Research Reports

Phytotoxicity and Pollination Disorders in Sweet Corn Due to Direct-silk Applications of Materials Used for Alternative Corn Earworm Control

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SUMMARY. Corn earworm [CEW (*Helicoverpa zea*)] is one of the most important pests of sweet corn (*Zea mays*) in New England. Conventional management of this pest is achieved through repeated applications of chemical insecticides through the silking period.

Organic growers, however, have few alternatives to prevent CEW infestation. Technology first developed in the 1930s and 1940s, using applications of mineral oil directly into the silk channel with an eyedropper, has been further researched in recent years using vegetable oils with and without pesticides, but pollination problems associated with these treatments have been observed. Several materials were evaluated for efficacy in controlling CEW populations and for phytotoxicity to the developing ear. Materials evaluated were corn oil, soy oil, carrageenan, corn oil mixed with *Bacillus thuringiensis* ssp. *kurstaki* (*Bt*), soy oil mixed with *Bt*, and carrageenan mixed with *Bt*. All treatments were compared with an untreated control. Treatments provided a range of 33% to 50% control of CEW infestation. The oil and *Bt* combinations provided some reduction in infestation compared with the untreated controls (33% vs. 100% infestation), but this level of control was inadequate for all wholesale markets and most direct markets. Additionally, oil-based treatments also caused significant injury to developing ears by reducing pollination quality, impacting the development of the kernels at the ear tip. This condition referred to as “cone-tip” is of concern since it may decrease marketability. The percent unmarketable ears due to cone-tips ranged from 0% to 13% for the untreated and carrageenan-based treatments. From 12% to 42% of ears were unmarketable due to the soy oil treatments. Corn oil treatments caused 10% to 50% cone-tips.

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Corn earworm (CEW) is a serious pest of sweet corn that can be difficult to manage, especially for organic growers. An

early method of controlling CEW in the United States during the 1930s and 1940s was injection of small amounts of mineral oil into the silk channel, either alone or mixed with an insecticide (Barber, 1938, 1940; Carruth, 1942; Marcovitch and Stanley, 1940). The oil is thought to coat the larva's spiracles and hamper breathing as the insect feeds on the silks and corn kernels. The addition of an insecticide provides another mode of action (neurotoxin, antifeedant, etc.) that increases levels of control. Growers and gardeners typically used an eyedropper or oilcan to treat individual ears once in a season, about 4 d after silks first appeared (Barber, 1940). Treating individual ears lost favor once chemical insecticide sprays became widely available. Growers quickly adopted them due to their high efficacy, ease of application, and relatively low cost.

Due to the environmental, human health, and resistance risks, as well as regulatory pressures associated with conventional pesticide use, many consumers and growers are now seeking alternatives to conventional pesticide use. Some researchers have revisited techniques used by growers before the development of synthetic pesticides. The Kerr Center for Sustainable Agriculture (KCSA) in Oklahoma and R. Hazzard of the University of Massachusetts Cooperative Extension began conducting experiments in the 1990s using oil silk treatments, combined with *Bacillus thuringiensis* spp. *kurstaki* (*Bt*) products in an effort to develop an organic management technique for CEW on small commercial farms (Cook et al., 2003, 2004).

In the 1940s, mineral oil was used, but, because it is a petroleum product, this material does not meet current organic certification standards (Hazzard, 2003). Recent research has focused on corn and canola oil because as food-grade products, they may be used in organic production.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg-ha ⁻¹	0.8922
28.3495	oz	g	0.0353
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

In researching the efficacy of direct-silk application of oils and *Bt*, a precise means of regulating the amount of the suspension that is applied to each ear also needed to be developed. A plastic, hand-held applicator called the Zea-Later (Johnny's Selected Seeds, Winslow, Maine) was developed by Hazzard (1998) to deliver a small, precise dose of oil (0.5 mL) to each ear. This volume is thought to be adequate to suffocate the CEW larva, but not enough to damage the developing corn tissue (Johnny's Selected Seeds, 2002). Oils applied to corn can damage the plant tissues if applied in a high enough dose (Hazzard, 1998).

The efficacy of oil treatments has been demonstrated in some experiments, but phytotoxicity or damage to the developing ear from reduced pollination quality as a result of these applications is not well documented (Cook et al., 2003, 2004; Hazzard, 2003). Early experiments by the authors found up to 88% cone-tip injury due to corn oil + *Bt* treatments (T.L. Jackson and D.T. Handley, unpublished). The objectives of this study were to determine the degree of injury to the ear that occurs following different direct-silk treatments, and whether alternative materials, such as soy oil or carrageenan, might be effective carriers for *Bt* when used with the Zea-Later for suppressing CEW populations, without the phytotoxic effects, and finally, to assess the marketability of the ears receiving the treatments.

Materials and methods

FIELD PREPARATION. Field studies were conducted in 2002 and 2003. In 2002, the experiment was done at three locations in Maine: Highmoor Farm (University of Maine Agricultural Experiment Station) in Monmouth (lat. 44°14'N, long. 70°02'W); Maxwell's Farm (commercial vegetable operation) in Cape Elizabeth (lat. 43°34'N, long. 70°12'W); and Anderson's Farm (commercial vegetable operation) in Dayton (lat. 43°33'N, long. 70°35'W). In 2003, the experiment was conducted at two locations: Highmoor Farm and Roger's Farm (University of Maine Agricultural Experiment Station) in Stillwater (lat. 44°55'N, long. 68°41'W).

A randomized complete-block design with four replications in 2002

or five replications in 2003 was used at each location. 'Delectable' sweet corn was mechanically planted in all locations with an in-row spacing of 10 inches and between-row spacing of 3 ft. In 2002, plots consisted of five rows 45 ft long. In 2003, each plot had four rows 35 ft long. There was no irrigation in any location, and no insecticide applied before treatment with the Zea-Later.

TREATMENT PREPARATION. The following silk treatments were evaluated for CEW control and phytotoxicity to the ear: corn oil (Hannaford Bros., Scarborough, Maine), corn oil + *Bt* (Dipel DF; Valent Agricultural Products, Richardson, Texas), soy oil (Golden Natur'l Spray Oil; Stoller Enterprises, Inc., Houston, Texas), soy oil + *Bt*, carrageenan (Viscarin GP-328NF; FMC Biopolymer, Philadelphia, Pa.), and carrageenan + *Bt*. The materials were mixed according to rates described by Hazzard (1998) and Cook et al. (2003). *Bt* treatments were mixed according to the manufacturer's recommended rate of 0.5 lb/acre of Dipel DF *Bt* when applied with the Zea-Later.

The corn oil treatment was prepared by mixing 1 L of corn oil with 1 mL food-grade soy lecithin (Fearn Natural Foods, Mequon, Wis.). The lecithin was added as an emulsifier to the corn oil + *Bt* formulation and was added to the corn oil treatment to ensure that the only difference between these treatments would be the presence or absence of *Bt*.

The soy oil used in the study was an Organic Materials Review Institute (OMRI)-listed product. The material is 93% soybean oil and 7% proprietary emulsifier. Because it already contained an emulsifier, no additional preparation was required.

The carrageenan treatment was prepared by the addition of 15 g of carrageenan powder to 950 mL distilled water heated to 52 °C. This liquid was allowed to sit overnight to form a gel with the approximate viscosity of the oils.

The corn oil + *Bt*, soy oil + *Bt*, and carrageenan + *Bt* solutions were prepared by mixing 1 oz Dipel DF with enough distilled water to make a paste. Once thoroughly mixed, the volume was adjusted to 100 mL by adding distilled water. The *Bt* and water paste was then added to the 900 mL corn oil and

lecithin solution, the soy oil, and the carrageenan gel.

All mixtures were shaken periodically during treatment in the field to ensure that the *Bt* remained in suspension.

MONITORING FOR CEW. The Monmouth, Cape Elizabeth, and Dayton sites were monitored for CEW from planting through harvest using Harstack (wire cone) style pheromone-baited traps (Maine Cage Co., Lewiston, Maine). Traps were placed within each field and baited with a CEW pheromone lure (Lure-tape; Hercon Environmental, Emigsville, Pa.). The numbers of moths in each trap were recorded twice weekly throughout the season. There was no trap at the Stillwater location in 2003.

TREATMENT APPLICATION AND HARVEST. Direct-silk applications of the treatments were made 8 d after 50% of the ears exhibited silks protruding 1 inch or more above the tip of the ear (i.e., silk day 8) (Cook et al., 2003), which corresponds with the application timing in other studies. Treatments were made directly into the silk channel using the Zea-Later or 1-mL plastic syringes calibrated to deliver 0.5 mL. One hundred ears per plot were treated in 2002 and 30 ears per plot were treated in 2003. Treated ears were flagged to ensure that only treated ears were harvested for analysis. Untreated ears in the control plots were also flagged. Treated and control ears were harvested from the plots when the silks had browned and the kernels were at the milk stage. Harvest dates were 27 Aug. through 11 Sept. 2002 and 25 Aug. through 5 Sept. 2003.

DATA COLLECTION AND ANALYSIS. Each treated ear was husked and examined for insect or treatment injury. The species and number of each larva found was recorded, as well as the extent of the cone-tip or other ear injury due to treatment. Cone-tips were classified into one of four classes based on the length of the area of undeveloped kernels at the ear tip: 0 = well-filled tips; 1 = <1 inch of undeveloped kernels; 2 = 1–2 inches; and 3 = >2 inches. Ears classified with cone-tips of 0 and 1 (<1 inch of unfilled kernels at the ear tip) were considered marketable, while cone-tips ratings of 2 and 3 (>1 inch) were considered unmarketable. Reduced pollination quality in areas of the ear

other than the tip was rated on a presence or absence basis, where an ear displaying poor pollination down the side, at the base, or all over was deemed poorly pollinated (Fig. 1).

The percent of infested ears, percentage of ears exhibiting poor pollination, and the cone-tip rating of each treatment group was subjected to analysis of variance using the PROC Means and PROC ANOVA functions of SAS (SAS version 8.2 for Windows; SAS Institute, Cary, N.C.). Mean separation was determined with Tukey's honestly significantly different test at the 0.05 level.

Results

INFESTATION. In 2002, the Cape Elizabeth location had the highest CEW populations over the season (Table 1). Pheromone trap catches of moths there were more than twice the catches in Monmouth and 14 times higher than the catches in Dayton. Moth captures >3 moths/week exceed the previously calculated economic threshold and necessitate an insecticide spray to prevent significant injury (Dill and Handley, 1996).

In 2002, 100% of the ears harvested in Monmouth and Cape Elizabeth were infested with CEW, thus no significant difference was observed between treatments. Under high pest pressure (>50 moths caught per week), none of the silk treatments tested provided adequate control of CEW (Table 2). In Dayton, where CEW populations were much lower, there were no significant differences in infestation among treatments.

In 2003, the CEW populations at Monmouth were more moderate, ≈31% of the 2002 trap catch (Table 1). In the 2003 experiments, significant differences were detected among the silk treatments for controlling CEW at the Stillwater and Monmouth locations. Corn oil + *Bt* and soy oil + *Bt* treated ears had the fewest infested ears (32.7% to 53%), followed by ears treated with one of the oils alone (70% to 79.3%). The cargeenan treatments had the highest levels of infestation, not significantly different from the untreated control, with nearly 100% of the ears classified as unmarketable due to CEW infestation (Table 2).

CONE-TIPS AND REDUCED POLLINATION QUALITY. No cone-tip ratings were made on the ears

Fig. 1. Sweet corn ears treated with various mixtures applied with the Zea-Later (Johnny's Selected Seeds, Winslow, Maine). (A) Ear treated with soy oil; this ear exhibits a cone-tip rating of 1. (B) Ear treated with soy oil + *Bt* (*Bacillus thuringiensis* spp. *kurstaki*); this ear exhibits a cone-tip rating of 2 and poor pollination all over the ear. (C) Ear treated with corn oil only; this ear has a cone-tip with a rating of 3 and poor pollination along the length of the ear.

Table 1. Weekly CEW moth trap catches during 2 years at three locations in Maine.

Date	2002			2003 ^a
	Dayton	Cape Elizabeth	Monmouth	Monmouth
1 July	0	2	0	0
8 July	1	4	0	0
15 July	0	2	0	0
22 July	0	1	0	0
29 July	5	25	2	6
5 Aug.	5	53	11	3
12 Aug.	0	238	3	90
19 Aug.	43	318	141	7
26 Aug.	0	116	188	1
Season total	54	759	345	107

^aNo data on Stillwater in 2003.

harvested from Cape Elizabeth and Monmouth in 2002. These ears were 100% infested with CEW and exhibited such extensive feeding damage that it was not possible to rate for cone-tip injury. In Dayton in 2002 and in Monmouth and Stillwater in

2003, all oil treatments caused significant cone-tip injury to the ears (Table 3). In Dayton, corn oil alone and soy oil alone caused the most severe cone-tips ($F = 67.33$; $df = 6$; $P < 0.0001$) (Table 3), with an average of just over 1 inch of cone-tip per

Table 2. Percent of nonmarketable sweet corn ears due to infestation by CEW at four locations in Maine.

Silk treatment ^z	Non-marketable ears (%)				
	2002 ^y			2003 ^y	
	Dayton	Cape Elizabeth	Monmouth	Monmouth	Stillwater
Soy oil	4.1 a	100	100	73.3 b	79.3 ab
Soy oil + <i>Bt</i>	1.6 a	100	100	33.3 c	57.7 c
Corn oil	5.9 a	100	100	70.0 b	74.7 ab
Corn oil + <i>Bt</i>	4.3 a	100	100	32.7 c	53.0 c
Carrageenan	6.2 a	100	100	95.3 a	93.3 a
Carrageenan + <i>Bt</i>	5.0 a	100	100	90.7 a	86.7 a
Control	4.9 a	100	100	69.7 b	96.0 a

^z*Bt* = *Bacillus thuringiensis* ssp. *kurstaki*.^yValues in the same column followed by the same letter are not significantly different via Tukey's honestly significantly different test at $P > 0.05$.**Table 3. Average cone-tip rating for corn ears receiving silk treatments to control CEW at three locations in Maine.**

Silk treatment ^z	Avg cone-tip rating (0–3 scale) ^y		
	2002 ^x	2003 ^x	
	Dayton	Monmouth	Stillwater
Soy oil	1.04 a	1.44 a	1.30 a
Soy oil + <i>Bt</i>	0.70 b	1.43 a	1.27 a
Corn oil	1.26 a	0.71 b	1.30 a
Corn oil + <i>Bt</i>	0.97 ab	0.87 b	1.11 a
Carrageenan	0.07 c	0.00 c	0.01 b
Carrageenan + <i>Bt</i>	0.09 c	0.50 c	0.03 b
Control	0.06 c	0.00 c	0.00 b

^z*Bt* = *Bacillus thuringiensis* ssp. *kurstaki*.^y0 = no cone-tip; 1 = cone length of <1 inch; 2 = cone length of 1–2 inches; 3 = cone length > 2 inches (1 inch = 2.54 cm).^xValues in the same column followed by the same letter are not significantly different via Tukey's honestly significantly different test at $P > 0.05$.

ear, or $\approx 14\%$ of the length of the ear. The carrageenan and carrageenan + *Bt* treatments were not significantly different from untreated controls at any location. Cone-tip observed in the control plots at Dayton was attributed to normal reduced pollination at the tip incited by varying weather conditions during pollination or silks clipped by incidental insects such as Japanese beetle (*Popillia japonica*), which were observed here and nowhere else.

In Monmouth, the soy oil and soy oil + *Bt* treatments were significantly more injurious to ears than any other treatments in 2003 ($F = 43.63$; $df = 6$; $P < 0.0001$) (Table 3). Corn oil + *Bt* and corn oil alone also caused significant cone-tipping. The carrageenan treatments had little cone-tip damage and were not significantly different from the untreated controls. At Stillwater in 2003, all of the oil-based treatments were statistically similar in cone-tip ratings ($F = 24.12$,

$df = 6$; $P < 0.0001$) (Table 3), causing an average of 1.2 inches of unpollinated kernels at the tip of treated ears, significantly higher than the carrageenan treatments and the untreated control.

Ears with cone-tip rating 1 (<1 inch) were considered marketable under circumstances where the cause of the injury can be explained to the consumer (e.g., a roadside stand; Cook et al., 2003). Ears with cone-tips greater than 1 inch, classes 2 and 3, were considered unmarketable. Over 80% of the ears from the control and carrageenan-based treatments were classified as marketable combined over the 2 years and three locations (Fig. 2). The addition of *Bt* did not appear to have any impact on cone-tip. Both oils decreased marketability substantially. Corn oil-treated ears were slightly more marketable.

The ears were also rated for poor kernel development due to poor pollination in areas other than the ear tip

(Fig. 1C). Less than 1% reduced pollination quality was observed in the 2002 Dayton experiment across treatments (Table 4). Also, no statistical differences between treatments were detected for reduced pollination in the 2003 Monmouth experiment. In the 2003 Stillwater experiment, all silk treatments were statistically similar regarding pollination quality and all treatments significantly reduced pollination compared with the untreated control. The ears receiving the corn oil + *Bt* treatment had the highest level of injury (21.3%), with the remaining treatments resulted in 8% to 11.3% of the ears showing signs of poor pollination. Only 1.3% of the untreated control ears exhibited reduced pollination quality in areas of the ear other than the tip.

Discussion

INFESTATION. During the 2003 growing season, ear infestation rates varied greatly according to treatments, ranging from a high of 97% at Monmouth control plots, to a low of 33% for corn oil + *Bt* treated plots. At Stillwater in 2003, 96% of the ears harvested from the control plots were infested while the lowest rate, 53% was achieved by application of soy oil + *Bt*. Our results agree with previous research (Cook et al., 2003, 2004; Hazzard, 2003), indicating that adding *Bt* to oil treatments applied to the silk channel is more effective for controlling CEW than applying oils alone. The mode of action of the oil is believed to be asphyxiation, while the *Bt* acts as a stomach poison. Our research supports the claim that these modes of action complement one another to provide greater level of control against CEW.

The efficacy of carrageenan with or without *Bt* was inconsistent. Carrageenan by itself provided little or no control of CEW, and when combined with *Bt* was still not as effective as either of the oils or oil + *Bt* treatments. However, the carrageenan-based treatments showed little phytotoxicity to the ears when compared with the oil treatments.

In two locations in 2002, when CEW moth catches were greater than 100 moths per week during silking, 100% of the ears were infested with CEW and not marketable. The fact that these two sites were 100% infested by CEW suggests that, under

Fig. 2. Percentage of sweet corn ears graded into three market classes due to cone-tip disorder as a result of silk treatment applied for control of CEW in the 2002 and 2003 growing seasons. Marketable ears have no cone-tip. Ears with cone-tips less than 1 inch are marketable with an explanation to the consumer. Cone-tips greater than 2 inches were considered nonmarketable. Vertical bars = SE, 1 inch = 2.54 cm.

Table 4. Percentage of corn ears showing reduced pollination following silk treatment for control of CEW at three locations in Maine.

Silk treatment ^z	Ears showing reduced pollination (%)		
	2002 ^y Dayton	2003 ^y Monmouth	2003 ^y Stillwater
Soy oil	0.5 a	5.3 a	9.3 a
Soy oil + <i>Bt</i> ^y	0.6 a	15.3 a	8.1 a
Corn oil	0.4 a	1.3 a	10.7 a
Corn oil + <i>Bt</i>	0.7 a	3.3 a	21.3 a
Carrageenan	0.5 a	2.0 a	11.3 a
Carrageenan + <i>Bt</i>	0.4 a	2.0 a	8.0 a
Control	0.5 a	0.0 a	1.3 b

^z *Bt* = *Bacillus thuringiensis* ssp. *kurstaki*.

^y Values in the same column followed by the same letter are not significantly different via Tukey's honestly significantly different test at $P > 0.05$.

high pest pressure, there was a complete breakdown in efficacy of all of the silk treatments. Even when moth trap counts were relatively low for most of the growing season, none of the treatments provided adequate levels of CEW control in this study.

The organic wholesale market tolerates no more than 4% insect infestation, slightly greater tolerance than 2% infestation allowed in conventional markets (Hazzard, 1991). Growers who retail their own crop may have a slightly higher tolerance, up to perhaps 10% infestation, because the ears may be inspected

before being sold. At more than triple the highest tolerance, the 33% infestation rate, which was the best of any of the treatments evaluated, was too high for any grower. Thus, the results of this study suggest that the silk treatments tested did not provide acceptable levels of control for CEW.

It may be possible that, under some circumstances, carrageenan, which did not cause significant toxicity, may be able to provide a suitable means to carry insecticidal materials such as *Bt*, neem, or spinosad into the silk channel to provide CEW control. However, it was clear from this study

that carrageenan by itself or in combination with *Bt* did not provide control of CEW.

CONE-TIPS AND REDUCED POLLINATION QUALITY. The silk treatments in this study were only marginally effective, and in some cases they caused severe injury to ears that rendered them unmarketable. In these experiments, ears treated with an oil-based material exhibited significantly higher rates of cone-tips than untreated ears or those treated with a carrageenan-based material (Table 3). Previous research noted similar effects (Carruth, 1942; Cook et al., 2003, 2004; Hazzard, 2003) but not to the extent found in these experiments. Even when cone-tips were evaluated, the importance of the disorder in assessing marketability was discounted (Cook et al., 2003).

Cook et al. (2003) reported cone-tip as a percentage of ear length and reported a range of injury from 2% to 20% of the ear length. Cook et al. (2003, 2004) reported reductions in cone-tip injury to $\approx 9\%$ of ear length by treating after silk day 5. However, they did not report how many ears were affected. In the experiments reported here cone-tip injury was an important factor resulting in unmarketable ears. The oil-based treatments resulted in up to 50% loss of marketable ears. In earlier work by the author, up to 88% of ears treated on silk days 6–8 sustained injury (T.L. Jackson and D.T. Handley, unpublished). It appears the degree of cone-tipping varies with environmental conditions and locations.

In experiments conducted in 2003, all ears receiving treatments showed a higher rate of undeveloped kernels in other areas of the ear than the control (Table 4) although only significantly higher at Stillwater. At Monmouth, the highest degree of poor pollination (15%), distinctly different from cone-tips, was found in ears treated with soy oil + *Bt*, although this was nonsignificant.

Cook et al. (2003) suggested that the oil placed in the silk channel coats the trichomes that cover the silks, rendering them unable to capture pollen grains, or perhaps inhibits the ability of the pollen tube to grow through the silk to the kernel. In these experiments, the authors observed that many ears treated with

the oil (corn or soy) and *Bt* solution had silks that had thinned and severed in the location where the material settled in the silk channel. It is possible that oil or *Bt* had a corrosive effect on silk tissue. These severed silks were generally associated with unpollinated kernels on the cob. Ears treated with carrageenan or carrageenan + *Bt* did not exhibit severed silks, suggesting that the oils, not the *Bt*, were responsible for the injury. This suggests phytotoxicity played some role in the malformation of ears treated with oil, perhaps interfering with pollination or injuring developing kernels. The death of silks may also have halted fertilization. The carrageenan-based treatments were statistically similar to untreated controls in cone-tips and pollination and thus appear to have little phytotoxic effect. Using carrageenan as a carrier for a toxin other than *Bt* may be an alternative to the oils in the future.

Application technique is also not likely to be responsible for the high rates of phytotoxicity and reduced pollination quality, as at least six different applicators and three Zea-Laters were used during the experiments in 2002 and 2003. Thus, it is probable that the injury observed in this study was a direct result of the oils that were applied to the silks which caused injury to the plant tissues, either by interfering with pollination or inhibiting seed development (Cook et al., 2003; Kuepper et al., 1991).

Cone-tip has not been used as an indicator of marketability in southern New England as consumer reaction to it is variable (Cook et al., 2003). It has been suggested that growers who sell directly through farm stands and farmers markets can explain the cause for the cone-tips, and therefore

mitigate the rejection of these ears based on the cone-tips. Among those consumers who prefer organically grown sweet corn, such an explanation by the grower may be adequate. However, it is unlikely that this type of explanation would be acceptable to wholesale markets where ears are expected to be filled to the tip and be less than 2% infested with insects (Hazzard, 1991).

Producers that market value-added products such as prehusked sweet corn might choose to cut off these tips before packaging to improve marketability. This would add to the labor costs. Alternatively, since the CEW only infests the tips of ears, producers could use this same technique to remove insect damage and not treat for CEW in the field.

In this study, treatment of sweet corn ears via direct-silk applications of vegetable oils alone or oils mixed with *Bt* had detrimental effects on kernel development, especially at the tips of the ear. In addition, the level of control of CEW was inadequate for any market. Ears treated with carrageenan or carrageenan mixed with *Bt* did not display the phytotoxicity associated with the oil treatments; however, they were even less effective in controlling CEW. Future research in this area might focus on how to make carrageenan or other non-oil-based silk treatments more efficacious.

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