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Relative susceptibilities of different populations of *Sitophilus zeamais* and *Prostephanus truncatus* to currently registered grain protectants in Zimbabwe

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Sitophilus zeamais **Motschulsky and** ***Prostephanus truncatus*** **(Horn) are the two most destructive post-harvest insect pests of maize worldwide. Bioassays were carried out to determine the efficacy of commercially available dilute dust grain protectants (pseudonamed protectant A, B, C, D, E and F) in controlling** ***S. zeamais*** **and** ***P. truncatus*** **under laboratory conditions. The products tested were: Hurudza® (fenitrothion 1.7% + deltamethrin 0.05%), Shumba Super Dust® (fenitrothion 1.0% + deltamethrin 0.13%), Actellic Super Chirindamatura Dust® (pirimiphos-methyl 1.6% + permethrin 0.3%), Chikwapuro® (pirimiphos-methyl 2.5% + deltamethrin 0.1%), Ngwena Yedura® (pirimiphos-methyl 2.5% + deltamethrin 0.2%) and Actellic Gold Chirindamatura Dust® (pirimiphos-methyl 1.6% + thiamethoxam 0.36%). These products were evaluated against four and five populations each of** ***P. truncatus*** **and** ***S. zeamais*****, respectively, collected from Headlands, Murehwa, Bindura, Zvimba and Masvingo. Laboratory cultures for both** ***P. truncatus*** **and** ***S. zeamais*****, provided courtesy of University of Zimbabwe Biological Sciences Department were also exposed to the dilute dust insecticides. None of the laboratory strains (both** ***P. truncatus*** **and** ***S. zeamais*****) had been subjected to any regular insecticide selection pressure specifically designed for its control for more than five years on whole maize grain. Although, all the grain protectants were very effective against** ***S. zeamais*** **and were not significantly different among themselves in their effects on adult insect mortality, some differences were noted with respect to** ***P. truncatus*****. The level of efficacy was also dependent on the population of** ***P. truncatus*** **tested. Actellic Super Chirindamatura Dust® was the least effective (11.6-34.6% mortalities) against** ***P. truncatus*** **while Actellic Gold Chirindamatura Dust® managed to control both** ***P. truncatus*** **and** ***S. zeamais*****, achieving 100% mortalities across all populations tested. While Hurudza® and Shumba Super Dust® were very effective against the Bindura and "laboratory" LGB; the two products seemed not to be effective against the Headlands and Murehwa LGB populations.**

Key words: *Prostephanus truncatus, Sitophilus zeamais,* grain protectants, susceptibility.

INTRODUCTION

Maize is a very important staple for many growing populations in most parts of the world. Its demand in the region is increasing relatively with the increasing populations, urbanization, changing diets and availability of new varieties. With this in mind, it is very essential to achieve sustainable production and preservation of the produce.

There are some major threats to the harvested produce from stored grain insect pests such as *Sitophilus oryzae, Sitophilus zeamais, Tribolium* *castaneum, Prostephanus truncatus* and *Rhizopertha dominica* (Anankware et al., 2012). Among these pests, *S. zeamais* and *P. truncatus* are the most damaging primary insect pest species of stored maize (De Groote et al., 2013). Anankware et al. (2012) also noted that infestation by these insect pests accounts for between 20 and 50% of post-harvest losses in maize, thus threatening food security.

The Larger Grain Borer causes extensive damage to maize in storage and it leads to serious losses to many resource-poor farmers who store grains on farm for use as food and seed without any chemical protectants. Literature shows that insect infestation may lead to quantitative and qualitative grain losses by feeding and burrowing into kernels for oviposition (Anankware et al., 2013; Mwololo et al., 2012). Quality deterioration is evidenced as the kernels become contaminated with dead beetles, pupae, frass and larval cocoons, some of which contain highly dangerous substances. Anankware et al. (2013), for example, reported that integuments of *S. granarius* L. contain various carcinogenic compounds.

Keba and Sori (2013) indicated that infestation of maize by the insect pests, particularly maize weevil commences in the field although the significant share of the damage to maize grains by maize weevil is done during storage period. The control of these insect pests is largely grounded on synthetic chemical insecticides (Keba and Sori, 2013; Machekano et al., 2012; Obeng-Ofori, 2010), however, the indiscriminate and repeated use of different conventional insecticides by farmers and marketers has led to the development of resistance (Korunić et al., 2016; Kljajić et al., 2014) and a resurgence in some insect pests (Anankware et al., 2012). *S. oryzae* is one of the post-harvest pests which is on record to have developed resistance to deltamethrin (Ceruti and Lazzari, 2003). Kljajić, et al. (2014) posited that the introduction of neonicotinoids (e.g. thiamethoxam, imidacloprid and acetamiprid) in the late 1990s made the control of crop pests resistant to organophosphates, pyrethroids and carbamates considerably easier due to their different mechanism of activity. However, later research studies carried out have shown that many neonicotinoid-based products have shown the residual efficacy of thiamethoxam significantly decreases as early as 60 days after treatment, and that field populations of *R. dominica* have demonstrated significant differences in their susceptibility to that insecticide (Kljajić et al., 2014; Wakil et al., 2013).

The commercially available synthetic grain protectants in Zimbabwe include Hurudza®, Shumba Super Dust®, Chikwapuro®, Ngwena Yedura®, Actellic Super Chirindamatura Dust®, Actellic Gold Chirindamatura Dust® and Phosphine fumigation tablets used in seed houses and commercial storage facilities. Fenitrothion ($C_9H_{12}NO_5PS$) and pirimiphos-methyl ($C_{11}H_{20}N_{30}3PS$) are the most widely used organophosphate active ingredients in grain protectants in Zimbabwe. Pirimiphos-methyl is the active ingredient in Chikwapuro®, Ngwena Yedura®, Actellic Super Chirindamatura Dust® and Actellic Gold Chirindamatura Dust®, whilst fenitrothion is used in Hurudza Grain Dust® and Shumba Super Dust®. The common synthetic pyrethroids in the dust formulations are deltamethrin ($C_{22}H_{19}Br_2NO_3$) and permethrin ($C_{21}H_{20}C_{l2}O_3$). With the exception of Actellic Super Chirindamatura Dust® and Actellic Gold Chirindamatura Dust®, all the other four grain protectants have the synthetic pyrethroid deltamethrin in the formulation. Actellic Super Chirindamatura Dust® has permethrin, while Actellic Gold Chirindamatura Dust® has thiamethoxam (a nicotinoid) as its second active ingredient.

The effectiveness of several of these organophosphorus-pyrethroid insecticides has become questionable as farmers from several provinces of the country have reported major losses due to the beetle in insecticide-treated stored maize. Observations made so far strongly indicate that loss of effectiveness of some of the grain protectants might be a result of insecticide resistance development. This has been worsened by smallholder farmers who often underdose their grain when they are either unable or unwilling to pay for enough insecticide to give a complete treatment. Under-dosing has a negative effect as the pests might become resistant to the insecticides, hence farmers come to distrust insecticide use and subsequently suffer unnecessary grain losses. This negatively impacts the grain market as it reduces the supply of better quality grain and so limits the potential for exports.

There are mixed responses to the effectiveness of these dilute dust insecticides. Some grain protectants which work very well in one province have lost trust in another province. It would appear that the incidences of insecticide resistance are not the same throughout the country, possibly indicating that different populations of stored grain insect pests differ in their susceptibilities to the insecticides. There is therefore a need to re-evaluate the efficacy of all stored grain insecticides available in the local market as well as register new ones, preferably with new active ingredients or modes of action.

This study was undertaken to determine the relative susceptibilities of different populations of *P. truncatus* and *S. zeamais* to currently registered dilute dust insecticides.

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Table 1. Trade names, active ingredients and recommended application rates of the commercial dilute dust insecticides that were used in the study.

Product trade name	Active ingredients	Application rate (g/50 kg of grain)
Shumba Super Dust®	Fenitrothion (1%) + deltamethrin (0.13%)	25
Ngwena Yedura®	Pirimiphos-methyl (2.5%) + deltamethrin (0.2%)	20
Actellic Super Chirindamatura Dust®	Pirimiphos-methyl (1.6%) + permethrin (0.3%)	25
Actellic Gold Chirindamatura Dust®	Pirimiphos-methyl (1.6%) + thiamethoxam (0.36%)	25
Hurudza Grain Dust®	Fenitrothion (1.7%) + deltamethrin (0.05%)	25
Chikwapuro Grain Protectant®	Pirimiphos-methyl (2.5%) + deltamethrin (0.1%)	20

The present study was undertaken to assess the efficacy of currently registered dilute dust protectants against different Zimbabwean populations of *S. zeamais* and *P. truncatus*.

MATERIALS AND METHODS

Location

The experiments were conducted in the laboratory at the Department of Biological Sciences, Faculty of Science, University of Zimbabwe.

Source and physical characteristics of maize grains

Clean, healthy dry grains of 30G19 PHB PIONEER HI-BRED maize variety bought from a local farmer in Bindura were used for both rearing of insects and the studies. The maize grains were checked visually for damage and then deep-frozen for two weeks to kill hidden infestations. The maize grains were then kept at an ambient temperature of 27±2°C and 65±5% relative humidity in the laboratory for moisture equilibration for three weeks before use in the experiments.

Test insects

The initial stock cultures of *P. truncatus* were originally obtained from naturally-infested maize sampled from farm granaries in Bindura, Murehwa, and Headlands. For *S. zeamais* starter cultures were from insects sampled from infested maize in Murehwa, Headlands, Zvimba and Masvingo. The laboratory cultures for both *P. truncatus* and *S. zeamais* were provided courtesy of Biological Sciences Department, University of Zimbabwe. These strains have been maintained for more than five years on whole maize grain and were used as the standard/susceptible populations in the experiments. Insects from these laboratory strains had not been subjected to any insecticide selection pressure during this period of rearing. All insect cultures were reared in a constant temperature and humidity (CTH) room. Culture jars were clearly labeled with date of culture, insect species and area of origin of the insect species/strain.

Insecticides and grain treatments

The insecticides used for the study were bought from a hardware shop in Harare. The application rates were as per the manufacturers' recommendations (Table 1). The amounts of grain and insecticide were weighed out using an electronic balance. The insecticides were added to grain in glass jars and thorough admixture was achieved by shaking and tumbling the jar for one minute. The control had untreated grain.

Determination of the relative susceptibilities of different populations of *S. zeamais* and *P. truncatus* to currently registered grain protectants.

Two hundred grammes of maize grains were separately admixed with various insecticides in 350 ml glass jars. The treatments included three replicates for each of the insect population and each of the following treatments: Untreated control, Hurudza®, Shumba Super Dust®, Actellic Super Chirindamatura Dust®, Chikwapuro®, Ngwena Yedura® and Actellic Gold Chirindamatura Dust®. These treatments were left for eight weeks before being infested. Thirty unsexed adult insects were introduced into each jar. Mortality counts were taken at day 7 post-infestation. An insect was considered dead if it did not respond to three probings of a blunt needle. Percentage mortality data were corrected for untreated control mortalities using Abbott's (1925) formula:

$$\text{Corrected treatment mortality} = \frac{(\%\ \text{mortality in treatment} - \%\ \text{mortality in control})}{(100 - \%\ \text{mortality in control})} \times 100$$

In the case of *P. truncatus*, data were analyzed by ANOVA as a factorial design comprising four geographic populations and seven grain protectants. For *S. zeamais*, data were analyzed as a factorial design of five geographic populations and seven grain protectants. Prior to analysis, % data were transformed by arcsine.

RESULTS

100% mortality was recorded across all the five *S. zeamais* populations and no significant differences ($P > 0.05$) in mortality were noted among these different populations. Significant effects of population ($F_{3,72} = 18.68$, $P < 0.05$), treatments ($F_{5,72} = 165.04$, $P < 0.05$) and population × treatment interaction ($F_{15,72} = 4.08$, $P < 0.05$) (Table 2) was observed in the case of *P. truncatus*. Mortality due to Chikwapuro®, Actellic Gold Chirindamatura Dust® and Ngwena Yedura® was highest across all the geographic strains and there were no significant differences among the three products. Actellic Super Chirindamatura Dust®, Shumba Super Dust® and

Table 2. Effects of different 8-week old treatments on percentage mortality (mean ± SE) of *P. truncatus* at 7 days post-infestation.

Treatment	Insect population			
	Bindura	**Headlands**	**Laboratory**	**Murehwa**
Shumba Super Dust®	54.3±0.04[a]	36.0±0.26[a]	70.2±0.24[a]	38.6±0.06[a]
Chikwapuro®	100±0.00[b]	97. 7±0.37[b]	98.8±0.09[b]	97.7±0.12[b]
Actellic Super Chirindamatura Dust®	34.6±0.22[a]	11.6±0.21[a]	71.4±0.32[a]	26.1±0.13[a]
Actellic Gold Chirindamatura Dust®	100±0.00[b]	100±0.00[b]	100±0.00[b]	100±0.00[b]
Ngwena Yedura®	100±0.00[b]	100±0.00[b]	100±0.00[b]	100±0.00[b]
Hurudza Grain Dust®	65.4±0.15[a]	33.7± 0.16[a]	82.1±0.08[ab]	57.9±0.11[a]

Means within a column followed by the same letter are not significantly different (P = 0.05).

Hurudza Grain Dust® achieved the least mortalities against the Bindura, Headlands and Murehwa LGB populations. However, these three protectants significantly controlled the susceptible laboratory strain achieving above 70% mortality.

DISCUSSION

These results reveal that *S. zeamais* was more susceptible to the commercially registered insecticides than *P. truncatus. Sitophilus* species are known to be significantly more susceptible to organophosphates compounds like pirimiphos-methyl (Kljajić et al., 2014). These insecticides 'cocktails' were able to control the maize weevils because of the presence of organophosphates compounds.

Contrary to the above scenario, the beetle *P. truncatus* are very susceptible to pyrethroids, while less to organophosphates, particularly pirimiphos-methyl (Kljajić et al., 2014; Golob and Hanks, 1990; Richter et al., 1998). Cocktail products which combine an organophosphate and a pyrethroid such as Actellic Super Chirindamatura Dust® were therefore developed to control both pests (Kljajić et al., 2014; Richter et al., 1998). The present study on susceptibility status of *S. zeamais* and *P. truncatus* clearly indicated that the later has become tolerant to some of the registered 'cocktail' insecticides in Zimbabwe.

The current results correspond to what Golob and Hanks (1990) observed when they sprayed cobs with insecticides such as permethrin or permethrin in a mixture with pirimiphos-methyl. However, earlier studies in Kenya and Tanzania (Tefera, 2012; Dales and Golob, 1997) saw Actellic Super (a cocktail of 1.6% pirimiphos-methyl and 0.3% permethrin) being promoted as a chemical which is effective against LGB. Also, at the time pyrethroid-organophosphate "cocktails" were introduced for stored-grain protection, a cocktail containing the same active ingredients for permethrin and pirimiphos-methyl was then able to provide effective control of postharvest insect pests. Nonetheless, synthetic pyrethroids were already known to select for resistance in insect populations very readily (Denholm et al., 1983). In the present study, Actellic Super Chirindamatura Dust®, a cocktail containing the same active ingredients for permethrin and pirimiphos-methyl, could not manage *P. truncatus* across the populations, except against the 'susceptible' laboratory strain. Therefore, development of resistance by *P. truncatus* is the most probable reason of the observed loss of effectiveness of Actellic Super Chirindamatura Dust® in the current studies.

Studies on loose grain in Togo revealed that the combination of pirimiphos-methyl and deltamethrin in concentrations of 7.5 and 0.25 ppm, respectively, as well as 5 and 0.5 ppm resulted in best protection of bagged grain against *P. truncatus* for nine months of storage (Richter et al., 1998). In another study carried out by von Berg and Biliwa (2008), it was revealed that deltamethrin (2 ppm) and the mixture of fenvalerate (7.5 ppm) and fenitrothion (37.5 ppm) satisfactorily controlled a wide range of beetles (including *P. truncatus*) for more than ten months. This is consistent with the results of the present study, where Chikwapuro® which is comprised of pirimiphos-methyl (2.5% m/m) and deltamethrin (0.1% m/m) and Ngwena Yedura® which has pirimiphos-methyl in the same concentration and 0.2% m/m deltamethrin, both managed to contain all populations of *S. zeamais* and *P. truncatus.* However, considering that the treatments were just eight weeks old at the time insects were introduced, the current results are not indicative of absence of resistance to Chikwapuro® and Ngwena Yedura® by LGB as farmers all over Zimbabwe are currently reporting poor control of the bostrichid by the two protectants as well as Shumba Super® (Chinwada, personal communication).

Results of the current study may also indicate that *P. truncatus* is now resistant to Actellic Super Chirindamatura Dust®. This is supported by very low LGB mortalities in Murehwa, Headlands and Bindura and a relatively high mortality against the susceptible laboratory strain. Actellic Gold Chirindamatura Dust®, which Syngenta recently registered, was quite effective as it gave 100% mortality across all the populations of *S.*

zeamais and *P. truncatus.* This level of control was due to the replacement of permethrin by thiamethoxam. This result probably indicates a need to increase application rates of the active ingredients in the organophosphate-pyrethroid cocktails, as suggested by FAO and WHO (1980) to raise the application rates of permethrin above the present 1 mg/kg grain level, though probably not above 2 mg.

CONCLUSION AND RECOMMENDATIONS

From the results of the study, it is imperative that farmers should divert their attention from synthetic chemical insecticides to other control measures, particularly use of local botanicals. In fact, local studies with as many plant species as possible is necessary so as to determine their usefulness in stored-product primary insect pest management, especially at the smallholder level.

Responsible departments and/or ministries, in this case, The Ministry of Agriculture through the Pesticide Registration Office, must be proactive and always conduct regular insecticide susceptibility tests on the major primary and secondary pests associated with stored grain. The information gleaned from such work will make it possible for the Pesticide Registration Office to know in advance which grain protectants needs to be de-registered when companies renew registrations for such products. The current scenario whereby many of the currently registered products available on the local market are clearly no longer efficacious against LGB is worrying as this threatens national food security.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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