Effects of Inherited Sterility and Insect Resistant Dent-Corn Silks on *Helicoverpa zea* (Lepidoptera: Noctuidae) Development[1]

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J. Entomol. Sci. 27(4):413-420 (October 1992)

ABSTRACT Male and female corn earworm, *Helicoverpa zea* (Boddie), adults were exposed to a substerilizing dose (10 krads) of gamma radiation after which their progeny were reared on a meridic diet containing selected concentrations of dry silk collected from resistant dent corn genotypes. Significant interactions were observed between the developmental time of progeny from irradiated females and progeny from normal parents and meridic diets with increasing degrees of resistance. A significant interaction also was observed between the mean larval weights of normal and substerile larvae and diets with increasing degrees of resistance. The 9-d weight of normal larvae was significantly higher than the weight of substerile larvae at the lowest degree of resistance, but differences between the weight of normal and substerile larvae at the highest degree of resistance were not significant. Larvae from irradiated male by normal female crosses were equally competitive with normal larvae for all measured parameters. Data from this study suggest that plant resistance and inherited sterility would be compatible control strategies for the management of *H. zea* populations.

KEY WORDS Insecta, corn earworm, F_1 sterility, integrated pest management, *Helicoverpa zea.*

The corn earworm, *Helicoverpa zea* (Boddie), is one of the most destructive pests of field crops in the United States. Annual agricultural losses and control costs can exceed $100 million in the southeastern United States alone (Sterling, 1983). The most successful control of *H. zea* has been the use of insecticides directed at the larval stage. However, larval resistance to insecticides and mounting concerns over air and ground water quality have encouraged scientists to seek alternative methods for controlling *H. zea.* Also, because insecticidal control of *H. zea* on corn, *Zea mays* L., and other early season hosts often is not economically justifiable, control strategies relying on biological and cultural control and host plant resistance sometimes are considered the most practical approaches in preventing seasonal population increases of *H. zea.* Area-wide suppression of *H. zea* may be the most desirable management approach, but success would necessitate the integration of various control strategies (Sparks, 1986).

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[1] Accepted for publication 22 July 1992.

The potential of inherited sterility as a component of area-wide management of *H. zea* was suggested by North and Holt (1971), Knipling (1979) and LaChance (1985). Studies by Carpenter et al. (1987c) demonstrated the effects of substerilizing doses of radiation and inherited sterility on *H. zea* reproduction. Carpenter et al. (1987a,b; 1989) and Carpenter and Gross (1989) demonstrated demonstrated that irradiated (10 krads) *H. zea* and their progeny were competitive with normal, laboratory-reared insects in their ability to survive under field conditions, to seek and secure mates, and to diapause. In addition, females mated to nonirradiated males and irradiated (10 krads) males had the same mating propensity and the same intermating interval.

The development and use of corn cultivars with high levels of resistance to *H. zea* could reduce the economic losses inflicted by the pest (Wiseman et al. 1984), as well as reduce the number of *H. zea* that complete development on corn and subsequently move to adjacent crops (Wiseman 1985, Wiseman and Widstrom 1986, Rogers 1989). Although resistance to *H. zea* has been identified in several crop species, some of the highest levels of resistance known in corn have been found in the silks of cv. 'Zapalote Chico' (Straub and Fairchild 1970, Wiseman et al. 1976, 1977, 1978). Several studies have confirmed the influence of plant resistance on predation (Isenhour et al. 1989), parasitization (Pair et al. 1986, Isenhour and Wiseman 1989), and microbial control (Hamm and Wiseman 1986) of *H. zea* and other pest species on corn. However, no information is available on the compatibility of plant resistance and an autocidal control strategy, such as inherited sterility, in controlling *H. zea*. Therefore, studies were conducted to define the relationship between plant resistance and inherited sterility that may impact successful integration of these strategies for management of *H. zea*.

Materials and Methods

H. zea adults were obtained from a colony maintained on pinto bean diet (Burton 1969) at the Insect Biology and Population Management Research Laboratory, Tifton, GA. Normal (N) moths and moths exposed to 10 krads (Carpenter et al. 1987c) were used to produce the substerile (T) males and females from which progeny were obtained for use in this study. After radiation, 10 pairs of moths of each cross (T × T, T × N, N × T) were held in 3.79 l cages for mating and egg production. Neonate larvae that emerged from eggs that were deposited on the second night of moth confinement were used for establishing infestations on diets. Normal neonate larvae were obtained from N×N crosses of moths obtained from the laboratory colony.

Zapalote Chico 2451#(P)C3 (ZC), a dent corn with silk and ear resistance to feeding by larvae of *H. zea* (Wiseman and Widstrom 1986) was selected for use in this study. The cultivar was planted in single-row plots, 6.1 m long and 0.76 m apart, at Tifton, Ga., in 1989, and maintained using accepted agronomic practices common to the area. Silks that had emerged within the previous 48 h were excised at the tip of the ear, bulked, oven-dried at 41°C for about 10 days, ground to a fine powder (1 mm screen) using a Cyclotec TC1093® (Fisher Scientific, Atlanta, GA) sample mill, and stored in a freezer at -10°C. Concentrations of 0, 15, and 30 mg silk/ml diet were mixed in a diluted (300 ml pinto bean diet : 120 ml distilled water) diet for bioassay (Wiseman and Isenhour 1989). Ten ml of the silk-pinto bean diet mixtures were dispensed into each of thirty 30-ml plastic diet cups and allowed to solidify for about 2 h. One neonate larva was then placed in each cup, and the cup was capped with a paper lid.

The experiment was arranged as a split-split-plot design with 15 replications and maintained at a 14:10 (L:D) photoperiod and 70 ± 5% RH. Whole plots were constant temperature regimes of 22 and 27 ± 2°C. Subplots were concentrations of silk per diet-mixtures, and the final split was insect genotypes of N×N, T×N, N×T, and T×T.

Data recorded were weight of larvae at 9 d, development time in days, weight of pupae, and time from egg hatch to adult eclosion. Data were analyzed as replicate means by General Linear Models Procedure, and significantly different means were separated by *t*-test (SAS Institute 1985) or the Waller-Duncan (1969) k ratio *t*-test, k = 100, $P \leq 0.05$.

Results and Discussion

A significant three-way interaction occurred among the weight of 9-d normal and substerile larvae, concentration of Zapalote Chico silk-pinto bean diets, and temperature (Table 1). The weight of 9-d larvae was lower at 22°C than at 27°C. An increase in the concentration of silk/ml diet significantly reduced the mean weight of 9-d larvae from each parental cross at both 22° and 27°C. However, at 22°C, significant differences were observed only for N×N and T×T larvae between the 0-15 mg/ml concentrations. The mean weight of 9-d N×N larvae was significantly higher than the mean weight of 9-d T×N larvae when they were reared on diet with 0.0 mg/ml at 22°C. When larvae were fed on pinto bean diet with 0-15 mg silk/ml of diet at 27°C, the mean weight of 9-d normal larvae was significantly higher than the mean weight of 9-d substerile larvae.

There was a significant three-way interaction among the mean developmental time for normal and substerile larvae that fed on silk-pinto bean diet with 0, 15, and 30 mg Zapalote Chico silk/ml diet at 22 and 27°C (Table 2). The developmental time for all larvae was significantly longer at 22°C than at 27°C. Each increase in the concentration of Zapalote Chico silks/ml of diet resulted in a significant increase in the developmental time for all except T×T larvae fed on pinto beans diets with 0 to 15 mg of silk/ml of diet at 27°C. The developmental time for T×T larvae was significantly greater than the developmental time for N×N larvae. Likewise, the developmental time for T×N larvae was significantly greater than the developmental time for N×N larvae, except when larvae were fed on the control pinto bean diet (i.e., free from silk). There were no significant differences in the developmental time of N×N and N×T larvae except when larvae fed on a diet with 15 mg of silk/ml of diet at 22°C.

There were no significant interactions among the mean weight of pupae from normal and substerile larvae that fed on a pinto bean diet with 0, 15, and 30 mg Zapalote Chico silk/ml diet at 22 and 27°C (Table 3); therefore, the data for temperature and silk concentration were pooled for analysis. The mean weight of pupae for N×T and T×T crosses was significantly less than the mean weight of pupae from N×N and T×N crosses. Also, there were significant differences

Table 1. Mean weight of 9-d-old *H. zea* larvae that fed on silk-pinto bean diet mixtures of resistant cv. Zapalote Chico.

Parental† cross (female × male)	Mean larval wt (mg) at indicated temp and silk concentration*					
	22°C			27°C		
	0	15	30‡	0	15	30
N×N	170.3 a	* 89.8 a	21.0 a	870.0 a	* 533.4 a	* 118.9 ab
T×N	82.6 b	34.9 a	7.9 a	538.8 c	* 245.3 c	* 68.0 b
N×T	128.4ab	60.3 a	19.0 a	768.1 b	* 387.7 b	* 175.7 a
T×T	105.2 ab	* 33.9 a	9.9 a	557.4 c	* 346.2 b	* 48.1 b

Means within a column not followed by the same letter (Waller and Duncan means separation) or column means separated by * (*t*-test) are significantly different ($P \le 0.05$; SAS Institute [1985]).

* mg silk/ml pinto bean diet.

† N, normal; T, irradiated with 10 krads.

‡ 30 mg silk concentration was significantly different from 0 mg silk concentration for each parental cross.

Table 2. Mean developmental time of *H. zea* larvae that fed on silk-pinto bean diet mixtures of resistant cv. Zapalote Chico.

Parental† cross (female × male)	Mean larval developmental time (d)*					
	22°C			27°C		
	0	15	30	0	15	30‡
N×N	19.3 c	* 20.7 c	* 27.4 b	12.8 b	* 14.3 b	* 18.5 c
T×N	22.2 ab	* 23.8 ab	* 30.1 a	14.1 ab	* 16.6 a	* 20.7 b
N×T	20.6 bc	* 22.4 b	* 28.4 b	13.2 b	* 15.2 ab	* 17.9 b
T×T	21.1 a	* 24.9 a	* 30.3 a	14.9 a	16.2 a	* 23.6 a

Means within a column not followed by the same letter (Waller and Duncan means separation) or column means separated by * (*t*-test) are significantly different ($P \le 0.05$; SAS Institute [1985]).

* mg silk/ml pinto bean diet.

† N, normal; T, irradiated with 10 krads.

‡ 30 mg silk concentration was significantly different from 0 mg silk concentration for each parental cross.

between the mean weight of pupae from larvae that fed on diet with 0, 15, and 30 mg of Zapalote Chico silk/ml of diet.

The mean number of days to adult eclosion following larval development on the silk/pinto bean diet was affected by the temperature regime and the concentration of Zapalote Chico silks/ml pinto bean diet (Table 4). The mean number of days to adult eclosion was significantly lower for larvae from each cross when they were reared at 27°C than when they were reared at 22°C. Each increase in the concentration of Zapalote Chico silks/ml of diet resulted in a significant increase in the mean number of days required for adult eclosion for all

Table 3. Mean pupal weight of *H. zea* larvae that fed on silk-pinto bean diet mixtures of resistant cv. Zapalote Chico.

Parental* Cross (female X male)	Mean pupal wt (mg)
NXN	527 a
TXN	513 a
NXT	474 b
TXT	463 b

Means within a column not followed by the same letter are significantly different (Waller and Duncan means separation, $P \leq 0.05$; SAS Institute [1985]).

* N, normal; T, irradiated with 10 krads.

larvae except for the NXN larvae that fed on 0-15 mg of silks/ml of diet at 22°C, and NXN and NXT larvae that fed on 0-15 mg of silks/ml of diet at 27°C.The mean number of days to adult eclosion for NXN and NXT larvae was not significantly different. The mean number of days to adult eclosion was significantly greater for TXN larvae than for NXN larvae, except when larvae were fed on the 0.0 mg/ml concentration at 27°C, and significantly greater for TXT larvae than NXN larvae, except when larvae were fed the 0.0 mg/ml concentration at 27°C and the 15 and 30 mg/ml concentration at 22°C.

The potential for using radiation-induced substerile *H. zea* moths to manage wild populations has been suggested by Carpenter et al. (1987a,c). A knowledge of the ability of the irradiated and released insects and their progeny to survive and interact with the wild population is prerequisite to a complete evaluation of this control strategy. Because most of the radiation-induced deleterious effects are manifested during the F_1 generation, the ability of F_1 larvae to compete with wild larvae is especially important (Carpenter et al. 1987b). If substerilized moths are released over a wide area, it is certain that their progeny will be reared on host plants with varying degrees of resistance to their feeding. Therefore, the effectiveness of this control strategy would be reduced if the F_1 larvae were greatly affected by host plant resistance.

In this study, a significant interaction was observed among the developmental times for larvae from different parental crosses, an increasing concentration of Zapalote Chico silks/ml in a pinto bean diet, and temperature. Time for larval development and adult eclosion for progeny of NXN and NXT crosses was not significantly different at the 0.0 mg/ml concentration but significantly more time was required for development of TXN than NXN larvae at the 30 mg/ml concentration (Tables 2, 4). A similar response was observed for progeny of NXN and TXT crosses at both temperature regimes (Table 4). Another significant interaction was observed among the mean weight of normal and substerile larvae, an increasing concentration of Zapalote Chico silks/ml in pinto bean diet, and temperature (Table 1). The mean weight of 9-d normal larvae was significantly higher than the mean weight of substerile larvae at the 0.0 mg/ml concentration, but differences between the mean weight of normal and substerile

Table 4. Mean days to adult eclosion for *H. zea* from larvae that fed on silk-pinto bean diet mixtures of resistant cv. Zapalote Chico.

Parental† cross (female X male)	Mean days to adult eclosion*					
	22°C			27°C		
	0	15	30‡	0	15	30‡
NXN	36.5 b	38.0 c	* 44.2 b	24.2 a	25.8 b	* 29.3 b
TXN	39.1 a	* 41.6 ab	* 47.8 a	25.3 a	* 28.7 a	* 33.9 a
NXT	37.0 b	* 39.5 bc	* 45.3 ab	24.6 a	26.2 b	* 29.3 b
TXT	37.2 ab	* 42.5 a	* 46.4 a	26.2 a	* 28.3 a	* 35.2 a

Means within a column not followed by the same letter (Waller and Duncan means separation) or column means separated by * (*t*-test) are significantly different ($P \leq 0.05$; SAS Institute [1985]).

* mg silk/ml pinto bean diet.

† N, normal; T, irradiated with 10 krads.

‡ 30 mg silk concentration was significantly different from 0 mg silk concentration for each parental cross.

larvae at the 30 mg/ml concentration were not significant. A similar response was observed between NXN and TXN larvae at 22°C. NXT larvae were equally competitive with NXN larvae for all measured parameters. TXN and TXT larvae were also competitive except in developmental time under the conditions stated above. Because most of the F_1 larvae produced from substerilized *H. zea* crosses were progeny of the NXT cross (Carpenter et al. 1987c), the data from this study suggest that plant resistance and inherited sterility would be compatible control strategies for the management of *H. zea* populations.

An additional benefit of integrating inherited sterility and host plant resistance could be realized if researchers in plant resistance programs used eggs or larvae from substerilized moths in their routine infestations. Larvae from irradiated males crossed with normal females would be recommended because they respond to various degrees of resistance similar to normal larvae and they are less fertile than TXN larvae. Researchers in plant resistance programs who use NXT larvae would produce sterile, or nearly sterile, moths from their routine infestations. These moths could then contribute to a reduction rather than an anticipated increase in the local wild pest populations.

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