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Advances in integrating insect growth regulators into storage pest management

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Abstract

Insect growth regulators (IGRs) are insecticides that mimic insect-produced hormones that regulate the developmental process. They generally have little or no mammalian toxicity, and are considered reduced-risk insecticides that are often exempt from tolerance requirements of regulatory agencies. Although IGRs have been available for more than 30 years, there is increased interest and application for stored-product pest control. Insect growth regulators can be used for direct application to stored grains, and worldwide perhaps the most common IGR used for this purpose is methoprene. Within the last few years, there has been new research showing that this IGR is very effective against *Rhyzopertha dominica* (Coleoptera: Bostrichidae), one of the most destructive pests of stored grain worldwide. However, one of the limitations of IGRs is that they generally do not kill adult insects. Recent studies show that the addition of methoprene to diatomaceous earth (DE), a natural product, or a contact insecticide will give complete control of this species on stored grains. Another application of IGRs is as surface treatments to flooring structures of mills, warehouses, and processing plants. Hydroprene (Gentrol) is particularly effective against late-instars of *Plodia interpunctella* (Lepidoptera: Pyralidae), *Tribolium castaneum* and *T. confusum* (Coleoptera: Tenebrionidae). Other IGRs that are effective against these insects when used as surface treatments are methoprene and pyriproxyfen. The final category where IGRs can be used in pest management programs is as aerosol spray treatments. In the United States, there are a number of facilities that have integrated methoprene aerosols into their control programs. The use of IGRs can easily be integrated into pest management strategies to control stored-product insects in bulk grain and in milling, processing, and storage facilities.

Key words: insect growth regulators, bulk grain, processing, food warehouse, insects.

Introduction

Insect growth regulators (IGRs) are produced naturally by insects to regulate the processes of molting and development from the egg to the adult stage. Although synthetic mimics of these chemicals have been tested and evaluated in stored products for more than 30 years (Obelander et al., 1997), there is an increased emphasis and renewed interest in IGRs for insect control (Mondal and Parween, 2001). However, it is important to evaluate these products in a manner that is realistic for commercial application. For example, many of the earlier studies cited in Oberlander et al. (1997) and Mondal and Parween (2001) describe tests in which IGRs were applied to insect diet, and results from these kinds of studies may not reflect actual exposure of insects in storage facilities.

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This paper will describe and discuss how IGRs can be used in three different application methods for insect control: as grain protectants in bulk storage, as residual surface treatments to flooring surfaces, and as aerosols or ultra-low volume (ULV) applications in large food warehouses. The first experiment will describe a study where the IGR methoprene was combined with diatomaceous earth (DE) for control of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) on rough rice. An obvious limitation of IGRs is that they do not kill adults, and combination treatments may be one way of alleviating this problem, while enhancing or improving insect control. The second study will describe an experiment in using the IGR hydroprene to control *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), a major pest of stored and processed food, and will be used to illustrate the discussion on using IGRs as contact toxicants. The third study will describe a test with methoprene aerosol to control *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), and also discuss how IGRs are being incorporated into aerosol insecticides for use in milling, processing, and food storage facilities.

Materials and methods

Experiment 1. Methoprene combined with diatomaceous earth (DE) for control of *R. dominica* on stored rough rice

The purpose of this test was to determine if combination treatments of DE and methoprene would kill adult *R. dominica* exposed on rough rice and limit progeny production. The rice varieties used in this test were as follows: long-grain, Cocodrie; short-grain, S-102; and medium-grain, M- 205. From each variety, five 200 g subsamples were weighed, and each sample was sprayed with individual 0.4 mL solutions of 0 (untreated control, water only), 0.25, 0.5, 0.75, and 1.0 mg (AI) methoprene/kg of grain in distilled water, using a Badger 100 artists' airbrush (Franklin Park, IL, USA). After the methoprene was applied, the 200 g of rice was divided into 5 portions containing 40 g each, and each portion was treated with Protect-It® 90 % DE at rates of 0, 125, 250, 375, and 500 ppm. Treatment with the DE was done by placing the 40 g of rice inside a 0.475 Liter glass jar, and hand-mixing for about one minute. Each of the 40 g portions was then divided into two 20 g lots, one of which was placed in a 29 mL vial, and the other was discarded. This resulted in 25 treatment combinations for each rice type.

Twenty 1 to 2 week-old unsexed adults of *R. dominica* were placed inside the vial for each treatment combination. All vials were placed in plastic humidity boxes containing a saturated sodium chloride (NaCl) solution to maintain r.h. at 75 %, or about 14 % moisture content (Greenspan, 1977). After 2 weeks of exposure, *R. dominica* adults were sieved from vials in each treatment combination to assess mortality, adults discarded, and rice, dust from feeding damage, and insect frass were returned to the vials. Vials were placed back in the humidity boxes and into the incubator, and after 8 weeks, adult progeny of *R. dominica* in treated rice and untreated rice were assessed.

Experiment 2. The IGR hydroprene for control of *P. interpunctella*

The purpose of this test was to determine if exposure of wandering-phase instars of *P. interpunctella* to hydroprene at different time-temperature combinations would either delay adult emergence or cause direct mortality of larvae. Five temperature incubators were set at 16, 20, 24, 28, and 32 °C, to be paired with exposure intervals of 1, 3, 6, 12, 18, 24, and 30 h (35 combinations), in each of 5 replicates conducted as separate blocks at monthly intervals. For each replicate, 40 concrete treatment arenas were constructed in two bottom portions of individual Petri dishes measuring 62 cm^2 by filling one portion completely to the top and the other one half-way to the top.

Solutions of hydroprene were formulated from a 9.0 % active ingredient [AI] commercial formulation to give a deposition of 0.0019 micrograms [AI]/cm^2 on the concrete in 0.17 ml, which was equivalent to the label rate. All solutions were sprayed on the 80 separate concrete pieces using the airbrush described in Experiment 1, and at each temperature, the remaining five sets of dishes were used for untreated controls exposed for 32 h. For each replicate, 10 wandering-phase *P. interpunctella* larvae were placed on the concrete dish portion that was filled half-way, the other piece placed on top, and the two halves were sealed together with tape. Inside each incubator, chambers were created to maintain humidity at 57 % using saturated NaCl (Greenspan, 1977). Upon completion of the individual exposure intervals, the larvae from the treated and untreated dishes were removed and placed on top of sterile filter paper inside new pesticide-free Petri dishes, and returned to the humidity chambers and to the incubators. The number of emerging adults inside each Petri dish was recorded every 24 h for 50 d, and, after 50 d, larvae that had not emerged as adults were considered as either dead or arrested by exposure to hydroprene.

Experiment 3. Methoprene aerosol for control of *T. castaneum* in food warehouses

The purpose of this study was to determine if late-instars of *T. castaneum*, a common insect pest of mills and storage facilities, would reach the adult stage after exposure to methoprene aerosol. A series of 6 replicated trials was conducted in a 70- by 23 m room that was part of a large commercial food storage facility. For each replicate, ten 3-week-old larvae and ten 4-week-old larvae were exposed in separate 100- by 15 mm Petri dishes containing about 250 mg of flour, at 15 positions on the warehouse floor spaced in three rows of five dishes. A separate set of 5 dishes of each larval age were placed in a separate room at the site for untreated controls. Methoprene aerosol was dispensed at the label rate of 3 ml of a 32 % AI commercial formulation/280 m^3, and the larvae were exposed to the aerosol for 2 h, then removed from the room and transported to the laboratory in Manhattan. Dishes containing the larvae were held on a laboratory counter at approximate conditions of 25 °C and 60 % relative humidity, and monitored for total adult emergence from the treated larvae.

Results

Experiment 1. Methoprene combined with diatomaceous earth for control of *R. dominica* on stored rough rice

All three main effects, rice type, DE level, and methoprene were significant ($P < 0.01$). On rice treated with DE alone, adult mortality at 500 ppm DE was about 60 % in long-grain and medium-grain rice and 25 % in short-grain rice (Figure 1A). In the absence of methoprene, there was no difference in progeny production within a variety with any level of DE, regardless of the parental mortality ($P = 0.05$, Figure 1B). When the results were averaged for all of the DE levels, there were more progeny ($P < 0.05$) produced in long-grain and short-grain rice (81.7 ± 7.6 and 73.7 ± 20.7, respectively) than in medium-grain rice (32.2 ± 7.9). This was reversed from the original parental mortality levels shown in Figure 1A. Possible reasons for these differences in progeny production are that the physical characteristics of the hull may have restricted neonate entry into the medium-grain kernels, or some differences in the kernel itself restricted larval growth and development. With any concentration of methoprene, progeny production was drastically reduced, with few or no progeny in any of the treatments.

Experiment 2. The IGR hydroprene for control of *P. interpunctella*

Exposure of *P. interpunctella* to hydroprene on concrete surfaces either delayed adult emergence or arrested development either in the larval or pupal stage. Within each temperature, the number of days taken for wandering-phase larvae to emerge as adults generally increased with increase in exposure period to hydroprene.

Within each exposure period, the development time decreased as temperature increased. The longest development time among the treatments of 47.2 ± 1.3 d occurred at 16 ºC when the larvae were exposed for 30 h, while the shortest development time of 7.0 ± 0.5 d occurred when the larvae were exposed for 1 h at 32 ºC. In the hydroprene treatments, there was also a relationship between the time of exposure and temperature in relation to larval mortality, as measured by inhibition of adult emergence (Figure 2). The greatest mortality occurred when larvae were exposed for 30 h at 28 ºC, while the minimum mortality occurred at 16 ºC when larvae were exposed for 1 h.

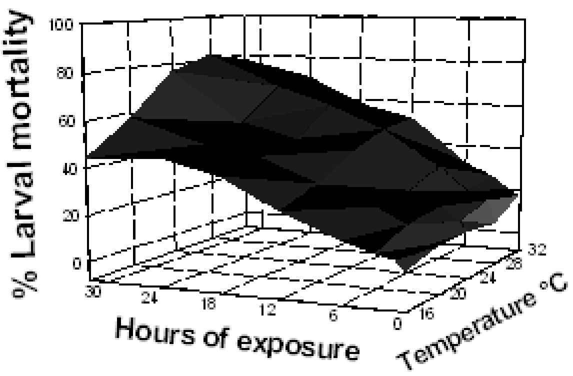

Figure 2. Percentage mortality of 5th-instar *P. interpunctella* exposed on concrete treated with hydroprene at different time-temperature combinations.

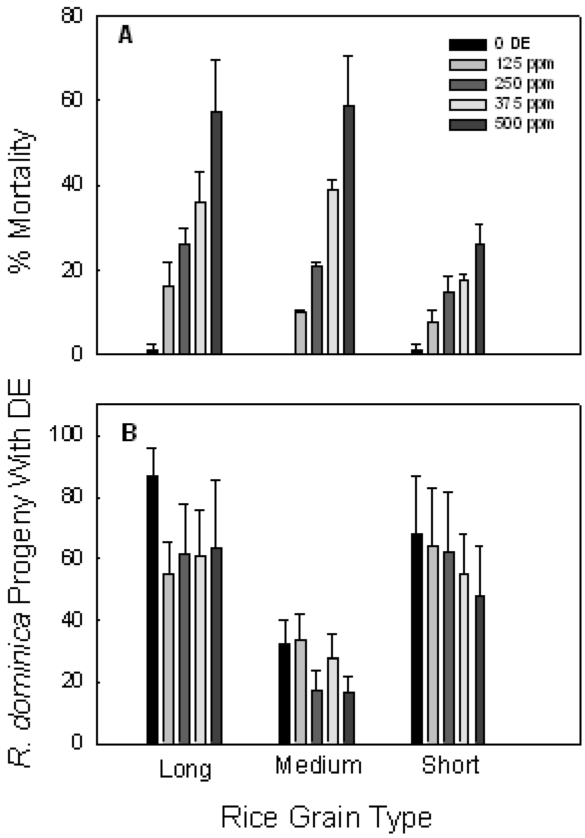

Figure 1. A - Percentage mortality (means ± SE) of adult *Rhyzopertha dominica* exposed on three different rice types treated with 0 to 500 ppm diatomaceous earth (DE); **B** - number of adult progeny from the 20 mixed-sex parental adults exposed in Figure 1A.

Experiment 3. Methoprene aerosol for control of *T. castaneum* in food warehouses

Adult emergence from untreated 3- and 4-week old *T. castaneum* larvae was 98.4 ± 0.7 and 96.7 ± 1.7 %, respectively. In the dishes exposed to aerosol, there were no significant differences in adult emergence with respect to the position where the larvae were exposed to methoprene aerosol or between the 3- and 4-week old larvae (P = 0.05), so all data were pooled. Adult emergence for exposed larvae was only 3.6 ± 0.8 %, and some of this survival was because larvae occasionally crawled underneath the filter paper and could have escaped exposure during the time of application.

Discussion

Mortality of *R. dominica* exposed on rice treated with DE was much lower than mortality levels obtained in a similar study in which *R. dominica* were exposed to combination rates of DE and methoprene applied to wheat, and this variation in efficacy of DE among different grain products has been documented in several recent studies (Arthur, 2004; Kavallieratos et al., 2005). Methoprene is very effective against eggs and early instars of *R. dominica*, and there is also evidence that fecundity of adult females may be reduced after exposure on grains treated with methoprene (Daglish and Pulvirenti, 1998). The combination of methoprene and DE has potential for increased use, and application rates of methoprene could be reduced to alleviate cost concerns.

Another advantage of using methoprene in combination with another insecticide is that it is not effective on *Sitophulus* spp. (Coleoptera: Curculionidae) (Samson et al., 1990), primarily because the female oviposits directly into the grain kernel, and the developing larva has little contact with the residues. Therefore, in sites where both *Sitophulus* spp. and *R. dominica* can be present, another insecticide would have to be combined with methoprene to give complete control. However, the choice of combination products is often limited by the susceptibility of individual species to an insecticide or to a group of insecticides. For example, some DE products are more effective against *Sitophilus oryzae* (L.) compared to *R. dominica* (Arthur, 2002), but the order of toxicity is reversed for pyrethroid insecticides (Arthur, 1995).

Incorporation of IGRs into management strategies to control *P. interpunctella* in food warehouses presents different issues than the use of IGRs in stored grain commodities. The familiarity and visibility of this pest to consumers, its ability to penetrate food packaging, and the essentially zero tolerance for insects in finished food products are challenges that must be faced when using IGRs or any other insecticide. Because IGRs can be considered reduced-risk insecticides, they represent excellent options for control in the warehouse environment. The tests in which wandering-phase *P. interpunctella* larvae were exposed on concrete treated with hydroprene show the potential of using IGRs to control this species in food warehouses, retail stores, and urban storage situations. Arbogast et al. (2002) showed reduction in population of several stored-product pests, including *P. interpunctella*, when hydroprene was applied as a spot-treatment in a botanical warehouse. In laboratory tests, exposure of *P. interpunctella* eggs prolonged the development time of the eggs and caused mortality in a dose-dependent manner similar to the results described for larval exposure (Mohandass et al., 2006).

One potential limitation for using hydroprene is that it can be volatile, which leads to degradation and a loss in residual efficacy within a few weeks after application (Arthur and Hoerneman, 2004). Depending on the needs of an individual facility, other IGRs may offer better residual control. In the United States, methoprene is also labeled for use as a residual surface treatment at a rate of about 0.003 micrograms [AI]/cm^2, which is about 50 % greater than the label rate of 0.0019 micrograms [AI]/cm^2 for hydroprene. Another IGR that has been recently labeled in the United States for surface treatments is pyriproxyfen. It apparently has greater residual activity than hydroprene and may even be effective at lower rates (Phillips et al., unpublished data). However, one cautionary note is that in laboratory studies, exposed insects have no opportunity to escape a surface treated with the IGR. Under field conditions, control may be reduced if insects either escape from or have no contact with the treated surface (Toews et al., 2005).

Recent field studies have documented populations of stored-product insects in and around food storage facilities and flour mills, and these studies indicate that these populations exert a constant infestation pressure (Doud and Phillips, 2000; Campbell and Mullen, 2004). When whole-plant treatments such as fumigation and heat are used to disinfest the facility, data from pheromone traps show a sharp decline and often a quick rebound and recovery to levels that existed before the control intervention (Roesli et al., 2003; Campbell and Arbogast, 2004). Although more limited-scale insecticides such as residual sprays and aerosols/ULVs may be more compatible for modern pest management programs than calendar-based fumigation, there is little data regarding field efficacy of IGRs when used as contact sprays and aerosols. Although methoprene is labeled as an aerosol and appears to be effective against immature stages of stored-product insects, in actual industry practice it is often combined with synergized pyrethrins or with a pyrethroid to kill adults. Long-term monitoring studies are being conducted to evaluate this combination approach for using IGRs in aerosol applications (J. F. Campbell, unpublished data).

In summary, there are many opportunities for the increased use of IGRs in management programs to control stored-product insects. In storage sites where the primary pest is *P. interpunctella*, and control is targeted toward the larval stages, IGRs used alone may be sufficient to give complete control, but when adult control is a necessity, the combination approach appears to be a good practical solution. In particular, the combination approach with aerosols offers new potential for use in mills and processing facilities that have historically relied on fumigation for insect pest management.

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Footnotes

This paper reports the results of research only. Mention of a chemical, proprietary name, or method of application does not constitute a recommendation or endorsement by the U. S. Department of Agriculture.

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