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SHORT COMMUNICATION

Induced Resistance Studied in Maize with the Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) and the Chemical Inducer Actigard®

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Induced resistance has been defined as the "qualitative or quantitative enhancement of a plant's defense mechanisms against pests in response to extrinsic physical or chemical stimuli." (Kogan and Paxton, 1983). Physical stimuli can include infection by a pathogenic organism (Jorgensen *et al.*, 1996; Morris *et al.*, 1998) and feeding by insects (Felton and Eichenseer, 1999). Chemical stimuli include such organic compounds as salicylic acid (Hammerschmidt and Smith-Becker, 1999), jasmonic acid (Staswick and Lehman, 1999), and the commercially available Actigard® 50WG (Tally *et al.*, 1999) (Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC 27419). Actigard® 50WG is registered in the U.S. to protect tomatoes, spinach and tobacco from fungal and bacterial pathogens. Srinivas *et al.* (2001a) showed that Actigard® did induce resistance in soybean to adult feeding of the bean leaf beetle, *Cerotoma trifurcata* (Forster) (Coleoptera: Chrysomelidae). However, Inbar *et al.* (2001) concluded that the active ingredient (i.e., BTH) in Actigard® had a negligible effect on whiteflies, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) and the cotton bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae), in cotton.

Documentation of induced resistance against insect herbivores has a relatively short history (Karban and Kuc, 1999). The direct effects of induced resistance against insect herbivores have been shown in tomato, *Lycopersicon esculentum* Miller (Solanaceae) (Thaler, 1999), cotton, *Gossypium hirsutum* L. (Malvaceae) (Karban and Carey, 1984), soybean, *Glycine max* (L.) (Leguminosae) (Lin *et al.*, 1990), and a number of other crops (Karban and Baldwin, 1997).

A few studies have been published documenting an induced response in maize, *Zea mays* L. (Graminae), to fungal pathogens such as *Helminthosporium carbonum* (Ullstrup) and *Puccinia sorghi* (Schw.) (Cantone and Dunkle, 1990; Morris *et al.*, 1998). Morse *et al.* (1991) showed that mechanical crushing damage to maize leaves similar to that of certain insects with chewing mouthparts did result in reduced aphid growth rates and dramatically lower aphid survival when corn leaf aphids fed on the plants subsequent to the initial mechanical damage. Turlings *et al.* (1993, 1995, 1998) conducted several studies on maize and showed a response to herbivore feeding that attracted parasitoids to the plant in its defense.

The studies reported here were conducted to determine if an induction response can be shown in maize to fall armyworm larvae during the seedling to early vegetative growth stages as a response to initial feeding by the fall armyworm and/or treatment by the chemical inducer Actigard® 50WG.

Materials and Methods

Three studies were conducted in the greenhouse of the Department of Agronomy and Horticulture of the University of Nebraska at Lincoln, Nebraska during 2000. Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), larvae for these studies were obtained from French Agricultural Research, Inc., RR 2, Box 294, Lamberton, MN 56152-9536. Growth stages of maize are according to Ritchie and Hanway (1982).

INDUCED RESISTANCE: These studies were conducted using Pioneer Hybrid 33P66 (Pioneer Hi-Bred International, Inc., 400 Locust Street, Suite 800, P.O. BOX 14453, Des Moines, IA 50306-3453). Four seeds were planted per 6 inch pot and the two treatments were replicated ten times in a completely randomized experimental design. Four 1st instar larvae were placed on each plant at V2 stage in half of the pots. At this time, all pots were covered with cylindrical cages constructed of Lexan® MR10 Sheet (General Electric Company, One Plastics Avenue, Pittsfield, MA 01201-3697) to confine the larvae to the plants intended to be infested and to treat all plants similarly. The larvae were allowed to feed on the plants for 24 hr and then removed. The plants were then allowed to grow one (V2 stage) and two weeks (V3 stage) until bioassays were conducted. Leaf disks 12 cm in dia. were removed from the first fully expanded leaf of each of the plants, the leaf area of the disks was measured using a LI-

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Table 1. Consumption of maize foliage by fall armyworm 4th instar larvae.

Treatment	Foliage consumed (cm^2) in 24 hr[a]	
	7 days post initial infestation date	14 days post initial infestation date
Initially damaged by herbivory	2.2b	1.2a
Not initially damaged by herbivory	3.2a	0.7b

[a] Means followed by the same letter are not significantly different ($P < 0.05$). Mean separations were by protected LSD.

COR 3100 Area Meter (Li-Cor, Inc., 4308 Progressive Ave., Lincoln, NE 68504), and the disks placed in a petri dish with a moist filter paper at the bottom. Each petri dish was then infested with one 4th instar larva. The larva was allowed to feed on the leaf disks for 24 hr, when the leaf disk area remaining was measured to determine the amount consumed.

ACTIGARD®-TREATED SEED: These studies were conducted using NC+ 3448 maize seed (NC+ Seeds, P.O. Box 4408, Lincoln, NE 68504) that had the following topically applied prior to planting: 1) Actigard® 50WG (Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC 27419) at 1.0 g ai/100 kg seed, 2) Actigard® 50WG at 2.5 g ai/100 kg seed, 3) Actigard® 50WG at 5.0 g ai/100 kg seed, 4) Actigard® 50WG at 7.5 g ai/100 kg seed, and 5) untreated. Four seeds were planted in each 6 inch pot and the five treatments were replicated five times in a randomized block experimental design. Each plant was infested with one 4th instar larva at the V2 growth stage. Larvae were confined to the seedlings with a Lexan® cylindrical cage and damage was rated using the rating scale developed by Wiseman *et al.* (1966) at 3 days and 5 days after infestation. This scale ranges from a rating of 0 when there is no visible damage to 10 when the plant is dead, dying, or almost completely destroyed.

ACTIGARD® FOLIAR TREATMENTS: These studies used Pioneer Hybrid 33P66. Four seeds were planted per 6 inch pot and the four treatments were replicated 12 times in a completely randomized experimental design. Actigard® 50WG was applied to V3 stage maize via a spray bottle to the point that runoff was occurring at the following rates: 0.0, 0.05, 0.5, and 5.0 mg a.i. Actigard® 50WG/ml of water carrier. Bioassays with leaf disks and one 4th instar larva per petri dish were conducted as described above except the larva was allowed to feed on the leaf disks for 24 hr 2 days and 8 days following treatment.

All statistical analyses were performed using ANOVA from PROC GLM (PROC GLM, SAS Institute 1990) and mean separations were conducted with the protected LSD.

Results and Discussion

INDUCED RESISTANCE: There were statistically significant differences in the consumption of maize foliage among plants that had and had not been previously fed on by fall armyworm larvae in this study (Table 1) ($F = 7.95$; d.f. = 1,17; $P = 0.0118$). This study indicates that fall armyworm larvae consumed less corn foliage from plants that had previously been damaged when the bioassays were conducted 7 days post initial infestation, however, these plants were more susceptible 14 days post initial infestation. This agrees with the findings of Underwood (1998) in studies on the timing of induced resistance and induced susceptibility with soybean and the Mexican bean beetle, *Epilachna varivestis* Mulsant (Coleoptera: Coccinellidae). She found that when induced resistance occurred, treated plants were initially more resistant than controls, then the resistance decayed, and then the same plants were more susceptible than the controls. A similar pattern of response was shown with the bean leaf beetle on soybean plants by Srinivas *et al.* (2001b).

ACTIGARD®-TREATED SEED: In this study, damage ratings were significantly lower when the plants had been treated with the 2.5 g a.i./100 kg rate of Actigard® 50WG at both 3 days and 5 days after infestation with fall armyworm larvae (Table 2) ($F = 7.45$; d.f. = 4,116; $P = 0.0052$ and $F = 4.32$; d.f. = 4,116; $P = 0.0448$). It is puzzling, however, that there was no significant effect when treatment rates were higher or lower than this and leads one to suspect a Type 2 statistical error.

ACTIGARD® FOLIAR TREATMENT: In this portion of the study, there were no significant differences in the amount of maize foliage consumed by fall armyworm larvae after feeding for 24 hr at intervals 2 days and 8 days post-treatment with Actigard® 50WG at foliar application rates of 0 to 5.00 mg a.i./ml of water ($F = 0.42$; d.f. = 3,44; $P = 0.7399$ and $F = 0.71$; d.f. = 3,41; $P = 0.5513$).

These results indicate that maize can be induced to resist defoliation by larvae of the fall armyworm by initial feeding by this insect. Seed treatment with the chemical inducer Actigard® did provide what appeared to be an induced response in plants grown from those seeds, but only at the one rate of application and not at higher or

Table 2. Fall armyworm larval damage to Actigard® 50WG seed-treated maize.

Actigard® 50WG treatment (a.i./100 kg seed)	Damage rating[ab]	
	3 days post-infestation	5 days post-infestation
Untreated	7.8a	8.8a
1.0 g	7.5a	8.8a
2.5 g	7.0b	8.3b
5.0 g	7.6a	8.9a
7.5 g	7.8a	9.1a

[a] Means followed by the same letter are not significantly different ($P < 0.05$). Mean separations were by protected LSD.

[b] Damage rating was 0 = no visible damage to 10 = plant dead, dying, or almost completely destroyed.

lower rates which leads one to question the validity of this result. Foliar applications of Actigard® did not provide an induced resistance response in this study. Future studies with maize should investigate the induced resistance phenomenon at other growth stages, with other chemical inducers, and/or with other insects.

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