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COMPARATIVE LETHALITY OF THREE INSECTICIDAL PLANT POWDERS, A DIATOMACEOUS EARTH AND THEIR MIXTURES TO ADULTS OF FOUR STORAGE BEETLES

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ABSTRACT

The lethality of powders made from rice husk (RHP), dry fruits of *Piper guineense* (PGP), dry flower buds of *Eugenia aromatica* (EAP) and a diatomaceous earth (SilicoSec) (DE), and some of their mixes to adults of *Sitophilus zeamais* Motsch., *S. granarius* L., *Lasioderma serricorne* F. and *Callosobruchus maculatus* F. was investigated under controlled conditions of 25° C and 60% relative humidity. The materials were tested singly at 2% of grain weight in glass Petri dishes against 20 adults of each beetle. Adult mortality was observed up to 10 days post treatment. One day post treatment DE produced 100% mortality in *L. serricorne* and *C. maculatus* which was significantly higher than mortality recorded in all other treatments. The mortality of *L. serricorne* (90.0%) and *C. maculatus* (86.7%) produced by *E. aromatica* powder was next to DE and was also significantly higher than mortality recorded in other treatments. As from 3 days post treatment DE and *E. aromatica* powder caused 100% mortality of *L. serricorne* and *C. maculatus* adults. DE and *E. aromatica* also caused 100% mortality of *S. zeamais* and *S. granarius* at 10 days post treatment. The adult storage beetles irrespective of species and at all times of observation suffered significantly lower mortality when exposed to grain treated with RHP and PGP. The combinations of EAP and DE (ratios 1:1, 3:1 or 1:3) produced generally higher mortality in *S. zeamais* and *S. granarius* than other combinations 3, 5 and 7 days post treatment. By 10 days post treatment all the EAP/DE and PGP/DE combinations produced 100% mortality of *S. zeamais* and *S. granarius*. One day post treatment EAP/DE combinations (ratios 1:1, 3:1 or 1:3) produced significant mortality (100%) in *C. maculatus* and *L. serricorne* . Adult mortality in RHP/DE (1:3) (88.3%) and PGP/DE (1:3) (83.3%) involving *C. maculatus*, and RHP/DE (1:1,1:3) (100%) and PGP/DE (1:1, 1:3) (86.7%, 100%) involving *L. serricorne* was also significant. By 2 days and 3 days post treatment all mixtures have produced 100% mortality in *C. maculatus* and *L. serricorne* adults except RHP/DE (3:1) (75%) and PGP/DE (1:1, 3:1) (80.0%, 78.3%) involving *C. maculatus*. EAP and DE applied at 0.01, 0.02, 0.03 and 0.04 g/20 g of grain produced 100% mortality of *C. maculatus* adults.

Keywords: Plant powders; diatomaceous earth; lethality; storage beetles

INTRODUCTION

Losses to stored food commodities associated with activities of different types of insects constitute a principal factor inducing food insecurity in many countries of the tropics and subtropics (Holst *et al*., 2000; Lale, 2001; Badii *et al*., 2011). Stored-product insects cause damage by eating portions of products and this is usually manifested by reduction in weight and volume, and also by contaminating food commodities with frass, exuviae and corpses of dead insects, altering their biochemical constitution or by outright reduction in the amounts of important nutrients. Insect pest infestation especially species that feed on the germ or embryo also results in reduced viability of damaged seeds. It has been reported that insect damage in stored grains and other durable commodities may amount to 10-40% in developing countries (Kostyukovsky and Shaaya, 2011).

Many synthetic insecticides formulated as dusts such as pirimiphos-methyl and permethrin are very effective for stored products protection, but their use has several drawbacks such as increasing costs, inconsistent supplies and hazards to man and the environment (Ofuya, 2003). Therefore, many scientists have conducted research over many years aimed at identifying botanicals which may replace synthetic insecticides (Kostyukovsky and Shaaya, 2011). In Nigeria, the biological efficacies of powders from a few plants including dry flower buds of clove, *Eugenia aromatica* (L.) Baill. and dry fruits of West African brown pepper, *Piper guineense* Schum and Thonn have been investigated and confirmed by many workers (Lale, 2010). Effective rates of application of insecticidal plant powders are much higher than for conventional synthetic dusts. For instance mixing stored cowpea seeds seed with 1.0 g or more of *P. guineense* dried fruit or neem kernel powders per 20 g of cowpea seed are recommended for control of *C. maculatus* (Anonymous, 1996). For complete control large quantities of these insecticidal plant powders are needed which may not be practicable for large scale storage. Ways of enhancement of insecticidal action of plant powders needed for storage protection should necessarily be sought and tested empirically. The insecticidal effects of these botanical powders may be enhanced by good formulation by mixing with other environment friendly insecticidal materials (Ofuya, 2009). Ofuya *et al*. (2007) have demonstrated the possibility of using organic flours from yam, cassava and plantain as diluents in the formulation of insecticidal dusts from dry flower buds of *E. aromatica* and dry fruits of *P. guineense*. However, relatively high percentage of the active plant material was required for effectiveness. Diatomaceous earth (DE) is a non-toxic safe substance made up from fossils of freshwater organisms and crushed to fine powder, which has been reported to be effective against storage insect pests by many workers (Stathers *et al*. 2004; Athanassiou *et al*., 2005; Demissie *et al*., 2008; Badii *et al*., 2014). Stathers *et al.* (2008) observed the great potential in the use of diatomaceous earth as grain protectants for small-holder farmers in sub Saharan Africa. An approach may be to combine insecticidal plant materials to which farmers are already familiar with diatomaceous earth and there seems to be limited information in this regard. This paper therefore reports results of a study to determine the efficacies of insecticidal dusts containing powder of *E. aromatica* or *P. guineense*, and a diatomaceous earth (Silico Sec®) in different proportions against the cowpea seed beetle, *Callosobruchus maculatus* Fabricius, the maize weevil, *Sitophilus zeamais* Linnaeus, the granary weevil, *S. granarius* L. and the cigarette beetle, *Lasioderma serricorne* Fabricius.

MATERIALS AND METHODS

The study was carried out at the Federal Research Centre for Cultivated Plants, Institute of Ecological Chemistry, Plant Analysis and Stored Product Protection, Berlin, Germany under controlled conditions of 25 ± 2° C and 60 ± 5% relative humidity.

Insects

The storage insects tested in the study are the cowpea seed beetle, *Callosobruchus maculatus* Fabricius, the maize weevil, *Sitophilus zeamais* Linnaeus, the granary weevil, *S. granarius* L. and the cigarette beetle, *Lasioderma serricorne* Fabricius. Their cultures are maintained at Institute of Ecological Chemistry, Plant Analysis and Stored Product Protection, Berlin, Germany using standard procedures (e.g. Tofel *et al*., 2015). *C. maculatus* was tested using blackeye cowpea whilst *S. zeamais*, *S. granarius* and *L. serricorne* were tested on yellow maize.

Insecticidal plants

The plants are West African brown pepper, *Piper guineense* and clove, *Eugenia aromatica* whose products have proven efficacy against many storage insects (Ofuya, 2009). Dry fruits of *P. guineense* and Dry flower buds of *E. aromatica* were purchased from the Central Spices Market in Kaduna, Nigeria (10.3333° N, 7.7500° E). Identity of each plant material was confirmed at Obafemi Awolowo University Herbarium, Ile-Ife, Nigeria. A much less insecticidal plant material, paddy rice husk (unpublished observation) was added for comparison. Paddy husk was obtained from a processing mill in Emure in Ekiti State, Nigeria (7.4500° N, 5.4667° E) and rice variety was Igbemo local grown by communities around the metropolis. The plant parts were further oven dried at 80^{o} C for a period of 24 h. Thereafter, the plant materials were pulverized in a laboratory mill and sieved to powder of particle size of ≤ 300 µm using British standard sieve (Ofuya and Dawodu, 2002). Each plant powder type was stored in separate plastic containers with tight fitted lids.

Diatomaceous earth (DE)

The diatomaceous earth (DE) used is SilicoSec, a natural silica powder obtained from processed fossilized diatoms. It is composed of 96% amorphous SiO_2 with particle size between 13 µm to 15 µm (Erb-Brinkmann, 2000).

Effect of singly applied insecticidal material on insect mortality

The insecticidal powders and DE were applied at 2% of grain weight (Lale, 2010). Twenty newly emerged adults of *C. maculatus*, *S. zeamais or L. serricorne* were dusted by shaking with 0.4 g of paddy rice husk, *E. aromatica*, *P. guineense* powders or DE in clear glass Petri dishes (9.0 cm diameter) containing 20 g of appropriate grain. There was a control treatment with no insecticidal material. Adult mortality was observed for up to 10 days post treatment. The experiment was replicated thrice.

Effect of mixing DE with insecticidal plant powders on insect mortality

Twenty newly emerged adults of *C. maculatus*, *S. zeamais or L. serricorne* were dusted by shaking with 0.4 g of mixture of DE with either, paddy rice husk, *E. aromatica*, or *P. guineense* powder in clear glass Petri dishes (9.0 cm diameter) containing 20 g of appropriate grain. Mixing was done in three ratios DE: plant powder – 1:1, 3:1, and 1:3, respectively, for each plant powder. The ratios were selected for the convenience of mixing. There was a control treatment with no insecticidal material. Adult mortality was observed for up to 10 days post treatment. Morphological changes in adults were noted. The experiment was replicated thrice.

Lethality of *E. aromatica* powder and DE at low dosages against *C. maculatus* adults

Twenty unsexed adults of *C maculatus* (< 2 days old) were separately dusted by shaking with either *E. aromatica* powder (EAP) or SilicoSec (DE) in clear glass Petri dishes (9.0 cm diameter) containing 20 g of cowpea seeds. Each product was tested 0.01, 0.02, 0.03 and 0.04 g respectively. There was a control treatment with neither RHA nor DE. Adult mortality was observed daily for up to 7 days. The experiment was replicated thrice.

Data analysis

Data was analyzed using the SigmaStat® 3.5 software (Systat Software GmbH, Germany). Mortality data, where necessary, were corrected as recommended by Abbott (1925) and the percentages were arcsine transformed and subjected to one-way analysis of variance (ANOVA. Where the ANOVA indicated significant difference between treatments, Least Significant Difference (LSD) method was used to separate means.

RESULTS

The adult storage beetles irrespective of species and at all times of observation suffered lower mortality which was significant, when exposed to grain treated with powders of rice husk and *P. guineense* at the same rate of 2% of grain weight (Table 1). One day post treatment DE produced 100% mortality in *L. serricorne* and *C. maculatus* which was significantly ($P < 0.05$) higher than mortality recorded in all other treatments. The mortality of *L. serricorne* (90.0%) and *C. maculatus* (86.7%) produced by *E. aromatica* powder was next to DE and was also significantly higher than mortality recorded in other treatments. As from 3 days post treatment DE and *E. aromatica* powder caused 100% mortality of *L. serricorne* and *C. maculatus* adults. DE and *E. aromatica* also caused 100% mortality of *S. zeamais* and *S. granarius* at 10 days post treatment.

The combinations of *E. aromatica* powder (EAP) and diatomaceous earth (DE) (ratios 1:1, 3:1 or 1:3) produced significantly higher mortality (80% or greater) in *S. zeamais* and *S. granarius* than other combinations 3 days post treatment except with the combination of *P. guineense* powder (PGP) and DE (1:3) (Table 2). A similar trend was largely followed 5 days and 7 days post treatments respectively. By 10 days post treatment all the EAP/DE and PGP/DE combinations produced 100% mortality of *S. zeamais* and *S. granarius* which was significantly higher than mortality produced by rice husk powder (RHP) and DE combinations except with RHP/DE (1:3) which caused 91.7% mortality.

One day post treatment EAP/DE combinations (ratios 1:1, 3:1 or 1:3) produced significantly higher mortality (100%) in *C. maculatus* and *L. serricorne* than other combinations except with RHP/DE (1:3) (88.3%) and PGP/DE (1:3) (83.3%) involving *C. maculatus*, and RHP/DE (1:1,1:3) (100%) and PGP/DE (1:1, 1:3) (86.7%, 100%) involving *L. serricorne* (Table 3). By 2 and 3 days post treatment all mixtures have produced 100% mortality in *C. maculatus* and *L. serricorne* adults except RHP/DE (3:1) (75%) and PGP/DE (1:1, 3:1) (80.0%, 78.3%) involving *C. maculatus*.

EAP and DE at 1, 2 and 3 days post treatment caused the same level of mortality to *C. maculatus* adults except with EAP at 0.01 g dosage when a significantly lower level of mortality was caused (Table 4). By 4 days post treatment EAP and DE applied at 0.01, 0.02, 0.03 and 0.04 g/20 g of grain produced 100% mortality of *C. maculatus* adults.

Table 1. Mean mortality of adults of four storage beetles in grain treated with a diatomaceous earth and three botanical powders applied at 2% of grain weight

	Mean % mortality (± SE) in:				
Insect/Powder type	**1 day**	**3 days**	**5 days**	**7 days**	**10 days**
S. zeamais					
Rice Husk	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a
P. guineense	0.0 ± 0.00a	0.0 ± 0.00a	1.6 ± 1.67a	3.3 ± 1.67a	6.7 ± 1.67a
E. aromatica	11.6 ± 1.67b	50.0 ± 2.89d	76.7 ± 3.33e	100.0 ± 0.00i	100.0 ± 0.00e
DE (SilicoSec)	10.0 ± 2.89ab	23.3 ± 1.67c	68.3 ± 4.41e	85.0 ± 2.89g	100.0 ± 0.00e
S. granarius					
Rice Husk	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a
P. guineense	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a	13.3 ± 4.41b	23.3 ± 4.41b
E. aromatica	8.3 ± 3.33ab	65.0 ± 2.89e	100.0 ± 0.00f	100.0 ± 0.00i	100.0 ± 0.00e

DE (SilicoSec)	5.0 ± 2.89a	58.3 ± 4.41e	73.3 ± 1.67e	91.7 ± 1.67h	100.0 ± 0.00e
L. serricorne					
Rice Husk	0.0 ± 0.00a	6.7 ± 1.67b	23.3 ± 3.33c	31.7 ± 4.41d	48.3 ± 1.67c
P. guineense	0.0 ± 0.00a	8.3 ± 1.67b	11.7 ± 1.67b	23.3 ± 1.67c	41.7 ± 3.33c
E. aromatica	90.0 ± 2.89c	100.0 ± 0.00f	100.0 ± 0.00f	100.0 ± 0.00i	100.0 ± 0.00e
DE (SilicoSec)	100.0 ± 0.00d	100.0 ± 0.00f	100.0 ± 0.00f	100.0 ± 0.00i	100.0 ± 0.00e
C. maculatus					
Rice Husk	0.0 ± 0.00a	6.7 ± 1.67b	18.3 ± 1.67c	31.7 ± 1.67d	45.0 ± 2.89c
P. guineense	1.6 ± 1.67a	21.7 ± 1.67c	51.7 ± 4.41d	61.7 ± 4.41f	66.7 ± 6.01d
E. aromatica	86.7 ± 1.67c	100.0 ± 0.00f	100.0 ± 0.00f	100.0 ± 0.00i	100.0 ± 0.00e
DE (SilicoSec)	100.0 ± 0.00d	100.0 ± 0.00f	100.0 ± 0.00f	100.0 ± 0.00i	100.0 ± 0.00e

Means along each column followed by the same letter (s) are not significantly different at the 5% level by Student-Newman-Keuls method.

Table 2. Mean mortality of adults of *S. zeamais* and *S. granarius* in grain treated with a diatomaceous earth in combination with any of three botanical powders applied (1:1, 3:1 and 1:3 ratios) at 2% of grain weight

Insect/Mixture	Ratio	Mean % mortality (± SE) in: 3 days	5 days	7 days	10 days
S. zeamais					
RHP + DE	1:1	65.0 ± 5.00	70.0 ± 5.00	75.0 ± 2.89	85.0 ± 2.89
	3:1	28.3 ± 4.41	38.3 ± 4.41	45.0 ± 2.89	50.0 ± 2.89
	1:3	65.0 ± 5.77	71 7 ± 6.01	78.3 ± 4.41	91.7 ± 3.33
PGP + DE	1:1	60.0 ± 5.77	70.0 ± 7.64	90.0 ± 2.89	100.0 ± 0.00
	3:1	43.3 ± 10.93	60.0 ± 10.41	83.3 ± 3.33	100.0 ± 0.00
	1:3	71.6 ± 1.67	68.3 ± 7.27	90.0 ± 2.89	100.0 ± 0.00
EAP + DE	1:1	80.0 ± 2.89	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	3:1	88.3 ± 3.33	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	1:3	80.0 ± 2.89	83.3 ± 4.41	100.0 ± 0.00	100.0 ± 0.00
S. granaries					
RHP + DE	1:1	48.3 ± 3.33	61.7 ± 3.33	75.0 ± 2.89	86.7 ± 1.67

	3:1	23.3 ± 3.33	46.7 ± 6.67	63.3 ± 6.67	78.3 ± 8.82
	1:3	56.7 ± 1.67	60.0 ± 2.89	65.0 ± 2.89	91.7 ± 3.33
PGP + DE	1:1	66.7 ± 8.82	83.3 ± 1.67	91.7 ± 1.67	100.0 ± 0.00
	3:1	55.0 ± 5.77	65.0 ± 5.77	81.7 ± 4.41	100.0 ± 0.00
	1:3	81.6 ± 1.67	91.7 ± 4.41	100.0 ± 0.00	100.0 ± 0.00
EAP + DE	1:1	80.0 ± 5.00	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	3:1	81.6 ± 3.33	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	1:3	80.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
LSD 0.001		23.56	23.64	13.69	12.33

Table 3. Mean mortality of adults of *C. maculatus* and *L. serricorne* in grain treated with a diatomaceous earth in combination with any of three botanical powders applied (1:1, 3:1 and 1:3 ratios) at 2% of grain weight

Insect/Mixture	**Ratio**	**Mean % adult mortality (± SE) in:**		
		1 day	**2 days**	**3 days**
C. maculatus				
RHP + DE	1:1	71.7 ± 4.41	100.0 ± 0.00	100.0 ± 0.00
	3:1	36.7 ± 4.41	75.0 ± 5.00	100.0 ± 0.00
	1:3	88.3 ± 6.01	100.0 ± 0.00	100.0 ± 0.00
PGP + DE	1:1	50.0 ± 15.26	80.0 ± 7.69	100.0 ± 0.00
	3:1	35.0 ± 13.23	78.3 ± 6.01	100.0 ± 0.00
	1:3	83.3 ± 8.82	100.0 ± 0.00	100.0 ± 0.00
EAP + DE	1:1	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	3:1	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	1:3	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
L. serricorne				
RHP + DE	1:1	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	3:1	75.0 ± 2.89	100.0 ± 0.00	100.0 ± 0.00
	1:3	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00

PGP + DE	1:1	86.7 ± 1.67	100.0 ± 0.00	100.0 ± 0.00
	3:1	68.3 ± 4.41	100.0 ± 0.00	100.0 ± 0.00
	1:3	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
EAP + DE	1:1	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	3:1	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
	1:3	100.0 ± 0.00	100.0 ± 0.00	100.0 ± 0.00
LSD 0.001		27.45	12.75	-

Table 4. Mortality of adults of *C. maculatus* in EAP and DE applied at different low dosages

Protectant	Dosage (g/20 g of grain	Mean % mortality (± SE) in: 1 day	2 days	3 days	4 days
DE					
	0.01	86.7 ± 3.33b	93.3 ± 3.33a	98.3 ± 1.67b	100.0 ± 0.00b
	0.02	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b
	0.03	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b
	0.04	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b
EAP					
	0.01	65.0 ± 8.66a	81.7 ± 4.41a	91.7 ± 1.67a	100.0 ± 0.00b
	0.02	90.0 ± 2.89b	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b
	0.03	96.7 ± 1.67b	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b
	0.04	98.3 ± 1.67b	100.0 ± 0.00b	100.0 ± 0.00b	100.0 ± 0.00b
LSD 0.001		18.43	10.19	4.34	-

DISCUSSION

It is thought that DEs are perhaps the most efficacious natural dusts in terms of insecticidal action (Shah and Khan, 2014). This has been largely substantiated by results obtained in this study. The DE was observed to be superior in lethality to adults of four storage beetles when compared with three insecticidal botanical powders EAP, RHP and PGP. All adults of *L. serricorne* and *C. maculatus* were killed within 1 day of shaking with DE treated grain whereas it took up to 10 days for complete mortality to be achieved with adults of *S. zeamais* and *S. granarius*. These results are consistent with earlier observations by Sadeghi *et al.* (2012) working with *L. serricorne* and *C. maculatus*; Badii *et al*. (2014) working with *C. maculatus*; Demissie *et al*. (2008) and Doumbia *et al*. (2014) working with *S. zeamais* and Mewis and Ulrichs (2001) and Collins and Cook (2006) working with *S. granarius*. It was observed that DE dust particles were trapped by the bodies of the adult beetles as they were shaken with treated grain. The mode of action of DE in causing mortality of insects has been confirmed to be due to effective absorption of epicuticular lipids and fatty acids leading to desiccation (Mewis and Ulrichs, 2001; Prasantha, 2003; Shah and Khan, 2014).

EAP ranked next to DE in lethality to the beetles and was superior to the other two botanicals. All adults of *L. serricorne* and *C. maculatus* were killed within 3 days of shaking with EAP treated grain whereas it took up to 10 days for complete mortality to be achieved with adults of *S. zeamais* and *S. granarius*. The adult storage beetles irrespective of species and all times of observation suffered significantly lower mortality when exposed to grain treated with RHP and PGP. EAP has been reported to exhibit contact as well as fumigant lethality to stored product pest beetles (Boeke *et al.*, 2001; Ofuya and Osadahun, 2005; Ofuya *et al*., 2007; Longe and Ofuya, 2009; 2010). Olotuah *et al.* (2007) also reported EAP to be superior to three other botanical plant powders including PGP in the control of *C. maculatus* and *S. zeamais*. The insecticidal activity of EAP has been suggested to be due to a number of chemical compounds (Dales, 1996) but especially eugenol (Lale, 2010).

An important finding in this study is the observation that DE could be mixed with insecticidal plant powders without jeopardizing its lethality against adult storage beetle pests. The combinations of EAP and DE (ratios 1:1, 3:1 or 1:3) produced generally higher mortality in *S. zeamais* and *S. granarius* than other combinations 3, 5 and 7 days post treatment. By 10 days post treatment all the EAP/DE and PGP/DE combinations produced 100% mortality of *S. zeamais* and *S. granarius*. One day post treatment EAP/DE combinations (ratios 1:1, 3:1 or 1:3) produced significant mortality (100%) in *C. maculatus* and *L. serricorne* . Adult mortality in RHP/DE (1:3) (88.3%) and PGP/DE (1:3) (83.3%) involving *C. maculatus*, and RHP/DE (1:1,1:3) (100%) and PGP/DE (1:1, 1:3) (86.7%, 100%) involving *L. serricorne* was also significant. By 2 days and 3 days post treatment all mixtures have produced 100% mortality in *C. maculatus* and *L. serricorne* adults except RHP/DE (3:1) (75%) and PGP/DE (1:1, 3:1) (80.0%, 78.3%) involving *C. maculatus*. Thus, the lethality of DE against adults of the four storage beetles was not mitigated by mixing with EAP, RHP or PGP. Mixing with DE may have putatively enhanced the lethality of PGP and RHP to the adult beetles. Stathers (2003) also reported increased efficacy in the control of the bostrichid, *Prostephanus truncatus* (Horn) when diatomaceous earths was combined with a Chinese plant extract. Yang *et al.* (2010) similarly carried out laboratory bioassays to determine the efficacy of garlic, *Allium sativum* L. essential oil applied alone or with DE against adults of *S. oryzae* and *Tribolium castaneum* L. and found that the combination treatment was significantly more effective than either treatment alone. When DE is mixed with grain at effective dosages visible residues are evident on the grains and this is neither desirable nor generally acceptable (Shah and Khan, 2014). It was observed in this study that mixing DE with EAP, RHP or PGP obliterated the residual powdery aspect and this can be an added advantage in this kind of formulation. Clearly, there is great promise in combining DE and botanicals for stored product protection against insect depredations. It was further observed in this study that DE and EAP applied at a dosage rate as low as 0.01 g/20 g of grain or 0.5 g/ 1 kg of grain or 0.25% of treated grain was effective in causing complete mortality of adult *C. maculatus* infesting the grain within 4 days post treatment. It is parsimonious that mixing DE and EAP at low dosages may also be effective in stored products protection against insect depredation, but this however requires empirical verification.

CONCLUSIONS

DE and EAP applied at 2% of grain weight are very lethal to adults of *C. maculatus*, *S. zeamais*, *S. granarius* and *L. serricorne* and may effectively prevent grain damage by these insects. DE and EAP applied at 0.05% of grain weight are sufficiently lethal to *C. maculatus*. The lethality of DE against adults of the four storage beetles was not mitigated by mixing with EAP, RHP or PGP. DE enhanced the lethality of PGP and RHP to the adult beetles. There is great promise in combining DE and botanicals for stored products protection against insect depredations. Therefore more botanicals need to be combined with different DE formulations and tested for efficacy against stored product pest insects, and compatibility as well as effective dosages determined.

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