RESPONSE OF HELICOVERPA ZEA TO DIET-OVERLAY BT TOXINS AND COTTON BT TRAITS FIELD PERFORMANCE IN TEXAS AND THE MID-SOUTH

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Abstract

When Bt cotton was introduced in the United States in 1996, management of the bollworm, *Helicoverpa zea*, had become much less problematic. However, in recent years unexpected *H. zea* damage in Bt cotton has become common place. It is not uncommon for dual-gene Bt cotton to require insecticide applications to manage *H. zea*. There has been much speculation surrounding the reasons for control failures among Bt cotton technologies including Bt resistance or tolerance, inadequate expression of Bt toxins expression due to plant phenology or environmental stressors. The objective of this project was to assess Bt resistance in Cry and Vip3a Bt toxin to determine if resistance is present. Additionally, we evaluated the efficacy of second and third generation Bt cotton at six locations within the Mid-South and two locations in Texas for efficacy towards *H. zea* and to determine if spraying Bt cotton for bollworms results in a reduction in damage and increased yields relative to non-Bt cotton. Our data demonstrates that all currently available Bt cotton technologies may suffer unacceptable bollworm injury. WideStrike appears to be most sensitive to experiencing control failures and benefits from insecticide applications targeting bollworms, if these applications are made in a timely manner. Bollgard II and TwinLink may also suffer control failures, but are less common than WideStrike. Cotton varieties containing the Vip3A toxin provided the greatest level of bollworm control.

Introduction

The cotton bollworm, *Helicoverpa zea*, is one of the most damaging pests of cotton grown in the southern U.S. In 1996, transgenic cotton containing genes expressing Bacillus thuringiensis (Bt) proteins were introduced into U.S. cotton and ushered in a new era in cotton insect pest management. The first Bt cotton introduced in the U.S. was Bollgard I which expressed the Cry1Ac endo-toxin. This toxin was highly effective towards tobacco budworm, *Chloridea virescens*, but moderately toxic towards bollworm, *H. zea*. Insecticide applications targeting tobacco budworm were completely eliminated, while those targeting bollworm were greatly reduced. To increase efficacy and for resistance management, dual and multi-Bt gene cotton varieties have since been introduced. Currently, Bt proteins used in transgenic cotton plants in the U.S. are categorized into three groups: Cry1, which contains Cry1Ab, Cry1Ac, and Cry1F; Cry2, which includes Cry2Ab and Cry2Ae; and Vip3a. The currently available Bt cotton technologies include: Bollgard 2 (Cry1Ac + Cry2Ab), WideStrike (Cry1Ac + Cry1F), TwinLink (Cry1Ab + Cry2Ae), WideStrike 3 (Cry1Ac + Cry1F + Vip3a), TwinLink Plus (Cry1Ab + Cry2Ae + Vip3a) and Bollgard 3 (Cry1Ac + Cry2Ab + Vip3a).

Although new Bt toxin introductions have increased the efficacy of transgenic cotton targeting lepidopteran pests, including bollworm, there are still incidents where unacceptable fruit injury is experienced and insecticidal oversprays are required to preserve yield. In recent years these incidents have become common and extensive in some areas including portions of Texas, the Mid-South and North Carolina. Bollworm resistance to Cry1Ac and Cry2Ab has been implicated as a primary causal factor contributing to Bt cotton efficacy failures.

The objectives of this project were to: 1) To estimate the susceptibility of the field populations of *H. zea* to Bt proteins, 2) To evaluate the efficacy of second and third generation Bt cotton for efficacy towards *H zea*, and 3) To determine if spraying Bt cotton for *H. zea* results in a reduction in fruit damage and increased yields relative to non-Bt cotton.

Materials and Methods

Bacillus thuringiensis Proteins

Susceptibility of *H. zea* was determined against four Bt proteins: Cry1Ac, Cry1F, Cry2Ab2, and Vip3a. Cry1Ac protein was provided by Bayer CropScience as lyophilized MVPII powders with 20.0% AI. Cry1F protein was provided by Corteva AgroScience as lyophilized powders with 53.0% AI. Cry2Ab2 protein was provided by Bayer CropScience in the form of lyophilized (freeze-dried) Bt-corn leaf powder expressing ~4 mg of Cry2Ab2 protein/g. BASF Corporation provided the Vip3Aa1 protein with a purity of 0.29%.

Insect Sources

A total of 20 field populations of *H. zea* were collected from across the Mid-South and Texas in 2018. F_1 or F_2 generations of these field-collected populations were used for the bioassays described below. Detailed collection information is listed in **Table 1**. In addition, two susceptible colonies were also used in the current study. One was obtained from a commercial source Benzon Research Inc., Carlisle, PA (CBW-BZ-SS); the other (CBW-LA-SS) was collected by Dr. David Kerns in Winnsboro.

Insect Bioassays

For each population, a diet-overlay bioassay was used to evaluate the larval susceptibility of *H. zea* to Cry1Ac, Cry2Ab2, Cry1F and Vip3A toxins. Each bioassay included 7-8 concentrations plus one untreated control. Diet-overlay concentrations for Cry1Ac and Cry2Ab2 ranged from 0, 0.01, 0.0316, 0.1, 0.316, 1.0, 3.16, to 10.0 μg/cm^2; diet-overlay concentrations for Vip3a1 were from 0, 0.01, 0.0316, 0.1, 0.316, 1.0, to 3.16 μg/cm^2; and diet-overlay concentrations for Cry1F ranged from 0, 0.02, 0.04, 0.2, 0.4, 2.0, 4.0, to 8.0 μg/cm^2. We used repeater pipets to dispense 0.8 ml per well of liquid diet (Southland Product, Inc. Lake Village, AR) into 128-well bioassay trays (C-D International, Pitman, NJ). Once the diet cooled and solidified, Bt protein solution suspended in 0.1% Triton-X100 was overlaid onto the diet surface of each well and allowed to air dry. A constant volume of 40 μl Bt protein solution was overlaid into each well for Cry1Ac, Cry1F, and Vip3a1 proteins, while a volume of 200 μl Bt protein solution per well was used for Cry2Ab2 protein. One neonate (< 24 h) of *H. zea* was released on the diet surface in each well. After larval inoculation, wells were covered with vented lids (C-D International, Pitman, NJ). Each combination of insect population by Bt protein concentration was replicated four times with 16-32 larvae in each replication. The bioassay trays were placed in an environmental chamber maintained at 26 ± 1 °C, 50% RH, and a 14:10 (L:D) h photoperiod. Larval mortality, and larval instar were recorded on the 7th day after inoculation.

Bioassay Data Analysis

Larval mortality was calculated based on the number of dead larvae plus survivors that were still in the first instar (mortality = dead+L1) divided by the total number of insects assayed, and was used to determine LC_{50} values and the corresponding 95% confidence limit (CL). Larval mortality at each concentration was first corrected based on the control mortality using the method of Abbott (1925), followed by Probit analysis to determine the LC_{50} that caused 50% mortality and the corresponding 95% confidence limit (CL). Where the LC_{50} 95% CLs for each field collected population did not overlap with the LC_{50} 95% CL of the CBW-BZ-SS susceptible colony, resistance ratio was calculated using the LC_{50} of a field population divided by the LC_{50} of the CBW-BZ-SS susceptible strain. In some cases, the LC_{50} value of an insect population was considered to be greater than the highest Bt protein concentration used in the bioassay if its larval mortality was <50% at the highest concentration assayed. If the LC_{50} value of an insect population was smaller than that of the CBW-BZ-SS, a negative sign was assigned to the resistance ratio. For purposes of defining resistance, we are considering resistance ratios e 10-fold as resistant.

Bt Cotton Technology Field Performance

Tests were conducted at six locations across the Mid-South and two locations in Texas to determine the impact of foliar insecticide applications targeting bollworms on fruit injury and yields in second and third generation Bt cottons. The Bt cotton technologies evaluated included: ST 5122 GLT, TwinLink™ (TL; Cry1Ab, Cry2Ae), ST 5471 GTLP TwinLink Plus™ (TL+; Cry1Ab, Cry2Ae, Vip3A19), ST 1518 B2XF, Bollgard II® (BG2; Cry1Ac, Cry2Ab), DP 1835 B3XF Bollgard II® (BG2; Cry1Ac, Cry2Ab, Vip3A19), PHY 333WRF, WideStrike® (WS; Cry1Ac, Cry1F), and PHY

330WRF3, WideStrike 3® (WS3; Cry1Ac, Cry1F, Vip3A19). A non-Bt variety (NBT) was included as a check, DP 1822 XF.

All tests were 5 x 2 factorials with factor A being the cotton technology and factor B being entries sprayed for bollworms with Prevathon at 20 fl-oz/ac, or untreated. Plots were 4 rows wide x 40-60 ft in length. Each factorial combination was replicated 4 times. Test locations included Tillar and Hooker, AR, Stoneville and Glendora, MS, Jackson, TN, Winnsboro, LA and College Station, TX. Foliar applications were made in accordance with the occurrence of larvae in the non-Bt cotton plots at each individual location. Prevathon applications occurred as follows: Tillar, AR (July 19), Hooker, AR (July 21), Stoneville, MS (July 16 and Aug 3), Glendora, MS (July 16 and Aug 3), College Station, TX1 and College Station, TX2 both on (June 22 and July 11), Jackson, TN (Aug 10)

Field Data Analysis

Insect densities, plant terminal, square, bloom and boll injury were determined prior to foliar treatment and weekly thereafter. At each evaluation, 25 each terminals, squares, bloom and bolls were sampled per plot. The number of bollworm larvae and damage plant tissue were recorded. At all locations, the middle two rows of each plot was harvested using a mechanized cotton picker. Seed cotton yields were converted to lint yields in lbs per acre based on an estimated 40% lint turnout.

All field data were analyzed using PROC GLIMMIX (PROC GLIMMIX SAS Institute Inc. 2011). Data was analyzed across test sites using the random effects of Site, Rep (site) and Bt Tech*Rep (Site). Where significant interactions (P = 0.05) were detected between Bt tech and spray, the SLICEDIFF option of the LSMEANS statement was utilized to determine if a given Bt tech differed, sprayed vs. non-sprayed for difference in yield response.

Results and Discussion

LC_{50} Values of Field-Collected Populations of *H. zea* to Bt Proteins

Detailed data of LC_{50} values for four Bt proteins are listed in **Tables 1-4** for Cry1Ac, Cry2Ab2, Cry1F and Vip3A1, respectively. The LC_{50} values of the susceptible CBW-BZ-SS was 0.10 μg/cm^2 with a 95% CL of 0.08-0.11 μg/cm^2 (Table 1). Compared to CBW-BZ-SS, 19 of 20 field populations (95%) exhibited significantly lower susceptibility to Cry1Ac protein. The only susceptible field-collected population, CBW-WB-LA-CC, originated from crimson clover in Winnsboro, LA; collected in early spring. Among the other field-collected populations, LC_{50} values ranged, 1.25 - >31.6 μg/cm^2, resulting in the resistance ratios from 12.5 - >316.0-fold.

The LC_{50} value of the CBW-BZ-SS on Cry2Ab2 diet was 0.20 μg/cm^2 with a 95% CL of 0.17-0.24 μg/cm^2 (Table 2). Compared to CBW-BZ-SS, 15 of 20 field populations (75%) exhibited significantly high LC_{50} values, ranging 2.22 - >10.00 μg/cm^2 resulting in resistance ratios of 11.1 - >50.0-fold. Susceptible populations were detected in collections from College Station, TX (CBW-CS-TX-VT3P), Grant Parish, LA (CBW-GR-LA-WS3), Natchez, MS (CBW-Natchez-MS-CC), Pine Bluff, AR (CBW-PB-AR-NBt corn) and Savannah County, TN (CBW-JK-TN-BG2).

The LC_{50} value of the CBW-BZ-SS on Cry1F diet was 0.73 μg/cm^2 with a 95% CL of 0.55-0.97 μg/cm^2 (Table 3). All 10 of the populations evaluated on Cry1F diet exhibited resistance, with LC50s >8.00 μg/cm^2, resulting in resistance ratios >10.9-fold. Note that Cry1F at the highest concentration of 8.0 μg/cm^2 failed to result in 100% mortality of the susceptible CBW-BZ-SS (93.75 ± 4.42%), indicating that Cry1F is generally not a highly effective toxin to *H. zea.*

The LC_{50} value of the CBW-BZ-SS on Vip3A1 diet was 0.20 μg/cm^2 with a 95% CL of 0.16-0.26 μg/cm^2 (Table 4). Compared to CBW-BZ-SS, all 23-field populations were susceptible to Vip3A1 protein, with the LC_{50} values ranging from 0.01 to 0.84 μg/cm^2. These LC_{50} values resulted in resistance ratios ranging from -20 – 4.2-fold. Among the 23 field populations evaluated, only 3 populations exhibited positive resistance ratios, CBW-JK-TN-OSC, CBW-CS-TX-WS and CBW-CS-TX-Leptra corn, with resistance ratios of 1.0-fold and 4.2-fold, respectively. The propensity of negative resistance values, some exceptionally low (CBE-JK-TN-BG2 with a resistance ratio of -20.0-fold) may indicate that the CBW-BZ-SS strain may not be a suitable reference strain. However, the LC_{50} of the other susceptible strain evaluated, CBW-LA-SS, did not differ from the CBW-BZ-SS. This may rather indicate that strains maintained on meridic diet for multiple generations may have evolved to better tolerate higher concentrations of Vip3A1, than those maintained on meridic diet for one or two generations. The field-collected strain with the highest LC_{50} value of 0.84 μg/cm^2 with a 95% CL of 0.69-0.97 μg/cm^2, CBW-CS-TX-Leptra-corn, was collected in College Station, TX from corn expressing Vip3A20. Relative to another field-collected population collected the same week from VT3P corn, CBW-CS-TX-VT3P, the CBW-CS-TX-Leptra-corn exhibits a resistance ratio of 21.0-fold. If the CBW-CS-TX-VT3P population is more indicative of baseline field susceptibility, then the diet bioassay results from the CBW-CS-TX-Leptra-corn population suggests a significant event.

These data suggest that susceptibility to Cry1Ac, Cry2Ab2 and Cry1F have been largely compromised in the Mid-South and in Texas. Susceptibility to Vip3A appears to be high, but with evidence of resistance to the current Cry toxins, selection pressure on Vip3A is undoubtable higher than desired, resulting in questionable durability of this toxin. This may be evident in the higher than expected LC_{50} for the CBW-CS-TX-Leptra-corn population originating from corn expressing Vip3A20.

Bt Cotton Technology Field Performance

Across all locations, seasonally averaged square and boll damage was consistently greatest in the untreated NBT, ranging 8.34-67.00% and 2.56-67.00% for damaged squares and bolls, respectively (Table 5). The Tillar, AR site suffered the greatest square damage to NBT, seasonally averaging 67.00%. Whereas damage was lowest at the Winnsboro, LA site which reported 8.34% square damage. Seasonal boll damage was greatest at the Jackson, TN site which averaged 67.00% boll damage, and lowest at the Winnsboro, LA site with 2.56% damage. Prevathon applications reduced square and boll damage in the NBT at all locations with the exception of Winnsboro, LA.

Across locations, fruit damage varied and appeared primarily due to variation in *H. zea* infestation intensity (Table 5). At the Tillar, AR location square damage was lower than the untreated NBT among all Bt technologies. Results were similar for boll damage, although WS did not differ from the NBT. At Tillar, AR, square and boll was similar across Bt technologies, with the exception of WS which had significantly higher square and boll damage than the other Bt technologies. Among the non-WS technologies, BG2 had higher square and boll damage than those expressing Vip3A, but did not differ from TL. At Tillar, AR, Prevathon application reduced square and boll damage in Bt technology cotton relative to its non-Prevathon counterpart for WS, BG2. Square damage at the Hooker, AR site was relatively low among Bt technologies, although BG2 did have significantly lower damage than WS. Additionally at Hooker, AR, TL+ and BG3 had fewer damaged squares than WS. Boll damage among Bt technologies at Hooker, AR was lower than WS for all technologies with the exception of TL. Among, Bt technologies, Prevathon applications at the Hooker, AR site resulted in lower square and boll damage for only WS. At Stoneville, MS, all of the untreated Bt technologies had lower square and boll damage than the untreated NBT except WS, which did not differ from the NBT. Similar to Hooker, AR, among the Bt technologies, only WS benefitted from Prevathon applications in reduced fruit damage. At Glendora, MS among the Bt technologies, WS had the greatest square damage, but was not significantly different from TL or BG2, and all Bt technologies exhibited significantly similar boll damage and were significantly lower than the NBT. NBT and WS were the only entries that benefitted in reduced fruit damage from Prevathon applications. *H. zea* infestation pressure appeared lowest that the Winnsboro, LA site as evidence in the lower incidence of fruit damage in the untreated NBT. At this location, all of the untreated Bt technologies had significantly less square and boll damage than the untreated NBT, and although there were significant differences in square and boll damage among Bt technologies, these were minor. The benefit from Prevathon applications at the Winnsboro, LA site was not realized; neither the NBT nor any of the Bt technologies exhibited significantly lower fruit damage when sprayed. Both College Station, TX locations produced similar results as expected since they were conducted in relatively close proximity to one another. At both locations, the untreated WS plots suffered less square damage than the NBT, but similar boll damage. All of the untreated non-WS Bt technologies had significantly less square and boll damage than the WS, but did not differ among each other. WS was the only Bt technology that significantly benefitted in reduced fruit damage when treated with Prevathon. Seasonal fruit damage was high and the Jackson, TN site, especially for boll damage which averaged 67%. Square and boll damaged was significantly greatest in the NBT followed by WS. All of the untreated non-WS Bt technologies suffered less square damage than the WS but did not differ among each other. Results were slight different for boll damage where although the untreated non-WS had significantly less boll damage than untreated WS, WS3, TL+ and BG3 suffered less damage than TL and BG2. Consequently, NBT, WS, TL and BG2 all benefitted in reduced boll damage from a Prevathon application, whereas there only NBT and WS benefitted in reduced square damage.

To normalize fruit damage data across locations for the untreated Bt technologies, square and boll damage were converted to percentage reduction relative to the untreated NBT (Table 6). The percent reduction generated provides insight into relative technology performance. When evaluating fruit damage across all locations, the differences in the percentage reduction in fruit damage relative to the untreated NBT is unclear. Although, WS3, TL, TL+, BG2 and BG3 all demonstrated better ability in preventing fruit damage than WS, there were no statistical differences among each other. This is due to the high amount variability of fruit damage among locations. For WS, performance for square damage reduction ranged 19.80-81.99%, and averaged 51.73% across locations. Boll damage reduction for WS ranged 7.17-71.77%, and averaged 32.85%. Performance of the other Bt technologies was markedly better than WS. Percentage reduction in square damage relative to the untreated NBT are as follows: TL squares ranged from 59.64-93.19%, and averaged 80.82%; while bolls ranged 49.65-93.75%, and averaged 78.76%. BG2 damaged square reduction ranged from 53.69-95.01%, and averaged 80.33%; and bolls ranged from 46.46-92.75%, and averaged 75.04%. For WS3, reduction in square damage ranged from 64.75-94.86%, and averaged 85.13%; and boll damage ranged from 69.79-97.71%, and averaged 86.02%. The TP+ technology saw a range of reduced square damage of 70.46-97.70%, and averaged 88.05%; and boll damage reduction ranged from 25.00-100.00%, and averaged 83.66%. BG3 exhibited a reduction in square damage of 72.29-98.53%, and averaged 89.16%; and the boll damage reduction ranged from 68.75-96.92%, and averaged 88.27%.

Box and whisker plots of square damage among untreated Bt technologies relative to the untreated NBT, depicts variability in relative technology performance (Figure 1). Additionally, the solid line within the box on a Bt technology represents the median, and the dotted line the mean. Because means may be greatly influenced by outliers, the median value should be better representative of performance across geographies. Based on the median values in Figure 1, WS strike can be classified as providing 48% efficacy, TL 86.75%, BG2 80.12%, WS3 90.79%, TL+ 94.96% and BG3 91.32%, across test locations for preventing square damage. The spread of the WS box and whisker plot is large relative to the other Bt technologies and the upper efficacy range of WS falls below the values for the other Bt technologies median values, with the exception of BG2 which were almost the same. Variability among the non-WS Bt technologies were fairly similar, although the spread for TL and BG2 are slightly larger than for the technologies expressing Vip3A.

The box and whisker plots for the percentage of boll damage relative to the untreated NBT are more variable than for square damage among the Bt technologies (Figure 2). Based on the median values across test sites, for boll protection WS strike may be classified as providing 23.45% efficacy, TL 81.71%, BG2 83.78%, WS3 91.29%, TL+ 96.03% and BG3 92.59%. Similar to the percentile spread for the reduction in square damage, the percentage reductions in boll damage for WS was highly variable with an upper range approaching 75% and the lower range < 10%. The other highly variable Bt technology was TL+, with the lower whisker near 25%. Because the box is concise and the upper two quartiles ranging from 95-100% the lower whisker appears to be an outlier. The box and whisker plot for BG2 also indicted high variability, but with 50% of the responses falling in the 85-92% upper two quartiles. TL was similar to BG2 but was less uniform within the lower two quartiles. BG3 and WS3 were very similar regarding the spread in percentage reduction in boll damage with 50% of the values > 90%.

The box and whisker plots depicting the range in the percentage reduction of squares and bolls damaged relative to the untreated NBT suggest that WS is largely ineffective for protecting cotton from *H zea* fruit damage. They also suggest that, although TL and BG2 offer some protection, that under high *H. zea* infestation intensity, failure may occur. Cotton technologies expressing the Vip3A toxin (WS3, TL+ and BG3) appear to be mostly effective, but outliers suggest that in isolated incidences, unexpected damage can occur.

Because yields vary greatly based on individual variety genetics, yields values presented in Table 7 are for reference. The primary value of yield data, for the purposes on this study, was to compare yields between plots treated with Prevathon and those left untreated within a Bt technology or the NBT. Table 8 depicts the percentage change in yield within a Bt technology entry from treating with Prevathon. Treating NBT with Prevathon resulted in a significant increase in yield at all sites, ranging 13.45% to 32.63%, and averaging 24.43% across locations. Despite its low efficacy, WS benefitted from Prevathon applications for 5 of the 8 locations, ranging -8.64% to 25.13%, and averaging 9.07% across locations. TL, BG3 and WS3 benefited from treatment at one location each, TL+ demonstrated a positive benefit at two locations, and no locations showed a benefit from treating BG2. The benefit in yield from treating *H. zea* in Bt cotton can be highly variable (Figure 3). Excessive precipitation in 2018 across the Mid-South and Texas was not conducive with a timely and efficient cotton harvest. Multiple test locations experienced delayed harvests by as long as 6 weeks resulting in significant lint loss. This is evident in reported low yields reported for most locations and undoubtedly impacted our ability to accurately access the benefit from treating with Prevathon.

These studies illustrate that *H. zea* damage and yield loss is common throughout much of the southern cotton belt and is most likely due to resistance to the Bt Cry proteins. The WideStrike technology appears to be compromised for *H. zea* control since Cry1F is largely ineffective and there appears to be widespread resistance to Cry1Ac. Resistance to the Cry2A toxins appears to be high in many areas as well, but this toxin appears to still offer adequate control except under high *H. zea* pressure. The Vip cotton varieties appear to offer the greatest level of *H. zea* control, but with resistance to Cry1A and Cry2A toxins there is concern that too much selection pressure is being exerted on this toxin. Additionally, under some conditions unexpected injury in Vip cotton has been noted. Thus, all cotton grown in the southern U.S. is at risk of unacceptable fruit loss due to *H. zea*, and may benefit from well-timed applications of effective insecticides such as Prevathon.

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Table 1. Cry1Ac, LC_{50} and 95% confidence limits (CL) based on larval mortality of *Helicoverpa zea* to three Bt proteins in 2018.

Insect strain	N[a]	LC_{50} (95% CL) (µg/cm^2)[b]	Slope ± SE	X^2	df	Resistance ratio[c]
CBW-CBW-BZ-SS	958	0.10 (0.08, 0.11)	1.55 ± 0.09	28.4	26	1.0
CBW-TX-SS	576	0.11 (0.08, 0.14)	1.39 ± 0.11	31.6	30	1.1
CBW-AM-TX-NBt corn	576	10.70 (8.55, 13.63)	1.94 ± 0.20	24.0	30	107.0 *
CBW-AX-LA-BG2	576	> 31.60	/	/	/	> 316.0 *
CBW-CS-TX-VT3P	576	13.26 (8.34, 24.81)	1.19 ± 0.16	22.9	30	132.6 *
CBW-EC-TX-BG2	576	1.25 (0.76, 2.09)	1.33 ± 0.17	62.6	30	12.5 *
CBW-GR-LA-WS3	576	2.28 (1.62, 3.29)	0.90 ± 0.07	38.1	30	22.8 *
CBW-IN-MS-SB	576	> 31.60	/	/	/	> 316.0 *
CBW-JK-TN-OSC	320	29.15 (16.67, 79.84)	0.84 ± 0.16	13.5	14	291.5 *
CBW-LB-TX-NBt corn	576	8.15 (3.59, 28.21)	0.71 ± 0.12	103.8	30	81.5 *
CBW-LI-TX-NBt corn	576	> 31.60	/	/	/	> 316.0 *
CBW-MU-TX-VT2P	576	16.41 (7.87, 50.04)	0.77 ± 0.11	42.3	30	164.1 *
CBW-Natchez-MS-CC	576	1.41 (0.98, 2.02)	1.24 ± 0.12	53.5	30	14.1 *
CBW-PB-AR-NBt corn	576	> 31.60	/	/	/	> 316.0 *
CBW-PLV-TX-GS	576	10.66 (5.33, 29.81)	1.02 ± 0.18	46.3	30	106.6 *
CBW-Thrall-TX-SMT	576	22.91 (10.60, 73.70)	0.64 ± 0.09	40.8	30	229.1 *
CBW-Wh-TX-BG2	576	> 31.60	/	/	/	> 316.0 *
CBW-JK-TN-BG2	576	> 31.60	/	/	/	> 316.0 *
CBW-WE-TX-BG2	576	23.21 (11.78, 60.50)	0.59 ± 0.07	20.2	30	232.1 *
CBW-Wall-TX-VT3P	576	14.80 (8.46, 32.67)	0.98 ± 0.13	52.6	30	148.0 *
CBW-WB-LA-CC	576	0.49 (0.31, 0.80)	1.69 ± 0.24	44.7	30	4.9
CBW-WB-LA-SC	576	> 31.60	/	/	/	> 316.0 *

[a] Total number of neonates assayed.

[b] The LC_{50} value of an insect strain was considered to be greater than the highest Bt protein concentration used in the bioassay if its larval mortality was <50% at the highest concentration. Larval mortality was calculated based on the number of dead larvae plus survivors that were still in the first instar (mortality = dead+L1) divided by the total number of insects assayed.

[c] Resistance ratio for Bt protein were calculated by dividing the LC_{50} value of an insect population by that of the susceptible strain (CBW-BZ-SS). If the LC_{50} an insect population was smaller than that of the CBW-BZ-SS, a negative sign was assigned to the resistance ratio.

* indicates significant resistance ratios that were e 10-fold.

Table 2. Cry2Ab2, LC_{50} and 95% confidence limits (CL) based on larval mortality of *Helicoverpa zea* to three Bt proteins in 2018.

Insect strain	N[a]	LC_{50} (95% CL) (μg/cm^2)[b]	Slope ± SE	X^2	df	Resistance ratio[c]
CBW-CBW-BZ-SS	960	0.20 (0.17, 0.24)	1.61 ± 0.09	30.7	26	1.0
CBW-TX-SS	448	0.69 (0.51, 0.95)	1.89 ± 0.22	32.2	22	3.4
CBW-AM-TX-NBt corn	448	6.67 (3.85, 15.24)	0.98 ± 0.14	26.2	22	33.4 *
CBW-AX-LA-BG2	448	> 10.00	/	/	/	> 50.0 *
CBW-CS-TX-VT3P	448	1.50 (0.85, 2.58)	1.16 ± 0.17	74.7	22	7.5
CBW-EC-TX-BG2	448	4.94 (2.69, 10.68)	1.12 ± 0.19	53.4	22	24.7 *
CBW-GR-LA-WS3	448	1.84 (0.77, 6.18)	1.47 ± 0.38	126.5	22	9.2
CBW-IN-MS-SB	448	4.73 (3.80, 11.50)	1.24 ± 0.17	25.8	22	23.7 *
CBW-JK-TN-OSC	448	> 10.00	/	/	/	> 50.0 *
CBW-LB-TX-NBt corn	448	2.49 (1.19, 7.84)	0.77 ± 0.15	63.1	22	12.5 *
CBW-LI-TX-NBt corn	448	9.02 (4.81, 23.46)	0.71 ± 0.09	32.1	22	45.1 *
CBW-MU-TX-VT2P	448	5.42 (3.64, 8.60)	1.14 ± 0.13	39.2	22	27.1 *
CBW-Natchez-MS-CC	512	0.20 (0.11, 0.35)	1.07 ± 0.15	84.4	26	1.0
CBW-PB-AR-NBt corn	448	0.93 (0.71, 1.19)	1.46 ± 0.13	31.5	22	4.7
CBW-PLV-TX-GS	448	2.22 (1.78, 2.76)	1.93 ± 0.16	22.6	22	11.1 *
CBW-Thrall-TX-SMT	448	2.66 (2.06, 3.46)	1.43 ± 0.12	30.3	22	13.3 *
CBW-Wh-TX-BG2	448	5.63 (2.66, 21.46)	1.06 ± 0.22	40.3	22	28.2 *
CBW-JK-TN-BG2	448	0.05 (0.01, 0.25)	1.06 ± 0.22	40.3	22	-4.0
CBW-WE-TX-BG2	448	> 10.00	/	/	/	> 50.0 *
CBW-Wall-TX-VT3P	448	4.99 (1.05, 203.08)	0.59 ± 0.21	175.8	22	25.0 *
CBW-WB-LA-CC	448	22.02 (11.28, 71.10)	1.10 ± 0.21	31.8	22	110.1 *
CBW-WB-LA-SC	448	2.12 (1.39, 3.23)	1.54 ± 0.19	60.5	22	32.3 *

[a] Total number of neonates assayed.

[b] The LC_{50} value of an insect strain was considered to be greater than the highest Bt protein concentration used in the bioassay if its larval mortality was <50% at the highest concentration. Larval mortality was calculated based on the number of dead larvae plus survivors that were still in the first instar (mortality = dead+L1) divided by the total number of insects assayed.

[c] Resistance ratio for Bt protein were calculated by dividing the LC_{50} value of an insect population by that of the susceptible strain (CBW-BZ-SS). If the LC_{50} an insect population was smaller than that of the CBW-BZ-SS, a negative sign was assigned to the resistance ratio.

* indicates significant resistance ratios that were e 10-fold.

Table 3. Cry1F, LC_{50} and 95% confidence limits (CL) based on larval mortality of *Helicoverpa zea* to three Bt proteins in 2018.

Insect strain	N[a]	LC_{50} (95% CL) (μg/cm^2)[b]	Slope ± SE	X^2	df	Resistance ratio[c]
CBW-CBW-BZ-SS	512	0.73 (0.55, 0.97)	1.68 ± 0.15	28.9	26	1.0
CBW-EC-TX-BG2	512	>8.00	/	/	/	> 10.9*
CBW-WH-TX-BG2	512	>8.00	/	/	/	> 10.9*
CBW-WE-TX-BG2	512	>8.00	/	/	/	> 10.9*
CBW-CS-TX-VT3P	512	>8.00	/	/	/	> 10.9*
CBW-Thrall-TX-SMT	512	>8.00	/	/	/	> 10.9*
CBW-Wall-TX-VT3P	512	>8.00	/	/	/	> 10.9*
CBW-AM-TX-NBt corn	512	>8.00	/	/	/	> 10.9*
CBW-LB-TX-NBt corn	512	>8.00	/	/	/	> 10.9*
CBW-LI-TX-NBt corn	512	>8.00	/	/	/	> 10.9*
CBW-PLV-TX-GS	512	>8.00	/	/	/	> 10.9*

[a] Total number of neonates assayed.
[b] The LC_{50} value of an insect strain was considered to be greater than the highest Bt protein concentration used in the bioassay if its larval mortality was <50% at the highest concentration. Larval mortality was calculated based on the number of dead larvae plus survivors that were still in the first instar (mortality = dead+L1) divided by the total number of insects assayed.
[c] Resistance ratio for Bt protein were calculated by dividing the LC_{50} value of an insect population by that of the susceptible strain (CBW-BZ-SS). If the LC_{50} an insect population was smaller than that of the CBW-BZ-SS, a negative sign was assigned to the resistance ratio.
* indicates significant resistance ratios that were e 10-fold.

Table 4. Vip3A1, LC_{50} and 95% confidence limits (CL) based on larval mortality of *Helicoverpa zea* to three Bt proteins in 2018.

Insect strain	N[a]	LC_{50} (95% CL) (µg/cm^2)[b]	Slope ± SE	X^2	df	Resistance ratio[c]
CBW-CBW-BZ-SS	448	0.20 (0.16, 0.26)	1.48 ± 0.12	21.8	22	1.0
CBW-TX-SS	448	0.16 (0.11, 0.25)	2.19 ± 0.36	28.0	22	-1.3
CBW-AM-TX-NBt corn	448	0.15 (0.13, 0.18)	2.82 ± 0.28	17.2	22	-1.3
CBW-AX-LA-BG2	448	0.05 (0.04, 0.06)	2.10 ± 0.20	20.7	22	-4.0
CBW-CS-TX-VT3P	448	0.04 (0.03, 0.05)	2.81 ± 0.29	18.2	22	-5.0
CBW-CS-TX-WS	448	0.37 (0.20, 0.71)	3.28 ± 0.97	26.8	22	1.9
CBW-EC-TX-BG2	448	0.05 (0.04, 0.06)	2.76 ± 0.28	15.5	22	-4.0
CBW-GR-LA-WS3	448	0.12 (0.10, 0.16)	2.67 ± 0.35	13.2	22	-1.7
CBW-IN-MS-SB	448	0.18 (0.12, 0.25)	2.46 ± 0.39	17.0	22	-1.1
CBW-JK-TN-OSC	448	0.21 (0.15, 0.31)	2.22 ± 0.31	24.1	22	1.0
CBW-LB-TX-NBt corn	448	0.17 (0.15, 0.20)	4.22 ± 0.50	2.2	22	-1.2
CBW-LI-TX-NBt corn	448	0.10 (0.08, 0.12)	2.50 ± 0.23	22.9	22	-2.0
CBW-LR-AR-Bt corn	448	0.05 (0.04, 0.06)	2.06 ± 0.24	25.5	22	-4.0
CBW-MU-TX-VT2P	448	0.03 (0.02, 0.04)	1.83 ± 0.19	16.9	22	-6.7
CBW-Natchez-MS-CC	448	0.19 (0.12, 0.31)	1.97 ± 0.31	49.3	22	-1.1
CBW-PB-AR-NBt corn	448	0.13 (0.11, 0.16)	3.13 ± 0.33	10.1	22	-1.5
CBW-PLV-TX-GS	448	0.09 (0.07, 0.11)	2.82 ± 0.28	16.0	22	-2.2
CBW-Thrall-TX-SMT	448	0.08 (0.07, 0.10)	2.11 ± 0.19	13.2	22	-2.5
CBW-Wh-TX-BG2	448	0.02 (0.01, 0.03)	2.88 ± 0.57	26.9	22	-10.0
CBW-JK-TN-BG2	448	0.01 (0.01, 0.02)	1.92 ± 0.27	9.1	22	-20.0
CBW-WE-TX-BG2	448	0.03 (0.03, 0.04)	2.53 ± 0.27	6.8	22	-6.7
CBW-Wall-TX-VT3P	448	0.16 (0.12, 0.22)	2.28 ± 0.29	22.0	22	-1.3
CBW-WB-LA-CC	448	0.06 (0.05, 0.07)	2.47 ± 0.24	13.2	22	-3.3
CBW-WB-LA-SC	448	0.05 (0.04, 0.06)	3.08 ± 0.33	11.5	22	-4.0
CBW-CS-TX-Leptra corn	448	0.84 (0.69, 0.97)	4.93 ± 1.01	19.0	22	4.2

[a] Total number of neonates assayed.

[b] The LC_{50} value of an insect strain was considered to be greater than the highest Bt protein concentration used in the bioassay if its larval mortality was <50% at the highest concentration. Larval mortality was calculated based on the number of dead larvae plus survivors that were still in the first instar (mortality = dead+L1) divided by the total number of insects assayed.

[c] Resistance ratio for Bt protein were calculated by dividing the LC_{50} value of an insect population by that of the susceptible strain (CBW-BZ-SS). If the LC_{50} an insect population was smaller than that of the CBW-BZ-SS, a negative sign was assigned to the resistance ratio.

* indicates significant resistance ratios that were e 10-fold.

Table 5. Seasonal mean square and boll damage among Bt cotton technology traits untreated or treated with Prevathon at 20 fl-oz/ac, 2018.[1]

		Tillar, AR		Hooker, AR		Stoneville, MS		Glendora, MS		Winnsboro, LA		College Station, TX1		College Station, TX2		Jackson, TN	
Bt	Insecticide	% Damaged		% Damaged		% Damaged		% Damaged		% Damaged		% Damaged		% Damaged		% Damaged	
tech[2]	treatment	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls
NBT	Untreated	67.00 a	36.00 a	25.34 a	14.00 a	22.25 a	7.25 a	17.67 a	15.00 a	8.34 ab	2.56 a	29.60 a	17.25 a	27.20 a	15.00 a	28.00 a	67.00 a
	Prevathon	19.00 c	8.50 cd	5.00 b	4.33 b	4.50 b	1.00 b	4.33 bc	2.33 b	10.33 a	1.69 ab	7.40 c	2.25 b	3.60 c	1.50 b	2.50 c	11.50 c
WS	Untreated	36.00 b	32.00 a	4.33 bc	3.67 bc	18.25 a	5.50 a	8.67 b	6.00 b	3.67 c	1.31 bc	15.20 b	14.25 a	8.00 b	12.50 a	14.00 b	40.50 b
	Prevathon	18.00 c	17.50 b	0.33 d	1.00 d	4.75 b	0.25 b	0.67 c	0.67 b	4.33 bc	0.56 cd	4.20 cd	2.50 b	3.00 cd	1.75 b	2.00 c	3.00 d
WS3	Untreated	4.82 e	3.50 de	2.34 cd	0.67 d	3.50 b	0.50 b	0.67	0.33 b	2.67	0.63 cd	3.00 d	1.25 b	1.40 cd	0.75 b	1.50 c	1.50 d
	Prevathon	2.50 e	2.50 de	1.33 d	1.00 d	2.50 b	0.25 b	1.67 bc	0.33 b	4.00 b	0.31 d	2.00 d	0.00 b	0.20 d	0.50 b	0.50 c	0.00 d
TL	Untreated	8.00 de	9.00 cd	2.00 cd	2.00 bcd	3.00 b	0.00 b	4.00 bc	4.00 b	3.00 c	0.94 bcd	3.60 cd	1.50 b	1.80 cd	1.00 b	5.00 c	10.50 c
	Prevathon	3.00 e	3.50 de	1.34 d	0.67 d	5.50 b	1.25 b	0.67	0.33 b	1.00 c	0.56 cd	1.40 d	0.75 b	0.40 cd	1.50 b	0.50 c	0.50 d
TL+	Untreated	1.50 e	1.50 de	1.33 d	0.67 d	6.50 b	1.76 b	0.33 c	1.00 b	1.67 c	0.25	1.00 d	0.50 b	1.40 cd	0.50 b	1.00 c	0.00 d
	Prevathon	1.00 e	0.50 e	2.33 cd	1.33 cd	3.25 b	0.00 b	0.67 c	0.00 b	4.34 bc	0.44	1.00 d	0.50 b	0.40 cd	0.00 b	0.00 c	0.00 d
BG2	Untreated	13.00 cd	13.00 bc	1.33 d	1.34 cd	4.25 b	1.00 b	5.67 bc	6.33 b	2.00 c	0.44 cd	2.40 d	1.75 b	1.80 cd	1.75 b	5.50 c	9.00 c
	Prevathon	2.50 e	2.00 de	2.00 cd	1.67 cd	3.00 b	0.25 b	1.34 bc	0.67 b	1.67 c	0.44 cd	1.00 d	0.00 b	0.60 cd	0.25 b	0.00 c	1.50 d
BG3	Untreated	1.50 e	3.00 de	2.33 cd	0.67 d	3.00 b	0.50 b	0.67 c	0.67 b	1.67 c	0.31 d	2.20 d	0.50 b	1.20 cd	0.75 b	0.50 c	0.50 d
	Prevathon	1.00 e	0.00 e	0.00 d	0.00 d	2.50 b	0.75 b	1.67 bc	1.00 b	2.33 c	0.31 d	1.00 d	0.25 b	0.60 cd	0.50 b	0.00 c	0.00 d

Means in a column followed by the same letter are not significantly different based on a F protected Tukey's HSD ($P < 0.05$).
[1]Prevathon at 20 fl-oz/ac applications: Tillar, AR (July 19), Hooker, AR (July 21), Stoneville, MS (July 16 and Aug 3), Glendora, MS (July 16, Aug 3), Winnsboro, LA (July 16, July 30), College Station, TX1 (June 22, July 11), College Station, TX2 (June 22, July 11), Jackson, TN (Aug 10).
[2]NBT (non-Bt, DP1822 XF, WS (WideStrike, PHY 333 WRF, WS3 (WideStrike 3, PHY 330 W3FE), TL (TwinLink, ST 5122 GLT), TL+ (TwinLink Plus, ST 5471 GLTP), BG2 (Bollgard II, ST 1518 B2XF), BG3 (DP 1835 B3XF).

Table 6. Percentage reduction in square and boll damage of non-treated Bt cotton technologies relative to a non-treated non-Bt cotton, 2018.

	Tillar, AR		Hooker, AR		Stoneville, MS		Glendora, MS		Winnsboro, LA		College Station, TX1		College Station, TX2		Jackson, TN		Across locations	
Bt	% Reduction		% Reduction		% Reduction		% Reduction		% Reduction		% Reduction		% Reduction		% Reduction		% Reduction	
tech[1]	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls	Squares	Bolls
WS	46.82 c	7.17 c	81.99 a	71.09 b	19.80 a	20.96 b	47.71 ab	71.77 a	53.34 a	26.74 a	47.91 b	19.25 b	67.84 b	6.55 b	48.40 b	39.30 c	51.73 b	32.85 b
WS3	92.70 ab	89.90 ab	91.08 a	96.30 a	84.57 b	73.53 ab	72.92 a	75.00 a	64.75 a	69.79 a	90.50 a	92.68 a	94.86 a	95.23 a	93.08 b	97.71 ab	85.13 a	86.02 a
TL	87.85 ab	73.77 ab	92.18 a	82.52 ab	86.31 b	75.00 a	59.64 b	80.89 a	60.30 a	49.65 a	87.19 a	90.89 a	93.19 a	93.75 a	79.95 ab	84.43 b	80.82 a	78.86 a
TL+	97.70 a	96.22 a	95.46 a	96.30 a	70.46 b	67.28 ab	73.33 a	25.00 a	80.58 a	91.32 a	96.43 a	95.83 a	94.45 a	97.36 a	96.03 b	100.00 a	88.05 a	83.66 a
BG2	80.60 b	59.26 b	95.01 a	92.75 ab	79.63 b	56.25 ab	53.69 ab	46.46 a	71.68 a	81.25 a	91.53 a	89.31 a	93.35 a	88.94 a	77.19 ab	86.30 ab	80.33 a	75.04 a
BG3	97.70 a	92.10 a	90.27 a	93.08 ab	86.09 b	68.75 ab	72.29 a	73.08 a	81.11 a	87.85 a	92.36 a	96.92 a	94.93 a	95.16 a	98.53 b	99.22 a	89.16 a	88.27 a

Means in a column followed by the same letter are not significantly different based on a F protected Tukey's HSD ($P < 0.05$).
[1]WS (WideStrike, PHY 333 WRF, WS3 (WideStrike 3, PHY 330 W3FE), TL (TwinLink, ST 5122 GLT), TL+ (TwinLink Plus, ST 5471 GLTP), BG2 (Bollgard II, ST 1518 B2XF), BG3 (DP 1835 B3XF).

Table 7. Yields (lbs-lint/ac) among Bt cotton technology traits untreated or treated with Prevathon at 20 fl-oz/ac, 2018.[1]

Bt tech[2]	Insecticide treatment	Tillar, AR	Hooker, AR	Stoneville, MS	Glendora, MS	Winnsboro, LA	College Station, TX1	College Station, TX2	Jackson, TN
NBT	Untreated	656.85 d	906.15 f	1146.80 e	605.92 f	750.44 e	904.51 e	653.10 e	631.92 g
	Prevathon	983.96 abc	1241.48 bcd	1682.14 abc	844.13 cde	876.77 de	1061.25 bcd	953.50 cd	934.71 f
WS	Untreated	887.67 bc	986.39 ef	1762.81 ab	892.88 abc	963.24 cd	1033.49 cde	1190.23 b	1088.46 cde
	Prevathon	863.19 c	1332.83 a-d	1614.56 bcd	923.84 abc	1169.12 ab	1208.19 ab	1391.05 a	1371.98 a
WS3	Untreated	1068.38 a	1148.63 c-f	1762.32 ab	855.03 abc	927.06 cd	1062.88 bcd	1167.38 b	1399.90 a
	Prevathon	875.62 bc	1426.58 ab	1558.40 bcd	896.32 abc	983.24 cd	1069.41 bcd	1175.55 b	1356.25 ab
TL	Untreated	844.70 c	1194.30 b-e	1510.07 cd	919.37 abc	887.36 de	1120.02 a-d	986.15 cd	1042.85 ef
	Prevathon	868.35 c	1334.79 abc	1530.81 bcd	1018.81 ab	1026.76 bcd	1087.37 bcd	1162.45 b	1139.78 cde
TL+	Untreated	1074.08 a	1152.88 def	1378.97 de	970.29 abc	963.24 cd	1115.12 bcd	1098.78 bc	1188.74 cd
	Prevathon	976.68 abc	1578.50 a	1556.77 bcd	1001.26 ab	1078.53 abd	1268.60 a	1092.28 bc	1223.34 bc
BG2	Untreated	976.50 abc	1120.29 c-f	1684.77 abc	830.25 bcd	865.59 de	1059.61 bcd	912.68 d	1020.04 ef
	Prevathon	871.32 bc	1268.99 bcd	1915.47 a	874.64 abc	1000.59 bcd	1146.14 abc	978.78 cd	1083.35 de
BG3	Untreated	974.96 abc	1120.29 c-f	1559.87 bcd	670.26 def	955.29 cd	986.14 de	1239.23 ab	1138.01 cde
	Prevathon	995.59 ab	1311.17 bcd	1487.21 dc	650.65 ef	1233.53 a	1009.00 cde	1242.48 ab	1126.21 cde

Means in a column followed by the same letter are not significantly different based on a F protected Tukey's HSD ($P < 0.05$).

[1]Prevathon at 20 fl-oz/ac applications: Tillar, AR (July 19), Hooker, AR (July 21), Stoneville, MS (July 16 and Aug 3), Glendora, MS (July 16, Aug 3), Winnsboro, LA (July 16, July 30), College Station, TX1 (June 22, July 11), College Station, TX2 (June 22, July 11), Jackson, TN (Aug 10).

[2]NBT (non-Bt, DP1822 XF, WS (WideStrike, PHY 333 WRF, WS3 (WideStrike 3, PHY 330 W3FE), TL (TwinLink, ST 5122 GLT), TL+ (TwinLink Plus, ST 5471 GLTP), BG2 (Bollgard II, ST 1518 B2XF), BG3 (DP 1835 B3XF).

Table 8. Percentage change in yield in Bt cotton technology from treatment with Prevathon, 2018.[1]

Bt tech[2]	Tillar, AR	Hooker, AR	Stoneville, MS	Glendora, MS	Winnsboro, LA	College Station, TX1	College Station, TX2	Jackson, TN	Across locations
NBT	32.63*	22.51*	31.35*	18.34*	13.45*	14.50*	30.35*	32.39*	24.43*
WS	-7.22	25.13*	-8.64	4.65	17.64*	14.63*	14.46*	19.90*	9.07*
WS3	-20.79*	22.21*	-16.51	4.32	4.93	0.55	0.72	-3.55	-0.45
TL	-0.17	9.30	1.17	8.83	12.28	-3.46	14.20*	8.20	6.31
TL+	-8.73	34.29*	10.72	1.77	8.05*	10.85*	-0.56	2.35	6.98*
BG2	-11.05	0.77	11.84	7.54	13.53	7.48	7.17	5.35	6.62
BG3	0.33	8.73	-7.26	-3.06	22.51*	1.69	0.22	-0.94	2.59

Values in a column and within a Bt technology with a * indicate a significant change in yield between non-treated and Prevathon-treated based on a PROC GLIMMIX using the SLICEDIFF option of the LSMEANS statement ($P < 0.05$).
[1]Prevathon at 20 fl-oz/ac applications: Tillar, AR (July 19), Hooker, AR (July 21), Stoneville, MS (July 16 and Aug 3), Glendora, MS (July 16, Aug 3), Winnsboro, LA (July 16, July 30), College Station, TX1 (June 22, July 11), College Station, TX2 (June 22, July 11), Jackson, TN (Aug 10).
[2]NBT (non-Bt, DP 1441RF, WS (WideStrike, PHY 333WRF, BG2 (Bollgard II, ST 4946GLB2), TL (TwinLink, ST 4949GLT), TL+ (TwinLink Plus, ST 5575GLTP).

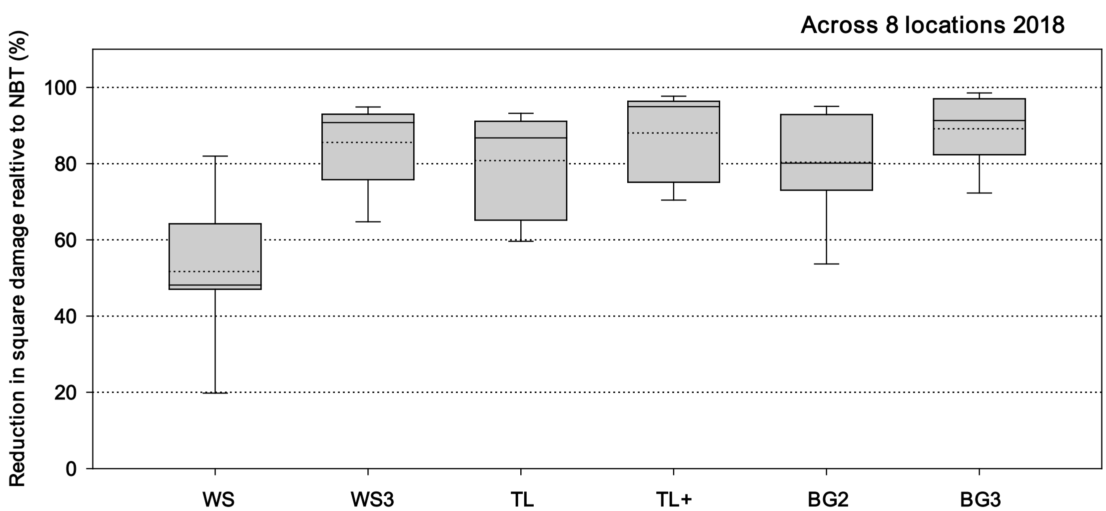

Figure 1. Box and whisker plot depicting the mean, median and variation in the percentage reduction in square damage within Bt technologies relative to a non-Bt variety across eight locations.

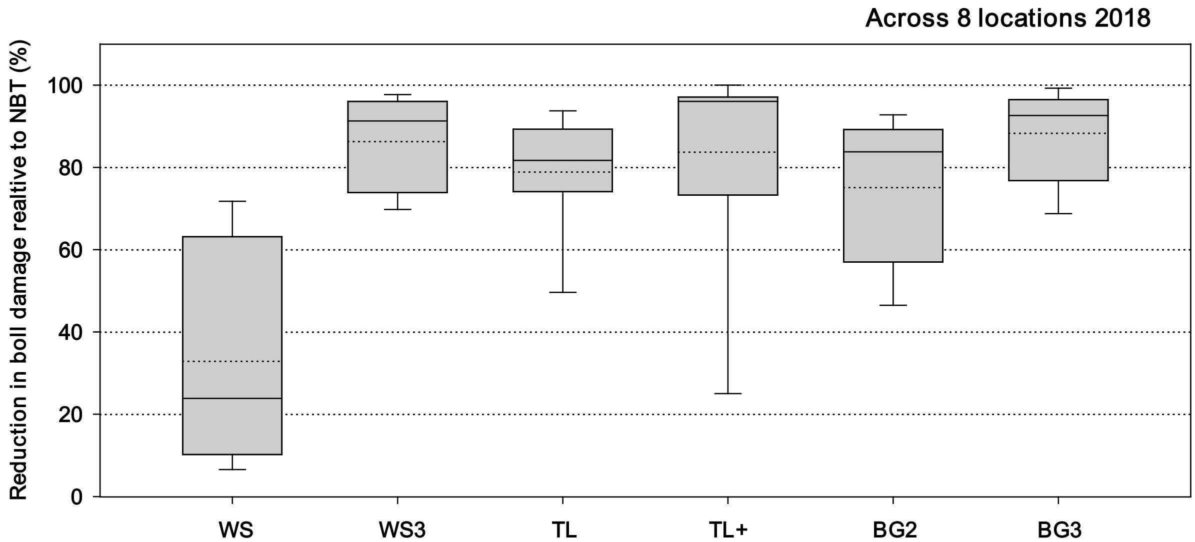

Figure 2. Box and whisker plot depicting the mean, median and variation in the percentage reduction in boll damage within Bt technologies relative to a non-Bt variety across eight locations

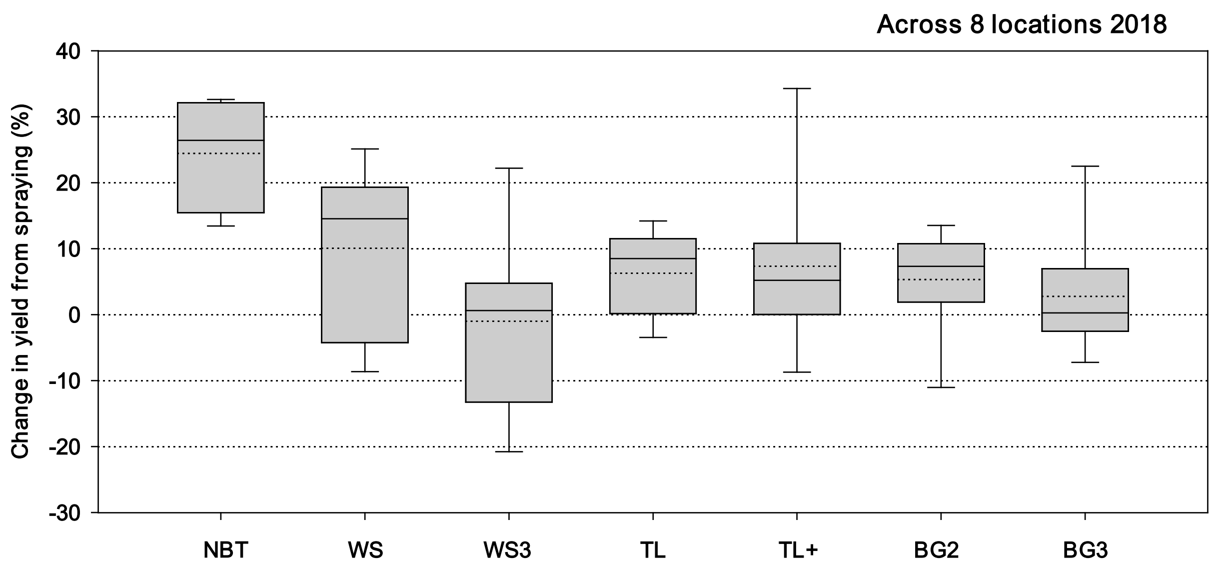

Figure 3. Box and whisker plot depicting the mean, median and variation in the percentage change in yield response in Bt technologies relative to a non-Bt variety across eight locations