PS7-16 – 6168

Efficacy of spinosad for insect management in farm stored maize

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Abstract

The effectiveness of spinosad and pirimiphos-methyl (Actellic) against key stored grain insects during on-farm maize storage was determined. Maize stored in 12.5 t capacity pilot bins and 112.5 t capacity elevator bins were treated with either 1 mg/kg spinosad, 4 mg/kg pirimiphos-methyl (Actellic), and combination of 1 mg/kg spinosad + 4 mg/kg Actellic in addition to control. Changes in residue levels of spinosad and pirimiphos-methyl (Actellic) during on-farm storage were also determined. The number of maize weevils and other injurious insects were not significantly different among the treatments. No substantial insect pressures and grain quality deterioration was observed even for untreated maize with less than 1 maize weevil found per kg of sample. Residue levels of spinosad and pirimiphos-methyl decreased by about 20 % and 15 % during Year 1, 36 % and 72 % between Years 1 and 2, and 0.01 loss and 36 % during Year 2 summer storage.

Key words: stored grain, post harvest, residual insecticides, protectants, insects, efficacy, grain quality.

Introduction

Spinosad is a biological insecticide derived from naturally occurring bacteria called *Saccharopolyspora spinosa* (Mertz and Yao) that exerts its toxic action on contact and ingestion of treated substrates. It was developed to provide rapid control of Lepidoptera and other pests with minimum disruption of beneficial insects and other non-target organisms. It has low mammalian toxicity (rate oral and dermal LD_{50}, > 5,000 mg/kg), and is nontoxic to some predatory insects (Bret et al., 1997). It is slightly toxic to some parasitoids and honeybees, degrades under sunlight, and has a novel mode of action (Salgado, 1997). It controls insects resistant to conventional pesticides, and is currently labeled for use on vegetable crops, ornamentals, forest trees, and it was recently registered for use on stored grains such as barley, wheat, sorghum/milo, maize (field, sweet, popcorn, grown for seed), rice and oats (Barker, 2005). The tolerance level for the active ingredient (spinosyns A and D) concentration is 1.0 ppm (0.9 kg of active ingredient per 3.79 L of water) by weight. Due to its low effective use rate, safety to the environment, safety to mammals, and safety to beneficial insects, spinosad was registered under the EPA's reduced risk program.

Spinosad at 1-20 mg/kg rates on hard red spring wheat (14 % moisture) was tested against adults of the lesser grain borer, rice weevil (*Sitophilus oryzae* (Linnaeus)), red flour beetle, and sawtoothed grain beetle (O*ryzaephilus surinamensis* (Linnaeus)) (Subramanyam et al., 2002). Spinosad provided effective control at rates of 1-3 mg/kg, and suppressed population growth of these species. Spinosad at 1 mg/kg effectively killed all adults of the lesser grain borer and completely suppressed progeny production. Effects on the rice weevil were dose-

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dependant, and rates ≥ 3 mg/kg were necessary for complete adult mortality and suppression of progeny production. Adults of the sawtoothed grain beetle and red flour beetle were not completely controlled. However, larvae hatching from eggs laid by the surviving adults succumbed to spinosad at rates ≤ 3 mg/kg. More recent evaluation of spinosad at 0.1 and 1 mg/kg rates on hard red winter, soft red winter, hard red spring, and durum wheats showed a similar pattern of susceptibility among the species (Tables 1-3 in Fang 2002). However, the effectiveness against the insects was more pronounced on hard wheat than on soft wheat. A similar trend in species susceptibility was evident on maize (Fang et al., 2002). Subramanyam et al. (2002) initiated tests in the fall of 2000 to determine the fate and efficacy of spinosad residues in farm-stored grain by confining spinosad-treated hard red winter wheat in wire-mesh pouches placed under the surface of grain stored in farm bins. Laboratory bioassays with lesser grain borers and red flour beetles on aged deposits of spinosad between November 2000 and November 2001 indicated that a rate of 1 mg/kg was effective in killing all red flour beetles and a rate of 0.1 mg/kg was effective against the lesser grain borer.

The specific objectives of this study were to (1) evaluate the effectiveness of spinosad and pirimiphos-methyl (Actellic) against key stored grain insects during on-farm maize storage in Indiana receiving the following treatments: untreated grain (control; no water added), 1 mg/kg spinosad, 4 mg/kg pirimiphos-methyl (Actellic), and combination of 1 mg/kg spinosad + 4 mg/kg Actellic, and (2) quantify changes in residue levels of spinosad and pirimiphos-methyl (Actellic) during on-farm storage of maize.

Materials and methods

Bin locations and preparation

On-farm storage location sites storage included the pilot bin facility of the Purdue Post-Harvest Education and Research Center (PHERC), which is located at the Purdue Agronomy Center for Research and Education (ACRE) in West Lafayette, Tippecanoe County, Indiana using four 12.5-t capacity pilot bins filled with approximately 10-t of shelled maize. Two other sites, Mohawk in Hancock County, Indiana and Reynolds in White County used four replicate steel bins of 112.5-t capacity in each site that were filled with 75-t of shelled maize.

Prior to filling, the bins at each of the sites were thoroughly cleaned to remove grain dust and debris leftover from the previous storage season. After cleaning, Cyfluthrin at the highest labeled rate (0.05 % cyfluthrin or 16 ml cyfluthrin per gallon of water) was sprayed on the surface of the bin walls both inside and outside of the bins to a height of 1.8 m (6 ft) from the base (around the bins) to kill residual insect infestations.

Stored grain treatment

Spinosad contains 28 % active ingredients spinosyn A and spinosyn D and 77.2 % inert ingredients. Actellic contains 57 % active ingredient (0-(2-(diethylamino)-6-methyl-4-pyrimidinyl) 0,0-dimethyl phosphorothioate) and 43 % inert ingredients. Regular tap water and spinosad (Lot# of Spintor-2SC® used: 0E24160P22In, Dow AgroSciences, Indianapolis, IN, USA) was mixed to a concentration of 0.6 %, or 5.54 ml per L of water to obtain the label rate of 1 ppm. Regular tap water and pirimiphos-methyl (Actellic 5E®, Agriliance, LLC, St. Paul, MN, USA) was mixed to obtain a concentration of 0.9 %, or 9.50 ml per L of water to obtain half the label rate of 4 ppm. Each of the pesticide treatments were prepared and mixed in separate applicator tanks with separate nozzles for application to avoid cross contamination of pesticides.

At each site, the four bins received the following four treatments at random: (1) untreated grain (control, no water added), (2) grain treated with an aqueous suspension of spinosad at a rate of 1 mg/kg (1 ppm), (3) grain treated with a combination of an aqueous suspension of spinosad at a rate of 1 mg/kg (1 ppm) and 4 mg/kg (4 ppm) pirimiphos-methyl, and (4) grain treated with an aqueous suspension of pirimiphos-methyl at a rate of 4 mg/kg (4 ppm). Moisture content of the grain in each of the bins prior to treatment application at the Mohawk and Reynolds farm sites ranged between 13.5 % and 14 % moisture content (wet basis) after artificial drying, while the grain in the bins at the PHERC site had moisture contents between 16.8% and 17.1% which was actively aerated during the storage period.

Temperature and relative humidity measurements

Ambient weather conditions outside the bins, grain temperatures, and temperature and relative humidity of the headspace air inside the bins were monitored at each of the farm sites. In each bin, grain bulk and temperature and relative humidity of the headspace were monitored using HOBO (H8 four-channel) loggers each connected to four TCMx-HA sensors (Onset Computer Corporation, Bourne, MA), except for PHERC bins which used the OPIGIMAC system (OPI System, Inc., Calgary, CA). Five temperature sensors were installed at a depth of 0.2 m from the grain surface and another five sensors at a depth of 2 m from the grain surface.

Residue analysis

Collected maize samples were frozen for a week at -20 °C to kill any live insects. Five hundred gram sample in each treatment was packaged and shipped to Dow AgroSciences (Indianapolis, IN) for analysis of spinosad residues, and the another ~500 gram sample was packaged and shipped to BioDiagnostics (River Falls, WI) during year one, and Central Analytical Laboratories (Metairie, LA) during year two for analysis of pirimiphos-methyl residues. Due to budget constraints, spinosad-treated corn samples were not analyzed for Actellic residues, nor were Actellic-treated samples analyzed for spinosad residues. The control samples were packaged and shipped to Dow AgroSciences and BioDiagnostics for spinosad and Actellic residue analysis, respectively, during year one. No control samples were tested in the second year trial. All samples were analyzed for residues using high performance liquid chromatography (HPLC) methods. The total spinosad residues, expressed as mg/kg, included residues of spinosyn A plus spinosyn D. The total pirimiphos-methyl (Actellic) residues were expressed in mg/kg. The limits of detection for pirimiphos-methyl and spinosad were 0.02 mg/kg and 0.002 mg/kg, respectively.

Statistical analyses

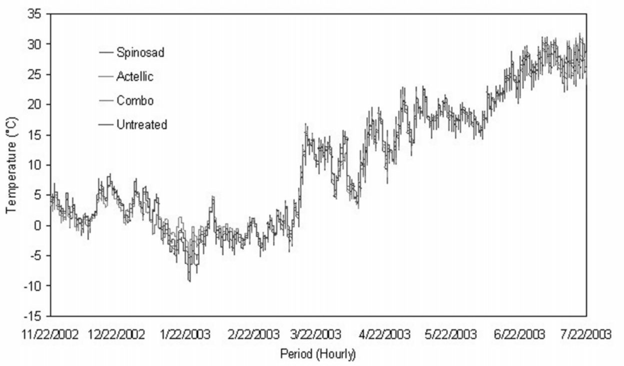
Four experimental research bins were selected at each farm site and treatments were randomly assigned to each of the four bins. Therefore, this experiment was designed as a completely randomized block design, with farm site serving as the block. Therefore, insect count data were subjected to analysis of variance (ANOVA) following appropriate transformation to determine main (treatment and sampling time) and interactive effects at the $\alpha = 0.10$ level. Repeated measures ANOVA were used to determine differences in insect counts over time among the treatments.

Results and discussion

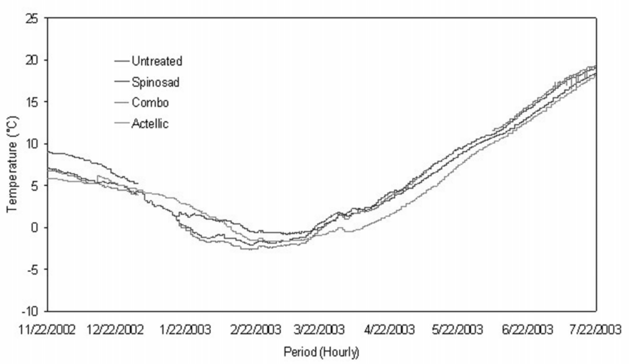
Temperature profiles

Grain temperature profile on the surface and 1.82 (6ft) below the gain surface from November 2002 to July 2003 for all the storage sites, Mohawk, Reynold and PHERC are shown in Figure 1. At the PHERC site, some software related problems prevented data collection during a few of the experimental months. All three farm sites showed similar temperature patterns. Temperature decreased during the cold winter months and gradually increased as the ambient temperature warmed up in the summer.

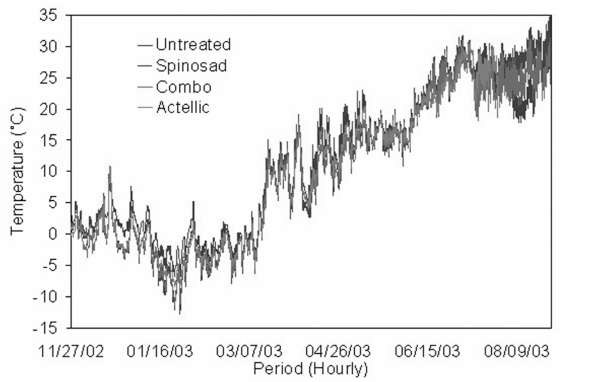
Temperatures of the grain at the surface and 2 m (6 ft) below the grain surface followed the ambient temperature trends closely. Average grain temperatures near the surface were below 10 °C for the first five months of the experiment (November 2002 to March 2003), and steadily increased from approximately 5 °C in mid-March 2003 to approximately 30 °C by July 2003. In January to March 2003, the temperatures started to drop below 0 °C. However, in mid-March 2003 these temperatures started to rise at a steady rate and eventually climbed to approximately 17 °C by July 2003.



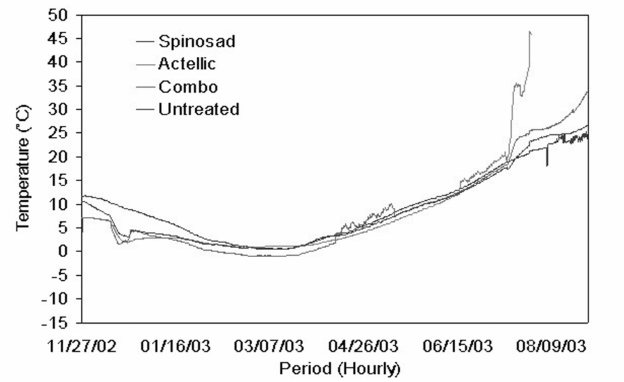
(a) Mohawk – surface



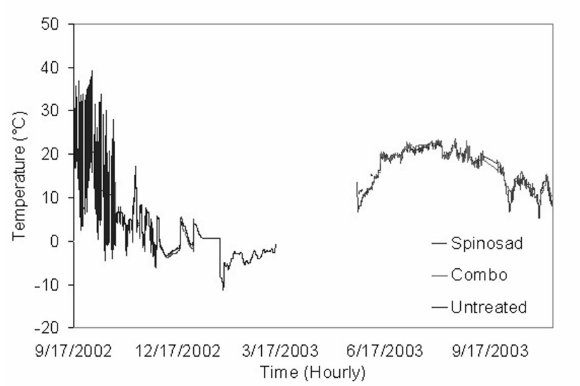
(b) Mohawk – 1.82 m (6ft)



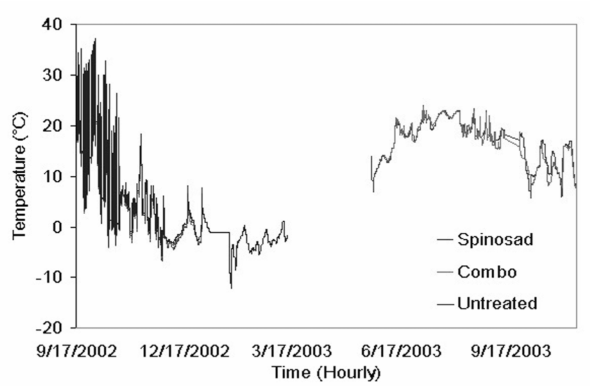
(a) Reynold – surface



(b) Reynold – 1.82 m (6ft)



(a) PHERC – surface



(b) PHERC – 1.82 m (6ft)

Figure 1. Temperature profiles in stored maize at the surface and 1.82 m (6 ft) below the grain from November 2002 to July 2003.

Grain quality changes

Table 1 summarizes the on-farm grain quality changes that occurred during months 0, 3, 6, 9 and 11 of the 2002 to 2003 experimental period for the untreated, spinosad-, Actellic- and spinosad-Actellic combination-treated maize samples. During the first six months, the on-farm stored maize in all treatments was graded between U.S. No. 1 and 2, but by month 9 the maize grades in all treatments began to shift towards U.S. No. 2 and 3. The maize was maintained between 14.2 % and 15.2 % moisture content during the storage period. The average test weight of the maize ranged between 55 to 57 lb/bu. Based on the Federal Grain Inspection Service (FGIS) results for the on-farm maize samples, the amount of insect damaged kernels (not reported in Table 1) and broken maize and foreign material (see Table 1) were not substantial and did not increase with storage time. The total damage in the maize samples in all treatments during storage, which included mold, insect, heat and weather damage, were not substantial in months 0, 3 and 6 and ranged from 0.9 ± 0.6 to 1.8 ± 0.7 percent.

Table 1. On-farm stored maize quality (mean ± SEM) reported by Titus Grain Inspection Service (FGIS guidelines) in the untreated (control), spinosad-, Actellic-, and spinosad-Actellic combination-treated maize samples during the 2002-2003 experimental period.

Month	Treatment	Grade No.[1]	Test Weight (lb/bu ± S.D.)	Moisture (% ± S.D.)	Total Kernel Damage (% ± S.D.)	Broken Maize & Foreign Material (% ± S.D.)
10/23/02	Untreated	1	56.6 ± 1.4	14.8 ± 1.4	1.6 ± 0.3	0.9 ± 0.6
01/23/03	Untreated	1	56.5 ± 0.8	14.5 ± 0.6	1.8 ± 0.7	0.9 ± 0.5
04/23/03	Untreated	2	56.6 ± 0.7	14.6 ± 0.3	1.3 ± 0.8	1.9 ± 1.2
07/23/03	Untreated	1	56.7 ± 0.6	14.4 ± 0.3	2.5 ± 0.9	0.9 ± 0.1
09/23/03	Untreated	2	55.9*	14.8*	4.1*	0.9*
10/23/02	Spinosad	1	56.1 ± 0.0	14.4 ± 1.5	1.4 ± 0.3	1.4 ± 0.5
01/23/03	Spinosad	1	56.6 ± 0.9	14.2 ± 0.9	1.7 ± 0.9	0.9 ± 0.2
04/23/03	Spinosad	1	56.7 ± 0.8	14.5 ± 0.9	1.1 ± 0.6	0.9 ± 0.2
07/23/03	Spinosad	2	56.4 ± 0.6	14.3 ± 0.9	4.2 ± 4.0	0.9 ± 0.4
09/23/03	Spinosad	3	56.3*	14.9*	6.8*	1.0*
10/23/02	Combo	2	55.8 ± 1.2	14.7 ± 1.5	1.6 ± 0.5	1.2 ± 0.5
01/23/03	Combo	1	56.2 ± 0.1	14.6 ± 0.6	1.3 ± 0.3	1.0 ± 0.5
04/23/03	Combo	1	56.2 ± 0.5	14.6 ± 0.6	0.9 ± 0.5	1.2 ± 0.3
07/23/03	Combo	1	56.5 ± 0.1	14.2 ± 0.7	1.4 ± 0.3	0.7 ± 0.2
09/23/03	Combo	2	55.9*	15.2*	2.8*	0.7*
10/23/02	Actellic	2	55.5 ± 0.6	15.2 ± 1.5	1.1 ± 0.6	1.2 ± 0.6
01/23/03	Actellic	1	56.4 ± 0.4	14.8 ± 0.5	1.5 ± 0.4	0.8 ± 0.5
04/23/03	Actellic	1	56.3 ± 0.7	14.7 ± 0.4	1.7 ± 0.3	1.1 ± 0.5
07/23/03	Actellic	2	56.8 ± 0.3	14.4 ± 0.3	4.7 ± 3.7	0.8 ± 0.3
09/23/03	Actellic	2	56.8*	15.0*	4.1*	0.6*

Each of the means in month 0-9 were averages across the three farm sites

* Means were based on one replicate for the PHERC maize samples

[1]See Appendix D for grade determining factors for maize

Insect Counts

Table 2 summarizes the number of maize weevils (maize weevil (*Sitophilus zeamais* (Motschulsky)) and any other insects injurious to stored maize found each month in the maize samples that were passed over the inclined sieve. There was a slight increase in insect presence during the storage period. There were no substantial differences between treatments.

Table 3 summarizes the number of dead secondary feeder pests that were found each month in the maize samples that were passed over the inclined sieves. Only the number of insects caught in the 9-month untreated sample was substantially higher than in any of the other treatments. Based on the results of Table 2 and 3, the total sieved insect counts (external/internal feeders) never exceeded the FGIS limit of 2 maize weevils or other insects injurious to stored grain per kilogram of maize.

Residue Analysis

Spinosad residue deposits were stable in all months in the combination treatment and ranged from 0.42 ± 0.10 mg/kg to 0.55 ± 0.20 mg/kg on the combination treated maize samples (Table 4). Although spinosad residue deposits dropped significantly after month 0 on spinosad-treated maize, they were stable during months 3, 6, 9 and 11 and ranged from 0.38 ± 0.14 mg/kg to 0.42 mg/kg in the spinosad-treated maize samples. The results of residue deposits on the spinosad-Actellic combination treated maize samples showed that the targeted rate of 4 mg/kg pirimiphos-methyl was not achieved at the time of application (month 0: 0.98 ± 0.19 mg/kg) (Table 5).

The pirimiphos-methyl deposits on combination treated maize samples were significantly lower in month 0 than in months 3 and 9 (Table 5). However, this residue data were for the PHERC farm site samples alone. In month 6, pirimiphos-methyl deposits were significantly lower than in months 3 and 9, but not significantly different than in month 0. Pirimiphos-methyl deposits ranged from 1.62 ± 0.53 mg/kg to 2.13 ± 0.53 mg/kg in months 3, 6 and 9.

Table 2. Number (mean ± SEM) of maize weevils and other insects injurious to stored maize that were found in on-farm maize samples that were passed over the inclined sieve for the untreated (control), spinosad-, Actellic-, and spinosad-Actellic combination-treated maize samples during the 2002-2003 experimental period.

Month	Date	Untreated	Spinosad	Combo	Actellic
0	10/23/2002	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
1	11/23/2002	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
2	12/23/2002	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
3	01/23/2003	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
4	02/21/2003	0.3 ± 0.6	0.0 ± 0.0	0.3 ± 0.6	0.3 ± 0.6
5	03/21/2003	0.3 ± 0.6	0.3 ± 0.6	0.3 ± 0.6	0.3 ± 0.6
6	04/23/2003	1.0 ± 1.7	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.2
7	05/23/2003	3.0 ± 5.2	1.0 ± 1.7	0.0 ± 0.0	0.7 ± 1.2
8	06/23/2003	1.0 ± 1.0	3.0 ± 4.4	2.7 ± 2.3	0.7 ± 1.2
9	07/23/2003	2.3 ± 2.3	0.6 ± 1.2	0.3 ± 0.6	0.3 ± 0.6
10	08/23/2003	3.0*	0.0*	0.0*	0.0*
11	09/23/2003	1.0*	0.0*	0.0*	0.0*

Pests that were found included: maize weevil (*S. zeamais* (Motschulsky)), rice weevil (*S. oryzae,* (Linnaeus)), red flour beetle *(T. castaneum,* (Herbst)), lesser grain borer *(R. dominica* (Fabricius))

Each of the means in month 0-9 were averages across the three farm sites

* Mean was based on one replicate for the PHERC maize samples.

Table 3. Number (mean ± SEM) of external feeders of stored grain found in the on-farm maize samples that were passed over the inclined sieve for the untreated (control), spinosad-, Actellic-, and spinosad-Actellic combination-treated maize samples during the 2002-2003 experimental period.

Month	Date	Untreated	Spinosad	Combo	Actellic
0	10/23/2002	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
1	11/23/2002	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
2	12/23/2002	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
3	01/23/2003	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
4	02/21/2003	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
5	03/21/2003	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
6	04/23/2003	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
7	05/23/2003	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
8	06/23/2003	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
9	07/23/2003	13.7 ± 21.9	1.3 ± 2.3	0.6 ± 1.2	0.3 ± 0.6
10	08/23/2003	4.0*	5.0*	0.0*	0.0*
11	09/23/2003	0.0*	0.0*	0.0*	0.0*

Pests that were found included: hairy fungus beetle (*T. stercorea* (Linnaeus)), foreign grain beetle (*A. Advena* (Waltl)), warehouse pirate bug (*X. flavipes* (Reuter)), flat grain beetle (*C. pusillus* (Schönherr))
Each of the means in months 0-9 were averages across the three farm sites
* Mean was based on one replicate for the PHERC maize samples.

Table 4. Spinosad residue analyses results (mean ± SEM) in untreated (control), spinosad-, and spinosad-Actellic combination-treated maize samples during the 2002-2003 experimental period.

Month - Date	Untreated[a] (mg/kg)	Spinosad[a] (mg/kg)	Combo[a] (mg/kg)
Month 0 - 10/23/2002	0.01 ± 0.01a	0.63 ± 0.11a	0.55 ± 0.20a
Month 3 – 01/23/2003	0.00 ± 0.00a	0.40 ± 0.16b	0.43 ± 0.10a
Month 6 – 04/23/2003	0.01 ± 0.01a	0.38 ± 0.14b	0.42 ± 0.10a
Month 9 – 07/23/2003	0.00 ± 0.00a	0.41 ± 0.01b	0.43 ± 0.06a
Month 11 - 09/22/2003	0.00*	0.42*	0.53*

Each of the means in month 0, 3, 6 and 9 were averages across the three farm sites
[a] Residue data were based on one replicate for the PHERC spinosad residues
* Means in the same column followed by different letters were significantly different ($P < 0.10$; Fischer's protected LSD).

Table 5. Pirimiphos-methyl residue analyses results (mean ± SEM) in untreated (control), Actellic, and spinosad-Actellic combination-treated maize samples during the 2002-2003 experimental period.

Month - Date	Untreated[a] (mg/kg)	Actellic[a] (mg/kg)	Combo[a] (mg/kg)
Month 0 - 10/23/2002	NA‡	0.44a*	0.98 ± 0.19a*
Month 3 - 01/23/2003	0.00 ± 0.00a	1.88 ± 0.79a	2.13 ± 0.47b
Month 6 - 04/23/2003	0.00 ± 0.00a	1.71 ± 1.30a	1.62 ± 0.53a
Month 9 - 07/23/2003	0.00 ± 0.00a	1.58 ± 0.54a*	1.85 ± 0.51b

* Residue data were based on one replicate for the PHERC test
† Residue data were based on replicates of Mohawk and Reynolds tests
‡ Residue data were not available for these months and treatments
[a] Means in the same column followed by different letters were significantly different ($P < 0.10$; Fischer's protected LSD)

Residue levels of spinosad and pirimiphos-methyl decreased by about 0.12 (20 % loss) and 0.29 mg/kg (15 % loss) during Year 1, 0.17 (36 % loss) and 1.24 mg/kg (72 % loss) between Years 1 and 2, and 0.01 (3 % loss) and 0.17 mg/kg (36 % loss) during Year 2 summer storage (data not shown).

Conclusions

The following conclusions were drawn with respect to the effectiveness of spinosad and pirimiphos-methyl (Actellic) against key stored grain insects during on-farm maize storage in Indiana:

1. Field trials were successful as maize was stored on-farm up to 12 months without any substantial insect pressures and grain quality deterioration. Even in untreated maize, less than 1 maize weevil (maize weevil or other insects injurious to stored maize) were found per kilogram of sampled maize.

2. Despite careful calibration, the target application rates (1 mg/kg spinosad and 4 mg/kg pirimiphos-methyl) were not achieved and resulted in 0.38 ± 0.14 to 0.63 ± 0.11 mg/kg of spinosad (59 - 61 % below target) and 0.98 ± 0.19 to 2.13 ± 0.47 mg/kg pirimiphos-methyl (50 - 75 % below target). These results point towards the need for improved protectant application techniques and equipment to achieve the product label rates.

3. Spinosad remained quite stable during a 25-month storage period, while pirimiphos-methyl remained stable through month 9.

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