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Insecticidal potency of mixtures of plant powders and Actellic Super™ (Pirimiphos-methyl + Permethrin) on *Callosobruchus chinensis* F. and *Sitophilus zeamais* Motch

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Abstract

Insect pests still cause substantial quantitative and qualitative grain loss ranging from 20 to 100% in small holder farming systems in tropical countries. Synthetic pesticides are recommended as stop gap measures for the management of stored product insect pests. However, their application has not been fully exploited in small scale farming due to environmental, health, and economic concerns. As a result, new researches have shifted focus to exploiting pesticidal plants as alternatives to synthetic pesticides. Therefore, the current study evaluated mixtures of plant powders and reduced amount of Actellic super™ (pirimiphos-methyl + permethrin) as alternative insecticide formulation against *Callosobruchus chinensis* and *Sitophilus zeamais*. Green grams and wheat grains were mixed with a mixture of plant powders in the ratios of 1:1, 1:3 and 1:9 to obtain four rates (0.0, 2.0, 6.0 and 10%w/w). Grains and plant powders were also mixed with reduced amount (10, 25, and 50 %) of recommended rate of Actellic Super™ to obtain dosages as above. Twenty unsexed adults, 1-5 day old *S. zeamais* and *C. chinensis* were introduced into treated grains. The mixture of *C. lusitanica*: *T. vogelii* powders in the ratios of 1:1, 1:3 and 1:9 caused mortality in *C. chinensis* of 55, 95 and 85%, respectively. At the same ratio, *E. saligna*: *L. camara* mixture produced mortality in *S. zeamais* of 77, 82, and 85% respectively. In mixture of *C. lusitanica* and *T. vogelii* and reduced amount of Actellic Super™ by 50% the mortality of *C. chinensis* was 85 and 80 % respectively. Similarly, *E. saligna* and *L. camara* and reduced amount of Actellic Super™ by 50% caused a mortality of *S. zeamais* of 48 and 97% respectively. The application of plant powders and reduced amounts of synthetic insecticide has the potential to be applied in stored product pest control

Keywords: *Plant powders, Callosobruchus chinensis, mortality, Sitophilus zeamais, Pirimiphos-methyl*

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Introduction

Food losses due to diseases and insect pest infestation are the most important impediments to the attainment of nutritional and food security in small scale farming. In tropical countries, grain storage is the most important and critical post-harvest operation with the duration being dependent upon market demand, size of production and farmers' consumption needs. In this scenario, insects and rodents cause substantial quantitative and qualitative grain loss in storage ranging from 20 to 100% depending on insect pest, type of grain, storage structure among others (Ogendo *et al*., 2012, Bett *et al*., 2017; Kiplagat *et al*., 2020; Bruce, 2020). Insect species especially from the orders Coleoptera and Lepidoptera are known to attack a wide variety of stored produce. In tropical countries, pest species of stored grain include the bostrichid beetles (*Prostephanus truncatus* Horn and *Rhyzopertha dominica* F.), bean bruchid (*Acanthoscelides obtectus* Say), cowpea beetles (*Callosobruchus* spp.) the grain weevils (*Sitophilus* spp.), angoumois grain moth (*Sitotroga cerealella* Olivier), Cow pea beetle *Callosobrucus chinensis* F.), Mexican bean weevil (*Zabrotes subfasciatus* Boheman) among others (Ogendo *et al*., 2008; Ogendo *et al*., 2012; Adjalian *et al*., 2015; Bett *et al*., 2016, Alves *et al*., 2019; Isman, 2020). The insect pests not only eat economically valuable quantities of food, but cause spoilage by contamination with faeces, odors, webbing, corpses, shedding of skins and by creating heat and moisture that permits the growth of micro-organisms (Ileke and Bulus, 2012; Pavela and Benelli, 2016, Bett *et al*., 2017, Bruce, 2020.

Synthetic pesticides are recommended as remedies for stored product insect pests. However, their application has not been fully exploited in small scale farming due to environmental, health, and economic concerns. Besides, the intensive use of synthetic insecticides results in pest resurgence and pests developing resistance. Phosphine is the recommended principal fumigant in many countries for the protection of stored food grains against major pests. However, phosphine has been reported to be carcinogenic and cause development of insect resistance to it (Ogendo *et al*., 2012, Bett *et al*., 2017). Insecticides of plant origin seem to be potential alternatives to undesirable synthetic insecticides because they are relatively safer, available, affordable and biodegradable. Therefore, it is imperative to study the efficacy, modes of action and safety of insecticidal extracts from plants against insect pests of stored products, in order to integrate them in pest management operations in small scale farming. In ancient farming practices, various indigenous plants were used to control pests that included black pepper, ginger, garlic, turmeric, clove, cinnamon, star anise tobacco among others (Kiruba *et al*., 2008; Paul *et al*., 2009; Isman, 2012; Bruce, 2020). As science advanced, botanical toxins have been extracted such as azadirachtin from *Azadirachta indica* A. Juss, rotenone from *Derris elliptica* Wall., pyrethrin from *Chrysanthemum cinerariifolium* Trevir. (Sae-Yun *et al*., 2006; Barceloux 2008; Shawkat *et al*., 2011, Isman, 2020). These extracts and other plant products have been observed to provide unique mode of action against storage insects due to their availability biodegradability, and broad-spectrum activity (Koul and Dhaliwal 2001; Regnault-Roger *et al*., 2005; Santos *et al*., 2011).

Many researchers have demonstrated that plant extracts have toxic, repellent and reproductive inhibition properties against various stored product insect pests (Ogendo *et al*., 2008; Rajendran and Sriranjini, 2008; Bett *et al*., 2016). A large number of essential oils, their chemical constituents of plants such as *Annona* spp., *Prema* spp, *Azadirachta indica*, *Mentha* spp. *Cupressus* spp., *Ocimum* spp., *Tithonia* spp. and *Eucalyptus* spp.) have been evaluated against insect pests of crops and have shown promise as control agents (Asmanizer *et al*., 2011, Adjalian *et al*., 2015, Bett *et al*., 2016). In other researches, plants that include *Azadiracta indica, Lantana camara, Tephrosia vogellii, Punica granalum, Lippia japonica and Vitex negundo* powders have been evaluated against different stored product insect pests (Duriligbo, 2010; Ishii *et al*., 2010; Gomah and Sahar, 2011; Chebet *et al*., 2013). However, few studies have explored the effectiveness of mixtures of plant powders and reduced amounts of synthetic dusts on stored product insect pests. The prospects of utilizing locally available botanical pesticides due to their being cost effective, environmentally friendly and sustainable in stored product insect pest management is scientifically stimulating. In view of this, the current study was designed to rationalize the use of mixtures of *Tephrosia vogelii* Hook, *Cupressus lusitanica* Miller, *Lantana camara* L. and *Eucalyptus saligna* Smith in different ratios and mixtures of the plant powders and reduced amount of Actelic supper™ (pirimiphos-methyl + permethrin) as alternative insecticides against *Callosobruchus chinensis* F. and *Sitophilus zeamais* Motch.

Materials and methods

Experimental conditions and rearing of test insects

Bioassays were conducted at the Integrated Biotechnology Laboratory at Egerton University, Kenya under controlled conditions of temperature (28±2°C), relative humidity (65±5%), and 24h darkness. The experimental and culture room was fitted with a humidifier, automated heating unit and a thermos-hygrometer calendar. The insects used in this study were obtained from a culture maintained at Egerton University Integrated Biotechnology Laboratory. *Callosobruchus chinensis* adults were allowed to lay eggs for 24-48hrs in green grams placed in 1L glass Kliner jars. The adults in the grain were shifted using an entomological sieve to separate eggs and adults. The eggs were then placed in separate Kliner jars containing grains to allow for development of eggs. Emerging adults (1-5 days old) were used in bioassays (Ogendo, 2008). *Sitophilus zeamais* were reared on whole wheat grains (Tapondjou, 2002). The *S. zeamais* adults were placed in 1L glass Kliner jars containing wheat grains and were allowed to lay eggs for between 24-48hrs. Then the adults were shifted from the wheat grains as above to separate eggs and adults. Emerging adults of *C. chinensis* and *S. zeamais* (1-5 day old) were used in bioassays. The cultures were maintained continuously during the study period. Clean dry wheat and green gram grains used for experiments, were obtained from the local market. The grains were placed in aluminium foil and kept in the oven at 100°C for 24 h to eliminate any latent insect infestation. The experimental design used in the study was randomized block design (RBD) with 4 replicates per treatment.

Preparation of test plant powders

Separate leaf samples of *Eucalyptus saligna*, *Tephrosia vogelii, Lantana camara* and *Cupressus lusitanica* were collected from Egerton University Botanical Garden and transported to Egerton Biotechnology Laboratory in labeled bags. The samples were dried under shade at ambient temperature (25°C) for two weeks. Dry samples were ground into fine powder using an electric laboratory hammer mill, weighed and stored in paper bags (Chebet *et al*., 2012).

Bioassays

Toxicity of mixture of plant powders against Callosobruchus chinensis and Sitophilus zeamais

In the first part of this bioassay, each plant powder was evaluated at a dose of 10% w/w by mixing 100 grams of green gram with 10 grams of each powder. In the second part green gram grains and wheat grains (100 g) were weighed into 100 ml glass jars and mixed with plant powders in the ratios of 1:1, 1:3 and 1:9, *C. lusitanica: T. vogelii* and in the ratios of 1:3 and 1:9 *T. vogelii*: *C. lusitanica* to obtain four different rates (0.0, 2.0, 6.0 and 10% w/w). Similarly, *L. camara,* and *E. saligna* powders were also mixed in ratios and concentrations as above. Grains treated with synthetic insecticide Actellic Super™ (Pirimiphos-methyl + Permethrin) (0.056% w/w) and untreated grain were used as positive and negative controls respectively. Twenty (N_T) unsexed adult *C. chinensis* adult beetles (1–5 days old) were placed into each experimental jar containing mixtures of *T. vogelii* and *C. lusitanica*. Similarly, *S. zeamais* adults were introduced in experimental jar containing mixtures *L. camara,* and *E. saligna.* The top of each jar was covered with reflex towel to prevent the insects from escaping. The jars were then kept in the experimental control room. The number of dead insects (N_D) was recorded at 1, 3, 7- and 10-days post-treatment to estimate adult insect mortality. Actual and corrected percent mortalities in all contact toxicity studies were computed according to (Ogendo *et al*., 2008; Bett *et al*., 2016) and Abbott (1925) respectively in equation 1 and 2

1. Actual Mortality (%) = $\frac{N_D}{N_T} X100$ …………………………………………………………. (1)

2. Corrected Mortality (P_T) = $\frac{(P_O - P_C)}{(100 - P_C)} X100$ …………………………………………… (2)

Where,
N_D =Numbers of dead insects
N_T =No of insects introduced
P_O =Observed percent mortality
P_C= Control percent mortalities

Toxicity of mixture of plant powders and actellic super™ Callosobruchus chinensis and Sitophilus zeamais

Green gram and wheat grains (100 g) were weighed into 100 ml glass jars and mixed with actellic super™ and plant powders but amount of actellic™ super applied was reduced by 50%, 25% and 10% of recommended rate (0.056 % w/w) to obtain three different dosages (2.0, 6.0 and 10% w/w). Twenty (NT) unsexed adult *C. chinensis* adult beetles (1–5 days old) were placed into each experimental jar containing mixtures of *T. vogelii*, *C. lusitanica* and Actellic Super™. Similarly, *S. zeamais* adults were introduced in experimental jar containing mixtures of *L. camara, E. saligna* and Actellic Super™. The top of each jar was covered with reflex towel to prevent the insects from escape. The jars were then kept in the experimental control room. The number of dead insects (N_D) were recorded at 1, 3, 7- and 10-days post-treatment to estimate adult insect mortality. Actual and corrected percent mortalities of *C. chinensis* and *S. zeamais* were computed as in equation 1 and 2 in sub-section 3.3.1 above.

Data analysis

Data on percentage insect mortality were corrected for natural mortality using Abbott formula (equation 3) (Abbott, 1925). The same data were further corrected for heterogeneity of treatment variances using arcsine-transformation before being subjected to one-way analysis of variance (ANOVA) using SAS version 14 (SAS, 2017, Bett *et al*., 2017). The differences between treatment means were determined using Tukey's Studentized (HSD) test (Bett *et al*., 2016; SAS, 2017).

Results

Toxicity tests mixtures of Cupressus lusitanica and Tephrosia vogelii powders against Callosobruchus chinensis

The results of pure leaf powders at a concentration of 10 %w/w and 10 days of exposure, *C. lusitanica* showed the highest mortality of *C. chinensis* at 60% while *T. vogelii* was at 42.5%. The mixture in different ratios of *C. lusitanica* and *T. vogelii* powder produced –duration and -dose dependent contact toxicity of *C. chinensis* (ANOVA: $F_{(2,3)}$ = 10.7-289; P< 0.01). At the highest concentration of 10% v/w and 10 days post treatment, the mixture in ratios of 1:1., 1:3 and 1:9 *C. lusitanica: T. vogelii* caused mortality of *C. chinensis* of 55, 95 and 85% respectively (Figure1). However, in the ratios of 1:3 and 1:9 *T. vogelii: C. lusitanica* at the same concentration and time post treatment mortality of *C. chinensis* was lower at 60 and 65% respectively (Figure2). Overall, powders at various ratios performed better at doses of 2 and 6 % w/w compared to zero and 10%. Moreover, higher percentage of *T. vogelii* in a blend resulted in more percent mortalities compared to the lesser amounts (Figures 1 & 2).

Toxicity test mixtures of Lantana camara and Eucalyptus saligna against Sitophilus zeamais

At the concentration of 10%w/w powders alone, *L. camara* showed the highest mortality of *S. zeamais* at 92% while *E. saligna* showed weak contact toxicity with 45% mortality. In the results of mixtures of powders of *L. camara* and *E. saligna* in different ratios, days after treatment, concentration of powder and ratios of mixture of powder significantly influenced mortality of *S. zeamais* (ANOVA: $F_{(1,3)}$ = 16.92-344.73; P< 0.001). At the ratio of 1:3 *E. saligna: L. camara* at a concentration of 10%- and 10-days post treatment mortality of *S. zeamais* was 82% while at ratio of 1:9 mortality was at 85% (Figure 3). Similarly, at a ratio of 1:3 and 1:9 *L. camara: E. saligna* at a concentration of 10% and 10days post treatment mortality of *S. zeamais* was 68% and 48% respectively (Figure 4). The mixtures of the powders at a ratio of 1:1 *L. camara*: *E. saligna* caused a mortality of 77% in *S. zeamais* (Figure 4). The higher the lantana ratio in the blend of *L. camara* and *E. saligna*, the higher the performance (% mortality), which are largely dose dependent.

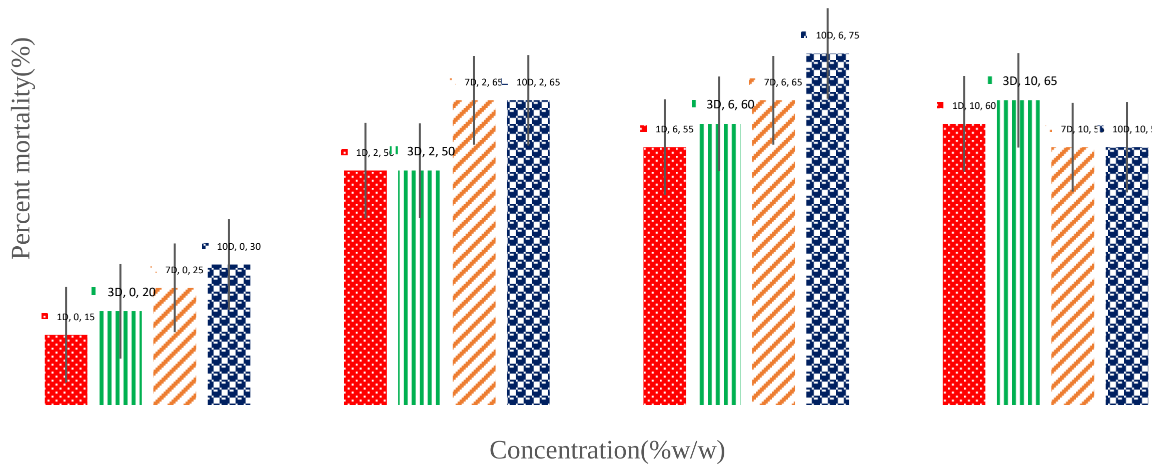


Figure 1(a-c): Percent mortality (Mean ± SE, n=4) of *C. chinensis* after 1-10 days(D) contact with four concentrations (% w/w) of (mixtures of *C. lusitanica* and *T. vogelii* powders at ratios of 1:1, 1:3 and 1:9.

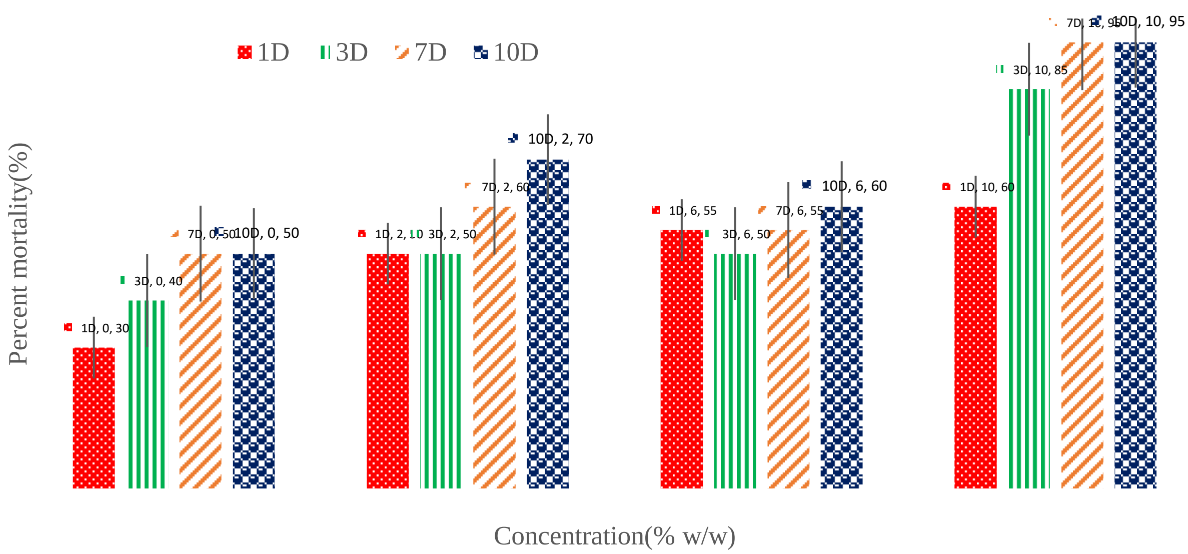


Figure 2(a-b): Percent mortality (Mean ± SE, n=4) of *C. chinensis* after 1-10 days(D) contact with four concentrations (% w/w) of mixtures of *T. vogelii and C. lusitanica* powders at ratios of 1:3 and 1:9

Mixtures of reduced amount of Actellic Super™, C. lusitanica and Tephrosia vogelii powders against Callosobruchus chinensis

Results for mixtures of reduced amount of Actellic super™, *C. lusitanica* and *T vogelii* powder showed that percent reduction of Actellic Super™, time (day) post treatment and concentration of plant powder and Actellic Super™ applied significantly influenced the percent mortality of *C. chinensis* (ANOVA: $F_{(2,3)}$ = 6.38-48.1; $P<$ 0.01-0.001). In the mixture of *C lusitanica* and reduced amount of Actellic Super™ by 10, 25, 50% at a concentration of 10%w/w and 10 days post treatment the mortality of *C. chinensis* was 100, 85 and 84 % respectively (Figure 5). Results also indicated that a mixture of *T. vogelii* and reduced amount of Actellic Super™ by 10, 25, 50% at same concentration and time post treatment caused a mortality of 97, 82 and 80% respectively (Figure 6). The Actellic Super™ treatment only at recommended dosage caused a mortality of 100 % of *C. chinensis* on day post-treatment. The two plant powders when independently mixed with Actellic Super at reduced rate and tested against *C. chinensis* gave insignificant results.

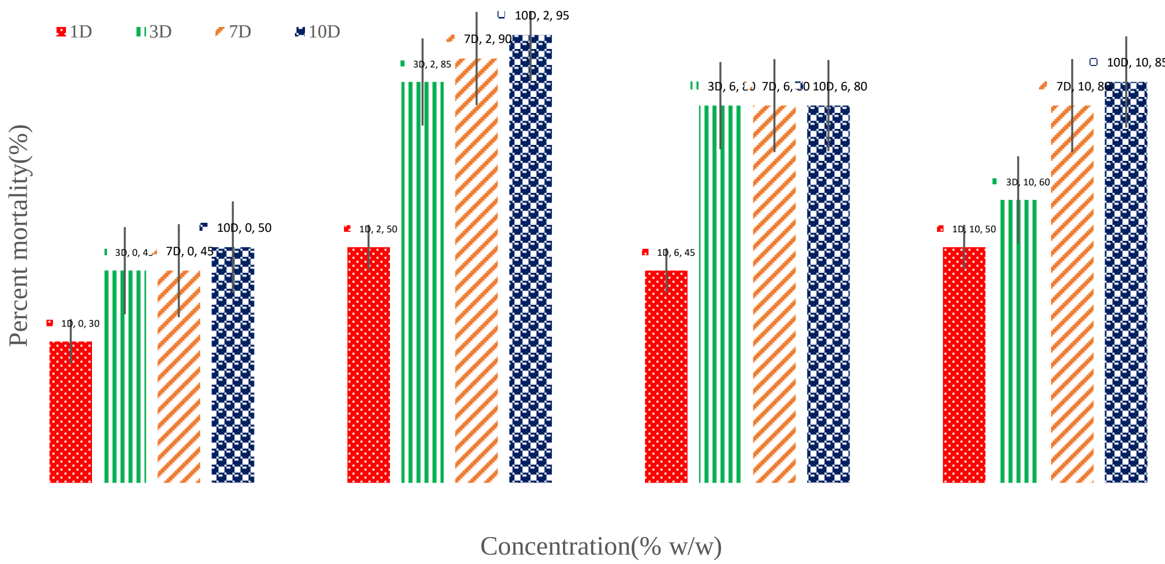


Figure 3(a-c): Percent mortality (Mean ± SE, n=4) of *S. zeamais after* 1-10 days(D) contact with four concentrations (% w/w) of mixtures of *E. saligna* and *L. camara* powders at ratios of 1:1, 1:3 and 1:9.

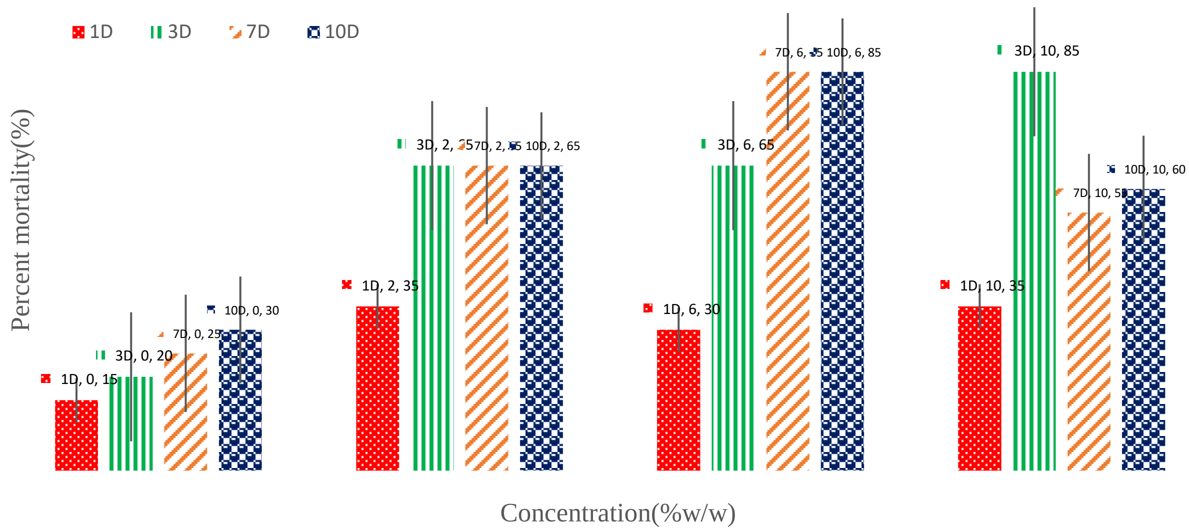


Figure 4(a-b): Percent mortality (Mean ± SE, n=4) of S. zeamais after 1-10 days(D) contact with four concentrations (% w/w) of mixtures of L. camara and E. saligna powders at ratios of 1:3 and 1:9.

Mixtures of Lantana camara and Eucalyptus saligna powders and reduced amount of Actellic Super™ against Sitophilus zeamais

The contact toxicity effects of mixtures of plant powders and reduced amounts of Actellic Super™ were significantly influenced by duration post-treatment, concentration of mixture applied and percent reduction in Actelic Super™ (ANOVA: $F_{(2,3)} = 5.0\text{-}1229.9$; $P< 0.01$). In mixture of *E. saligna* and reduced amount of Actellic Super™ by 10, 25, 50% at a concentration of 10%w/w and 10 days post treatment resulted in percent mortality of *S. zeamais* of 40, 47 and 48% respectively (Figure 7). On the other hand, the mixture of *L. camara* and reduced amount of Actellic Super™ by 10, 25, 50% at same concentration and days post treatment the mortality of *S. zeamais* was 93, 95and 97 percent respectively (Figure 8). The Actellic Super™ was still effective against *S. zeamais* and cased a mortality of 100% three days post-treatment. Blending *L. camara* with actelic super at reduced rate and tested against *S. zeamais* showed better control than a similar treatment with *E. saligna*

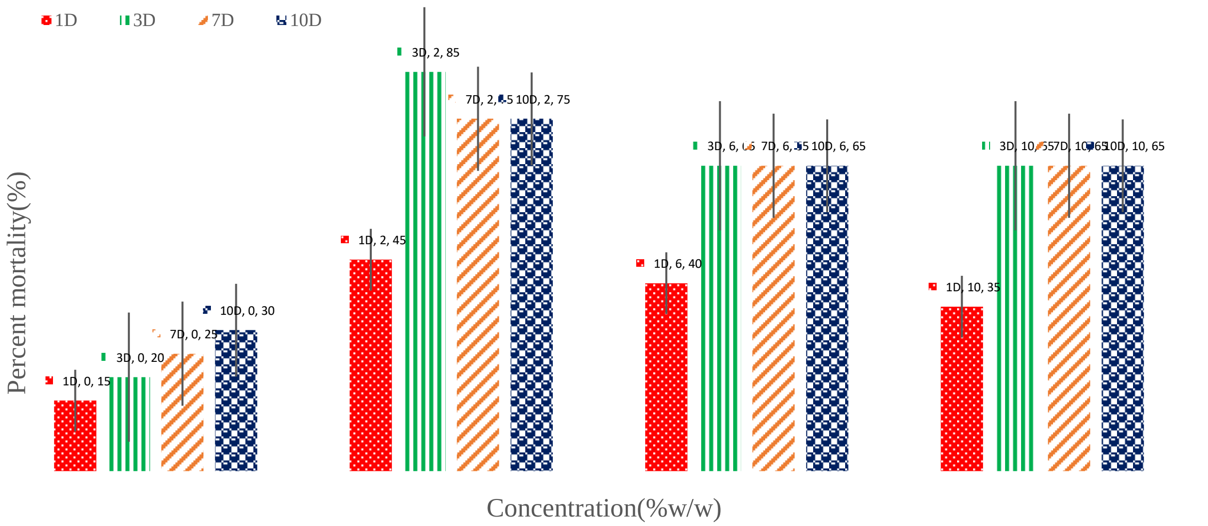
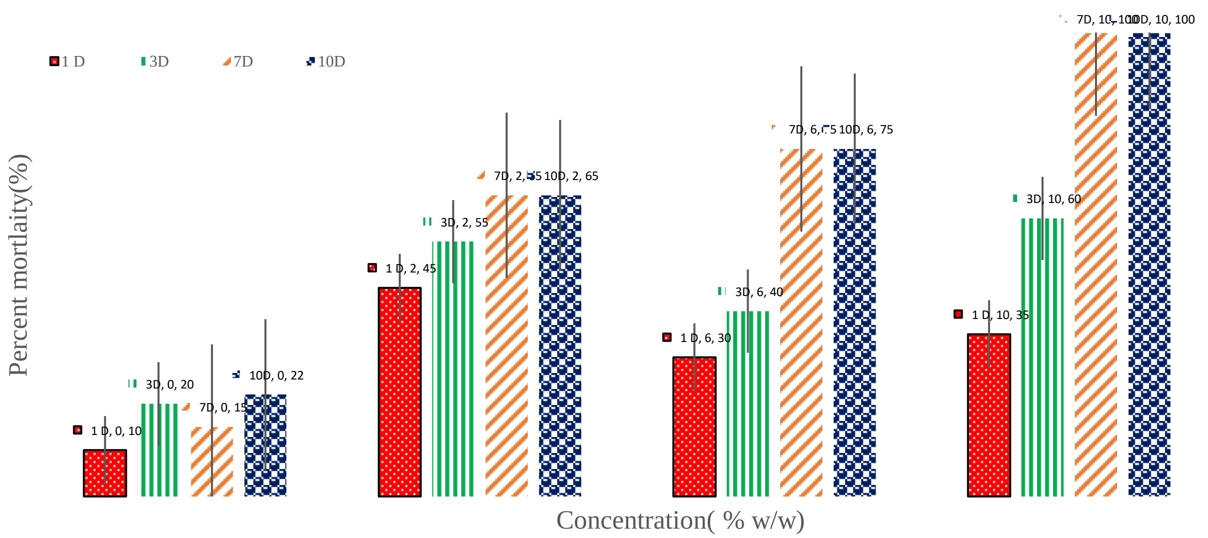
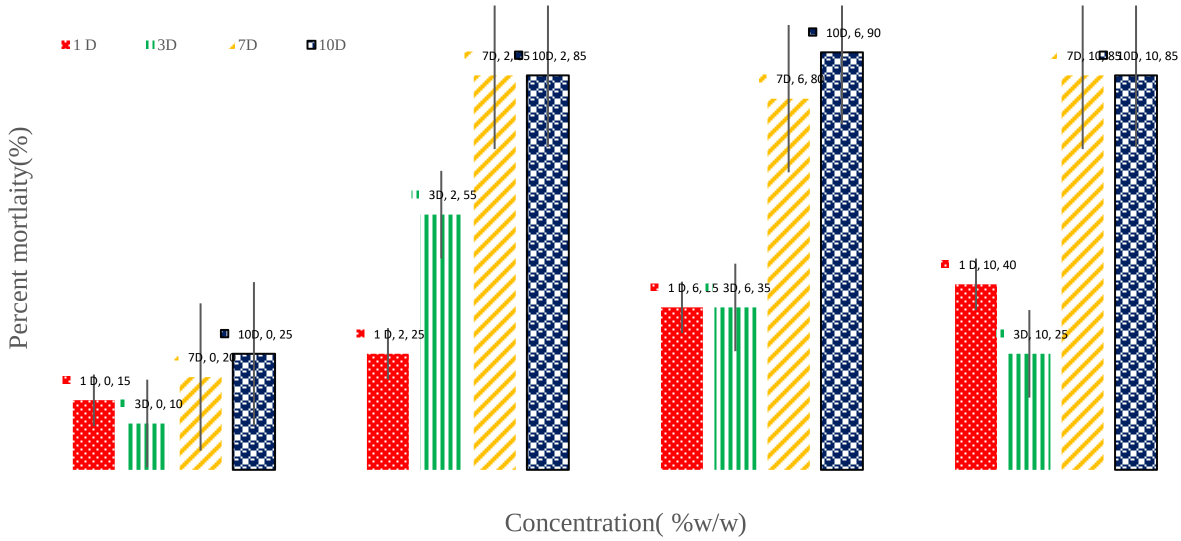


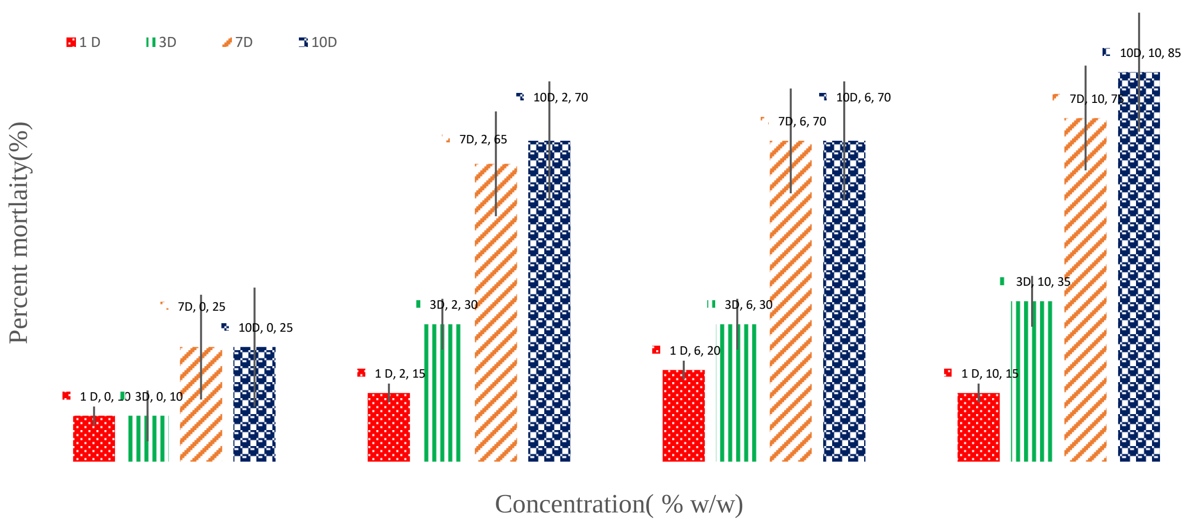
Figure 5(a-c): Percent mortality (Mean ± SE, n=4) of C. chinensis after 1-10 days(D) contact with four concentrations (% w/w) of mixtures of C. lusitanica powders and reduced amount of Actellic Super™



(a) *T. vogelii* and Actellic Super™ reduction by 10%



(b)*T. vogelii* and Actellic Super™ reduction by 25%



(c) *T. vogelii* and Actellic Super™ reduction by 50 %

Figure 6(a-c): Percent mortality (Mean ± SE, n=4) of C. chinensis after 1-10 days(D) contact with four concentrations (% w/w) of mixtures of T. vogelii powders and reduced amount of Actellic Super™

Discussion

In the current study we found that contact toxicity of pure plant powders of *C. lusitanica, T. vogelli* against *C. chinensis* and *L. camara* and *E. saligna* against *S. zeamais* showed moderate to high mortality. The findings indicated that the toxicity of pure plant powders of *C. lusitanica, T. vogelli* against *C. chinensis* and *L. camara* and *E. saligna* against *S. zeamais* depended on plant powder concentration applied, insect species and duration post-treatment. Previous studies have reported inter-plant variations in contact toxicity of plant powders due to variations in chemical constituents and differential responses by the test insect species (Arriaga *et al*., 2005, Ogendo *et al*., 2008; Rajendran and Sriranjini, 2008; Regnault-Roger *et al*., 2012, Baccaria *et al*., 2020, Bernard *et* *al*., 2020). The fact that the *C. lusitanica* and *L. camara* pure plant powders at a dose of 10 % w/w caused a mortality of 60-92% in *C. chinensis* and *S. zeamais* 10 days post treatment proves that the plant powders have toxicity comparable to synthetic and other botanical insecticides. The findings of the current study support the findings of other researchers that observed that plant powders from different plants have varied insecticidal properties (Ogendo *et al*., 2004; Shayesteh and Ashouri, 2010). Shayesteh and Ashouri (2010) observed complete mortality and reduction of F1 progeny emergence of *Rhyzopertha dominica* with black pepper powder at 2.5 % concentration. In addition, Chikukura *et al*., (2011) evaluated leaf powders of *Lippia javanica* Burm.f. and wood of *Spirostachys africana* Sond and found them potent against storage insects by keeping the treated grains in polypropylene bags and then stored in improved brick and grass thatched smallholder granaries. The possible cause of varied toxicities could be explained by the compound structure-insecticidal activity relationships that influence their degree of penetration into the insect cuticle and neurotoxicity (Ogendo *et al*., 2008). Furthermore, the variable mortalities observed could also be due to inconsistencies in efficacy, and relatively lower persistence and residual activity (Isman 2006).

The results of contact toxicity effects of C. *lusitanica* + *T. vogelii* and *E. saligna* + *L. camara* plant powders were significantly influenced by days post treatment, concentration of mixture applied and insect species. When plant powders were mixed, mortality of *C. chinensis* and *S. zeamais* increased significantly to 95-97%. The fact that mixtures of *E. saligna* powder alone caused low mortality to *S. zeamais* but when mixed with *L. camara* mortality significantly increased lends credence to the idea that plant powders have synergist effects against insect pests. The current results support the findings of other researchers who have proposed the synergistic combination of two or more different plant species in botanical formulations as a new control tool in the renewed effort to control pests. Oparaeke *et al*., (2005) found synergistic activity of cashew nutshell + garlic bulb; cashew nutshell + African pepper and garlic bulb + chilli pepper to be effective toxicants against legume flower bud thrips, legume pod borer larvae and pod sucking bugs as shown by increased grain yields by 4 - 5 times. In another research, Talukder and Khanam (2009) investigating the toxic properties of combination of *Acorus calamus* L. rhizomes and *Thevetia neriifolia* Juss found that the plant extracts were effective against *S. oryzae* 24 h post-treatment. The combination of *Cymbopogon nardus* L. and *Ocimum basilicum* L. at 0.5 % w/w was also found to effectively repel *Tribolium castaneum* adults (Iliyasu and Gabriella, 2015). In a relatively recent study, Tamiru *et al.,* (2016) reported synergism among insecticidal plants *Jatropha curcas* (L.), *Datura stramonium* (L.), *Chenopodium ambrosioides* (L.), *Schinus molle* (L.) and *Azadrachta indica* (A. Juss) against *Zabrotes subfasciatus* which augmented potency and reduced dosage rates. Synergistic combination of plant essential oils constituents has also been reported by other authors (Gallarado *et al*., 2012; Koul *et al*., 2013; Alves *et al*., 2019). Koul *et al*., (2013) found thymol and linalool to be synergistically toxic against *Helicoverpa armigera*, *Spodoptera litura* and *Chilo partellus* whereas carvacrol was antagonistic in all combination compounds in terms of acute toxicity and feeding and oviposition deterrence. The synergistic effect of botanical insecticides could be due to combined factors such as, properties of botanical formulations (Obuya, 1990; Omotoso, 2005). According to Isman, (2012) the use of a mixture of plants rather than a single oil interferes with the development of resistance by a pest, because detoxifying a complex of substances rather than only one or a few components is much more difficult for insects. Furthermore, a mixture may target more than a single site of action, acting on both physiological and behavioral parameters. Therefore, the new idea of utilizing synergistic mixtures of different botanical formulations offers a chance to enhance effectiveness of botanical pesticides in order to manage insect pests of crops.

The results of contact toxicity of separate mixtures of plant powders of *T. vogelii, C lusitanica, L. camara* and *E. saligna* and reduced amounts of Actellic Super™ varied according to duration post treatment, dose of mixture applied insect, insect species and percent reduction in Actellic Super™. The findings indicated that when powders were mixed with reduced Actellic Super™ by 50%, the mixture was still potent with mortality of 85-97% of C. *chinesis* and *S. zeamais*. This observation demonstrates mixtures of readily available pesticidal plant powders and synthetic insecticide dusts can reduce the amount of synthetic insecticide used to protect products from insect infestation. This observation can be a milestone having in mind that despite insecticidal activity of many plant powders being reported their application in insect pest management practices has been minimal. The reasons advanced are related to variable efficacy and minimal performance of plant powders as compared to synthetic insecticide dusts. However, there has been an advocacy to drastically reduce synthetic insecticides to the minimal in the management of crop pests and diseases.

Results from different research activities have proved that plant extracts especially essential oils in combination or when mixed with other synthetic insecticides can have synergistic insecticidal activity against Lepidopteran and Dipteran pests (Agona & Muyinza, 2003, Jansen *et al*., 2006, Koul *et al*., 2013). The synergistic activity of mixtures of essential oils and synthetic insecticides have been reported against field crop pests (Isman *et al*., 2011 Faraone *et al*., 2015; Alves *et al*., 2019), stored product pests (Alleke and Oni, 2011; Athanasiou *et al*., 2013, Tamiru *et al*., 2016), and mosquitos (Tong and Bloomquist 2013; Norris *et al*., 2019). A combination of botanical and synthetic insecticide may target more than a single site of action, acting on both physiological and behavioral parameters. In developing countries where farmers practice small scale farming synthetics insecticides are imported and hence unavailable and unaffordable. Therefore, mixtures of synthetic insecticide dusts with readily available insecticidal plant powders will reduce bulk density of imported insecticides hence making it affordable to small holder farmers.

Conclusion

The results of the study suggest that combinations of *T. vogelii, C lusitanica, L. camara* and *E. saligna* and reduced amounts of Actellic Super™ as a formulation can be employed as an eco-friendly natural or semi natural alternative to protect stored products from insect pests. The idea of blending botanical insecticides with conventional insecticides enhanced efficacy and may increase opportunities for plant extracts in managing stored product insect pests, while reducing inputs of synthetic insecticides. Since most synthetic insecticides are imported in developing countries, it will result in savings of foreign exchange. The cultivation and processing of pesticide plants would probably have a positive impact on the economy of rural areas by creating employment and as source of income for rural communities. However, more investigations need to be carried out on antagonistic action of mixtures and effects on natural enemies of pest species and other non-target organisms including humans and livestock. However, overall the findings from this study may be integrated in pest management protocols as a new formulation in stored grain pest control.

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