

Efficacy and economics of fresh-market *Bt* transgenic sweet corn in Virginia

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Abstract

The effectiveness and cost of managing the suite of insect pests that attack sweet corn in Virginia were evaluated using multiple foliar applications of pyrethroid insecticides and *Bt* transgenic sweet corn in 2000 and 2002. Several *Bt* cultivars and their non-transgenic isolines were tested in different locations in Virginia to examine efficacy over a range of growing conditions and pest pressure. Overall, insect damage was far less in the *Bt* cultivars than in the non-*Bt* isolines that were not sprayed or sprayed with lambda-cyhalothrin up to six times. When insect pressure was low to moderate, *Bt* sweet corn did not require supplementary insecticide applications for a high percentage ($\geq 88\%$) of ears to be considered fresh-market quality. In contrast, when insect pressure was extremely high, *Bt* sweet corn required two insecticide applications for a high percentage ($\geq 88\%$) of ears to be considered fresh-market quality. Based on an economic comparison between insecticide-treated conventional sweet corn and *Bt* sweet corn, growers should expect a \$547/ha gain by growing *Bt* sweet corn. If *Bt* sweet corn was sprayed twice with an insecticide, this gain should be approximately \$1777/ha. We conclude that *Bt* sweet corn is an effective and economically sound pest management strategy for growers in Virginia.

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1. Introduction

Fresh-market sweet corn is a high-value crop that must be insect and insect-damage free to be marketable. Consequently, successful insect pest management is a major factor in the commercial production of sweet corn. In Virginia and most of the eastern and central US, sweet corn is attacked primarily by three main lepidopteran pests: corn earworm [*Helicoverpa zea* (Boddie)], European corn borer [*Ostrinia nubilalis* (Hübner)], and the fall armyworm [*Spodoptera frugiperda* (Smith)] (Adams and Clark, 1995; Burkness et al.,

2001). All three species may infest corn ears, rendering the ear unmarketable. *O. nubilalis* may infest the stalk as well, potentially causing reduced ear weight or stalk lodging (Capinera, 2001). *H. zea* eggs are typically oviposited onto corn silks. After neonates emerge from the eggs, they travel along the silk into the ear (Prostak, 1995a). *O. nubilalis* and *S. frugiperda* eggs are normally oviposited onto leaves (Capinera, 2001). After eggs hatch, larvae initially feed on leaf tissue and then tunnel into ears or other parts of the plant (Adams, 1995; Prostak, 1995b; Mason et al., 1996). Once inside the ear, the husk protects larvae from exposure to insecticides, making chemical control of lepidopteran pests in sweet corn challenging. Moreover, larval and adult sap beetles

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[*Carpophilus* spp.] can be problematic in sweet corn previously infested by lepidopteran larvae. In Virginia sweet corn planted in June must be treated with insecticide sprays twice weekly during the silking period (~4–8 sprays) to effectively control lepidopteran pests (Kuhar and Speese, 2002; Kuhar et al., 2003; Cordero et al., 2004). Because of time constraints and inclement weather, growers may miss a timely insecticide application, resulting in only moderate protection of the ears. Treating sweet corn repeatedly with insecticides is not only expensive, but there is health and environmental risks associated with the insecticides used (Bartholomew, 1995; Clark and Los, 1995), which typically include synthetic pyrethroids or the carbamate, methomyl.

Since many of the lepidopteran insects that attack sweet corn are susceptible to the crystalline proteins produced by the soil bacterium, *Bacillus thuringiensis* spp. *kurstaki* Berliner, transgenic sweet corn expressing the gene(s) for production of the insecticidal protein(s) may provide an efficacious and environmentally sound means of insect control (Lynch et al., 1999a, b). In the mid-1990s, researchers from Novartis Seeds, Inc. (now Syngenta Seeds) successfully transferred a codon-modified *cryIA(b)* gene from *B. t. kurstaki* to several of their sweet corn inbreds using the 35S promoter (Armstrong et al., 1995). In field trials in Georgia, Lynch et al. (1999a) demonstrated that this event, referred to as BT-11, expressed in 8 different sweet corn hybrids conferred a high degree of resistance to feeding by neonate and early instar *H. zea* and *S. frugiperda*, resulting in significantly reduced ear damage compared with that of the non-*Bt* isolines. Recent studies in Georgia (Lynch et al., 1999b) and the Midwestern US (Burkness et al., 2001, 2002) have indicated that *Bt* sweet corn hybrids may eliminate or greatly reduce the need for chemical control. The objectives of this research included evaluation of the field efficacy of *Bt* transgenic sweet corn with and without insecticide sprays, and exploration of the economics of growing *Bt* sweet corn versus non-transformed sweet corn sprayed with insecticides in Virginia.

2. Materials and methods

2.1. *Bt* sweet corn experiments, 2000

Field efficacy trials were conducted at Virginia Tech's Eastern Shore Agricultural Research and Extension Center (ESAREC) near Painter, VA in 2000. One trial was planted on 12 May (designated as "Trial 1") and the other on 12 June ("Trial 2"). Both trials evaluated the *Bt* cultivar GSS-0966 (Attribute™, Syngenta Seeds Inc.) and its non-transgenic isolate, Prime Plus, with and without foliar applications of the pyrethroid λ -cyhalo-

thrin (Warrior®T, Syngenta Crop Protection, Inc., Greensboro, NC), one of the most efficacious insecticides for insect control in sweet corn. Lambda-cyhalothrin was used at a rate of 0.034 kg active ingredient/ha in all treatments. Flight activity of *H. zea*, *O. nubilalis*, and *S. frugiperda* adults was monitored at the ESAREC daily from 1 May to 1 September using a blacklight trap containing a 15-W bulb (F15T8-BL, Philips Lighting Company, Somerset, NJ) and a collection bucket with a dichlorvos killing agent (Adams and Clark, 1995).

In Trial 1, four treatments were arranged in a randomized complete block and replicated six times. Each sweet corn plot consisted of four 6.1-m long rows. Rows were spaced 0.9 m apart and plants were approximately 0.25 m apart within rows. Treatments included: (1) GSS-0966 only; (2) GSS-0966 plus one spray of λ -cyhalothrin on 6 July; (3) Prime Plus only; and (4) Prime Plus with four sprays of λ -cyhalothrin (6, 11, 16, and 20 July). The insecticide-treated plots were initially sprayed at the beginning of the silk stage. All applications were made using a compressed-gas backpack sprayer that delivered 287 l/ha.

For Trial 2, treatments included GSS-0966 and Prime Plus with or without foliar applications of λ -cyhalothrin at the same rate mentioned above. Treatments included: (1) GSS-0966 only; (2) GSS-0966 with one spray on 1 Aug (at beginning silk stage); (3) GSS-0966 with two sprays (1 and 6 August); (4) GSS-0966 with three sprays (1, 6, and 9 August); (5) GSS-0966 with four sprays (1, 6, 9, and 12 August); (6) GSS-0966 with five sprays (1, 6, 9, 12, and 15 August); (7) GSS-0966 with six sprays (1, 6, 9, 12, 15, and 19 August); (8) Prime Plus with six sprays (1, 6, 9, 12, 15, and 19 August); and (9) Prime Plus without sprays. These nine treatments were arranged in a randomized complete block design replicated 6 times. Plots consisted of six 12.2-m long rows with row and plant spacing as described above. All λ -cyhalothrin sprays were applied at a rate of 0.034 kg active ingredient/ha with a tractor mounted sprayer equipped with a boom that directed three hollow cone nozzles/row (two drop nozzles oriented to each side of the row and one nozzle over the top of each row) and delivered 507 l/ha of spray.

Plots were harvested in Trial 1 on 25 July and Trial 2 on 21 August. In both trials, 50 ears from each plot were harvested by hand and evaluated as marketable (no insect damage) or damaged. Although ears with minor damage confined to the first 4 cm of the tip are considered suitable for processing, they are not suitable for fresh market sale, which is the primary source of commercial sweet corn production in Virginia. The number of live insects (*H. zea*, *O. nubilalis*, *S. frugiperda*, and sap beetles [*Carpophilus* spp.]) per ear also was recorded. Data were analyzed using analysis of variance procedures in SAS (PROC GLM) following a square-root ($x+0.01$) transformation to account for zeros in

the data. Means were separated using Fisher's Protected LSD at $P < 0.05$.

2.2. *Bt* sweet corn experiments, 2002

This experiment was conducted at three locations: (1) ESAREC; (2) Virginia Tech's Tidewater Agricultural Research and Extension Center (TAREC) near Suffolk; and Virginia Tech's Kentland Research Farm near Blacksburg. Painter and Suffolk are both located in southeastern Virginia, where insect pest pressure in sweet corn is generally much greater than in Blacksburg, located in western Virginia.

At each location, three *Bt*- Attribute™ sweet corn cultivars, BSS-0977 (a supersweet bi-color), GSS-0966 (a supersweet yellow), and BC-0801 (a sugar-enhanced bi-color), and their non-transformed isolines, Bigtime, Prime Plus, and Jackpot, respectively, were evaluated. Unlike experiments in 2000, cultivars were not treated with insecticides. The six cultivars were arranged in a randomized complete block and replicated six times. Individual plots consisted of two 6.1-m long rows. Rows were spaced 0.9 m apart and plants approximately 0.25 m apart within rows. Seed was sown on 3 May, 5 June and 6 June at ESAREC, TAREC, and Kentland, respectively. Plots were thinned to exactly 50 plants per plot approximately 20 days after emergence. On 19, 22 and 25 July at the ESAREC, 12 August at TAREC, and 23 and 24 August at Kentland, all mature ears were harvested from each plot and the total number of ears and percentage damaged ears was recorded. Multiple harvest dates were necessary due to the different maturation rates of the cultivars. In addition, ten stalks were cut from each plot and evaluated for number of *O. nubilalis* tunnels and live larvae or pupae. Because environmental conditions differed at each location, data were analyzed separately for each location. Also, we were not interested in detecting a *Bt* gene by cultivar interaction, rather we wanted to compare efficacy of the *Bt* gene within each cultivar. Thus, data were analyzed using a one-way analysis of variance procedure in SAS (PROC GLM) following a square-root ($x + 0.01$) transformation to account for zeros in the data. Means were separated using Fisher's Protected LSD at $P < 0.05$.

2.3. Partial budgeting analysis

A partial budgeting analysis of sweet corn production in Virginia with respect to pest management was done for each of the following: (1) *Bt* cultivar with no insecticides; (2) *Bt* cultivar with two pyrethroid applications; (3) non-*Bt* cultivar with five pyrethroid applications; and (4) non-*Bt* cultivar with no insecticides. Net profit was calculated as potential market value of crop – [total crop production costs + dollar loss from insect damage]. Potential market value of the crop was

estimated to be \$17,900/ha based on a maximum fresh-market sweet corn yield in the absence of insect pressure = 4475 dozen ears/ha and a retail crop value = \$4.00/dozen ears in Virginia (O'Dell et al., 2001). Total crop production costs were based on the following: (1) average seed costs of *Bt* sweet corn and non-transformed cultivars based on information provided by Syngenta Seeds Inc. in December 2003; (2) insecticide application costs based on foliar spray applications of λ -cyhalothrin at 0.034 kg active ingredient/ha at market prices (\$/ha insecticide + \$/ha cost of application based on 10 operating hours/acre/season using Whittle (2001); and (3) all remaining non-insect management production costs of sweet corn in Virginia based on O'Dell et al. (2001). Typical percentage fresh-market yield loss to insect damage of non-*Bt* sweet corn was estimated for a conventional insecticide program of five pyrethroid sprays and for no insecticides using mean data from several sweet corn insecticide efficacy studies conducted at the ESAREC (Nault and Speese, 1999, 2000, 2001; Kuhar and Speese, 2002; Kuhar et al., 2003; Cordero et al., 2004), and from the experiments herein. Percentage yield loss to insect damage of *Bt* sweet corn with or without two insecticide sprays was derived from the combined results of the experiments herein.

3. Results

3.1. *Bt* sweet corn experiments, 2000

During Trial 1, *O. nubilalis* and *H. zea* flight activity was relatively low and no *S. frugiperda* moths were detected until plots were harvested (Fig. 1). Nonetheless, overall damage to ears in the untreated Prime Plus plots was moderate to moderately high (Table 1). The percentage of fresh-market quality ears was significantly affected by treatment ($F = 201.6$; $df = 3, 5$; $P < 0.0001$). The *Bt*-transgenic GSS-0966 cultivar with or without an insecticide spray averaged approximately 88–90% fresh market quality ears, which was significantly more than the non-*Bt* Prime Plus with four insecticide applications

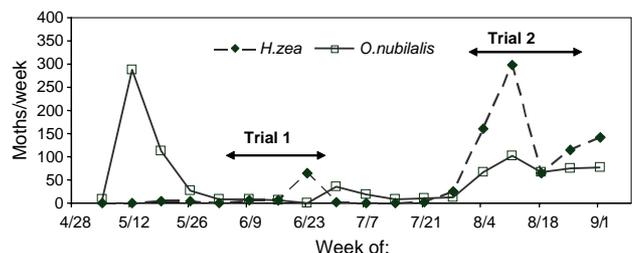


Fig. 1. Catch of *O. nubilalis* and *H. zea* adults (moths/wk) at a black light trap installed at the ESAREC near Painter, VA in 2000. Horizontal lines with arrows indicate the fresh silk to harvest period of sweet corn for Trials 1 and 2.

Table 1

Mean percentage (\pm SEM) of fresh market quality ears and mean number of insect pests per ear in *Bt*-transgenic sweet corn and the non-*Bt* isolate that were either treated or not treated with λ -cyhalothrin during ear development, (Trial 1), Painter, VA, 2000

Cultivar	Treatment	% Fresh market ears	Mean no. larvae/ear		Mean no. <i>Carpophilus</i> spp./ear	
			<i>H. zea</i>	<i>O. nubilalis</i>	Larvae	Adults
Prime Plus	Untreated	20.0 \pm 1.9 c	0.06 \pm 0.01 a	0.07 \pm 0.01 a	1.02 \pm 0.21 a	0.48 \pm 0.13 a
Prime Plus	Treated (4 \times)	49.0 \pm 3.8 b	0.00 \pm 0.00 b	0.01 \pm 0.00 b	0.08 \pm 0.04 b	0.04 \pm 0.02 b
GSS-0966	Untreated	88.0 \pm 3.4 a	0.00 \pm 0.00 b	0.00 \pm 0.00 b	0.09 \pm 0.04 b	0.05 \pm 0.02 b
GSS-0966	Treated (1 \times)	89.7 \pm 2.4 a	0.00 \pm 0.00 b	0.02 \pm 0.02 b	0.08 \pm 0.05 b	0.04 \pm 0.02 b

Means in a column with a letter in common are not significantly different ($P > 0.05$, LSD). Treated plots were sprayed as indicated with λ -cyhalothrin at 0.034 kg/ha.

Table 2

Mean percentage (\pm SEM) of fresh-market quality ears and mean number of insect pests per ear in *Bt*-transgenic sweet corn and the non-*Bt* isolate that were either treated or not treated with λ -cyhalothrin during ear development, (Trial 2), Painter, VA, 2000

Cultivar	Total sprays ^a	% Fresh market ears	<i>H. zea</i>	Percentage of ears containing ^b		
				<i>S. frugiperda</i>	<i>O. nubilalis</i>	<i>Carpophilus</i> spp.
GSS-0966	0	68.5 \pm 9.1 b	8.0 \pm 1.8 b	1.0 \pm 0.6 bc	0.0 \pm 0.0 b	10.0 \pm 1.6 bc
GSS-0966	1	70.5 \pm 5.7 b	6.5 \pm 1.0 b	2.0 \pm 1.2 bc	0.0 \pm 0.0 b	6.0 \pm 2.4 c
GSS-0966	2	87.5 \pm 2.1 a	2.5 \pm 0.5 b	0.5 \pm 0.5 c	0.0 \pm 0.0 b	4.5 \pm 2.6 c
GSS-0966	3	88.0 \pm 3.2 a	2.0 \pm 0.8 b	1.0 \pm 0.6 bc	0.0 \pm 0.0 b	6.0 \pm 2.8 c
GSS-0966	4	90.0 \pm 6.2 a	2.5 \pm 2.5 b	0.0 \pm 0.0 c	0.0 \pm 0.0 b	2.0 \pm 1.4 c
GSS-0966	5	88.0 \pm 3.6 a	4.0 \pm 1.2 b	1.0 \pm 1.0 bc	0.0 \pm 0.0 b	1.0 \pm 1.0 c
GSS-0966	6	87.0 \pm 3.3 a	4.5 \pm 3.3 b	1.5 \pm 1.5 bc	0.0 \pm 0.0 b	1.5 \pm 1.0 c
Prime Plus	6	26.7 \pm 4.9 c	6.7 \pm 2.4 b	4.2 \pm 0.8 ab	2.5 \pm 0.8 b	20.0 \pm 9.5 b
Prime Plus	0	0.8 \pm 0.8 d	33.3 \pm 3.3 a	5.8 \pm 2.1 a	11.7 \pm 2.9 a	50.8 \pm 8.1 a

Means in a column with a letter in common are not significantly different ($P > 0.05$, LSD).

^aTreated plots were sprayed as indicated with λ -cyhalothrin at 0.034 kg/ha in a volume of 507 l/ha.

^bPercentage damaged ears by each species will not necessarily add up to 100 because some ears had more than one kind of damage.

(49%) or Prime Plus with no sprays (20%) (Table 1). There was no difference in percentage marketable ears between the GSS-0966 with or without an insecticide spray ($P > 0.05$). There was a significant treatment effect on the mean numbers of *H. zea* larvae ($F = 21.4$; $df = 3,5$; $P < 0.0001$), *O. nubilalis* larvae ($F = 3.8$; $df = 3,5$; $P = 0.0322$), sap beetle larvae ($F = 19.2$; $df = 3,5$; $P < 0.0001$), and sap beetle adults ($F = 9.8$; $df = 3,5$; $P = 0.0008$) per ear. All treatments had significantly fewer insects per ear than the Prime Plus with no sprays treatment ($P < 0.05$; Table 1).

During Trial 2, *O. nubilalis* and *H. zea* moth activity was much greater than during Trial 1, especially between 1 and 21 August (Fig. 1). Larval damage by these species was prevalent in untreated Prime Plus plots (Table 2). Additionally, sap beetle pressure was very high during this experiment, contributing significantly to ear damage. The percentage of fresh-market quality ears was affected by treatment ($F = 42.6$; $df = 3,8$; $P < 0.0001$). The GSS-0966 with two to six insecticide sprays averaged approximately 87–90% fresh market quality ears, which was significantly more than all other

treatments ($P < 0.05$; Table 2). The GSS-0966 with only one or no insecticide application averaged 68–71% marketable ears, which was more than Prime Plus with six insecticide sprays (26.7%) and Prime Plus with no sprays (0.8%). There was also a significant treatment effect on the percentage of ears containing *H. zea* larvae ($F = 20.7$; $df = 3,8$; $P < 0.0001$), *S. frugiperda* larvae ($F = 3.0$; $df = 3,8$; $P = 0.0165$), *O. nubilalis* larvae ($F = 14.8$; $df = 3,8$; $P < 0.0001$), and sap beetles ($F = 13.1$; $df = 3,8$; $P < 0.0001$). All treatments had significantly fewer insects per ear than the Prime Plus without insecticides treatment, except for the density of *S. frugiperda* in the Prime Plus treatment sprayed six times ($P < 0.05$; Table 2).

3.2. *Bt* sweet corn experiments, 2002

Mean total number of ears was not significantly different between the *Bt* lines and non-*Bt* isolines at all locations, except at ESAREC where the cultivar BSS-0977 yielded an average of 36.5 ears versus only 23.3 ears for the non-transformed Bigtime ($P < 0.05$; Fig. 2).

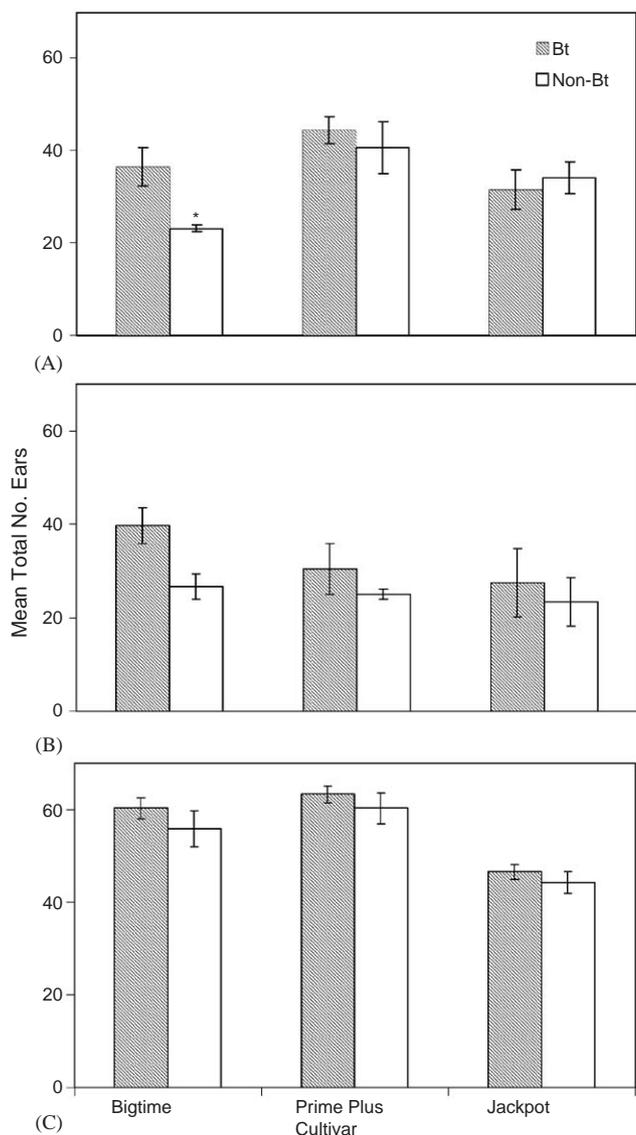


Fig. 2. Mean total number (\pm SEM) of mature ears produced per 50 plants by *Bt* sweet corn hybrids and non-*Bt* isolines at three locations in Virginia in 2002: (A) ESAREC near Painter; (B) TAREC near Suffolk; and (C) Kentland Farm near Blacksburg. The asterisk indicates a significant difference $P < 0.05$ between *Bt* and non-*Bt* ($n = 6$).

In most cases, there was a trend for more ears produced by the *Bt* cultivar than the non-*Bt* cultivar, suggesting that *Bt* plants may have been more vigorous than non-*Bt* plants (Fig. 2).

The percentage of fresh-market ears was significantly higher in the *Bt* lines compared with the non-*Bt* isolines for all cultivars and locations ($P < 0.05$; Fig. 3). The *Bt* lines averaged 50–96% marketable ears versus 0–21% for the non-transformed cultivars. For all cultivars and locations combined the average fresh market yield was 79.6% for *Bt* lines versus 7.7% for the non-*Bt* isolines.

The mean number of *O. nubilalis* tunnels per 10 stalks was significantly lower in the Attribute lines compared

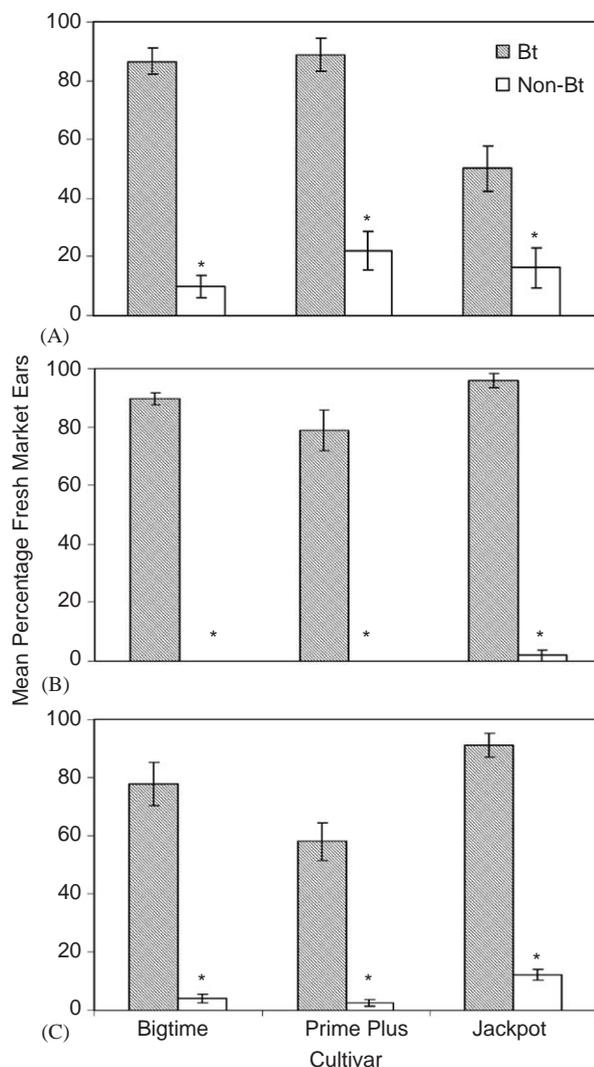


Fig. 3. Mean percentage (\pm SEM) of fresh-market quality ears produced by *Bt* sweet corn hybrids and non-*Bt* isolines at three locations in Virginia in 2002: (A) ESAREC near Painter; (B) TAREC near Suffolk; and (C) Kentland Farm near Blacksburg. The asterisk indicates a significant difference $P < 0.05$ between *Bt* and non-*Bt* ($n = 6$).

with the non-*Bt* isolines for all cultivars and locations ($P < 0.05$; Fig. 4). *O. nubilalis* stalk damage was essentially absent in the *Bt* lines, indicating the *Bt* gene was expressed in green tissue as well as silks and husk. The number of *O. nubilalis* tunnels per 10 plants ranged from 5 to 45 in non-transformed cultivars. The significant *O. nubilalis* stalk damage in non-*Bt* cultivar treatments was probably responsible for the slight reduction in ear number in non-*Bt* cultivars as compared with *Bt* sweet corn lines.

3.3. Partial budgeting analysis

Using an average fresh-market yield loss to insect damage of 21.8% for non-*Bt* sweet corn sprayed five

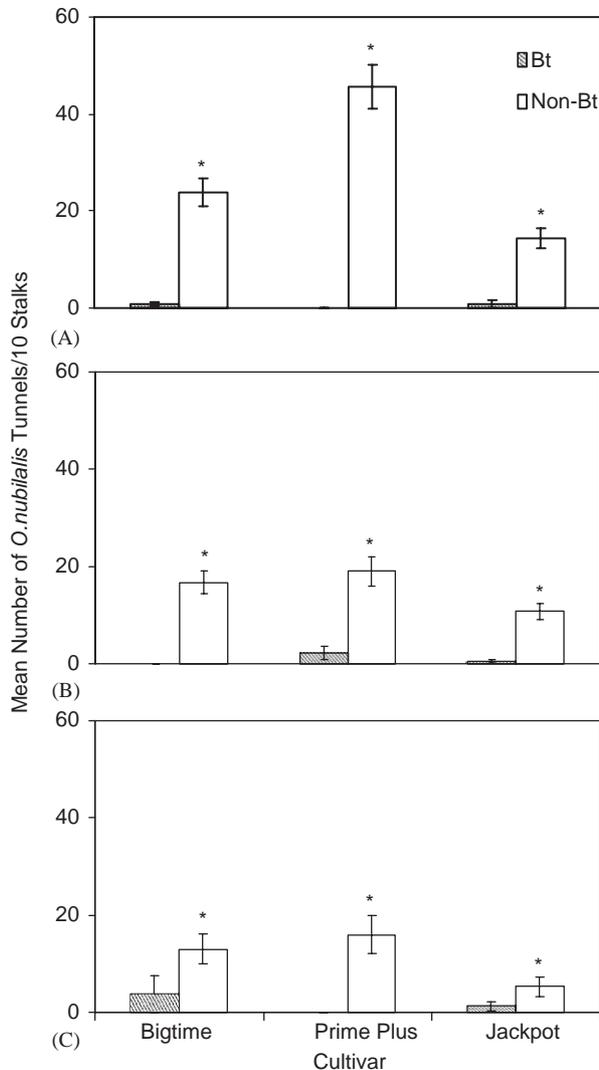


Fig. 4. Mean number (\pm SEM) of *O. nubilalis* stalk tunnels per 10 plants in *Bt* sweet corn hybrids and non-*Bt* isolines at three locations in Virginia in 2002: ESAREC near Painter; (B) TAREC near Suffolk; and (C) Kentland Farm near Blacksburg. The asterisk indicates a significant difference $P < 0.05$ between *Bt* and non-*Bt* ($n = 6$).

times with pyrethroids, 12.0% for *Bt* sweet corn sprayed two times with pyrethroids, 19.5% for sweet corn with no insecticides, and 85.0% for unsprayed non-*Bt* sweet corn, the cost benefit of growing *Bt* sweet corn in Virginia with respect to pest management is shown in Table 3. Based on these data, it is not profitable to grow fresh market sweet corn in Virginia without controlling insects; rather, an estimated net loss of \$7235 would be expected. The net profit is higher for *Bt* cultivars alone (\$4345/ha) compared with that of conventional non-*Bt* cultivars with five applications of insecticides (\$3798/ha). However, the overall net profit would be highest for *Bt* cultivars with two applications of a pyrethroid insecticide (\$5575/ha).

4. Discussion

Bt sweet corn hybrids provided significant protection against insect pests in Virginia. Three different *Bt* hybrids averaged 50–96% fresh-market quality ears compared with 0–21% for non-transformed hybrids. In similar studies conducted in the Midwest, Burkness et al. (2002) obtained an average of 70–90% fresh market quality ears in the *Bt* hybrids compared with 14–41% fresh market quality ears in the non-transgenic hybrids.

Although the *cry1A(b)* gene from *B. t. kurstaki* that was transferred into sweet corn hybrids is not toxic to non-lepidopteran species, densities of sap beetle, *Carpophilus* spp., larvae and adults were lower in the *Bt* sweet corn lines than in the non-*Bt* lines. Because these insects typically infest ears that have been previously damaged by other pests, usually corn earworm, we believe that this observation is primarily a consequence of achieving excellent control of the lepidopteran pest complex.

The use of *Bt* sweet corn hybrids provided better insect control than non-*Bt* sweet corn treated with conventional insecticide applications. Under moderate pest pressure, the *Bt* hybrid, GSS 0966, averaged 88% marketable ears compared with 49% in the non-*Bt* isolate, Prime Plus, treated with four applications of λ -cyhalothrin. Under heavy pest pressure, GSS-0966, averaged 69% marketable ears compared with 27% in the Prime Plus treated with six applications of λ -cyhalothrin. Similar results were obtained by Lynch et al. (1999b) in Georgia using the *Bt* transgenic cultivar GH-0937 and the non-*Bt* hybrids, Bonus and Silver Queen, with up to 5 applications of the carbamate insecticide, methomyl.

In addition to ear protection, *Bt* sweet corn also had significantly less stalk damage by *O. nubilalis*, which in some instances may have contributed to numerically higher yields (numbers of ears produced) in the *Bt* hybrids compared with non-*Bt* hybrids. Sorensen and Holloway (2001) obtained a similar reduction in stalk tunnels with a *Bt* Attribute™ hybrid in North Carolina. Stalk tunneling by *O. nubilalis* can reduce yields by severely weakening the plant, allowing entry to certain plant pathogens, and causing it to lodge or drop ears (Mason et al., 1996). *Bt*-transformed field corn typically provides 80–100% control of *O. nubilalis* tunnel damage, which often results in substantial economic increases in grain yield under heavy pest pressure (Pilcher and Rice, 2001, 2003).

Based on our economic cost–benefit analysis, it is not profitable to grow fresh-market sweet corn in Virginia without adequate insect pest management. By not protecting the ears from insect damage, a net loss of approximately \$7500 per hectare would be expected. Even though the cost of *Bt*-transgenic seed is nearly twice as high as traditional seed, it costs approximately \$135/ha less to produce acceptable ($\geq 88\%$) market

Table 3
Partial budgeting (US dollars) comparisons of sweet corn production in Virginia using different insect pest management approaches

	Fixed costs(\$/ha) ^a	Seed cost (\$/ha) ^b	Insecticide applications (\$/ha) ^c	Total input cost (\$/ha)	Estimated yield loss (%) from insect damage	Estimated (\$/ha) loss from insect damage ^h	Net profit ⁱ
Non- <i>Bt</i> + 5 pyrethroid sprays	9725	195	280	10,200	21.8% ^d	3903	3798
<i>Bt</i> + 2 pyrethroid sprays	9725	340	113	10,178	12.0% ^e	2148	5575
<i>Bt</i> without sprays	9725	340	0	10,065	19.5% ^f	3490	4345
Non- <i>Bt</i> without sprays	9725	195	0	9920	85.0% ^g	15,215	−7235

^aBased on O'Dell et al. (2001).

^bBased on estimate provided by Syngenta Seeds, Inc. in December 2003.

^cCost of material for 5 applications of λ -cyhalothrin at 0.034 kg/ha at current market price + \$/ha cost of application based on 25 operating hours/ha/season).

^dMean (100—% fresh market ears) using a standard insecticide program of 5 applications of a pyrethroid was derived from sweet corn insecticide efficacy studies conducted at the ESAREC from 1998 to 2003 and from the 2000 Trial 2 study herein.

^eMean (100—% fresh market ears) from *Bt* sweet corn plots with two insecticide applications in ESAREC 2000 Trial 1 study.

^fMean (100—% fresh market ears) derived from *Bt* sweet corn plots in ESAREC 2000 Trials with no insecticide and 2002 ESAREC, TAREC, and Kentland studies.

^gMean (100—% fresh market ears) derived from the untreated control plots in sweet corn insecticide efficacy studies conducted at the ESAREC from 1998 to 2003.

^hBased on an ideal fresh market yield (in the absence of insect pressure) of 4475 dozen total ears/ha \times proportion insect damage \times \$4.00/dozen.

ⁱNet profit = potential value—[total cost/ha + \$ loss from insect-damaged ears]. The potential value is estimated at \$17,900/ha = maximum fresh market yield (in the absence of insect pressure) of 4475 dozen total ears/ha \times \$4.00/dozen.

quality sweet corn with *Bt* cultivars versus growing the conventional non-*Bt* isolines and treating them with five insecticide applications. Since marketable yield would be slightly higher (2.3%), on average, in the *Bt* lines compared with insecticide-sprayed sweet corn, the overall net profit would be approximately \$547/ha more for the *Bt* lines versus conventional sweet corn production with insecticides. If *Bt* sweet corn was sprayed twice with an insecticide, this gain should be approximately \$1777/ha. Assuming that the *Bt* sweet corn ears can be marketed equivalently to non-transformed cultivars, the *Bt*-transgenic approach to pest management may be a sound investment for Virginia sweet corn growers because it alleviates the time demands as well as the health and environmental risks associated with multiple insecticide sprays. Moreover, growers often cannot make it to the field in a timely manner to accomplish the intensive insecticide spray regime recommended for sweet corn production. Consumer acceptance of *Bt* sweet corn as well as other transgenic crops will be a major factor governing the future use of this effective pest management strategy. Studies on this topic have recently been conducted in the eastern United States (J.S. James and S.J. Fleischer, Pennsylvania State University, *personal communication*), but have not yet been published.

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