Research Article

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Mortality and reproductive effects of ingested spinosad on adult bollworms

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Abstract

BACKGROUND: Upon emergence from their pupal cells, bollworm, *Helicoverpa zea* (Boddie), adults actively seek and feed on plant exudates before they disperse and reproduce on suitable host plants. This nocturnal behavior of the bollworm may be exploited as a pest management strategy for suppression of the insect by using an attractant/stimulant mixed with an insecticide to induce feeding to cause adult mortality or reproductive reduction/inhibition. This study aimed to determine in the laboratory whether or not spinosad when mixed with sucrose solution as a feeding stimulant and ingested by bollworm could influence mortality and reproduction of the insect.

RESULTS: Sublethal concentrations of spinosad fed to laboratory-reared females confined with males significantly reduced percentage hatch of eggs at 0.1 mg L^{-1}, and it was reduced to near zero at 2.5 mg L^{-1} when compared with females fed 2.5 M sucrose solutions only. The lethal concentration (LC_{99}) for males captured from the field in sex-pheromone-baited traps was 73 mg L^{-1} for 24 h response. Proboscis extension response was not inhibited significantly even at 10 g L^{-1}. In spite of a 137-fold increase in lethal dose concentration, spinosad did not inhibit feeding.

CONCLUSION: A detailed study of laboratory-reared and field-collected bollworm adults relative to mortality and reproduction after ingestion of spinosad indicates that spinosad would be useful in an attract-and-kill strategy to control the insect when mixed with a feeding attractant/stimulant. Field validation of the data is warranted.
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Keywords: spinosad; attract-and-kill; *Helicoverpa zea*; bollworm; corn earworm; adult control

1 INTRODUCTION

Spinosad, a metabolite of *Saccharopolyspora spinosa* Mertz and Yao, is the active ingredient in Tracer®, a 'Naturalyte' insect control product that comprises two macrocyclic compounds, spinosyn A and spinosyn D.[1] It is both a contact and stomach poison for many caterpillar species and was registered in the United States in 1997 for use on cotton. Spinosad has low mammalian and environmental toxicity, with reduced risk to wildlife compared with traditional insecticides.[2,3] It has also been formulated as Entrust™ for use in organic production (Dow AgroSciences). In a season-long study, it was reported that cotton treated with spinosad was found to have fewer damaging larvae and higher numbers of beneficial insects compared with cotton treated with conventional pesticides.[4]

The nocturnal and the post-emergence behavior of the bollworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), is to seek food as soon as it emerges from its pupal cells.[5] This nocturnal behavior of the adult could be utilized by developing a feeding attractant that could be used to attract adults to an area treated with a feeding stimulant and toxicant mixture. The adults would be induced to feed and thus cause mortality of the insect. Several authors have identified a number of feeding attractants for several noctuid species of Lepidoptera in the United States.[6–10] Recently, researchers have developed an attracticide for old-world bollworm, *Helicovera armigera* (Hübner), moths in Australia that is based on plant volatile compounds.[11,12]

In a field study, *H. zea* suffered major mortality upon emergence when they fed on thiodicarb-baited sorghum–water mixture banded around corn.[13] In the Coastal Plains of Texas, it is estimated that a million *H. zea* moths would be killed in corn fields by treating one row width approximating 1 ha area with 20 g methomyl using 190 L of a sucrose-syrup-based feeding stimulant.[14] In a laboratory study, sublethal concentrations of emamectin benzoate mixed with 2.5 M sucrose solutions ingested by female *H. zea* moths significantly reduced larval hatch of eggs and significantly impacted upon the survival of larvae to the pupal stage, and killed the adults at higher concentrations.[15]

The objective of the research reported here was to evaluate spinosad as the toxicant in a feeding stimulant formulation. The authors sought to characterize the effect of spinosad on toxicity, proboscis extension, gustation, reproduction and survival of the progeny when it is provided in a feeding stimulant solution to the adult bollworm.

2 MATERIALS AND METHODS

2.1 Test solutions

Samples of spinosad 480 g L^{-1} SC (Tracer™) were obtained from Dow AgroSciences, Indianapolis, Indiana. The appropriate amount

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of spinosad SC was added to 100 mL of a feeding stimulant solution containing 2.5 M sucrose (Sigma Chemical Co., St Louis, MO) to give a 10 g AI L^{-1} stock solution. This stock solution was used to prepare all other test solutions by appropriate dilution with the feeding stimulant solution. Test results were expressed as mg L^{-1}. All test solutions were refrigerated after mixing and warmed to room temperature with warm tap water before testing.

2.2 Test insects

2.2.1 Field

All bollworm moths used in the feeding response and toxicity studies were feral males captured in pheromone-baited traps. Wire cone traps[16] baited with zealure (Hercon Environmental, Emigsville, PA) were located close to corn, cotton or sorghum fields in an agricultural area of the Brazos River Valley in Burleson County, southwest of College Station, Texas. Only males captured during the previous night were used in the study. The males were collected early in the morning and placed in a screened cage in an outdoor insectary, and were fed by providing deionized-water-soaked sanitary napkins.

2.2.2 Laboratory

Bollworm moths used to determine the effects of spinosad at sublethal concentrations on reproduction were reared in the laboratory at 26.6±2 °C and 14 : 10 h light : dark photoperiod. Eggs were obtained from the USDA-ARS, Southern Insect Management Laboratory, Stoneville, Mississippi, by overnight express mail. Larvae hatching from eggs were placed on an artificial diet (Stonefly *Heliothis* diet, Ward's Natural Science, Rochester, NY) in 22.5 mL soufflé cups with a plastic lid (SOLO Cup Co., Urbana, IL). After pupation, the insects were sexed and placed separately in 4 L glass jars for emergence. Only moths that emerged the previous night were used in the study.

2.3 Toxicity determination

Two tests were conducted to assess the toxicity of spinosad to the bollworm. Test 1 was used to determine LC values for 24 and 48 h responses. In test 1, males were fed spinosad for 30 min to satiation with continuous teasing of proboscides. Each group of ten males was placed in a 1 L glass jar without food and checked after 24 and 48 h for mortality. Males were considered dead when they could not get on their feet after they were forced on their backs. At least five replicates of ten males per replication per each concentration were evaluated. In test 2, bollworm moths were fed various concentrations of spinosad (1.0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0 and 20.0 mg L^{-1}) and were compared with control insects that ingested 2.5 M sucrose solutions only. With the calculation of LC values, mean lethal time was determined by feeding 15 feral bollworm males at 73 mg L^{-1} (1 × LC_{99}), 365 mg L^{-1} (5 × LC_{99}), 730 mg L^{-1} (10 × LC_{99}), 1825 mg L^{-1} (25 × LC_{99}) and 7300 mg L^{-1} (100 × LC_{99}) (see Table 1 for the determination of 73 mg L^{-1} as LC_{99}). Each adult was placed individually in a sealed plastic soufflé cup after feeding, and was observed for mortality at 15, 30 and 45 min and every hour during a 6 h period. Thereafter, the males were checked twice at 24 h intervals. The mid-point of the interval during which the adults were considered dead was used in calculations.

2.4 Proboscis extension response

The methods used to determine the proboscis extension response were similar to those described earlier.[17,18] Briefly, they comprised holding a moth with the index finger and the thumb and touching the front tarsi to the test solutions in a porcelain multiwell plate by raking the front legs across it while avoiding contact of other body parts with the solution. The proboscis extension response was evaluated soon after sunset in an insectary under red light using feral males captured in pheromone-baited traps. The test concentrations comprised spinosad at 1, 10, 100, 1000 and 10 000 mg L^{-1}. Each concentration was replicated 10 times, with ten moths in each replication. If the proboscis was completely elicited a positive response was recorded, and if no elicitation of proboscis occurred a zero response was recorded. Partial responses that did not result in contact of the proboscis with the test solution were considered a zero because the moth could not have fed on the solution.

Table 1. Toxicity of spinosad (mg L^{-1}) when mixed with 2.5 M sucrose and ingested by male bollworm captured in pheromone-baited traps[a]

	Number of hours after feeding	
Probit statistics	24	48
Slope (± SEM)	1.99 ± 0.18	2.12 ± 0.19
χ^2	4.00 (6) ns	6.79 (6) ns
LC_{10}	1.13 a	0.63 a
95% CL	(0.76–1.49)	(0.33–0.95)
LC_{50}	4.96 a	2.52 b
95% CL	(4.29–5.67)	(1.91–3.11)
LC_{90}	21.83 a	10.13 b
95% CL	(17.35–29.84)	(8.11–13.80)
LC_{99}	73.06 a	31.45 a
95% CL	(49.23–127.43)	(21.22–57.79)

[a] LC values within each row followed by the same lower-case letter are not significantly different based upon lack of overlap in 95% confidence limits. ns = not significant at P = 5% (POLO PC).

2.5 Feeding response

Gustatory response was determined by the amount of each test solution ingested by individual males. The word gustatory is used because of the lack of a more suitable term that represents ingestion in most adult Lepidoptera. Males were placed in an apparatus equipped with alligator clips to hold the wings in a vertical position (Fig. 1). Test solutions in 0.5 mL disposable centrifuge tubes were provided to each insect, and, if the males did not extend the proboscis upon contact, the proboscis was teased with an insect pin to initiate feeding. Males were allowed to feed until satiation for at least 30 min. Test solutions were weighed on an electronic balance (model A-200DS; Denver Instrument Co., Denver, CO) before and after feeding. Extra tubes on which males did not feed were used to correct the difference between before and after feeding loss due to evaporation. At least ten males were tested on each concentration of spinosad.

2.6 Reproductive effects

One-day-old laboratory-reared females were fed spinosad using procedures described for the gustatory response, and the amount of test solution ingested by each female was determined. Each female was paired with a male, and they were placed in a 1 L glass jar capped with paper toweling at the top and paper toweling strips provided for the moths to climb and deposit eggs. A dental

Figure 1. Feeding apparatus used to conduct gustatory response studies of *Helicoverpa zea*.

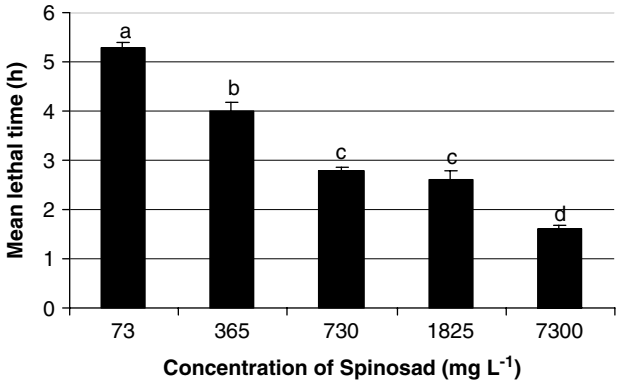

Figure 2. Mean lethal time (in hours) for feral male bollworms ingesting spinosad mixed with 2.5 M sucrose solutions.

wick inserted into a 10% sucrose solution through a hole on the plastic lid of a Solo cup was provided for the moths as a feeding solution. Starting with the second day, and for three consecutive days thereafter, the eggs were counted after moving the moths to a clean jar along with the food cup. To determine larval hatch, eggs deposited on the paper toweling were sampled by cutting off pieces of paper towel containing about 25–30 eggs. Pieces of paper toweling containing the eggs were placed in a Solo cup, capped and examined for three consecutive days for larval hatch. At the end of each test, or in the middle of the test if the females died or were in copula, females were dissected to determine the number of spermatophores in the bursa copulatrix. Eggs from unmated females were not used to determine larval hatch.

Four tests were conducted to determine the effect of ingestion of spinosad by female bollworm on larval hatch of eggs. Test 1 comprised concentrations of spinosad at 0.05, 0.1, 0.25, 0.5 and 1 mg L^{-1}, and in test 2 the concentrations of spinosad were broadened to include 0.01, 0.25, 1.00 and 2.5 mg L^{-1}. In test 3, five laboratory-reared females were fed concentrations of spinosad at 0.5 and 1 mg L^{-1}, and five pheromone-baited trap-captured males were fed 2.5 M sucrose solutions and were released inside a 6 × 2 × 2 m cage established in a cotton field, and replicated 3 times. From 24 h thereafter, daily samples of ca 25 *H. zea* eggs were collected for five consecutive days from each cage and held in the laboratory in a soufflé cup for larval hatch. Test 4 was conducted to determine the effect of ingestion of spinosad by male bollworm. In test 4, the male bollworms were fed spinosad concentrations of 0.01, 0.04, 0.1, 0.4 and 1.0 mg L^{-1} and were paired with female bollworms that ingested 2.5 M sucrose solutions only. Tests 1, 2 and 4 were conducted in the laboratory.

During each egg viability check in tests 1 and 2, a minimum of ten larvae in each concentration in each replication were reared to the pupal stage on insect diet (Section 2.2). Approximately 3 weeks after the placement of the larvae on the diet, each soufflé cup was examined for the presence of pupae. Pupae were washed, sexed and counted.

2.7 Data analysis

Analyses of variance of the data were conducted using PROC GLM procedures.[19] Significant mean values were separated using Tukey's Studentized range test (HSD) at the 5% level, except on one occasion when the *F*-value was significant at the 10% level. Lethal concentration (LC) values were determined using POLO software.[20] Significant difference in LC values was determined on the basis of the lack of overlap in CL values at the 95% level. The non-parametric PROC NPAR1WAY procedure was used to determine whether the ingestion of spinosad by bollworm females influenced survival of larvae to the pupal stage. The bar graph relative to the percentage survival of larvae to the pupal stage is shown in lieu of Wilcoxon scores. The Kruskal–Wallis test is also shown.

3 RESULTS AND DISCUSSION

3.1 Mortality

For feral male bollworms captured in pheromone-baited traps, the dosage mortality equation was consistent with the probit model for 24 and 48 h responses with $\chi^2 = 4.00$ and 6.79 and df = 6 for 24 and 48 h responses respectively (Table 1). The χ^2 values were less than the tabular values for appropriate degrees of freedom. The LC_{50} (95% CL) values for feral males were 4.96 (4.29–5.67) and 2.52 (1.91–3.11) mg L^{-1} for 24 and 48 h responses respectively. These values were significantly different from each other, which suggests that some moths took 48 h to die. This is in agreement with a report from Australia that spinosad produced very high mortality of *H. armigera* but moths took much longer to die.[21] The LC_{90} (95% CL) values for feral males were 21.83 (17.35–29.84) and 10.13 (8.11–13.80) mg L^{-1} for 24 and 48 h responses respectively. These values were significantly different from each other. Based upon the LC_{10} values for 24 and 48 h responses, it appears that the sublethal dose for spinosad is likely to be near 1 mg L^{-1}.

The mean lethal time varied significantly between concentrations ($F = 61.31$; df = 4, 69; $P < 0.0001$). The mean lethal time was 5.3 h (1 × LC_{99}), 4 h (5 × LC_{99}), 2.8 h (10 × LC_{99}), 2.6 h (25 × LC_{99}) and 1.6 h (100 × LC_{99}) (Fig. 2). The relationship between mean lethal time and concentrations of spinosad was inverse. The mean lethal time at 73 mg L^{-1} was significantly different from that at 365 mg L^{-1}. The mean lethal times at 730 and 1825 mg L^{-1} were comparable. Spinosad at 7300 mg L^{-1} caused the quickest mortality of bollworm at 1.6 h. The optimum spinosad dose to cause the quickest mortality appears to be near 730 mg L^{-1}. This is an important consideration when evaluating adult mortality in the field, because, the longer it takes an adult to die, the more time it has to disperse from the treated area.

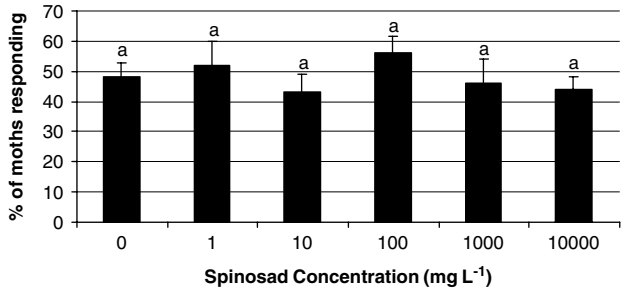

Figure 3. Proboscis extension response of male bollworm to 2.5 M sucrose solution and various concentrations of spinosad mixed with the sucrose solution.

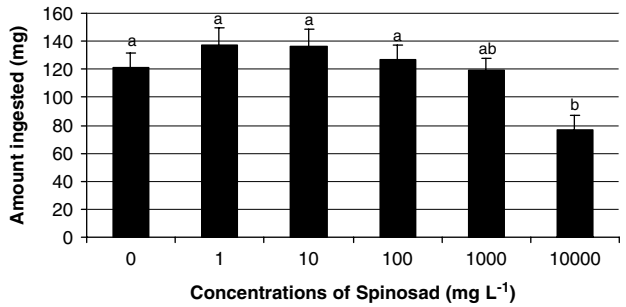

Figure 4. Gustatory response by laboratory-reared females fed 2.5 M sucrose solutions and various concentrations of spinosad mixed with 2.5 M sucrose solutions.

3.2 Proboscis extension

The concentrations of spinosad did not significantly influence the proboscis extension response of bollworm ($F = 0.60$; df = 5, 53; $P > 0.05$). There was no significant negative response to the toxicant solution with respect to proboscis extension even up to 10 g L^{-1} (Fig. 3). This is significant because feeding initiation will not occur without extension of the proboscis. That the bollworm can initiate feeding activity on spinosad/sugar solutions even at 137 × LC_{99} is noteworthy and significant.

3.3 Gustatory response

The concentration of spinosad significantly influenced gustatory response of bollworm ($F = 4.46$; df = 5, 108; $P < 0.001$). There was no significant difference in ingestion of spinosad up to 1 g L^{-1} when compared with moths fed 2.5 M sucrose alone (Fig. 4). Bollworms ingested significantly less spinosad at 10 g L^{-1} compared with 100 mg L^{-1}, but there was no significant difference in ingestion of spinosad between 1 and 10 g L^{-1}.

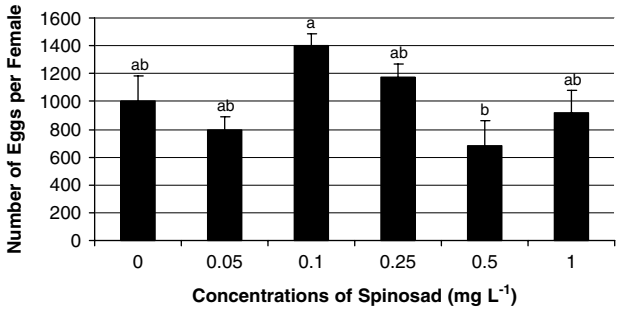

Figure 5. Egg deposition by laboratory-reared females that ingested 2.5 M sucrose solution alone and various concentrations of spinosad mixed with the sucrose solution.

3.4 Fecundity

Spinosad significantly influenced the fecundity of females compared with those females that ingested 2.5 M sucrose solutions alone ($F = 2.91$; df = 5, 27; $P < 0.05$). Figure 5 shows that ingestion of spinosad at 0.1 mg L^{-1} resulted in significantly greater egg deposition compared with bollworm females that ingested spinosad at 0.5 mg L^{-1}. There was no significant difference in fecundity between bollworm females that ingested spinosad at 0.1 mg L^{-1} compared with females that ingested 2.5 M sucrose solution only. Nevertheless, there was no consistent trend in oviposition rate between treatments (Fig. 5).

3.5 Larval hatch

In test 1, the concentrations of spinosad and days of evaluations significantly influenced the larval hatch of eggs when females were fed spinosad, and compared with females fed 2.5 M sucrose solution ($F = 45.00$; df = 5, 239; $P < 0.0001$ for concentrations of spinosad and $F = 14.44$; df = 2, 239; $P < 0.0001$ for days of evaluations). There was no significant interaction between concentrations of spinosad and days of evaluation. When eggs deposited for all 3 days were pooled, larval hatch was similarly reduced significantly ($F = 33.53$; df = 1, 43; $P < 0.0001$). The percentage larval hatch was significantly depressed at 0.1 mg L^{-1} through all 3 days of evaluation when compared with moths fed 2.5 M sucrose solution alone (Table 2). At 1 mg L^{-1}, less than 10% of larval hatch occurred at day 2 and day 3 and when all three days of evaluations were pooled. Similarly, in test 2,

Table 2. Mean percentage larval hatch of eggs deposited by female bollworm after ingesting various concentrations of spinosad mixed with 2.5 M sucrose solution[a]

Spinosad concentration (mg L^{-1})	Mean larval hatch (%) (± SEM)			
	Day 1	Day 2	Day 3	Total
0	83.8 (±2.1) a	85.5 (±2.3) a	86.7 (±2.1) a	85.18 (±2.0) a
0.05	66.9 (±3.7) ab	37 (±5.6) b	41.3 (±5.3) b	48.1 (±4.2) b
0.1	55.0 (±4.5) b	41.6 (±4.6) b	44 (±4.8) b	47 (±4.2) b
0.25	54.3 (±4.3) b	18.6 (±4.0) c	19.4 (±3.8) c	32 (±3.5) c
0.5	32.2 (±3.8) c	20.5 (±4.1) c	10.3 (±3.1) c	20.8 (±2.9) c
1	18.1 (±4.0)c	4.8 (±1.2) c	4.4 (±1.6) c	8.2 (±1.4) d

[a] Means within each column followed by the same lower-case letter are not significantly different ($P > 0.05$) according to Tukey's HSD test.

Table 3. Mean percentage larval hatch of eggs deposited by female bollworm after ingesting various concentrations of spinosad mixed with 2.5 M sucrose solution[a]

Spinosad concentration (mg L^{-1})	Mean larval hatch (%) (± SEM)			
	Day 1	Day 2	Day 3	Total
0	81.2 (±3.2) a	72.7 (±9.8) a	70.6 (±9.5) a	86.8 (±1.4) a
0.01	69.2 (±9.0) a	47.6 (±12.4) ab	54.4 (±12.6) a	48.6 (±9.6) a
0.25	54.2 (±9.9) ab	33.9 (±6.9) bc	16.2 (±3.9) b	35.9 (±6.9) b
1.00	44.1 (±4.8) bc	0.83 (±0.43) c	12.4 (±4.4) b	22.6 (±5.1) bc
2.5	0.0 (±0.0) c	0.0 (±0.0) c	3.6 (±1.6) b	1.2 (±0.53) c

[a] Means within each column followed by the same lower-case letter are not significantly different ($P > 0.05$) according to Tukey's HSD test.

concentrations of spinosad and days of evaluations significantly influenced larval hatch of eggs ($F = 12.52$; df = 4, 35; $P < 0.0001$ for concentrations of spinosad and $F = 2.47$; df = 2, 35; $P < 0.1$ for days of evaluations). The larval hatch at 1 mg L^{-1} was significantly different from that of moths fed 2.5 M sugar solutions only during all three days of evaluations, and larval hatch was reduced to zero at day 1 and day 2 at 2.5 mg L^{-1} (Table 3).

Similarly to the results of tests 1 and 2, larval hatch of eggs was significantly depressed in test 3 when female bollworms were released inside a 6 × 2 × 2 m cage ($F = 7.48$; df = 2, 11; $P > 0.01$). Spinosad significantly depressed larval hatch of eggs at 1 mg L^{-1} compared with the moths fed 2.5 M sucrose solutions (Fig. 6). There was no significant difference in larval hatch between 0.05 and 1 mg L^{-1}.

When male bollworms were fed various concentrations of spinosad and were paired with female bollworms that ingested 2.5 M sucrose solutions, there was no significant difference in larval hatch between treatments ($F = 0.71$; df = 5, 37; $P > 0.05$) (Table 4).

3.6 Mating frequency

There was no significant difference in the number of spermatophores per female between treatments in tests 1 and 2 ($F = 1.07$; df = 5, 105; $P > 0.05$ for test 1 and $F = 0.08$; df = 4, 24; $P > 0.05$ for test 2). Nonetheless, multiple mating with four spermatophores per female was common in both tests, and mating frequency reached as high as 5 or 6× in both tests.

3.7 Survival of pupae

The relationship between larval survival to the pupal stage and the concentrations of spinosad is shown in Fig. 7. Spinosad significantly influenced larval survival to the pupal stage (Npar1way procedure: $F = 16.83$; df = 5, 82; $P < 0.0001$; Kruskal–Wallis test: $\chi^2 = 37.51$; df = 5; $P < 0.0001$). Also, the ingestion of spinosad significantly impacted upon the survival of female and male pupae (Npar1way procedure: female pupae – $F = 12.71$; df = 5, 82; $P < 0.0001$; Kruskal–Wallis test: $\chi^2 = 31.43$; df = 5; $P < 0.0001$; male pupae – $F = 13.47$; df = 5, 82; $P < 0.0001$; Kruskal–Wallis test: $\chi^2 = 34.71$; df = 5; $P < 0.0001$).

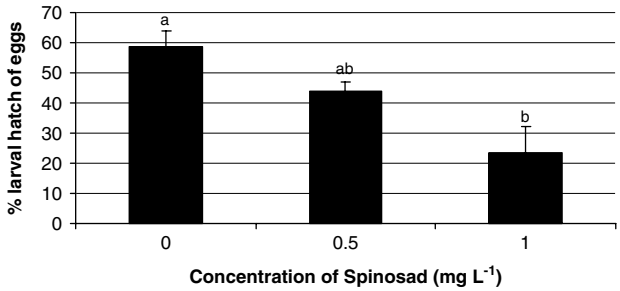

Figure 6. Mean percentage larval hatch of eggs deposited on cotton foliage by laboratory-reared females fed 2.5 M sucrose solution and concentrations of spinosad at 0.5 and 1 mg L^{-1} and released inside a 6 × 2 × 2 m cage.

4 CONCLUSION

Data presented in this report demonstrate that spinosad has excellent potential for use in the development of a behavior-based pest management alternative for suppression of bollworm in field crops. The less aggressive nature and environmental compatibility

Table 4. Mean percentage larval hatch of eggs deposited by female bollworm ingesting 2.5 M sucrose solution and paired with male bollworm fed various concentrations of spinosad mixed with 2.5 M sucrose solution[a]

Spinosad concentration (mg L^{-1})	Mean larval hatch (%) (± SEM)			
	Day 1	Day 2	Day 3	Total
0	62.8 (±11.5) a	79.6 (±11.9) a	72.3 (±11.5) a	71.2 (±10.9) a
0.01	61.1 (±14.2) a	71.4 (±15.8) a	53.9 (±14.5) a	62.1 (±14.1) a
0.04	66.5 (±11.4) a	73.2 (±13.8) a	62 (±14.4) a	72.4 (±10.7) a
0.1	37.1 (±13.6) a	60.3 (±16.5) a	70.5 (±9.7) a	55.4 (±5.1) a
0.4	50.4 (±18.2) a	82.7 (±9.5) a	85.9 (±2.5) a	74.7 (±7.6) a
1	67.3 (±7.4) a	91.1 (±2.5) a	67.1 (±13.7) a	75 (±5.0) a

[a] Means within each column followed by the same lower-case letter are not significantly different ($P > 0.05$) according to Tukey's HSD test.

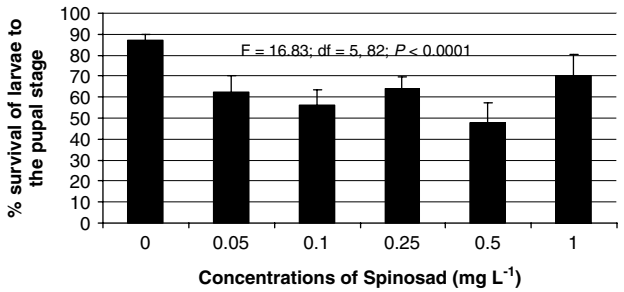

Figure 7. Relationship between survival of larvae to the pupal stage when female bollworms were fed 2.5 M sucrose solutions and various concentrations of spinosad mixed with the sucrose solution (Npar1way procedure).

of spinosad have been reported by several authors.[3,4,22] Combined with such desirable attributes, spinosad requires an extremely low amount of active ingredient to kill 99% of the bollworm population (LC_{99} = 73 mg L^{-1}). Furthermore, a sublethal concentration of 2.5 mg L^{-1} spinosad is capable of reducing the larval hatch of eggs to near zero. It is expected that for wild female populations the amount of spinosad required to depress larval hatch of eggs to near zero is likely to be higher than 2.5 mg L^{-1}.

Several authors have reported that spinosad bait sprays (GF-120) have significantly reduced Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), and Caribbean fruit fly, *Anastrepha suspensa* (Loew),[23] apple maggot, *Rhagoletis pomonella* (Walsh),[24] blueberry maggot, *R. mendax* (Curran),[25] and melon fly, *Bactrocera cucurbitae* (Coquillett).[26] Recently it was reported that, although GF-120 sprays significantly reduced the number of fruit fly pupae in mango, *Mangifera indica* L., orchards in Benin, West Africa, the efficacy of such sprays was limited by rainfall which washed away and reduced its effectiveness.[27] Regardless of rainfall, the spinosad ingested by the bollworm not only causes reduction in reproduction but also dampens the survival of the progeny. Nonetheless, spinosad being washed off when mixed with a feeding stimulant is a limiting factor that should be addressed under field conditions.

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DISCLAIMER

Mention of a commercial or property product does not constitute an endorsement for its use by the US Department of Agriculture.

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