A comparison of the effect of two diatomaceous earth formulations on *Plodia interpunctella* (Hübner) and the effect of different commodities on diatomaceous earth efficacy

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Abstract

The efficacy of two diatomaceous earth formulations was tested on five commodities; maize, wheat, birdseed, sunflower and barley, against *Plodia interpunctella* (Lepidoptera: Pyralidae). Exposure to DE began at either the egg stage or 3rd instar stage and the reduction in emergence to adult was noted. There was no significant difference between the freshwater and marine (Protect-It) DE. When eggs were placed on treated diet, the LD_{90} was 135, 143 and 805 ppm for maize, wheat and birdseed, respectively. When 3rd instars were placed on diet, LD_{90} was 382, 444, and 1156 ppm for maize, sunflower and birdseed respectively.

Keywords: DE, Wheat, Maize, Birdseed, Sunflower, Indian meal moth

1. Introduction

Plodia interpuntella (Hübner) (Pyralidae: Lepidoptera), the Indian meal moth is a world-wide pest of many stored products including dried fruit and vegetables, nuts and cereals (Na and Ryoo, 2000; Barak and Harein, 1981; Harein and Subramanyam, 1990). In most cases, where raw durables are stored, *P. interpunctella* inhabits the top several centimeters of the stored bulk. Direct feeding on commodities is of concern, however, deposition of frass and webbing is a major cause for product rejection due to contamination (Carrillo et al., 2006).

One of the most particular aspects of *P. interpunctella*'s biology is how strongly correlated development and ultimately survival is with the commodity, lighting and temperature. Variation in the toughness of endosperm among varieties of the same class of grain has shown to affect development and mortality (Abdel-Rahman, 1968). The ability for *P. interpunctella* populations to quickly tolerate localized conditions is also cited as a mechanism for survival (Subramanyam and Hagstrum, 1993). Altering conditions such as photoperiod, temperature or diet will influence developmental time, food consumption, survival and fecundity. Therefore, disrupting any or all of these factors in an ongoing way may assist in maintaining the commodity quality.

Diatomaceous earth (DE) has been used as an alternative synthetic insecticides for many years, and as it does not break down rapidly, a single application can be used in an ongoing way to disrupt aspects of insect development as long as the commodity remains dry. The DEs are typically comprised of approximately 70 – 90% amorphous silicon dioxide with the balance comprised of inorganic oxides and salts. These products are mined from quarries, crushed, sieved to remove rocks, and for some formulations synergists are added. When processed into a dust, particle size distribution is between 0.5 – 100 microns, with the majority being in the range of between 10 – 50 microns (Korunic, 1998; Subramanyam and Roesli, 2000).

DE insecticides are known to protect commodities against stored-product pests in two ways. First, DE particles are picked up by the insect as they walk through the commodity. The body of adult stored-product insects is made up of an exoskeleton covered with waterproofing waxes and lipids. The wax layer on the insect's epicuticle is damaged, insects lose water through the cuticle and die from desiccation (Ebeling, 1971; Subramanyam and Roesli, 2000). In addition, another mode of action of DE is its ability to repel insects.

The objective of this study was to examine the effect of two diatomaceous earth formulations on *P. interpunctella* on wheat, barley, maize, birdseed and sunflower. A second objective was to determine if eggs or early instar larvae are more susceptible to DE on various commodities than 3rd instar larvae.

2. Materials and methods

Plodia interpunctella used in this study were from laboratory cultures. Cultures were reared on cracked wheat at 16% moisture content. All cultures, experiments and rearing were at 25°C and 70% r. h. with 16 hours light and 8 hours dark, as these conditions are considered optimal for pyralid moths production and to minimize induction of diapause. Insects were treated with one of two diatomaceous earth formulations; one from a marine deposit (P1, Protect-It®, Hedley Technologies Inc, Mississauga, Canada) and the other a freshwater deposit (P2). The formulations were both buff-colored with crystalline content of less than 1%. Both formulations were sieved using a #30 mesh sieve to remove clumps and both had 10% silica aerogel as part of the formulation. Application rates to the commodities described below were 0, 100, 200, 300, 500, 700 or 1000 ppm.

Experiments were conducted with five commodities; wheat, cv Katepwa (14% mc), barley, cv Robust (13% mc), cleaned feed maize, many varieties (13.5% mc for eggs experiments and 11.0% mc for larval experiments), Sunflower, cv Pioneer 6150 (4.5% mc) and birdseed, Kaytee brand (comprised of oilseed sunflower, millet, cracked maize, peanuts, safflower and calcium carbonate with undetermined moisture content).

Six hundred grams of each commodity were placed into a 4-L jar and were treated with one of the formulations at one of the seven doses. After application, jars were sealed and were shaken for one minute by hand, after which 200 g were placed in to each of three 1-L jars to serve as replicates. One hundred 1-d old *P. interpunctella* eggs were introduced into each treatment jar. Also, for each experiment, 100 eggs from the same cultures were placed onto moistened filter paper to determine percent hatch. Third instar larvae were also tested against the DE with sunflower, maize and birdseed to determine if there was an effect of early larval mortality on these commodities. Treatments were prepared as described and 50 early third instar larvae for each replicate were introduced. The total number of adults that emerged from each jar was observed daily once emergence began until emergence was complete. This was approximately six - eight weeks after the initial adults had emerged and until there were several observations of no emergence. Those that emerged were counted and recorded. The percentage of reduction of adult emergence was compared to that of the untreated control.

3. Results

Egg viability was very good, with hatch rates of 96% (maize), 93% (wheat), 98% (barley) and 92% (birdseed and sunflower). This would indicate that much of the mortality associated with the controls could be associated with the performance of the insect on the host food as adult emergence on the control food varied: 94% (maize), 69% (wheat), 0% barley, 85% (birdseed) and 80% (sunflower) (Table 1). Overall, the DE formulations could control *P. interpunctella*. In all cases, except for the P1 on birdseed, greater than 95% control was achieved at the higher dosages (Table 1). In addition, those that did emerge as adults on the various commodities at higher rates were noticeably smaller, and in many cases were somewhat deformed (mostly non functional wings).

Table 1 Adult emergence (± standard error of the mean) of *Plodia interpunctella,* 100 eggs were exposed to various levels of two diatomaceous earth formulations on three different commodities.

Commodity	DE	Dose (ppm)	Adult Emergence±SEM	Reduction Compared to Control (%)
Wheat	P1	Control	69.0±2.2	0
		100	19.0±2.5	68
		200	3.3±0.3	94
		300	0	100
Wheat	P2	0	59.0±2.2	0
		100	17.7±2.7	70
		200	2.3±0.3	96
		300	0	100
Maize	P1	0	95.0±1.7	0
		300	19.5±2.7	80

Commodity	DE	Dose (ppm)	Adult Emergence±SEM	Reduction Compared to Control (%)
		500	4.3±0.7	96
		700	0	100
Maize	P2	0	95.0±1.7	0
		300	14.0±3.0	86
		500	5.0±1.2	95
		700	1.0±0.1	99
Birdseed	P1	0	84.3±6.5	0
		100	62.3±7.1	27
		300	44.0±3.0	48
		500	21.0±3.1	75
		700	5.3±2.2	94
Birdseed	P2	0	84.7±6.5	0
		100	75.3±2.9	11
		300	55.3±3.3	35
		500	18.0±4.0	79
		700	3.0±1.5	97

There was no significant difference between the two formulations (Table 2). Wheat (LD_{90}; 143 ppm) and maize (135 ppm) required the least DE to control *P. interpunctella* from the early instar larvae, whereas birdseed required considerably more (860 ppm, Table 2).

When 3rd instars were exposed to on the treated commodities, complete control occurred at the highest doses (1000 ppm, Table 3) on maize and birdseed, but not for the sunflower seed, where only 85% reduction of adult emergence occurred. Birdseed required the least DE to control third instars (LD_{90}; 382 ppm), while maize required 444 ppm and sunflower required 1158 ppm (Table 4). On maize the LD_{90} for eggs was 380 ppm compared to 444 ppm for 3rd instars, in contrast, on birdseed more DE was required to control *P. interpunctella* exposed from the egg stage (860 ppm) then the 3rd instars (382 ppm).

Table 2 Probit analysis (LD_{50} and LD_{90}) (90% CI) of the mortality of *Plodia interpunctella* when exposed to three commodities treated with one of two diatomaceous earth formulations.

Commodity	Duration (d)	DE	LD_{50} (90% CI) (ppm)	LD_{90}(90% CI) (ppm)
Maize	59	P1	56 (41 – 68)	135 (122 – 150)
Wheat	57	P1	74 (61 – 84)	143 (131 – 160)
Birdseed	61	P1	251 (106 – 348)	806 (590 – 1744)
Maize	59	P2	36 (18 – 51)	129 (110 – 147)
Wheat	57	P2	68 (53 – 79)	139 (126 – 155)
Birdseed	61	P2	366 (318 – 404)	600 (540 – 698)

Table 3 Adult emergence (± standard error of the mean) of *Plodia interpunctella*, 50 3rd instar larvae are exposed to various levels of a P1, marine diatomaceous earth formulation on three different commodities.

Commodity	Dose (ppm)	Adult Emergence±SEM	Reduction Compared to Control (%)
Sunflower	0	40±1.0	0
	100	36±2.0	10
	300	18±2.0	55
	500	14±3.0	65
	1000	6±1.0	85
Birdseed	0	42±2.0	0
	100	34±2.0	19
	300	10±1.0	76
	500	1±1.0	98
	1000	0	100
Maize	0	38±1.0	0
	200	19±3.0	50

Commodity	Dose (ppm)	Adult Emergence±SEM	Reduction Compared to Control (%)
	400	8±3.0	79
	600	3±1.0	93
	800	1±1.0	98
	1000	0	100

Table 4 Probit analysis (LD_{50} and LD_{90}) (90% CI) of the mortality of *Plodia interpunctella* when exposed to three commodities treated with, P1, a marine diatomaceous earth formulation.

Commodity	Duration (d)	LD_{50} (90% CI) (ppm)	LD_{90} (90% CI) (ppm)
Maize	60	199 (172-223)	444 (400-503)
Sunflower	60	289 (239-338)	1158 (940-1545)
Birdseed	60	178 (159-204)	382 (340-436)

4. Discussion

Diatomaceous earth is an effective insecticide against many stored-product insect pests. There are several factors that determine the efficacy of DE, the main ones being: type of DE, target species, commodity treated and moisture content (McLaughlin, 1994; Korunic, 1998; Subramanyam and Roesli, 2000).

We only tested two DE formulations and found no difference between the two DE, however, caution should be exercised when extrapolating from our results to other DE, since there can be a four-fold difference in efficacy between DE (Korunic 1998). Snetsinger (1988) proposed that marine DE was less effective than freshwater DE, although a more recent study found just the opposite (Korunic, 1998)

There is very little information available on the efficacy of DE against pyralid moths (Wilbur et al., 1971; Nielsen, 1998, Arthur and Brown, 1994; Subramanyam et al., 1998; Mewis and Ulrichs, 2001). We found to control *P. interpunctella,* 200 to 1000 ppm were needed depending upon commodity. Arthur and Brown (1994) conducted field trials and found that 6,690 ppm Insecto on peanuts had no infestation over a six-month test, although there was only very low infestation in the untreated controls. Compared to other species *P. interpunctella* is relatively sensitive to DE (wheat, LD_{50} 74 ppm) compared to *Cryptolestes ferrugineus* (Stephens) (50 ppm), *Sitophlius oryzae* (L.) (300 ppm) and *Tribolium castaneum* (Herbst) (500 ppm) (Korunic 1998). In this study we exposed either 1st instars or the 3rd instars for as long as 61 d, whereas other studies used adult beetles exposed for a few days to a few weeks. When comparing larvae of *T. castaneum, Oryzaephilus surinamensis* (L.) and *P. interpunctella* all had very similar sensitivity to DE (Subramanyam et al., 1998).

Commodities have a large influence on DE rates. For Protect-It to control *C. ferrugineus* only 100 ppm is needed for wheat, but 150 is needed for barley, 500 ppm needed for oats and rye and 1000 ppm needed for maize (Canadian insecticide label, registration number 24259). Maize and sunflower seed is often cited as requiring more DE than wheat or barley (Subramanyam and Roesli 2000), but we saw no difference between wheat and maize for *P. interpunctella.* Sunflower and maize have a great deal more oil content then wheat, and therefore the DE may be rendered less active on these commodities.

The insect life stage also affects DE efficacy. Later instars of *P. interpunctella* are more resistant to DE than younger instars (Subramanyam et al., 1998). We found similar results for maize, but not for birdseed. In these tests, late instars were on the DE-treated diet for a less time than when placed on as eggs, so is it expected that the amount of DE required to control the insects would be less. The results with birdseed are unusual. Additional testing would be required to determine if these observations are repeatable, and if so why early instars require more DE than 3rd instars for complete kill.

In general, there was very high survival to adults on all diets except barley. No adults emerged from any of the treatments on barley. If *P. interpunctella* are to be successful when infesting barley, they likely require a proportion of the barley to be cracked or broken, thereby exposing endosperm that larvae could easily feed upon. It is also possible that barley requires higher moisture contents to be acceptable for *P. interpunctella* or it may be that barley has an attribute that causes *P. interpunctella* to perform poorly. Subramanyam and Harein (1989) found few *P. interpunctella* larvae in farm bins of barley. Finally, this lot of barley may have been treated with insecticide. Further studies would be required to determine if barley is a poor host for *P. interpunctella.*

Further studies are required to determine if these rates are capable of protecting these commodities under field conditions. DE is repellant, so fewer eggs may be laid on the commodity. Larvae may move more because they are repelled by the DE. In addition to this, constant water stress may reduce the fecundity of any surviving adults. Finally, there are several parasitoids of pyralid moths, and these could be adversely affected by the DE (Perez-Mendoza et al., 1999).

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