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Full Length Research Paper

Insecticidal activity of botanical pesticides on *Callosobrunchus chinensis* (L.) (Coleoptera: Bruchidae) in stored green gram, *Vigna radiata* (L)

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***Callosobrunchus chinensis* is a pest of pulses including green gram, *Vigna radiata*, which is a good source of plant protein. Farmers in rural Tanzania apply botanical pesticides to protect green gram from insect pests. The botanicals used in Bubinza and Ngh'anya villages in Magu District were *Azadirachta indica*, *Agave sisalana* ash, *Eucalyptus camaldulensis*, *Cymbopogon citratus* and *Tegetes minuta*. Laboratory experiments investigated insecticidal activity of the botanicals against *C. chinensis* at different doses of 2.5%wxw; 5.0%wxw and 7.5%wxw during varying experimental periods. The findings revealed varying percentage mortality of *C. chinensis* as follows: *Azadirachta indica* > *Agave sisalana* ash > *Eucalyptus camaldulais* > *Cymbopogon citratus* >*Tagetes minuta* and the efficiency of the botanicals was reflected by the mortality of the insects that reached up to 100% in various doses while the LC_{50} (*C. chinensis*) occurred at or below 2.5% during 1 – 7 days period. ANOVA showed significant differences, $P < 0.0001$ in the percentage mortality of *C. chinensis* among the botanicals at each dose. It was concluded that the botanicals possess high insecticidal activity against *C. chinensis* and hence could be employed in the management of *C. chinensis* infesting green gram.**

Key words: Botanical pesticides, *Callosobruchus chinensis,* Bruchidae, green gram, insecticidal activity, mortality.

INTRODUCTION

The beetle, *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae), is a major insect pest of pulses, including green gram, *Vigna radiata* (L) grown in the tropical and sub-tropical areas (Hill, 1987; Rajapakse and van Emden, 1997; Salunke et al., 2005). A couple of researchers have reported *C. chinensis* to cause significant economic losses to pulses in East Africa particularly under subsistence farming systems (Mphuru, 1981; Machocho et al., 2012).

According to Credland (1992) and Hill (2009), among others, the adult female bruchid beetle 3-4 mm long has a fecundity of up to 90 eggs which are laid on to the outside of the pods and if the pods have dehisced, eggs are laid directly on to the seeds. Each *Collosobrunchus* egg has a large space enclosed between the egg and the testa of the seed to which it is attached and this space is connected to the exterior by a short funnel at the posterior end of the egg and hence permitting the ovicidal effect of applied oils for the pest control (Credland, 1992; Kazi et al., 2003). If infested pods from farms are harvested and taken into farm stores, further mating and postembryonic development of the insect takes place in stored legume.

It is reported by Quzi (2007) that infestations of pulses by *Collosobrunchus spp*. often originate from farm stores as the adults can fly for up to about half a mile. Egg hatching takes place after about six days producing scarabaeiform type of larvae that are tiny and dirty white or yellow in colour with a dark brown head and strong mandibles and thoracic sclerites used to bore their way into the seed for feeding and development. And that the whole life cycle of *Collosobrunchus spp*. is about 4 – 5 weeks and have about six or seven overlapping generations in a year. At a temperature of about 28°C and about 70% Relative Humidity, attack by *Collosobrunchus spp.* causes weight losses, and reduces quality and viability of pulse seeds. Distinctive sexual dimorphism in *Collosobrunchus spp* is shown in the antennae where in males antennae are prominently serrate type, while in females the antennae are moniliform. Further, female *Collosobrunchus* have tips of abdomen exposed while those of males are covered by elytra (Chapman, 1998; Quzi, 2007).

The green gram has recently become popular in East Africa especially in the marginal areas (Machocho et al., 2012). It serves as an alternative source of protein and income generation; besides it is easily cooked and does not cause flatulence (Purseglove, 1972). Ecologically, the crop is drought tolerant and gives reasonable yields with as little as 650 mm of rainfall annually (Machocho et al., 2012). Additionally, it is adapted to poor soils because it forms associations with mychorrhiza (Kasiamdari et al., 2002) and is a relay crop, hence plays an important role in promoting food security and conserving the environment respectively. Increased production of this legume offers a high potential for income generation from both domestic consumption and export opportunities thus making the green gram an attractive option for smallholder farmers. In the same vein, increased consumption of green gram will help alleviate malnutrition in the region.

The current production of green gram is, however, constrained by diseases, pest infestations and inappropriate agronomic practices (Machocho et al., 2012). The best practices, particularly fertilizer application as well as pest and disease control entail the application of industrial chemicals. Being resource poor, farmers who are also the main producers and consumers of the legume cannot afford the expensive chemicals. Consequently the majority of rural farmers use indigenous pesticide materials in various combinations although little has been documented, validated and/or promoted (NRI, 2006). There is, therefore, a need to develop integrated crop production and pest management strategies that are cost effective and ecosystem friendly.

In cases of chemical control of bruchids, the pulses could be fumigated by Methyl Bromide by approved operators only. Small-holder farmers and other stakeholders such as food protectionists are, however, increasingly questioning the safety and efficacy of the industrial chemical pesticides. It is advanced by Carson (2002) and Rotimio and Evbuomwan (2012) among others that, chemicals can control pests both in farm fields and in storage but are hazardous to ecosystems and also unavailable to smallholder farmers. Further, Isman (2006) and Rajendran and Sriranjini (2008) report that the synthetic chemicals lose their effectiveness gradually due to development of resistance in *C. chinensis* and that, toxic residues of these chemicals may pose risk to human health and the environment.

Pest control can also be carried out by cultural practices such as growing this vulnerable crop a bit far from farm stores which are the primary source of infestations. The traditional pesticide materials are especially used for non-commercial crops. The materials are, however, not consistent and often produce poor results given the very little investigation done on appropriate doses and resultant effect on pests (Agona and Muyinza, 2003). Crop pest problem is more pronounced in the rural areas, as smallholder farmers are yet to fully integrate synthetic pesticides into their insect pest management systems due to subsistence nature of production and hence they rely on unimproved traditional knowledge systems to meet their protection needs (Warren, 1991; Mihale et al., 2009).

In Tanzania however, pest management activities have rarely been supported by thoroughly controlled local studies as most interventions have been conducted in crisis during the outbreak of crop pests (SUA, 2009). It is against this background that investigations of responses of *C. chinensis* to various botanical pesticides were carried out in the laboratory using different doses of the materials at varying durations after treatment considering its biology. The indigenous pest management constitutes actions and skills that are deliberately initiated, maintained and or intensified by an individual or local community in order to prevent, reduce or eliminate the damage that pests cause while considering the ecological as well as socio-economic consequences (Warrren, 1991). It is further advanced by Rutatora and Mattee (2001), Scoones and Thompson (1994) that farmers generate appropriate technological innovations that are sustainable and take into account the socio-cultural and economic milieu of their communities. Based on the above evidence, it was imperative to collect information and the materials from a specific area where green gram is produced. It is worth noting further that the income generating aspect of green gram is becoming more significant in the surveyed villages principally in the vicinity of urban markets where populations increasingly rely on the legume as an inexpensive source of protein Agricultural extension staff personal communication.

In this regard, alternative methods such as the use of ash, edible oils and plant products that could be easily used by farmers need to be considered. Farmers and researchers often claim the successful use of ash and plant parts (Deng et al., 2009) in insect pest control. Mihale et al. (2009) report that botanicals are used as grain protectants around the Lake Victoria Basin because they have insecticidal properties against stored grain insect pests and also are safer for human health and the environment. The major objective of this study therefore was to investigate the efficiency of diverse dosages of local botanical insecticides employed in stored green gram by the resource poor households to prevent *C. chinensis* infestation. It was hypothesized that the insecticidal activity of the botanicals will be revealed by the mortality of *C. chinensis* at each dose and in each duration of the treatment. It is advanced that improvements in green gram storage pest management using botanical materials could reduce losses and malnutrition and also will increase income of the smallholder farmers.

MATERIALS AND METHODS

Selected study area and botanical insecticide materials

Two villages, namely Bubinza and Ngh'anya in Magu district, Mwanza region, were selected for their being renowned in green gram production in the Lake Victoria Basin in Tanzania (Machocho et al., 2012). The materials available and used by farmers at domestic and small-scale farm level to control the insect pest of green gram in storage were collected. Men and women were involved in the investigation given that both were engaged in green gram production practice.

Information were gathered through informal interviews and hence identification and inventorying of the materials. The botanicals for the tests were collected and taxonomically identified with the support of a taxonomist in the Department of Botany, University of Dar es Salaam. The materials were (1) Neem leaves, *Azadirachta indica* powder which was used as a standard given the plant's known effect on insect pests (Kazi et al., 2003; Khater, 2012) hence considered as a positive control material; (2) Eucalyptus, *Eucalyptus camaldulensis*; (3).*Tegetes minuta,* known to induce insecticidal effects (Deng et al., 2009); (4) Sisal stem, *Agave sisalana* ash; (5) Lemon grass and *Cymbopogon citratus*.

Preparation of botanical pesticide materials

The selected pesticide plant leaves free from obvious/apparent pest infestations and/or infection by disease pathogens were sampled and thoroughly washed using distilled water. The materials were dried for one week in shade in the laboratory to avoid photodegradation of active ingredients by UV light (Khater, 2012). They were then ground by using an electric blender with a grinder (400 W Motor) and sieved through a 1 mm mesh sieve to obtain powder. The materials in powder form were used by most farmers, a situation which guided its selection for this study. Sisal stems were collected, sliced, dried and burnt to produce ash.

Establishment of insect cultures in the laboratory

The green gram, *Vigna radiata* infested with bruchids were collected from farmers' stores and also from the local markets in the study area were introduced in Kilner jars (1 – 2 L) in the laboratory in order to raise insects required for the different treatments. Entomological keys were used to identify the insects infesting the green gram. A closely related species to *C. maculatus* known as *C*. *chinensis* was found to be more abundant and was hence sampled for the tests with the botanical pesticide materials.

Fresh green gram was purchased from farmers and petty traders in the local markets and these were disinfested by deep freezing for one week and later dried and equilibrated with the experimental conditions of ambient temperature and relative humidity of about 20 - 28°C and 70-80% respectively to avoid possible infection by fungi as reported by Rotimi et al. (2006) and Varma and Anandhi (2010). *C. chinensis* from the cultures were introduced in the equilibrated green gram samples in jars and kept for ten days to deposit eggs. The insects were then removed from the samples and thereafter the emerging adult insects were referred to as parents and were collected for seven days uninterruptedly. The parents were sexed, conditioned and finally used in the pesticides treatments to determine their responses to different insecticide materials presented at different doses and some parent insects were used in the untreated samples referred to as controls.

Bioassays

Green gram seeds (50 g) free from infestation were placed in separate experimental glass bottles and mixed thoroughly by using glass rods with each powdered botanical material in dosages of 2.5%wxw (1.25 g); 5.0%wxw (2.50 g) and 7.5%wxw (3.75 g) and this measure is referred to as percent weight by weight (w/w) (Ogendo, 2009; Ilоba and Ekrakene, 2006; Khater, 2012). The weights of the botanical materials were calculated by using the following formula:

$$\text{Weight of a botanical material (g)} = \frac{\text{Weight of green gram (g)} \times \text{\% dose}}{100}$$

The grams mixed with the botanicals were infested with seven to ten day old 12 pairs of female and male (sex ratio 1:1) parent *C. chinensis* from the established cultures. The bottles were tightly covered with perforated pieces of aluminium foil to contain insects and to permit gaseous exchange. Three replicates were set for each dose of the treatments for every experimental period namely: 1 - 7, 8 - 14 and 15 - 21 days. Controls were set containing only the green grams and *C. chinensis* in three replicates. At the end of each period, the dead insects in

Table 1. Mean percentage mortality (%±SE) of *C. chinensis* in the botanical pesticides treatments at three different doses (% w/w) during the 1 – 7 days experimental period (mean of three replicates).

Botanical pesticide	Insect mortality in three doses		
	2.5% w/w	5.0% w/w	7.5% w/w
Azadirachta indica	95.83 ± 0.57[a]	100.00[a]	100. 00[a]
Agave sisalana ash	83.33 ± 0.88[b]	91.66± 0.86[b]	91.66 ± 0.33[b]
Eucalyptus camaldulais	72.22 ± 0.55[c]	83.33 ± 0.55[b]	87.50 ± 0.87[b]
Cymbopogon citratus	59.72 ± 0.86[d]	75.00 ± 1.15[c]	79.16 ± 0.56[c]
Tagetes minuta	55.5 5± 0.33[d]	63.88 ± 0.33[d]	70.83 ± 1.00[d]

Values in the same column followed by the same letter superscript are not significantly different at P<0.05 by the Tukey-Kramer multiple comparisons test.

each treatment replicate were removed, recorded and their numbers compared with the original infestations of 24 parent insects in each replicate to calculate percentage mortality of *C. chinensis*. Mortality level so determined indicated the insecticidal activity of the botanical material against the insect pest.

Data analysis

During the different time intervals of the experiments, the numbers of the dead *C. chinensis* were calculated at different doses of the botanicals and a non-parametric one way analysis of variance (ANOVA) test according to Sokal and Rohlf (2012) was employed to test differences among the percentage mortality of *C. chinensis* in the different botanical materials at doses 2.5% w/w, 5.0% w/w and 7.5% w/w. To compare mortality percentage of insects between the different insecticidal botanical materials at each dose, the Tukey-Kramer Multiple comparisons test was carried out. Further, given the nature of this study the Lethal Concentration 50 (LC_{50}) of the different botanical pesticides were calculated during the 1st - 7th day period of the experiment as outlined by Klaassen et al. (1986). Effectiveness of the pesticides was calculated according to Abbott's (1925) formula at the dose of 7.5% w/w in the 15th - 21st day period.

RESULTS

Green gram treatment for storage

Smallholders have reported that preparation of green gram for storage at their homesteads starts off by drying the seeds to a level that meets their satisfaction. The pesticide materials applied to the grams were reported to have varying capabilities for the control of bruchid insects for a period of about three months. The seeds earmarked for next season's planting were reported to be treated with the available insecticide materials at slightly higher concentrations than those for home utilization or sale. The farmers expressed that their traditional materials met their expectations of crop loss and storage costs reduction. They also asserted that the materials do not affect the palatability or taste of the stored green gram and further the farmers noted that some of the materials namely *A. indica* and *C. citratus* are used for medicinal purposes.

Effect of *A. indica* to *C. chinensis* in treated green gram

Only one insect survived out of the 24 parent insects introduced in the seeds treated with neem powder at 2.5% during the period of seven days (Table 1). There were no any insect which survived in doses 5.0% and 7.5% during the same period. Further, during the 8 – 14 and 15 – 21 days experimental periods, there was no any insect that survived in green gram at all three doses of *A. indica* as mortality was 100% (Tables 2 and 3).

Number of *C. chinensis* in green gram treated with *Agave sisalana* ash

There were insects recorded at the dose of 2.5% during the first and second experimental periods, 1 – 7 and 8 – 14 days where mortality was 83.33 ± 0.88% and 93.05 ± 0.33% respectively (Tables 1 and 2). During the 15th – 21st day period, there were no insects which survived in all the three doses of the botanicals as insect mortality was 100% (Table 3).

Mortality of *C. chinensis* in *Eucalyptus camaldulais* treated green gram

In treatments with *E. camaldulais*, there were varying numbers of insects at all doses in the 1 – 7 days period in all doses. At the doses of 2.5%, 5.0% and 7.5%, the mean mortality in insects was 72.22 ± 0.55%, 83.33 ± 0.55% and 91.66 ± 0.87% (Table 1). During the 8 – 14 days period, there was 83.33 ± 0.58% mean insect

Table 2. Mean percentage mortality (%±SE) of *C. chinensis* in the botanical pesticides treatments at three different doses (% w/w) during the 8 – 14 days experimental period (mean of three replicates).

Botanical pesticide	Insect mortality in three doses		
	2.5% w/w	**5.0% w/w**	**7.5% w/w**
Azadirachta indica	100.00[a]	100.00[a]	100.00[a]
Agave sisalana ash	93.05 ± 0.33[a]	100.00[a]	100.00[a]
Eucalyptus camaldulais	83.33 ± 0.58[b]	100.00[a]	100.00[a]
Cymbopogon citratus	66.66± 0.56[c]	90.27 ± 0.88[b]	94.44 ± 0.33[a]
Tagetes minuta	55.55± 0.33[d]	70.83 ± 0.54[c]	86.11 ± 0.65[b]

Values in the same column followed by the same letter superscript are not significantly different at P<0.05 by the Tukey-Kramer multiple comparisons test.

Table 3. Mean percentage mortality (%±SE) of *C. chinensis* in the botanical pesticides treatments at three different doses (% w/w) during the 15 – 21 days experimental period (mean of three replicates).

Botanical pesticide	Insect mortality in three doses		
	2.5% w/w	**5.0% w/w**	**7.5% w/w**
Azadirachta indica	100.00[a]	100.00[a]	100.00[a]
Agave sisalana ash	100.00[a]	100.00[a]	100.00[a]
Eucalyptus camaldulais	94.44 ± 0.33[a]	100.00[a]	100.00[a]
Cymbopogon citratus	86.11± 0.66[b]	93.05 ± 0.66[b]	100.00[a]
Tagetes minuta	65.27± 0.88[c]	79.16 ± 0.57[c]	97.22 ± 0.33[b]

Values in the same column followed by the same letter superscript are not significantly different at P<0.05 by the Tukey-Kramer multiple comparisons test.

mortality at the dose of 2.5% while in the same period, mortality was 100% at the doses of 5.0% and 7.5%. During the 15th - 21st day period, few survivors were recorded at the dose of 2.5% while mortality at 5.0 and 7.5% was 100%.

Numbers of *C. chinensis* in green gram treated with *Cymbopogon citratus*

There were some insects that survived in all doses of *C. citratus* during the first and second experimental periods at the dose of 2.5% although mortality was high at dose of 5.0%wxw (90.27 ± 0.88%) and 7.5%wxw (94.44 ± 0.33%) (Table 2). During the third experimental period, mortality of the insects in the *C. citratus* treatment was 100% at the dose of 7.5% (Table 3).

Effect of *Tagetes minuta* to *C. chinensis* in treated green gram

The insects survived comparatively well as mortality in seeds treated with *T. minuta* at all doses were 55.55 ± 0.33%, 63.88 ± 0.33% and 70.83 ± 1.00% in 2.5%wxw, 5.0%wxw and 7.5%wxw doses respectively in the first experimental period (Table 1). During the 8th – 15th days period, mortality was 55.55 ± 0.33%, 70.83 ± 0.54% and 86.11 ± 0.65% at the doses of 2.5%wxw, 5.0%wxw and 7.5%wxw respectively. However, during the third period of the experiment, highest mortality of C. *chinensis* was recorded at the dose of 7.5% (Table 3).

Analysis of response of *C. chinensis* in the treatments at different doses and experimental periods

In general, the bruchid, *C. chinensis* responded variously to the different botanical pesticide materials. Dead insect at all doses and during all periods were increasing in number as follows: *Azadirachta indica>Agave sisalana* ash> *Eucalyptus camaldulais* > *Cymbopogon citratus* > *Tagetes minuta*.

ANOVA of insect percentage mortality in the five botanical treatments at 2.5%, 5.0% and 7.5% doses during the three experimental periods of 1 - 7, 8 - 14 and 15 - 21 days indicated extremely significant differences where F values ranged from 14.175 to 109.88 at P < 0.0001. Tukey-Kramer Multiple comparisons test showed varying differences of insect mortality between treatments at each dose at $P < 0.05$. Tables 1, 2 and 3 show the trend in the mean percentage mortality of insect as indicated by the number of dead insects in the green gram treated with different botanical pesticide materials at three doses during the three experimental periods.

In this study, the LC_{50} (*C. chinensis*) (% w/w) occurred during the 1st-7th days period in the different botanical materials as follows: in *A. indica* and *A. sisalana* ash, the LC_{50} was less than 2.5%, while in *E. camaldulais, C. citratus* and *T. minuta*, the LC_{50} was at 2.5% w/w. Effectiveness of the four botanical pesticides calculated using figures recorded at dose of 7.5% during the 15th - 21st days period of the experiment was 94% while that of *T. minuta* was 85%.

In the controls, it was revealed that very few insects did die in all the three experimental periods. Insect numbers were about the same as the initial infestations, ranging from 24 to 22 during the experimental periods and thus, mortality in these controls ranged from 0 to 8%.

DISCUSSION

Green gram crop in storage

Smallholder farmers reported that attack and damage of stored green gram by *Collosobrunchus spp* cause untimely sale of the harvested seeds hence resulting in short storage periods and ultimately causing post-harvest price collapse and marked seasonal price fluctuation. Amongst the farmers, the state of affairs was a disaster and at the same time triggered their mental faculties to think about a continued search for dosage change and more pesticide materials within their reach. Paul (2007), for instance reported the presence of various pesticide materials in Tanzania which could be used in insect pest control.

Effect of the botanical pesticide materials to *C. chinensis*

The insecticidal effect of the materials against *C. chinensis* which varied among doses in different treatments was indicated by the number of the initial infesting insects which died after application of the pesticide materials in various doses at different experimental periods. In *A. indica* leaves powder treatment, mortality in insects was highest starting at the dose of 2.5% while in the case of *A. sisalana* stem ash and *E. camaldulensis*, most insects died during the early days of the experiment particularly higher doses higher starting with 5.0%. This condition could be explained probably by the parent insects being knocked off by effects of the applied insecticides. Varying insect mortality continued to be exhibited throughout the experimental periods in all treatments. *C. citratus* and *T. minuta* caused least mortality of the insect pest at lower doses but at higher doses they showed promising effectiveness against *C. chinensis*. Further the promising bioactivity of the materials were evident very early where the LC_{50} (*C. chinensis*) (% w/w) in *A. indica* and *A. sisalana* ash occurred during the 1st-7th days period at the dose less than 2.5%, while that in *E. camaldulais, C. citratus* and *T. minuta* occurred at 2.5% w/w.

It is reported by Kazi et al. (2003) and Khater (2012) that Azadirachtin ($C_{35}H_{44}O_{16}$) is the main insecticidal constituent in crude Neem which acts as an insect anti-feedant affecting insect physiology as it interferes with the peripheral nervous system and that it is also a toxicant when ingested by an insect. Further, the efficacy of *A. indica* is linked to its action as a growth regulator on larval insects by disrupting the moulting process, growth inhibition and malformation that ultimately contributes to insect mortality. However, the crude material is reported to be non toxic to mammals hence safe to use as an insecticide to protect stored products for human consumption. *A. indica* was used in this study as a standard or positive control material for its renowned effect on insect pests (Paul, 2007; Khater, 2012).

For the comparatively less effective materials, responses of the insects were indicated by the death of relatively fewer insect parents in treatments during the varying experimental periods. Salunke et al. (2005) for instance note that specific properties of the different pesticide materials are considered to result in varied responses and this was demonstrated by *C. chinensis* mortality recorded in green gram treated with different pesticides at different doses and durations of treatments. The botanical materials used in this study may be either chemically poisonous and or physically repelling due to strong smell which could kill and or repel the insect pests thus inhibiting them from feeding, a situation which could lead to their death (Agona and Muyinza, 2003; Salunke et al., 2005).

The *A. sisalana* stem ash applied to the green gram may have been corrosive to some weak areas of the cuticle. If the ash acts on the less sclerotized parts of the cuticle, particularly inter-segmental areas of the sternite and pleurite, it may reduce cuticle impermeability to water which could cause fluids loss and finally insect dehydration and death. Due to abrasion by ash, the cuticle may also become dysfunctional in protecting the insect against pathogens (Chapman, 1998). It is further reported in Muthangya et al. (2013) that waste water from sisal is acidic, pH of 5.57 a condition which might have contributed to the damaging of the insects' cuticle and hence causing their death due to desiccation.

Some ash particles of *A. sisalana* stem could as well get their way to the insect tracheal system through spiracles and trachea up to the tracheoles and hence interfere with normal gaseous exchange in the insects. Tracheoles contain specific column of fluids close to its terminal in muscle tissues and their ends lack cuticular material hence gaseous exchange take place by diffusion at the gas-fluid interface where oxygen diffuses through fluids into tissues (Chapman, 1998). This process could be interrupted by the ash particles and hence lower the insects metabolic activity which depends on appropriate gaseous exchange through the fluid medium. The ashes were observed to also hinder insects' locomotion in the treatments when feeding and may be during probing to deposit eggs.

E. camaldulais showed great effectiveness against *C. chinensis* in this research and was ranked third in the list of the evaluated botanicals. This observation could be supported by Thomas (2012) who reports that some *Eucalyptus* species are known to possess natural insect repellent and that there is evidence that components in eucalyptus oil, in particular the compounds p-methane-3-8-dioi and eucamol which confuses insects particularly mosquitoes, make them unable to find a host. It is however cautioned that *Eucalyptus* should be reapplied regularly to maintain protection against the insect pests and vectors of diseases.

Further, *C. citratus* showed effectiveness against the insect pest particularly at doses higher than 2.5% and also during prolonged exposure to treatments. The protective effect of the essential oils of *C. citratus* was also reported by Hanifah et al. (2011) against house dust mites and by Paranagama et al. (2003) on *Sitotroga cerealella* populations infesting paddy. *T. minuta* was found to be effective against *C. chinensis* at higher doses and increased exposure in this study. The toxicity of *T. minuta* was also reported by Perich et al. (1995) and Ireri et al. (2010) that extracts from the plant were largely responsible for significant mortality at P<0.05 in mosquitoes and *Phlebotomus duboscqi*.

CONCLUSION AND RECOMMENDATIONS

Response of the pulse beetle, *C. chinensis* varied with the employed botanical insecticide material types, the doses applied as well as the duration of the treatment. The insecticidal activity of the botanical materials resulted into varying percentage mortality of *C. chinensis* and consequently the reduction of the insect pest populations.

On the basis of the observed high mortality of *C. chinensis*, it is concluded that the evaluated botanical pesticides showed high insecticidal activity and their efficiency was exhibited by the mortality of the insect pest that reached up to 100% in various doses. In this regard, the botanicals could be used to control *C. chinensis* in rural storage systems at the identified doses of 2.5%, 5.0% and 7.5% w/w depending on the motive for the gram storage. And that, *A. indica, A. sisalana* and *E. camaldulais* could be strongly promoted as most effective control materials even at lower doses, while *C. citratus* and *T. minuta* could also be employed particularly in the storage of green gram for regular consumption.

In the light of the findings, it is recommended that the use of the botanical pesticides could be disseminated to other areas in the country. Smallholder farmers in other areas could be sensitized on the importance of applying locally endowed insecticide materials which are readily available, sustainable, environment friendly given that they are both eco-friendly and have no price tag.

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