Status of Bt Sweet Corn Performance and Insecticide Control Requirements

Dr. Galen P. Dively
Department of Entomology, University of Maryland, College Park, MD 20742

Sweet corn producers must rely on timely pest monitoring and effective insecticide sprays to control ear-invading insects. In the Northeast, corn earworm and European corn borer are the primary ear invaders, followed by sap beetles and fall armyworm as secondary pests. The level of infestation varies with the year, time of season, and location. For instance, corn borer infestations have been very low during the past decade due to regional population suppression resulting from the high adoption of Bt field corn. Still, corn earworm infestations typically can cause damage on 10 to 25% of the ears in early plantings, and often greater than 50% ear damage in late plantings if not controlled. Insecticide control programs are costly, pose exposure risks to the applicator and farm workers, and require considerable time and management to implement.

The cheaper pyrethroids (Group 3A) have been the popular choice, but control efficacy has significantly declined due to resistance in corn earworm populations. Spray mixtures of Lannate® (Group 1A) plus a pyrethroid are often used to circumvent the resistance problem and improve control of sap beetles. Rotations and mixtures with different active ingredients such as Coragen (Group 28), Radiant (Group 5), Blackhawk (Group 5), as well as premix products (i.e. Besiege (Group 3A + 28), Voliam Xpress (Group 3A + 28), and Consero (Group 3A + 5) are also increasingly used. However, the reality is that pyrethroids are no longer providing enough ear protection on many farms, so it is becoming necessary to switch or rotate to one of these alternative products. For all insecticides, timing the first spray at early silking, applying subsequent sprays on a schedule that are based on moth pressure, and achieving adequate spray coverage of the ear zone are critical components of effective control. Corn earworm eggs are laid directly on the silks; once larvae hatch, they quickly move down the silk channel and begin feeding on the ear tip, where they are protected from insecticidal sprays. Thus, it is absolutely necessary to target larvae before they enter the ear by protecting silk tissue when moth pressure is high.

These problems and challenges with conventional insecticide applications can essentially be eliminated with Bt technology. Transgenic Bt technology expresses insect-active toxins from the bacterium, *Bacillus thuringiensis* (Bt) in tissues of the sweet corn plant. This technology has revolutionized the way many corn insect pests are managed, particularly European corn borer, which is virtually 100% controlled by Bt sweet corn. However, the expressed toxins alone do not always provide 100% control of corn earworm or fall armyworm, and thus supplemental insecticide sprays are often needed to ensure quality sweet corn ears, especially during high moth activity. For Bt sweet corn production, there are three types commercially available: Attribute® hybrids (expressing Cry1Ab toxin), Attribute® II hybrids (expressing Cry1Ab and Vip3A), both from Syngenta Seeds, and Performance Series™ hybrids (expressing the Cry1A.105 and Cry2Ab2 toxins) from Seminis Seeds. Expression of the Bt toxin in these hybrids is highly effective against European corn borer, eliminating all whorl and silk sprays in areas where this pest is the primary problem. However, efficacy of Cry1Ab sweet corn for controlling corn earworm has been highly variable since 2008, with increasing concerns over lack of field efficacy. In this article, we present research findings from 21 years of monitoring changes in field efficacy in Bt sweet corn, as evidence of resistance development in corn earworm populations to multiple Cry toxins.

Plots of Bt sweet corn paired with non-Bt hybrids (same genetic line as Bt hybrid) were established at five University of Maryland Research and Education farm facilities (Salisbury, Wye, Beltsville, Upper Marlboro, and Clarksville) from 1996 to 2016 to evaluate corn earworm infestations in ears as a direct measure of efficacy. Plots were not sprayed, so any ear protection observed was a result of the Bt technology. Attribute® hybrids were evaluated during all years, whereas Performance Series™ and Attribute® II hybrids expressing pyramided Bt toxins were developed later and included in trials from 2008 to 2016, alongside Attribute® sweet corn at the same locations. All plots were planted during June to encourage high infestations of corn earworm and sampled to assess ear damage when ears reached fresh market maturity. The following variables were recorded as measures of control efficacy against corn earworm: percentage of ears damaged, kernel area consumed, average instar stage of larvae, and the proportion of late instar (4th – 6th instars) found in ears.

Attribute® hybrids from Syngenta Seeds have been commercially available since 1996, and acreage has increased significantly with the introduction of improved fresh market hybrids and availability of 25K seed units for smaller producers. When first introduced, expression of Cry1Ab toxin in these hybrids provided greater than 95% control of all worms, with very minor injury to a few kernels at the ear tip and only early instar larvae if present (**Fig. 1**). The ear protection allowed producers to eliminate pre-silk treatments and reduce insecticide applications during silking by 70 to 90%.

Figure 1. Representative level of ear protection during 1996-2000 by Attribute® sweet corn (GSS0966) compared to the non-Bt Prime Plus hybrid (right) planted at the same time and exposed to high corn earworm and fall armyworm pressure.

However, ear damage, kernel consumption, instar age, and proportion of late instars have progressively increased since 2000 in Attribute® hybrids. The upper ears in **Fig. 2** shows the representative ear damage typical of BC0805 Bt sweet corn under high corn earworm pressure during 2010-2016. Based on 89 trials evaluated, the percentage of ears damaged in Attribute® Cry1Ab expressing hybrids increased from less than 10% in 1996 to an average of 84% in 2016. The amount of kernel area consumed has more than tripled during the same time, and the proportion of live larvae reaching later developmental stages in ears has increased from less than 5% in 1996 to an average 81% in 2016. These results clearly demonstrate the reduced efficacy of Attribute® sweet corn, and indicate increased resistance in corn earworm populations to the Cry1Ab toxin. This reduction in efficacy was unrelated to corn earworm pressure, because moth activity monitored in blacklight traps has actually declined over the past decade at the farm sites. Sweet corn producers in the Mid-Atlantic growing Attribute® hybrids can apply insecticide sprays to compensate for the reduced efficacy.

Figure 2. Representative level of ear protection during 2010-2016 by Attribute® sweet corn (BC0805, upper ears) compared to the non-Bt Providence hybrid (lower ears) planted side by side and exposed to high corn earworm and fall armyworm pressure.

Seminis Seeds has developed and is now marketing pyramided Bt sweet corn under the Performance Series™ trade name. Some Bt hybrids available are Temptation, Obsession, Passion, and SV9010SA. These hybrids express three insecticidal toxins: Cry1A.105 and Cry2Ab to control lepidopteran larvae, and Cry3Bb1 to control rootworms, as well as herbicide tolerant traits. When this Bt sweet corn was first evaluated in 2010, control efficacy was similar to the level of ear protection by Attribute® hybrids in the late 90's, providing 100% control of fall armyworms and more than 95% control of corn earworms, with very few surviving larvae and only minor injury on the ear tip. However, control efficacy rapidly declined during the last three years, as evident in **Fig. 3** showing unacceptable levels of earworm damage on the ear tip of both single and pyramided Cry-expressing sweet corn. Note that the Attribute® ears show extensive feeding injury by fall armyworm on the side kernels, whereas the Obsession II ears are undamaged by this pest. Six late plantings of Performance Series™ hybrids at research farm sites in

2016 averaged 67% damaged ears with 74% of the surviving corn earworms reaching the late developmental stages.

Figure 3. Representative level of ear protection during 2016 by Attribute® sweet corn (BC0805, left) compared to Performance Series™ sweet corn (Obsession II, right). Both hybrids were planted side by side and exposed to high corn earworm and fall armyworm pressure.

The Attribute® II type of Bt sweet corn by Syngenta Seeds expresses a new Bt gene combination to broaden the spectrum of activity and reduce resistance development. Introduced commercially in 2013, this sweet corn expresses a novel vegetative insecticidal toxin, Vip3A, from *B. thuringiensis*, pyramided with the Cry1Ab toxin. The Vip3A toxin is highly effective against a range of important lepidopteran pests including black cutworm, fall armyworm, corn earworm, and western bean cutworm. Of 13 field trials comparing Attribute® II hybrids with non-Bt hybrids, no live larvae and virtually no ear damage were found in the pyramided hybrids, indicating 100% control efficacy of corn earworm, fall armyworm and European corn borer. The non-Bt hybrids, without insecticide protection, averaged between 43 and 100% ears infested with late instar larvae. **Figure 4** illustrates the level of ear protection by the Vip3A + Cry1Ab expressing Attribute® II hybrid Remedy, compared to Obsession II.

Figure 4. Representative level of ear protection during 2016 by Attribute® II sweet corn (Remedy, left) compared to Performance Series™ sweet corn (Obsession II, right). Both hybrids were planted side by side and exposed to high corn earworm and fall armyworm pressure.

In summary, the field-evolved resistance and associated reduction in efficacy reported could be localized to some extent because Attribute® hybrids still provide moderate to high control efficacy in other areas, particularly northern states where corn earworm does not overwinter. Many factors can contribute to development of insect resistance. The relatively low acreage of Bt sweet corn hybrids is unlikely to have exerted enough selection pressure alone to account for changes in corn earworm susceptibility. Instead, the high adoption rate of Bt field corn and cotton, with the Cry1Ab toxin being used since 1996, has contributed to the selection pressure on earworm populations. Additionally, Cry1Ab and related Cry1Ac toxins are expressed at a moderate dose in these crops and refuge compliance is decreasing, which together have contributed significantly to the evolution of resistance. Unfortunately, corn earworm resistance to the Cry toxins is likely to increase, and spread, with the shift to 'refuge in bag' corn hybrids that contain a blend of 95% Bt and 5% non-Bt seeds. Similarly, due to northward influxes of potentially resistant moths from southern source regions, the risk of further evolution of resistance may increase with the reduced refuge size (from 50% to 20%) in regions where Bt cotton is used. Apart from reductions in the refuge size, there are also concerns that pollen-mediated gene flow between Bt and refuge plants in a seed blend could accelerate resistance evolution. Finally, the potential existence of cross resistance between Cry1Ab and the other Cry toxins may also compromise the efficacy and durability of the new pyramided traits in Bt field and sweet corn.