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Original Research Article

Effects of biopesticides extracted with a homemade solvent on stored maize protection

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Abstract

Synthetic chemicals continue to play an important role in reducing storage losses attributable to insect pest activities. However, the adverse effects associated with some patented chemicals make synthetic pesticides less attractive and have given the drive to search for alternative methods of pest control. This study evaluated the effects of a traditional gin, akpeteshie crude extracts made of four timber species, neem (*Azadirachta indica*), mahogany (*Khaya senegalensis*), teak (*Tectona grandis*) and cedrela (*Cedrela odorata*) on the maize weevil *Sitophilus zeamais* on stored maize grains in the laboratory. Home-made extracts of the test tree plants at concentrations of 0.5, 1.0 and 2% were tested as grain protectants or as insect poisons. All tested extracts in their respective concentrations performed well in the reduction of live insects during maize storage as compared to a non-extract treatment. The mode of action of all the extracts was generally concentration and time-dependent. On average neem extract was the most effective followed by mahogany, teak, and cedrela in that order. Neem and mahogany extracts performed well in reducing grain damage at a concentration of 2% and at 0.5% concentration of cedrela extract respectively. All extracts reduced progeny emergence and acted both as a repellent or a toxicant. The extracts performed better as compared to the untreated control in the viability of maize seeds leading to germination, and subsequent seedling emergence. The relatively low weight loss of the stored grains treated with these crude extracts during the 90-day experimental period at a maximum concentration of 2% is predictive that they can be adopted as safe and alternative grain protectants against weevils in store. The unknown phytochemicals in these akpeteshie hardwood extracts may be responsible for the insecticidal properties against the weevils. For some concentrations of the extracts, germination was inconsistent which led to the suspicion of allelopathy.

Keywords: crude extracts; akpeteshie; stored maize; weevils; hardwood; seed viability; sustainability; smallholder farmers

INTRODUCTION

Maize is an important source of carbohydrates in the tropics and constitutes a major staple (FAO, 2019), and a source of raw material in industry (Makate, 2010), for example as a constituent in animal rations (Bathla et al., 2019) especially in the poultry industry (Huma et al., 2019; Scheiterle and Birner, 2018). It is conservatively estimated that about 25% of maize produced in West Africa annually is destroyed or damaged by diseases and pests (Mulungu and Ng'ombe, 2019) before reaching the consumer. In Ghana, maize which is grown in all 16 regions (WABS, 2008; Danquah et al., 2020) accounts for about 50% of local cereal production (Appiah-Twumasi et al., 2020;

Darfour and Rosentrater, 2016). It is harvested and stored for about six months before consumption as human food or in feed mills (Scheiterle and Birner, 2018). Lobulu (2019) identified field and post-harvest losses as the most important constraints that limit maize production, and this has similarly been reiterated in Ghana by Obour et al. (2022).

The importance of maize in both domestic and industrial applications suggests that conscious efforts must be made to reduce crop losses along the value chain, especially in the post-harvest sector (Affognon et al., 2015). The greatest losses are incurred during storage and particularly occur in developing countries (Kumar and Kalita, 2017).

It has been reported that 40% of postharvest losses are due to insect and mite infestation worldwide (Bradford et al., 2018), which justifies the need to make strenuous efforts to control them (Granella et al., 2021).

Insect pests destroy stored products by either direct feeding or reduction in grain quality (Berge et al., 2022). Insect species that feed on the endosperm cause weight and quality loss while those that feed on the germ, result in low seed viability (Nwosu et al., 2015). Maize weevils are responsible for both field and stored maize damage (Abass et al., 2018; Van Duong et al., 2020). Infestations initiated in the standing crop continue after harvesting (Hamel et al., 2020).

The maize weevil *Sitophilus zeamais* (Motschulsky) Curculionidae is a serious pest of stored maize (Sori and Ayana, 2012) and can cause considerable losses (Ojo and Omoloye, 2012; Sabbour, 2012; Bhusal and Khanal, 2019). It is virtually cosmopolitan in the tropics (Paes et al., 2012) and occurs in the more humid regions of the world, especially where maize is grown (Van Duong et al., 2020). According to Opit et al. (2014) about 15% of maize grains harvested in Ghana are lost annually to *S. zeamais* and in some cases, total loss can occur (Gariba et al., 2021). The adult weevil feeds and lives for up to five months (Van Duong et al., 2020) and sometimes from several months to a year in stored grains (Ojo and Omoloye, 2016). Van Duong et al. (2020) showed that the presence of *Sitophilus* spp. in maize grains led to a reduction in germination. Its destructive status is pronounced when maize is stored on-farm, with no control of moisture content, and without chemical protectants (Simbarashe et al., 2013; Nwosu et al., 2015). There is also a health risk associated with consumption of weevil-infested maize grain; as they enhance the growth of *Aspergillus* spp. (Van Duong et al., 2020) which contaminate maize with aflatoxin (Suleiman et al., 2013; Befikadu 2014; Omotayo et al., 2019).

Insect control in stored food products relies heavily on the use of strategies such as fumigants (Sugri, 2021) residual contact insecticides (Morrison III et al., 2020), resistant cultivars or manipulation of the storage atmosphere (Van Duong et al., 2020). Even though synthetic chemicals continue to play an important role in reducing storage losses due to insect pest activities insecticide resistance (Attia et al., 2020), toxic residues in food, environmental pollution, adverse effects on non-target insects (Gajger et al., 2017), increased risk to workers safety and the high cost of some patented chemicals (Sawicka, 2019) makes them unattractive.

Numerous successes have been recorded in the protection of stored grains by using biorational products (Derkyi et al., 2010; Sintim, 2014) such as botanical insecticides (Rajashekar et al., 2012). Several authors including recently Mohammad et al. (2023) have evaluated the insecticidal effects of various plant parts on *S. zeamais* with varying degrees of success (Yohannes et al., 2014; Parwada et al., 2018). Most phytochemicals generally have low mammalian toxicity (Kapinova et al., 2018) or have low persistence (Chaudhary, 2017; Trivedi et al., 2018), contain a myriad of chemicals which is ideal to delay resistance, and are readily available (Talukder et al., 2009).

The bioactivity of allelochemicals from tropical trees against insects has been reported (Grzywacz et al., 2014) but commercial exploitation has been quite slow (Chaudhary, 2017). Some plant-derived oils have also been used in the protection of storage grains (Sintim, 2014; Chaubey, 2019). Other tested plant parts include seeds (Tilahun and Daniel, 2016) powders, and wood ashes (Akob and Ewete, 2007). Tree plants like neem (Ahmad et al., 2015), teak (Rahmat et al., 2019), mahogany (Baba et al., 2020) and cedrela (Okwute, 2012; Tilahun and Daniel, 2016; Gómez-Tah et al., 2020) have also been exploited in pest management to some extent (Regnault-Roger et al., 2012).

Smallholder farmers with low technical and resource capabilities could be introduced to technologies that rely on local ingredients (Obeng-Ofori, 2007) to sustainably reduce grain losses. The search for alternative methods of pest control remains the most decisive quagmires in the post-harvest schema (Sawicka, 2019). In the storage environment, there is the need to be cautious in employing persistent insecticides being cognisant of residues. The use of an inexpensive insecticide in low-income settings will be welcomed if the make-up ingredients are readily available and affordable as indicated by Amoabeng et al., (2014).

Many experiments conducted on neem, mahogany, cedrela, and teak show that several parts of these plants can be processed and applied as insecticides to control stored produce insect pests (Ahmad et al., 2015; Tilahun and Daniel, 2016; Rahmat et al., 2019; Baba et al., 2020; Gómez-Tah et al., 2020). This study extends the above approaches by evaluating the efficacy of the hardwood extracts of neem, mahogany, teak, and cedrela for the protection of stored maize against infestation by *Sitophilus zeamais*. The innovation here is to test the efficacy of bio-alcohol, akpeteshie which is typically 98.95% v/v (proof) ethanol as a solvent for the extraction of the active principles from these four timber species as a biopesticide.

MATERIALS AND METHODS

Source of experimental materials

Four tropical hardwoods: cedrela (*Cedrela odorata)* (P. Browne), Meliaceae, neem (*Azadirachta indica*) (A Juss) Meliaceae, teak (*Tectona grandis)* (L. f) Lamiaceae and mahogany (*Khaya senegalensis*) (A Juss) Desrousseaux/Meliaceae were selected for the experiments. Due to rural economics and farmscape applicability, a homemade alcohol "akpeteshie" (Tulashie et al. 2017; Tagba et al., 2018; Cooking with Sindaco 2022) with a purity (proof) of 63% was purchased from local distillers and was used as the solvent for the extraction of active principles from the four timber species available in an area which has a vibrant wood industry. Dried grains of Pannar 53 maize variety with a moisture content of 12.5% were used. The grains were sterilised in a freezer at −12 °C for 28 days to destroy any incipient infestation. The sterilised grains were conditioned prior to any experiment. The plant parts of teak, neem, and mahogany were collected from growing trees, whilst cedrela lumber was secured from a sawn timber market.

Insect culture

The initial stock of *S. zeamais* used for the experiment was obtained from a commercial maize market in Sunyani, Ghana. Maize variety Pannar 53 whole grains were obtained from a farmer's field and were dried to 12.5 %, frozen, and conditioned before use. About 120 unsexed weevils were introduced into 1000 g grain in 1.25 L Kilner™ jars. The containers were covered with nylon screen nets (1 mm) and tightly fastened with rubber bands or perforated jar lids, to secure the insects. These introduced insects for oviposition were sieved out after one week. The setup in three replicates was placed on shelves at 28 ± 2 °C, 65–70% RH, 12:12 photoperiod and monitored daily until emergence of F1 progenies as described by (Haines, 1991) and modified by Ojo and Omoloy (2016). Set-up conditions apply to all subsequent indoor experiments.

Preparation of plant extracts

Heartwoods and barks in a 1:1 ratio by weight were cleaned of any adhering material for each plant specimen. It was chopped into 15–20 mm pieces and sun-dried at 55 °C for 72 hours. The dried plant materials were pounded into flakes using traditional wooden mortar and pestle and later pulverised into fine powder using an electric blender, OMEGA BL 390S OMEGO 11–2. One hundred grams of wood powder for a plant specimen was extracted with 700 ml of 63% purity akpeteshie for 48 hours in a transparent glass container measuring 1250 ml. The mixtures were manually agitated intermittently to help speed up the extraction process. These were, decanted and sieved using Whatman No-2 filter paper. The containers with the crude extracts were left exposed on lab benches to evaporate the excess solvent using a ceiling fan for two days at ambient conditions. The resultant slurry or powdery material constituted the final crude extract. The final crude extract was preserved in sealed bottles at 4 °C until used for bioassays. The total extractable components recorded as percentage yield was obtained using the formula $W2 - W1 / W0 \times 100$, where W2 is the weight of the extract and the container, W1 is the weight of the container alone, and W0 is the weight of the initial dried sample.

Bioassay procedures

Effects of the extracts on adult weevil and progeny emergence

One hundred grams of freeze-sterilised maize grains were treated with different concentrations each of either teak, mahogany, neem, or cedrela reconstituted crude akpeteshie extracts, (0.5, 1.0 and 2.0 g/100 ml) in 460 ml containers. The test solutions were stirred continuously until a dispersion was formed which was evenly spread over the surface of the grain and allowed to dry. These were infested with 20 newly emerged (3–10-days-old) weevils from the progenies of the initial stock and allowed oviposition. They were all sieved out after seven days and data were taken on the mortality rate. The set-up which was in three replicates was monitored for 60 days for the F_1 progeny emergence. The number of adults that emerged during the 60-day period was counted daily and sieved out. The grains were weighed at 30, 60, and 90 days to determine the weight loss of the grains in storage. The weight differences over time were recorded as the monthly weight loss of grains. The control setup was treated with only the solvent, akpeteshie. Another set-up without insects or solvent or extract was made to make up for corrections in moisture loss due to the natural dryness of the default grain. In all toxicity experiments where mortalities were ≥5%, the controls were used as a correction for natural mortalities using Abbott (1925).

Toxicity by topical application

Newly emerged (3–10-day-old) adult weevils of mixed sexes were first transferred into Petri dishes lined with moist filter paper and the insects were chilled for two minutes to immobilise them to enable topical treatment to be carried out. The immobilised insects were sprayed to mild wetness with different concentrations of teak, cedrela, neem or mahogany extracts (0.5, 1.0, and 2.0 g/00 ml), separately. The control insects were treated with only the solvent and maintained at 28 ± 2 °C, 65–75 RH. Twenty insects each treated with the various extracts were placed in separate dishes lined with filter paper and provided with maize grains as described by Obeng-Ofori and Reichmuth (1997). The insects were examined at 12-hour intervals for two continuous days and those that did not move or respond to a punch from a pin were considered dead. There were three replications for each treatment and the control.

Contact toxicity by the residual effect

Three 1-ml vials for each extract concentration or control were used. The three concentrations, 0.5, 1.0, and 2.0 g/100 ml solvent were dispensed into the vials and allowed to air dry. Ten newly emerged weevils (3–10-day-old) were introduced into each vial. The insects were examined at 12 hours intervals for 24 hours. All environmental conditions were the same as in previous bioassays.

Repellent effect of surfaces treated with plant extracts

Concentrations (0.5, 1.0, and 2.0 g/100 ml w/v) of the plant extracts to solvent were applied to half filter paper disc of diameter 7.5 cm. The other half was treated with solvent, akpeteshie only. The extract-treated filter papers were air-dried to evaporate the solvent after which the two halves were joined together with a masking tape and placed in Petri dishes. Twenty adult weevils which were immobilised at 4 °C for two minutes were put in 5-ml caps and then placed in the middle of the joined filter papers and covered as described by Ahmad et al. (2022). The numbers of insects present in either the control or treated section was recorded after 1, 2, 6, 12, and 18 hours. There were three replications for each treatment. The percentage repellency (PR) was determined using the formula adopted by Liu et al. (2012) and Kadir et al. (2014) as $PR = \{(Nc - Nt) / No)\} \times 100\%$. Where Nc: represents the number of insects in control, Nt: number of insects on the extract, No = Nc + Nt. Where No represents the number of insects introduced which was 20. All negative PR were treated as zero, an indication that the extract was an attractant.

Grain damage

The protection of grains offered by the test extracts against weevil feeding or damage was assessed. Fifty maize kernels were randomly selected from a bulk of treated grains at the highest concentration (2%) of each extract for this study. The number of seeds damaged by the weevil in each sample was counted. Seeds with typical weevil emergence holes were considered damaged.

Germination test in Petri dish

Filter paper in Petri dishes was moistened with distilled water enough to enhance imbibition. Ten treated seeds for each extract and the same number of untreated maize seeds as control treatment were randomly selected. The maize seeds were placed on the moistened filter paper in Petri dishes. This was covered and placed on laboratory benches. Germinated seeds were counted after five days and were recorded. Percentage germination was calculated using the relation (Akinbuluma, 2020):

$$\text{Percent germination} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds moistened}} \times 100$$

Seedling emergence using soil media

The viability of treated and untreated seeds was tested after exposing treated seeds to weevils for three months. Ten undamaged grains were selected from each treatment and sowed in nursery bags filled with soil. They were left on a laboratory bench exposed to sunlight for 5–10 days. There were three replicates per treatment. Emerged seedlings were counted during the 5–10 days after sowing and the percentage of seedling emergence was calculated using the relation:

$$\text{Percent emergence} = \frac{\text{Number of seeds that emerged}}{\text{Total number of seeds sowed}} \times 100$$

Statistical analyses

Data analyses were conducted using GENSTAT procedures and graphs were plotted using a spreadsheet. Data from three replications were used in these analyses. Significant differences are reported at 0.05 level using the Least Significant Difference test GENSTAT® (2012). Data for non-significant comparisons are represented in chats as ± standard error of the mean (SEM).

RESULTS

Yield of plant extracts

Figure 1 shows the percentage yield of the akpeteshie bio-alcohol (63% purity) extracts of teak, neem, mahogany, and cedrela. The yields obtained were between 5.8% and 13.3%. Cedrela gave the highest yield (13.3%) while teak was the least (5.8%). Neem yield was 6.9% and mahogany was 12.7%.

One hundred grams of wood powder consisting of equal weights of barks and heartwood for a plant material was extracted with 700 ml of 63% alcohol (akpeteshie) and evaporated to dryness. Error bars in all extracts represent SEM.

Moisture loss in grains coated with extracts

The initial moisture content for all grains used for all experiments was 12.5%, which was ideal to maintain the viability of seeds in store. Results obtained with the experiment to determine moisture changes in grains coated with plant extracts indicated that the maximum moisture loss by the 90^{th} day was 10.4% of the initial weight. Generally, mahogany extracts had the highest moisture losses among the test plants. Mahogany extract at 0.5% led to a moisture loss of 10.4% (Figure 2d) after 90 days. The default grain treatment had lower weight losses (maximum 0.7) than the extract-coated grains for all concentrations at each inspection period (Figure 2). In all extract treatments weight loss was least for the 2% concentration at each storage period (maximum 5.4% for teak at 90 days). For the plant extract treatments, weight loss increased with decreasing concentration. The grains that were treated with only solvent had their highest weight loss of 6.2% at 90 days.

Effects of extracts on adult weevil and progeny emergence

For all treatments and extracts, weevil emergence started 36 days after oviposition initiation (Figure 3). At day 60, there was no further weevil emergence in the treatments where 2% neem/teak extracts were used as oviposition deterrents. In all three tested concentrations of either neem or teak, the total number of emerged adult weevils was less than three individuals (Figure 3a & b). Grains treated with 2% concentration of cedrela, or mahogany extracts had a cumulative of 8 or 6 weevils, respectively, emerging at 60 days after

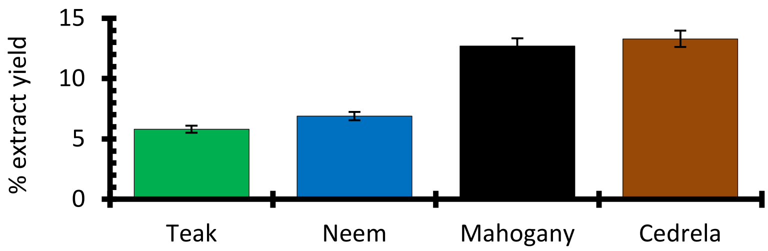

Figure 1. Yield of akpeteshie bio-alcohol (63% purity) extracts of four lumber species

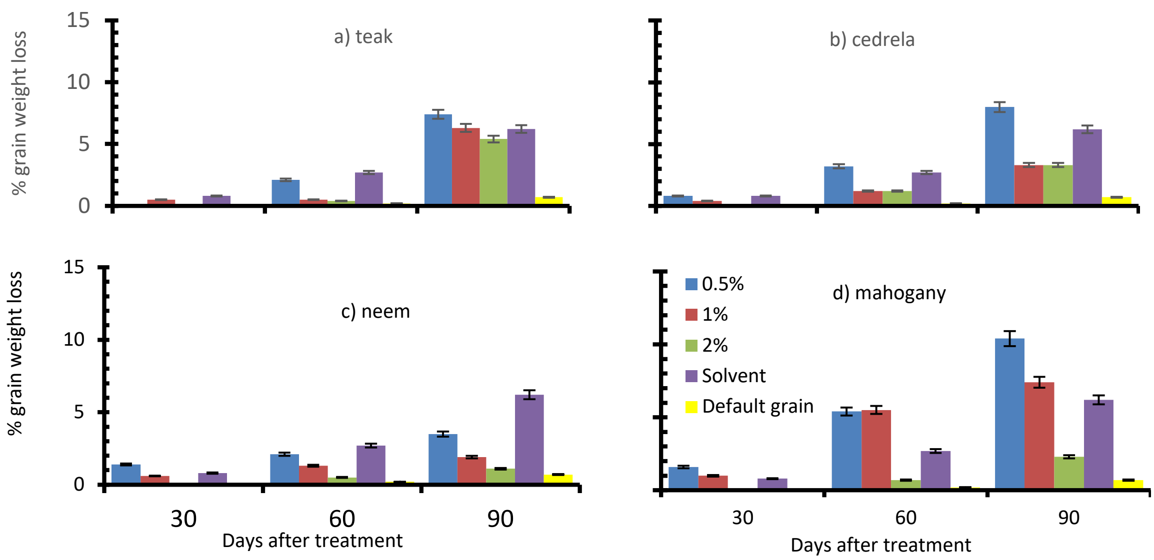

Figure 2. Weight loss in maize grains treated with akpeteshie bio-alcohol (63% purity) plant extracts. Error bars in all extracts represent SEM.

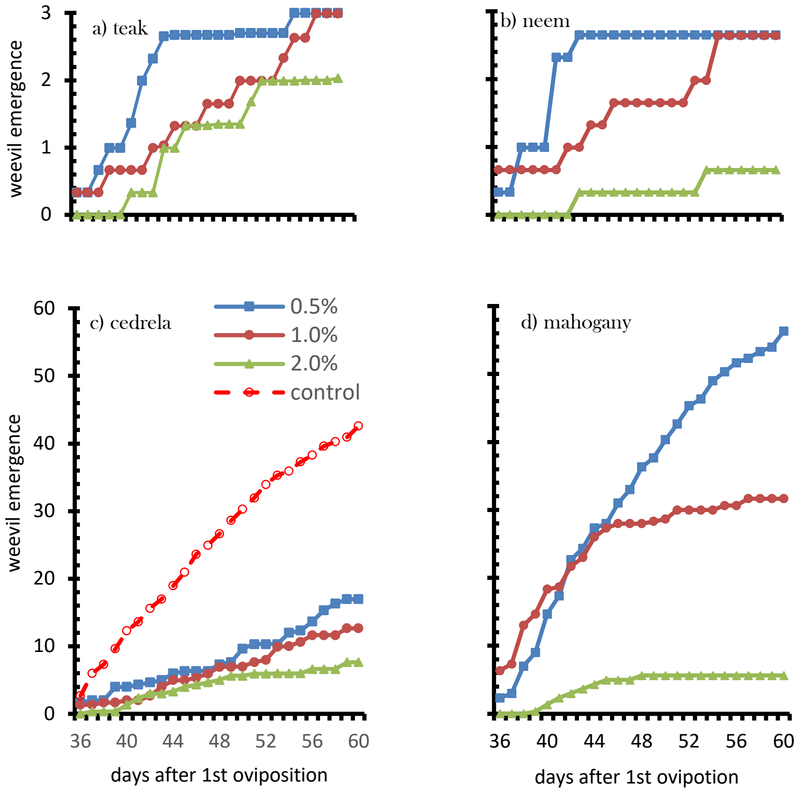

Figure 3. The effect of akpeteshie bio-alcohol (63% purity) plant extracts on cumulative progeny emergence

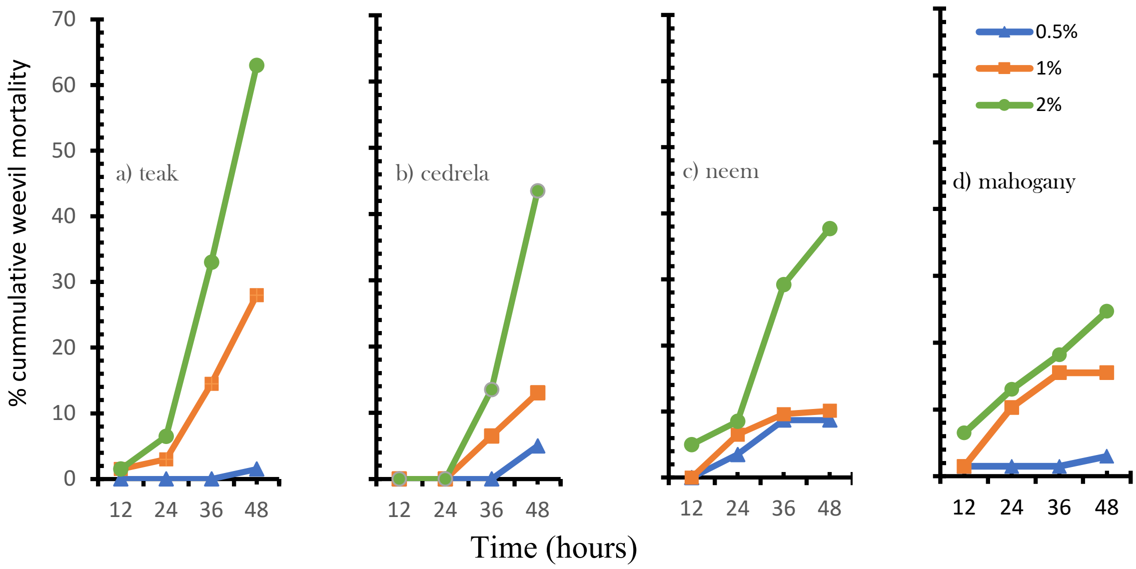

Figure 4. Toxicity by topical application on weevils with akpeteshie bio-alcohol (63% purity) plant extracts. Mortality was corrected using Abbott (1925).

the first oviposition. However, unlike the neem and teak treatments where weevil emergence terminated for all concentrations, in the case of mahogany and cedrela, concentration below 2% offered only limited protection similar to the untreated grains. There was continuous weevil emergence in the 0.5% and 1% treatments for cedrela and mahogany on the 60th day after oviposition initiation (Figure 3c & d). when the experiment was terminated

In this experiment and subsequent ones that recorded adult mortality, none of the control treatments had a mortality ≥ 5 %, hence no correction for intrinsic or natural mortality was made.

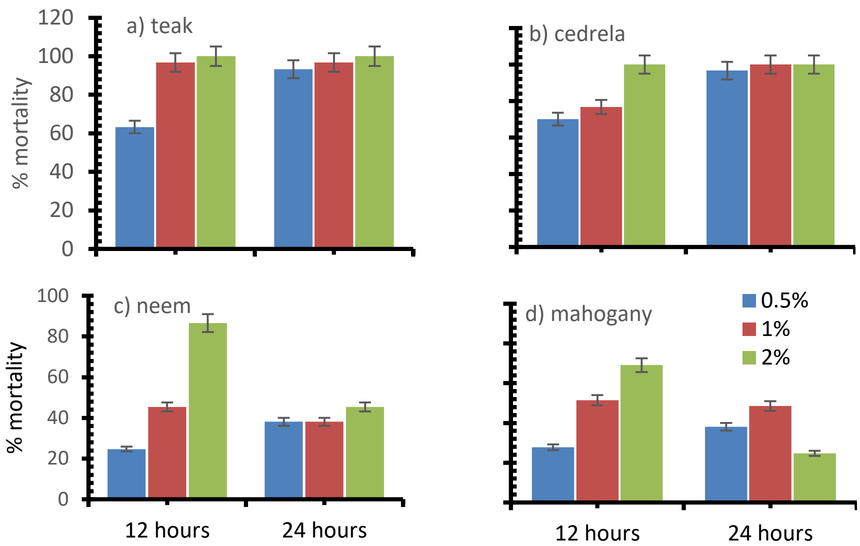

Figure 5. Contact toxicity on weevils by residual effect of vials treated with akpeteshie bio-alcohol (63 % purity) plant extracts. Error bars in all extracts represent SEM.

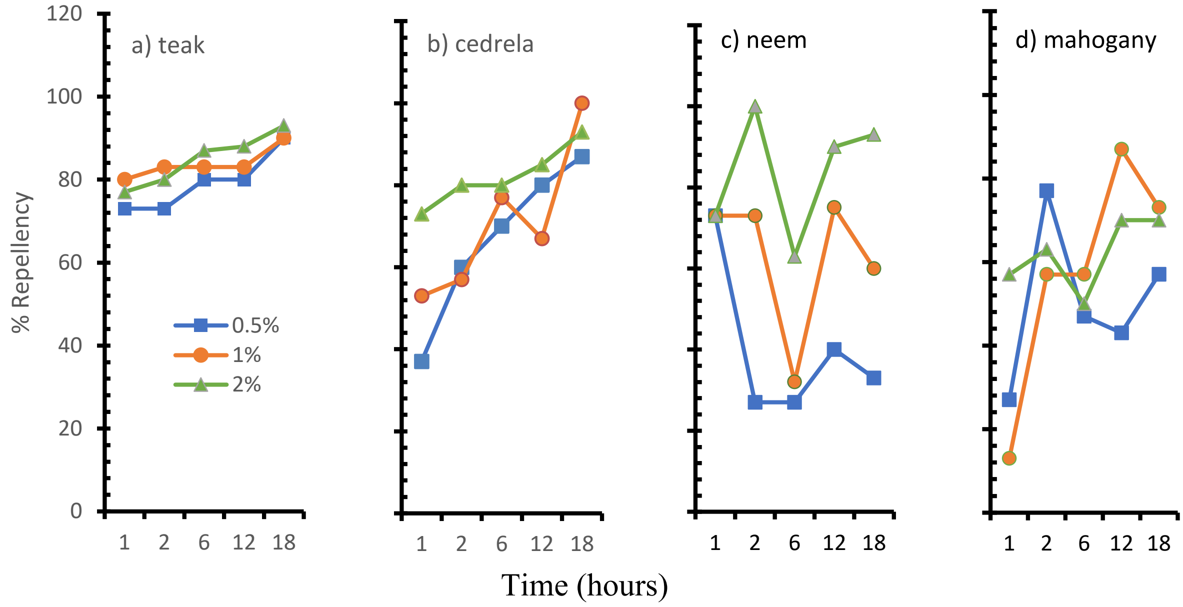

Figure 6. Repellent effect of vial surfaces treated with akpeteshie bio-alcohol (63% purity) plant extracts

Toxicity by topical application

For all plant extracts tested, mortality due to contact toxicity by topical application was concentration-dependent (Figure 4). Teak extracts were the most potent in causing adult mortality. The 2% teak extract caused 63% at 48 hours when the experiment was terminated. Mahogany was the least effective at 2% with 25% mortality at 48 hours. The concentration at 0.5% had low mortalities for all plant extracts. The highest mortality for any extract at 0.5% concentration was 10% which was recorded from the neem treatment 36 hours after application.

Contact toxicity by the residual effect

Teak and cedrela extracts had the best residual effect of 100% mortality at 12 hours for the 2 % concentration (Figure 5). Neem had 86.6% mortality and mahogany had the least mortality (69.1%) from the 2% concentration at 12 hours. There were no weevil mortalities in the control treatment where solvent only was applied on the vial surfaces and exposed to the weevils. Teak and cedrela-treated surfaces were still potent at 24 hours but for neem and mahogany, weevil mortality at 24 hours after treatment had a maximum of 48.5%. In all tested extracts, toxicity was time-dependent except

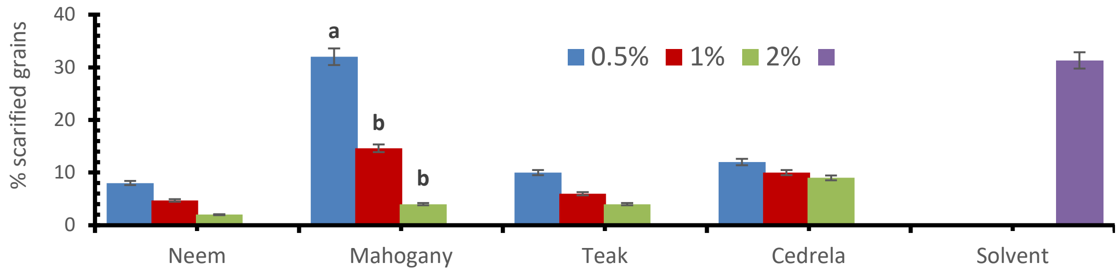

Figure 7. Grains with weevil exit holes/scars on treatment with akpeteshie bio-alcohol (63% purity) plant extracts. Error bars in all extracts represent SEM. Different letters within the mahogany extracts denote statistically significant differences among the concentrations at $p < 0.05$.

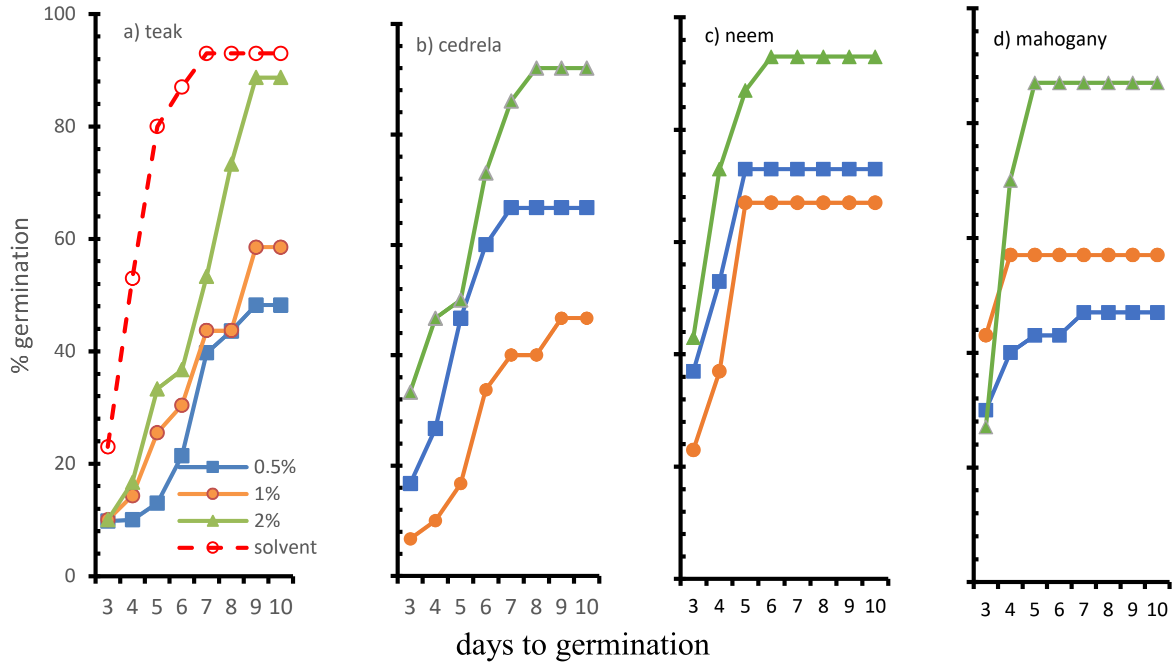

Figure 8. Viability of maize grains treated with akpeteshie bio-alcohol (63% purity) plant extracts

for mahogany at 2% concentration where mortality at 12 hours (69.1%) was higher than at 24 hours (24.7%).

Repellent effect of surfaces treated with plant extracts

The location of insects between the treated and solvent halves of the filter paper was the measure of repellence. All the extracts showed some level of repellence by the 18th hour. Generally, teak and followed by cedrela had the most consistent repellence with time (Figure 6). The repellent effects of neem and mahogany were less consistent with time. Neem and mahogany repellence effects for some concentrations were 100% at a stage but subsequently reduced with time to as low as 63% in the case of neem for example. All the tested teak concentrations (0.5%, 1%, and 2%) had repellence effects of at least 90% at 18 hours after exposure of the weevils towards the extract-treated half of the filter paper or the solvent-treated half.

Grain damage

Grains treated with extracts were better protected than control which was treated with only solvent (Figure 7). The percentage of grains with damage was concentration-dependent for all the extracts. That is, for each plant extract, the 2% treatment gave the best protection. Neem was the best among the four plant extracts in protecting grains against weevil damage. The 0.5% neem extract led to 8 % grain damage whilst the solvent control had 31% of the gains with damage holes or scars. Of the four plant extracts mahogany gave the least protection to grains against weevil damage. Within the mahogany concentration, the 0.5% concentration significantly ($p < 0.05$) increased the percentage of grain damage than the others (1% and 2%).

Germination test in Petri dish

Whole grains treated with plant extract at 2% had no inhibited germination in Petri dishes and led to

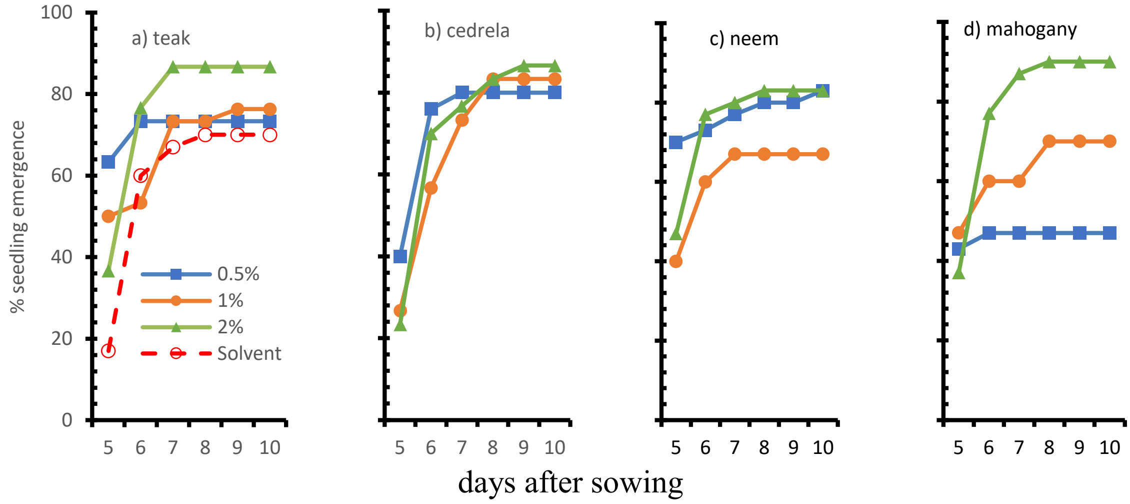

Figure 9. Seedling emergence of maize grains treated with akpeteshie bio-alcohol (63% purity) plant extracts

a high percentage of seed viability (93%). The higher percentage of seed germination recorded at 2% extract level, was comparable to the control. The solvent-only treated grains had a higher (100%) germination which was however not significantly different ($p \leq 0.05$) from the extracts at 2% application. The lower plant extract concentrations of 1% or 0.5% however reduced seed germination to as low as 63% (Figure 8).

Seedling emergence using soil media

In simulated field conditions, seeds treated with various extract concentrations led to a maximum of 90% seedling emergence after 10 days. Mahogany-treated seeds (2%) had a seedling emergence of 90%, teak and cedrela had 86% and the least was neem 83% (Figure 9). The control had 70% seedling emergence for seeds treated with the solvent. Mahogany somehow at the least extract concentration (0.5%) gave the least seedling emergence (47%). Neem extract concentrations were inconsistent although they were generally effective with a potency sequence of 2% ≥ 0.5% > 1% (Figure 9).

DISCUSSION

Yield of plant extracts

Solvents usually considered in the extraction of plant preparations include polar solvents (e.g., water, alcohols), intermediate polar, such as acetone, dichloromethane, and the nonpolar, n-hexane, ether, or chloroform all at the best purity available. In commercial preparations, the plant material could be macerated, digested, or decocted before one or a combination of Soxhlet, superficial, ultrasound-assisted, or microwave-assisted extractions. These processes have been explained in Sasidharan et al. (2011). The yield from plant extracts is reported to be dependent on the polarity of the solvent(s) used (Nawaz et al., 2020), the intrinsic properties of the plant material, and the extraction technique (Mahdi-Pour et al., 2012; Dhanani et al., 2017). Other considerations could be the boiling point that will make the extract easy to evaporate after the extraction process, pH, or temperature. In an experiment by Truong et al. (2019) methanol was reported to be the most effective solvent for the extraction of active principles from an evergreen citrus plant, which resulted in an extraction yield of 33.2%. The selected solvent used in this experiment which was home-made ethanol was informed solely on its availability, intended use of the final product, and economic considerations of the targeted beneficiaries. The total extractable components obtained, 5.8–13.3%, were comparable to those of other commercial solvents as reported by Iloki-Assanga et al. (2015), Nawaz et al. (2020) or Gonfa et al. (2020).

Moisture loss in grains coated with extracts

Seed moisture content is a factor that contributes to the viability of seed grains in terms of germination and seedling vigour (Siddique and Wright, 2003). Most often, an optimum moisture content is needed for grain storage, however, there exist a range of moisture content beyond which seed viability is lost. These experiments, similar to Gallo et al. (2015) investigated the hygroscopic consequences of applying the extracts or solvent on grain seeds in storage. In all, the maximum loss of moisture with these extracts/solvent treatments does not raise concerns in terms of opening up the grains to ambient moisture movements. These were necessary to be clarified since wood is known to have high hygroscopic properties (Skulberg et al., 2022).

Effects of the extracts on adult weevil and progeny emergence

Grain treatment against insect pests acts by either repelling adults, preventing oviposition and subsequent juvenile development (Ayalew, 2020) hence control measures target these life cycle activities of the insect pest. The best control options in the store aim to repel the adult or prevent oviposition in order to avoid frass or insect cadavers in food. Once the repellence barrier is broken, through successful oviposition, the next barrier is the ability for the egg to hatch. This is an indirect measure of the ovicidal effect of the extracts. In these experiments, the ovicidal effect was measured through the relative number of larvae that succeeded and emerged as adults. Many authors have tested the ovicidal effects of plant materials and their results were encouraging. For example, Govindarajan et al. (2011) showed that the repellent activity of botanical extracts against mosquitoes was dose-dependent and Reegan et al. (2015) reported on hexane extracts that showed 100% oviposition deterrent activity against adult female mosquitoes. Valizadeh et al. (2021) also gave an indication of the ovicidal activity of essential oils. Ayalew (2020) also concluded that botanical powders and oils were recommended for the protection of stored maize from infestation from weevils.

Toxicity by topical application

Topical application of insecticides can be recommended for infested grains in store although it is a difficult procedure when the grain is bulky. Targeting the insects during the application process requires a wider space to expose the insects. Topical application of botanical insecticides in store has been described by Gariba et al. (2021) who used strictly controlled procedures for dose applied specifically at the notum with success. Our experiment used the real-life blanket application procedure of spraying to target the cuticle of the insect. In an experiment by Asogwa and Osisanya (2003), they compared *Cedrela odorata* extracts at an extremely low concentration of 8000 ppm to a commonly used stored produce synthetic insecticide and concluded that the botanical extract through topical application caused low adult mortality of only 36%. With 20% v/v of essential oil through a topical application on *S. zeamais*, Ekeh et al. (2018) concluded that there was high mortality, and effectiveness was dependent on dosage and also exposure period which was similar to the results obtained for the plant extracts tested in this experiment.

Contact toxicity by the residual effect

Contact toxicity from residual insecticides is a well-known strategy used in stored product protection. The objective is to keep a potent toxicant residue on the holding surface or on the plant material during the storage period. The first report on the successful activity of the insecticide Spinosad for example on stored-product beetles employed contact toxicity (Toews and Subramanyam, 2003), who used Petri dishes spiked with the toxicant before introducing the different stages of three beetle species separately to death over time. In experiments by Bett et al. (2017) using a low concentration of 0.2% v/w oils as potential residual contact toxicants, they employed a strategy where the treated grains or surfaces were held for up to 120 days before introducing the insects. In this experiment, the adult insects were introduced on day one of the test surface treatment and monitored over time. Holding grains for 120 days before introducing the insects should be ideal for a situation where one could control the time of arrival of the insects after treatment in real life. For example, if grains are kept in hermetic or chilled environments before exposure to ambient conditions then the strategy of Bett et al. (2017) will be applicable. In this experiment, the endpoint was a live adult insect perhaps due to the high toxicities of some of the extracts. However, in other experiments by Guru-Pirasanna-Pandi et al. (2018) long-term effects of contact toxicity for F1/F2 populations which they termed transgenerational effect were monitored and decreased even for a high 4% extract concentration treatment.

Repellent effect of surfaces treated with plant extracts

Repellence effects in insect control has been linked more often to olfaction from fumigants (DeGennaro, 2015). However, solid and liquid toxicants after application also volatilizes and give repellent effects. Although Deletre et al. (2016) indicated that there were different repellent phenomena, such as expellency, irritancy, deterrency, odour masking, and visual masking, it is difficult to quantify these phenomena individually since they were all related to behavioural mechanisms. The chequered repellence trend in the neem and mahogany treatments could be due to the exhibition of one or several of the phenomena described by Deletre et al. (2016) over time. Semiochemicals function as attractants or repellents. Insects tend to learn before adopting even preferred volatiles, hence initial responses are often irregular. Volatile oils identified from ethanolic extracts of cedrela stem bark (Akinbuluma, 2020) at 1.0% (v/v) had mortality, oviposition deterrence, and repellence effects on weevils and could subsequently influence seed germination. Most plants have volatiles which could be attractants or repellents. Mahogany for example has been reported to possess several volatiles (Baba et al., 2020) some of which serve as olfactory cues that attract insect pests to the tree. The insecticidal and repellent potential of neem have also been evaluated on weevils and were reported to be effective (Perera et al., 2018).

Grain damage

Insects that feed on grains either select a section or consume the whole grain. The larva of the maize weevil, the destructive stage lives inside the grain and exits when it reaches the adult stage. Damage to grains infested with the maize weevil leaves the kernel hollow, sometimes with only the testa remaining with quantitative or physical weight loss (Stathers et al., 2020). Efforts to use extracts in preventing grain damage meant, the initial stage of oviposition and larva entry into the kernel after hatching must be curtailed. Once the larva enters the grain, it becomes difficult to control since the extracts are not normally systemic and stay in the outer shell of the grain. The findings of Parwada et al. (2018) and Gariba et al. (2021) are similar to these results in that generally botanicals decrease the extent of weevil damage if the concentration is increased. However, it will be preferred if the amount of extract on the grain for protection could be minimal to avoid tainting and colouring of grains that are for human consumption (Abass et al., 2014). It is well known that neem products protect grains from damage (Kemabonta and Falodu, 2013; Gariba et al., 2021). However, the source of the neem material, be it leaf, bark, root, or seed determines variations in potency. Another source of variation in the potency of extracts is the solvent used and the rate of application. These experiments are unique in the sense that homemade ethanol which is available to resource-limited farmers was used as the solvent.

Germination test in Petri dish

The use of plant products including extracts, soots and ashes as seed dressing is an ancient practice (Nelson et al., 2012). The objective of these seed dressings has been to protect the seed from pests including insects but also to analyse its allelopathic effects on seed germination (Bargmann et al., 2014; Khasabulli et al., 2018). There have been concerns that several plant products used as seed dressings have exhibited allelopathic characteristics and interfered with germination (Laizer et al., 2021; Zhao et al., 2022). Some schools of thought have indicated that the reduction in seed viability from seed dressings could also be a physical attribute (Xiao et al., 2019) since some compounds could increase the porosity of the seed testa and reduce viability over time (Macêdo et al., 2020; Bai et al., 2020). Results obtained from these plant extracts indicated that all the extracts were as good as the control for the 2% application rate as they gave comparative seed germination. The high concentration showed no deleterious effects on viability, unlike the lower doses which exhibited the rare occurrence of allelopathy as indicated by Soltys (2013). These results are however in contrast to that reported by Zhao et al. (2022) where in their report, the higher concentrations of sesame extracts rather exhibited higher allelopathy likewise a promotional germination reported by Wang et al. (2018) when they used aqueous extracts from four shrubs. In other reported allelopathic situations which contrasts with our results, low maize leaf aqueous extracts (0.5% and 1%) stimulated germination but became an inhibitor as concentration increased (Peng, 2018). The most plausible explanation for a compound that inhibits germination only at low concentrations and below a control treatment could be allelopathy.

Seedling emergence using soil media

The ability of seeds to germinate and emerge is a critical component of crop yield as it dictates plant population density and are considered the most vulnerable phases of a plant's phenology (Lamichhane et al., 2019; Möhler, 2021). In experiments with interventions that could impinge on germination and seedling survival, it becomes imperative to validate the applicability of such innovations on a farmscape (farmscape has been defined as the composition, structure, and diversity of land covers within a farm https://doi.org/10.1016/j.agee.2010.07.004) scenario as suggested by Li et al. (2017), Margreiter et al. (2020) and Shinohara et al. (2021). Seeds could germinate and emerge from moistened filter paper, but this needs to be confirmed using soil media to expose the seeds to the normal uncertainties expected on the farm. These efforts align with Powell (2022) who indicated that the substrate for germination and seedling emergence was a factor worth considering. The viability of treated seeds on soil media was tested after exposing the treated grains to weevils. The results obtained for this experiment on seedling emergence and growth were concentration dependent similar to that reported by Lidório et al. (2020). This implied that the concentrated extracts gave some protection to the intact seeds against weevil damage.

CONCLUSION

Storage of maize without reductions in both quality and quantity is a critically important aspect of food security especially in developing countries. There is renewed enthusiasm towards the paradigm of sustainability which calls for the use of renewable products in a sustainable manner. Several bioresources have been screened for bioactivity against pests of agricultural products, however, most of these products do not advance beyond laboratory successes due to cost or non-applicability. Our experiments have shown that the locally distilled solvent used was effective, reproducible, and easily available in rural settings where resource-limited farmers need. The innovation could also support the ecological approach to insect control in stored produce as it takes care of the environment, the safety of the farmer, and the final consumer as it is devoid of chemical residues and subsequently as a food security measure. Although the production of local ethanol is widespread, the composition of the initial raw materials is location specific. These results could be adopted in indigenous pest management strategies for stored produce after the economic feasibility and acceptance have been determined on a farmer scale level. We, therefore, recommend the use of homemade solvents to sustainably extract botanical insecticides as a cost-saving mechanism and on an economic case-by-case basis in integrated insect management programs.

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CONFLICT OF INTEREST

The authors declared no conflicts of interest with respect to the research, authorship, and publication of this article.

ETHICAL COMPLIANCE

The authors have followed ethical standards in conducting the research and preparing the manuscript.

REFERENCES

Abass A.B., Ndunguru G., Mamiro P., Alenkhe B., Mlingi N., Bekunda M. (2014): Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania. Journal of Stored Products Research. https://doi.org/10.1016/j.jspr.2013.12.004

Abass A.B., Fischler M., Schneider K., Daudi S., Gaspar A., Rüst J., Kabula E., Ndunguru G., Madulu D., Msola D. (2018): On-farm comparison of different postharvest storage technologies in a maize farming system of Tanzania Central Corridor. Journal of Stored Products Research 77: 55–65. https://doi.org/10.1016/j.jspr.2018.03.002

Abbott W.S. (1925): A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18: 265–267. https://doi.org/10.1093/jee/18.2.265a

Affognon H., Mutungi C., Sanginga P., Borgemeister C. (2015): Unpacking postharvest losses in sub-Saharan Africa: a meta-analysis World Develop. 66: 49–68. https://doi.org/10.1016/j.worlddev.2014.08.002

Ahmad K., Adnan M., Khan M. A., Hussain Z., Junaid K., and Saleem N. (2015): Bioactive neem leaf powder enhances the shelf life of stored mungbean grains and extends protection from pulse beetle. Pakistan Journal of Weed Science Research 21: 71–81. https://doi.org/10.28941/pjwsr.v21i1.575

Ahmed S., Tabassum Mh., Hassan B. (2022): Evaluation of antitermite properties of wood extracts from *Pongamia pinnata* (L.) Pierre (Leguminosae) against subterranean termites An Acad Bras Cienc 94: e20190591 doi 10.1590/0001-3765202220190591

Akinbuluma M.D. (2020): Volatile oils from *Cedrela odorata* L. as protectants against *Sitophilus zeamais* (Coleoptera: Curculionidae). American Journal of Essential Oils and Natural Products 8: 20–24.

Akob C.A., Ewete F.K. (2007): The efficacy of ashes of four locally used plant materials against *Sitophilus zeamais* (Coleoptera: Curculionidae) in Cameroon. International Journal of Tropical Insect Science 27: 21–26. https://doi.org/10.1017/S1742758407699615

Amoabeng B.W., Gurr G.M., Gitau C.W., Stevenson P.C. (2014): Cost: benefit analysis of botanical insecticide use in cabbage: implications for smallholder farmers in developing countries. Crop

Protection 57: 71–76. https://doi.org/10.1016/j.cropro.2013.11.019

Appiah-Twumasi M., Donkoh S.A., Ansah I.G.K. (2020): Farmer innovations in financing smallholder maize production in Northern Ghana. Agricultural Finance Review 80: 421–436. https://doi.org/10.1108/AFR-05-2019-0059

Asogwa E.U., Osisanya E.O. (2003): The control of *Sitophilus zeamais* (Motsch) in stored maize using crude bark and wood extracts of *Cedrela odorata* (L. Kennedy) and Pirimiphos-methyl. Bioscience Research Communications 15: 134–139.

Attia M.A., Wahba T.F., Shaarawy N., Moustafa F.I., Guedes R.N.C., Dewer Y. (2020): Stored grain pest prevalence and insecticide resistance in Egyptian populations of the red flour beetle *Tribolium castaneum* (Herbst) and the rice weevil Sitophilus oryzae (L.). Journal of Stored Products Research 87: 101611. https://doi.org/10.1016/j.jspr.2020.101611.

Ayalew A.A. (2020): Insecticidal activity of *Lantana camara* extract oil on controlling maize grain weevils. Toxicology Research and Application 2020: 4. https://doi.org/10.5061/dryad.8kprr4xjf

Baba G.O., Onu I., Adamu R.S., Utono I.M. (2020): Field bioefficacy of mahogany seed extract (*Khaya senegalensis*: Meliaceae, (desv.) a. Juss) for management of bollworm infestation on cotton in Zaria, Nigeria. Acta Entomology and Zoology 1: 31–36. https://doi.org/10.33545/27080013.2020.v1.i1a.

Bai Y., Xiao S., Zhang Z., Zhang Y., Sun H., Zhang K., Wang X., Bai Z., Li C., Liu L. (2020): Melatonin improves the germination rate of cotton seeds under drought stress by opening pores in the seed coat. Peer Journal of Plant Biology 6: 8 e9450. https://doi.org/10.7717/peerj.9450

Bargmann T., Vandvi V., Måren I.E. (2014): Life after fire: smoke and ash as germination cues in ericads, herbs and graminoids of northern heathlands. Applied Vegetation Science 17: 670–679. https://doi.org/10.1111/avsc.12106

Bathla S., Jaidka M., Kaur R. (2019): Nutritive Value. In (Ed.), Maize – Production and Use. IntechOpen. https://doi.org/10.5772/intechopen.88963

Befikadu D. (2014): Factors affecting quality of grain stored in Ethiopian traditional storage structures and opportunities for improvement. International Journal of Sciences: Basic and Applied Research 18: 235–257.

Bett P.K., Deng A.L., Ogendo J.O., Kariuki S.T., Kamatenesi-Mugisha M., Mihale J.M., Torto B. (2017): Residual contact toxicity and repellence of *Cupressus lusitanica* Miller and *Eucalyptus saligna* Smith essential oils against major stored product insect pests. Industrial Crops and Products 110: 65–74. https://doi.org/10.1016/j.indcrop.2017.09.046

Bhusal K., Khanal D. (2019): Role of Maize Weevil, *Sitophilus zeamais* Motsch. on spread of *Aspergillus section* flavi in different Nepalese maize varieties. Advances in Agriculture 2019: pp 5. https://doi.org/10.1155/2019/7584056

Bradford K.J., Dahal P., Van Asbrouck J., Kunusoth K., Bello P., Thompson J., Wu F. (2018): The dry chain: Reducing postharvest losses and improving food safety in humid climates. Trends in Food Science and Technology 71: 84–93. https://doi.org/10.1016/j.tifs.2017.11.002.

Chaubey M.K. (2019): Essential oils as green pesticides of stored grain insects. European Journal of Biological Research 9: 202–244. http://dx.doi.org/10.5281/zenodo.3528366

Chaudhary S., Kanwar R.K., Sehgal A., Cahill D.M., Barrow C.J., Sehgal R., Kanwar J.R. (2017): Progress on *Azadirachta indica* based biopesticides in replacing synthetic toxic pesticides. Frontiers in Plant Science 8: 2. https://doi.org/10.3389/fpls.2017.00610

Cooking with Sindaco (2022): Local gin process 100% alcohol (Akpeteshie), https://fb.watch/gGyyvCdPSk/

Danquah F.O, Ge H., Frempong L.N., Korankye B.A. (2020): Resource-use efficiency in maize production: the case of smallholder farmers in Ghana. Agronomia Colombiana 38: 404–417. https://doi.org/10.15446/agron.colomb.v38n3.85069

Darfour B., Rosentrater K.A. (2016): Maize in Ghana: an overview of cultivation to processing. American Society of Agricultural and Biological Engineers paper number 162460492, St. Joseph, Michigan. doi: 10.13031/aim.20162460492

Deletre E., Schatz B., Bourguet D., Chandre F., Williams L., Ratnadass A., Martin T. (2016): Prospects for repellent in pest control: current developments and future challenges. Chemoecology 26: 127–142. https://doi.org/10.1007/s00049-016-0214-0

Derkyi N.S.A., Acquaah S.O., Owusu-Akyaw M. (2010): Bioactivity of some natural products against the cowpea storage weevil *Callosobruchus maculatus* L. International Journal of Biological and Chemical Sciences 4: 616–623. doi: 10.4314/ijbcs.v4i3.60465

Dhanani T., Shah S., Gajbhiye N.A., Kumar S. (2017): Effect of extraction methods on yield, phytochemical constituents and antioxidant activity of *Withania somnifera*. Arabian Journal of Chemistry 10: S193–S1199. http://dx.doi.org/10.1016/j.arabjc.2013.02.015

Ekeh F.N., Odo G.E., Nzei J.I., Ohanu C.M., Ugwu F., Ngwu G., Njokuocha R. (2018): Effects of aqueous and oil leaf extracts of *Pterocarpus santalinoides* on the maize weevil, *Sitophilus zeamais* pest of stored maize grains. African Journal of Agricultural Research 13: 617–626. https://doi.org/10.5897/AJAR2018.13014

FAO (2019): What are the world's most important staple foods? FAO Production Yearbook for 2019.

Gajger I.T., Sakač M., Gregorc A. (2017): Impact of thiamethoxam on honeybee queen (*Apis mellifera* carnica) reproductive morphology and physiology. Bulletin of Environmental Contamination and Toxicology 99: 297–302. https://doi.org/10.1007/s00128-017-2144-0

Gallo L., Ramírez-Rigo M.V., Piña J., Bucalá V. (2015): A comparative study of spray-dried medicinal plant aqueous extracts. Drying performance and product quality. Chemical Engineering Research and Design 104: 681–694. http://dx.doi.org/10.1016/j.cherd.2015.10.009

Gariba S. Y., Dzidzienyo D. K., Eziah V. Y. (2021): Assessment of four plant extracts as maize seed protectants against *Sitophilus zeamais* and *Prostephanus truncatus* in Ghana. Cogent Food and Agriculture 7:1. https://doi.org/10.1080/23311932.2021.1918426

GENSTAT® for Windows TM (2012): Introduction 15th Edition, VSN International, Hemel Hempstead.

Gómez-Tah J.R., Ruz-Febles N.M., Campos-Navarrete M.J., Canul-Solís J.R., Castillo-Sánchez L.E. (2020): Ethanolic extract of *Cedrela odorata* and *Delonix regia* for the control of *Anthonomus eugenii*. Journal of Entomology and Zoology Studies 8: 1349–1352.

Gonfa T., Teketle S., Kiros T. (2020): Effect of extraction solvent on qualitative and quantitative analysis of major phyto-constituents and in-vitro antioxidant activity evaluation of *Cadaba rotundifolia* Forssk leaf extracts. Cogent Food & Agriculture 6. https://doi.org/10.1080/23311932.2020.1853867

Govindarajan M., Mathivanan T., Elumalai K., Krishnappa K., Anandan A. (2011): Ovicidal and repellent activities of botanical extracts against *Culex quinquefasciatus*, *Aedes aegypti* and *Anopheles stephensi* (Diptera: Culicidae). Asian Pacific Journal of Tropical Biomedicine 1: 43–48. https://doi.org/10.1016/S2221-1691(11)60066-X

Granella S.J., Granella S., Bechlin T.R., Bechlin T., Christ D., Coelho S.R.M. (2021): A potential role of nitric oxide in postharvest pest control: A review. Journal of the Saudi Society of Agricultural Sciences. https://doi.org/10.1016/j.jssas.2021.12.002

Grzywacz D., Stevenson P.C., Mushobozi W.L., Belmain S., Wilson K. (2014): The use of indigenous ecological resources for pest control in Africa. Food Security 6: 71–86. https://doi.org/10.1007/s12571-013-0313-5

Guru-Pirasanna-Pandi G., Adak T., Gowda B., Patil N., Annamalai M., Jena M. (2018): Toxicological effect of underutilized plant, *Cleistanthus collinus* leaf extracts against two major stored grain pests, the rice weevil, *Sitophilus oryzae* and red flour beetle, *Tribolium castaneum*. Ecotoxicology and Environmental Safety 154: 92–99. DOI: 10.1016/j.ecoenv.2018.02.024

Haines C.P. (Ed). (1991): Insects and arachnids of tropical stored product pests: Their biology and identification. Natural Resources Institute, UK.

Hamel D., Rozman V., Liška A. (2020): Storage of cereals in warehouses with or without pesticides. Insects 11: 846. http://dx.doi.org/10.3390/insects11120846

Huma B., Hussain M., Ning C., Yuesuo Y. (2019): Human Benefits from Maize. Scholar Journal of Applied Sciences and Research 2: 4–7.

Iloki-Assanga S.B., Lewis-Luján L.M., Lara-Espinoza C., Gil-Salido A.A., Fernández-Angulo D., Rubio-Pino J. ., Haines D.D. (2015): Solvent effects on phytochemical constituent profiles and antioxidant activities, using four different extraction formulations for analysis of *Bucida buceras* L. and *Phoradendron californicum*. BMC Research Notes 8: 396. https://doi.org/10.1186/s13104-015-1388-1

Kadir R., Ali Nm, Soit Z., Khamaruddin Z. (2014): Anti-termitic potential of heartwood and bark extract and chemical compounds isolated from *Madhuca utilis* Ridl. H. J. Lam and *Neobalanocarpus heimii* King P.S. Ashton. Holzforschung 68: 713–720. https://doi.org/10.1515/hf-2013-0101

Kapinova A., Kubatka P., Golubnitschaja O., Kello M., Zubor P., Solar P., Pec M. (2018): Dietary phytochemicals in breast cancer research: anticancer effects and potential utility for effective chemoprevention. Environmental Health and Preventive Medicine 23: 36. https://doi.org/10.1186/s12199-018-0724-1

Kemabonta K.A., Falodu B.B. (2013): Bio-efficacy of three plant products as post-harvest grain protectants against *Sitophilus oryzae* (Linnaeus) (Coleoptera: Curculionidae) on stored wheat (*Triticum aestivum* Linnaeus). International Journal of Natural Science 4: 259–264.

Khasabulli B.D., Musyimi D.M., Georg O., Gichuhi M. (2018): N. Allelopathic effect of *Bidens pilosa* on seed germination and growth of *Amaranthus dubius*. Journal of Asian Scientific Research 8: 103–112. https://doi.org/10.18488/journal.2.2018.83.103.112

Kumar D., Kalita P. (2017): Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods 6: 8. doi: 10.3390/foods6010008

Laizer H.C., Chacha M.N., Ndakidemi P.A. (2021): Allelopathic effects of *Sphaeranthus suaveolens* on seed germination and seedling growth of *Phaseolus vulgaris* and *Oryza sativa*. Advances in Agriculture, 2021, 9 p. https://doi.org/10.1155/2021/8882824

Lamichhane J.R., Constantin J., Schoving C., Maury P., Debaeke P., Aubertot J., Dürr C. (2020): Analysis of soybean germination, emergence, and prediction of a possible northward establishment of the crop under climate change. European Journal of Agronomy 113: 125972. https://doi.org/10.1016/j.eja.2019.125972

Lidório H., Sobrinh J., Menegae J., Leão J., Nunes U., Munareto J., Barbier G., Leivas A. (2020): Aqueous extracts of plants on the physiological and sanitary quality of *Chenopodium quinoa* seeds as an alternative to conventional seed treatment. Journal of Agricultural Studies 8: 237–250. doi:http://dx.doi.org/10.5296/jas.v8i2.15848

Liu Z.L., Chu S.S., Zhi Q.L. (2012): Chemical composition and toxicity of essential oil of *Boenninghausenia sessilicarpa* (Rutaceae) against two grain storage insects. Journal of Medicinal Plants Research 6: 2920–2924. https://doi.org/10.5897/JMPR11.526

Lobulu J., Shimelis H., Laing M., Mushongi A. A. (2019): Maize production constraints, traits preference and current Striga control options in western Tanzania: farmers' consultation and implications for breeding. Acta Agriculturae Scandinavica B 69: 734–746. https://doi.org/10.1080/09064710.2019.1652680

Macêdo J.F.S., Ribeiro L.S., Bruno R.L.A., Alves E. ., de Andrade A.P., Lopes K.P., da Costa F.B., Zanuncio J.C., Ribeiro W.S. (2020): Green leaves and seeds alcoholic extract controls *Sporobulus indicus* germination in laboratory conditions. Scientific Reports 10: 1599. https://doi.org/10.1038/s41598-020-58321-y

Mahdi-Pour B., Jothy S.L., Latha L.Y, Chen Y. Sasidharan S. (2012): Antioxidant activity of methanol extracts of different parts of *Lantana camara*. Asian Pacific Journal of Tropical Biomedicine 2: 960–965. https://doi.org/10.1016/S2221-1691(13)60007-6

Makate N. (2010): The susceptibility of different maize varieties to post-harvest infestation by *Sitophilus zeamais* (MOTSCH) (Coleoptera: Curculionidae). Scientific Research and Essay 5: 30–34. http://hdl.handle.net/10311/1411

Margreiter V., Pagitz K., Berg C., Schwager P., Erschbamer B. (2020): Pros and cons of using a standard protocol to test germination of alpine species. Plant Ecology 221: 1045–1067. https://doi.org/10.1007/s11258-020-01061-w

Mohammad Y.M., Haniffa H.M., Sujarajiini V. (2023): Insecticidal effect of selected medicinal plants on *Sitophilus zeamais* Mostschulsky in stored maize. Biocatalysis and Agricultural Biotechnology 48:102635. https://doi.org/10.1016/j.bcab.2023.102635.

Möhler H., Diekötter T., Bauer G.M., Donath T.W. (2021): Conspecific and heterospecific grass litter effects on seedling emergence and growth in ragwort (*Jacobaea vulgaris*). PLoS ONE 16: e0246459. https://doi.org/10.1371/journal.pone.0246459

Mulungu K., Ng'ombe J.N. (2019): Climate change impacts on sustainable maize production in Sub-Saharan Africa: A Review. In (Ed.) Maize – Production and Use. IntechOpen. https://doi.org/10.5772/intechopen.90033

Morrison III, W.R., Arthur F.H., Bruce A. (2021): Characterizing and predicting sublethal shifts in mobility by multiple stored product insects over time to an old and novel contact insecticide in three key stored commodities. Pest Management. Science 77: 1990–2006. https://doi.org/10.1002/ps.6228

Nawaz H., Shad M.A., Rehman N., Andaleeb H., Ullah N. (2020): Effect of solvent polarity on extraction yield and antioxidant properties of phytochemicals from bean (*Phaseolus vulgaris*) seeds. Brazilian Journal of Pharmaceutical Sciences 56: e17129. https://doi.org/10.1590/s2175-97902019000417129

Nelson D C., Flematti G R., Ghisalberti E L., Dixon K W., Smith S.M. (2012): Regulation of seed germination and seedling growth by chemical signals from burning vegetation. Annual Review of Plant Biology 63: 107–130. DOI: 10.1146/annurev-arplant-042811-105545

Nwosu L.C., Adedire C.O. Ogunwolu E.O. (2015): Feeding site preference of *Sitophilus zeamais*

(Coleoptera: Curculionidae) on maize grain. International Journal of Tropical Insect Science 35: 62–68. DOI: https://doi.org/10.1017/S1742758415000065

Obeng-Ofori D. (2007): The use of botanicals by resource poor farmers in Africa and Asia for the protection of stored agricultural products. Stewart Postharvest Review: 3: 1–8. DOI: 10.2212/spr.2007.6.10

Obeng-Ofori D., Reichmuth C.H. (1997): Bioactivity of eugenol, a major component of essential oil of *Ocimum suave* (Wild.) against four species of stored-product Coleoptera. International Journal of Pest Management 43: 89–94. DOI: 10.1080/096708797229040

Obour P.B., Arthur I.K., Owusu K.T. (2020): Maize production failure in Ghana: a case study of Ejura – Sekyedumase municipality. Sustainability 14: 3514. https://doi.org/10.3390/su14063514

Ojo J.A., Omoloye A.A. (2012): Rearing of maize weevil, *Sitophilus zeamais* on an artificial maize-cassava diet. Journal of Insect Science 12: 69. https://doi.org/10.1673/031.012.6901

Ojo J.A., Omoloye A.A. (2016): Development and life history of *Sitophilus zeamais* (Coleoptera: Curculionidae) on cereal crops. Advances in Agriculture 2016: 1–8. https://doi.org/10.1155/2016/7836379

Okwute S.K. (2012): Plants as potential sources of pesticidal agents: A review. In (Ed.), Pesticides – Advances in Chemical and Botanical Pesticides. IntechOpen. https://doi.org/10.5772/46225

Omotayo O.P., Omotayo A.O., Mwanza M., Babalola O.O. (2019): Prevalence of mycotoxins and their consequences on human health. Toxicological Research 35: 1–7. https://doi.org/10.5487/TR.2019.35.1.001

Opit G. P., Campbell J., Arthur F., Armstrong P., Osekre E., Washburn S., Baban O., McNeill S., Mbata G., Ayobami I., Reddy P. V. (2014): A report on assessment of maize postharvest losses in the middle belt of Ghana. United States Agency for International Development. https://doi.org/10.14455/doa.res.2014.134

Paes J.L., Faroni L.R.D., Dhingra O.D., Cecon P.R., Silva T.A. (2012): Insecticidal fumigation action of mustard essential oil against *Sitophilus zeamais* in maize grains. Crop Protection 34: 56–58. https://doi.org/10.1016/j.cropro.2011.11.021

Parwada C., Chikuvire T.J., Kamota A., Mandumbu R., Mutsengi K. (2018): Use of botanical pesticides in controlling *Sitophilus zeamais* (maize weevil) on stored *Zea mays* (maize) grain. Modern Concepts & Developments in Agronomy 1: 64–67. https://doi.org/10.31031/MCDA.2018.01.000517

Peng M.W., Wang M., Jiang P., Chang Y.L., Chu G.M. (2018): The impact of low temperature on seed germination of two desert species in Junggar basin of China. Applied Ecology and Environmental Research 16: 5771–5780. DOI: 10.15666/aeer/1605_57715780

Perera A., Karunaratne M., Chinthaka S. (2018): Bioactivity and Volatile profiling of *Azadirachta indica* leaves for the management of maize weevil, *Sitophilus zeamais* (Motsch.) infestations. Journal of Tropical Forestry and Environment 8:10–24. https://doi.org/10.31357/jtfe.v8i1.3479

Powell A. A. (2022): Seed vigour in the 21st century. Seed Science and Technology, Suppl. 50: 45–73. https://doi.org/10.15258/sst.2022.50.1.s.04

Rahmat B., Kurniati F., Pajar L. (2019): The effectiveness of teak wood-sawdust liquid smoke and areca-nut extract as a pesticide on *Pomacea canaliculate*. American Journal of Agricultural and Biological Sciences 14: 69–74. https://doi.org/10.3844/ajabssp.2019.69.74

Rajashekar Y., Bakthavatsala, N., Shivanandappa T. (2012): Botanicals as grain protectants. Psyche: A Journal of Entomology 13 pp. Article ID 646740. https://doi.org/10.1155/2012/646740

Reegan A.D., Gandhi M.R., Paulraj M.G., Ignacimuthu S. (2015): Ovicidal and oviposition deterrent activities of medicinal plant extracts against *Aedes aegypti* L. and *Culex quinquefasciatus* Say mosquitoes (Diptera: Culicidae). Osong Public Health and Research Perspectives 6: 64–69. https://doi.org/10.1016/j.phrp.2014.08.009.

Regnault-Roger C., Vincent C., Arnason J.T. (2012): Essential oils in insect control: low-risk products in a high-stakes world. Annual Review of Entomology 57: 405–424. https://doi.org/10.1146/annurev-ento-120710-100554

Sabbour M.M. (2012): Entomotoxicity assays of two nanoparticle materials 1-(Al203 and TiO2) against *Sitophilus oryzae* under laboratory and store conditions in Egypt. Journal of Novel Applied Sciences 1: 103–108. https://civilica.com/doc/418871

Sasidharan S, Chen Y, Saravanan D, Sundram KM, Yoga Latha L. (2011): Extraction, isolation and characterization of bioactive compounds from plants' extracts. African Journal of Traditional, Complementary, and Alternative Medicines 8: 1–10. DOI:10.4314/AJTCAM.V8I1.60483

Sawicka B. (2019): Postharvest losses of agricultural produce. W. Leal Filho et al. (eds.), Zero Hunger, Springer Nature Switzerland AG. pp 1–16. doi:10.1007/978-3-319-69626-3_40-1.

Scheiterle L., Birner R. (2018): Assessment of Ghana's comparative advantage in maize production and the role of fertilizers. Sustainability 10: 4181. http://dx.doi.org/10.3390/su10114181

Shinohara T., Ducournau S., Matthews S., Wagner M-H., Powell A.A. (2021): Early counts of radicle emergence, counted manually and by image analysis, can reveal differences in the production of normal seedlings and the vigour of seed lots of cauliflower. Seed Science and Technology 49: 219–235. DOI: https://doi.org/10.15258/sst.2021.49.3.04

Siddique A.B., Wright D. (2003): Effects of different seed drying methods on moisture percentage and seed quality (viability and vigour) of pea seeds (*Pisum sativum* L.). Journal of Agronomy 2: 201–208. DOI: 10.3923/ja.2003.201.208

Simbarashe M., James C., Sipiwe G. (2013): Screening of stored maize (*Zea mays* L). Journal of Plant Research 3: 17–22. DOI: 10.5923/j.plant.20130303.01.

Sintim H.O. (2014): A justification for the advances in natural products in plant and grain protection. Proceedings of the Annual Meeting of the Sunyani Polytechnic Lecture Series #VII, Sunyani, Ghana. Pp. 408–423. ISBN: 978-9988-0-9955-X

Skulberg K.R., Nyrud A.Q., Nore K. (2022): Hygroscopic buffering effects in exposed cross-laminated timber surfaces and indoor climate in a Norwegian primary school, Wood Material Science and Engineering 17: 43–52. https://doi.org/10.1080/17480272.2021.2019830

Soltys D., Krasuska U., Bogatek R., Gniazdowska A. (2013): Allelochemicals as bioherbicides-present and perspectives. In Herbicides-current research and case studies in use (eds Price, A. J. and Kelton J. A.) IntechOpen. DOI: 10.5772/56185

Sori W., Ayana A. (2012): Storage pests of maize and their status in Jimma Zone, Ethiopia. African Journal of Agricultural Research 7: 4056–4060. http://10.140.5.162//handle/123456789/2839

Stathers T.E., Arnold S.E.J., Rumney C.J. Hopson C. (2020): Measuring the nutritional cost of insect infestation of stored maize and cowpea. Food Security 12: 285–308 https://doi.org/10.1007/s12571-019-00997-w

Sugri I., Abubakari M., Owusu R.K., Bidzakin J.K. (2021): Postharvest losses and mitigating technologies: Evidence from Upper East Region of Ghana. Sustainable Futures 3: 100048. https://doi.org/10.1016/j.sftr.2021.100048.

Suleiman R., Rosentrater K. A., Bern C. T. (2013): Effects of deterioration parameters on storage of maize. Agricultural and Biosystems Engineering Conference Proceedings and Presentations. http://lib.dr.iastate.edu/abe_eng_conf/339.

Tagba P., Osseyi E., Fauconnier M.L., Lamboni C. (2018): Aromatic composition of 'sodabi', a traditional liquor of fermented oil palm wine. Advance Journal of Food Science and Technology 14: 15–22, 10.19026/ajfst.14.5421

Talukder D., Khanam L. A. M. (2009): Toxicity of four plant based products against three stored product pests. Journal of Bio-Science 17: 149–153. https://doi.org/10.3329/jbs.v17i0.7124

Tilahun F.E., Daniel H.B. (2016): Effect of neem leaf and seed powders against adult maize weevil (*Sitophilus zeamais* Motschulsky) mortality. International Journal of Agricultural Research 11: 90–94. DOI: 10.3923/ijar.2016.90.94

Toews M.D. Subramanyam B. (2003): Contribution of contact toxicity and wheat condition to mortality of stored-product insects exposed to spinosad. Pest Management Science 59: 538–544. https://doi.org/10.1002/ps.660

Trivedi A., Nayak N. Kumar J. (2018): Recent advances and review on use of botanicals from medicinal and aromatic plants in stored grain pest management. Journal of Entomology and Zoology Studies 6: 295–300.

Truong D.H., Nguyen D.H., Ta N.T.A., Bui A.V., Do T.H., Nguyen H. C. (2019): Evaluation of the use of different solvents for phytochemical constituents, antioxidants, and *in vitro* anti-inflammatory activities of *Severinia buxifolia*. Journal of Food Quality 8178294. https://doi.org/10.1155/2019/8178294

Tulashie S.K., Appiah A.P., Torku G.D., Darko A.Y. Wiredu A. (2017): Determination of methanol and ethanol concentrations in local and foreign alcoholic drinks and food products (Banku, Ga kenkey, Fante kenkey and Hausa koko) in Ghana. Food Contamination 4: 14. https://doi.org/10.1186/s40550-017-0059-5

Berhe M., Subramanyam B., Chichaybelu M., Demissie G., Abay F., Harvey J. (2022): Post-harvest insect pests and their management practices for major food and export crops in East Africa: an Ethiopian case study. Insects 13: 1068. https://doi.org/10.3390/insects13111068

Valizadeh B., Jalali Sendi J., Oftadeh M., Ebadollahi A., Krutmuang P. (2021): Ovicidal and physiological effects of essential oils extracted from six medicinal plants on the elm leaf beetle, *Xanthogaleruca luteola* (Mull.). Agronomy 11: 2015. https://doi.org/10.3390/agronomy11102015

Van Duong N., Khanh L.Q., Xuan B.T., Hung C.T. Que L.X. (2020): Using oxygen depletion to reduce maize weevils without chemicals in a storage minienvironment. Vietnam Journal of Chemistry 58: 327–332. https://doi.org/10.1002/vjch.2019000168

WABS (2008): Maize value chain study in Ghana: enhancing efficiency and competitiveness, Accra Ghana. http://wwwvaluechains4poororg/file/Maize_Value Chain_WAB_Dec_08pdf

Wang J., Zhang R., Huang Y., Feng S. (2018): Allelopathic effects of aqueous leaf extracts from four shrub species on seed germination and initial growth of *Amygdalus pedunculata* Pall. Forests 9: 711. https://doi.org/10.3390/f9110711

Xiao S, Liu L.T., Wang H., Li D.X., Bai Z.Y., Zhang Y.J., Sun H.C., Zhang K., Li C.D. (2019): Exogenous melatonin accelerates seed germination in cotton (*Gossypium hirsutum* L.). PLoS ONE 14: e0216575. https://doi.org/10.1371/journal.pone.0216575

Yohannes A., Asayew G., Melaku G., Derbew M., Kedir S., Raja N. (2014): Evaluation of certain plant leaf powders and aqueous extracts against maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae). Asian Journal of Agricultural Science 6: 83–88. http://dx.doi.org/10.19026/ajas.6.5152

Zhao J., Yang Z., Zou J. Li Q. (2022): Allelopathic effects of sesame extracts on seed germination of moso bamboo and identification of potential allelochemicals. Scientific Reports 12: 6661 https://doi.org/10.1038/s41598-022-10695-x

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