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Efficacy of methoprene for multi-year protection of stored wheat, brown rice, rough rice and corn

F.H. Arthur

USDA, Agricultural Research Service, Center for Grain and Animal Health Research, 1515 College Avenue, Manhattan, KS, 66502, United States

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ABSTRACT

Hard red winter wheat, brown rice, rough rice, and corn were treated with the insect growth regulator (IGR) methoprene at rates of 1.25 and 2.5 ppm, held for 24 months at ambient conditions in buckets on the floor of a grain bin, and sampled every two months. Bioassays were done by exposing 10 mixed-sex adults of *Rhyzopertha dominica* (F.), the lesser grain borer, and *Tribolium castaneum* (Herbst), the red flour beetle, on wheat, *R. dominica* and *Sitotroga cerealella* (Oliver), the Angoumois grain moth, on brown rice and rough rice, and *T. castaneum* and *S. cerealella* on corn. Sample size for all commodities was about 80 g, and these samples were held for 3 months at 27°C-60% r.h. Both rates of the IGR completely suppressed adult progeny development of *R. dominica* with little resulting feeding damage, sample weight loss, or insect damaged kernels (IDK). Some adult progeny production of *S. cerealella* and resulting IDK occurred at both rates on rough rice, brown rice, and corn, but was far less than in untreated controls. There was little adult progeny production but some feeding damage caused by larval *T. castaneum* in the treated wheat and corn but again far less than in untreated control. Allowing continual exposure of parental adults on grains treated with an IGR, rather than exposing those parental adults for a short time period, may give more accurate evaluations of residual efficacy. Results show that methoprene used as a grain protectant will give residual control of stored product beetles for 24 months, but complete control of *S. cerealella* may require inclusion of a contact insecticide.

1. Introduction

The insect growth regulator methoprene, a juvenile hormone (JH) analog that inhibits molting and development in immature insects, has been utilized for many years as a grain protectant in Australia (Daglish, 2008). A commercial formulation was available in the United States (US) in the mid-1980s (Diacon®), relaunched in 1999, and in 2002 was replaced by s-methoprene with the name Diacon II® (EPA Registration Number 2724-427). All formulations were 33% active ingredient [AI], 288 mg AI/ml (Diacon® II, EPA Registration Number 2724-427). Label specifications allowed application at 1, 2.5, and 5 ppm (mg AI/kg). This formulation was replaced in 2011 by (Diacon® IGR), which had the same amount of AI, but the label rates were changed to 1.25 and 2.5 ppm (EPA Est. No. 2724-TX-1).

JH analogs such as methoprene are generally effective against externally-feeding stored grain insects because all life stages of those insects will be exposed to the insecticide as they develop from the egg to the adult stage (Athanassiou et al., 2011a,b). They are also effective on internally-feeding stored grain insects such as *Rhyzopertha dominica* (F.), the lesser grain borer, and *Prostephanus truncatus* (Horn), the larger grain borer (Kavallieratos et al., 2012a,b), because the egg is laid outside the grain kernel, and the neonate will be exposed to the insecticidal residues before it can bore into the grain kernel. *Sitotroga cerealella* (Olivier), the Angoumois grain moth, can infest stored corn and stored rice (Perez-Mendoza et al., 2004). The female also lays eggs outside the grain kernel and the larvae will bore into the kernel after hatching, thus it is also considered to be an internal feeder. There has been little recent research in the US regarding susceptibility of *S. cerealella* to insecticides, including IGRs, currently used as protectants in stored grain management. The effects of IGRs are generally manifest in the immature stages, and though they are not generally toxic to adults, there is some evidence of indirect effects from adult exposure to methoprene, such as reduced fecundity (Daglish and Pulvirenti, 1997; Chanbang et al., 2008a,b; Wijayaratne et al., 2012).

E-mail address: frank.arthur@ars.usda.gov.

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Wheat and small grains, and also corn kernels, can be readily infested by internally-feeding stored grain insects. Bulk rice in bins is generally stored in the husk (hull) and is classified as rough rice or paddy rice. The hull will offer some protection of the kernel, as it may limit penetration by neonates of *R. dominica* and *S. cerealella* (Cogburn, 1974; Chanbang et al., 2008a,b; Kavallieratos et al., 2012a,b; Arthur et al., 2013). However, *S. cerealella* can penetrate intact rice hulls (Cogburn et al., 1983). Once the hull is removed during the initial milling process, the rice is classified as brown rice, and the loss of the protective hull facilitates infestation by stored product insects (Sittisang and Imura, 1987). In addition, the red flour beetle, *Tribolium castaneum* (Herbst), a cosmopolitan grain pest, can readily feed and develop on brown rice (Kavallieratos et al., 2015). The US Food and Drug Administration classified brown rice as a whole grain in 2008, which opened up a new market for brown rice as a gluten-free replacement for wheat. Brown rice is generally stored in bags rather than in bins or flat storages, but there are currently little data regarding efficacy of methoprene as a protectant of brown rice. In addition, there are several recent studies that indicate efficacy of IGRs, when used alone and in combination with other insecticides as grain protectants, will vary depending on the specific grain commodity (Athanassiou et al., 2009, 2011a; Kavallieratos et al., 2012a,b).

Laboratory trials evaluating IGRs for control of stored product insects usually involve exposure of adults for limited time periods, typically one or two weeks, and then assessing resulting progeny development (Athanassiou et al., 2011b). Few tests have examined the impact of continual adult exposure for several months, including effects on quality parameters such as feeding damage and commodity weight loss. Also, residual efficacy is usually assessed for different time periods for up to a year; there are no recent studies that have been conducted for a multiple-year storage period. The objectives of this study were to determine: 1) residual efficacy of methoprene for protection of multiple commodities, wheat, brown rice, rough rice, and corn, 2) species differences and commodity differences in terms of progeny production and selected quality parameters, and 3) progeny production and quality loss on different commodities due to continual adult exposure of different species for multiple weeks.

2. Materials and methods

2.1. General methods

This test was initiated during the summer of 2012 at the USDA-ARS-Center for Grain and Animal Health Research (CGAHR), Manhattan, KS, USA. The methoprene formulation used was the current commercial product Diacon® IGR, 288 mg AI/ml (33% AI, Central Life Sciences, Shaumberg, IL, USA). The application rates were 1.25 and 2.5 ppm (mg/kg), the commodities were wheat, corn, brown rice, and rough rice, and the experimental replicate unit was an 11 kg lot for each of the commodities. Label directions specify different amounts of the formulation to be mixed with 8.92 L to treat each respective commodity. Thus, each replicate of each application rate was formulated in a 25 ml flask, and the amount dispensed for a given commodity was in proportion to the label directions. Experimental procedures will be described first for wheat, then for the other commodities.

2.2. Wheat

A ratio of 90% whole wheat and 10% cracked wheat comprised each 11-kg lot. The target concentrations for each replicate were prepared by measuring appropriate volumes of the commercial product. Each of the two rates were prepared using 7.7 ml of formulated spray per each of the four replicate 11 kg lots, which is proportional to the label volume spray rate of 18.92 L gallons of formulated spray per 27,272 kg of wheat (0.7 ml/kg). Separate solutions were formulated for each replicate for each application rate. Each replicate was spread onto a cardboard form that was about 0.25 m^2. A Badger 100 artists' airbrush (Franklin Park, IL, USA) was used to mist the formulated spray directly onto the wheat. Approximately one-third of the formulated spray was dispensed at one time, the wheat was mixed using a piece of cardboard, and this procedure was repeated two more times. These treatments were done inside a laboratory room in one of the buildings at CGAHR.

The wheat was treated on 19 July 2012. After each replicate was sprayed, it was emptied from the cardboard form into a 20-L capacity bucket (4 buckets for each of the two rates). Immediately after adding the wheat to the bucket, subsamples were taken to evaluate the efficacy of methoprene. Approximately 80 mg from each replicate was placed into each of two 120-ml vials. The same amount of untreated wheat, obtained from the laboratory, was placed into each of eight 120-ml vials for the untreated controls. These samples were termed the time 0 samples (immediately after treatment). After this first subsampling, all buckets containing the treated wheat were moved to the floor of a 27 metric ton (MT) capacity empty grain bin at the CGAHR. The treated wheat was held for 24 months inside the grain bin. A HOBO recording computer with two cable attached to an insulated metal rod was placed inside one of the replicate buckets to monitor temperature at approximate depths of 2.5 and 19 cm. The sampling procedure to evaluate residual activity described above was repeated every two months for 24 months. The final samples were taken on 23 July 2014.

The next day after the samples were taken from the buckets, including the time 0 samples, 10 mixed-sex adult *R. dominica* aged one week were added to one of the vials of wheat from each replicate sample for the two application rates (8 vials) and to each of 8 vials of untreated wheat. Ten one-week adult *T. castaneum* were added to the remaining vial of treated wheat from each replicate and concentration and to the remaining 8 vials of untreated wheat. The vials were then placed in a walk-in chamber set at 27 °C and 60% r. h. on a 16:8 h light: dark cycle. They were held inside the chamber for 3 months, then the vials were removed, and held for several days in a freezer at about −18C. The vials were removed from the freezer, and allowed to warm to room temperature (about 25 °C, according to random sampling with a HOBO temperature recording unit). The contents were then weighed, the insects sieved, and all adults tabulated. The number of original parental adults (10) was subtracted from this total. The wheat was sieved again, and the feeding damage was weighed, and the whole wheat was weighed. One hundred kernels from the each of the vials containing the *R. dominica* were removed and later examined under a stereo microscope for adult emergence holes (classified then as insect damaged kernels or IDK). The samples were then discarded.

2.3. Brown rice

The same treatment procedures were followed for brown rice as for wheat, but the test insect species were *R. dominica* and *S. cerealella* instead of *T. castaneum*. The volume spray rates were adjusted to match the specific label instructions for rice (0.9 ml of formulated spray per kg). The brown rice was treated on 14 August 2012, and samples were taken at time 0 as described for wheat. After the initial time 0 samples were taken, the buckets containing the rice were moved to the same bin as the wheat. After samples were taken, 10 newly emerged adult *S. cerealella* were put in each of the four replicate vials for the two treatments and the eight jars for the controls. Ten adult *R. dominica* were placed in the remaining vials, again as described above. Vials were held in the chamber for 3