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Effects of Transgenic Bacillus thuringiensis Maize Grain on B. thuringiensis- Susceptible Plodia interpunctella (Lepidoptera: Pyralidae)

Kristopher L. Giles
Oklahoma State University - Main Campus

Richard L. Hellmich
Iowa State University, richard.hellmich@ars.usda.gov

Cort T. Iverson
Iowa State University

Leslie C. Lewis
Iowa State University

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Abstract
Percentage survivorship, developmental time, adult body length, and sex ratio of Plodia interpunctella (Hu¨ bner) reared on Þeld-produced grain from sixteen cultivars of maize, Zea mays L., including several transgenic Bacillus thuringiensis (Bt) Berliner hybrids and selected non-Bt isolines, were evaluated under laboratory conditions. Compared with isolines, development was delayed and survivorship reduced for P. interpunctella reared on grain from transgenic hybrids with the CaMV/35s promoter that express Cry1Ab protein. Similarly, compared with non-Bt hybrids, a transgenic hybrid with the CaMV/35s promoter that expresses Cry9C protein delayed development, decreased survivorship, and caused reductions in adult body length of P. interpunctella. In contrast, no signiÞcant differences in P. interpunctella developmental times or survivorship were observed between transgenic hybrids with the PEPC promoter expressing Cry1Ab and their isolines. Additionally, developmental time, survivorship, and adult body length were similar between P. interpunctella reared on a transgenic hybrid with the CaMV/35s promoter expressing Cry1Ac and non-Bt hybrids. Our data demonstrate that transgenic Bt maize grain, especially grain from hybrids with the CaMV/35s promoter expressing Cry1Ab or Cry9C, can signiÞcantly affect B. thuringiensis-susceptible P. interpunctella populations up to 4 or 5 mo after harvest.

Keywords
Plodia interpunctella, Bacillus thuringiensis, Zea mays, Bacillus thuringiensis Berliner, maize

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Effects of Transgenic *Bacillus thuringiensis* Maize Grain on *B. thuringiensis*-Susceptible *Plodia interpunctella* (Lepidoptera: Pyralidae)

KRISTOPHER L. GILES, RICHARD L. HELLMICH,[1] CORT T. IVERSON,[1] AND LESLIE C. LEWIS[1]

Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater, OK 74078–3033

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ABSTRACT Percentage survivorship, developmental time, adult body length, and sex ratio of *Plodia interpunctella* (Hübner) reared on field-produced grain from sixteen cultivars of maize, *Zea mays* L., including several transgenic *Bacillus thuringiensis* (Bt) Berliner hybrids and selected non-Bt isolines, were evaluated under laboratory conditions. Compared with isolines, development was delayed and survivorship reduced for *P. interpunctella* reared on grain from transgenic hybrids with the CaMV/35s promoter that express Cry1Ab protein. Similarly, compared with non-Bt hybrids, a transgenic hybrid with the CaMV/35s promoter that expresses Cry9C protein delayed development, decreased survivorship, and caused reductions in adult body length of *P. interpunctella.* In contrast, no significant differences in *P. interpunctella* developmental times or survivorship were observed between transgenic hybrids with the PEPC promoter expressing Cry1Ab and their isolines. Additionally, developmental time, survivorship, and adult body length were similar between *P. interpunctella* reared on a transgenic hybrid with the CaMV/35s promoter expressing Cry1Ac and non-Bt hybrids. Our data demonstrate that transgenic Bt maize grain, especially grain from hybrids with the CaMV/35s promoter expressing Cry1Ab or Cry9C, can significantly affect *B. thuringiensis*-susceptible *P. interpunctella* populations up to 4 or 5 mo after harvest.

KEY WORDS *Plodia interpunctella, Bacillus thuringiensis, Zea mays, Bacillus thuringiensis* Berliner maize

TRANSGENIC *Bacillus thuringiensis* (Bt) Berliner maize, *Zea mays* L., hybrids that express crystal proteins (Cry proteins, endotoxins) from *B. thuringiensis* are highly effective management tools against field pests such as *Ostrinia nubilalis* (Hübner) and *Helicoverpa zea* (Boddie) (Koziel et al. 1993, Armstrong et al. 1995, Ostlie et al. 1997, Jouanin et al. 1998, Lynch et al. 1999). Significant yield protection or reductions in damage from Bt maize are common in agricultural systems where lepidopteran pests limit profitable production (Koziel et al. 1993, Armstrong et al. 1995, Lynch et al. 1999; K.L.G., unpublished data).

Bacillus thuringiensis maize hybrids have two expression profiles based on gene promoters. Plants with the cauliflower mosaic virus (CaMV) 35s promoter express endotoxins for the full season throughout the entire plant, including the grain, whereas those with the combination of the maize phosphoenolpyruvate carboxylase (PEPC) and a maize pollen-specific promoter express in green tissue and pollen (Koziel et al. 1993). Cry protein has been observed, at varying levels, in Bt maize hybrid grain, including hybrids with the PEPC promoter expressing Cry1Ab and hybrids with the CaMV/35s promoter expressing Cry1Ab, Cry1Ac, or Cry9C proteins (Koziel et al. 1993; Mendelsohn 1998a, 1998b, 1999). Koziel et al. (1993) demonstrated that kernels from hybrids with the CaMV/35s promoter contain nearly 10 times the level of Cry1Ab protein compared with kernels from hybrids with the PEPC promoter.

The release of several elite Bt maize hybrids that express high levels of Cry protein in kernels warrants investigations into their potential effects on insect pests of stored grain (Koziel et al. 1993, Armstrong et al. 1995, Ostlie et al. 1997, Lynch et al. 1999). The Indianmeal moth, *Plodia interpunctella* (Hübner), has been shown to be susceptible to Cry proteins, including Cry1Ab and Cry1Ac (Johnson et al. 1998). Significant levels of Cry protein present in stored grain may not only provide effective control of *P. interpunctella* but also may select for resistance among natural populations (McGaughey 1985). The documented ability of *P. interpunctella* populations to develop resistance to control tactics such as insecticides and commercial *B. thuringiensis* products makes it a prime target for evaluation on Bt maize grain (Beeman et al. 1982, Summer et al. 1988, McGaughey and Johnson 1992, Tabashnik and McGaughey 1994).

The objective of this study was to document the effects of Bt maize grain on the development, survivorship, sex ratio, and adult body length of

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[1] USDA–ARS Corn Insects and Crop Genetics Research Unit, and Department of Entomology, Iowa State University, Ames, IA 50011.

Table 1. Transgenic *B. thuringiensis* and isogenic corn hybrids evaluated for effects on *P. interpunctella*

Treatment/hybrid	Growing season	Supplier	Event	Bt Protein	Promoter	Trademark
		Transgenics and isolines				
7050cb	1996	Mycogen Seeds	—	—	—	—
NG7059BT	1996, 1997	Mycogen Seeds	176	Cry1Ab	PEPC	NatureGard
4494	1996	Novartis Seeds	—	—	—	—
454	1996	Novartis Seeds	176	Cry1Ab	PEPC	KnockOut
B73 × MO17	1996, 1997	Public	—	—	—	—
B73 × MO17(MON810)[a]	1996, 1997	Monsanto	MON810	Cry1Ab	CaMV/35s	YieldGard
N6800	1996, 1997	Novartis Seeds	—	—	—	—
N6800Bt	1996, 1997	Novartis Seeds	BT11	Cry1Ab	CaMV/35s	YieldGard
X7780	1996	Cargill	—	—	—	—
X7780BT	1996	Cargill	MON810	Cry1Ab	CaMV/35s	YieldGard
		Transgenics				
34RO6	1997	Pioneer Hi-bred	MON810	Cry1Ab	CaMV/35s	YieldGard
AGREVOCry9c[b]	1997	AgrEvo	CBH351	Cry9c	CaMV/35s	Starlink
DK580BT	1997	DeKalb Genetics	DBT418	Cry1Ac	CaMV/35s	Bt-Xtra
NK7070BT	1997	Novartis Seeds	BT11	Cry1Ab	CaMV/35s	YieldGard
Control[c]	1996, 1997					

[a] Experimental hybrid (near B73 × MO17).
[b] Garst experimental hybrid.
[c] Controls were standard diet formulations evaluated in 1996 and 1997.

B. thuringiensis-susceptible *P. interpunctella.* In an effort to isolate the effects of transgenic grain, we evaluated several *B. thuringiensis* hybrids (with CaMV/35s or PEPC promoters) and their non-*B. thuringiensis* isolines. Additionally, we evaluated several other *B. thuringiensis* cultivars, including hybrids with the CaMV/35s promoter expressing Cry1Ab, Cry1Ac, or Cry9C proteins.

Materials and Methods

Treatments and Bioassays. Percentage survivorship, developmental time, adult body length, and sex ratio of *B. thuringiensis*-susceptible *P. interpunctella* on field-produced grain from 14 maize cultivars (Table 1) were evaluated under laboratory conditions. Crystal proteins expressed in transgenic maize cultivars include Cry1Ab, Cry1Ac (both derived from *B. thuringiensis* subsp. *kurstaki*), and Cry9C (derived from *B. thuringiensis* subsp. *tolworthi*). All maize grain was grown 1 km south of Ames, IA, in replicated field plots with standard agricultural practices during the 1996 and 1997 growing seasons. In October 1996 and 1997, 20 ears were randomly collected from replicated field plots for each maize hybrid listed in Table 1. Samples were transported to the laboratory in burlap sacks and stored in a cool, dry outdoor storage room until the following spring.

Bioassays were initiated 4 or 5 mo after harvest, during March of 1997 and 1998 at the USDA–ARS Corn Insects and Crop Genetics Research Unit, Ames, IA. Approximately 250 ml of cracked maize grain from each hybrid was placed individually into pint-size sterilized glass jars covered with filter paper. To decrease mortality levels associated with the inability of *P. interpunctella* larvae to penetrate intact kernels (Hockensmith et al. 1986, Alloytey and Goswami 1990, Mbata 1990), all maize grain was cracked by blending samples for 2 s. To prevent cross-contamination, the blender was thoroughly cleaned between processing for each hybrid sample. A standard rearing diet formulation (250 ml per jar), which served as the control (Table 1), was supplied by the U.S. Grain Marketing Research Laboratory, Manhattan, KS. This diet formulation consisted of cracked wheat, wheat shorts, wheat germ, yeast, sorbic acid, methyl-*p*-hydroxy benzoate, honey, glycerin, and distilled water.

Plodia interpunctella eggs from two very similar *B. thuringiensis kurstaki*-susceptible colonies were supplied by the U.S. Grain Marketing Research Laboratory, Manhattan, KS. Eggs from susceptible colony UE 343 were supplied in 1997, whereas eggs from susceptible colony 37-6 were supplied in 1998 (Friesen 2000).

After 3 d of conditioning grain at 27°C and 70% RH, 50 randomly collected *P. interpunctella* eggs were added to each glass jar. Glass jars were securely covered with filter paper to prevent escape of larvae, permit airflow, and maintain constant humidity. Grain treatments were replicated four times each year of the study. Treatments (jars) were randomized within shelves for each replicate in Percival Scientific environmental chambers (Boone, IA) maintained at 27°C under a photoperiod of 16:8 (L:D) h and 70% RH. Ten days after initiating experiments, rolled pieces of corrugated cardboard were added to each jar to provide suitable pupation sites. All jars were systematically monitored each day for 60 d to document adult emergence.

Measures and Analyses. During the 1997 experiment (1996 field-collected grain), days to first adult emergence and percentage survivorship to the adult stage were recorded for each jar. During the 1998 experiment (1997 field-collected grain), days to first adult emergence, average days to adult emergence, percentage survivorship to adult, sex ratio, and adult body length (tip of head capsule to tip of abdomen for each individual) for insects in each jar were recorded. Voucher specimens are deposited in the Department

Table 2. Days (mean ± SE) to first adult emergence at 27°C and 70% RH for *P. interpunctella* reared on 1996 and 1997 field-collected grain, and average days to adult emergence on 1997 field-collected grain

Treatment/hybrid	Promoter	*n*	D to 1st adult	Avg d to adult
		1996[a]		
Control	—	4	22.5 ± 0.9a	—
7050cb	None	4	29.8 ± 0.9b	—
X7780	None	4	29.8 ± 0.9b	—
B73 × MO17	None	4	30.0 ± 0.9b	—
N6800	None	4	30.5 ± 0.9b	—
4494	None	4	30.8 ± 0.9bc	—
NG7059BT	PEPC	4	31.3 ± 0.9bc	—
454	PEPC	4	33.3 ± 0.9c	—
B73 × MO17(MON810)	CaMV/35s	4	36.8 ± 0.9d	—
X7780BT	CaMV/35s	4	36.8 ± 0.9d	—
N6800Bt	CaMV/35s	1	58.0 ± 1.8e[b]	—
		1997[c]		
Control	—	4	20.3 ± 0.3a	26.4 ± 0.1a
B73 × MO17	None	4	25.3 ± 0.5b	33.6 ± 0.2b
N6800	None	4	25.3 ± 0.5b	33.6 ± 0.2b
NG7059BT	PEPC	4	25.3 ± 0.3b	33.9 ± 0.2b
DK580BT	CaMV/35s	4	26.0 ± 0.4bc	34.0 ± 0.2b
B73 × MO17(MON810)	CaMV/35s	4	28.0 ± 1.3cd	40.3 ± 0.6c
34RO6	CaMV/35s	4	28.5 ± 1.3d	40.5 ± 1.3c
N6800Bt	CaMV/35s	4	29.3 ± 0.9d	40.3 ± 1.7c
NK7070BT	CaMV/35s	4	29.3 ± 0.6d	40.1 ± 0.4c
AGREVOCry9C	CaMV/35s	4	32.5 ± 0.9e	44.3 ± 1.0d

Least square means (LSMEANS) were compared by the least significant difference test (STDERR PDIFF, SAS Institute 1996).
[a] $F = 39.17$; df = 10, 30; $P = 0.0001$ (ANOVA).
[b] Estimated mean from one value with PROC GLM and LSMEANS comparisons.
[c] Days to first adult: $F = 17.8$; df = 9, 30; $P = 0.001$ (ANOVA). Average days to adult: $F = 45.4$; df = 9, 30; $P = 0.0001$ (ANOVA).

of Entomology and Plant Pathology Museum, Oklahoma State University, Stillwater.

All statistical analyses were performed with SAS version 6.12 (SAS Institute 1996). Preliminary analysis indicated that sex did not significantly affect developmental time, survivorship, or adult body length among grain treatments; therefore, males and females were pooled for analysis. Because maize hybrid treatments and *P. interpunctella* colonies varied between years (Table 1), data were analyzed separately for each year of the study. Days to first adult emergence, average days to adult emergence, percentage survivorship, sex ratio, and adult body length (mean values per jar) were analyzed by analysis of variance (PROC GLM). Treatment means and lsmeans were compared by the least significance difference test (LSD, STDERR PDIFF). A 0.05 significance level was chosen for all statistical analyses.

Results and Discussion

Effects of Transgenic Maize Grain on *P. interpunctella*. *Development.* Developmental times for *P. interpunctella* to first adult emergence on cracked isogenic maize grain ranged from 25.3 to 30.8 d, whereas average days to adult emergence was 33.6 d for hybrids B73 x MO17 and N6800 (Table 2). Similarly, Alloytey and Goswami (1990) demonstrated that at 30°C, 76.5% RH, and a photoperiod of 12:12 (L:D) h, the average developmental time for *P. interpunctella* on broken to ground maize kernels ranged from 28.1 to 34.0 d, respectively.

For maize hybrids grown in 1996 and 1997, significant differences in the days to first adult emergence were detected among grain treatments (Table 2). A general trend among maize treatments was observed in which isogenic hybrids were the most suitable diets for *P. interpunctella* development to first adult, followed by Bt transgenic hybrids with the PEPC promoter, and finally Bt transgenic maize hybrids with the CaMV/35s promoter (Table 2). Compared with isolines, development was delayed for *P. interpunctella* reared on maize grain from transgenic hybrids with the CaMV/35s promoter (X7780BT versus X7780, B73MO17(MON810) versus B73 × MO17, N6800Bt versus N6800). In contrast, no significant differences in developmental times were observed between transgenic hybrids with the PEPC promoter versus their isolines (NG7059BT versus 7050cb, 454 versus 4,494).

The evaluation of several additional Bt transgenic maize hybrids with the CaMV/35s promoter from 1997 field-grown corn revealed similar delayed development for both average days to first adult, and average days to adult emergence (Table 2). However, DK580BT (expressing Cry1Ac protein) was similar in effect to isogenic grain treatments (Table 2). Johnson et al. (1998) demonstrated that *P. interpunctella* is susceptible to Cry1Ac. Apparently, *P. interpunctella* is unaffected by the level of crystal protein in the grain of DK580BT.

The variability in developmental times between years may be attributable to several factors, including levels of protein in the grain, differences in the level of grain cracking, moisture levels in grain samples, or

Table 3. Percentage survivorship (mean ± SE) at 27°C and 70% RH from egg to adult for *P. interpunctella* reared on 1996 and 1997 field-collected corn grain

Treatment/hybrid	Promoter	*n*	Survivorship, %,[a]
	1996[b]		
Control	—	4	67.5 ± 7.5a
7050cb	None	4	67.0 ± 12.4a
NG7059BT	PEPC	4	59.0 ± 2.5ab
454	PEPC	4	54.5 ± 2.5ab
4494	None	4	53.5 ± 7.5abc
X7780	None	4	45.5 ± 5.0bc
B73 × MO17	None	4	43.5 ± 8.7bc
N6800	None	4	36.5 ± 5.0c
X7780BT	CaMV/35s	4	9.5 ± 3.0d
B73 × MO17(MON810)	CaMV/35s	4	9.0 ± 2.5d
N6800Bt	CaMV/35s	4	0.5 ± 0.5d
	1997[c]		
NG7059BT	PEPC	4	77.5 ± 3.2a
DK580BT	CaMV/35s	4	73.5 ± 5.5a
B73 × MO17	None	4	73.0 ± 2.6a
N6800	None	4	71.0 ± 5.0a
Control	—	4	64.5 ± 4.4a
34RO6	CaMV/35s	4	37.0 ± 6.1b
B73 × MO17(MON810)	CaMV/35s	4	36.5 ± 7.5b
NK7070BT	CaMV/35s	4	26.0 ± 1.8bc
N6800Bt	CaMV/35s	4	24.0 ± 5.7bc
AGREVOCry9C	CaMV/35s	4	19.0 ± 4.2c

[a] Percentage based on number of adults emerging from 50 eggs. Means compared by the LSD (SAS Institute 1996).
[b] $F = 14.9$; df = 10, 33; $P = 0.0001$ (ANOVA).
[c] $F = 23.5$; df = 9, 30; $P = 0.0001$ (ANOVA).

small differences in susceptibility between *P. interpunctella* colonies (Abdel-Rahnab et al. 1968, Hockensmith et al. 1986, Wright et al. 1987, Alloytey and Goswami 1990, Mbata 1990, Friesen 2000).

Survival. Survivorship for *P. interpunctella* on isogenic maize grain treatments ranged from 36.5 to 73% (Table 3). Previous studies have reported high levels of variability for survivorship of *P. interpunctella* ranging from 7.0 to 74.5% among maize cultivars for cracked or milled grain treatments (Abdel-Rahnab et al. 1968, Hockensmith et al. 1986, Mbata 1990). Mbata (1990) observed the low range of these values on maize cultivars that are resistant to the stored grain beetle *Sitophilus zeamais* Motschulsky.

For hybrids grown in 1996 and 1997, significant differences in the percentage of *P. interpunctella* surviving to the adult stage were detected among grain treatments (Table 3). Bt transgenic maize hybrids with the CaMV/35s promoter expressing Cry1Ab or Cry9C resulted in the lowest levels of survivorship on 1996 (0.5–9.5%) and 1997 (19.0–37.0%) field-grown maize. Similar to developmental data, levels of protein in the grain, differences in the level of grain cracking, moisture levels in grain samples, or small differences in susceptibility between *P. interpunctella* colonies may have contributed to differences in survivorship for cultivars between years.

Significant reductions in percentage survivorship for *P. interpunctella* on transgenic hybrids with the CaMV/35s promoter versus isolines (X7780BT versus X7780, B73MO17(MON810) versus B73 × MO17, N6800Bt versus N6800) were evident (Table 3). Also, no significant differences in survivorship were observed between Bt-transgenic hybrids with the PEPC promoter versus their isolines (NG7059BT versus 7050cb, 454 versus 4494). *P. interpunctella* survivorship on 1997 field-collected grain from egg to adult was not distinguishable among DK580BT, isogenic maize hybrids, and the lone Bt transgenic hybrid with the PEPC promoter (NG7059BT).

Table 4. Adult *P. interpunctella* body length (LS mean ± SE) at 27°C and 70% RH reared on 1997 field-collected maize grain

Treatment/hybrid	Promoter	*n*	Adult length, mm[a] LSMean ± SE[a]
Control	—	4	5.93 ± 0.06a
N6800	None	4	5.75 ± 0.06b
DK580BT	CaMV/35s	4	5.70 ± 0.06bc
NG7059BT	PEPC	4	5.68 ± 0.06bcd
B73 × MO17	None	3	5.67 ± 0.07bcd
N6800Bt	CaMV/35s	4	5.63 ± 0.06bcd
34RO6	CaMV/35s	4	5.55 ± 0.06cde
B73 × MO17(MON810)	CaMV/35s	4	5.53 ± 0.06def
AGREVOCry9C	CaMV/35s	4	5.45 ± 0.06ef
NK7070BT	CaMV/35s	4	5.38 ± 0.06f

[a] Length from tip of head capsule to tip of abdomen.
Least square means were compared by the least significant difference test (STDERR PDIFF, SAS Institute 1996). $F = 7.5$; df = 9, 29; $P = 0.0001$ (ANOVA).

Sex Ratio and Adult Body Length. For 1997 field-collected grain, the percentage female of surviving *P. interpunctella* adults ranged from 44.1 to 59.9, but were statistically similar among grain treatments ($F = 0.9$; df = 9, 30; $P = 0.5034$). Similarly, Abdel-Rahnab et al. (1968) did not detect significant sex ratio differences for *P. interpunctella* reared on nine varieties of milled maize.

Previous studies on *P. interpunctella* reared on cracked maize grain demonstrated significant differences among cultivars for pupal and adult weight (Hockensmith et al. 1986, Mbata 1990). However, Abdel-Rahnab et al. (1968) were unable to detect significant differences in adult weight or wing length for *P. interpunctella* reared on nine cultivars of milled maize. Altered body size or weight may affect *P. interpunctella* fecundity. Indeed, Mbata (1985) demonstrated that heavier *P. interpunctella* females were more fecund.

Despite a great deal of overlap in *P. interpunctella* adult body length among grain treatments from 1997 field-grown maize, significant differences were detected (Table 4). *P. interpunctella* larvae reared on Bt transgenic maize hybrids with the CaMV/35s promoter and expressing Cry1Ab or Cry9C were smaller (5.38–5.63 mm) than larvae reared on all other maize grain treatments (5.67–5.75 mm). Reductions in adult body length for *P. interpunctella* reared on transgenic hybrids with the CaMV/35s promoter and expressing Cry1Ab versus their isolines (B73MO17(MON810) versus B73 × MO17, N6800Bt versus N6800) were not significantly different ($P > 0.1305$).

Implications for Stored Transgenic Bt Maize. To adequately compare the benefits and risks associated with production of transgenic Bt maize, all relevant

ecological interactions must be studied. The presence of Cry proteins in the kernels of hybrids evaluated during this study has been well documented (Koziel et al. 1993; Mendelsohn 1998a, b; 1999). For Bt-Xtra hybrids (Table 1), up to 43 ng of Cry1Ac/g of dry kernel weight has been observed. Cry1Ab levels in the kernels of YieldGard hybrids range from 0.2 to 0.9 μg/g fresh weight. Levels of Cry9C in Starlink hybrids are as high as 18.6 μg/g of dry kernel weight. Cry1Ab levels in kernels of NatureGard hybrids are nearly 10 times lower than levels in the kernels of Yieldgard hybrids. Johnson et al. (1998) reported differing levels of toxicity for Cry1Ab and Cry1Ac on *P. interpunctella* larvae; the LC_{50} value for Cry1Ab was 0.33 μg per larva, whereas the LC_{50} value for Cry1Ac was 0.49 μg per larva. Although Cry protein levels among hybrids were not measured during this study, our data suggests that Cry protein levels in Bt maize grain with the CaMV/35s promoter expressing Cry1Ab or Cry9C are high enough to affect *P. interpunctella* development and survivorship up to 4 or 5 mo after harvest.

Based on survivorship and development data, grain from hybrids with the CaMV/35s promoter expressing Cry1Ab or Cry9C deliver a "moderate dose" of Cry protein to *P. interpunctella;* only N6800Bt in 1996, which caused 99.5% mortality, might be considered a "high dose" (Ostlie et al. 1997). Similar to the theorized development of resistance by *O. nubilalis* to Bt maize, resistance development of *P. interpunctella* to Bt maize grain could be fostered by moderate levels of survivorship and development delays that increase nonrandom mating (Ostlie et al. 1997, Gould 1998). In the absence of resistance development, these hybrids would be beneficial to *P. interpunctella* control in stored grain. However, given the observed effects of some Bt maize hybrids on *P. interpunctella* survivorship and development, and documented ability of *P. interpunctella* populations to develop resistance to *B. thuringiensis,* the benefit of using currently available Bt transgenic maize hybrids for Indianmeal moth control could be short lived (McGaughey 1985). Finally, the development of resistance, and potential for cross-resistance, could limit the usefulness of some commercial *B. thuringiensis* products or hybrids expressing unique Cry proteins targeted for *P. interpunctella* control (McGaughey 1994, McGaughey and Johnson 1994, Tabashnik and McGaughey 1994, Gould 1998).

Future studies on *P. interpunctella* should quantify protein levels over time to more accurately predict effects of Bt maize grain on *P. interpunctella* population processes including reproduction. Additionally, these studies should evaluate the effects of transgenic Bt maize grain on both Bt-resistant and Bt-susceptible populations of *P. interpunctella.*

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