Contribution of Maize Hybrid Genetics and Water Stress in the Mitigation of Pre-Harvest Losses attributed to Lepidopteran Feeding

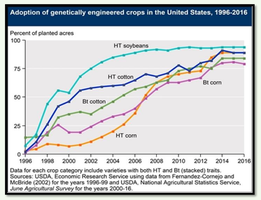
Luke Pruter[1], Michael Brewer[1], Thomas Isakeit[2], Seth Murray[3]

1 Texas A&M AgriLife Research, Department of Entomology, Corpus Christi, TX
2 Texas A&M AgriLife Extension, Department of Plant Pathology, College Station, TX
3 Texas A&M University, Department of Soil and Crop Sciences, College Station, TX

INTRODUCTION

One of the most common problems facing southern U.S. corn farmers is the injury brought on by ear feeding lepidopteran pests [1]. The fall armyworm and corn earworm are residents of the region [2, 3]. Ear injury by these insects can reduce yield although the relationship is variable across hybrids [4], and possibly water stress conditions. Corn growers have the option to manage insect injury on corn with the use of genetically modified seed containing Bt transgenes, however there is added cost to the seed and the interaction with water stress is not known. This poster compares the effects of hybrid background and their commercial *Bt* transgenes in their ability to reduce pre-harvest losses due to insect feeding in water stress and non-stressed conditions.

BACILLUS THURINGIENSIS (Bt) transgenes

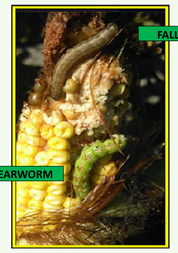


Bacillus thuringiensis (or *Bt*) transgenes express *Bt* toxins. When ingested by a target Lepidoptera species, the toxin destroys the digestive tract of the caterpillar [6]. Since the release of transgenic *Bt* maize in 1996, many different types of *Bt* transgenes have been developed. *Bt* corn has become increasingly popular over the last 15 years [8]. There is a wide range of Lepidoptera control in corn with commercially available *Bt* transgenes [5].

TARGET PESTS

The corn earworm is an active resident of much of the southern and central U.S. throughout the year [7].

Heliocoverpa zea



Spodoptera frugiperda

The fall armyworm is native to southern regions of the United States. It overwinters in the southern-most areas [6].

OBJECTIVES

Objective 1: Describe ear quality and yield, and insect-derived ear injury under two water stress conditions using isogenic hybrids with and without *Bt* transgenes. Five families of hybrids were used.

Objective 2: Evaluate the relative contribution to yield and insect ear injury of the *Bt* transgenes in common among the hybrid families and across the two water stress conditions.

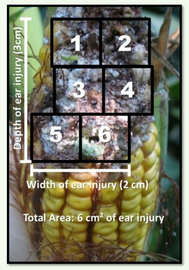
METHODOLOGY

A split plot design of 2 water stress conditions (main plot) and 13 hybrids (split plot) were replicated 4 times in Corpus Christi, 2017. Plots were 6 rows, 1 meter by 6 meters.

Ear injury measurements: total area of insect feeding injury and the deepest point of insect injury measured from the tip of the ear.

Ear quality measurements were ear circumference and length, and harvest weight adjusted for moisture % to calculate bushels/acre.

Analyses: For objective one, visuals and descriptive statistics were used to compare behavior of the measurements across different hybrid families and *Bt* transgenes. For objective two, an analysis of variance was performed using a 2 factor, fixed-model split-plot design. Given similarity of injury by *Bt* transgenes across hybrid families, Student's LSD mean separations were used for ear injury and yield comparison across Bt transgenes separately for the two water stress conditions.



Bt Transgene /Abbreviation Guide

Bt Transgene Trade Name	Transgene Abbreviation	Lepidopteran Protection	Lepidopteran targeted *Bt* Proteins
No *Bt* Transgene	RR/RR2	No	None
Genuity® DroughtGard™	DG	No	None
Genuity® Smart Stax™	SS	Yes	Cry1A.105, Cry1Fa2, Cry2Ab2
Genuity® VT Double Pro™	VT2P	Yes	Cry1A.105, Cry2Ab2
Genuity® VT Triple Pro™	VT3P	Yes	Cry1A.105, Cry2Ab2
YieldGard™ + Herculex™	YHR	Yes	Cry1Ab, Cry1Fa2
Agrisure® Viptera 3111™	V	Yes	Vip3Aa20

Lepidopteran protection based upon past work [4, 5]

WATER STRESSED

NON-WATER STRESS

OBJECTIVE 1: HYBRID FAMILY P-1319

P 1319 + VYHR (WATER STRESSED)

HYBRID FAMILY P 1319

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	13.80 ± 0.27	*Bt proteins expressed*	Vip3Aa20, Cry1Fa2, Cry1Ab
Ear length (cm)	18.44 ± 0.52	Area of ear injury cm²	0.01 ± 0.01
Bushels per acre	83.04 ± 4.85	Depth of ear injury cm	0.01 ± 0.01

P 1319 + YHR (WATER STRESSED)

HYBRID FAMILY P 1319

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	13.45 ± 0.19	*Bt proteins expressed*	Cry1Fa2, Cry1Ab
Ear length (cm)	17.68 ± 0.38	Area of ear injury cm²	3.71 ± 0.28
Bushels per acre	81.60 ± 6.11	Depth of ear injury cm	2.35 ± 0.19

P 1319 + RR (No *Bt*) (WATER STRESSED)

HYBRID FAMILY P 1319

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	13.52 ± 0.61	*Bt proteins expressed*	No *Bt* Proteins
Ear length (cm)	16.35 ± 1.08	Area of ear injury cm²	7.70 ± 0.45
Bushels per acre	37.49 ± 4.12	Depth of ear injury cm	4.43 ± 0.30

P 1319 + VYHR (NON-WATER STRESS)

HYBRID FAMILY P 1319

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	13.29 ± 0.29	*Bt proteins expressed*	Vip3Aa20, Cry1Fa2, Cry1Ab
Ear length (cm)	18.23 ± 0.54	Area of ear injury cm²	0.00 ± 0.00
Bushels per acre	89.31 ± 5.08	Depth of ear injury cm	0.00 ± 0.00

P 1319 + YHR (NON-WATER STRESS)

HYBRID FAMILY P 1319

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	13.51 ± 0.33	*Bt proteins expressed*	Cry1Fa2, Cry1Ab
Ear length (cm)	18.84 ± 0.40	Area of ear injury cm²	3.61 ± 0.48
Bushels per acre	83.98 ± 1.53	Depth of ear injury cm	2.34 ± 0.29

P 1319 + RR (No *Bt*) (NON-WATER STRESS)

HYBRID FAMILY P 1319

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	13.26 ± 0.50	*Bt proteins expressed*	No *Bt* Proteins
Ear length (cm)	15.82 ± 0.74	Area of ear injury cm²	6.48 ± 1.36
Bushels per acre	60.70 ± 7.07	Depth of ear injury cm	3.93 ± 0.67

OBJECTIVE 1: HYBRID FAMILY 8700

B&H 8700 SS (WATER STRESSED)

HYBRID FAMILY B&H 8700

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.98 ± 0.31	*Bt proteins expressed*	Cry1A.105, Cry2Ab2, Cry1Fa2, Cry3Bb1, Cry34Ab1/Cry35Ab1
Ear length (cm)	17.13 ± 0.75	Area of ear injury cm²	6.15 ± 0.52
Bushels per acre	79.95 ± 3.00	Depth of ear injury cm	3.52 ± 0.27

B&H 8700 VT3P (WATER STRESSED)

HYBRID FAMILY B&H 8700

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.99 ± 0.15	*Bt proteins expressed*	Cry1A.105, Cry2Ab2, Cry3Bb1
Ear length (cm)	17.29 ± 0.09	Area of ear injury cm²	4.25 ± 0.65
Bushels per acre	89.43 ± 5.75	Depth of ear injury cm	2.66 ± 0.30

B&H 8700 VT2P (WATER STRESSED)

HYBRID FAMILY B&H 8700

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.63 ± 0.11	*Bt proteins expressed*	Cry1A.105,Cry2Ab2
Ear length (cm)	16.8 ± 0.29	Area of ear injury cm²	12.08 ± 6.31
Bushels per acre	87.11 ± 3.28	Depth of ear injury cm	3.71 ± 0.65

B&H 8700 RR (No *Bt*) (WATER STRESSED)

HYBRID FAMILY B&H 8700

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	13.76 ± 0.30	*Bt proteins expressed*	No *Bt* proteins
Ear length (cm)	16.95 ± 0.50	Area of ear injury cm²	13.26 ± 2.01
Bushels per acre	38.06 ± 3.09	Depth of ear injury cm	5.78 ± 0.50

B&H 8700 SS (NON-WATER STRESS)

HYBRID FAMILY B&H 8700

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.07 ± 0.74	*Bt proteins expressed*	Cry1A.105, Cry2Ab2, Cry1Fa2, Cry3Bb1, Cry34Ab1/Cry35Ab1
Ear length (cm)	16.55 ± 0.34	Area of ear injury cm²	7.48 ± 1.33
Bushels per acre	86.14 ± 10.85	Depth of ear injury cm	3.93 ± 0.65

B&H 8700 VT3P (NON-WATER STRESS)

HYBRID FAMILY B&H 8700

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	15.29 ± 0.17	*Bt proteins expressed*	Cry1A.105, Cry2Ab2, Cry3Bb1
Ear length (cm)	19.07 ± 1.35	Area of ear injury cm²	5.19 ± 0.53
Bushels per acre	108.14 ± 4.66	Depth of ear injury cm	3.08 ± 0.27

B&H 8700 VT2P (NON-WATER STRESS)

HYBRID FAMILY B&H 8700

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.83 ± 0.26	*Bt proteins expressed*	Cry1A.105, Cry2Ab2
Ear length (cm)	17.71 ± 0.40	Area of ear injury cm²	5.91 ± 0.47
Bushels per acre	97.48 ± 6.48	Depth of ear injury cm	3.64 ± 0.74

B&H 8700 RR (No *Bt*) (NON-WATER STRESS)

HYBRID FAMILY B&H 8700

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	13.51 ± 0.34	*Bt proteins expressed*	No *Bt* Proteins
Ear length (cm)	16.68 ± 0.61	Area of ear injury cm²	12.40 ± 1.56
Bushels per acre	36.70 ± 3.82	Depth of ear injury cm	6.39 ± 1.02

OBJECTIVE 1: HYBRID FAMILY 67

DKC 67-72 VT2P (WATER STRESSED)

HYBRID FAMILY 67

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.21 ± 0.30	*Bt proteins expressed*	Cry1Fa2, Cry1Ab
Ear length (cm)	18.25 ± 0.57	Area of ear injury cm²	2.94 ± 0.75
Bushels per acre	93.58 ± 3.82	Depth of ear injury cm	1.70 ± 0.38

DKC 67-70 RR2 (No *Bt*) (WATER STRESSED)

HYBRID FAMILY 67

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.35 ± 0.32	*Bt proteins expressed*	No *Bt* Proteins
Ear length (cm)	17.65 ± 0.51	Area of ear injury cm²	6.39 ± 1.08
Bushels per acre	62.07 ± 3.50	Depth of ear injury cm	3.55 ± 0.47

DKC 67-72 VT2P (NON-WATER STRESS)

HYBRID FAMILY 67

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.28 ± 0.66	*Bt proteins expressed*	Cry1A.105, Cry2Ab2
Ear length (cm)	18.11 ± 1.08	Area of ear injury cm²	2.76 ± 0.39
Bushels per acre	112.56 ± 7.88	Depth of ear injury cm	2.00 ± 0.18

DKC 67-70 RR2 (No *Bt*) (NON-WATER STRESS)

HYBRID FAMILY 67

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.33 ± 0.17	*Bt proteins expressed*	No *Bt* Proteins
Ear length (cm)	18.32 ± 0.35	Area of ear injury cm²	4.92 ± 1.17
Bushels per acre	89.65 ± 10.23	Depth of ear injury cm	2.93 ± 0.48

OBJECTIVE 1: HYBRID FAMILY 66

DKC 66-42 DGVT2P (WATER STRESSED)

HYBRID FAMILY 66

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.61 ± 0.17	*Bt proteins expressed*	Cry1A.105, Cry2Ab2
Ear length (cm)	17.54 ± 0.22	Area of ear injury cm²	5.32 ± 0.64
Bushels per acre	95.23 ± 3.17	Depth of ear injury cm	2.78 ± 0.22

DKC 66-40 SS (WATER STRESSED)

HYBRID FAMILY 66

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.76 ± 0.15	*Bt proteins expressed*	Cry1A.105, Cry2Ab2, Cry1Fa2, Cry3Bb1, Cry34Ab1/Cry35Ab1
Ear length (cm)	17.83 ± 0.39	Area of ear injury (cm²)	3.39 ± 0.29
Bushels per acre	90.19 ± 3.87	Depth of ear injury (cm)	2.00 ± 0.29

DKC 66-42 DGVT2P (NON-WATER STRESS)

HYBRID FAMILY 66

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.98 ± 0.17	*Bt proteins expressed*	Cry1A.105, Cry2Ab2
Ear length (cm)	18.16 ± 0.54	Area of ear injury cm²	3.78 ± 0.74
Bushels per acre	100.32 ± 10.24	Depth of ear injury cm	2.05 ± 0.31

DKC 66-40 SS (NON-WATER STRESS)

HYBRID FAMILY 66

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.74 ± 0.18	*Bt proteins expressed*	Cry1A.105, Cry2Ab2, Cry1Fa2, Cry3Bb1, Cry34Ab1/Cry35Ab1
Ear length (cm)	17.88 ± 0.25	Area of ear injury cm²	3.87 ± 0.70
Bushels per acre	94.78 ± 1.18	Depth of ear injury cm	2.13 ± 0.27

OBJECTIVE 1: HYBRID FAMILY GP-280

GP-280 V (WATER STRESSED)

HYBRID FAMILY GP-280

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.38 ± 0.04	*Bt proteins expressed*	Vip3Aa20
Ear length (cm)	19.76 ± 0.55	Area of ear injury cm²	0.10 ± 0.07
Bushels per acre	75.48 ± 1.93	Depth of ear injury cm	0.08 ± 0.05

GP-280 RR (No *Bt*) (WATER STRESSED)

HYBRID FAMILY GP-280

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.34 ± 0.23	*Bt proteins expressed*	No *Bt* Proteins
Ear length (cm)	19.53 ± 0.16	Area of ear injury cm²	7.88 ± 2.13
Bushels per acre	64.30 ± 4.93	Depth of ear injury cm	4.11 ± 0.75

GP-280 V (NON-WATER STRESS)

HYBRID FAMILY GP-280

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.24 ± 0.23	*Bt proteins expressed*	Vip3Aa20
Ear length (cm)	19.34 ± 1.00	Area of ear injury cm²	0.26 ± 0.13
Bushels per acre	86.83 ± 6.39	Depth of ear injury cm	0.17 ± 0.05

GP-280 RR (No *Bt*) (NON-WATER STRESS)

HYBRID FAMILY GP-280

YIELD STATISTICS		INSECT DAMAGE	
Ear circumference (cm)	14.28 ± 0.09	*Bt proteins expressed*	No *Bt* Proteins
Ear length (cm)	19.72 ± 0.63	Area of ear injury cm²	8.18 ± 0.88
Bushels per acre	73.88 ± 6.69	Depth of ear injury cm	4.71 ± 0.47

OBJECTIVE 1: INSECT ABUNDANCE

Heliocoverpa zea **was the predominate species detected, outnumbering *Spodoptera frugiperda* six to one, and was equally represented across hybrids. Moderate ear feeding pressure was observed: average cm² of ear injury for non-*Bt* hybrids was 8.77 cm², compared with >12 cm² of ear injury seen in past years.**

OBJECTIVE 2: INSECT DAMAGE RESULTS (area cm²)

WATER STRESSED

Bt Transgene	Student's LSD Mean Separation			Least Sq. Mean	Std. Error
RR	A			8.88	1.19
VT2P	A	B		7.51	1.63
DGVT2P	A	B	C	5.32	2.30
VT3P	A	B	C	4.25	2.30
SS		B	C	4.77	1.63
YHR		B	C	3.71	2.30
V			C	0.10	2.30
VYHR			C	0.01	2.30

Damage Increasing →

NON-WATER STRESS

Bt Transgene	Student's LSD Mean Separation			Least Sq. Mean	Std. Error
RR	A			4.49	0.33
VT3P	A	B		3.08	0.66
SS		B		3.03	0.47
VT2P		B		2.82	0.47
YHR		B		2.34	0.66
DGVT2P		B		2.06	0.66
V			C	0.17	0.66
VYHR			C	0.00	0.66

Bt **transgene was a significant factor relating to the amount of ear injury caused by insect feeding (P<0.001). The pattern of insect damage in both water stressed and non-water stressed treatments was similar (there was no *Bt* by water stress interaction). Also, water stress itself was not found to be a significant factor related to insect injury (P=0.434). This indicates that a *Bt* transgene will be equally effective regardless of the soil moisture profile. Looking at the transgene effect across the hybrids, hybrids containing no *Bt* transgenes (RR) have significantly more insect ear injury, than hybrids with *Bt* transgenes (P=0.014). Also, the hybrids containing the Agrisure® Viptera™ *Bt* transgene (VYHR and V) had 30 fold less injury than its closest comparator (YHR [water stressed] and DGVT2P (non-water stressed).**

OBJECTIVE 2: YIELD RESULTS (bushels/acre)

WATER STRESSED

Bt Transgene	Student's LSD Mean Separation			Least Sq. Mean	Std. Error
DGVT2P	A			95.23	5.60
VT2P	A			90.46	3.96
VT3P	A	B		89.43	5.60
SS	A	B		85.07	3.96
VYHR	A	B		83.04	5.60
YHR	A	B		81.60	5.60
V		B		75.48	5.60
RR			C	50.48	2.80

Yield (bu./acre) Increasing →

NON-WATER STRESS

Bt Transgene	Student's LSD Mean Separation			Least Sq. Mean	Std. Error
VT3P	A			108.14	8.99
VT2P	A			105.02	6.36
DGVT2P	A			100.32	8.99
SS	A			90.46	6.36
VYHR	A			89.31	8.99
V	A			86.83	8.99
YHR	A	B		83.98	8.99
RR		B		65.28	4.50

As with the ear injury measure, there was no significant interaction between *Bt* transgene and water stress. In contrast to ear injury, yield differences between water stressed and non-water stressed plots were very apparent (P<0.001). *Bt* transgene status also affected yield, but differences across hybrids were less apparent than seen when analyzing the ear injury data.

CONCLUSIONS

Soil moisture levels have a significant effect on yield, but have little effect on the effectiveness of a *Bt* transgene to reduce ear injury caused by lepidopteran species. A *Bt* transgene hybrid will likely not make up for a poor hybrid selection, or poor performance in water stress conditions. A farmer would be prudent to select a high yielding hybrid before selecting a *Bt* transgene package, especially if water stress conditions are anticipated.

FUTURE DIRECTION

The hybrids of this study are being tested for aflatoxin and fumonisin contamination to determine the effect that water stress and *Bt* transgenes have on pathogen accumulation.

REFERENCES

[1] Ni, X., Wilson, J. P., Buntin, G. D., Guo, B., Krakowsky, M. D., Lee, R. D., & Schmelz, E. A. (2011). Spatial patterns of aflatoxin levels in relation to ear-feeding insect damage in pre-harvest maize. *Toxins*, *3*(7), 920-931.

[2] Vickery, R. A. (1929). *Studies on the fall army worm in the Gulf Coast district of Texas*. US Government Printing Office.

[3] Smith, M. S., & Riley, T. J. (1992). Direct and interactive effects of planting date, irrigation, and maize earworm (Lepidoptera: Noctuidae) damage on aflatoxin production in pre-harvest field maize. *Journal of economic entomology*, *85*(3), 998-1006.

[4] Brewer, M., Odvody, G., Anderson, D., & Remmers, J. (n.d). A Comparison of *Bt* Transgene, Hybrid Background, Water Stress, and Insect Stress Effects on Maize Leaf and Ear Injury and Subsequent Yield. *Environmental Entomology*,*43*(3), 828-839.

[5] Buntin, G., Flanders, K., & Lynch, R. (2004). Assessment of experimental Bt events against fall armyworm and maize earworm in field maize. *Journal Of Economic Entomology*, (2)

[6] Sousa, F. F., Mendes, S. M., Santos-Amaya, O. F., Araújo, O. G., Oliveira, E. E., & Pereira, E. G. (2016). Life-History Traits of *Spodoptera frugiperda* Populations Exposed to Low-Dose Bt Maize. *Plos ONE*, *11*(5), 1-18. doi:10.1371/journal.pone.0156608

[7] Harding, J. (1976). Heliothis spp.: seasonal occurrence, hosts and host importance in the Lower Rio Grande Valley. *Environmental Entomology*, (4), 666-668.

[8] Wechsler, S. J. (Ed.). (2016, November 2). Recent Trends in GE Adoption. Retrieved October 15, 2016, from https://www.ers.usda.gov