COMPARATIVE TOXICITY OF SPINOSAD TO *FRANKLINIELLA* SPP. (THYSANOPTERA: THRIPIDAE), WITH NOTES ON A BIOASSAY TECHNIQUE

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The western flower thrips *Frankliniella occidentalis* (Pergande) is a very serious worldwide pest of ornamental, vegetable, and fruit crops in the field and greenhouse (Tommasini and Maini 1995). It is an efficient vector for tomato spotted wilt virus, a serious disease of a wide variety of plants, including vegetable, flower, and ornamental crops (Allen et al. 1990). Western flower thrips are difficult to control effectively with insecticides (Brodsgaard 1994), and resistance has developed to organophosphate, carbamate, pyrethroid, and macrocyclic lactone insecticides after repeated exposure (Immaraju et al. 1992).

Spinosad (DowElanco, Indianapolis, IN), a new natural macrocyclic lactone insect control product with a unique mode of action, was highly efficacious against *F. occidentalis* in field experiments with pepper conducted in North Florida during 1996 and 1997 (J. E. F, J. S., and S. M. Olson, unpublished data). Another abundant flower thrips species, *F. tritici* (Fitch), was not significantly suppressed by spinosad in these experiments and spinosad did not have detrimental effects on populations of the minute pirate bug, *Orius insidious* (Say), a key predator of *F. occidentalis.* Thus, spinosad has the potential to be an important new tool for managing *F. occidentalis.* For this reason and because *Frankliniella* species differ in their ability to transmit tomato spotted wilt virus (Sakimura 1962, 1963), an understanding of the comparative toxicity of spinosad to various species of *Frankliniella* is needed. Knowledge of spinosad toxicity and the development of an effective bioassay will facilitate resistance monitoring for these pests.

Previous resistance or efficacy bioassays for *F. occidentalis* have employed either topical application (Robb 1989), detached leaves as a substrate for the insecticide (e.g., Immaraju et al. 1992), or a residue-on-glass technique (Brodsgaard 1994). Our objectives were to develop an insecticide bioassay procedure suitable for three common species of flower thrips in Florida, F. *occidentalis, F. tritici, and F. bispinosa* (Morgan), and to determine the toxicity of spinosad to these flower thrips species as a possible explanation for control differences in field plots.

Flower thrips were collected from wild radish, *Raphanus raphanistrum* L., growing 50-300 m from pepper fields at the North Florida Research and Education Center of the University of Florida in Quincy. Collection dates were May 27-29, 1997. Adults were aspirated into glass tubes (6 mm diam.) and then emptied into individual plastic diet cups (35 ml) with uncoated paper caps. The cups were provided with sections (20 mm) of snap bean pods sealed at either end with a thin layer of paraffin. After sealing, bean pod sections were submerged for 30 sec in 10 different concentrations of a 0.24 kg ai/l suspension concentrate of spinosad (SpinTor® 2SC, Dow AgroSciences, Indianapolis, IN) in distilled water, and allowed to air dry for 1 hr. Individual cups were placed into a sealed plastic rearing container (5.7 liter), the bottom of which was covered with moist paper toweling. These containers were held in a controlled-environment chamber maintained at 23° ± 2°C, 60% RH and a photoperiod of 14: 10 (L: D). The trial was replicated four times with three diet cups per replicate.

Because of the fragile nature of thrips and the difficulty in separating living individuals into the three species, no attempt was made to standardize the numbers of each species or the total number of individuals placed in each diet cup. We attempted to place a minimum of 20 individuals into each cup. Table 1 lists the range and mean numbers of each species used in this trial. These numbers are representative of the relative species abundance on wild radish on the collection dates. If less than 5 of any one species was present in any replicate, that replicate was repeated the following day using newly prepared solutions.

Although bioassay development will not be dealt with in detail here, a few observations are relevant. We initially evaluated glass snap-cap vials in addition to plastic diet cups as bioassay containers. The vials had a small opening which made them more difficult to use and plastic caps which promoted the formation of excess moisture, thus diet cups were chosen for further evaluation. We evaluated thrips survival in empty diet cups, in cups with bean sections only, with a small piece of moistened paper toweling only, and with both bean sections and toweling. Thrips survival at 24 hrs was minimal in empty cups. The paper toweling resulted in excess moisture which trapped and drowned some thrips. Cups with snap bean sections only resulted in the highest (virtually 100%) survival. Uncoated paper caps were chosen over wax coated caps because the latter resulted in excessive moisture in the cups. The sealed plastic rearing containers with moist paper toweling did not promote excess moisture in the cups, but moisture from the paper toweling did result in a slight expansion of the paper caps to provide a better seal and less desiccation of bean sections. The ends of bean sections were coated with paraffin to reduce desiccation and to serve as a barrier to prevent thrips from crawling inside the bean section. Finally, we chose to treat only the bean sections and not the cup itself because preliminary trial observations suggested that thrips spent most of their time on the bean sections.

Mortality was evaluated at 24 ± 1 hrs. Thrips were considered dead if they were unable to stand upright and/or move forward when probed. Individuals were segregated into living and dead, placed in alcohol and the respective numbers of each species determined under a dissecting microscope. No mortality was observed in untreated controls for *F. occidentalis* and *F. tritici*. For *F. bispinosa*, mortality (3%) was observed in only one replicate. Mortality for the various doses were corrected for control mortality (Abbott 1925). Data were analyzed with analysis of regression using a log-probit model. The analytical software used was Statgraphics Plus® (Manugistics, Inc., Rockville, MD).

The most common species in our samples was *F. bispinosa*, while *F. occidentalis* was the least common (Table 1). Numbers of *F. bispinosa* used in the bioassay were >3X those of *F. occidentalis* and numbers of *F. tritici* were >2X those of *F. occidentalis*. In contrast, Salguero Navas et al. (1991), also working in North Florida, found that *F. oc-*

TABLE 1. RANGE AND MEAN NUMBERS OF EACH *FRANKLINIELLA* SPECIES USED IN THE BIOASSAY.

Species	Mean/ Replicate	Range/ Replicate	Total # Tested	Sex Ratio F:M
F. occidentalis	8.8	5-21	379	2.14:1.0
F. tritici	18.3	7-42	803	2.00:1.0
F. bispinosa	30.7	14-62	1352	2.21:1.0
All species combined	57.6	34-87	2534	2.13:1.0

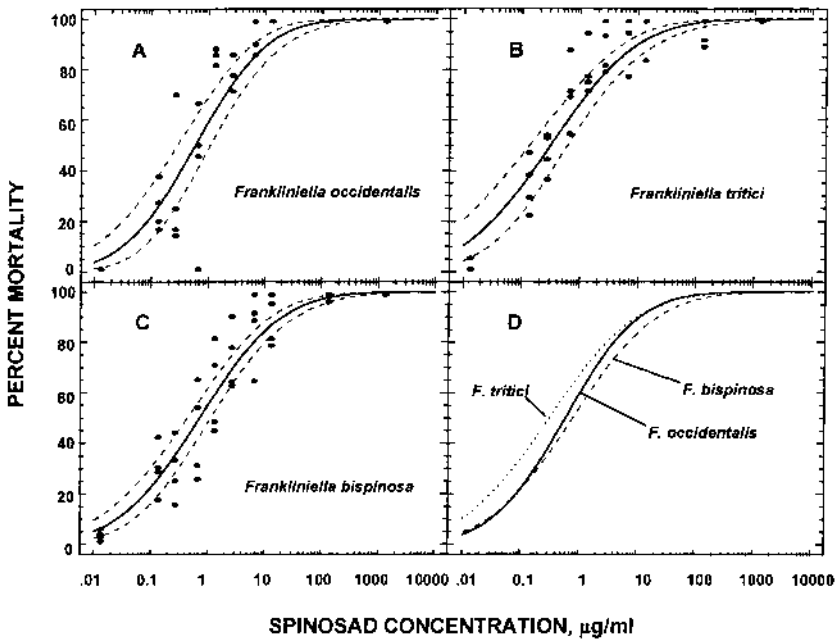

Fig. 1. Mortality of *Frankliniella* spp. in response to spinosad; responses of *F. occidentalis* (A), *F. tritici* (B), and *F. bispinosa* (C), and all three species combined (D). Solid lines are the predicted dose response curves (log-probit model) and dashed lines represent corresponding 95% confidence intervals. Dose response curves for all three species of *Frankliniella* are compared in Figure D.

cidentalis was generally the most abundant species of *Frankliniella* in tomato flowers in the spring and *F. bispinosa* was relatively uncommon in their study. Our results may represent a host preference of *F. bispinosa* for wild radish. An unusually warm winter in 1996-97 may have also contributed to the differences. Sex ratios of *Frankliniella* spp. tested are also given in Table 1. There was roughly a 2 to 1 ratio of females to males with only minor differences between species. Dose responses of males and females were not significantly different for any species, so data for the two sexes were combined.

Dose-response curves were similar for all three *Frankliniella* species (Figure 1). Regressions of dose/mortality data were highly significant for all three species (R^2 = 75-85%, $P < 0.00001$) (Table 2). The regression slope for the *F. occidentalis* data was significantly higher than that for the other two species based on non-overlapping standard error values. Standard error values around the regression slopes for *F. tritici* and *F. bispinosa* data did overlap, indicating that slopes for these species were not significantly different. Although *F. tritici* was numerically more susceptible than *F. bispinosa* as indicated by the lower LC_{10}, LC_{50}, LC_{90} and LC_{99} values, the 95% confidence intervals around these values for the three species overlapped. Thus, there were no significant differences among the three species.

Data presented here suggest that spinosad is equally toxic to the three species of *Frankliniella* tested and that differential toxicity of spinosad to *Frankliniella* spp. is probably not responsible for differences in relative species abundance between non-

TABLE 2. PARAMETERS OF REGRESSIONS (LOG-PROBIT MODEL) AND PREDICTED VALUES DESCRIBING SPINOSAD TOXICITY TO *FRANKLINIELLA* SPP.

	F. occidentalis	*F. tritici*	*F. bispinosa*
R-Squared (%)	76.35	74.96	85.50
Probability Level	< 0.00001	< 0.00001	< 0.00001
Slope (SE)	0.437 (0.040)	0.368 (0.035)	0.383 (0.026)
Intercept (SE)	0.227 (0.132)	0.427 (0.115)	0.124 (0.085)
LC_{10} (µg/ml)	0.032	0.0096	0.025
95% Confidence Limits	0.0097 - 0.075	0.0022 - 0.028	0.011 - 0.051
LC_{50} (µg/ml)	0.594	0.31	0.72
95% Confidence Limits	0.293 - 1.09	0.14 - 0.61	0.44 - 1.13
LC_{90} (µg/ml)	11.19	10.18	20.59
95% Confidence Limits	6.07 - 23.03	5.47 - 20.95	12.73 - 35.93
LC_{99} (µg/ml)	122.50	173.98	315.96
95% Confidence Limits	53.80 - 368.86	72.72 - 568.82	156.89 - 760.15

treated and spinosad-treated field plots (J. E. F., J. S., and S. M. Olson, unpublished data). Field rates of spinosad that have demonstrated activity against *Frankliniella* spp. (75-100 g ai/ha) will result in concentrations of 50-200 ppm of spinosad in normal application volumes. Although laboratory results may not translate directly to field activity, these concentrations exceed concentrations needed to provide greater than 90% mortality of all three species based on our bioassay. Differences in species abundance in spinosad-treated field plots may thus be due to factors other than differential toxicity (e. g., migration or competition).

Populations of *F. occidentalis* have been shown to have multiple resistance mechanisms and have developed cross-resistance to insecticides within the same chemical group and to those in other classes (Zhao et al. 1995). Consequently, alternating insecticides from different classes with different modes of action as a sole resistance management tactic poses risks. Insecticide selection pressure can be minimized by using noninsecticidal methods in conjunction with carefully selected insecticides used only when needed. The efficacy of spinosad demonstrated in our research reported here, combined with its compatibility with the key natural enemy of flower thrips, make it a potentially important tool for integrated pest management programs. Further, the baseline knowledge of spinosad toxicity reported here will help to develop a resistance monitoring program to determine the effectiveness of integrated pest management programs in minimizing resistance development.

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SUMMARY

A bioassay technique was developed and used to determine the toxicity of spinosad to three species of *Frankliniella*: *F. bispinosa*, *F. occidentalis*, and *F. tritici*. Dose response curves for the three species were similar and regressions of dose/mortality data were highly significant (R^2 = 75-85%, P < 0.00001 for all species). 95% confidence intervals around LC_{10}, LC_{50}, LC_{90} and LC_{99} values for the three species overlapped, suggesting that there were no significant differences among the three species tested.

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