively, which were statistically higher than *S. alata* (1.67%) and the control (1.67%). These plant species represent eco-friendly and sustainable alternatives for maize weevil management especially for resource-constraint farmers in developing countries in line with Sustainable Development Goals.
Key words Maize weevil, botanicals, insecticides, siam weed, tithonia, eucalyptus, SDG

Graphical abstract



1 Introduction

Maize or corn (*Zea mays* L.) is an important cereal crop of the world belonging to the Gramineae family [1]. It is a third leading crop of the world after rice and wheat [2]. In many parts of the world, including Asia, Latin America and Africa, maize serve as a staple food and cash crop [3]. It is an affordable source of carbohydrates, protein, iron, vitamin B, minerals and dietary fiber for smallholder farmers [4]. Furthermore, maize is extensively used in several industries such as for biogas, methane and beer production, as well as a major feed component for livestock [5, 6]. Some other products that can be gotten from maize include cornstarch, oil, glues, corn bear and ethanol [7]. All components of the maize plant possess economic value: the grain, leaves, stalk, tassels and cob can all be used to produce a diverse array of food and non-food products [8]. Due to its high yield potential among the cereals, it is often referred to as 'queen of cereals' globally [9]. The world production of dry maize grains is 1137 million tons globally [5] with the United State of America (USA) contributing about 35% of the world maize production. It is known as the mother grain of America and is the driver of US economy. In Africa, maize production was around 75million tons in 2018, representing 7.5% of world maize production. The largest African producer is Nigeria with over 33million tons, followed by South Africa, Egypt and Ethiopia [10]. In Cameroon maize is one of the most important cereal crops just like in other African countries. In 2023, maize production for Cameroon reached 2318,238 metric tons, which corresponds to 10% increase from 2022 production levels [11].

In storage, maize faces several insect pests such as the grain borer (*Prostephanus truncates* (horn); Coleoptera: Bostrichidae) and maize weevil (*Sitophilus zeamais* (Motschulsky); Coleoptera: Curculionidae), which are responsible for damage to the grain, resulting into considerable economic losses and affecting food security [12]. The maize weevil is by far the most important storage pest of maize, which causes enormous economic damage [13]. The infestation can occur from the field to the store [5, 14]. Adult weevils lay eggs inside the grains, and the developing larvae feed within the kernels, consuming a considerable portion of stored maize, reducing its weight and nutritional value and making it unfit for human or animal consumption, and reducing seed viability [13, 15]. The larvae creates openings in the kernels that allow secondary infections from various fungi, molds, and bacteria to enter the grains [16] Some likely outcomes of secondary infections include further deterioration of grain quality, production of mycotoxins, and increase the risk of human and animal health issues [17]. Infestation by *S. zeamais* can lead to significant grain losses in storage ranging from 20% - 90%, and sometimes 100% loss in cases of severe infestation [18, 19]. Consequently, maize weevil is direct threat to food security and contributes to poverty especially in vulnerable tropical and subtropical regions with poor postharvest management and inappropriate grain storage conditions [20, 21].

Farmers have resulted to different methods of controlling this insect such as the use of synthetic insecticides which have negative effects on humans as well as the environment and non-target organisms [22]. However, in the recent past a lot of research has been going on in order to identify indigenous, benign and ecofriendly botanicals for managing stored maize pest such as the use of cypress leaf powder [23] and others. In a research carried out by Chougourou et al. [24], it was realized that *Chenopodium ambrosioides* and *Adenia cissampeloides* powders were effective in the management of *Callosobruchus maculatus* on stored pulse grains. Ehisianya et al. [25] did an assessment of some plant powders and realized that they act as protectants of stored maize grains against maize weevil *Sitophilus zeamais*. In

2015, Achiri and Njweng [23] reported the maize weevil were highly repelled by cypress leaf powder, even though very limited mortality effect was recorded.

Botanicals provide a cheaper and safer alternative to synthetic insecticide and are considered safe in pest control because they have low or none pesticide residue making them safe to the people, environment and ecosystem [26]. Indigenous plants such as *Eucalyptus grandis, Senna alata, Tithonia diversifolia* and *Chromolaena odorata* have been reported to have some insecticidal properties are widely distributed in Cameroon. These indigenous plants are locally available, cheap and require only limited processing. In fact, the anti-insect effects of seed extracts of *Senna alata* have been demonstrated [27]. Pujiarti and Fentiyanti [28] reported that *Eucalyptus deglupta* essential oils have repellent activity against *C. quinquefasciatus* mosquito. The oil extracts of *Eucalyptus grandis* have been proven by Toloza et al*.* [29] to have pesticidal and antifeedant effects on insects. Some of the main constituents of *Chromolaena ododrata* oil include sesquiterpenes and monoterpenoids, which have insecticidal and repellent activity against Coleopteran storage pest [30, 31]. In field application, aqueous extracts of *Chromolaena odorata* controlled coleopteran pest [32] and lepidopteran pest [33]. The insecticidal properties of the essential oil and powder extracts of Siam weed have been demonstrated on coleopteran pests in the laboratory [34, 35]. A major constituent of *Tithonia diversifolia* essential oil, the monoterpenoid α-pinene, β-pinene, limonene and sesquiterpenes [35-37] have insecticidal and repellent activities against coleopteran storage pests [38]. Sesquiterpene lactones in *Tithonia diversifolia* have been shown to be toxic to the coleoptera *Callosobruchus maculatus* [39]. In storage applications, ground *Tithonia diversifolia* leaves controlled the cowpea weevil in the studies, although the efficacy varied [40].

This study is designed to ascertain the potential plant bio-active materials in *S*. *alata*, *E*. *grandis*. *C*. *odorata* and *T*. *diversifolia* as powders against maize weevil since they are widely used as medicinal plant. Furthermore, *T. diversifolia* and *C. odorata* have been used as dual-purposed plant; demonstrating both plant protection and plant nutrition potentials [41, 42]. We hypothesize that these plant powders will reduce the impact of maize weevils on stored maize grains, thus sustainably increasing the shelf life of stored maize, which lends weight to the ideals of SDG1, SDG2 and SDG12.

2 Materials and Methods

2.1 Experimental Site

This study was carried out in the Entomology laboratory of the Teaching and Research Farmhouse of the Faculty of Agriculture and Veterinary Medicine, the University of Buea.

The site is located between latitudes 4^0 3’ N and 4^0 12’N and longitudes9^0 12’E and 9^0 20’E. The climate is characterized by mono-modal rainfall regime with heavy rainfall from June to October and 2,800 mm annual average, while the dry season starts from November to early March with 28 °C annual average (i.e., ranging between 19–30 °C monthly). The average relative humidity is 86%. Weather parameters during the study period are presented in Fig. 1.

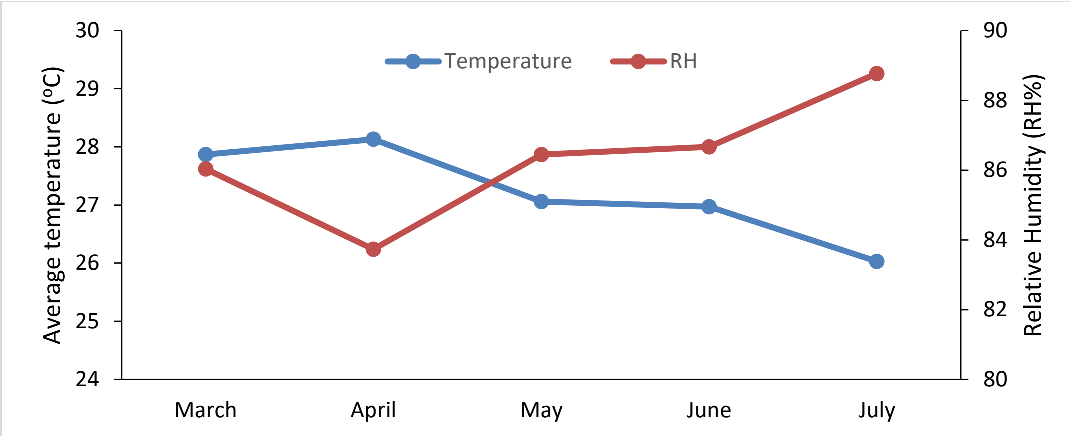


Fig. 1 Weather parameters during the study period between March and July for 2023.

2.2 Maize Collection and Insect Culture

5kg of dry maize was bought from traders in the Muea market located in Buea municipality, South West Region, Cameroon. Cracked, broken grains and other debris were sorted out from whole grains. The maize grains were heat sterilized at 40-50 ^{o}C for 20 minutes to kill residual eggs. *Sitophilus zeamais* adults were obtained from infested maize in warehouse in the same local market reared in laboratory conditions (approximately, 12:12 photoperiods, temperature of 27 ^{o}C and humidity of 65%). The insects were stored in sterilized maize grains for 70 days during which time three generations must have passed.

2.3 Botanical materials/powders

All identified plant materials to be investigated were collected by hand picking from the bushes in the Buea municipality and air-dried (in order that the leaves should not lost their active volatile components) under shade for three weeks in the Faculty of Agriculture and Veterinary Medicine Research Lab Buea. This was to ensure that volatile active components were retained in the dried samples.

Each of the dried plant materials were ground to powder using a laboratory mortar. The powder was sieved through a 0.5mm mesh and 250g of each, packaged in polythene zip lock bags, labeled and kept in the refrigerator for later use. They were used as direct admixtures to the maize grains at rates calculated on a weight of powdered material per weight of grain (wt/wt) basis that is 100g of maize and 5g of plant powder, for germination test, mortality test, and hatching evaluation against *S. zeamais*.

2.4 Experimental Design

The experiment was arranged in a completely randomized design (CRD) with five treatments and three replicates in the entomology laboratory. Five treatments were assessed: T1 - maize with *Tithonia diversifolia*, T2 - maize with *Senna alata*, T3 - maize with *Eucalyptus grandis*, T4 - maize with *Chromolaena odorata*, and T5 - maize only (Control). *Tithonia diversifolia* (Hemsl.) A. Gray 1883 was collected on the campus of the University of Buea ($4^{o}08^{I}53.3^{II}$N, $9^{o}16^{I}55.2^{II}$ E). *Chromolaena odorata* (L.) R. M. King & H. Rob 1970 was collected on the campus of the University of Buea ($4^{o}08^{I}52^{II}$N, $9^{o}16^{I}55.2^{II}$E). *Eucalyptus grandis* Hill ex Maiden 1862 was collected from Santa, North West Region of Cameroon ($5^{o}79^{I}46.1^{II}$N, $10^{o}16^{I}40.2^{II}$E). *Senna alata* (L.) Roxburgh 1832 *was* collected on the campus of the University of Buea

($4^{o}08^{I}55.3^{II}N$, $9^{o}16^{I}59.9^{II}E$). All plant materials were identified by Dr. Abwe M. Ngone and voucher specimens were deposited at the Herbarium of the Limbe Botanic Garden, South West Region of Cameroon with their respective Identifications (Table 1).

Table 1 Details of botanicals used in the study

Treatment	Family	Common name	State of collection	Identification
Tithonia diversifolia	Asteraceae	Mexican sunflower	Flowering	Tange D. Achiri #7162 10 March 2023
Senna alata	Fabaceae	Ringwormbush	Flowering	Tange D. Achiri #2411 05 March 2023 with Wirdzenyuy S. Mensiy
Eucalyptus grandis	Myrtaceae	Eucalyptus	Fruiting	Wirdzenyuy S. Mensiy #1452 23 March 2023
Chromolaena odorata	Asteraceae	Siam weed	Flowering	Tange D. Achiri #7166 10 March 2023

2.4.1 Effect of Plant Powders on F1 emergence (Adult Weevil emergence)

100g of selected maize was measured using an electronic balance and poured in 100ml glass bottles. 20 unsexed adults maize weevil were introduced into the glass bottles containing 100g of uninfected maize grain and covered with muslin cloth to allow ventilation, and tied with rubber bands to prevent the weevils from leaving the glass bottles. After 14 days, the adult maize weevils were removed and 5g of the different powders were added into the bottles to observe the effect on hatching (Adult emergence). Emerging insects were removed after 14 days and continuous removal after every 3 days for 2 weeks to prevent mating and subsequent oviposition by the F1 progeny. Each treatment was replicated three times. The F1 percent reduction or F1 inhibition ratio (IR%) was estimated using equation 1.

$$\boldsymbol{F1\ percentage\ reduction}\ (\%) = \frac{N_c - N_t}{N_c}\ \boldsymbol{x\ 100} \quad \text{.................................... eq. 1}$$

Where N_c is the number of weevils in the control and N_t is the number of weevils in the treatments.

2.4.2 Mortality Test

For mortality test, 100g of sterilized maize was selected and put in the 1L glass bottles and 5g of the plant powders was added. The bottled was shaken for 5 second after which 20 adult weevils were introduced in the glass bottles. The bottles were covered with a muslin cloth to allow ventilation and fastened with a rubber band to prevent escape. The number of dead insects were recorded every two days for 2 weeks. After the two weeks of setup, all insects were removed and the setup allowed standing for another two weeks, thereafter, the maize seeds were used for seed viability test.

2.4.3 Viability test (Germination test)

Viability test was carried out to assess the effect of the plant powders on postharvest maize stored with weevils and treated with bio-active plant powders after the mortality test. After the mortality test assessment, 12 seeds were randomly collected from each glass vial for germination test. Plastic cups (height = 5cm, diameter = 4cm) were filled with steam-treated topsoil to three-quarter capacity. Two holes (diameter = 0.5cm) were made at the bottom of the plastic cups. Thirty-six plastic cups were used per treatment (12 plastic cups for seeds from each vial). A seed was inserted 1cm deep into the soil in the cup and irrigated with 5 mL of water. The cups were properly labelled and kept on a table in the yard in front of the laboratory in a complete randomized design (CRD). The number of seeds that germinated per treatment was recorded over a period of 5 days beginning from the 5th day after setup. The number of seeds that germinated from each glass vial was express as a percentage using equation 2 below (eq. 2).

$$Number\ of\ seeds\ that\ germinated\ (\%) = \frac{\sum_1^i x_i}{n} \times 100 \text{ .... eq. 2.}$$

Where n is the number of maize seeds (12) collected per glass vial and x_i is the number of seeds that germinated per glass vial from the *i*th treatment.

2.5 Data Analysis

Normality and homogeneity of variance tests were conducted using Kolmogorov-Smirnov test and Levene's test, respectively, prior to one-way analysis of variance (ANOVA) test for statistical significance for F1 emergence, mortality and germination test. Means that were significantly different were separated using the *posthoc* test Duncan's Multiple Range Test (DMRT) at an alpha (α) level of 0.05. A 2-independent sample t-test was used to assess if significant differences existed between the weevil mortality of week 1 and week 2. Correlation analysis was conducted. All statistical analyses were done using SPSS (ver. 23).

3. Results

3.1 Effect of plant bio-active powders on F1 generation emergence

The effect of plant powders on the hatching or emergence of F1 generation is shown in figure 2. There was a significant difference ($F = 19.440$, $df = 4,10$, $P < .001$) in the number of F1 generation. The highest F1 generation of maize weevils emerged from the control treatment with 15 weevils. This was followed by *S. alata* treatment with 7 F1 maize weevils. The smallest number of F1 emergence occurred from *C. odorata* and *T. diversifolia* treatments, which was 5 maize weevils each (Fig. 2).

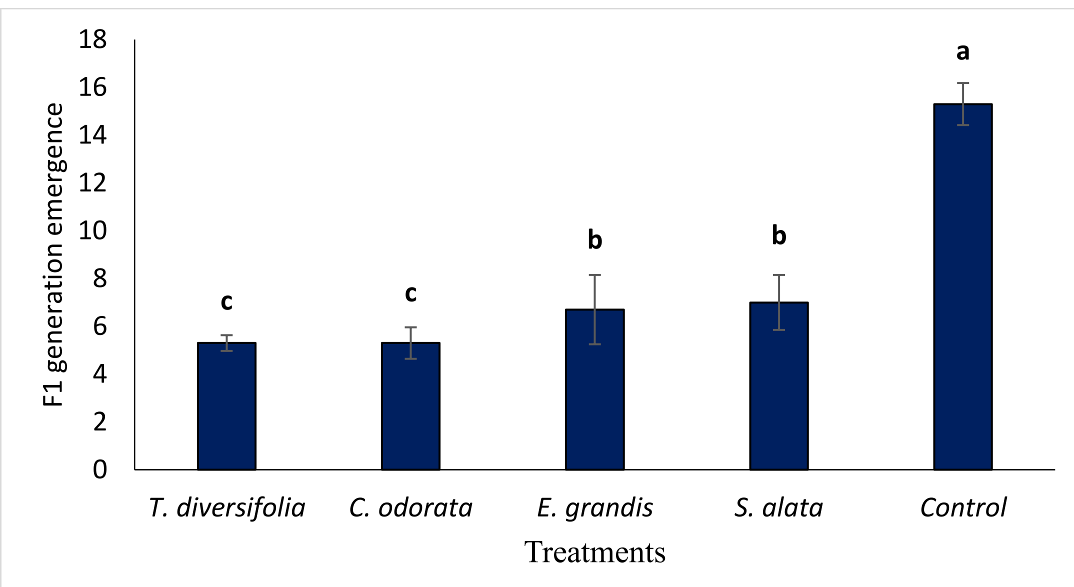


Fig. 2 Effect of different plant bio-active powders on F1 generation emergence of maize weevil. Mean bars with different letter(s) are significantly different (DMRT, *P* < .05)

3.2 F1 Percent reduction or F1 inhibition rate

The F1 percent reduction or inhibition rate (IR) by plant powders was estimated with the control treatment as the reference. The percent reduction by plant powders are represented in fig. 3. There was a significant difference (F=2.990, df = 3, 8, *P* = .047) in the percent reduction from the different plant powders. The highest percent reduction was recorded from *C. odorata* (66.67%), followed by that of *T. diversifolia* (64.44%). The lowest percent reduction was observed from *S. alata* treatment (53.33%). The percent reduction recorded from *E grandis* was 55.56% (Fig. 3).

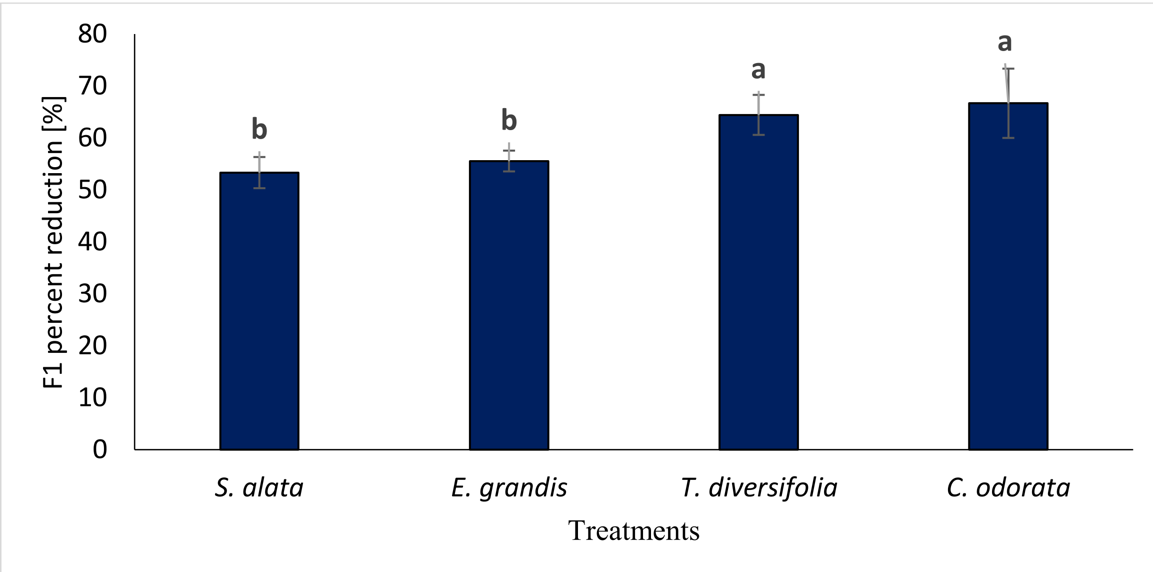


Fig. 3 Effect of different plant bio-active powders on F1 percent reduction of maize weevil. Mean bars with different letter(s) are significantly different (DMRT, *P* < .05)

3.3 Effect of plant bio-active powders on adult mortality of maize weevil

The mortality of maize weevil as a result of plant powders shown in Table 2. The mortality of maize weevil was recorded over two-week period. The data revealed that there was no significant difference in the mortality between week 1 and week 2 for the control (t = -1.0, df = 4, *P* = .423) and *S. alata (*t = -1.0, df = 4, *P* = .423) treatments. However, there was a significant difference in the mortality between week 1 and week 2 for *E grandis* (t = -9.192, df = 4, *P* = .001), *T. diversifolia* (t = -6.50, df = 4, *P* = .003) and *C odorata* (t = -9.889, df = 4, p = .001) (Table 2). Within week 1, there was no significant difference (F = 1.667, df = 4,10, *P* = .233) in the mortality of maize weevil from different treatments. Nevertheless, for week 2, there was a significant difference (F = 42.357, df = 4,10, *P* <.001) in the mortality of maize weevil by different plant powders. In week 2, the highest mortality was observed from *C odorata* (26.67%), followed by that of *T. diversifolia* (25.00%). The smallest mortality was observed from control and *S. alata* treatments at 1.67%. The cumulative mortality (%) of maize weevil after two weeks as a result of plant powders is shown in Fig 3. Maize weevil cumulative mortality differed significantly (F = 41.556, df = 4,10, *P* <.001) over a period of two weeks. The highest cumulative maize weevil mortality (30.0%) was recorded from *C. odorata* treatments, followed by that of *T. diversifolia* (28.33%). The least cumulative maize weevil mortality was observed from control and *S. alata* treatments in at 1.67% (Fig. 4).

Table 2 Effect of plant bio-active powders on adult mortality of maize weevil

Treatment	Week 1	Week 2	t – statistic
Control	0.0 ± 0.0aA	1.67 ± 1.11aA	t = -1.0, *P* = .423
Senna alata	0.0 ± 0.0aA	1.67 ± 0.83aA	t = -1.0, *P* = .423
Eucalyptus grandis	1.67 ± 1.8aA	23.33 ± 2.88bB	t = -9.192, *P* = .001
Tithonia diversifolia	3.33 ± 2.89aA	25.00 ± 2.36bB	t = -6.50, *P* = .003
Chromolaena odorata	3.33 ± 2.88aA	26.67 ± 2.89bB	t = -9.899 *P* = .001
	F = 1.667	*F* = 42.357	
	P = .233	*P* < .001	

Means within the same column with different lowercase letter(s) are significantly different (DMRT, *P* < .05). Means within the same column with different uppercase letter(s) are significantly different (t-test, *P* < .05)

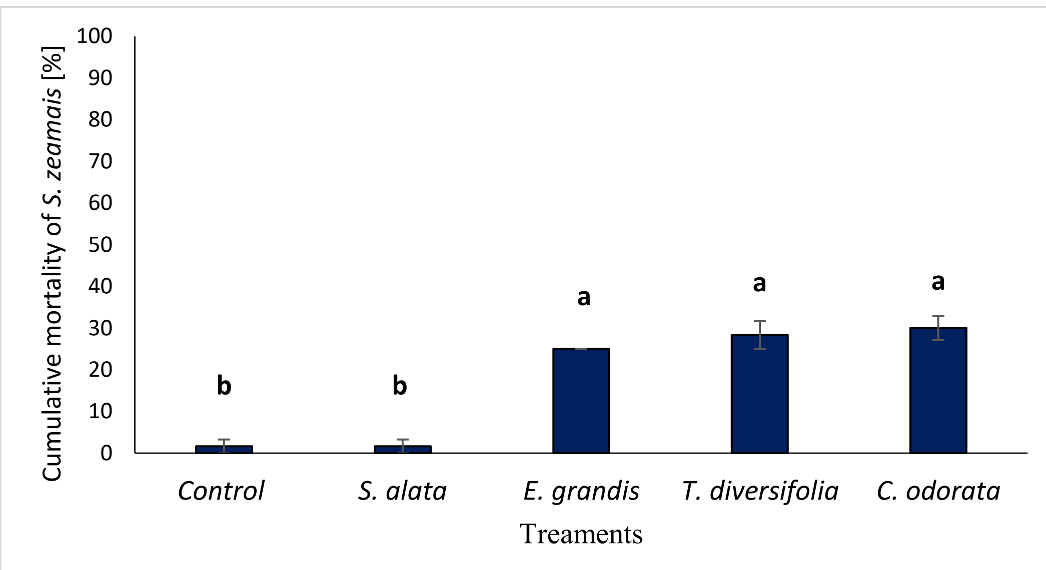


Fig. 4 Effect of different plant bio-active powders on cumulative mortality of maize weevil. Mean bars with different letter(s) are significantly different (DMRT, *P* < .05)

3.4 Effect of plant bio-active powders on germination of maize grains stored with maize weevil

The effect of plant powders on germination of maize after storage is presented in fig. 5. There was a significant difference (F = 37.70, df = 4, 10, *P* <.001) in the percentage germination of maize from different treatments. The highest percentage germination (94.44%) was observed from *C. odorata* and *T. diversifolia* treatments. This was followed by 86.11% observed from *E. grandis* treatment. The lowest percentage germination was 55.56%, recorded from control treatments (Fig. 5).

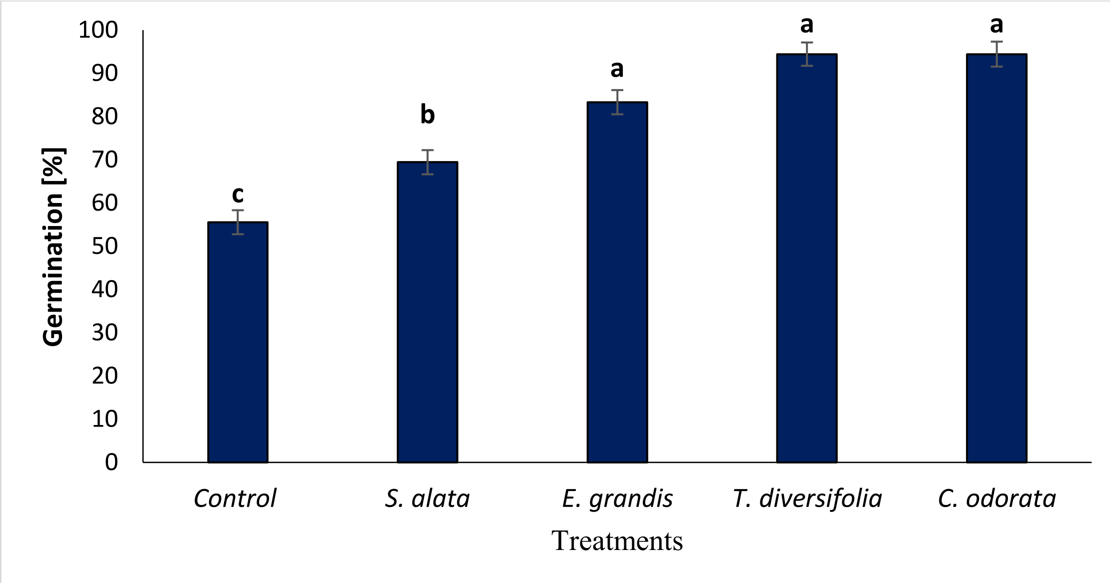


Fig. 5 Effect of different plant bio-active powders on germination of maize grains stored with maize weevil. Mean bars with different letter(s) are significantly different (DMRT, $P < .05$)

3.5 Correlation analysis of some measured parameters

Pearson-product moment correlation was conducted for some parameters (F1 generation emergence, percentage germination and cumulative mortality). There was a strong negative correlation ($r = -0.800$, $P < .001$) between F1 generation emergence and seed germination percentage (Fig. 6). Furthermore, there was a strong negative correlation ($r = -0.670$, $P < .001$) between cumulative mortality and F1 generation emergence (Fig. 7). A strong and positive correlation ($r = 0.887$, $P < .001$) was also recorded between cumulative mortality and germination percentage (Fig. 8).

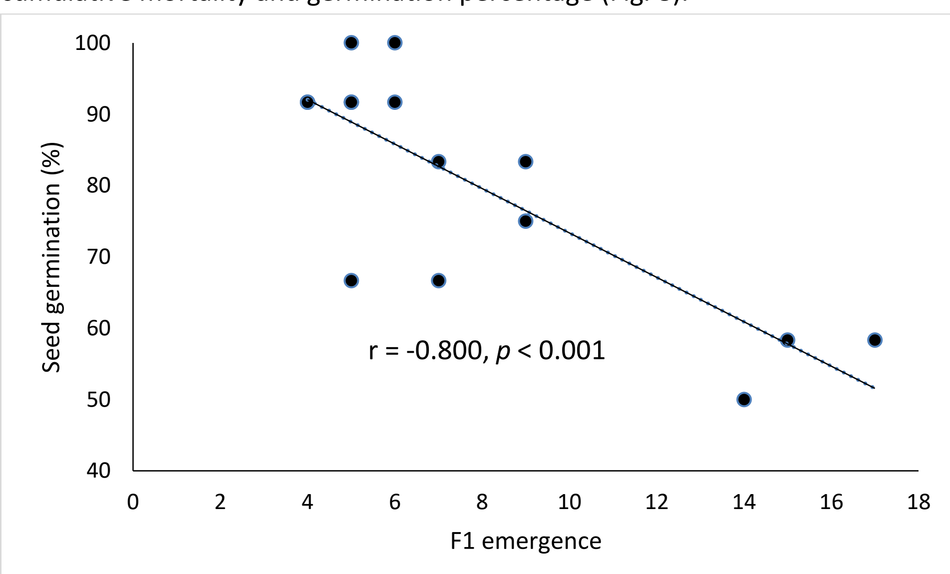


Fig. 6 Correlation analysis between F1 generation emergence and seed germination percentage

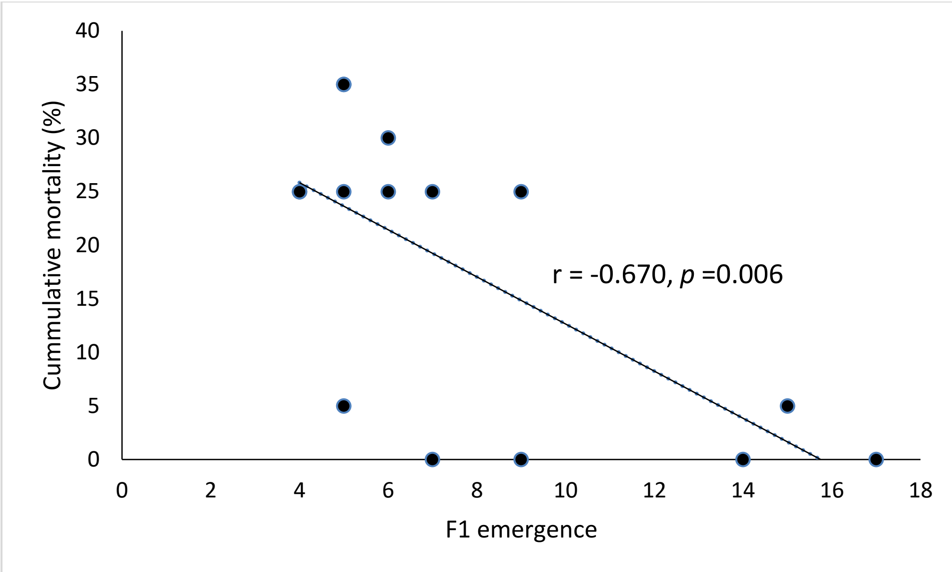


Fig. 7 Correlation analysis between F1 generation emergence and cumulative mortality

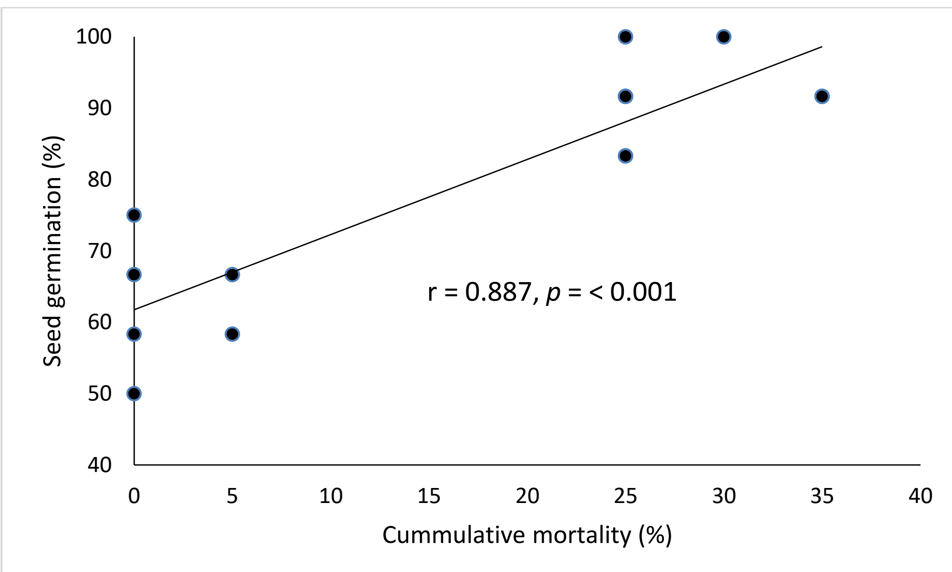


Fig. 8 Correlation analysis between cumulative weevil mortality (%) and seed germination percentage

4 Discussion

Many studies have been conducted to ascertain the effectiveness of some plant bio-active material against insect pest as sustainable alternatives of synthetic insecticides. In this study, the effect of some plant powders were studied on some biological parameters of maize weevils. The number of F1 generation emergence varied across treatments. The number of F1 generation emergence from the control was three times greater than that of *T. diversifolia* and *C. odorata* and twice that of *E. grandis* and *S.alata.* This result implies that the plant bio-active material present in these plant powders hindered F1 generation emergence. To what extend this plant bio-active material hinder F1 generation was estimated using the percentage hatching reduction. *C. odorata* and *T. diversifolia* recorded the highest percentage hatching reduction, at 66.67% and 64.44% respectively. This reveals that *C. odorata* and *T. diversifolia* were more efficient in reducing hatching and F1 generation emergence. Using the effect of plant bioactive material on hatching and F1 generation emergence is one of the methods used to evaluate the potency of plant bio-active material against insect pests [43-45]. Akob and Ewete [43] investigated the effect of plant powders on F1 generation emergence and reported differences among the plant powders tested (*Cupressus arizonica, Eucalyptus grandis, Ozimum gratissimum* and *Vetiveria zizanioides*). The findings of the current study are similar to those of Akob and Ewete [43]. F1 generation was greatly reduced (above 60%) in *C. odorata* and *T. diversifolia.* This could be due to the high secondary metabolite content in them. *T. diversifolia* is reported to have high content of sesquiterpenes, diterpeniods some of which have biological activities against insects [46]. The reduction of F1 generation may be a consequence of increased mortality of insect's juvenile stages such as the eggs and larvae due to ovicidal and larvicidal nature often associated with the secondary metabolites in plant based insecticides [47, 48]. Obeng-Ofori and Akumoah [45] have also reported high content of alkaloids and flavonoids in *C. odorata* these secondary metabolites have been reported to have very high anti-insect activity.

Variations in F1 emergence from maize treated with plant bio-active materials is common and it could indicate that plant material have different types and different concentrations of secondary metabolites [49]. For instance, Barre and Jenber [50] reported neem seed powder was as effective as the synthetic Malathion 5% in protecting maize grains with no F1 emergence i.e 100% F1 reduction, however, F1 emergence was reported with a reduction percent or inhibition rate of 91.0%, 50.0%, 44.0% and 33.0% from garlic, lantana, ginger rhizome and pepper powder, respectively. The current study is on par with [5] as they show variations in F1 emergence or F1 percent reduction (inhibition rate) from different plant materials. The potential of plant bio-active material to reduce the production of F1 generation of maize weevil is widely reported [23, 47, 48, 51].

Mortality of adult maize weevil as a result of the different plant bio-active material was low (< 5.0%) for all botanicals after the first week. However, by the second week, mortality soar to or greater than 25.0% observed from *T. diversifolia* and *C. odorata*.

The low mortality of maize weevil in week one of the experiment suggest that plant based insecticides especially in powder form are slow to kill insects compared to their synthetic counterparts [52]. Obeng-Ofori and Dankwah [52] reported a rapid knockdown action of synthetic insecticides, which instantly killed maize weevils compared to botanicals that killed weeks later. For all botanical tested (*Lantana camara*, *Moringa oleifera*, *Citrus sinensis* and *Hyptis suaveolens*), Gariba et al. [53] observed that more than 50% of maize weevil survived more than one week after setup, unlike for Actellic 25 EC (Pirimiphos-methyl) that all insects died within the first week.

The subsequent mortality in the second week could be as a result of the huge deposits of secondary metabolites in the plants. Ignacio et al. [54] reported that plants with high secondary metabolites have very low palatability or cause malaise upon ingestion by insects and could lead to death. This may explain the high cumulative mortality observed from *T. diversifolia* and *C. odorata.* The highest cumulative mortality observed in the current study was 30.0%. Nevertheless, higher mortalities have been observed from plant bioactive materials, especially those extracted in some solvents and as essential oils [45, 55]. In addition to the insecticidal properties of the botanicals due to the concentration of secondary metabolites, it is suggested that adult mortality of maize weevil might be due to the effective adhesion of dust particles to spiracles of pest and their death resulting from suffocation [53].

Seed germination after storage (with plant bio-active material and weevil) was assessed as a way to ascertain the degree of damage of maize grain by maize weevil, i.e how far the plant bio-active material could prevent maize grain damage by maize weevil. Germination was very high for *T. diversifolia, C. odorata* and *E. grandis* exceeding the certification limit of maize seed germination at 70% [56]. This suggest there was little insect activity on the grains stored with T. *diversifolia, C. odorata* and *E. grandis.* The high secondary metabolite content in these plants could have prevented feeding from any larvae hatched from any egg laid, or from the adults [54]. The findings of this study is on per with that of Ehisianya et al. [25]. The current study shed light on the fact that the use of plant products by farmers to store their grains does not have any negative influence on germination of the treated seeds. This remark is on par with findings of many other researchers [23, 53, 57]. In fact, consistently, maize grains treated with botanicals have recorded germination percentage greater than the certification limit of 70% with some reaching 100% similar to synthetic insecticides [50, 58].

The correlation analysis revealed varied associations between the measured variables. There was a negative correlation between F1 emergence and germination and between cumulative mortality and F1 generation emergence. This means that when F1 generation emergence was high, germination was low, implying that the emerging F1 destroyed the maize grains, leading to low germination of the seeds. On the other hand, there was a positive correlation between cumulative mortality and germination. This suggest that high mortality of adults leads to few eggs laid and less maize grain damage, consequently high germination rates. Additionally, Medugu et al. [59] reported that botanical powders weaken insects, resulting to a decrease in the number of eggs laid vis-à-vis their usual rate.

5 Conclusion

High anti insect properties observed from *T diversifolia* and *C odorata* revealed in the current study suggest that they could be adopted as plant protectants of maize grains against the maize weevil *Sitophilus zeamais*. The plant powders did not show any negative effect on maize seed variability as germination was very high. As a result, *T diversifolia* and *C odorata* are recommended as eco-friendly and sustainable maize grain protectants against the maize weevil. Further research with these plants extracted in different solvents and their shelf life are recommended.

Acknowledgements

We are grateful to the staff of the Entomology Laboratory for devoting their time to this study. We extend our gratitude to the Department of Agronomic and Applied Molecular Sciences of the University of Buea for proving lab space and their support throughout the research.

Author contributions

Tange Denis Achiri, Mamudou Jallow and Wirdzenyuy Susane Mensiy developed the concept and study design. Data collection was conducted by Tange Denis Achiri, Wirdzenyuy Susane Mensiy and Tanyi

Clovis Bessong, while data cleaning and formal analysis were carried out by Tange Denis Achiri, Oben Tom Tabi, Manju Evelyne, Lendzemo Eugene Tatah, Tanyi Clovis Tanyi and Njualem Dominic Khumbah. The initial manuscript was drafted by Tange Denis Achiri and Wirdzenyui Susane Mensiy, and all authors subsequently reviewed, edited, and approved the final version.

Funding
This work did not receive any funding.

Data availability
The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declarations
Ethics approval and consent to participate
Not applicable

Consent for publication
Not applicable.

Clinical trial registration
This study did not involve any clinical trials

Competing interests
The authors declare no competing interests.

References

1. Lyon F. Trust, networks and norms: the creation of social capital in agricultural economics in Ghana. World Dev. 2000;28(4):663-681. https://doi.org/10.1016/S0305-75X(99)00146-1
2. Sandhu KS, Singh N, Malhi NS. Some properties of corn grains and their flours, physiochemical, functional and chapti making properties of flours. Food Chem. 2007;101;938-946.
3. Yaouba A, Yaouba N, Tatsadjieu DPM, Jazet CM. Inhibition of fungal development in maize grains under storage condition by essential oils. Int J Biosci. 2012;2(6):41-48.
4. Kumar D. Jhariya NA. Nutritional and economical importance of corn. Res J Pharm Sci. 2013;2:7-8.
5. Erenstein O, Jaleta M, Sonder K, Mottaleb K, Prasanna BM. Global maize production, consumption and trade: Trends and R&D implications. Food Secur. 2022;14:1295–1319. https://doi.org/10.1007/s12571-022-01288-7
6. Gul H, Rahman S, Shahzad A, Gul S, Qian M, Xiao Q, Liu Z. Maize (*Zea mays* L.) Productivity in response to nitrogen management in Pakistan. Am J Plant Sci. 2021;12(8):1173–1179. https://doi.org/10.4236/ajps.2021.128081.
7. Dilip K, Aditya N. (2013). Nutritional, medicinal and economic importance of corn. Res J Pharm Sci. 2013;2(7):7-8.
8. Khawar J, Zahid A, Muhammad E. Maize: cereal with a variety of uses. DAWN – Business. [cited 2025 Jan 23]. Available from www.dawn.com/2007/03/12/ebr5.htm

9. Nand V. Effect of spacing and fertility levels on protein content and yield of hybrid and composite maize (*Zea mays*) grown in rabi season. J Agri Vet Sci. 2015;8:26-31.
10. Badu-Apraku B, Fakorede MAB, Menkir A, Sanogo D. Conduct and management of maize field trials. Ibadan: IITA; 2012. p59.
11. Ndoye A, Dia K, Ly R. AAgWa Crop Production Forecasts Brief Series: Cameroon – Maize. AAgWa Crop Production Forecasts Brief Series, No.12. Kigali, Rwanda: AKADEMIYA2063. 2023. https://doi.org/10.54067/acpf.12
12. Shiberu T. Determination of the appropriate doses of promising botanical powders against maize weevil, *Sitophilus zeamais* Mots (Coleoptera: Curculionidae) on maize grain. Agri Res Techn: Open Access J. 2017;6(5):104–108. https://doi.org/10.19080/artoaj.2017.06.555698.
13. Ukeh D, Arong G, Ogban E. Toxicity and oviposition deterrence of *Pipper guineense* and *Monodora myristica* against *sitophilus zeamais* on stored maize. J Entom. 2008;5(4):295-299.
14. Tadesse M. Post-harvest loss of stored grain, its causes and reduction strategies. Food Sci Qual Manag. 2020;96:26-35.
15. Nta AI, Bassey DA, Etim IF, Imalele E. Bioinsecticidal activities of *Azadirachta indica* and *Moringa oleifera* against maize weevil (*Sitophilus zeamais*) and rice weevil *(Sitophilus oryzae*). A review. Glo J Pure Appl Sci. 2024;30(3):271-281. https://doi.org/10.4314/gjpas.v30i3
16. Maqsood S, Shafi MU, Javaid A, Khan IH, Ali M, Ferdosi MFH. Control of insect pests and yield improvement in brinjal by plant extracts. Int J Bio Biotech. 2023;20(2):329-335.
17. Suleiman M, Yusuf M. The potential of some plant powders as biopesticides against *Sitophilus zeamais* (motsch.) (Coleoptera: Curculionidae) and *Callosobruchus maculatus* (F.) (Coleoptera: bruchidae) on stored grains: a review. Bayero J Pure Appl Sci. 2012;4(2):204-207. https://doi.org/10.4314/bajopas.v4i2.41.
18. Neupane BP, Sharma PN, Aryal S, Shrestha J. Evaluation of locally available botanicals for the management of maize Weevil (*Sitophilus zeamais* Motsch) in Room storage condition. Psyche: J Entom. 2023;6. https://doi.org/10.1155/2022/3362779.
19. Nsobinyenui D, Mensi WS, Kwanda BN, Abdulai AN, Sama V, Achiri DT, et al. Toxicity of some botanical powders on maize weevil *Sitophilus zeamais* Motschulsky 1855 (Coleoptera: Curculionidae). Sust Food Agri. 2022;3(2):69-74. https://doi.org/10.26480/sfna.02.2022.69.74.
20. Lopez-Castillo LM, Silva-Fernandez SE, Winkler R, Bergvinson DJ, Arnason JT, Garcia-Lara S. (2018). Postharvest insect resistance in maize. J Stored Prod Res. 2018;77:66-76. https://doi.org/10.1016/j.spr.2018.03.004.
21. Midega CAO, Murage AW, Pittchar JO, Khan ZR. Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya. Crop Prot. 2016;90:142-149. https://doi.org/10.1016/j.cropro.2016.08.033.
22. Farrar JJ, Baur ME, Elliot SF. Measuring integrated pest management impacts in California and Arizona. J Integr Pest Manag. 2016;7(1):13. https://doi.org/10.1093/jipm/pmw012.
23. Achiri DT Njweng MA. (2015).Bioactivity of cypress leaf powder (*Cupressus macrocarpa*) on cowpea and maize weevils in Cameroon. Int J Interdiscip Multidiscip Stud. 2015;2(4):1-10.
24. Chougourou CD, Zoclanclounon A, Agbaka A, Togola A. Toxicity of two plant powders as biopesticides in the management of *Callosobruchus maculatus* F. (Coleoptera: Chrysomelidae, Bruchinae) on two stored grain legumes. J Appl Biosci. 2015;86:7900-7908. https://doi.org/10.4314/jab.v86i1.5.

25. Ehisianya CN, Ikpi PO, Okore OO, Obeagu IA. Assessment of plant powders as protectants of stored maize grain against maize weevil, *Sitophilus zeamais* (Motsch). [Coleoptera: Curculionidae). Nigerian Agri J. 2019;50(1):37-45

26. Talukder F, Islam M, Hossain, M, Rahman M, Alam M. Toxicity effects of botanicals and synthetic insecticides on *Tribolium castaneum* and *Rhyzopertha dominica*. Bangladesh. J Env Sci. 2004;10(2):365–371.

27. Ramanan M, Muthukumaran N. Anti-insect effect of *Senna alata* L. seed solvent extracts on *Spodoptera litura* Fab. J Phamacog Phytochem. 2009;8(2):401-405.

28. Pujiarti R, Fentiyanti PK. Chemical compositions and repellent activity of *Eucalyptus tereticornis* and *Eucalyptus deglupta* essential oils against *Culex quinquefasciatus* mosquito. Thailand J Pharm Sci. 2017;41(1):19–24.

29. Toloza AC, Zygadlo J, Cueto GM, Biurrun F, Zerba E, Piccolo MS. Fumigant and repellent properties of essential oils and component compounds against permethrin-resistant *Pediculus humanus* capitis (Anoplura: Pediculidae) from Argentina. J Med Entom. 2006;43(5):889–895.

30. Avlessi F, Alitonou GA, Djenontin ST, Tchobo F, Yèhouénou B, Menut C, Sohounhloué D. Chemical composition and biological activities of the essential oil extracted from the fresh leaves of *Chromolaena odorata* (L. Robinson) growing in Benin. ISCA J Biological Sci. 2012;1(3):7-13.

31. Lawal O, Opoku A, Ogunwande I. (2015). Phytoconstituents and insecticidal activity of different solvent leaf extracts of *Chromolaena odorata* L., against *Sitophilus zeamais* (Coleoptera: Curculionidae). Eur J Med Plants. 2015;5(3):237-247. https://doi.org/10.9734/EJMP/2015/6739.

32. Onunkun O. Evaluation of aqueous extracts of five plants in the control of flea beetles on okra (*Abelmoschus esculentus* L. Moench). J Biopest. 2012;5:62-67. https://doi.org/10.57182/jbiopestic.5.0.62-67.

33. Amoabeng BW, Gurr GM, Gitau CW, Stevenson PC. Cost: Benefit Analysis of Botanical Insecticide Use in Cabbage: Implications for Smallholder Farmers in Developing Countries. J Crop Prod. 2014;57:71-76. http://dx.doi.org/10.1016/j.cropro.2013.11.019.

34. Bouda H, Tapondjou LA, Fontem DA, Gumedzoe MYD. Effect of essential oils from leaves of *Ageratum conyzoides, Lantana camara* and *Chromolaena odorata* on the mortality of *Sitophilus zeamais* (Coleoptera, Curculionidae). J Stored Prod Res. 2001;37(2):103-109. https://doi.org/10.1016/s0022-474x(00)00011-4.

35. Ajao AA, Moteekee AN. *Tithonia diversifolia* (Hemsl) A. Gray. (Asteraceae: Heliantheae), an invasive plant of significant ethnopharmacological importance: a review. S Afr J Bot. 2017;113:396-403. https://doi.org/10.1016/j.sajb.2017.09.017.

36. Chukwuka KS, Ojo OM. Extraction and characterization of essential oils from *Tithonia diversifolia* (Hemsl.) A. Gray. Am J Essent Oil Nat Prod. 2014;1(4):1-5.

37. Lamaty G, Menut C, Zollo PHA, Kuiate JR, Bessiere JM, Koudou J. Aromatic plants of tropical central Africa. III. Constituents of the essential oil of the leaves of *Tithonia diversifolia* (Hemsl.) A. Gray from Cameroon. J Essent Oils. 1991;3(6):399-402. https://doi.org/10.1080/10412905.1991.9697973.

38. Moronkola DO, Ogunwande IA, Walker TM, Stzer WN, Oyewole IO. Identification of the main volatile compounds in the leaf and flower of *Tithonia diversifolia* (Hemsl) Gray. J Nat Med. 2007;61:63-66. https://doi.org/10.1007/s11418-006-0019-5.
39. Green PWC, Belmain SR, Ndakidemi PA, Farrell IW, Stevenson PC. Insecticidal activity of *Tithonia diversifolia* and *Vernonia amygdalina.* Ind Crops Prod. 2017;110. https://doi.org/10.1016/j.indcrop.2017.08.021.
40. Mkenda PA, Stevenson PC, Ndakidemi P, Farman DI, Belmain SR. Contact and fumigant toxicity of five pesticidal plants against *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) in stored cowpea (*Vigna unguiculata*). Int J Trop Insect Sci. 2015;35: 172-184. https://doi.org/10.1017/S174275841500017X
41. Ngosong C, Mfombep PM, Mjume AC, Tening AS. Comparative advantage of T*tithonia* and *Mucuna* residues for improving tropical soil fertility and tomato productivity. Int J Plant Soil Sci. 2016;12:1-13.
42. Ranasinghe RHAA, Ratnayake RMCS, Kannangara BTSDP. Effect of foliar and soil-applied liquid organic fertilizers on growth of *Basella alba* L. and *Centella asiatica* L. J Agri Sci-Sri Lanka. 2021;16(3):393-409. http://doi.org/10.4038/jas.v16i03.9466.
43. Akob CA, Ewete FK. Control of *Sitophilus zeamais* Motschulsky (Coleaptera: Curculionidae) with local plant materials in the western highlands of Cameroon. J Cameroon Acad Sci. 2010;9(1):3-10.
44. Jallow M, Pitan OOR. (2023). Evaluation of some Plant Powders as Natural Biopesticides Against Maize Weevil *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae). Middle East J Agri Res. 2023;12(4):823-830.
45. Obeng-Ofori D, Akuamoah RK. Biological effects of plant extracts against the rice weevil *Sitophilus oryzae* in stored maize. J Ghana Sci Ass. 2000;2(2):62-29.
46. Kandungu J, Anjarwalla P, Mwaura L, Ofori DA, Jamnadass R, Stevenson PC, et al.. Pesticidal plant leaflet, *Tithonia diversifolia* (Hemsley) A. Gray. ISBN 978-92-9059-347-8. 2013.
47. Tapondjou LA, Adlerb C, Boudaa H, Fontem DA. Efficacy of powder and essential oil from Chenopodium ambrosioides leaves as post-harvest grain protectants against six-stored product beetles. J Stored Prod Res. 2002;38: 395–402. https://doi.org/10.1016/S0022-474X(01)00044-3, 2-s2.0-0037124553.
48. Wahedi J. (2012). 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 Uni J Sci Res. 2012;2(2):2251–0702.
49. Kifle F, Girma M, Gebresilassie A, Wodehawariat Y, Ele E. Chemical composition and insecticidal potential of botanical fractionation extracts for the management of *Sitophilus zeamais* Motschulsky, 1855 (Coleptera: Curculionidae) in stored maize. Heliyon, 2025;11(3):242131. https://doi.org/10.1016/j.heliyon.2025.e42131.
50. Barre J, Jenber AJ. 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. 2022;8(12):e11859. https://doi.org/10.1016/j.heliyon.2022.e11859.
51. Danga SP, Nukenin EN, Fotso GT, Adle C. Use of NeemPro®, a neem product to control maize weevil *Sitophilus zeamais* (Mostch.) (Coleoptera: Curculionidae) on three maize varieties in Cameroon. Agric Food Secur. 2015;4(18):2–7. https://doi.org/10.1186/s40066-015-00-z.

52. Obeng-Ofori D, Dankwah JA. Biological effects of four protectants applied to store Bambara groundnut against infestation by *Callosobruchus maculatus* (Fab) (Coleoptera: Bruchidae). J Ghana Sci Ass. 2004;37(1):33-42. https://doi.org/10.4314/gjas.v37i1.2077

53. Gariba SY, Dzidzienyo DK, Eziah VY. Assessment of four plant extracts as maize seed protectants against *Sitophilus zeamais* and *Protephanus truncates* in Ghana. Cogent Food and Agri. 2021;7:1918426. https://doi.org/10.1080/23311932.2021.1918426.

54. Ignacio JM, Schilman PE, Barrozo RB. Impact of alkaloids in food consumption, metabolism and survival in a blood-sucking insect. Scientific Report. 2020;10:9443. https://doi.org/10.1038/s41598-020-65932-y

55. Suleiman M, Sani I. Insecticidal activity of ethanolic leaf extracts against the maize weevil, *Sitophilus zeamais* Mostch (Coleoptera: Curculionidae). HSOA Arch Zool Stud. 2018;1(004):2-7. https://doi:10.24966/AZS-7779/100004.

56. International Seed Testing Association (2007). International Rules for Seed Testing. Bassersdorf, Switzerland: ISTA; 2007. 84p.

57. Foidl N, Makkar HPS, Becker K. The potential of *Moringa oleifera* for Agricultural and industrial uses. In: What development potential for Moringa products? 2001 20 Oct – 2 Nov; Dar Es Salaam. Tanzania. 2001.

58. Kifle F, Girma M, Gebresilassie A, Woldehawariat Y, Ele, E. Evaluation of crude extracts from plants for controlling maize infestations caused by weevil *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae). Psyche: J Entomo. 2024 https://doi.org/10.1155/2024/5993907.

59. Madugu MA, Okrikata E, Dunuwel DM. Management of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) using Nigerian raw diatomite. J Appl Sci Env Manag. 2020;24(9):1663–1669. https://doi.org/10.4314/jasem.v24i9.26.