MULTI-LOCATION EVALUATION OF AGRONOMIC TRAITS IN MAIZE HYBRIDS

A Thesis

by

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Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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December 2012

Major Subject: Plant Breeding

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ABSTRACT

Maize (*Zea mays* L.) is one of the main crops grown in the United States. Genetic improvement over the last century has seen a shift from using open-pollinated varieties to single cross hybrids. This has resulted in major grain yield gains and improved management methodologies. However, there is still concern about reduced genetic diversity in elite corn germplasm and the potential effects this could have on future maize productivity in the presence of numerous abiotic and biotic pressures. One solution to this issue is the incorporation of exotic germplasm into existing maize improvement programs. This exotic material must be evaluated and characterized because too much or poorly matched exotic material can lead to reduced productivity. The use of multiple environments representative to the target improvement area is the best way to determine the true potential of certain material. The objectives of this research were to: i) estimate the responses of hybrids to aflatoxin and their agronomic performance across a range of environments under inoculation with *Aspergillus flavus*; ii) identify the hybrids within each group that exhibit the lowest levels of contamination; iii) analyze the relationship between agronomic performance and aflatoxin accumulation; and iv) determine how Genotype x Environment interactions affect these traits.

Agronomic data was collected in ten Texas environments in 2005 for hybrids created from yellow, white, and Quality Protein Maize material that was crossed with one of two elite temperate inbred testers, LH195 or LH210. Response to aflatoxin was measured in eight of these environments. U.S. commercial hybrids were used as checks. Significant differences between hybrids were observed at different environments for different traits. Overall the experimental hybrids had lower aflatoxin accumulation than the commercial checks. They also yielded lower and had lower test weights and 1000 kernel weights. However, there were some hybrids that were competitive with the commercial checks for these agronomic traits. The incorporation of this material into established U.S. lines could be beneficial with regards to aflatoxin accumulation and kernel quality, which could ultimately translate to higher yields and crop quality.

DEDICATION

This thesis has been a long time coming, but here it is. I appreciate everyone who helped me finally get it done. Mom, thank you for helping me to realize that yes, I actually *could* do this. Dad, thank you for all the times you stopped to say, “This is why you’re going to college,” even though I apparently didn’t listen.

ACKNOWLEDGMENTS

Special thanks to everyone involved in conducting this research. All the help, insight, and guidance are greatly appreciated.

Thanks to my fellow graduate students and undergraduate student workers in the Corn Breeding and Genetics Program. Kerry and Brett, I appreciate all the time spent together, whether working or not. Matthew and Adam, thanks for handling so much of the grunt work. Dennis, Ted, and Jeb from the Crop Testing Program, thank you for all the time spent on the road managing plots; this would not have been possible without your involvement. Thanks also to Dr. Bill Rooney for stepping into the unofficial mentor role during the latter steps of this process, and to Dr. Tom Isakeit for all the work done in the lab.

I was privileged to work under Dr. Javier Betrán for my Master's degree, and I learned a great deal from him. I want to thank him for all of his guidance throughout the course of this research, and for the encouragement to make it through these final stages.

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CHAPTER I

INTRODUCTION

Maize (*Zea mays* L.) is one of the main crops grown in the United States. Primarily used as grain feed for livestock, maize is also found in many food products and has numerous industrial applications. The majority of US maize production takes place in the Corn Belt, which spreads through Nebraska, Iowa, Illinois, Indiana, and into Ohio. Total U.S. maize grain production for 2005 was estimated at over 11.1 billion bushels (281.9 million Megagrams) harvested from over 75.1 million acres (30.4 million hectares), with an average yield of 147.9 bushels per acre (9.27 Megagrams per hectare). For Texas, maize acreage in 2005 was 2,050,000 acres (830,250 ha) planted and 1,850,000 acres (749,250 ha) harvested. Grain production was approximately 210,900,000 bushels (5,356,016 Mg), with an average yield of 114 bushels per acre (7.15 Mg ha^{-1}) (NCGA, 2006). Even though both the Texas and national figures are lower than the previous year, this production level is the second highest on record (USDA NASS, 2006). The increase in production is due to additional production area and improved management and hybrids. In 2011, approximately 12.4 billion bushels (314.9 million Mg) were harvested from over 83.9 million acres (34 million ha). The national average yield was slightly lower, however, at 147.2 bushels per acre (9.23 Mg ha^{-1}). In Texas the numbers were lower than previous years due to extreme drought conditions in some areas. Harvested maize acreage was 1,470,000 acres (595,350 ha) out of 2,050,000 (830,250 ha) planted. Grain production was approximately 136,710,000 bushels (3,471,887 Mg), with an average yield of 93 bushels per acre (5.83 Mg ha^{-1}) (USDA NASS, 2012).

In addition to livestock feed and human food, maize is used in many industrial applications, including certain industrial chemicals and organic compounds to replace compounds typically from non-renewable sources (Texas Corn Producers, 2012). Maize is also produced for its biomass, which is used as a forage or silage and energy production.

The definitive origin of maize is unknown, but it is believed to have evolved from teosinte (*Zea mexicana*). Systematic genetic improvement over the past century has resulted in major gains in grain yield and a shift from using open-pollinated varieties to single cross hybrids. Management methodologies have improved as well; plant spacing has decreased because newer hybrids are able to withstand higher populations without a negative impact on yield. Corn plants also respond well to modern agronomic practices including the application of pesticides, fertilizers and water (Wilkes, 2004).

There is a continual concern about reduced genetic diversity in elite corn germplasm and the potential effects this could have on future maize productivity under challenging climatic and environmental conditions. One way to mitigate this issue is to incorporate exotic germplasm into existing maize improvement programs (Goodman et al., 2000; Holland, 2004). There is a balance; too much or the wrong exotic material will reduce productivity (dos Santos et al., 2000; Lewis and Goodman, 2003). Therefore, each exotic source of germplasm must be evaluated and characterized. The best way to determine the true potential of certain material is through the use of multiple environments that are representative of the target areas where improvement is desired.

Another concern in warm and dry production areas such as South Texas is aflatoxin contamination. Aflatoxin is a carcinogenic mycotoxin produced by the fungus *Aspergillus flavus*. This toxigenic substance has been shown to cause liver cancer in humans (Castegnaro and McGregor, 1998; Moreno and Kang, 1999; Munkvold, 2003) and is a health risk to livestock (Anderson et al., 1975). Abiotic stresses such as hot, dry climates and biotic stresses such as insect damage contribute to aflatoxin contamination of maize grain (Windham et al., 1999). As these conditions vary by year and environment, evaluation of natural occurrence of the toxin is limited in scope (Windham and Williams, 2002). Numerous cultural practices have been implemented in order to reduce both pre- and post-harvest aflatoxin contamination in grain. Agronomic practices similar to disease management plans are not the most effective, due to the fact that *Aspergillus* overwinters on crop residue in the soil. Various control methods for harvest timing and grain handling and storage can be used to hinder levels of contamination if pre-harvest prevention cannot be obtained, but optimal conditions still only provide a short term solution (Cleveland et al., 2003; Munkvold, 2003). By far the best method for control of aflatoxin accumulation is genetic resistance (Munkvold, 2003). There are currently no commercially available hybrids that exhibit resistance to aflatoxin accumulation, but there are some populations and inbred lines with exotic backgrounds that have shown some resistance. However, most of this germplasm that has been developed in public breeding programs also exhibits, for the most part, poor agronomic performance. Research has been conducted to incorporate the advanced agronomic performance of elite temperate lines with this more exotic material that shows potential for resistance to aflatoxin accumulation (Betrán et al., 2002; Campbell and White, 1995; Guo et al., 1995; Hamblin and White, 2000; Naidoo et al., 2002; Windham and Williams, 2002).

This thesis presents three experiments conducted during the summer season of 2005 in multiple environments representing the maize producing regions of Texas. These experiments examine a variety of hybrids developed from exotic sources of germplasm and compare and contrast their performance with that of multiple hybrids that are produced commercially throughout the United States. This thesis will take into account numerous agronomic characteristics that will help to illustrate the performance and potential improvements gained from this exotic-derived material. These experiments will also evaluate the performance of the hybrids in the presence of *Aspergillus flavus* to determine if resistance or reduced risk to aflatoxin contamination is a potential gain from utilization of the material. Hopefully the results of these experiments will provide valuable data that can be incorporated into future research.

The objectives are: i) estimate the responses of hybrids to aflatoxin and their agronomic performance across a range of environments; ii) identify the hybrids within each group that exhibit the lowest levels of contamination; iii) analyze the relationship between agronomic performance and aflatoxin accumulation; and iv) determine how Genotype x Environment interactions affect these traits.

CHAPTER II

MATERIALS AND METHODS

Materials

This study involves numerous experimental and commercial maize hybrids and examines important agronomic characteristics and the level of aflatoxin contamination in these hybrids across a range of environments. For these tests, three sets of hybrids were evaluated. The yellow hybrid group consisted of twenty experimental hybrids and five popular commercial U.S. hybrids (Table 1). The white hybrid group (Table 2) and the Quality Protein Maize (QPM) group (Table 3) each consisted of twenty-one experimental hybrids and four popular U.S. commercial hybrids. The experimental hybrids in each group were developed from inbreds selected in the Maize Breeding and Genetics Program at Texas A&M University. Seed used for planting these tests was obtained by crossing selected inbreds with one of two elite temperate commercial testers, LH195 and LH210, representing the two main heterotic groups in U.S. maize germplasm, the Stiff Stalk and the non-Stiff Stalk heterotic groups. These testers can therefore be instrumental to understand the heterotic response of the exotic lines without previously determined classification. Furthermore, they are parents of commercial hybrids and harbor proven agronomic and yield performance. They each have a good general combining ability that allows the interaction between them and the other parents to be seen easily in the resulting hybrids.

The ten different environments varied from subtropical to temperate climates and were representative of the maize production regions of Texas (Table 4). Due to poor field conditions resulting in no crop production, the experiments with white and QPM maize hybrids were not analyzed in College Station.

Table 1. Entry number and pedigree of experimental and commercial yellow hybrids evaluated across Texas environments in 2005.

Entry	Pedigree
1	LAMA2002-25-5-B/LH210
2	LAMA2002-42-B-B/LH195
3	LAMA2002-60-9-B/LH195
4	NC300/CML288-B-2-B-B-B/LH195
5	(CML 326/Tx772)-B-1-B-B-B-B/LH195
6	(CML 326/Tx772)-B-11-B-B-B-B/LH195
7	(CML288/NC300)-B-9-B1-B-B-B/LH195
8	(Tx772 x Tx745)-1-91-1-B-B-B/LH195
9	((Tx772 x Tx745) x Tx745)-9-1-B-B-B-B/LH195
10	((Tx772 x T246) x Tx772)-1-5-B-B-B-B/LH195
11	(Tx772/CML326)-B-B5-B-B/LH195
12	((CML 408/B104)x(CML 411/B104))-2-1-B-B/LH210
13	((B104/NC300)x(CML 415/B104))-4-1-B-B/LH210
14	((B104/NC300)x(CML 415/B104))-4-2-B-B/LH210
15	((B104/NC300)x(CML285/B104))-2-3-B-B/LH210
16	(CML285/B104)-B-4-B-B-B-B/LH210
17	(B104-1 x Tx714-B/B110 x FR2128-B)-7-1-B-B-B-B/LH210
18	(Tx601 x B104-B/FR2128-B x Bord)-2-2-B-B-B/LH210
19	Tx759(Tx6252/Va35)-1-1-2-2-3-6-1-B-B-B-B-B/LH210
20	(B110 x FR2128-B/B104-1/CML343)-B-B-11-B-B-B/LH210
21	P31B13
22	P32R25
23	BH 8913
24	DKC 69-72
25	W4700

Table 2. Entry number and pedigree of experimental and commercial white hybrids evaluated across Texas environments in 2005.

Entry	Pedigree
1	(CML269/Tx110)/(CML311/Tx110)-1-B-B-B-B/LH195
2	Tx114/CML78-B-1-B-B-B/LH210
3	(Tx114 (B73w)-B x CML343/Tx110 x Pop24)-B-B-B-4-B-B-B/LH210
4	CML311-B/CI66-B/Tx114 (B73w)-B x CML343)-B-B-B-2-B-B-B/LH210
5	Tx130 (Va35w)-B-B-B-B-B/LH195
6	CML343-B-B-B-B-B-B/LH195
7	Tx114 (B73w)-B-B-B-B-B/LH210
8	(Tx114 (B73w)-B x CML343/Tx110 x Pop24)-B-B-B-1-B-B-B-B/LH195
9	CML269/TX130-B-B-B-1-1-B-B-B-B/LH195
10	(Tx114 (B73w)-B x CML343/Tx110 x Pop24)-B-B-B-2-B-B-B-B/LH210
11	CML269/TX130-B-B-B-1-2-B-B-B/LH195
12	CML269/TX130-B-B-B-4-2-B-B-B/LH195
13	(CML269/Tx114)-B-B-B1-B/LH210
14	CML269/TX114-B-B-B-B-B/LH210
15	CML269/TX114-B-B-B-1-1-B-B-B-B/LH210
16	(Tx106-Tx714)-1-1-714-1-2-B-B-B-B/LH210
17	(CML184-B-B/CML176)-B-3-B-B-B-B/LH210
18	(Tx811-B x CML176-B)-B-B-B-B-1-B-B-B/LH195
19	Tx114/CML343
20	(B110 x FR2128-B/B104-1/CML343)-B-B-11-B-B-B/LH210
21	(Tx811-B x CML176-B)-B-B-B-B-1-B-B-B/LH210
22	Rx949
23	Rx953
24	Wilson 1851W
25	Triumph 1910W

Table 3. Entry number and pedigree of experimental and commercial Quality Protein Maize hybrids evaluated across Texas environments in 2005.

Entry	Pedigree
1	Pop. 69 Templado Amarillo QPM-B-B-B1-8-B-B-B/LH195
2	Pop. 69 Templado Amarillo QPM-B-B-B2-11-B-B-B/LH195
3	Pop. 69 Templado Amarillo QPM-B-B-B6-8-B-B-B/LH195
4	Tx802-B-B-B /CML161-B-3-B-B-B/LH195
5	(P69Qc3HC107-1-1#-4-2#-4-B-B-1-4-B-B-B-B-B X CML 193)-B-B-1-B-B-B/LH195
6	(P69Qc3HC107-1-1#-4-2#-4-B-B-1-4-B-B-B-B-B X CML 193)-B-B-2-B-B-B/LH210
7	(Tx802 x Ko326y)-18-1-1-1-B-B-B-B-B-B/LH195
8	CML161-B-B-B/LH195
9	Tx806-B-B-B-B/LH195
10	(B97-B-B/(Ko326y x Tx806)-6-1-1-1-B-B)x((Ko326y x Tx806)-6-1-1-1-B-B/NC300)-B1-B-2-B-B/LH195
11	((B73 o2/o2-B -B/B104)x(Tx714/(Ko326y x Tx806)-6-1-1-1-B-B))-B-B-2-B-B/LH210
12	(B104-1-B-B/(Tx802 x Ko326y)-18-1-1-1-B-B))-B-B-B-3-B-B/LH210
13	((Ko326y x Tx806)-6-1-1-1-B-B/B104))-B-B-B-B-B/LH210
14	(Tx802-B-B-B/B104)-1-18-B-1-B-B/LH210
15	Temp. SSLate (B37,B73,B84) B-44-B-B-B/LH210
16	Temp. SSLate (B37,B73,B84) B-76-B-2-B-B/LH210
17	(Tx811-B x CML 176-B)-B-B-B-B-2-B-B-B/LH195
18	Tx811-B-B-B/LH195
19	CML176-B-B-B/LH195
20	(CML184-B-B/CML176)-B-3-B-B-B-B/LH210
21	(Tx811-B x CML176-B)-B-B-B-B-1-B-B-B/LH210
22	P31B13
23	BH 8913
24	DKC 69-72
25	W4700

Field Analysis

Experiments were set up in alpha lattice designs with incomplete blocks and three replications per environment. Experimental units were two-row plots in all locations except College Station, Corpus Christi, and Weslaco, where one-row plots were used. Planting dates ranged from February to May depending on typical regional planting dates (Table 4). Standard cultural and agronomic practices were also observed based on the region in question. In College Station data was collected only on the yellow hybrids. Aflatoxin accumulation was analyzed in all environments except Dumas and Dalhart.

Table 4. General information for Texas environments used in the experimental evaluation of yellow, white and QPM hybrids in 2005.

Location	Code	Latitude	Elevation (m)	Plot area (m^2/plot)	Watering system	2005 Planting date
College Station*	CS	30°37’	96.0	4.06	Irrigated	Mar. 12
Weslaco	WE	26°09’	22.5	5.40	Rainfed	Feb. 16
Corpus Christi	CC	27°46’	12.9	4.08	Rainfed	Feb. 17
Castroville	CA	29°21’	228.2	14.76	Irrigated	Mar. 4
Wharton	WH	32°17’	126.4	16.38	Rainfed	Mar. 15
Granger	GR	29°17’	30.3	15.60	Rainfed	Mar. 18
Bardwell	BA	30°42’	172.4	12.37	Rainfed	Mar. 11
Prosper	PR	33°14’	194.2	12.18	Rainfed	Mar. 24
Dalhart†‡	DA	35°51’	1114.7	11.86	Irrigated	May 12
Dumas†‡	DU	36°06’	1203.4	11.87	Irrigated	May 11

*College Station was used for the yellow hybrid experiment only.
†Latitudes and elevations are estimates for these locations.
‡Dumas and Dalhart were analyzed for combine harvest data only.

Agronomic traits measured included flowering data, plant and ear heights, plant population, lodging, grain yields, test weights, moisture content, and 1000 kernel weights. Flowering data was measured as either days to silking from planting when 50% of plants per plot had silks showing or days to anthesis as days after planting when 50% of plants per plot were shedding pollen. Plant heights were taken pre-harvest at the end of the growing season and were measured as the average height in cm from ground to tip of tassel, while ear heights were measured as the average height from ground to base of primary ear. Plant populations were measured at this time by counting total number of plants per plot and converting to plants per hectare. Stalk lodging was measured as the proportion of lodged plants with broken stalks below the primary ear. Root lodging was measured as the proportion of plants that stood at an angle greater than 30 degrees from the vertical. Lodging was expressed as a percentage by dividing the number of lodged plants into the total number of plants per plot. Grain yield (Mg ha^{-1} adjusted to 15.5% moisture), moisture (%), and test weights (kg hl^{-1}) were measured using computer system in combine harvester for all environments with two-row plots. Grain yield and test weight data for one-row plot locations were taken by hand in the lab, as were 1000 kernel weights (g).

Aflatoxin Analysis

Grain samples from the experiments were also evaluated for response to aflatoxin under inoculation with *Aspergillus flavus*. Plots were inoculated using one of two non-wounding methods. Ground inoculation, used in Weslaco and Corpus Christi, involved spreading *A. flavus* infested kernels on the soil surface between rows once the plots reached the midsilk stage. Silk channel inoculation involved introducing a solution of *A. flavus* spores into the silk channel of selected ear samples six to ten days after silking. Each ear sample received 3 mL of the solution ($1.0*10^7$ spores/mL) from a repeating syringe (Zummo and Scott, 1989).

In Weslaco and Corpus Christi, entire plots were harvested by hand, shelled, and bulked. In all other locations where aflatoxin accumulation was measured, eight ear samples were selected for inoculation. These were also hand harvested, shelled, and bulked. Bulked samples were then ground using a Romer mill (Romer Labs, Union, MO), and 50 g subsamples were then quantified for aflatoxin accumulation using VICAM Aflatest® antibody columns (VICAM, Watertown, MA).

Statistical Analysis

For analysis of variance of aflatoxin concentrations, the data was transformed using the base 10 logarithm in order to equalize variances. Individual environment analysis of variance for agronomic data was conducted using Proc GLM in SAS 9.0 (SAS Institute, 2002). Contrasts were calculated to compare the performance of the experimental hybrids to that of the commercial hybrids. The data was also analyzed using restricted maximum likelihood with REMLtool™ as randomized complete blocks (Welen, 2003). Adjusted means were estimated using the method with the lowest mean square error. Trait correlations were illustrated using singular value decomposition (SVD) of hybrid by trait tables for each environment. Stability analysis was conducted with principle component analysis SVD of genotype by environment two-way tables using the Biplot add-in for Microsoft Excel® and linear regression of hybrid performance using SAS (Eberhart and Russell, 1966; Lipkovich and Smith, 2001). Biplots allow plant breeders to visualize data from multiple environments to determine stability across environments. They also illustrate relationships between environments, which entries are best suited for which environments, and relationships among traits at individual or multiple environments. Stability is an important trait for maize breeders to measure because elite hybrids must be able to respond and perform well across multiple environments in order to determine the best regions for future adaptation, and to appeal to a broader potential target base. Data was then combined for analysis across all environments. Overall means were determined using Proc Mixed in SAS 9.0. Overall means were also used to determine trait correlations using SVD.

CHAPTER III

RESULTS: YELLOW HYBRIDS

Single Environment Analysis

ANOVA and Means

For grain yield, replications within environments were significantly different (P<0.01) at four environments, but in-field variation for grain yield was not a problem based on low error terms for most environments (Table 5). Grain yields were significantly different (P<0.05) among hybrids in all environments except Granger. There were significant differences (P<0.01) between experimental and commercial hybrid yields at all environments except Granger (Table 5).

Table 5. ANOVA table for grain yield (Mg ha^{-1}) for experimental and commercial yellow hybrids at each Texas environment in 2005.

Source	df	Mean Square								
		WE†	CC	CA	WH	GR	BA	PR	DA	DU
Rep	2	1.69	0.38	3.24**	5.49**	5.06**	0.23	1.42**	3.12	2.78
Hybrid	24	1.01*	1.40**	2.24**	4.43**	0.64	1.36**	0.84**	5.82**	4.27**
Error	48	0.55	0.17	0.60	0.56	0.37	0.44	0.22	1.98	1.28
Exp*Check	1	4.23**	10.63**	14.81**	32.14**	1.12	13.26**	2.68**	20.75**	20.02**
Repeatability		0.46	0.88	0.73	0.87	0.42	0.67	0.74	0.80	0.70

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

Wharton, Dumas, and Castroville had the highest environmental means for grain yield while the means for Prosper, Corpus Christi, and Weslaco were the lowest (Table 6) (Figure 1). Prosper suffered from extreme drought conditions during the growing season and Corpus Christi sustained heavy insect damage, each resulting in significantly lower yields. Grain yield was not calculated in College Station because only aflatoxin ear samples were harvested within plots.

In all environments the U.S. commercial check hybrids yielded higher than the experimental hybrids (Figure 1). Coefficients of variation were rather high, over 10% in all but two environments (Table 6).

For test weights, reps within environment were significant ($P<0.05$) at College Station and Granger, where soil differences and drainage issues caused field variation (Table 7). Significant differences among hybrids ($P<0.01$) were detected at Weslaco, Corpus Christi, Castroville, Wharton, Bardwell, Dalhart, and Dumas. In only three environments, significant differences ($P<0.01$) were detected between experimental and commercial hybrids (Table 7).

Table 6. Mean grain yields (Mg ha^{-1}) for experimental and commercial yellow hybrids at each Texas environment in 2005.

	---------- Mg ha^{-1} ----------								
Entry	WE†	CC	CA	WH	GR	BA	PR	DA	DU
1	4.81	3.52	8.02	9.48	5.91	5.33	0.86	4.42	8.36
2	4.77	3.15	7.92	7.81	5.54	6.31	0.79	5.03	7.62
3	4.81	2.93	7.94	8.46	4.70	5.55	1.57	7.48	7.93
4	4.32	3.04	8.30	10.87	6.03	6.37	1.34	6.42	6.66
5	4.78	1.80	5.69	6.64	4.65	5.63	1.08	4.93	6.70
6	3.64	1.53	7.11	7.61	5.21	5.30	1.48	4.80	7.98
7	3.89	2.23	8.36	8.09	6.11	5.88	1.78	7.01	6.80
8	5.03	2.26	7.17	9.08	6.24	5.58	0.66	4.91	6.91
9	5.06	2.36	7.26	8.42	5.93	6.43	1.67	7.24	8.41
10	5.35	1.84	6.42	6.18	5.15	5.21	0.93	8.30	8.01
11	4.79	2.58	7.86	8.03	5.53	6.01	1.86	3.91	8.01
12	5.66	3.21	7.84	7.61	6.01	6.39	1.62	6.30	8.72
13	5.60	3.44	9.19	9.28	6.47	6.72	1.89	5.08	10.18
14	5.39	3.12	8.15	8.70	6.03	4.97	2.06	6.07	10.01
15	5.47	2.98	8.23	9.11	5.80	6.45	2.56	5.60	8.31
16	5.69	3.44	8.14	9.83	4.89	6.63	1.85	8.09	10.46
17	4.95	3.05	8.00	9.44	5.49	6.36	1.17	6.90	9.58
18	5.22	2.82	7.12	9.20	6.00	6.05	1.66	6.82	9.30
19	4.81	2.92	6.38	8.27	5.87	7.07	2.28	5.57	9.24
20	5.56	2.98	8.00	8.65	6.45	6.31	1.55	6.45	8.03
21	6.16	4.75	9.06	10.60	6.18	6.60	1.36	6.79	8.54
22	5.45	3.03	8.46	10.06	5.64	6.73	1.61	7.09	9.83
23	4.83	3.82	8.83	10.69	5.88	7.58	2.18	9.17	9.72
24	5.84	3.80	8.88	10.36	6.12	7.08	2.51	7.35	9.77
25	5.46	3.27	8.59	9.99	6.23	7.22	2.36	9.76	10.38
Overall Mean	5.09	2.95	7.88	8.90	5.76	6.23	1.63	6.46	8.62
L.S.D. (0.05)	1.24	0.62	1.30	0.94	1.09	1.10	0.79	1.94	1.50
C.V., %	14.62	13.83	9.82	8.37	10.54	10.65	28.87	21.76	13.13

† WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

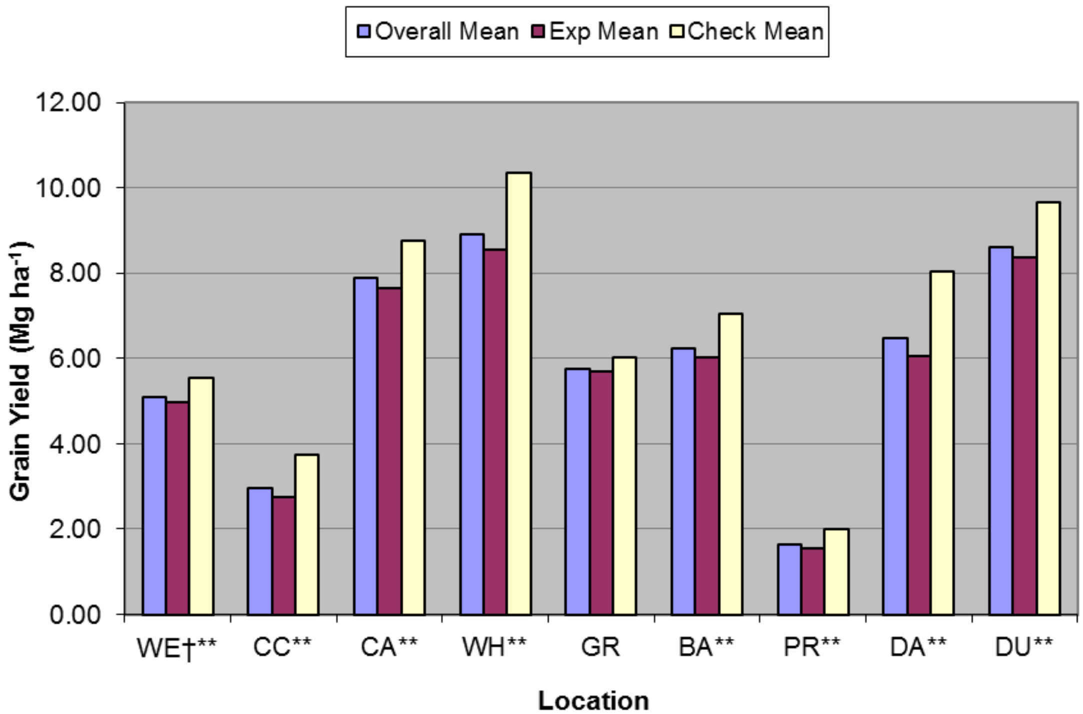

Figure 1. Grain yield means for all hybrids, experimental and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
† WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

Table 7. ANOVA table for test weights (kg hL^{-1}) for yellow hybrids at each Texas environment in 2005.

Source	df	Mean Square									
		CS†	WE	CC	CA	WH	GR	BA	PR	DA	DU
Rep	2	769.77*	9.39	5.00	1.18	0.30	10.66*	0.47	50.65	0.56	1.41
Hybrid	24	194.34	10.84**	14.28**	8.95**	11.75**	4.61	14.25**	82.57	12.07**	7.77**
Error	46	156.96	3.05	6.22	0.59	0.36	3.04	1.25	66.26	1.01	1.11
Exp*Check	1	9.72	---	3.96	0.20	28.23**	0.68	0.13	1.34	20.43**	10.32**
Repeatability		0.11	0.72	0.56	0.93	0.97	0.34	0.91	0.20	0.91	0.86

*Significant at P<0.05
**Significant at P<0.01
†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

Castroville and Dumas had the highest test weight means, while Corpus Christi and College Station had the lowest (Table 8) (Figure 2). Statistical differences were detected between experimental and check hybrids (P<0.01) at Wharton, Dalhart, and Dumas. In some environments the check hybrids had higher test weights, while in others the experimental hybrids had higher test weights (Figure 2). Coefficients of variation were below 4% in all environments except College Station and Prosper, which were both above 10%.

Table 8. Mean test weights (kg hL^{-1}) for experimental and commercial yellow hybrids at each Texas environment in 2005.

	kg hL^{-1}									
Entry	CS†	WE	CC	CA	WH	GR	BA	PR	DA	DU
1	87.57	73.16	70.23	76.21	71.60	72.98	72.22	75.27	72.94	73.03
2	76.57	73.46	70.53	76.79	72.43	73.81	72.92	51.26	74.95	75.71
3	74.63	72.12	68.56	75.38	72.71	70.11	71.04	70.76	75.93	76.66
4	76.60	75.17	72.80	77.20	74.47	72.66	74.79	76.48	76.51	77.39
5	74.30	76.40	70.18	75.97	73.49	73.05	73.25	76.76	71.28	75.13
6	74.55	77.85	73.48	78.39	75.30	74.02	75.26	78.14	77.09	77.45
7	76.70	73.02	68.99	77.54	74.04	73.45	76.84	75.02	73.18	73.36
8	57.67	74.53	64.81	74.45	73.41	72.03	73.61	75.92	71.82	74.55
9	56.67	74.79	68.83	74.22	70.94	69.11	72.39	74.18	72.29	75.29
10	76.10	74.97	71.98	76.69	72.91	72.42	74.55	76.46	74.96	75.55
11	77.53	75.78	74.18	77.62	76.34	73.88	75.07	77.74	74.87	77.75
12	72.20	72.87	65.90	73.98	70.97	71.47	72.26	72.23	72.46	73.52
13	74.43	73.82	69.41	74.62	71.34	72.02	75.05	76.33	73.38	76.25
14	75.93	71.27	67.89	74.84	71.18	71.52	70.86	75.28	72.80	75.52
15	56.37	71.11	66.10	73.74	70.52	70.36	67.72	67.01	70.92	72.37
16	73.27	72.67	71.88	75.12	72.76	72.92	73.05	72.77	73.22	76.05
17	54.07	70.63	66.61	70.59	66.65	69.31	67.19	71.46	70.05	72.02
18	74.73	77.65	69.81	74.86	72.80	72.11	72.39	73.70	77.52	75.20
19	74.97	73.81	70.26	75.66	72.56	72.17	72.17	74.56	75.33	75.88
20	70.30	72.04	70.81	72.23	69.79	71.61	71.53	74.40	72.42	73.31
21	74.93	73.81	71.82	75.16	73.84	71.46	73.92	75.17	72.55	76.37
22	72.67	73.94	69.40	74.20	73.37	72.68	73.67	75.35	75.28	75.41
23	75.37	73.15	71.12	76.13	74.23	72.52	72.46	72.11	76.77	75.99
24	57.63	73.53	71.97	75.90	74.40	71.54	72.34	70.40	75.09	76.06
25	73.67	73.64	70.48	75.30	73.29	71.51	70.64	71.48	76.39	76.52
Overall Mean	71.58	73.81	69.92	75.31	72.61	72.03	72.69	73.21	74.00	75.29
L.S.D. (0.05)	21.55	2.88	3.49	1.11	1.00	3.05	1.88	13.71	1.43	1.61
C.V., %	17.55	2.36	3.57	1.02	0.82	2.42	1.54	11.12	1.36	1.40

†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

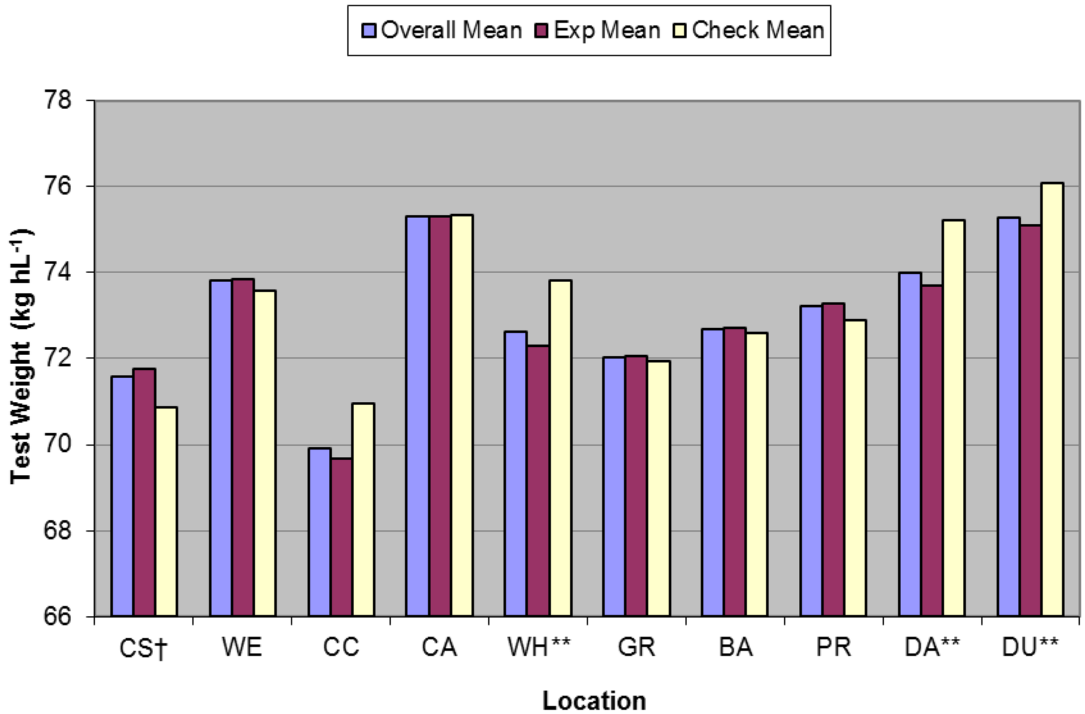

Figure 2. Test weight means for all hybrids, experimental and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

For 1000 kernel weights, replications within environments were significant (P<0.01) at College Station, Castroville, Wharton and Granger. Hybrids were significantly different (P<0.01) at all environments and differences between experimental and commercial hybrids were detected (P<0.05) at all environments except Bardwell (Table 9).

Table 9. ANOVA table for 1000 kernel weights (g) for yellow hybrids at each Texas environment in 2005.

Source	df	Mean Square						
		CS†	CC	CA	WH	GR	BA	PR
Rep	2	10163.96**	72.85	2218.36**	4176.34**	4277.69**	656.54	402.25
Hybrid	24	1398.05**	936.40**	1333.60**	1555.57**	1210.39**	893.27**	2645.60**
Error	48	500.57	237.80	348.79	431.32	414.46	307.57	427.64
Exp*Check	1	4741.78**	1779.53**	2268.75*	3177.94**	3382.89**	595.02	2343.61*
Repeatability		0.64	0.75	0.74	0.72	0.66	0.66	0.84

*Significant at P<0.05
**Significant at P<0.01
†CS: College Station, WE: Weslaco , CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Wharton and Castroville had the highest 1000 kernel weight means, and Corpus Christi and Weslaco had the lowest (Table 10) (Figure 3). In all locations except Prosper, commercial check hybrid means were higher than experimental hybrid means (Figure 3). Coefficients of variation were below 10% for all environments (Table 10).

Table 10. Mean 1000 kernel weights (g) for experimental and commercial yellow hybrids at each Texas environment in 2005.

	---------- g ----------							
Entry	CS†	WE	CC	CA	WH	GR	BA	PR
1	271.70	222.22	232.33	319.94	334.14	249.91	240.33	247.47
2	266.10	230.40	232.02	312.68	293.18	271.83	246.83	246.76
3	266.17	223.08	196.15	269.28	282.25	233.33	197.33	175.19
4	232.21	203.36	194.76	264.03	316.44	238.71	227.50	200.03
5	235.71	230.48	220.66	261.30	302.52	218.27	228.00	283.15
6	251.91	231.52	248.46	272.11	310.45	259.09	232.17	223.39
7	256.82	204.03	179.86	270.72	284.41	184.88	210.17	217.07
8	197.97	204.01	207.94	242.63	265.33	228.37	240.50	240.99
9	239.81	229.67	215.12	278.16	320.57	229.82	228.67	242.61
10	219.79	209.46	213.02	261.52	287.23	238.93	231.67	216.68
11	239.19	202.17	194.28	261.27	281.41	234.98	231.17	232.14
12	226.30	261.37	212.56	305.25	340.74	267.69	261.67	245.53
13	254.46	223.93	227.30	291.17	310.82	257.52	281.67	283.63
14	287.86	226.71	224.31	322.72	288.71	265.97	252.83	199.61
15	249.47	214.72	218.59	272.09	272.02	230.52	220.83	202.30
16	246.44	243.83	220.47	292.34	298.03	234.59	257.33	239.23
17	221.20	230.62	227.53	275.24	309.41	249.04	237.17	291.77
18	230.38	209.92	221.10	243.91	275.86	241.63	215.83	191.55
19	260.28	245.24	242.58	252.58	326.82	259.81	237.50	230.65
20	235.32	242.35	237.95	288.57	339.21	270.72	250.00	275.42
21	283.43	226.27	222.50	290.54	305.84	240.75	238.17	222.63
22	268.34	248.23	231.90	286.64	345.28	251.56	240.67	258.09
23	241.08	215.51	217.38	289.83	317.33	273.84	247.50	210.57
24	279.00	241.71	234.49	310.90	327.33	294.47	247.33	180.16
25	261.60	235.87	244.96	290.13	312.67	241.87	243.83	223.68
Overall Mean	248.90	226.27	220.73	281.02	305.92	246.72	237.87	231.21
L.S.D. (0.05)	33.72	25.36	26.65	30.55	31.83	36.26	29.56	31.83
C.V., %	8.98	6.98	6.99	6.64	6.78	8.21	7.37	8.94

†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

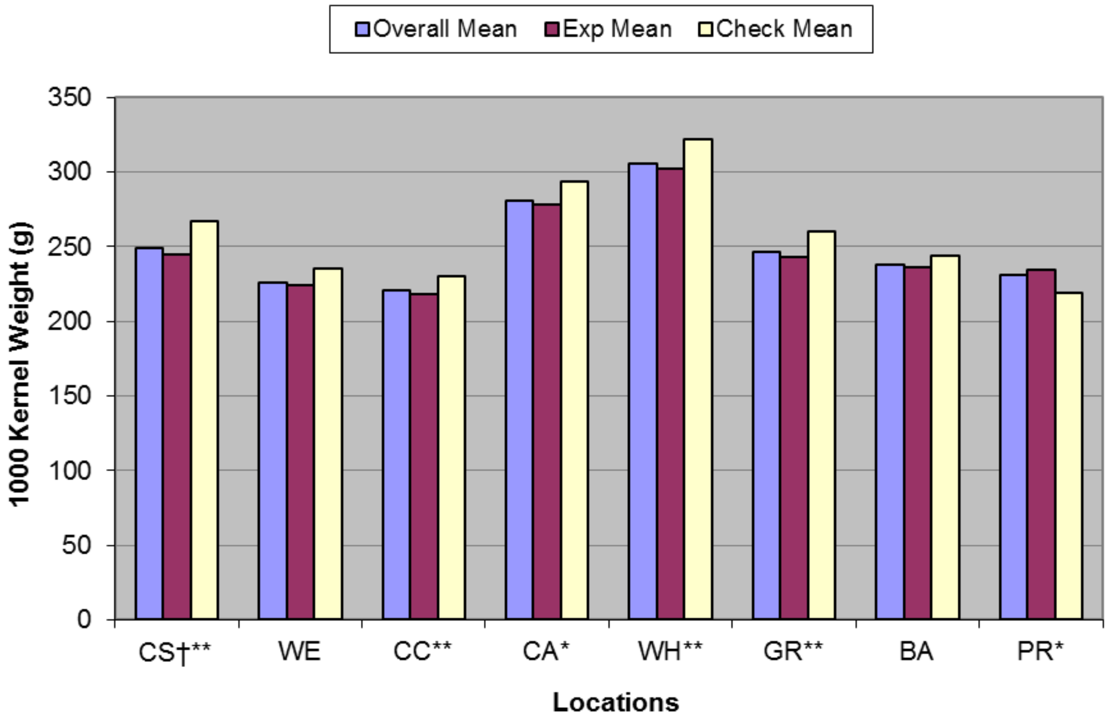

Figure 3. 1000 kernel weight means for all hybrids, experimental and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

For aflatoxin accumulation, reps within environments were significant (P<0.05) at College Station and Castroville. Significant differences between hybrids (P<0.05) were detected at College Station, Weslaco, Corpus Christi, and Bardwell and differences between the commercial and experimental hybrids (P<0.01) were detected only at Granger (Table 11).

Table 11. ANOVA table for the antilogarithmic aflatoxin concentration (ng g^{-1}) for yellow hybrids at each Texas environment in 2005.

Source	df	Mean Square							
		CS†	WE	CC	CA	WH	GR	BA	PR
Rep	2	1121696.89**	21612.37	339265.33	69181.32*	82423.56	133552.91	1218.28	23421.72
Hybrid	24	290619.98*	23286.06*	747301.33**	24520.31	303267.42	73143.94	131309.46**	157957.11
Error	48	144947.73	13182.32	190952.83	21252.95	209742.19	65380.02	46120.14	113809.94
Exp*Check	1	427971.87	6156.27	1723692.00**	663.05	50684.72	360338.99*	57907.41	37252.16
Repeatability		0.50	0.43	0.74	0.13	0.31	0.11	0.65	0.28

*Significant at P<0.05
**Significant at P<0.01
†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Weslaco, Castroville, and Bardwell had the lowest means for aflatoxin accumulation, while Corpus Christi, College Station, and Granger had the highest accumulations (Table 12) (Figure 4). In all locations except Castroville and Bardwell, mean concentration levels for commercial check hybrids were higher than those for the experimental hybrids (Figure 4). Coefficients of variation were relatively high for all environments, ranging from 37.99 to 114.22 (Table 12).

Table 12. Mean antilogarithmic aflatoxin concentrations (ng g^{-1}) for experimental and commercial yellow hybrids at each Texas environment in 2005.

	ng g^{-1}							
Entry	CS†	WE	CC	CA	WH	GR	BA	PR
1	199.53	35.42	529.05	263.88	735.70	398.29	181.38	387.88
2	92.62	36.88	230.41	76.07	79.43	308.53	129.87	275.49
3	398.11	77.73	687.86	102.35	125.89	277.33	67.33	146.69
4	199.53	27.33	520.48	73.60	63.10	442.79	59.03	260.02
5	857.63	141.94	1605.83	66.47	316.23	404.11	98.45	899.50
6	584.39	25.16	1465.89	121.00	199.53	306.76	15.18	342.61
7	116.60	29.53	426.87	30.93	73.57	283.86	14.16	286.62
8	68.12	26.67	1125.38	114.10	42.98	307.26	85.23	165.27
9	316.23	52.80	934.54	57.82	99.86	330.90	110.41	55.80
10	107.97	18.24	1265.90	184.37	368.72	256.04	192.35	336.28
11	146.79	29.72	1246.52	55.78	271.21	365.43	338.84	64.37
12	501.19	191.43	739.78	170.33	198.20	1053.90	468.06	260.50
13	429.83	60.79	515.11	145.31	125.89	352.86	215.23	467.74
14	368.72	36.26	937.56	36.58	314.12	438.03	134.03	125.00
15	926.19	82.02	1513.91	140.18	429.83	437.22	635.62	251.94
16	271.21	159.62	1085.43	324.94	735.70	389.22	634.45	326.74
17	368.72	267.61	1765.22	262.66	429.83	311.24	130.80	372.65
18	199.53	196.56	1527.21	107.13	341.43	355.47	100.83	64.46
19	630.96	39.10	1278.50	217.82	464.19	271.27	145.31	96.01
20	501.19	67.08	1013.21	129.66	630.96	105.54	724.44	99.13
21	1000.00	37.47	1632.68	116.60	292.89	262.85	135.24	446.27
22	501.19	115.21	2438.93	119.54	398.11	729.12	135.18	629.65
23	681.24	152.19	1283.22	163.04	735.70	519.40	112.02	100.09
24	368.72	93.76	688.02	133.72	251.19	965.83	101.58	311.67
25	341.43	138.39	884.71	58.10	158.49	297.51	263.94	84.59
Overall Mean	407.10	85.56	1093.69	130.88	315.31	406.83	209.16	274.28
L.S.D. (0.05)	625.02	188.49	717.38	239.33	753.14	421.32	352.56	553.83
C.V., %	76.41	108.17	37.99	88.31	114.22	59.11	83.42	97.60

†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

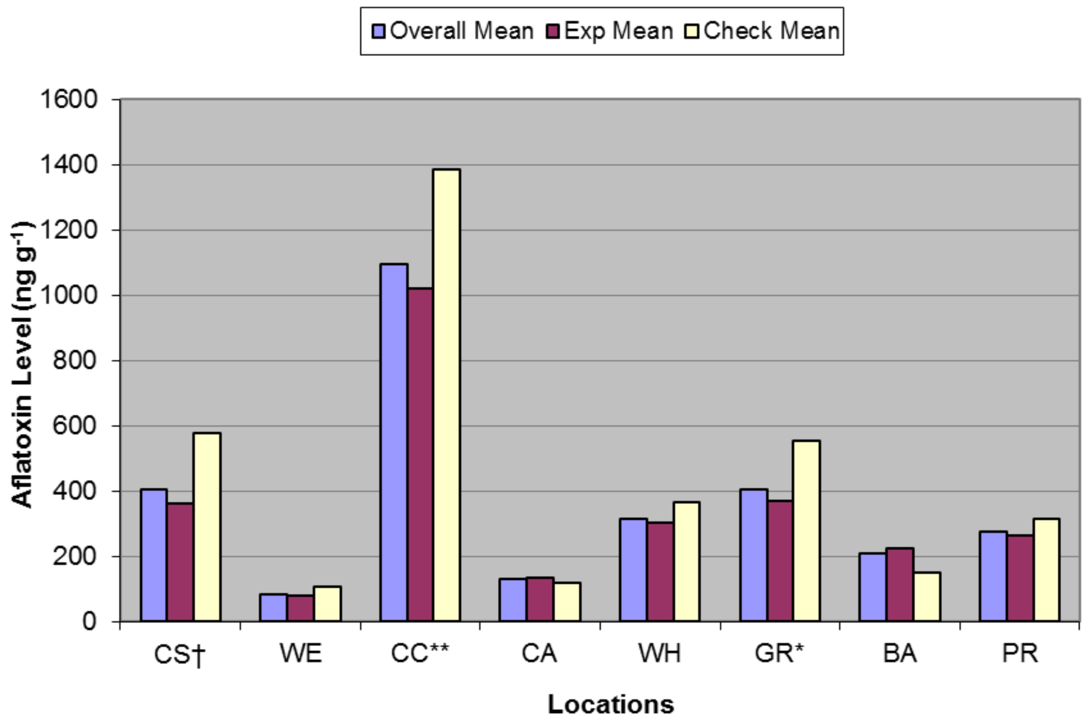

Figure 4. Aflatoxin accumulation means for all hybrids, experimental and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at $P<0.05$
**Significant differences between experimental and check hybrids at $P<0.01$
†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Combined Environment Analysis

ANOVA and Means

Analysis of variance across environments showed that there were significant differences among environments, reps within environments, and hybrids for all traits. There was also significant interaction between environments and hybrids for grain yield, 1000 kernel weights, and aflatoxin accumulation (Table 13).

Table 13. ANOVA table for grain yield (Mg ha^{-1}), test weights (kg hL^{-1}), 1000 kernel weights (g), and aflatoxin accumulation (ng g^{-1}) across all Texas environments for experimental and commercial yellow hybrids in 2005.

Source	df	Mean Square Grain Yield	df	Mean Square Test Weight	df	Mean Square 1000 Kernel Weight	df	Mean Square Aflatoxin Level
Env	8	451.42**	9	153.84**	8	240428.94**	7	7880709.19**
Reps(Env)	18	2.53**	16	105.89**	17	2584.84**	16	224046.55**
Hybrid	24	9.24**	24	89.15**	24	2735.27**	24	412199.05**
Env*Hybrid	192	1.60**	205	27.11	180	825.11**	168	190601.56**
Error	424	0.69	369	29.95	336	367.40	375	100365.70
Exp*Check	1	101.80**					1	729497.71**
Repeatability		0.93		0.66		0.87		0.76

*Significant at P<0.05
**Significant at P<0.01

Overall mean grain yield for the commercial hybrids (6.79 Mg ha^{-1}) was higher than that of the experimental hybrids (5.74 Mg ha^{-1}). Four of the commercial hybrids (P31B13, BH 8913, DKC 69-72, and W4700) were the highest yielding varieties. The highest yielding experimental hybrid, which ranked fifth overall, was Entry 16 ((CML285/B104)/LH210) (Table 14).

Table 14. Means for grain yield (Mg ha^{-1}), test weights (kg hL^{-1}), 1000 kernel weights (g), and aflatoxin accumulation (ng g^{-1}) across all Texas environments for experimental and commercial yellow hybrids in 2005.

Entry	Pedigree	Grain Yield Mg ha^{-1}	Test Weight kg hL^{-1}	Kernel Weight g	Aflatoxin Accumulation ng g^{-1}
1	LAMA2002-25-5-B/LH210	5.63	74.52	264.8	341.4
2	LAMA2002-42-B-B/LH195	5.44	71.84	262.5	153.7
3	LAMA2002-60-9-B/LH195	5.71	72.79	230.4	235.4
4	(NC300/CML288)-B-2-B-B-B/LH195	5.93	75.41	234.6	205.7
5	(CML 326/Tx772)-B-1-B-B-B-B/LH195	4.66	73.98	247.5	548.8
6	(CML 326/Tx772)-B-11-B-B-B-B/LH195	4.96	76.15	253.6	382.6
7	(CML288/NC300)-B-9-B1-B-B-B/LH195	5.57	74.21	226.0	157.8
8	(Tx772 x Tx745)-1-91-1-B-B-B/LH195	5.32	71.28	228.5	241.9
9	((Tx772 x Tx745) x Tx745)-9-1-B-B-B-B/LH195	5.86	70.87	248.1	244.8
10	((Tx772 x T246) x Tx772)-1-5-B-B-B-B/LH195	5.27	74.66	234.8	341.2
11	(Tx772/CML326)-B-B5-B-B/LH195	5.40	76.08	234.6	314.8
12	((CML 408/B104)x(CML 411/B104))-2-1-B-B/LH210	5.93	71.79	265.1	447.9
13	((B104/NC300)x(CML 415/B104))-4-1-B-B/LH210	6.43	73.67	266.3	289.1
14	((B104/NC300)x(CML 415/B104))-4-2-B-B/LH210	6.06	72.71	258.6	298.8
15	((B104/NC300)x(CML285/B104))-2-3-B-B/LH210	6.06	68.62	235.1	552.1
16	(CML285/B104)-B-4-B-B-B-B/LH210	6.56	73.37	254.0	490.9
17	(B104-1 x Tx714-B/B110 x FR2128-B)-7-1-B-B-B-B/LH210	6.10	67.86	255.3	488.6
18	(Tx601 x B104-B/FR2128-B x Bord)-2-2-B-B-B/LH210	6.02	74.08	228.8	361.6
19	Tx759(Tx6252/Va35)-1-1-2-2-3-6-1-B-B-B-B-B/LH210	5.82	73.74	256.9	392.9
20	(B110 x FR2128-B/B104-1/CML343)-B-B-11-B-B-B/LH210	6.00	71.84	267.4	408.9
21	P31B13	6.67	73.90	253.8	490.5
22	P32R25	6.43	73.60	266.3	633.4
23	BH 8913	6.97	73.99	251.6	468.4
24	DKC 69-72	6.86	71.89	264.4	364.3
25	W4700	7.03	73.29	256.8	278.4
Overall Mean		5.95	73.05	249.8	365.4
Experimental Hybrid Mean		5.74	72.97	247.6	344.9
Commercial Hybrid Mean		6.79	73.33	258.6	447.0
L.S.D (0.05)		0.68	2.65	15.4	248.8
C.V., %		13.95	7.52	8.34	75.52

For test weight, the commercial hybrids (73.33 kg hL^{-1}) performed slightly better overall than the experimental hybrids (72.97 kg hL^{-1}) (Table 14). The experimental hybrids had a much wider range in test weights (67.86 to 76.15 kg hL^{-1}) than the commercial hybrids (71.89 to 73.99 kg hL^{-1}). Commercial hybrids had higher overall 1000 kernel weight means than the experimental hybrids. The top kernel weight mean came from an experimental hybrid, Entry 20 ((B110xFR2128-B/B104-1/CML343)-B-B-11-B-B-B/LH210) (267.44 g). P32R25 ranked second in test weights and was the only commercial hybrid in the top five. The lowest five 1000 kernel weight means also belonged to experimental hybrids (Table 14).

Entry 2 in the yellow experiment, LAMA2002-42/LH210, had the lowest aflatoxin accumulation (153.66 ng g^{-1}). The highest accumulations were in Entry 22, P32R25 (633.37 ng g^{-1}). Experimental hybrids had lower overall aflatoxin contamination levels than the commercial hybrids (Table 14).

Principal Component Analysis

As expected, the SVD biplot for grain yield grouped the environments into sets (Figure 5). Weslaco and Prosper were grouped and had similar vector lengths, indicating that these two locations had a high correlation and discriminated the hybrids similarly. Bardwell showed the shortest vector length among locations, meaning it exhibited the least amount of variation between hybrids. Dalhart had the longest vector length, which indicates high yields with a large amount of variation among hybrids. Hybrid points that are plotted close to environment vectors show adaptation for those particular environments with respect to grain yield. Entry 4 (NC300/CML288-B-2-B-B-B/LH195) was plotted directly on the Wharton vector. This particular entry was the highest yielding among all yellow hybrids at all locations (10.87 Mg ha^{-1}, Table 6). Entry 11 produced its highest yield in Wharton and was relatively more adapted to the environment in Granger.

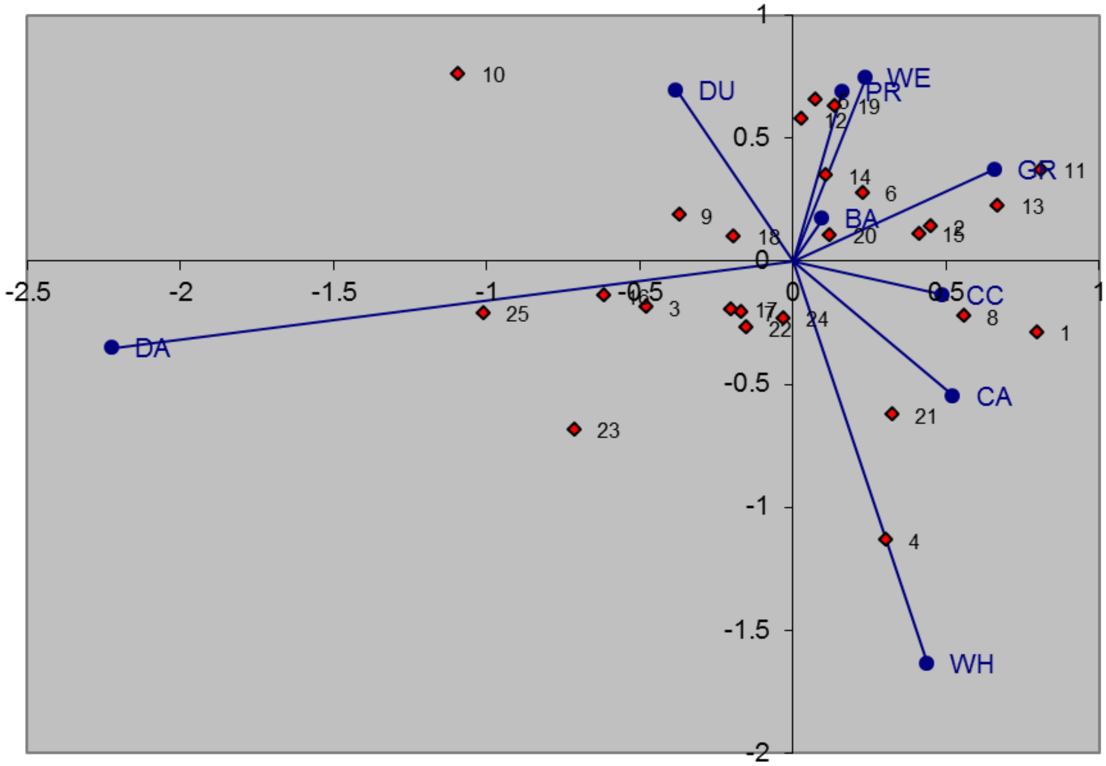

Figure 5. Singular Value Decomposition Biplot for grain yields for yellow hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

The SVD biplot for test weight showed significant environmental grouping for all locations except for College Station and Prosper (Figure 6). College Station exhibited the longest vector length, indicating large variation among hybrids for test weight. Entry 1 (LAMA2002-25-5-B/LH210) had the highest test weight at College Station (87.57 kg hL^{-1}, Table 8). Entries 8, 9, 15, 17 and 24 all showed the lowest test weights at College Station among yellow hybrids. Entry 2 (LAMA2002-42-B-B/LH195) showed low test weights at all locations (Table 8).

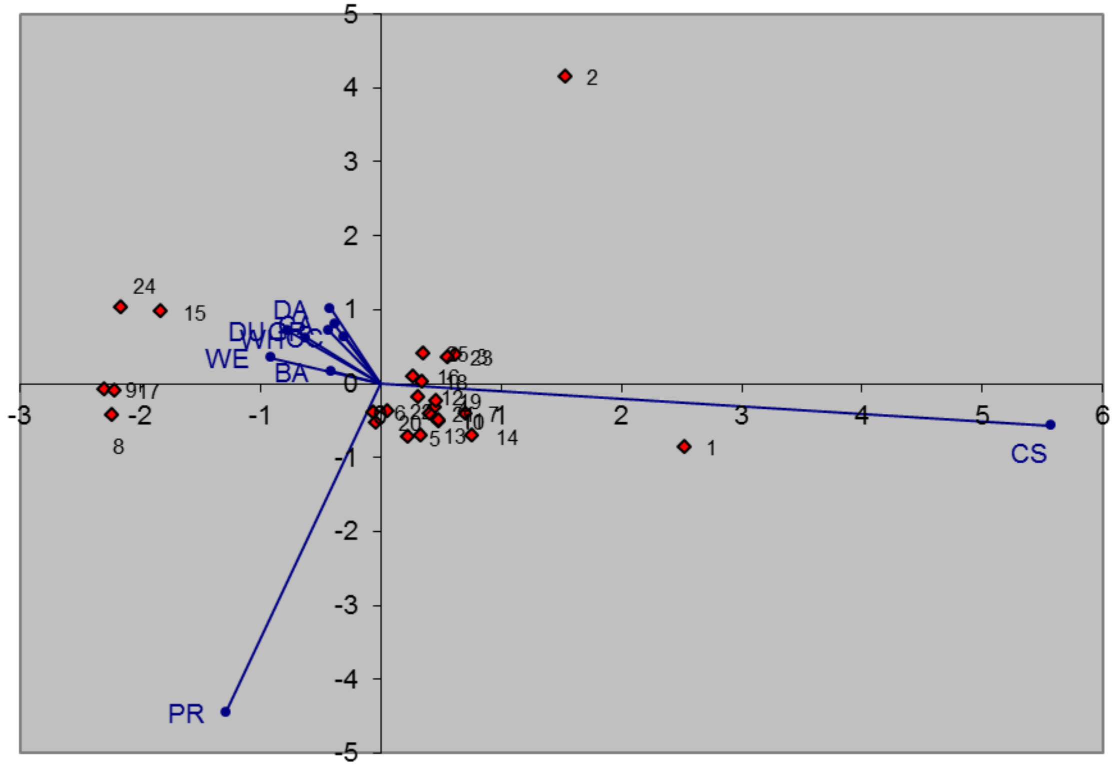

Figure 6. Singular Value Decomposition Biplot for test weights for yellow hybrids across all Texas environments in 2005.

†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

The SVD biplot for 1000 kernel weight shows that Castroville and College Station appear to be positively correlated, but College Station exhibits more variation among hybrids (Figure 7). Bardwell, Wharton, Weslaco, and Corpus Christi grouped closely and with short vectors, suggesting low weights with minimal variation within each location. Weslaco showed the least variation and Prosper the most variation among 1000 kernel weights. Entry 13 showed the highest test weight at Prosper, while Entry 24 showed the lowest.

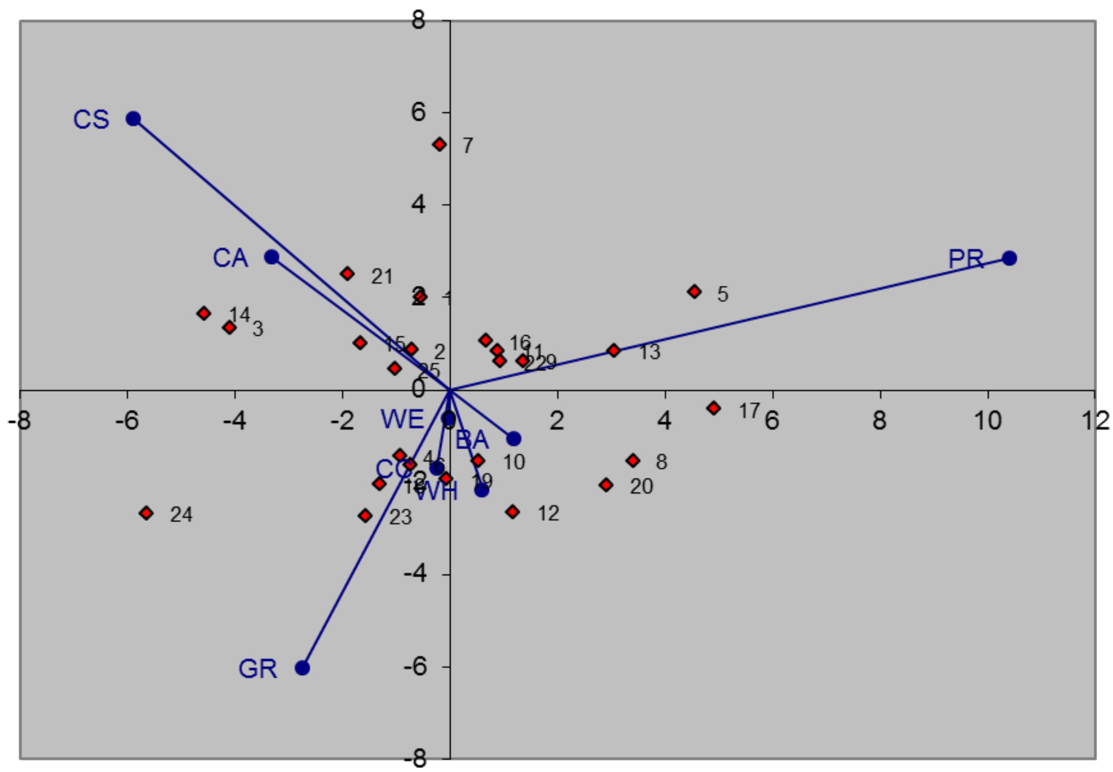

Figure 7. Singular Value Decomposition Biplot for 1000 kernel weights for yellow hybrids across all Texas environments in 2005.

†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

SVD biplot for aflatoxin accumulation shows some environmental grouping (Figure 8). Corpus Christi showed the longest vector, illustrating the higher and more varied aflatoxin levels due to severe insect damage at that location. No environments exhibited highly positive correlation with others with respect to aflatoxin levels. Entry 22 produced the highest level of aflatoxin accumulation for the entire yellow group at

Corpus Christi. Entries 12 and 24 are plotted close to the Granger vector, and both of those entries produced their highest levels of accumulation in that environment.

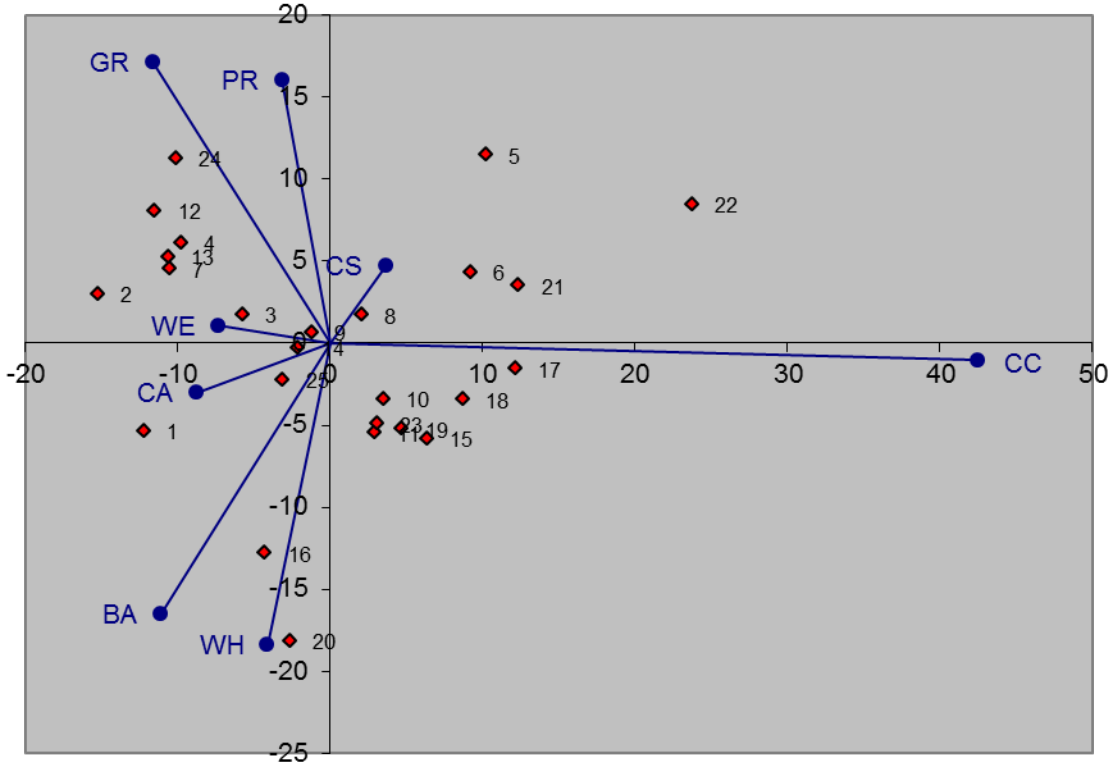

Figure 8. Singular Value Decomposition Biplot for antilogarithmic aflatoxin concentration for yellow hybrids across all Texas environments in 2005.

†CS: College Station, WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

SVD biplot for trait means across environments among yellow hybrids shows that grain yield and test weight are positively correlated (Figure 9). Aflatoxin accumulation was negatively correlated to grain yield and yield components (test weight and 1000 kernel weight).

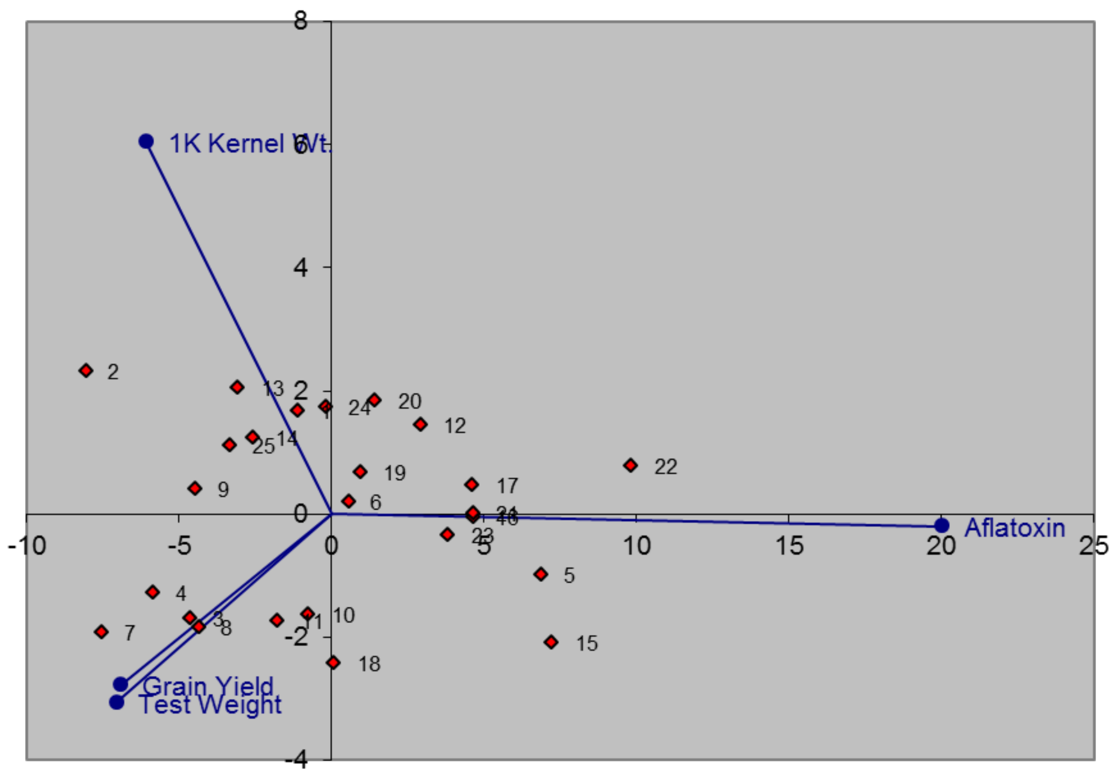

Figure 9. Singular Value Decomposition Biplot for trait means for yellow hybrids across all Texas environments in 2005.

Discussion and Conclusions

In 2005 corn yields were below average in Texas due to extended periods of drought. In the current study, there was a wide range of environmental means for grain yield, as well as hybrid differences both within and across environments. Irrigated locations tended to have a yield advantage over rainfed sites, but timely rains in Wharton contributed to its high yields. At all locations, the commercial checks had higher mean yields than the experimental hybrids, but there were several experimental hybrids with grain yield means above 6 Mg ha^{-1}, which was competitive with the commercial checks. Environment affected test weight; heavier test weights were from the irrigated locations and the lighter test weights were from the rainfed environments. Experimental hybrids had higher test weights than commercial checks at five of the ten environments.

The yellow hybrid with the lowest level of aflatoxin accumulation was Entry 2 (LAMA2002-42-B-B/LH195) (153.66 ng g^{-1}); however, this hybrid ranked 20th overall for grain yield (5.44 Mg ha^{-1}). The highest yield of Entry 2 was in Castroville at 7.92 Mg ha^{-1}, slightly greater than the location mean of 7.88 Mg ha^{-1}. The other two hybrids in the experiment with LAMA backgrounds, Entry 1 (LAMA2002-25-5-B/LH210) and Entry 3 (LAMA2002-60-9-B/LH195), had the 12th and 4th lowest accumulations, respectively. These LAMA lines appear to show a level of tolerance to aflatoxin accumulation, which could prove valuable in the future and may become more evident with further testing. The second and third lowest accumulations were found in Entry 7 ((CML288/NC300)-B-9-B1-B-B-B/LH195) (157.77 ng g^{-1}) and Entry 4 ((NC300/CML288)-B-2-B-B-B/LH195) (205.74 ng g^{-1}) (Table 14).

Aflatoxin accumulation is not positively correlated with grain yield and yield components (test weight, 1000 kernel weight); lines with low accumulations for the most part had low yields. Exotic maize is typically not adapted to the temperate regions of Texas and does not produce high yields. However, these exotic varieties should be crossed with other elite temperate testers to see if higher yields can be achieved, while maintaining the resistance that was observed. Further testing in other southern United States environments is necessary to evaluate whether this resistance can be carried forward into future populations.

CHAPTER IV

RESULTS: WHITE HYBRIDS

Single Environment Analysis

ANOVA and Means

For grain yield, replications within environments were significant (P<0.05) at all environments except Weslaco, Granger, and Bardwell. Significant differences among hybrids were detected (P<0.01) at all environments except Bardwell, Prosper, and Dalhart. There were also significant differences detected between experimental and commercial hybrids at five environments (Table 15).

Table 15. ANOVA table for grain yield (Mg ha^{-1}) for white hybrids at Texas environments in 2005.

Source	df	Mean Square								
		WE†	CC	CA	WH	GR	BA	PR	DA	DU
Rep	2	0.53	1.58*	1.78*	5.73**	0.46	0.90	2.36**	114.20**	11.49**
Hybrid	24	1.32**	2.74**	2.64**	4.57**	1.27**	1.20	0.41	4.10	3.54**
Error	48	0.30	0.45	0.53	0.88	0.61	0.81	0.32	3.38	0.92
Exp*Check	1	2.32**	0.51	15.87**	35.26**	10.22**	1.72	0.11	0.30	4.64*
Repeatability		0.63	0.72	0.67	0.68	0.35	0.19	0.12	0.10	0.59

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

Dumas exhibited the highest mean for grain yield, followed by Wharton, Castroville, and Dalhart. The lowest means were at Prosper, Corpus Christi, and Weslaco (Table 16) (Figure 10). In all environments except Dumas and Weslaco, experimental hybrids yielded higher than commercial hybrids (Figure 10).

For test weight, there were significant differences between hybrids ($P<0.05$) at all environments except Bardwell. Differences between experimental and commercial hybrids were detected at Weslaco, Castroville, and Wharton (Table 17). Highest test weight means were exhibited at Castroville, followed by Dumas, Granger, and Weslaco. Lowest test weight means were at Corpus Christi, Bardwell, and Wharton (Table 18) (Figure 11).

For 1000 kernel weight, significant differences between replications within environments were detected at Corpus Christi and Wharton. Hybrids exhibited significant differences at all environments, while differences between experimental and commercial hybrids occurred at Weslaco and Castroville (Table 19).

Table 16. Mean grain yields (Mg ha^{-1}) for experimental and commercial white hybrids at each Texas environment in 2005.

	---- Mg ha^{-1} ----								
Entry	WE†	CC	CA	WH	GR	BA	PR	DA	DU
1	4.07	3.58	7.59	8.00	6.89	5.16	1.63	7.09	7.88
2	4.64	4.16	8.55	8.99	6.59	6.00	1.46	6.35	9.83
3	4.92	3.00	8.37	9.04	6.65	5.26	2.00	5.12	8.74
4	5.39	3.64	7.78	7.82	5.54	3.95	1.33	7.77	6.66
5	3.09	2.52	6.40	6.85	5.59	5.57	0.97	8.20	10.57
6	3.68	3.10	8.29	8.64	5.76	6.16	0.79	9.09	8.22
7	4.74	3.53	7.81	8.27	6.60	5.95	1.32	7.94	9.15
8	4.32	1.74	7.98	8.75	5.34	5.50	0.80	5.49	5.44
9	4.41	3.54	7.60	7.13	6.48	6.32	1.78	8.22	8.64
10	4.39	3.26	7.53	8.33	6.17	5.37	1.23	6.00	8.96
11	3.86	3.15	7.56	8.34	6.26	5.21	1.09	8.54	8.33
12	3.16	3.47	7.38	8.12	5.72	4.91	0.84	7.12	8.51
13	4.35	3.58	5.65	7.80	6.59	4.90	1.73	7.26	9.42
14	4.77	4.64	7.39	9.67	6.00	5.71	1.39	9.45	9.92
15	4.68	4.38	8.14	9.71	5.93	5.02	1.54	6.79	8.58
16	4.72	3.98	8.16	10.38	5.71	6.37	1.84	5.99	9.24
17	4.41	5.55	7.93	7.91	5.96	4.79	1.25	6.95	9.04
18	4.52	3.89	8.23	7.59	6.90	5.80	0.97	9.71	7.61
19	4.18	2.21	7.70	9.17	6.56	5.65	1.77	7.11	8.77
20	5.20	3.03	7.47	8.30	7.03	5.12	1.41	7.82	7.68
21	5.22	5.72	7.33	7.93	5.90	5.46	1.54	8.99	9.14
22	5.16	3.50	8.33	8.56	7.03	5.66	0.99	6.82	8.14
23	4.49	4.23	5.75	5.59	4.27	4.70	0.75	7.29	8.89
24	4.41	3.07	4.82	4.97	4.22	3.83	1.79	7.67	10.45
25	3.78	1.85	6.92	6.87	5.41	5.62	1.40	7.03	8.03
Overall Mean	4.42	3.53	7.47	8.11	6.04	5.36	1.34	7.43	8.64
L.S.D. (0.05)	0.91	1.10	1.20	1.54	1.28	1.48	0.92	3.02	1.58
C.V., %	12.48	18.93	9.76	11.58	12.98	16.76	41.81	25.04	11.13

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

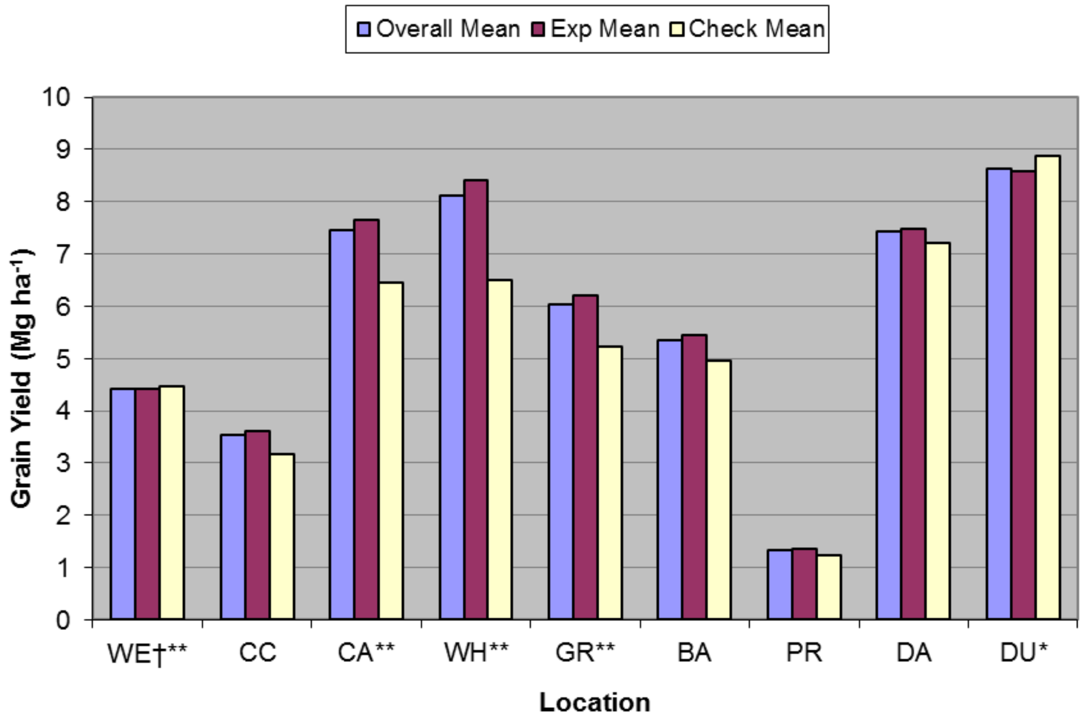

Figure 10. Grain yield means for all hybrids, experimental hybrids, and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

Table 17. ANOVA table for test weights (kg hL^{-1}) for white hybrids at Texas environments in 2005.

Source	df	Mean Square							
		WE†	CC	CA	WH	GR	BA	DA	DU
Rep	2	1.49	5.26	0.60	0.41	1.38	48.09	5.81	0.15
Hybrid	24	25.18**	16.31**	14.33**	15.57**	6.87*	191.76	13.55**	7.60**
Error	46	5.85	1.68	0.71	0.47	3.89	141.33	3.69	0.83
Exp*Check	1	33.73*	0.33	24.81**	20.35**	11.57	264.95	6.65	1.48
Repeatability		0.62	0.81	0.91	0.94	0.28	0.15	0.57	0.80

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, DA: Dalhart, DU: Dumas

Table 18. Mean test weights (kg hL^{-1}) for experimental and commercial white hybrids at each Texas environment in 2005.

	---------- kg hL^{-1} ----------							
Entry	WE†	CC	CA	WH	GR	BA	DA	DU
1	74.08	68.25	74.04	70.37	71.14	69.30	72.89	74.07
2	69.69	68.19	74.65	71.15	73.40	70.82	73.16	74.26
3	78.89	68.70	77.36	74.19	74.59	75.37	73.41	77.38
4	74.43	68.23	77.04	71.25	74.33	48.63	75.86	76.80
5	74.14	69.03	76.57	75.35	71.18	73.60	72.04	75.59
6	73.52	70.31	74.80	69.97	73.29	73.59	71.79	73.35
7	71.21	67.82	75.83	71.52	73.07	70.09	72.55	75.51
8	70.56	67.46	76.13	73.83	72.26	70.44	70.84	74.07
9	73.48	71.28	77.37	74.12	74.75	76.11	76.89	76.39
10	71.86	68.22	73.40	70.08	74.20	70.77	68.28	72.96
11	73.49	71.79	76.63	74.49	74.50	74.54	74.47	76.16
12	73.63	72.76	77.67	76.06	75.19	79.58	73.68	76.96
13	74.39	71.46	73.19	73.63	73.82	71.09	73.97	75.23
14	74.24	71.63	77.16	74.49	75.45	74.13	74.49	75.48
15	66.99	66.55	71.10	68.40	71.30	44.77	71.13	72.89
16	70.29	68.58	73.62	70.48	73.14	70.12	73.46	74.08
17	75.81	74.63	77.91	74.48	76.07	77.96	72.00	76.72
18	77.91	74.09	78.69	74.10	75.30	76.42	73.33	77.56
19	68.15	69.76	74.91	69.83	72.89	73.59	78.36	78.01
20	71.56	68.85	72.85	70.57	73.91	70.28	72.73	72.99
21	77.70	73.84	79.50	76.93	75.89	77.18	74.52	76.21
22	76.19	67.55	78.21	74.59	76.45	75.39	72.77	77.09
23	73.04	71.44	75.63	71.47	73.07	74.23	70.49	73.98
24	70.37	68.48	73.63	71.76	73.43	72.09	73.05	74.89
25	74.46	67.19	77.71	73.78	74.78	76.18	72.44	76.64
Overall Mean	73.20	69.84	75.82	72.68	73.90	71.45	73.14	75.41
L.S.D. (0.05)	3.97	2.13	1.39	1.13	3.24	19.52	3.16	1.50
C.V., %	3.30	1.86	1.11	0.95	2.67	16.64	2.63	1.21

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, DA: Dalhart, DU: Dumas

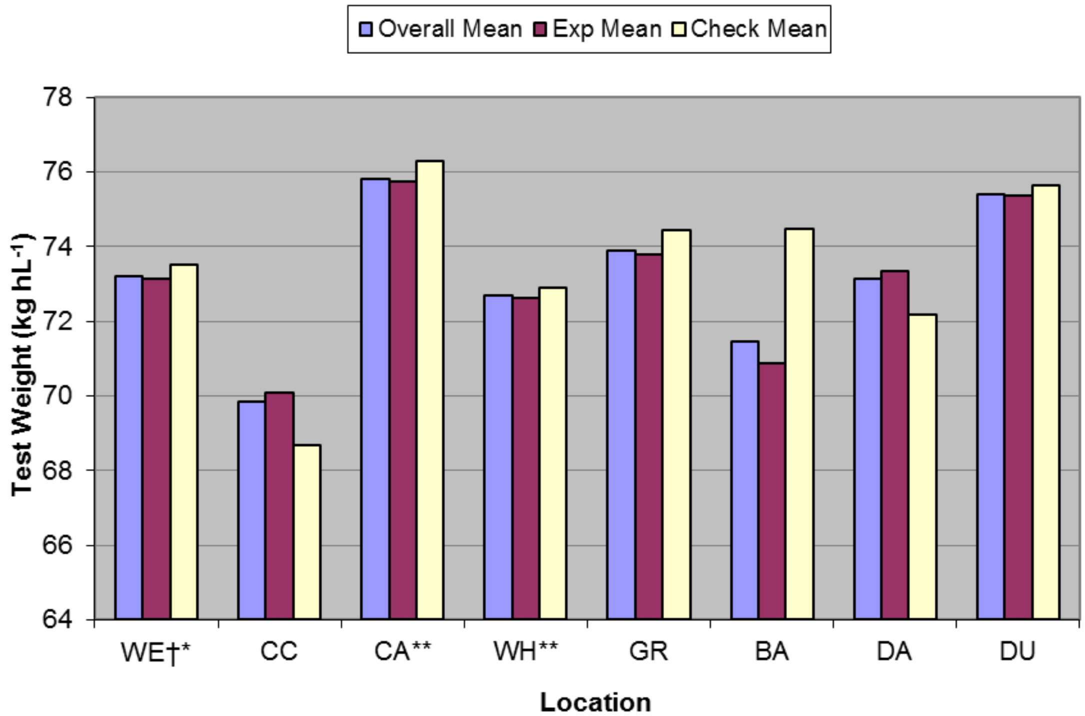

Figure 11. Test weight means for all hybrids, experimental hybrids, and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, DA: Dalhart, DU: Dumas

Table 19. ANOVA table for 1000 kernel weights (g) for white hybrids at Texas environments in 2005.

Source	df	Mean Square						
		WE†	CC	CA	WH	GR	BA	PR
Rep	2	634.70	1402.29**	149. 31	6115.50**	508.87	65.30	1559.24
Hybrid	24	1284.93**	749.14**	1813.36**	1602.30*	1846.05**	1414.55**	1637.58**
Error	48	460.49	224.57	304.04	843.10	461.01	331.55	566.82
Exp*Check	1	2658.16*	55.21	4299.87**	1050.94	624.96	822.12	85.33
Repeatability		0.47	0.54	0.71	0.31	0.60	0.62	0.49

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Highest means for 1000 kernel weight were exhibited at Wharton, Castroville, and Granger. The lowest means were from Weslaco, Corpus Christi, and Prosper (Table 20) (Figure 12). In all environments, commercial hybrids had higher environmental 1000 kernel weight means than experimental hybrids (Figure 12).

Table 20. Mean 1000 kernel weights (g) for experimental and commercial white hybrids at each Texas environment in 2005.

	------------------	------------------	------------------	g	------------------	------------------	------------------
Entry	WE†	CC	CA	WH	GR	BA	PR
1	237.54	225.67	272.06	253.33	281.36	199.62	219.07
2	211.07	211.33	261.84	290.17	265.49	216.71	206.09
3	217.18	198.83	266.86	259.50	224.30	189.79	188.79
4	184.62	215.70	303.49	306.00	268.37	255.82	224.73
5	195.17	191.83	250.12	263.83	230.45	221.49	261.59
6	207.01	212.33	308.68	320.50	265.50	247.33	257.33
7	188.29	191.50	267.09	268.33	234.64	202.57	178.78
8	217.43	200.00	236.03	254.00	197.75	220.89	200.74
9	192.96	224.67	290.14	248.50	257.89	242.77	239.52
10	198.90	235.50	271.62	295.00	247.50	245.77	212.64
11	218.18	219.17	263.04	254.67	231.56	237.72	231.53
12	245.75	195.17	238.32	280.83	247.40	189.29	231.05
13	226.07	198.67	213.12	251.67	240.25	209.83	230.74
14	206.13	198.17	260.92	292.33	236.55	197.92	196.98
15	189.78	204.00	246.73	258.33	223.26	196.68	187.61
16	188.26	222.17	243.40	269.50	235.87	211.91	226.79
17	178.16	134.17	265.58	287.67	254.32	249.59	210.19
18	168.38	230.67	249.34	285.83	227.97	197.32	220.72
19	185.05	197.50	274.41	240.83	247.94	202.34	204.08
20	201.60	258.17	298.46	316.00	305.09	256.69	261.30
21	199.05	200.33	268.63	283.83	228.76	235.49	190.22
22	223.75	213.83	314.10	312.33	288.24	232.32	253.38
23	210.20	217.33	255.50	249.00	245.38	198.31	237.81
24	225.02	213.17	309.13	288.33	274.95	257.08	241.89
25	218.28	224.83	276.66	287.50	240.69	215.86	214.75
Overall Mean	205.35	209.39	268.21	276.71	248.06	221.25	221.13
L.S.D. (0.05)	35.23	24.62	28.64	47.67	35.25	29.96	39.09
C.V., %	10.54	7.06	6.49	10.49	8.66	8.21	10.77

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

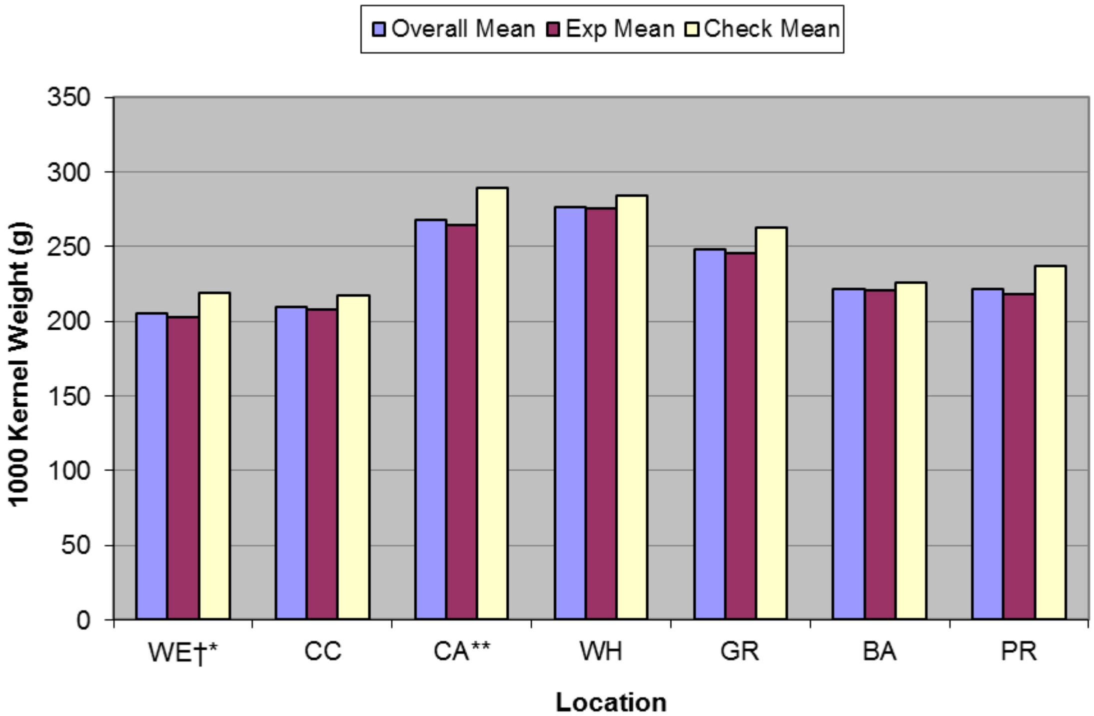

Figure 12. 1000 kernel weight means for all hybrids, experimental hybrids, and commercial check hybrids across Texas environments in 2005.

*Significant at differences between experimental and check hybrids P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

For aflatoxin accumulation, hybrids showed significant differences (P<0.05) at Weslaco, Corpus Christi, Wharton, and Bardwell. Differences between commercial and experimental hybrids were detected in Weslaco only (Table 21). Weslaco exhibited the lowest aflatoxin accumulation, with Castroville being the second lowest. Corpus Christi again had the highest accumulation, followed by Prosper and Wharton (Table 22) (Figure 13).

Table 21. ANOVA table for antilogarithmic aflatoxin concentrations (ng g^{-1}) for white hybrids at Texas environments in 2005.

Source	df	Mean Square						
		WE†	CC	CA	WH	GR	BA	PR
Rep	2	6700.68	379989.33	136300.85	22987.29	69196.46	347100.57	78284.44
Hybrid	24	16041.58*	754330.22**	89142.51	1302315.29*	61825.11	1110208.68**	600140.19
Error	48	7372.68	301915.72	90335.63	666884.31	84305.43	393406.30	569050.62
Exp*Check	1	51876.75*	451632.00	36652.85	145816.65	-----------	210167.10	355627.47
Repeatability		0.37	0.43	------	0.32	------	0.48	0.03

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Table 22. Mean antilogarithmic aflatoxin concentrations (ng g^{-1}) for experimental and commercial white hybrids at each Texas environment in 2005.

	ng g^{-1}						
Entry	WE†	CC	CA	WH	GR	BA	PR
1	81.45	1233.33	151.45	179.39	570.56	596.52	766.09
2	102.54	1266.67	51.18	796.87	277.87	173.45	892.71
3	186.99	1696.67	646.00	1030.92	431.54	21.24	933.03
4	49.69	1615.56	--------	2903.48	372.13	736.36	1997.64
5	178.45	1900.00	263.06	375.97	380.29	--------	919.09
6	9.97	573.33	83.80	1465.17	202.76	58.23	628.04
7	233.80	1290.00	192.65	776.07	336.94	206.29	442.21
8	81.51	1416.67	133.11	130.85	258.29	218.53	879.46
9	116.76	1766.67	130.28	320.46	751.67	348.95	971.64
10	168.35	2033.33	135.69	129.41	400.66	1519.11	842.71
11	116.58	1333.33	130.56	100.66	132.54	820.06	1372.36
12	70.88	870.00	34.80	133.99	176.43	15.99	557.48
13	150.99	996.67	115.25	268.57	213.85	186.77	925.89
14	84.26	710.00	173.62	569.29	290.78	490.87	987.94
15	271.18	1833.33	170.71	232.10	--------	2676.97	1563.83
16	156.31	1080.00	157.62	1543.09	458.37	1348.24	1058.47
17	28.34	830.00	59.83	384.51	166.66	271.42	335.52
18	37.83	1440.00	198.80	1823.39	163.80	-17.02	276.11
19	82.16	703.33	121.94	752.15	567.54	52.27	1557.03
20	33.82	1466.67	753.55	555.61	493.49	644.19	1507.14
21	39.24	300.00	89.83	117.40	382.56	--------	320.52
22	51.83	1900.00	88.02	661.46	239.74	286.73	1491.68
23	70.44	1233.33	143.33	988.06	--------	763.65	1000.19
24	85.55	1570.00	210.61	535.87	--------	1174.15	999.13
25	86.09	2400.00	28.04	681.60	383.23	253.79	392.11
Overall Mean	103.00	1338.36	170.41	698.25	347.80	512.55	944.72
L.S.D. (0.05)	140.96	902.05	493.42	1340.6	479.53	1030.26	1238.40
C.V., %	83.36	41.45	176.37	116.95	82.45	121.51	79.85

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

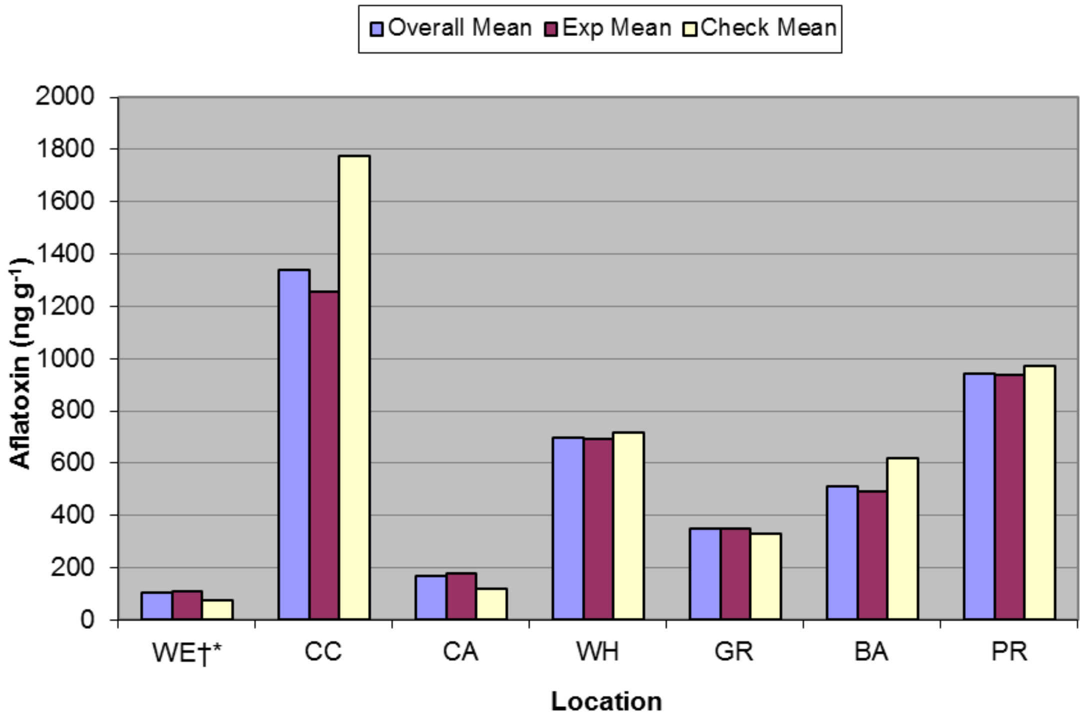

Figure 13. Aflatoxin accumulation means for all hybrids, experimental hybrids, and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at $P<0.05$
**Significant differences between experimental and check hybrids at $P<0.01$
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Combined Environment Analysis

ANOVA and Means

Analysis of variance across environments showed that there were significant differences among environments and among hybrids, and that there was significant interaction between environments and hybrids, ($P<0.01$) for all traits (Table 23).

Table 23. ANOVA table for grain yield (Mg ha^{-1}), test weights (kg hL^{-1}), 1000 kernel weights (g), and aflatoxin accumulation (ng g^{-1}) across all Texas environments for experimental and commercial white hybrids in 2005.

Source	df	Mean Square Grain Yield	df	Mean Square Test Weight	df	Mean Square 1000 Kernel Weight	df	Mean Square Aflatoxin Level
Env	8	429.26**	8	44858.58**	6	60786.02**	6	14153932.42**
Reps(Env)	18	15.45**	18	7.02	14	1490.75**	14	148651.38
Hybrid	24	4.60**	24	97.73**	24	5523.44**	24	952365.31**
Env*Hybrid	192	2.14**	192	24.17**	144	802.16**	141	506582.15**
Error	426	0.90	430	17.67	330	458.61	326	307622.20
Exp*Check	1	9.30**	1	121.05**	1	6907.02**		
Repeatability		0.80		0.82		0.92		0.68

*Significant at P<0.05
**Significant at P<0.01

Overall mean grain yield for the experimental hybrids was higher than that of the commercial hybrids. The highest yielding variety was Entry 14, CML269/TX114 /LH210 (Table 24). The lowest overall yielding variety was Entry 24, Wilson 1851W.

Table 24. Means for grain yield (t ha^{-1}), test weights (kg hL^{-1}), 1000 kernel weights (g), and aflatoxin accumulation (ng g^{-1}) across all Texas environments for experimental and commercial white hybrids in 2005.

Entry	Pedigree	Grain Yield Mg g^{-1}	Test Weight kg hL^{-1}	Kernel Weight g	Aflatoxin Accumulation ng g^{-1}
1	(CML269/Tx110)/(CML 311/Tx110)-1-B-B-B-B/LH195	5.77	71.77	241.2	511.3
2	Tx114/CML78-B-1-B-B-B/LH210	6.28	71.92	237.5	508.8
3	(Tx114 (B73w)-B x CML343/Tx110 x Pop24)-B-B-B-4-B-B-B/LH210	5.90	74.99	220.8	706.6
4	CML311-B/CI66-B/Tx114 (B73w)-B xCML343)-B-B-B-2-B-B-B/LH210	5.54	70.82	251.3	1095.9
5	Tx130 (Va35w)-B-B-B-B-B/LH195	5.53	73.44	230.6	573.2
6	CML343-B-B-B-B-B-B/LH195	5.97	72.58	259.8	431.6
7	Tx114 (B73w)-B-B-B-B-B/LH210	6.14	72.20	218.7	496.9
8	(Tx114 (B73w)-B x CML343/Tx110 x Pop24)-B-B-B-1-B-B-B-B/LH195	5.04	71.95	218.1	445.5
9	CML269/TX130-B-B-B-1-1-B-B-B-B/LH195	6.01	75.05	242.4	629.5
10	(Tx114 (B73w)-B x CML343/Tx110 x Pop24)-B-B-B-2-B-B-B-B/LH210	5.69	71.22	243.9	747.0
11	CML269/TX130-B-B-B-1-2-B-B-B/LH195	5.82	74.51	236.6	572.3
12	CML269/TX130-B-B-B-4-2-B-B-B/LH195	5.47	75.69	232.5	265.7
13	(CML269/Tx114)-B-B-B1-B/LH210	5.70	73.35	224.3	408.3
14	CML269/TX114-B-B-B-B-B/LH210	6.55	74.63	227.0	472.4
15	CML269/TX114-B-B-B-1-1-B-B-B-B/LH210	6.09	66.64	215.2	1013.7
16	(Tx106-Tx714)-1-1-714-1-2-B-B-B-B/LH210	6.26	71.72	228.3	828.9
17	CS04-LH210-372	5.98	75.70	225.7	296.6
18	(Tx811-B x CML 176-B)-B-B-B-B-1-B-B-B/LH195	6.14	75.92	225.8	560.4
19	Tx114/CML343	5.90	73.19	221.7	548.1
20	(B110 x FR2128-B/B104-1/CML343)-B-B-11-B-B-B/LH210	5.90	71.72	271.0	779.2
21	(Tx811-B x CML 176-B)-B-B-B-B-1-B-B-B/LH210	6.36	76.47	229.5	174.4
22	Rx949	6.02	74.78	262.6	674.2
23	Rx953	5.11	72.92	230.5	649.5
24	Wilson 1851W	5.03	72.21	258.5	703.3
25	Triumph 1910W	5.21	74.15	239.8	603.6
Overall Mean		5.82	73.18	235.7	587.9
Experimental Hybrid Mean		5.91	73.12	233.4	574.6
Commercial Hybrid Mean		5.34	73.51	247.8	657.7
L.S.D. (0.05)		0.79	1.60	17.28	434.23
C.V., %		16.37	6.46	9.07	93.56

For test weight, the commercial hybrids performed slightly better than the experimental varieties. Entry 21 ((Tx811xCML176)/LH210) had the highest overall test weight mean, while Entry 15 (CML269/TX114/LH210) had the lowest. For the experimental hybrids, test weight means ranged from 66.64 to 76.47 kg hL^{-1}. The range for commercial hybrid means was 72.21 to 74.28 kg hL^{-1}. Commercial hybrids also had higher overall 1000 kernel weight means than experimental hybrids. The highest kernel weight mean was from Entry 20 ((B110 x FR2128 /B104-1/CML343)/LH210) and the lowest from Entry 15 (CML269/TX114/LH210) (Table 24).

Entry 21 ((Tx811xCML176)/LH210) had the lowest overall mean for aflatoxin accumulation. Entry 4, (CML311/CI66/Tx114 (B73w) xCML343)/LH210, had the highest. The means of the experimental hybrid were lower than those for the commercial hybrids (Table 24).

Principal Component Analysis

The SVD biplot for grain yield grouped the environments into two clear sets. Granger, Castroville, Bardwell, Wharton and Weslaco formed one, while Corpus Christi, Dumas and Prosper formed the other (Figure 14). Dumas and Dalhart have similar vector lengths, indicating similar yield variability within each location. Entry 8 showed stronger adaptation to Wharton and Castroville. Entries 5, 23, and 24 were more adapted to Corpus Christi and Dumas. Entry 18 at Dalhart produced the highest yield for both that location and that hybrid. Its placement shows that this hybrid could be well adapted to that environment for yield.

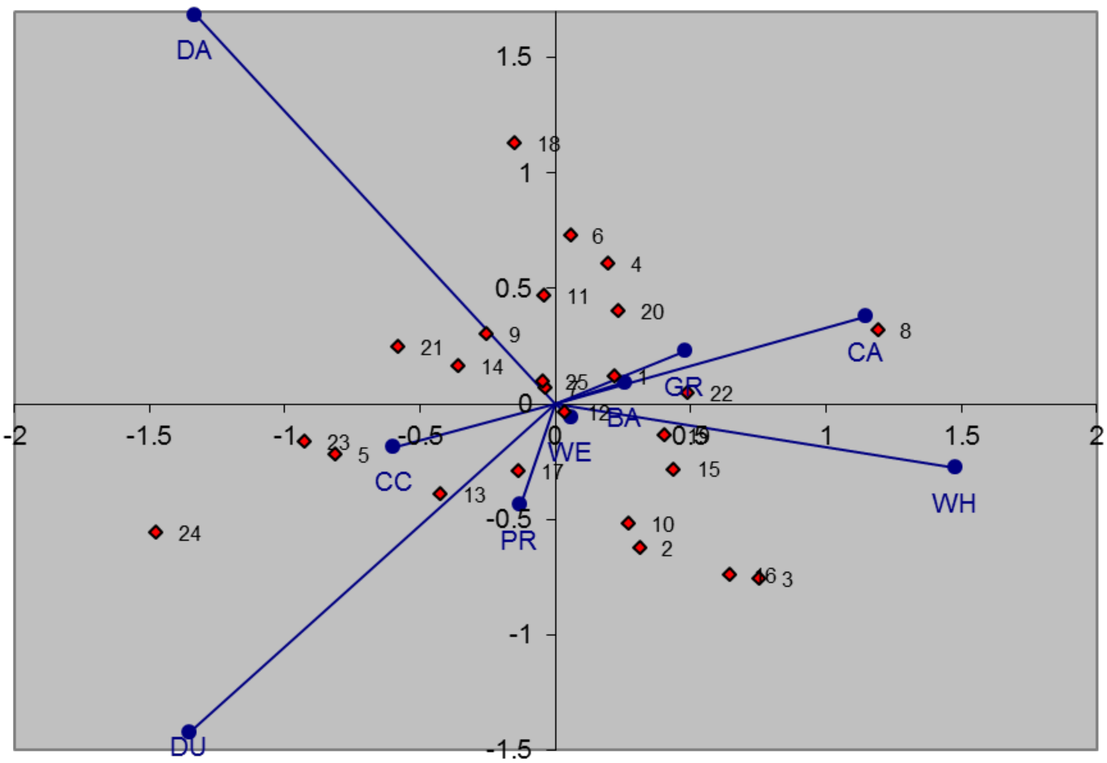

Figure 14. Singular Value Decomposition Biplot for grain yields for white hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

SVD biplot for test weight showed some grouping of environments. Weslaco, Wharton, and Castroville grouped together, while Granger, Corpus Christi, Dumas, and Dalhart grouped together (Figure 15). Bardwell performed differently than all other environments, exhibiting the most variation among hybrids. Entry 15 at this environment showed the lowest test weight for the entire set of white hybrids at all locations, followed by Entry 4 at Bardwell. Entry 19 had the highest test weight for Dalhart, but had low test weights at other locations. Entry 3 at Weslaco produced the highest test weight for all yellow hybrids. The close grouping of most of the hybrids reflects the similar test weights exhibited across all environments.

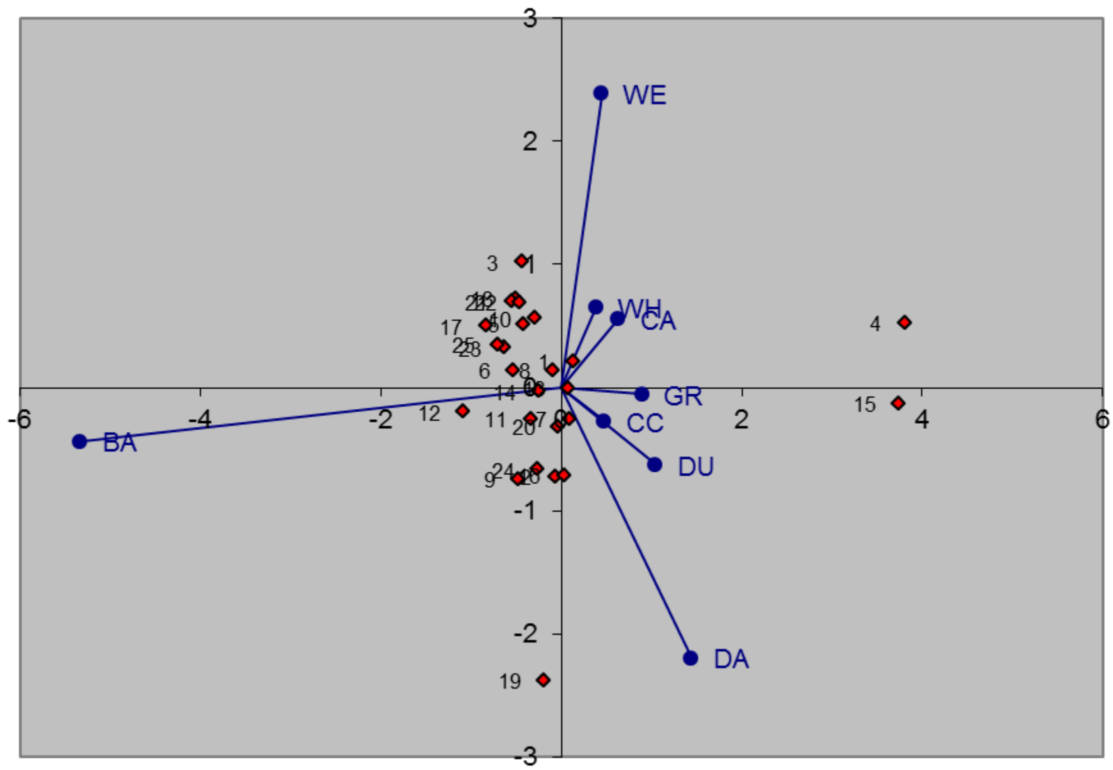

Figure 15. Singular Value Decomposition Biplot for test weights for white hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, DA: Dalhart, DU: Dumas

The SVD biplot for 1000 kernel weight shows two distinct groupings for environments. Castroville, Wharton, Bardwell and Granger grouped together, and Prosper and Weslaco grouped together (Figure 16). Corpus Christi was not highly correlated with any other environment and showed high levels of variation among hybrids along with Weslaco. Granger was closely correlated with Bardwell for expression of 1000 kernel weight, and showed the lowest amount of variation. The lowest test weight of all hybrids was Entry 17 at Corpus Christi, while Entry 6 at Wharton showed the highest.

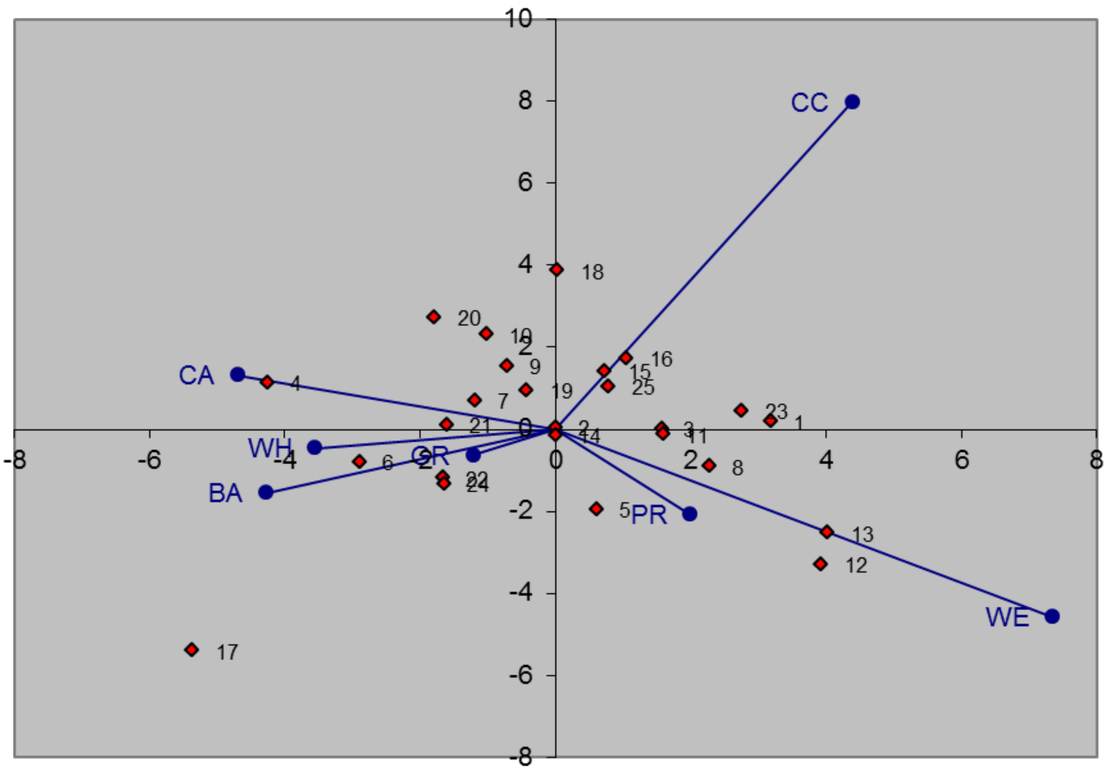

Figure 16. Singular Value Decomposition Biplot for 1000 kernel weights for white hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

SVD biplot for aflatoxin accumulation shows that Castroville, Granger and Weslaco discriminated hybrids similarly (Figure 17). Wharton appears to be different from all other environments. Entries 10, 11, 15, and 24 exhibited high levels of accumulation at Bardwell, and their placement on the scatterplot suggests that the environment was favorable to those hybrids expressing those levels. Entry 4 in Wharton reported the highest levels for the experiment.

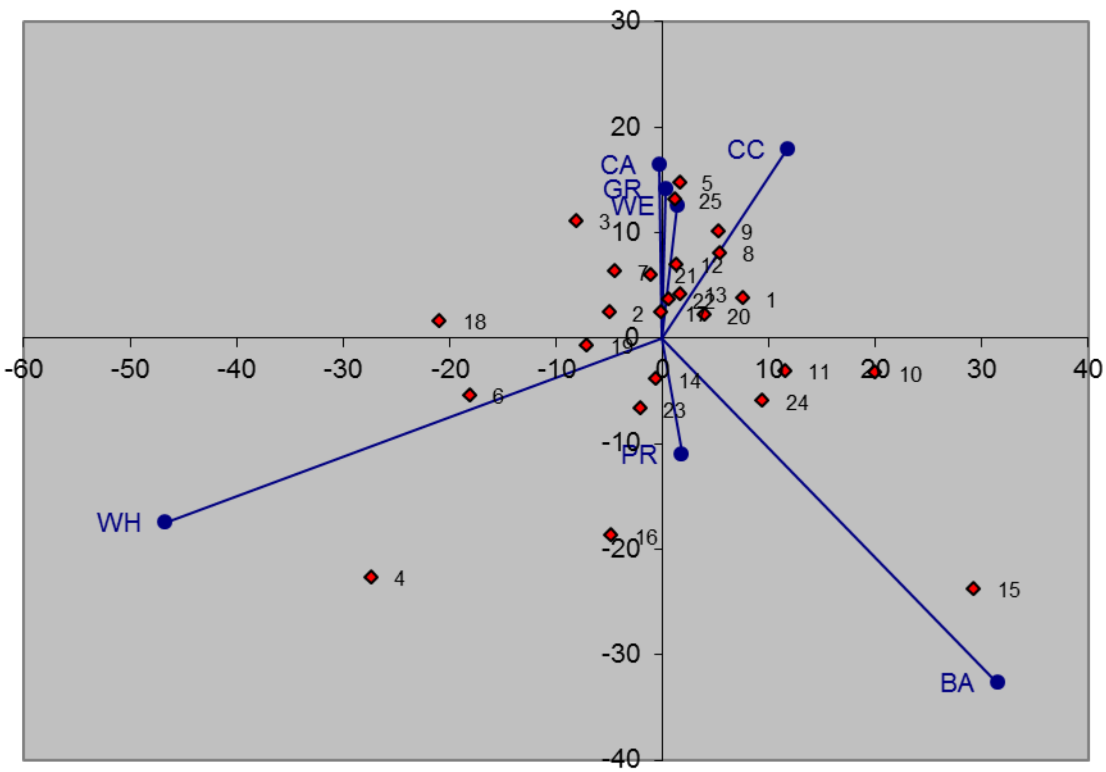

Figure 17. Singular Value Decomposition Biplot for antilogarithmic aflatoxin concentrations for white hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

For the SDV biplot for trait means across environments, grain yield and test weight were highly correlated with similar levels of variation among entries and locations (Figure 18). Aflatoxin concentration was negatively correlated with yield and yield components (test weight and 1000 kernel weight). Entries 4 and 15 each had an aflatoxin concentration mean that was almost double that of the overall mean.

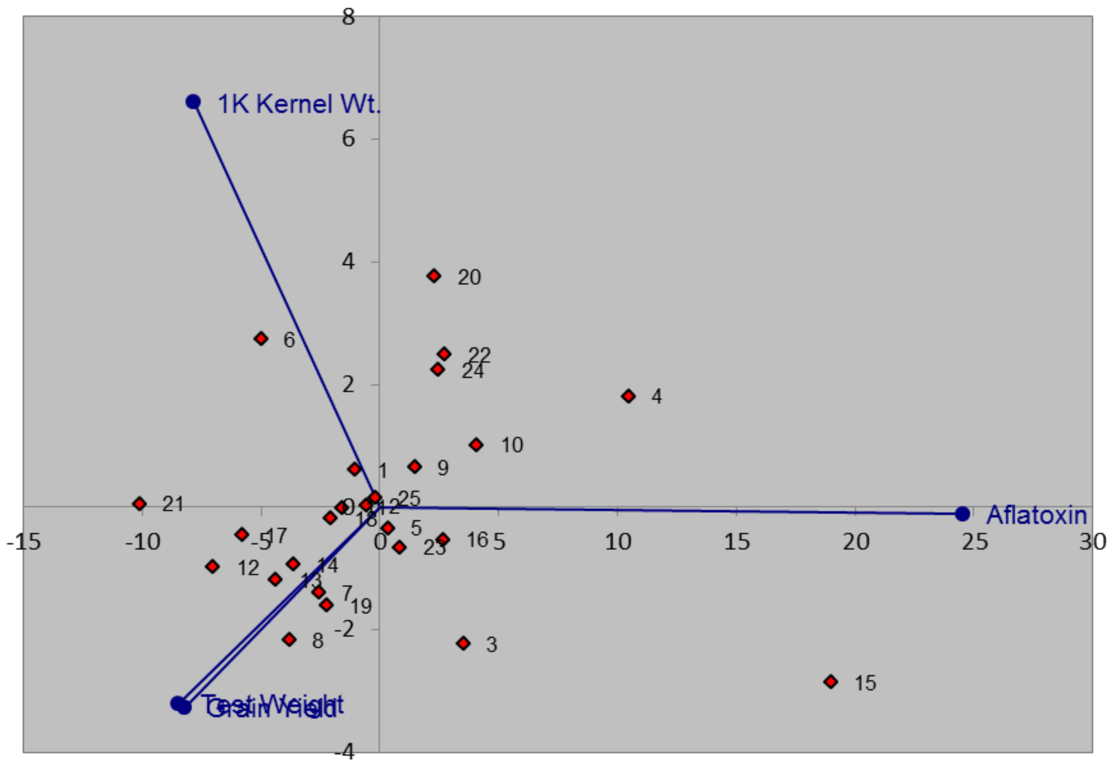

Figure 18. Singular Value Decomposition Biplot for trait means for white hybrids across all Texas environments in 2005.

Discussion and Conclusions

In all but two locations, experimental white hybrids yielded higher than both the commercial check mean and the overall mean. These differences between experimental and commercial hybrids were significant at Castroville and Wharton.

Environment affected test weight, as irrigated environments had higher test weights than rainfed ones. Castroville showed the highest test weights among all environments, followed by Dumas. The lowest were found in Corpus Christi where heavy insect damage was observed, followed by Bardwell, which suffered from drought conditions throughout the year.

The white hybrid with the lowest aflatoxin accumulation was Entry 21 ((Tx811-B x CML176-B)-B-B-B-B-1-B-B-B/LH210) (174.43 ng g^{-1}). This hybrid was also the second highest yielding overall (6.36 Mg ha^{-1}) and had the highest test weight (76.47 kg hL^{-1}). The combination of Tx811 and CML176 could account for this hybrid's high yield and low accumulation, and indicates adaptation to Texas environments. This experimental variety in particular could benefit from further testing in other southern environments and in combination with other elite testers to demonstrate its potential value in stressed environments. Other hybrids with low accumulation levels were Entry 12 (CML269/TX130-B-B-B-4-2-B-B-B/LH195) (265.65 ng g^{-1}) and Entry 17 ((CML184-B-B/CML176)-B-3-B-B-B-B/LH210) (296.61 ng g^{-1}). These hybrids yielded 21st and 10th overall, but also had the fourth and third highest test weights, respectively.

Aflatoxin accumulation is not positively correlated with grain yield and test weight. As expected, hybrids with lower levels of aflatoxin accumulation typically had lower yields as well. These experimental lines that show resistance to high levels of accumulation, in particular the CML populations, could serve as germplasm source for potential hybrid combination with elite temperate testers with the goal of combining yield potential and aflatoxin resistance. If this exotic material does show actual resistance to aflatoxin accumulation then those resistance factors could be passed along to offspring to maintain a resistance in future populations.

CHAPTER V

RESULTS: QUALITY PROTEIN MAIZE HYBRIDS

Single Environment Analysis

ANOVA and Means

Significant differences among replications were found in Corpus Christi, Wharton, Granger, Prosper, and Dumas (Table 25). Hybrids showed significant differences at all environments except Prosper. There were also significant differences between commercial and experimental hybrids at all environments except Granger and Prosper.

Table 25. ANOVA table for grain yield (Mg ha^{-1}) for QPM hybrids at Texas environments in 2005.

Source	df	Mean Square								
		WE†	CC	CA	WH	GR	BA	PR	DA	DU
Rep	2	0.01	5.04**	0.43	4.47**	1.74*	0.15	3.20**	3.11*	0.26
Hybrid	24	0.70*	1.98**	2.44**	2.92**	2.26**	1.40**	0.75	5.44**	7.08**
Error	48	0.33	0.42	0.24	0.78	0.48	0.45	0.56	0.91	0.76
Exp*Check	1	8.22**	25.03**	17.44**	17.25**	2.07	9.41**	1.69	29.55**	81.90**
Repeatability		0.36	0.65	0.82	0.58	0.65	0.51	0.15	0.71	0.81

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

Dumas, Wharton, and Castroville produced the highest environmental means for grain yield. Lowest means were recorded at Prosper, Corpus Christi, and Weslaco (Table 26) (Figure 19). Commercial hybrid means were greater than experimental hybrid means at all environments (Figure 19). For test weights, hybrids were significantly different ($P<0.01$) at all environments except Corpus Christi. There were significant differences between experimental and commercial hybrids ($P<0.05$) at four of the ten environments (Table 27). For test weight, Castroville and Dumas again showed the highest environmental means and Corpus Christi the lowest (Table 28) (Figure 20). Prosper data was recorded but not used due to severe drought conditions.

For 1000 kernel weight, experimental and commercial hybrids showed significant differences ($P<0.01$) in all environments except Granger and Prosper (Table 29). Granger and Castroville showed the highest overall environmental means for 1000 kernel weights. Environments with the lowest means were Prosper, Weslaco, and Corpus Christi (Table 30) (Figure 21). Commercial hybrids also exhibited higher means than experimental hybrids at all environments (Figure 21).

Table 26. Mean grain yields (Mg ha^{-1}) for experimental and commercial QPM hybrids at each Texas environment in 2005.

	Mg ha^{-1}								
Entry	WE†	CC	CA	WH	GR	BA	PR	DA	DU
1	5.01	4.40	7.24	8.53	7.04	5.84	1.27	4.39	6.93
2	4.39	4.21	7.02	7.12	7.02	5.81	1.94	3.84	7.15
3	4.93	4.83	7.57	7.98	6.92	6.11	1.89	4.84	8.15
4	4.04	3.74	7.74	6.93	5.97	5.89	1.80	3.35	8.62
5	4.37	3.90	6.85	5.69	6.23	5.43	1.64	4.06	6.06
6	4.79	4.16	8.30	7.85	7.89	5.79	2.25	3.41	8.08
7	4.35	3.76	6.98	7.78	6.24	6.66	1.77	2.58	5.06
8	4.63	4.38	7.85	7.22	7.04	5.49	1.47	5.59	8.75
9	4.75	3.82	7.15	7.55	7.33	6.32	2.22	1.62	8.03
10	4.60	3.94	7.10	8.48	6.99	6.50	2.07	3.57	8.19
11	3.91	2.89	6.30	6.43	6.34	5.69	1.94	3.77	9.39
12	4.71	4.06	7.04	7.98	6.13	6.10	2.40	4.95	8.03
13	4.22	3.98	7.40	8.31	6.70	6.05	1.22	4.68	8.92
14	4.64	4.37	8.04	9.00	6.87	5.49	3.01	4.46	8.65
15	3.75	3.71	7.15	7.25	6.91	6.04	2.21	4.43	9.07
16	4.04	3.49	6.15	7.56	6.70	6.60	2.58	5.02	8.95
17	4.43	4.18	8.19	6.89	7.22	4.61	1.75	6.46	6.65
18	3.56	3.17	7.31	7.32	6.07	5.07	1.88	6.62	7.64
19	4.68	4.47	8.23	7.65	6.48	6.51	1.85	6.14	6.93
20	4.56	5.12	7.96	8.13	7.31	5.36	3.22	4.80	9.47
21	5.00	5.51	6.41	6.75	5.82	5.32	2.32	6.16	9.30
22	5.77	6.28	9.51	9.39	8.72	7.26	2.04	5.41	10.65
23	5.61	5.81	8.94	9.90	7.70	6.96	3.67	5.20	10.53
24	5.16	5.21	8.99	9.21	6.98	6.99	3.08	6.40	10.48
25	4.74	4.62	9.16	8.56	6.69	7.25	2.72	6.57	10.87
Overall Mean	4.59	4.32	7.62	7.82	6.85	6.04	2.17	4.73	8.42
L.S.D. (0.05)	0.94	1.07	0.80	1.45	1.14	1.10	1.23	1.57	1.43
C.V., %	12.54	15.05	6.41	11.29	10.15	11.09	34.48	20.17	10.36

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

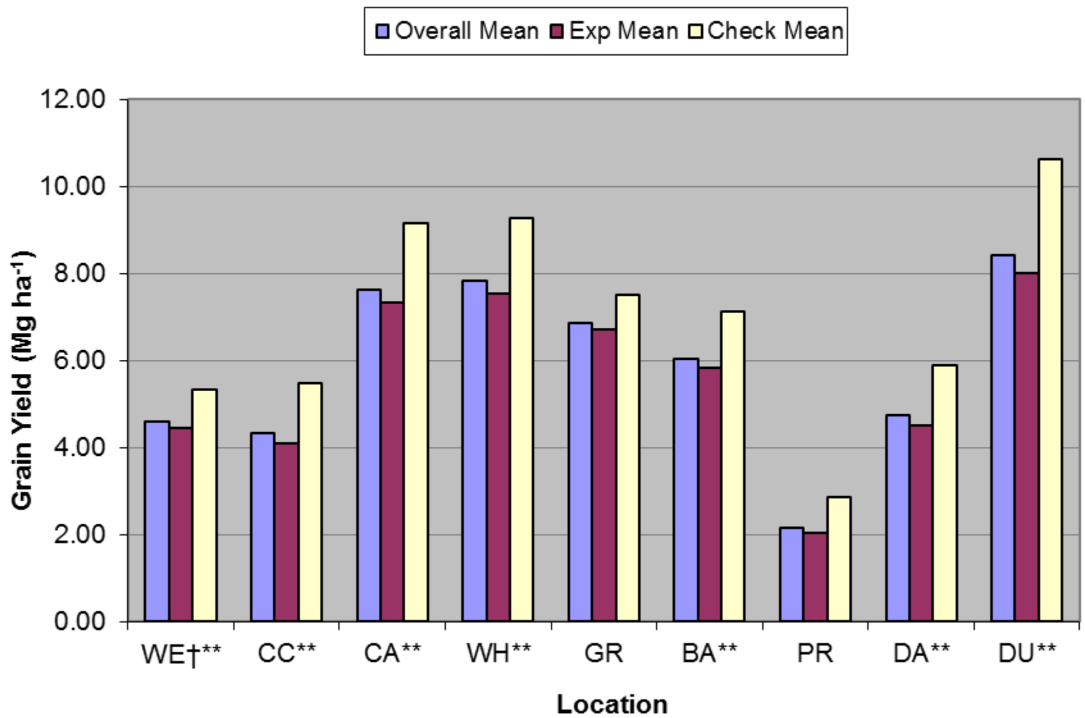

Figure 19. Grain yield means for all hybrids, experimental and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

Table 27. ANOVA table for test weights (kg hL^{-1}) for QPM hybrids at Texas environments in 2005.

Source	df	Mean Square							
		WE†	CC	CA	WH	GR	BA	DA	DU
Rep	2	0.64	114.66	0.11	0.54	0.21	1.37	6.81	2.66
Hybrid	24	9.37**	67.03	6.31**	9.00**	6.41**	25.20**	33.94**	6.01**
Error	48	0.83	76.00	0.39	0.51	2.57	10.36	3.84	1.02
Exp*Check	1	0.94	6.80	1.70*	3.91**	9.33	3.86	19.34*	34.84**
Repeatability		0.84	--------	0.88	0.89	0.43	0.42	0.80	0.71

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, DA: Dalhart, DU: Dumas

Table 28. Mean test weights (kg hL^{-1}) for experimental and commercial QPM hybrids at each Texas environment in 2005.

	---------- kg hL^{-1} ----------							
Entry	WE†	CC	CA	WH	GR	BA	DA	DU
1	76.89	73.66	78.06	75.10	74.94	75.52	75.74	76.70
2	74.59	73.63	77.93	74.50	75.38	78.15	75.01	76.28
3	75.03	73.45	77.70	75.25	75.24	77.63	75.46	78.33
4	73.17	72.63	78.34	74.61	76.48	76.24	73.80	75.76
5	72.66	71.24	76.11	71.60	72.96	74.65	71.71	72.67
6	72.84	69.76	76.59	71.06	74.15	73.90	70.21	73.01
7	74.78	72.76	76.69	73.84	74.44	73.18	75.02	73.96
8	73.84	72.95	77.87	74.21	74.96	68.15	72.55	74.90
9	73.11	72.12	74.86	72.60	74.29	74.60	60.16	75.42
10	71.18	70.43	75.22	72.08	74.33	72.19	72.77	75.07
11	72.39	67.94	73.53	69.56	72.55	66.06	75.67	74.22
12	71.05	69.43	74.02	70.42	71.09	72.37	74.98	74.56
13	73.00	71.27	75.60	71.51	72.51	74.36	74.64	74.73
14	74.20	71.73	76.76	73.00	75.97	68.45	73.66	75.25
15	70.73	65.16	74.30	71.45	72.39	70.27	75.20	77.13
16	70.07	67.31	74.36	71.74	73.60	72.98	77.54	75.93
17	71.42	71.21	75.58	73.06	74.55	73.30	75.15	74.73
18	71.22	70.49	76.81	73.78	74.33	73.87	73.98	76.70
19	74.94	50.27	78.21	74.66	76.95	73.71	72.90	76.28
20	74.96	74.61	77.87	73.80	74.28	75.86	74.76	75.59
21	75.66	74.06	78.75	76.92	77.38	75.95	76.11	76.96
22	73.55	70.46	76.22	73.16	74.16	73.35	76.70	77.39
23	73.05	70.60	76.19	73.06	73.72	71.76	70.56	77.65
24	70.92	70.00	75.90	73.33	75.34	72.33	75.57	76.45
25	70.90	69.15	75.62	70.85	75.16	70.13	74.98	76.88
Overall Mean	73.05	70.25	76.36	73.01	74.45	73.16	73.79	75.70
L.S.D. (0.05)	1.49	14.31	1.02	1.17	2.63	5.28	3.22	1.66
C.V., %	1.24	12.41	0.82	0.98	2.15	4.40	2.66	1.33

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

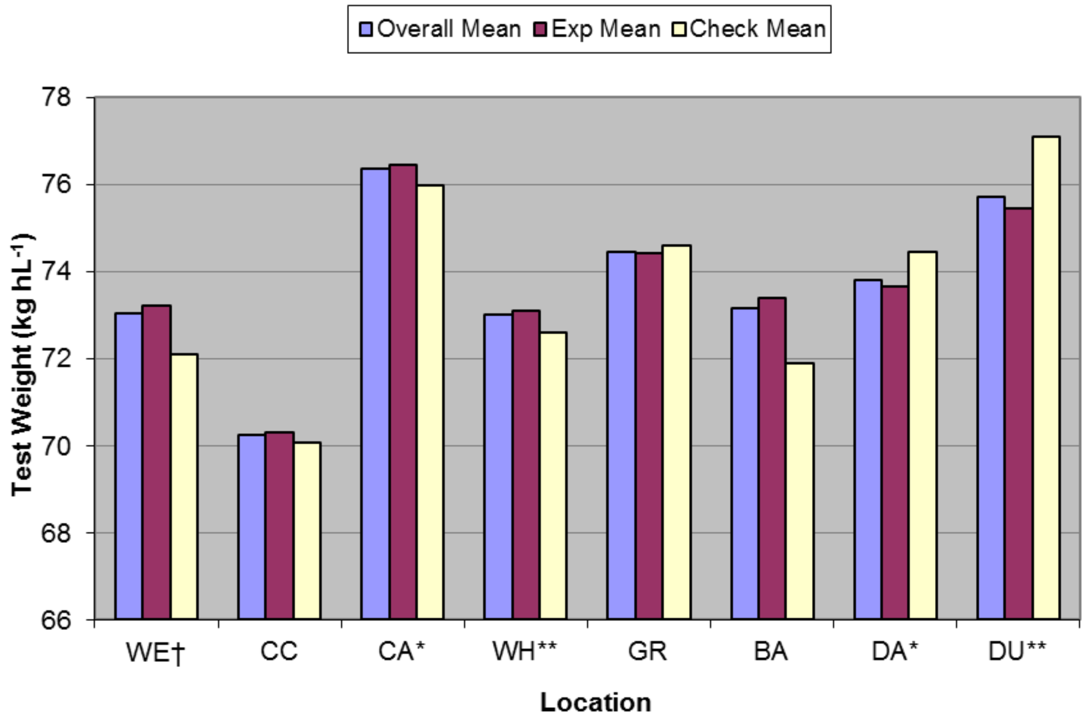

Figure 20. Test weight means for all hybrids, experimental and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, DA: Dalhart, DU: Dumas

Table 29. ANOVA table for 1000 kernel weights (g) for QPM hybrids at Texas environments in 2005.

Source	df	Mean Square						
		WE†	CC	CA	WH	GR	BA	PR
Rep	2	190.77	341.64	325.29	2175.42*	13453.87	649.26	1650.91*
Hybrid	24	1080.48**	1295.62**	1406.75**	1252.77**	14513.90	1198.16**	1452.88**
Error	48	179.16	141.90	213.14	568.02	15563.84	252.99	447.42
Exp*Check	1	1842.64**	5838.84**	5188.86**	5724.70**	2216.80	2025.48**	1400.37
Repeatability		0.72	0.80	0.74	0.38	------	0.65	0.53

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Table 30. Mean 1000 kernel weights (g) for experimental and commercial QPM hybrids at each Texas environment in 2005.

	g						
Entry	WE†	CC	CA	WH	GR	BA	PR
1	237.54	204.56	269.24	284.98	273.32	234.45	191.26
2	211.07	209.62	267.01	263.77	278.75	229.13	209.00
3	217.18	211.88	258.73	281.15	267.45	237.71	224.06
4	184.62	206.84	275.46	272.02	248.54	257.30	172.81
5	195.17	215.19	276.85	259.01	280.37	239.62	208.04
6	207.01	209.92	292.58	272.99	296.81	232.97	244.48
7	188.29	209.76	255.45	249.66	227.46	215.64	188.44
8	217.43	224.36	307.69	271.84	300.23	276.12	231.37
9	192.96	200.70	252.23	251.00	260.00	206.73	203.73
10	198.90	214.67	258.87	278.04	277.06	267.52	207.15
11	218.18	195.05	268.26	242.20	257.40	236.32	220.39
12	245.75	229.74	307.31	317.66	289.49	260.79	198.42
13	226.07	224.76	308.18	290.04	282.38	260.69	200.48
14	206.13	193.22	264.45	275.50	254.82	218.12	172.12
15	189.78	172.13	251.54	259.81	254.38	220.35	217.23
16	188.26	179.63	244.23	249.99	274.50	232.50	210.03
17	178.16	165.75	250.19	258.69	228.45	206.94	150.93
18	168.38	174.91	244.54	259.16	246.78	199.72	180.91
19	185.05	181.42	257.41	230.20	213.18	196.68	173.29
20	201.60	200.10	270.03	255.55	271.64	245.81	197.65
21	199.05	195.07	268.71	270.30	237.94	220.64	219.96
22	223.75	226.81	292.66	298.50	278.28	250.72	188.22
23	210.20	207.94	284.17	303.15	310.19	259.90	204.78
24	225.02	253.51	325.29	296.97	334.80	255.08	215.66
25	218.28	230.47	275.75	270.98	290.00	257.36	225.14
Overall Mean	205.35	205.52	273.07	270.53	282.75	236.75	202.22
L.S.D. (0.05)	21.97	19.56	23.98	39.13	204.81	26.13	34.74
C.V., %	6.52	5.80	5.34	8.81	44.12	6.73	10.45

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

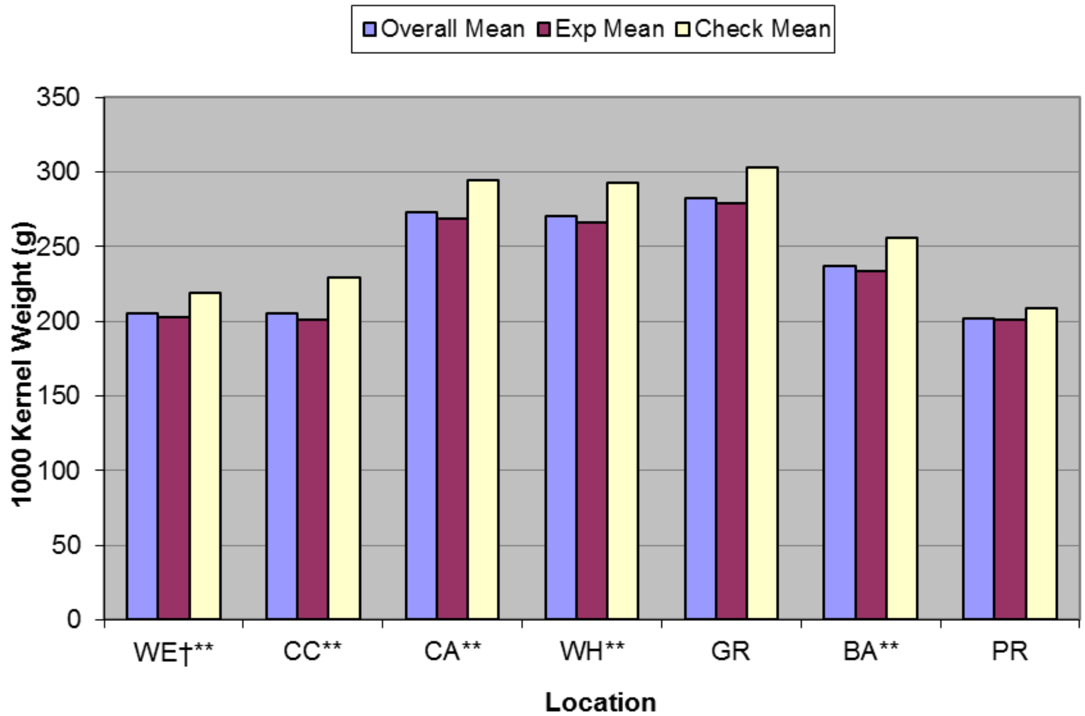

Figure 21. 1000 kernel weight means for all hybrids, experimental hybrids, and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

For aflatoxin accumulation, hybrids were significantly different (P<0.05) at all environments, and significant differences between experimental and commercial hybrids were detected at Corpus Christi and Granger (Table 31). Weslaco again exhibits the lowest environmental mean for aflatoxin accumulation, followed by Castroville (Table 32) (Figure 22). The highest means were again observed at Corpus Christi, and the second highest levels were at Wharton. In Castroville, Wharton, and Bardwell, commercial hybrids showed lower environmental means than experimental hybrids (Figure 22).

Table 31. ANOVA table for antilogarithmic aflatoxin concentrations (ng g^{-1}) for QPM hybrids at Texas environments in 2005.

Source	df	Mean Square						
		WE†	CC	CA	WH	GR	BA	PR
Rep	2	77953.12**	3013720.59**	54882.17	7267.37	29767.81	3335.62	1205242.45
Hybrid	24	44465.37**	863420.70**	130754.35*	1988195.19**	162721.83*	584248.98**	756886.49*
Error	48	13249.41	218199.62	65863.14	754366.61	86367.05	255636.03	384120.69
Exp*Check	1	11077.76	938008.70*	17.81	1942304.40	584887.10*	651415.27	1532617.47
Repeatability		0.54	0.60	0.33	0.45	0.31	0.39	0.33

*Significant at P<0.05
**Significant at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Table 32. Mean antilogarithmic aflatoxin concentrations (ng g^{-1}) for experimental and commercial QPM hybrids at each Texas environment in 2005.

	ng g^{-1}						
Entry	WE†	CC	CA	WH	GR	BA	PR
1	80.00	222.36	167.80	956.67	163.99	61.59	86.25
2	24.00	465.74	594.85	260.00	329.08	174.97	684.96
3	21.67	281.74	133.89	1345.00	221.18	18.69	343.89
4	129.33	652.37	206.71	632.33	245.83	153.41	146.86
5	148.33	2102.32	1012.33	1093.33	430.17	365.12	517.18
6	63.33	1292.79	123.51	2466.67	335.93	921.38	1551.49
7	93.33	1470.68	165.47	89.33	392.41	91.92	53.74
8	48.67	533.63	451.35	287.00	143.22	308.57	1486.85
9	209.33	790.33	164.65	610.00	500.74	181.93	341.60
10	89.33	784.31	174.53	243.33	366.56	57.42	659.31
11	416.67	1419.15	364.90	2496.67	500.54	630.60	345.88
12	300.00	1311.39	187.09	1213.33	628.09	1095.67	---------
13	405.33	804.14	209.42	2316.67	567.84	1102.47	620.15
14	160.00	1507.84	224.37	2533.33	304.24	525.22	238.27
15	400.00	1437.05	115.52	450.00	511.31	1822.09	483.09
16	137.67	540.32	247.06	180.00	231.27	354.75	20.68
17	103.67	989.81	179.61	34.67	328.79	53.22	---------
18	93.67	1396.17	85.79	234.00	350.09	75.13	539.14
19	14.00	96.04	65.89	87.00	163.46	35.27	188.69
20	39.33	931.10	190.44	255.67	195.91	162.41	344.28
21	172.67	310.80	166.55	240.00	366.33	69.78	377.54
22	103.67	1660.92	79.71	826.67	699.15	378.79	1839.21
23	156.67	953.12	621.12	503.33	395.56	335.18	238.28
24	323.33	1721.57	193.58	580.00	1342.16	118.37	294.39
25	140.00	1234.50	70.95	284.67	461.17	13.56	184.94
Overall Mean	154.96	996.41	247.88	808.79	407.00	364.30	444.81
L.S.D. (0.05)	188.97	767.28	421.55	1425.9	485.76	830.50	1019.87
C.V., %	74.28	46.89	102.67	107.39	71.33	137.34	133.50

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

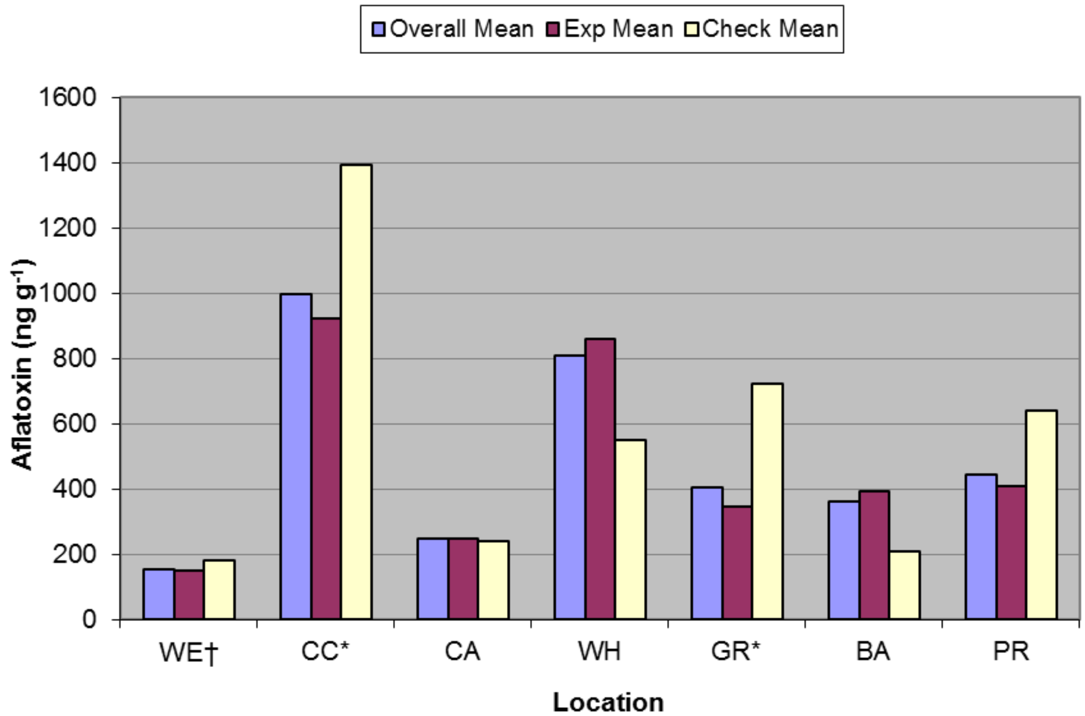

Figure 22. Aflatoxin accumulation means for all hybrids, experimental and commercial check hybrids across Texas environments in 2005.

*Significant differences between experimental and check hybrids at P<0.05
**Significant differences between experimental and check hybrids at P<0.01
†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

Combined Environment Analysis

ANOVA and Means

Analysis of variance across environments shows that there were significant differences between environments and hybrids, as well as a significant interaction between environments and hybrids, (P<0.01) for all traits (Table 33). There were also significant differences between reps within environments for grain yield, test weight, and aflatoxin accumulation.

Table 33. ANOVA table for grain yield (Mg ha^{-1}), test weights (kg hL^{-1}), 1000 kernel weights (g), and aflatoxin accumulation (ng g^{-1}) across all Texas environments for experimental and commercial QPM hybrids in 2005.

Source	df	Mean Square Grain Yield	df	Mean Square Test Weight	df	Mean Square 1000 Kernel Weight	df	Mean Square Aflatoxin Level
Env	8	313.58**	8	40853.59**	6	95220.35**	6	6787971.11**
Reps(Env)	18	2.05**	18	66.67**	14	2679.41	14	627452.73**
Hybrid	24	9.97**	24	97.68**	24	7244.18**	24	1249715.77**
Env*Hybrid	192	1.75**	192	58.32**	144	2480.42**	141	546620.32**
Error	431	0.55	432	33.16	330	2500.53	326	258290.50
Exp*Check	1	148.00**	1	189.73*	1	22372.28**	1	173505.80
Repeatability								

*Significant at P<0.05
**Significant at P<0.01

The mean grain yield for commercial hybrids was higher than that of the experimental hybrids (Table 34). The highest yielding hybrid overall was Entry 22, while the lowest was Entry 5. The highest yielding experimental hybrid was Entry 20; this was the only experimental hybrid in the top 5 highest yielders.

Table 34. Means for grain yield (Mg ha^{-1}), test weights (kg hL^{-1}), 1000 kernel weights (g), and aflatoxin accumulation (ng g^{-1}) across all Texas environments for experimental and commercial QPM hybrids in 2005.

Entry	Pedigree	Grain Yield Mg g^{-1}	Test Weight kg hL^{-1}	Kernel Weight g	Aflatoxin Accumulation ng g^{-1}
1	Pop. 69 Templado Amarillo QPM-B-B-B1-8-B-B-B/LH195	5.63	75.83	242.2	248.4
2	Pop. 69 Templado Amarillo QPM-B-B-B2-11-B-B-B/LH195	5.39	75.68	238.3	361.9
3	Pop. 69 Templado Amarillo QPM-B-B-B6-8-B-B-B/LH195	5.91	76.01	242.6	338.0
4	Tx802-B-B-B /CML161-B-3-B-B-B/LH195	5.34	75.13	231.1	309.6
5	(P69Qc3HC107-1-1#-4-2#-4-B-B-1-4-B-B-B-B-B X CML 193)-B-B-1-B-B-B/LH195	4.91	72.95	239.2	809.8
6	(P69Qc3HC107-1-1#-4-2#-4-B-B-1-4-B-B-B-B-B X CML 193)-B-B-2-B-B-B/LH210	5.83	72.69	251.0	965.0
7	(Tx802 x Ko326y)-18-1-1-1-B-B-B-B-B-B/LH195	5.02	74.33	219.2	336.7
8	CML161-B-B-B/LH195	5.83	73.68	261.3	465.6
9	Tx806-B-B-B-B/LH195	5.42	72.15	271.7	399.8
10	(B97-B-B/(Ko326y x Tx806)-6-1-1-1-B-B)x((Ko326y x Tx806)-6-1-1-1-B-B/NC300)-B1-B-2-B-B/LH195	5.71	72.91	243.2	339.3
11	((B73 o2/o2-B -B/B104)x(Tx714/(Ko326y x Tx806)-6-1-1-1-B-B))-B-B-2-B-B/LH210	5.18	71.49	234.0	882.1
12	(B104-1-B-B/(Tx802 x Ko326y)-18-1-1-1-B-B))-B-B-B-3-B-B/LH210	5.71	72.24	264.2	654.4
13	((Ko326y x Tx806)-6-1-1-1-B-B/B104))-B-B-B-B-B/LH210	5.72	73.45	256.1	860.9
14	(Tx802-B-B-B/B104)-1-18-B-1-B-B/LH210	6.06	73.63	226.3	784.8
15	Temp. SSLate (B37,B73,B84) B-44-B-B-B/LH210	5.61	72.08	223.6	745.6
16	Temp. SSLate (B37,B73,B84) B-76-B-2-B-B/LH210	5.68	72.94	225.6	244.5
17	(Tx811-B x CML 176-B)-B-B-B-B-2-B-B-B/LH195	5.60	73.63	205.6	196.9
18	Tx811-B-B-B/LH195	5.41	73.90	210.6	396.3
19	CML176-B-B-B/LH195	5.88	72.24	205.3	92.9
20	(CML 184-B-B/CML 176)-B-3-B-B-B-B/LH210	6.21	75.21	234.6	302.7
21	(Tx811-B x CML 176-B)-B-B-B-B-1-B-B-B/LH210	5.84	76.47	230.2	243.4
22	P31B13	7.23	74.37	251.3	798.3
23	BH 8913	7.15	73.32	254.3	457.6
24	DKC 69-72	6.95	73.73	272.3	653.3
25	W4700	6.80	72.96	252.6	341.4
Overall Mean		5.84	73.72	239.5	489.2
Experimental Hybrid Mean		5.61	73.74	236.0	475.2
Commercial Hybrid Mean		7.03	73.60	257.6	562.7
L.S.D (0.05)		0.71	4.10	30.38	450.99
C.V., %		12.68	8.73	20.88	102.67

With regards to test weight, the experimental hybrids had a higher mean than the commercial hybrids and the overall mean. The highest test weight was from Entry 21, the only commercial hybrid in the top 5 entries. The lowest overall was Entry 11. The highest experimental hybrid was Entry 3. Commercial hybrids had higher 1000 kernel weight means than experimental hybrids. The highest kernel weight came from Entry 24, and the lowest was from Entry 19. The highest experimental hybrid kernel weight was from Entry 9.

For aflatoxin accumulation, experimental hybrids had a lower mean than the commercial hybrids. The lowest overall accumulation was in Entry 19. The highest was Entry 6. The lowest commercial hybrid was Entry 21, while the highest was Entry 22.

Principal Component Analysis

SVD biplot for grain yield shows grouping for environments. Castroville, Corpus Christi discriminated hybrids similarly and had similar levels of variation within the environment (Figure 23). Prosper showed the lowest yields among environments but also exhibited the lowest amount of variation. Dumas and Dalhart performed differently than all other environments. Dumas produced the highest yields, but Dalhart expressed more variation among hybrids. Entries 7 and 9 produced relatively low yields compared to the means across all environments, which explains their outlier positions on the scatterplot.

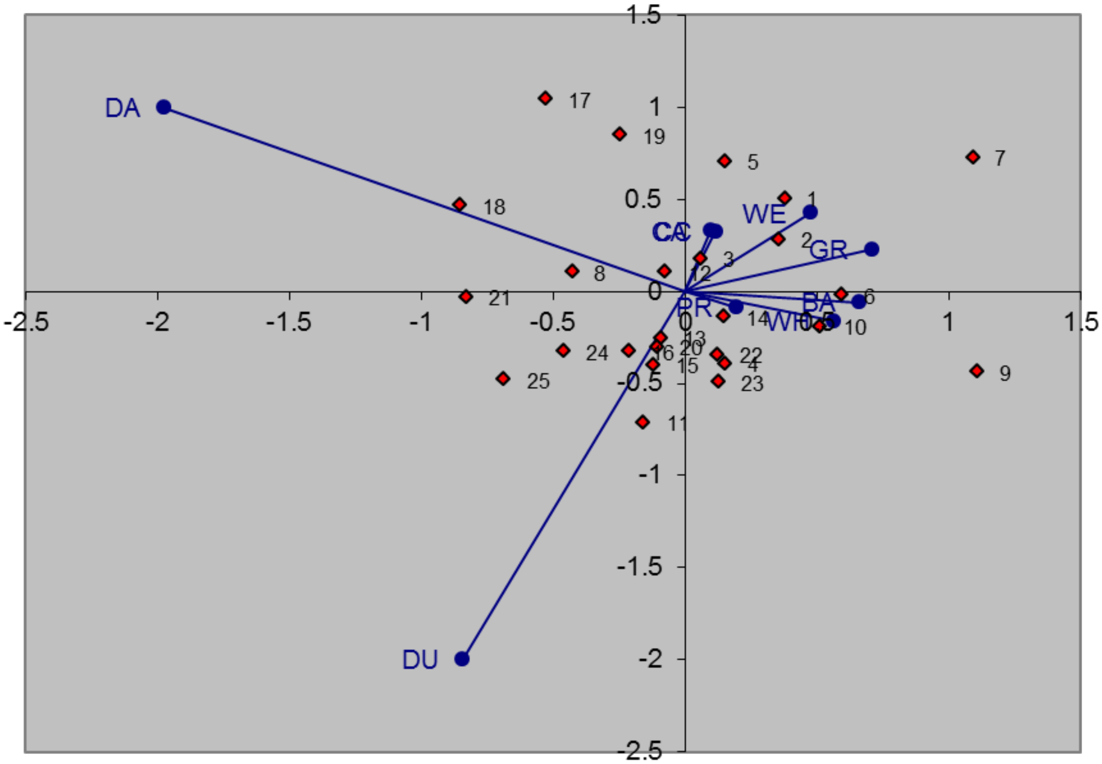

Figure 23. Singular Value Decomposition Biplot for grain yields for QPM hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper, DA: Dalhart, DU: Dumas

SVD biplot for test weight shows that all environments except Bardwell and Dalhart appear to be positively correlated (Figure 24). This shows that these environments exhibit low amounts of variation individually, and are also positively correlated regarding expression of test weights. Entry 9 had very low test weights at Dalhart, while Entries 8, 11, and 14 had low test weights at Bardwell.

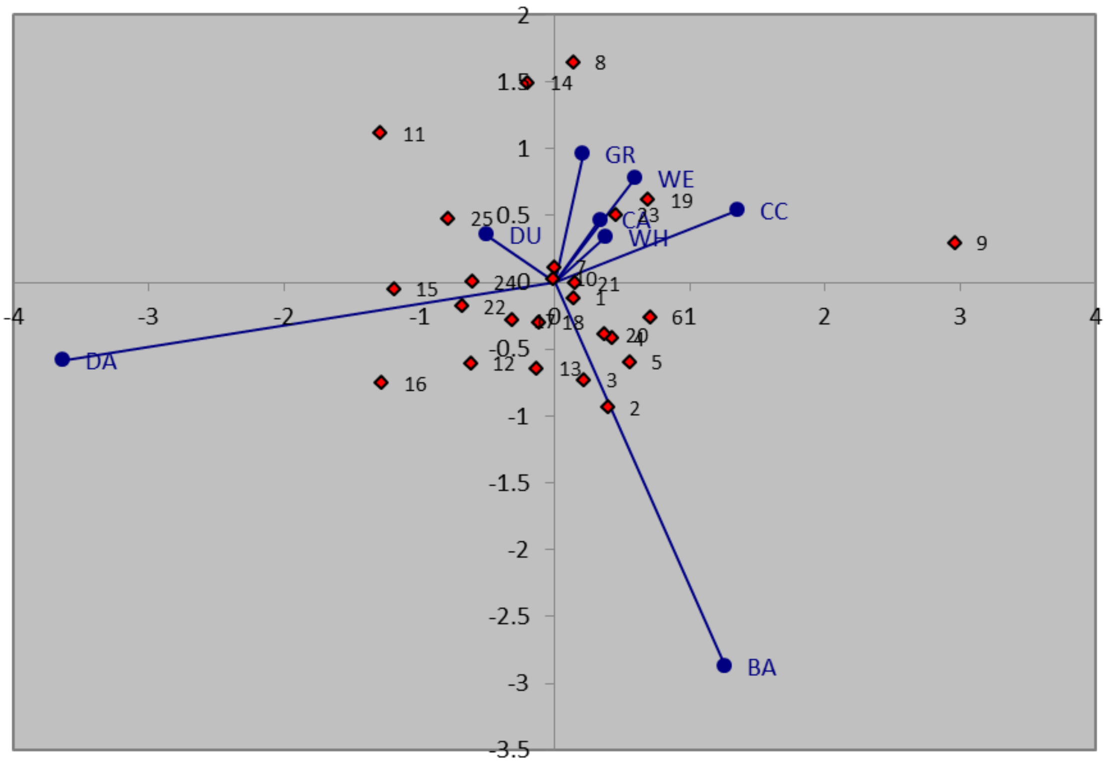

Figure 24. Singular Value Decomposition Biplot for test weights for QPM hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, DA: Dalhart, DU: Dumas

SVD biplot for 1000 kernel weight shows that Prosper had the most variation (Figure 25). Grainger and Weslaco also showed significant variation in 1000 kernel weights. These three locations were not positively correlated with any of the other locations for this trait. Entries 23 and 24 both showed low test weights in Prosper but had high test weights in Grainger.

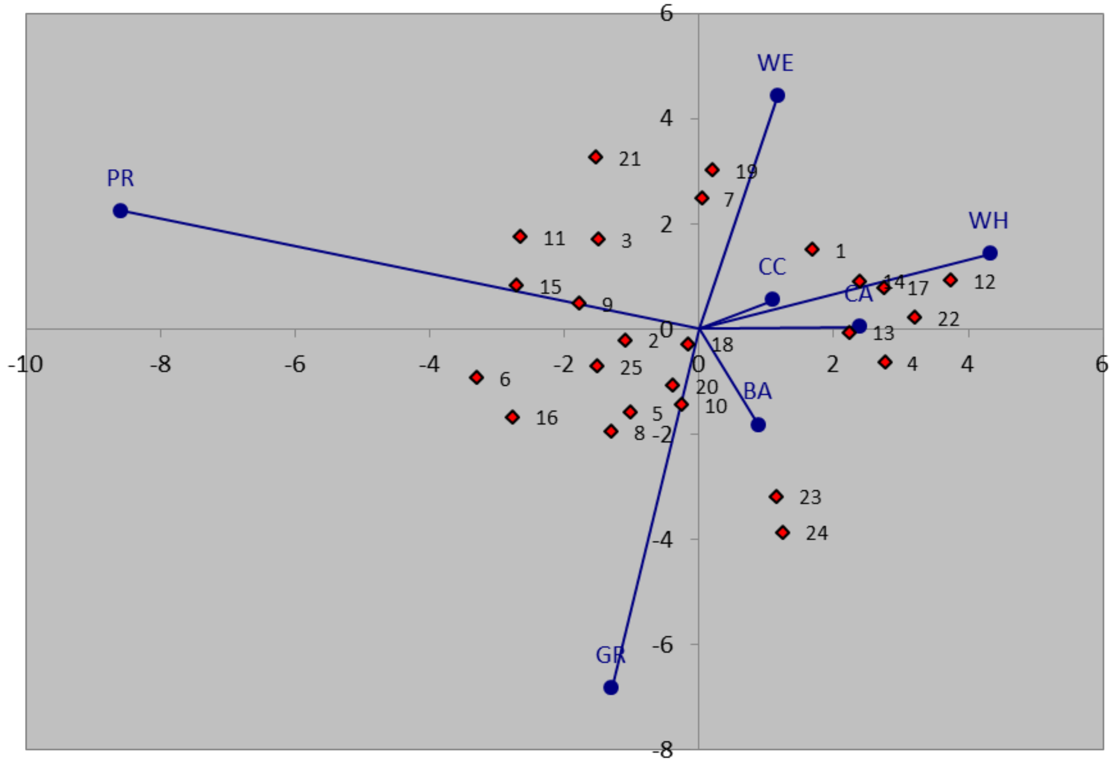

Figure 25. Singular Value Decomposition Biplot for 1000 kernel weights for QPM hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

SVD biplot for aflatoxin accumulation shows that Weslaco and Granger are highly correlated (Figure 26). Wharton appeared to show the highest levels of variation. Wharton and Prosper are not highly correlated with any other environments with regard to aflatoxin accumulation.

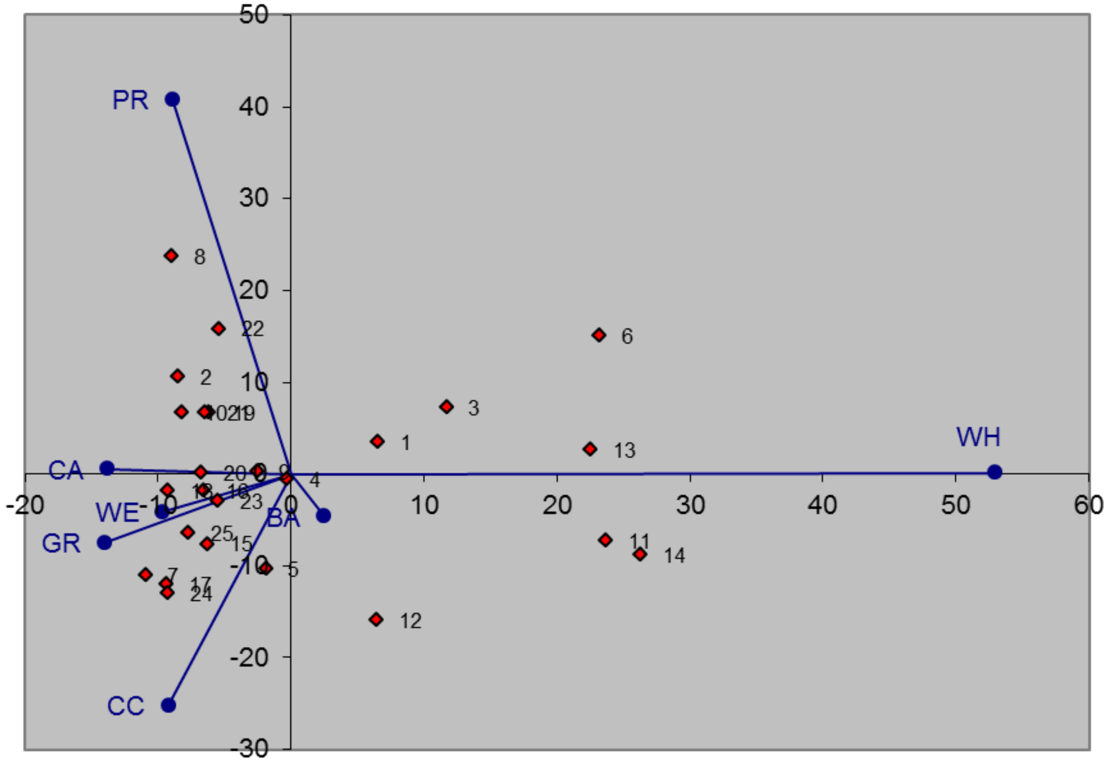

Figure 26. Singular Value Decomposition Biplot for antilogarithmic aflatoxin concentrations for QPM hybrids across all Texas environments in 2005.

†WE: Weslaco, CC: Corpus Christi, CA: Castroville, WH: Wharton, GR: Granger, BA: Bardwell, PR: Prosper

For the SDV biplot for trait means across environments, grain yield and test weights are highly correlated, with highly similar levels of variation (Figure 27). Aflatoxin accumulation was not correlated with yield and yield components (test weight and 1000 kernel weight).

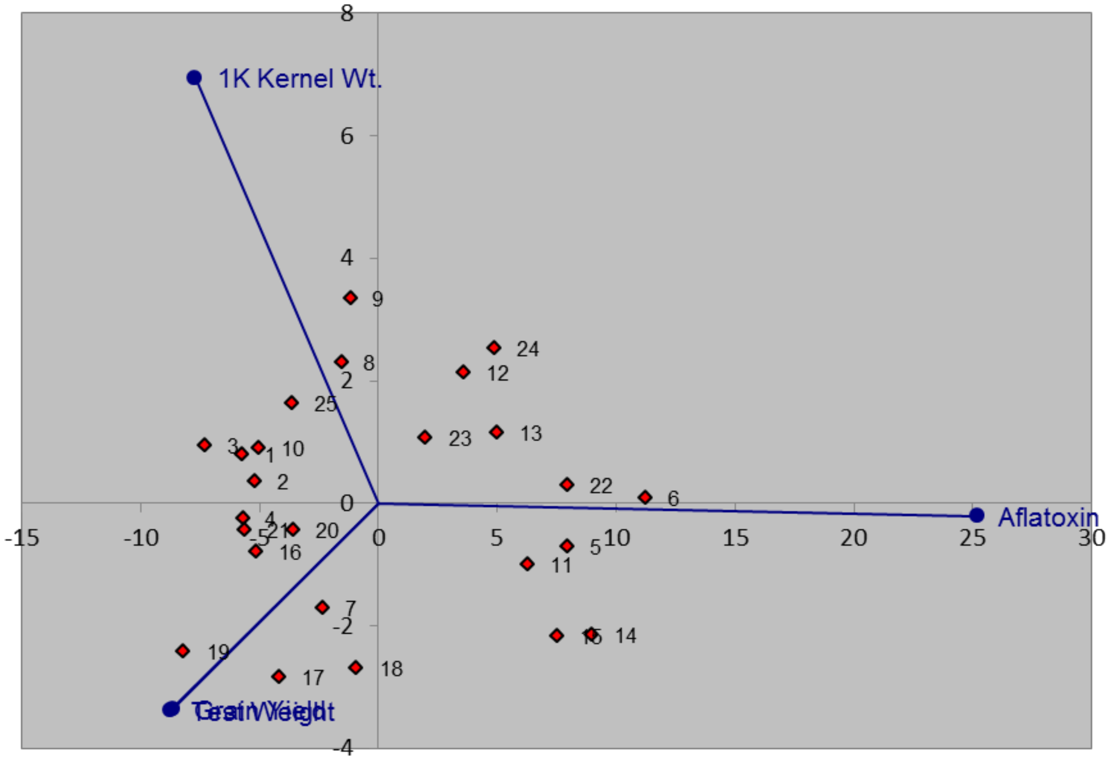

Figure 27. Singular Value Decomposition Biplot for trait means for QPM hybrids across all Texas environments in 2005.

Discussion and Conclusions

Experimental QPM hybrids had lower yields than the commercial checks at all environments. Test weights for experimental hybrids were comparable to or, in some environments, better than those of the commercial checks.

Environment affected test weight, as the higher test weights were from the irrigated locations. 1000 kernel weights for experimental QPM hybrids were lower than those of the commercial checks in all environments.

Entry 19 (CML176-B-B-B/LH195) had the lowest aflatoxin accumulation (92.91 ng g^{-1}). This hybrid had the 8th highest yield (5.88 Mg ha^{-1}) and the fourth lowest test weight (72.24 kg hL^{-1}) among QPM hybrids. Entry 17 ((Tx811-B x CML176-B)-B-B-B-B-2-B-B-B/LH195) had the second lowest accumulation (196.87 ng g^{-1}), followed by Entry 21 ((Tx811-B x CML176-B)-B-B-B-B-1-B-B-B/LH210) (243.38 ng g^{-1}). Once again, the hybrids with Tx811 and CML176 show low levels of aflatoxin accumulation. Entry 21 ranked 9th in yield (5.84 Mg ha^{-1}) while Entry 17 ranked 18th (5.60 Mg ha^{-1}).

As was observed in the other experiments, aflatoxin accumulation is not positively correlated with grain yield and test weight. The exotic backgrounds of several of these QPM lines are not adapted to Texas environments and are not able to produce high yields. Because some aflatoxin resistance was observed in these hybrids with exotic backgrounds, further testing in different southern environments is necessary to estimate their potential as source germplasm for aflatoxin resistance.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Single environments did not easily discriminate between hybrids for aflatoxin accumulation. For the yellow and QPM experiments, Corpus Christi and Granger showed significant differences between hybrids. For the white experiment only Weslaco showed significant differences. Overall the experimental hybrids in each group had lower accumulations than the commercial check hybrids.

Across environments, aflatoxin accumulation was not positively correlated with grain yield or yield components (test weight and 1000 kernel weight) for any of the hybrid sets. For the most part, hybrids that showed low levels of accumulation also had low yields. There are some exceptions to this: Entry 21 in the white hybrid set had the lowest accumulation and the second highest yield in that set. The lowest and third lowest accumulations in the QPM set, Entry 19 and 21, had yield means equal to or greater than the overall mean yield for that set. These hybrids with low accumulations are promising sources for new alleles that could provide resistance, but further testing with additional elite temperate testers is needed to better adapt them to the southern U.S., which would ideally result in improved agronomic performance. Lower accumulation paired with higher yield makes White Entry 21 a potentially useful hybrid for production purposes.

Because the same two elite testers, LH195 and LH210, were used in all of the experiments, it is possible to make inferences about trends in relative performance of experimental hybrids. This is especially true of hybrids with similar population backgrounds. Differences among hybrids could be attributed to differences among the experimental inbred parents and their combining abilities with these testers. As the experimental lines with exotic backgrounds have not been selected to maximize heterotic complementarities with temperate testers used, we expect a handicap in yield versus commercial checks that greatly exploit them.

The yellow hybrid set as a whole produced the highest yield of the three hybrid sets. Several experimental hybrids were competitive with the commercial checks, but only one of them, Entry 16, was within the top five yielding entries. Several yellow hybrids also had relatively low levels of aflatoxin accumulation. These have potential for use in production agriculture; further testing in other southern Texas environments would be needed to see if these results can be replicated.

The experimental white hybrid set had the highest average level of aflatoxin accumulation by almost 100 ng^{-1} g. Selection against aflatoxin accumulation is needed for theses hybrids to be of any value commercially. They also produced the lowest 1000 kernel weight average among experimental hybrid groups. All but one experimental white hybrid had a mean yield higher than the check mean, and all but seven yielded at or above both the experimental and overall means. These hybrids certainly have potential to be competitive with what is commercially available.

The experimental QPM hybrid set produced the lowest overall mean yield among the experimental hybrid sets, but the checks used for the QPM set produced the highest mean yield as a group. Coincidentally the four hybrids used as checks were also used as checks in the yellow set. This difference in yield could be attributed to field variation in certain locations. As noted above there are also several QPM hybrids with relatively low aflatoxin levels under inoculation; this could be attributed to the flintier kernel type of this QPM material, which was less prone to damage. However, due to the lower yields more selection and testing would be needed to determine whether higher yields could be obtained from this type of material.

Overall there were differences seen among hybrids at different environments for different traits. There was also a high level of Genotype x Environment interaction exhibited for all traits. This research emphasizes the necessity to observe and evaluate hybrids in multiple environments in order to best illustrate their potential performance. There are numerous hybrids that are competitive with the commercial checks for a variety of these traits. Some of the more tropical materials, such as the CIMMYT and LAMA lines, have certain characteristics that would be valuable in U.S. programs if the proper hybrid combinations could be made and targeted to the best environments. In order to assess the full value and potential of these hybrids for production agriculture, and for the experimental inbred lines for further use in breeding programs, more selection and testing is needed. The incorporation of this material into established U.S. lines could be beneficial with regards to aflatoxin accumulation and kernel quality, which could ultimately translate to higher yields.

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