# Approaches and Technologies for Challenges in Agriculture: A View from a Texas Maize Breeding Program

TEXAS A&M AGRILIFE RESEARCH

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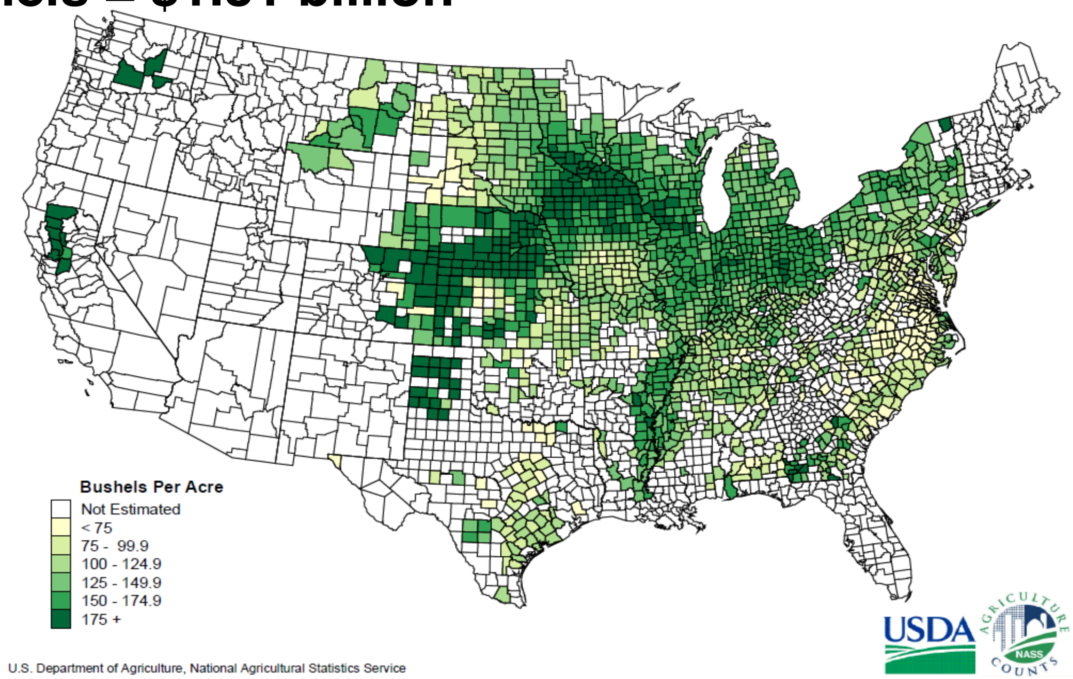
# Maize in Texas

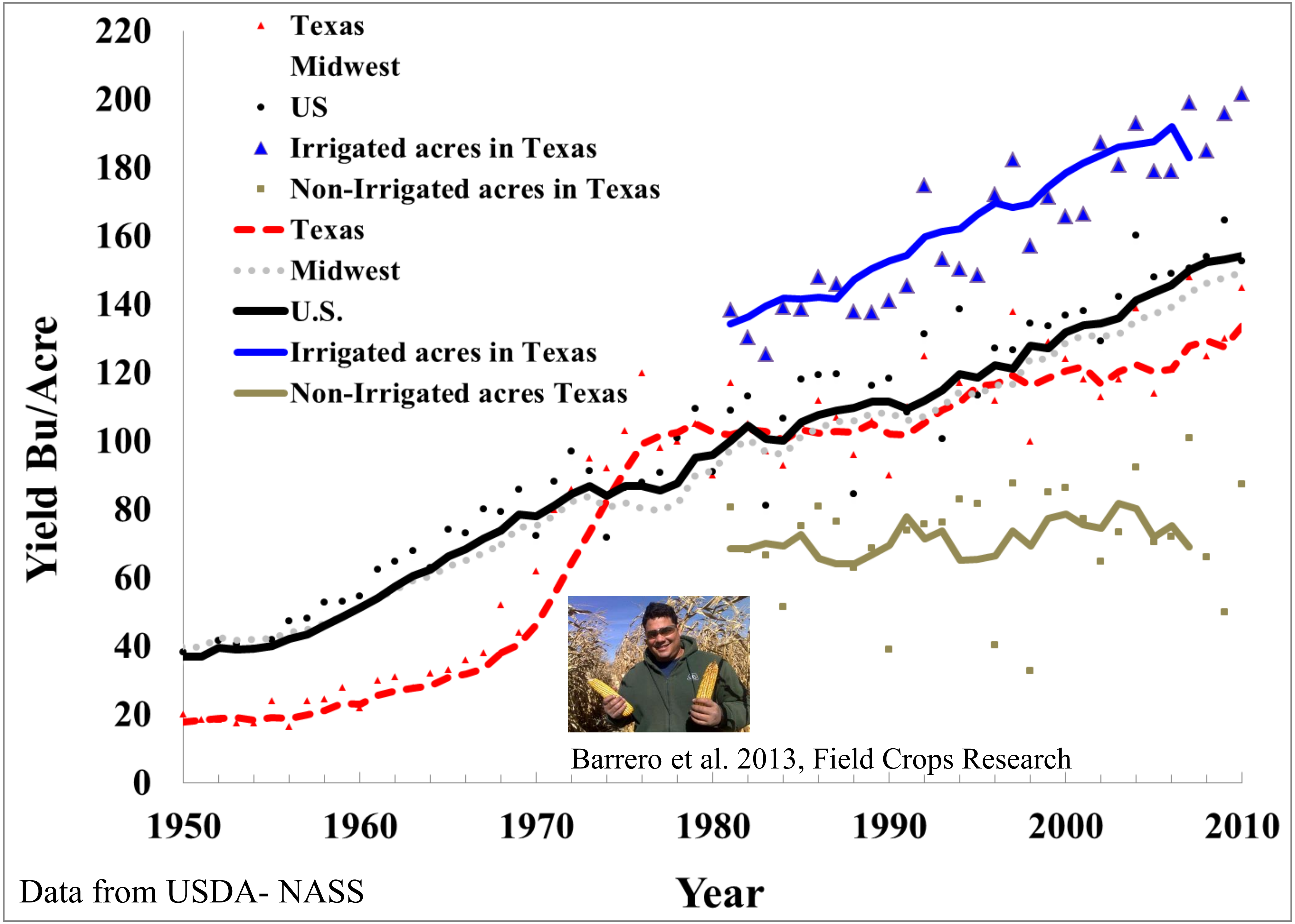
| 2013 Region | Acreage planted | Average yield |
|---|---|---|
| High Plains | 951,000 acres (855,000 harvested) | 204.8 bu/acre |
| Rest of Texas | 1,479,000 acres (1,234,000 harvested) | 89.6 bu /acre |

**Texas 2010 – 300 million bushels = $1.5 billion (12th in Country)**
**Texas 2011 – 136 million bushels, heat and drought = $0.9 billion**
**Texas 2012 – 202 million bushels = $1.46 billion**
**Texas 2013 – 283 million bushels = $1.36 billion**
**Texas 2014 – 295 million bushels = $1.31 billion**

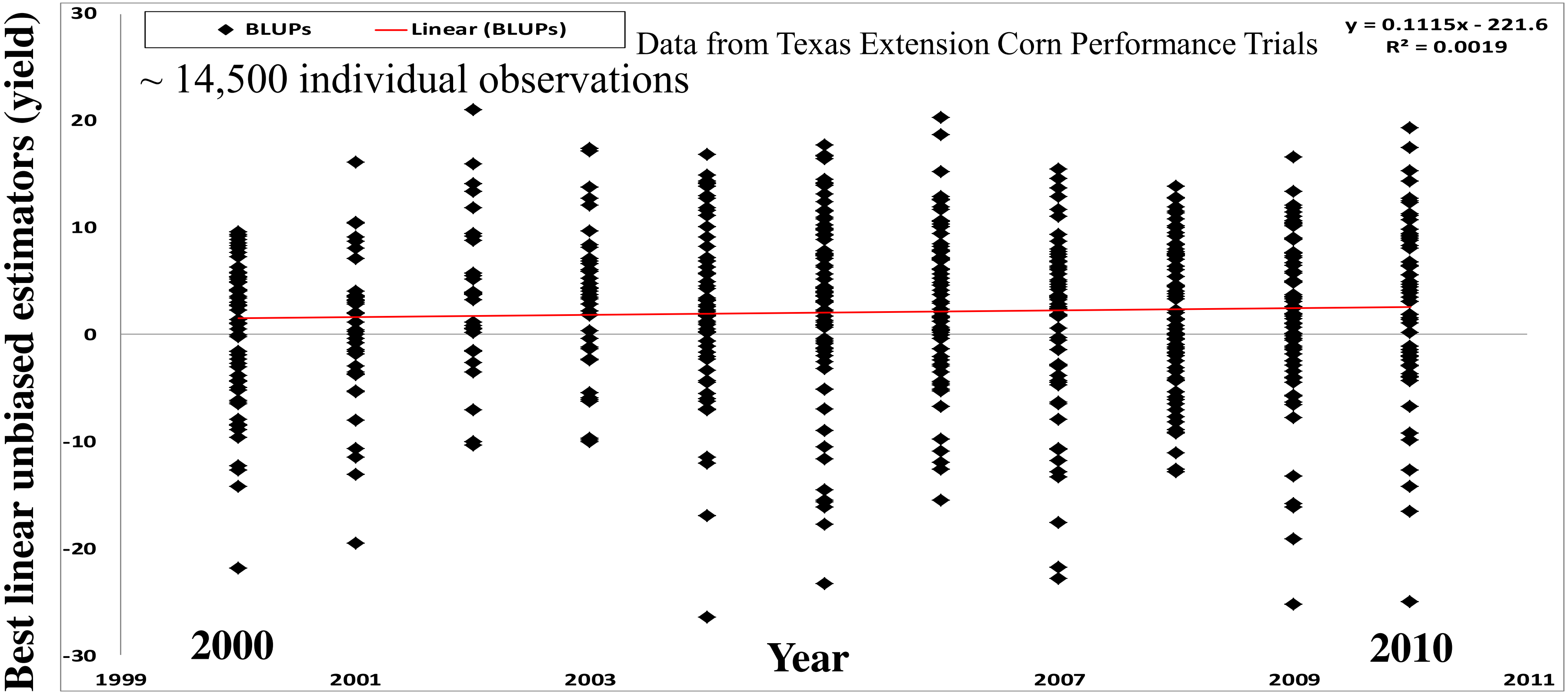
| | |
|---|---|
| Texas Acres | 2,430,000 |
| Acres per bag of seed | ~ 3 |
| Cost per bag of seed | ~ $150 |
| Total $ on seed | ~ $121 million |



# Texas maize production



# Meta-analysis - minimal genetic yield gain in commercial varieties grown in Texas over the last 11 years




| Hybrid | BLUP | SE | Year | Locs |
|---|---|---|---|---|
| TG895W | -37.38 | 7.088 | 2007 | 1 |
| TRX01601X | -25.03 | 6.892 | 2010 | 2 |
| F3025 | -19.52 | 7.002 | 2001 | 3 |
| DKC6469GENVT3P | 19.35 | 8.548 | 2010 | 1 |
| 6361RB | 20.3 | 3.928 | 2006 | 10 |
| 5202B | 20.99 | 7.037 | 2002 | 3 |

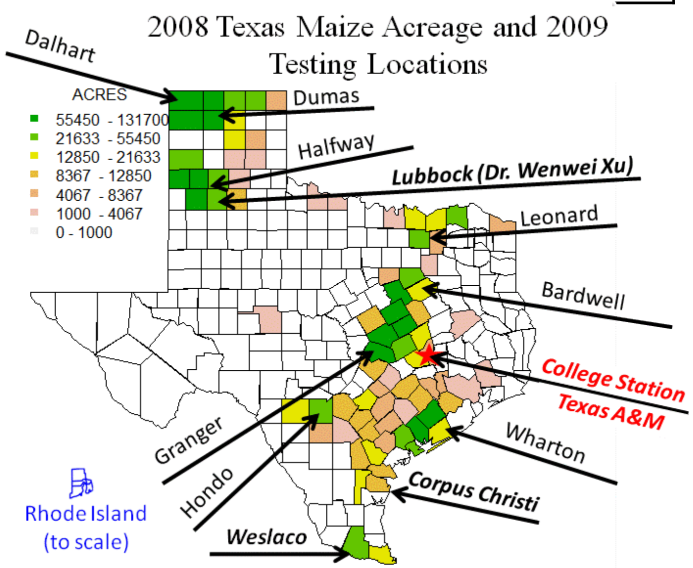
Barrero et al. 2013, Field Crops Research

# Agronomic traits are more highly correlated with yield in the lower yielding Texas environments

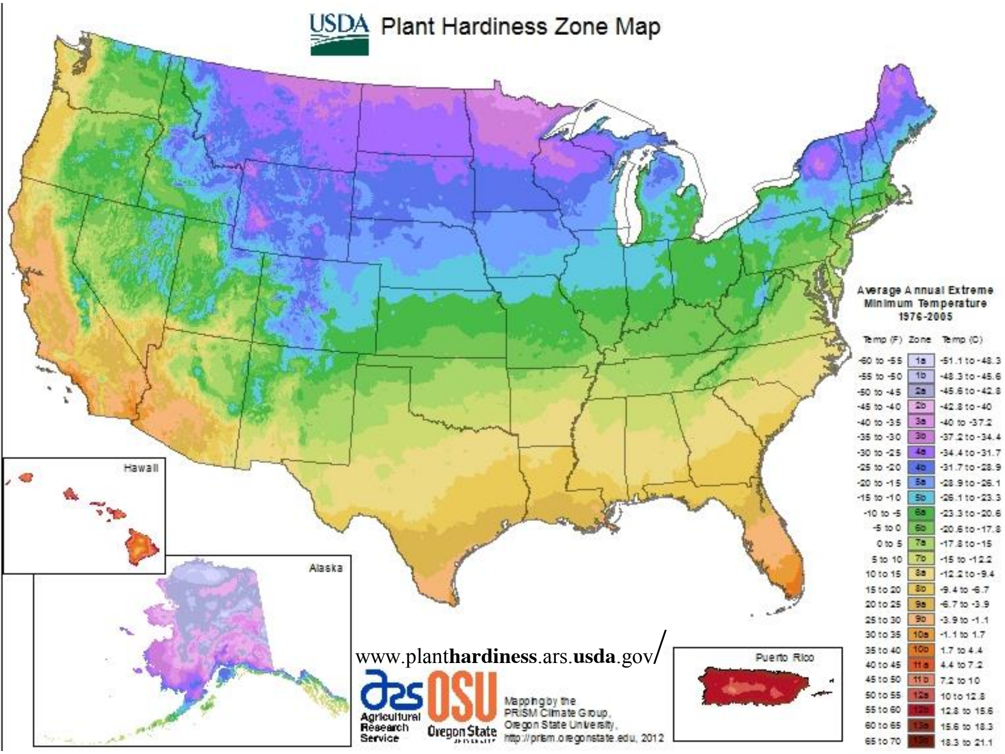
| | Grain yield (tons/ha) | | | |
|---|---|---|---|---|
| | **Texas** | **High Plains** | **Rest of Texas** | **Dryland** |
| **Plant height (cm)** | $0.61^{***}$ | $0.19^{***}$ | $0.46^{***}$ | $0.45^{***}$ |
| **Ear height (cm)** | $0.56^{***}$ | 0.03NS | $0.40^{***}$ | $0.35^{***}$ |
| **Days to silk** | $0.13^{***}$ | $-0.25^{***}$ | $0.05^{***}$ | $-0.08^{***}$ |
| **Plant density (plants/ ha)** | $0.66^{***}$ | $0.44^{***}$ | $0.51^{***}$ | $0.36^{***}$ |
| **Lodging (% plants/ plot)** | $-0.16^{***}$ | $-0.24^{***}$ | $-0.15^{***}$ | $-0.21^{***}$ |
| **Moisture (%)** | $0.55^{***}$ | $0.04^{*}$ | $0.28^{***}$ | $0.30^{***}$ |
| **Test weight (kg/hl)** | $0.33^{***}$ | 0.04NS | $0.45^{***}$ | $0.50^{***}$ |

~ 14,500 individual observations on each trait
~ 1,000 commercial hybrids

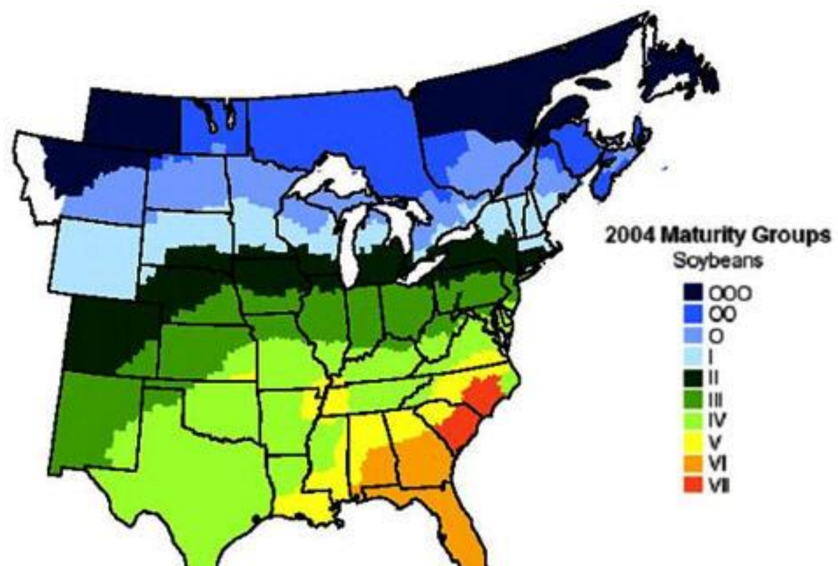
Barrero et al. 2013, Field Crops Research



# Midwestern bias observed between USDA heat zone map and maize relative maturity zones

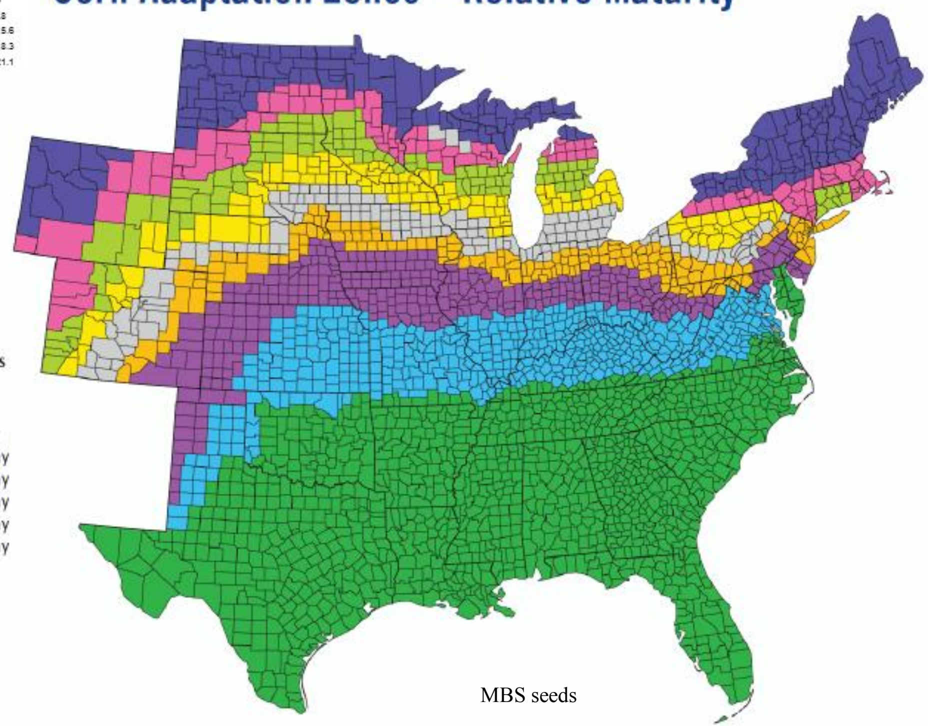



www.plant**hardiness**.ars.**usda**.gov/




https://www.pioneer.com/CMRoot/pioneer/us/images/agronomy/field_facts/soybeans/maturity_ratings/soybean_maturity_fig1.jpg

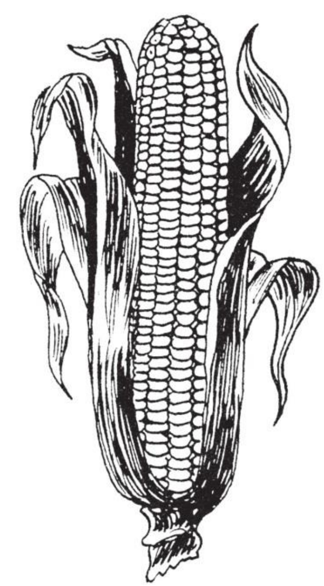
Corn Adaptation Zones – Relative Maturity




MBS seeds

# Why do we need a public breeding program on corn? Aren't the companies doing this?

- Not targeting Texas or the south - a unique adaptation (aflatoxin, heat, drought, etc.)
- Unique traits / exotic introgression – colored corn, QPM, perennial corn, high biomass corn
- Graduate student training
  - Primarily in industry
- New breeding methods
- Long-term high risk research
  - perennials



# Most commercial inbred lines are not adapted to Texas heat and drought

**LH195RR2**

**Tx777**

**Tx777 x LH195RR2**

**Tx782 X LH287RR2**

# 2013 inbreds and hybrids demonstration

LH195 LH195 x Tx775 Tx775

Tx773 Tx773 x TR7322 TR7322

# Previous phase of public corn breeding at Texas A&M (the last seven to eleven years) – *Corn breeding at A&M started in 1927*

Identify parents and make crosses
*(one to two years)*

**Temperate high yield corn**

X

**Tropical corn with good traits: Aflatoxin resistance, stress tolerance, etc.**

Self pollinate and select
*(three to five years)*

Discard trash

Cross AgriLife inbred to two older commercial tester lines
*(one to two years)*

**AgriLife inbred corn: ears look good but does it yield and have resistance?**

X

**Stiff stalk tester inbred**

**Non-stiff stalk tester inbred**

**Assisting Texas Growers Increase Profit**

$$$

**Test hybrid aflatoxin resistance Ok yield**

***(~two years)***

Discard trash

FINISHED GERMPLASM RELEASE!

(BLACK BOX)

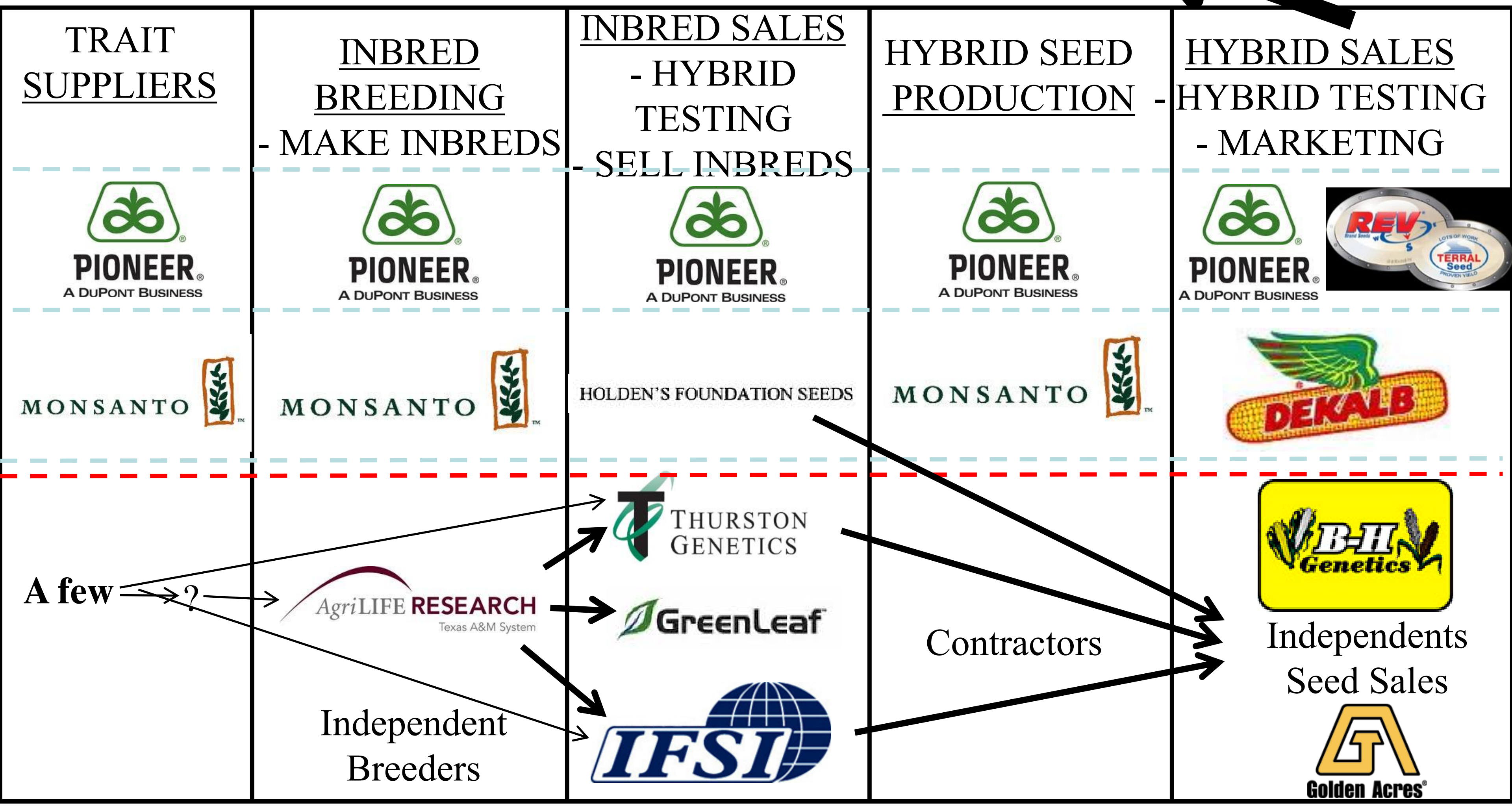
***Along the way we:***
***1) Trained students***
***2) Increased knowledge and wrote papers***
***3) Assisted growers, students and researchers with co***
***research***

# Increasing focus on best yielding lines

| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|
| Summer Testers | 2 | 4 | 15 | 17 | 12 | 5 |
| Summer TAMU lines | 646 + 2 ISO | 665 | 278 | 67 | 37 + 2 ISO | 7 +2 ISO |
| Winter Testers | 2 | **9** | 10 | 19 | 14 | - |
| Winter TAMU lines | 364 + 2 ISO | 70 | 25 | 33 | 32 | - |

Only get yield data in time to make decisions for winter nursery the following year (maybe)

# Today's corn seed chain and where public breeders fit (a personal opinion)

# 723 hybrids tested in 2012 across six environments

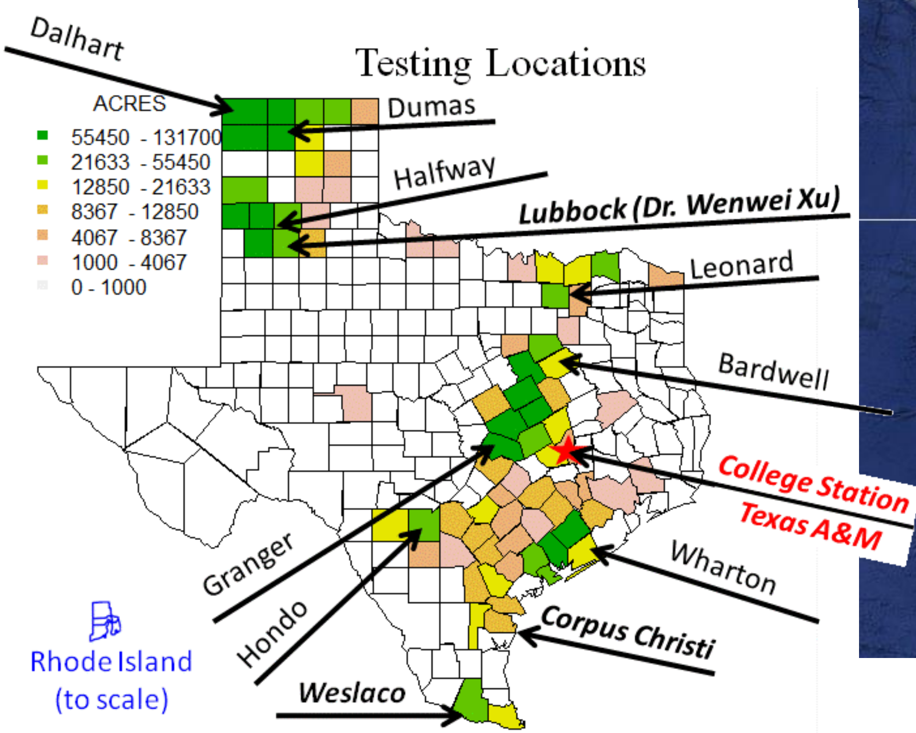
| Rank | Hybrid | Bu/ Acre above mean | Std Error | P |
|---|---|---|---|---|
| 1 | *Tx777 X SS2* | 51.5 | ± 11.3 | **** |
| 2 | *Tx954 X SS5* | 49 | ± 16.8 | ** |
| 3 | *Commercial Hybrid #09 (TX company)* | 46.8 | ± 5.4 | **** |
| 4 | *Commercial Hybrid #08 (TX company)* | 46.2 | ± 13.7 | *** |
| 5 | *Commercial Hybrid #02 (TX company)* | 45.1 | ± 4.8 | **** |
| 6 | *Tx114 X Tx120* | 44 | ± 14.5 | ** |
| 7 | *Commercial Hybrid #04 (National company)* | 43.3 | ± 6.7 | **** |
| 8 | *Commercial Hybrid #05 (National company)* | 42.3 | ± 13.7 | ** |
| 9 | *NSS1 X Tx150* | 40.7 | ± 11.3 | *** |
| 10 | *Tx773 X NSS2* | 38.1 | ± 8.9 | **** |
| 11 | *SS1 X Tx149* | 37.5 | ± 9.6 | *** |
| 12 | *DKB 64-69* | 37.2 | ± 6.1 | **** |
| 13 | *Tx777 X NSS2* | 37.1 | ± 9.6 | *** |
| 14 | *Tx775 X NSS2* | 37 | ± 14.5 | * |
| 15 | *SS1 X Tx904* | 36 | ± 14.6 | * |
| 16 | *Commercial Hybrid #11 (TX company)* | 35.9 | ± 6.3 | **** |
| 17 | *Tx150 X SS4* | 35.5 | ± 10.2 | *** |
| . | . | . | . | . |
| 29 | *TX740 X SS3* | *31.9* | *± 8.9* | *** |
| . | . | . | . | . |
| 50 | *Commercial Hybrid #06 (TX company)* | 26.5 | ± 6.4 | **** |
| . | . | . | . | . |
| 56 | *Commercial Hybrid #10 (National company)* | 25.6 | ± 13.7 | NS |
| 57 | (LAMA2002-22-3-B-B1-B-B/LAMA2002-10-1-B-B-B-B)-2-3-B-2-1 **X SS2** | 25.4 | ± 12.4 | * |
| 58 | *Commercial Hybrid #07 (TX company)* | 24.9 | ± 13.7 | NS |
| 60 | *TX740 X NSS2* | *12.6* | *± 16.8* | NS |

**Table 1: Grain yield (Bu $Ac^{-1}$) trial results over 15 trials in 2013.**

# 2013 SERAT yield data from North Carolina out of 37 hybrids including 7 commercial checks

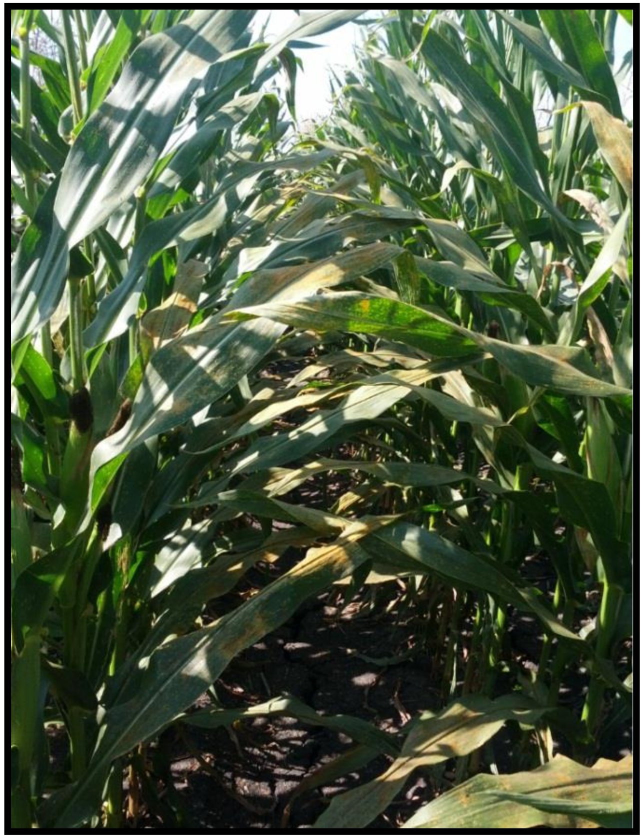
Dr. Matt Krakowsky, USDA- NCSU

# Important origins of germplasm to the TAMU Maize Breeding Program

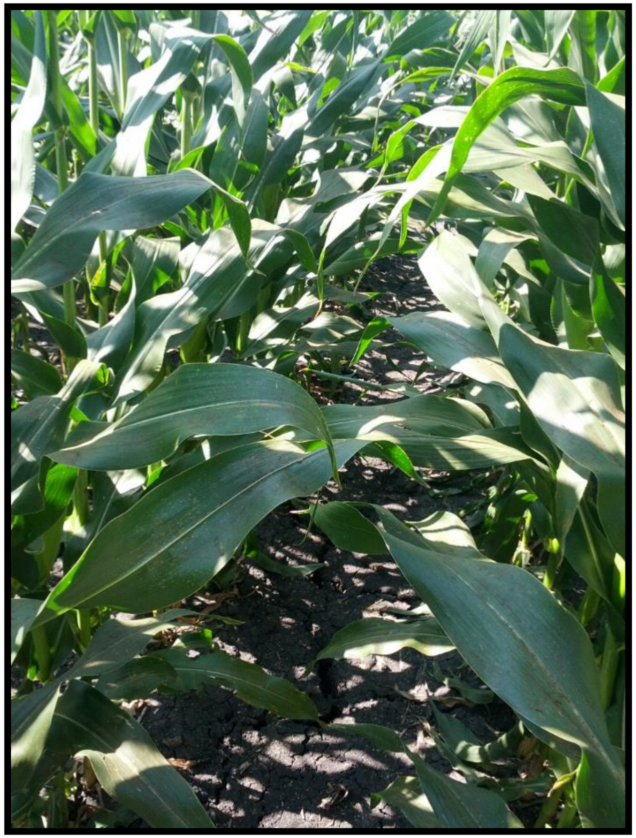



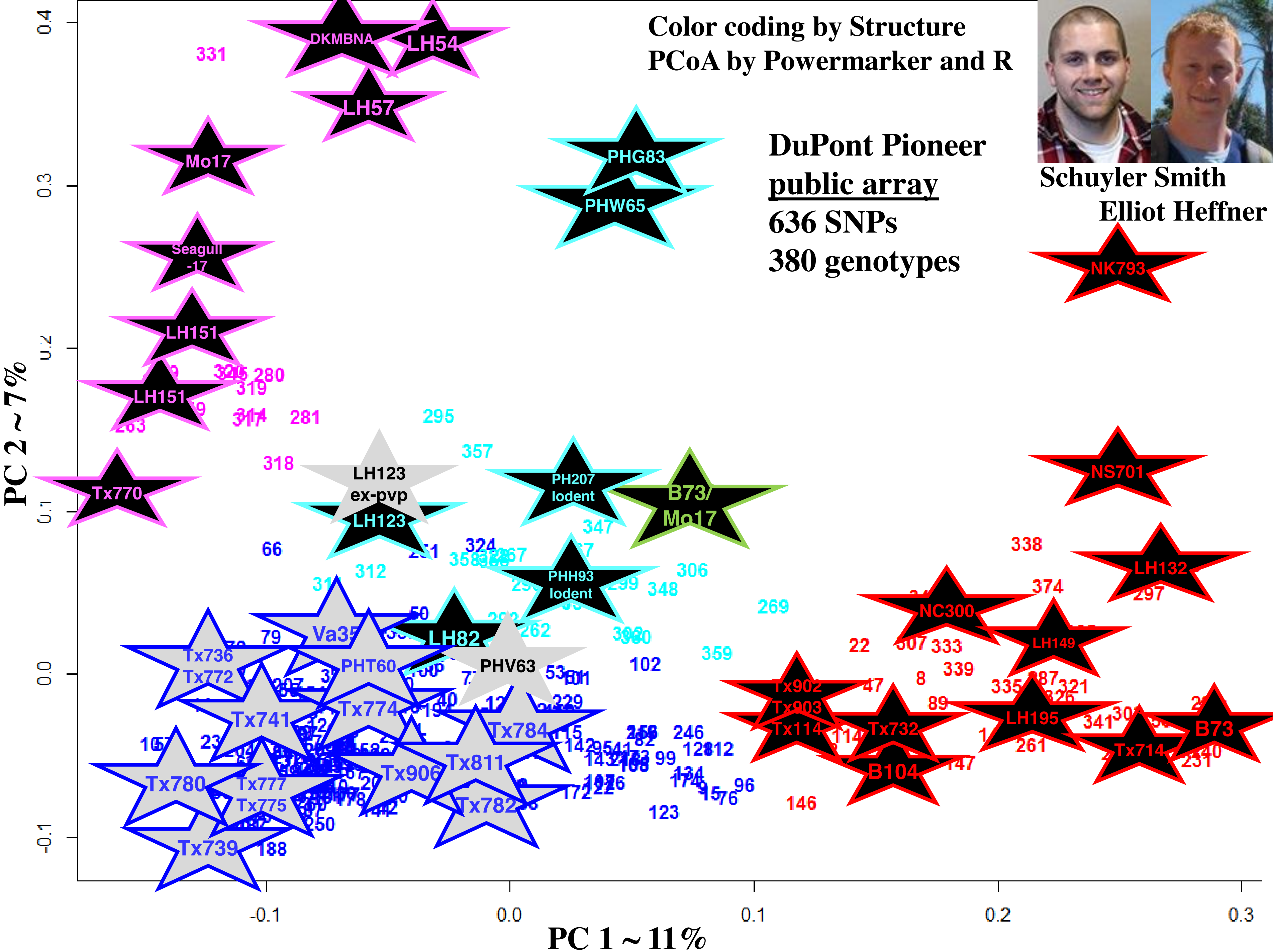
# Southern rust resistance

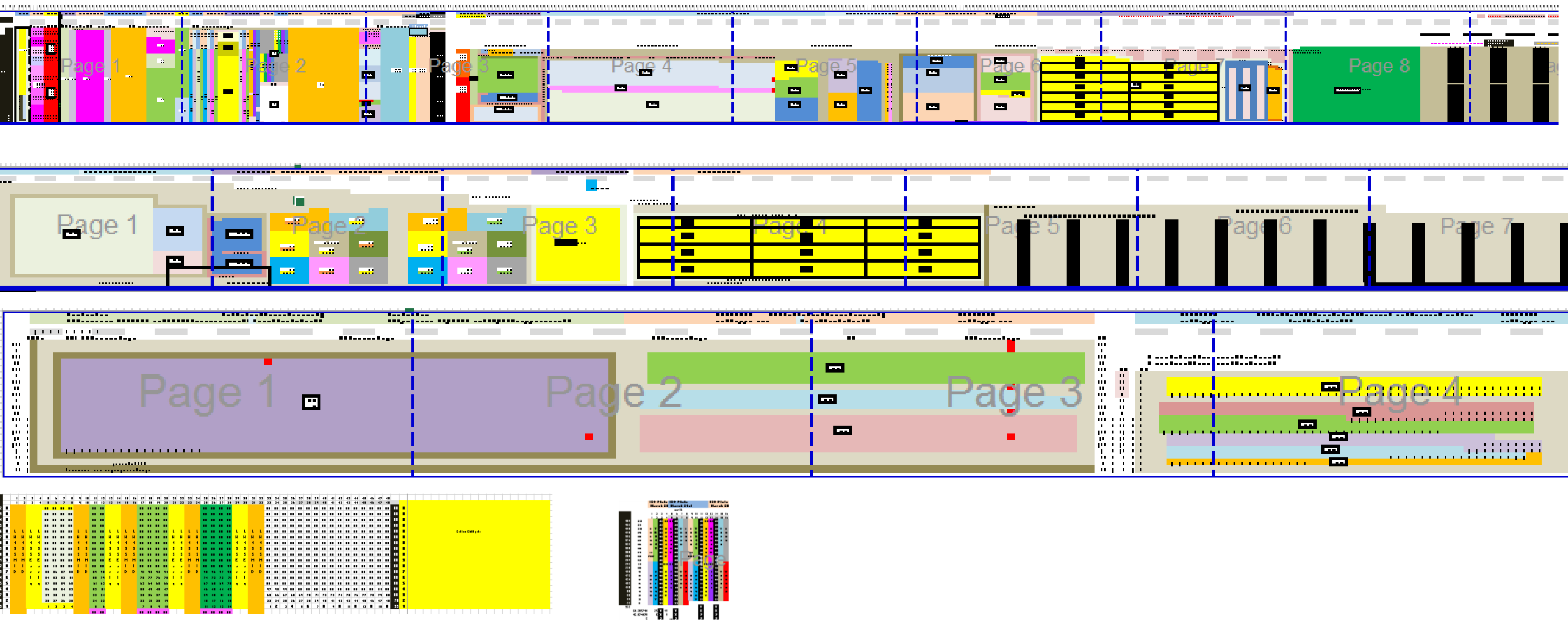
**Commercial hybrids from 100% temperate material**



**TAMU Hybrids with ½ tropical background**




Color coding by Structure
PCoA by Powermarker and R
DuPont Pioneer
public array
636 SNPs
380 genotypes
Schuyler Smith
Elliot Heffner
PC 2 ~ 7%
PC 1 ~ 11%
DKMBNA
LH54
LH57
Mo17
Seagull -17
LH151
LH151
Tx770
PHG83
PHW65
LH123 ex-pvp
LH123
PH207 Iodent
B73/ Mo17
PHH93 Iodent
LH82
PHV63
Va35
PHT60
Tx736
Tx772
Tx741
Tx774
Tx784
Tx780
Tx777
Tx775
Tx906
Tx811
Tx782
Tx739
NK793
NS701
LH132
NC300
LH149
LH195
Tx902
Tx903
Tx114
Tx732
B104
Tx714
B73



## Summer yield trials

- Generally seed limited
- 2 row- 2rep; 1 row - 2rep; 1 row 1rep
- Generally 8 to 12 commercial checks per test
- ~20 acres in College Station into ~ 20 tests
- Late planting, limited irrigation treatments
- Combine harvested
- Aflatoxin testing
- Row / column effects are often highly significant

## Summer nursery

- ~7 acres in College Station into ~ 20 groups
  - Yellows
  - Whites
  - Coloreds
  - Genetics
  - Student projects
- 2 isolation blocks, but very hit or miss

Perennial breeding requires planning

# Corn breeding program timeline

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prepare Nursery | | CS | CS | | | | | WE | | | | |
| Plant Nursery | | | CS | | | | | WE | | | | |
| Pollinate | | | | | | CS | | | | WE | | |
| Harvest | | | | | | | | CS | | | | WE |
| Process Seed | WE | WE | | | | | | CS | CS | | | |
| | | | | | | | | | | | | |
| Prepare Yield Trials | WE | | CS | | | | | | | | | |
| Plant Yield Trials | | WE | CS | CS | | | | | | | | |
| Agronomics | CS | | | CS | CS | CS | CS | | | | | |
| Notes | | | | CS | CS | CS | | | | | | |
| Inoculate AF | | | | | CS | | | | | | | |
| Harvest | | | | | | WE | | CS | | | | |
| Grind, NIRS, Aflatest | | | | | | | | | CS | | | |
| Analyze Data | | | | | | | | | | | | |

CS = College Station, TX
WE= Weslaco, TX

Downtime!

# Information management

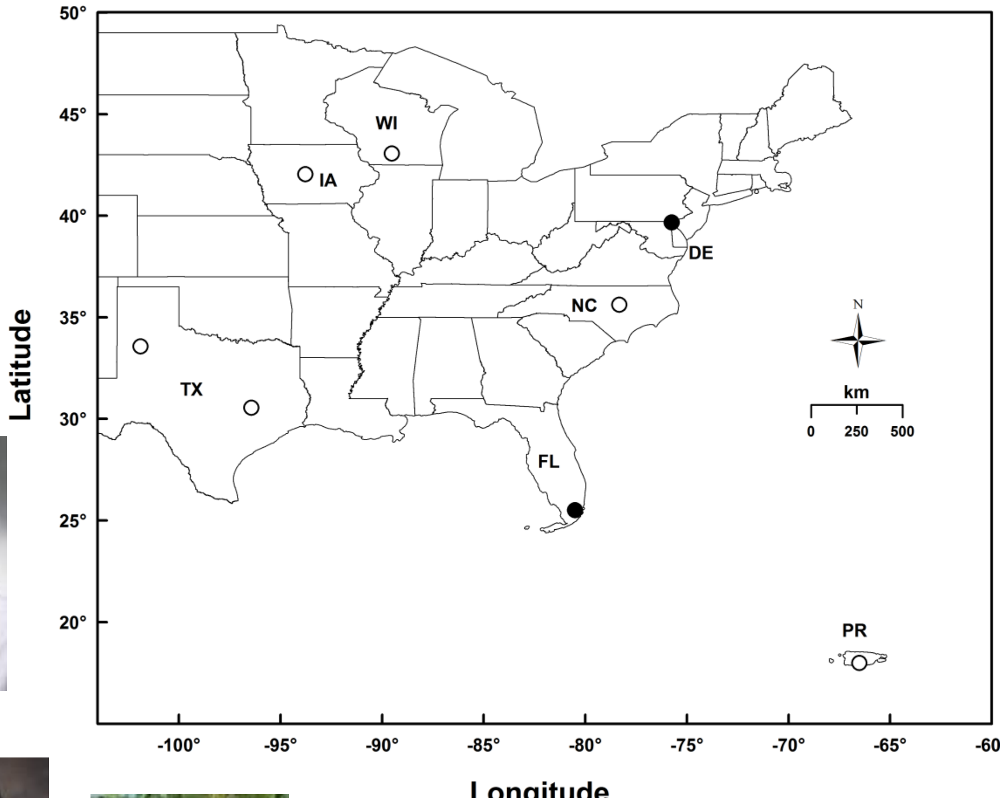

- **In 2012 –**
  - **Over 4679 Summer yield trial plots:**
    - **Yield**
    - **Stand count**
    - **Flowering time**
    - **Height**
    - **Other traits**
    - **Some with subsampled grain**
  - **Summer nursery >6007 seed stocks**
  - **Weslaco winter nursery (2011) 3584 seed stocks**
  - **Genotyping results >2000 plants**
- **Multiplied by 5-10 years of seed in cooler**
- **Still no single data format we are really happy with**

# Unadapted germplasm to the Midwest (IA)


Mahan et al. 2013, Crop Science

# Maize ATLAS

Adaptation Through Latitudinal Artificial Selection




Design,
Simulations
Analysis


FT-NIRS

http://maizeatlas.org/

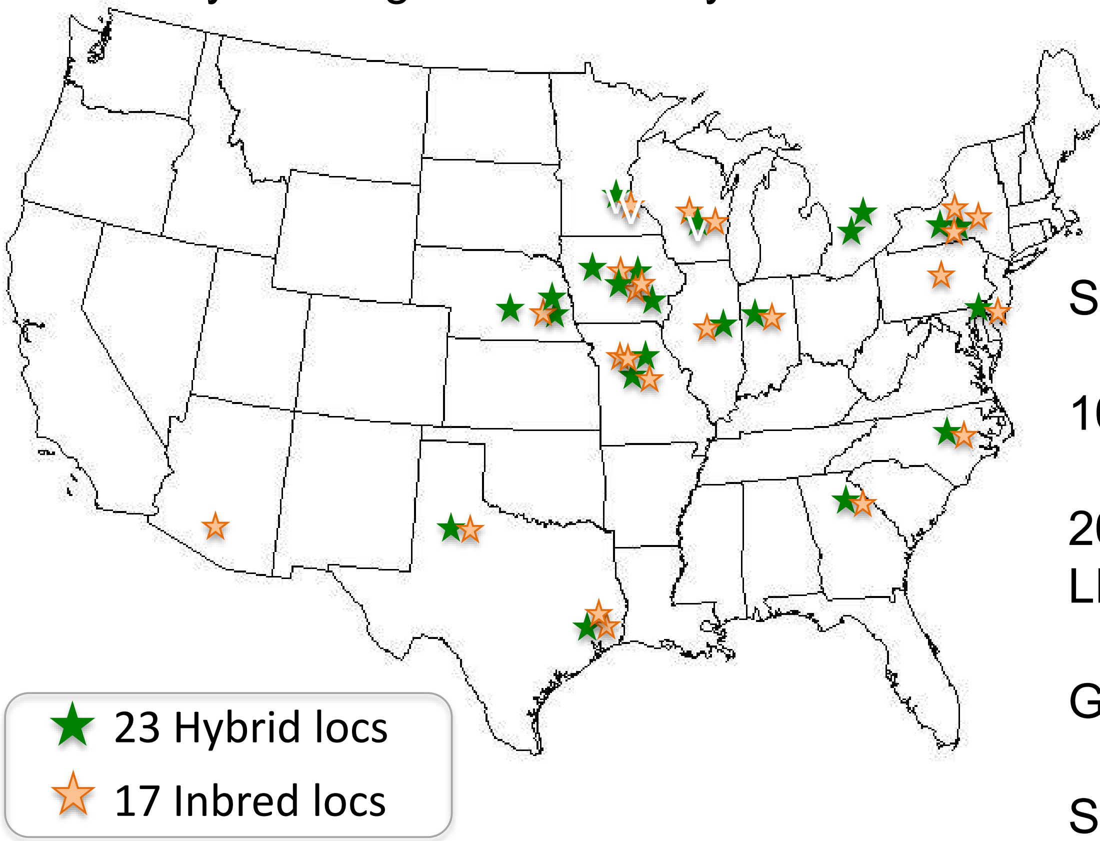
USDA United States Department of Agriculture

National Institute of Food and Agriculture

# G2F: Maize G X E Project

Goal: To Enhance ability to predict plant performance and a deeper understanding of relevant biology

Apply the maize genome sequence, multi-location phenotypes and environmental data to identify useful genetic diversity




Build and strengthen the community of maize breeders and researchers

Set of ~250 hybrids, 2 reps per loc.

10 hybrids common across locations

2014 testers are LH198, LH185, LH195, PB80 and CG102

Genotyped using GBS

Set of 31 inbreds

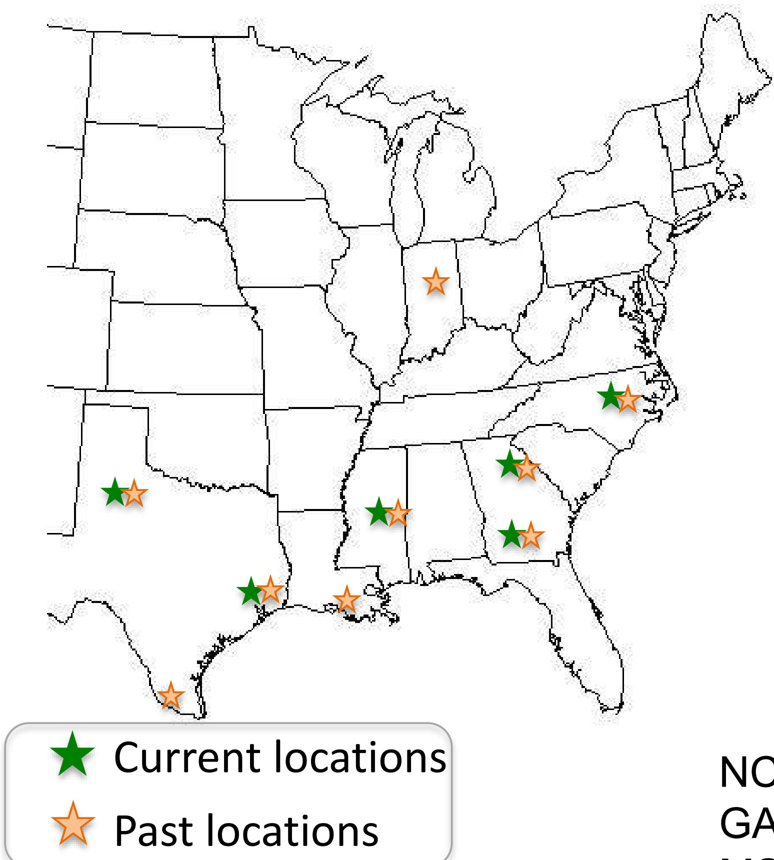
Genomes to Fields

IOWA CORN GROWERS ASSOCIATION

*Courtesy of Dr. Natalia de Leon, and the work of many researchers throughout the US*

# Southeast Regional Aflatoxin Trials (SERAT)

Goal: To determine the multi-environmental adaptation and phenotype of breeding material for aflatoxin resistance, with high yield and associated agronomic traits.




* Started in 2003
* Set of ~32 hybrids, 3 reps per loc.
  - Investigators enter ~ 7 hybrids
  - ~4 checks
* Inoculated for *Aspergillus flavus* (various methods)
*Measure yield, aflatoxin and other traits

<u>Current project expansion (USDA and AMCOE)</u>

*Inbred screening
*Interaction of resistance genetics and atoxigenics
*Meta-analysis of historical data

NC – Dr. Krakowsky
GA – Drs. Ni, Guo,Scully
MS – Drs. Williams, Windham, Warburton
Tx1 – Drs. Xu, Odvody
Tx2 – Drs. Isakeit and Murray
**Companies:**
BH Genetics – Dr. Raab and Arnold, Pioneer, Monsanto – Dr. Gorman

AMCOE

USDA United States Department of Agriculture National Institute of Food and Agriculture

# Aflatoxin contamination


- Produced by fungus *Aspergillus flavus* L.
- US federally regulated at 20ppb
  - Above 500ppb corn must be destroyed!
- Can lead to acute death
  - *Kenya 2004: 125 people died, 192 poisoned (levels to 2,000ppb)*
  - *US 1998: 25 dogs died eating levels of 100-200ppb for 3 months*
- Potent chronic carcinogen, leads to stunting, and other health problems in humans and animals
  - 1.7cm decrease in height for highly exposed children in Benin
  - Higher rates of liver cancer in China
  - Varying sensitivities among species
- $14 - $250 million loss from mycotoxins in 2008



Courtesy of Velazquez, Bailey, Deng, and Dixon; Texas AgriLife (2010 - unpublished data)

# Challenges in developing lines with good aflatoxin resistance and yield under stress

*How do we separate these various correlated traits ?*

- Husk Coverage
  - Long, cover tips
  - Tight and thick
- Maturity
  - Flowering time
  - Days to maturity
- Kernel hardness
- Ear nod (ear droop)
- Earworm resistance
- **Drought tolerance**

*How do we make gains from selection on this many traits ?*

Row number

Ear length

**YIELD**

Kernel size

Stress Resistance

Stay Green

Lodging

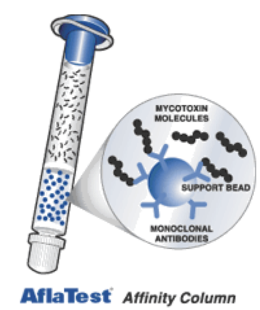
Kernel density

# Inoculating yield trials with colonized kernels


# Harvesting yield trials


**Fourier Transformed Near Infrared Reflectance Spectroscopy FT-NIRS (Thermo Antaris II)**

**Vicam AflaTest immunoaffinity columns**



# Multi-parent populations to pyramid aflatoxin resistance sources and yield

• Develop 4-way and 8-way cross populations from known sources of resistance (Warburton et al.)

• Select inbred lines from these populations across different environments and investigators

- Phenotypic for yield
- Using markers for aflatoxin (Warburton)

## ← 4-Way Cross Populations; Ne=200+

a (Tx740/Mp313E)//(Tx772/Mp715) fourway 3 sib mated

b.(Tx772/Mp313E)//(Tx740/Mp715) fourway 3 sib mated

## 8-Way Cross Populations (3 ); Ne=100+→

c ((CML 108/Mp715))//(A6 /Tzi 8)///((Tzi 18/Ki3)//(NC334/Hi27))

d. ((CML 108/NC334)//(Tx740/CML 348))///((Tzi 18/Mp313E)//(CML 311/Mp715))

e. ((Tzi 18/CML 69)//(Tzi 8/Mp313E))///((CML 108/A6)//(CML 311/Mp715))

# Hybrid crossing scheme

**Tx714 (~~*zmlox4-10::mu/zmlox4-10*~~)**

**Tx714 (~~*zmlox5-3::mu/zmlox5-3*~~)**


**Pollen *zmlox4-10::mu***

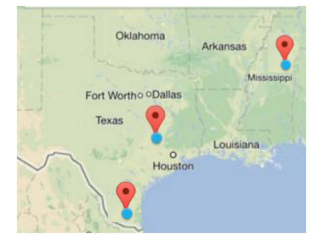
**2010**
**2011**

**X**

**Inbred females**
**357 diverse lines**

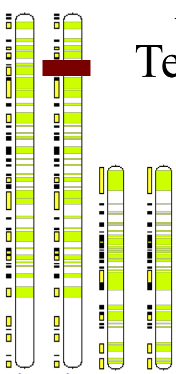
**Pollen *zmlox5-3::mu***

**2010**
**2011**



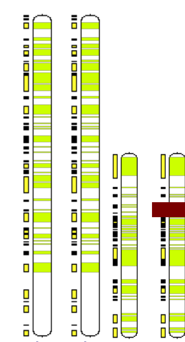

**College Station, TX**
**Weslaco, TX**

**Hybrids (*ZmLOX4/~~zmlox4-10::mu~~*)**



*A. flavus* inoculated
Test aflatoxin resistance

**Hybrids (*ZmLOX5, ~~zmlox5-3::mu~~*)**
Limited and full irrigation
Test drought tolerance



2011, 2012 Yield trials:
3410 plots in College Station, TX
580 plots in Mississippi State, MS

Testers used:
**Va35** [(C103 X T8) T8] – **NSS** – *Warburton et al. 2013, Crop Science*
**TX714** [(K55/3*B73)-B-B-B)/B73]-1-B-B – **SS** – Barerro et al. 2015 PLoS ONE

# Pleiotropic effects of loci – agronomics and yield

| QTL variant | Bin | Chr. | B73 | Mo17 | Effect | Description |
|---|---|---|---|---|---|---|
| **Grain yield** | | | | | | |
| 1 | 7.04 | 7 | C | N | 5-7 bu/ac | Leucine rich repeat |
| 2 | 2.03 | 2 | N | A | 3 to 8 bu/ac | PUT-2-171a-Zea_mays-13770 |
| 3 | 9.06 | 9 | N | A | 3-5 bu/ac | ATP-dependent CLP protease |
| **Plant height** | | | | | | |
| 1 | 7.04 | 7 | C | N | 2 inches | Leucine rich repeat |
| 4 | 3.05 | 3 | A | C | 1 to 3 inches | Chromatin assembly factor I |
| 3 | 9.06 | 9 | N | A | ~1.5 inches | ATP-dependent CLP protease |
| **Days to silk** | | | | | | |
| 1 | 7.04 | 7 | C | N | 1.8 days | Leucine rich repeat |
| 5 | 8.05 | 8 | C | N | 1 day | Protein tyrosine kinase motif |

| CHR | MAF | FDR_adj_P | Log10 | Effect | R2 (%) |
|---|---|---|---|---|---|
| CS11-WW[a] (log10 [aflatoxin + 10]) | | | | | |
| 4 | 0.32 | 0.2 | 5.48 | -0.03 | 5.27 |
| CS12-WW[a] (log10 [aflatoxin + 10]) | | | | | |
| 4 | 0.32 | 0.23 | 5.43 | -0.07 | 5.69 |

Barerro et al. 2015 PLoS ONE

# Great….more significant QTV SNPs….
# But how do you validate and use them?

- Confirm with other studies
- Develop iso-lines?
    - Labor/ time,
    - Genetic background / context dependent,
    - Relevance?

- Develop a bi-parental population relevant for other reasons?
    - Which parents to cross?

- Screen germplasm collections for individuals with the SNPs of interest (Romay et al. 2013)
    - >4000 lines!
    - ~700,000SNPs!

Romay *et al. Genome Biology* 2013, **14**:R55
http://genomebiology.com/2013/14/6/R55

Genome **Biology**

**RESEARCH** **Open Access**

Comprehensive genotyping of the USA national maize inbred seed bank

Maria C Romay[1], Mark J Millard[2,3], Jeffrey C Glaubitz[1], Jason A Peiffer[4], Kelly L Swarts[5], Terry M Casstevens[1], Robert J Elshire[1], Charlotte B Acharya[1], Sharon E Mitchell[1], Sherry A Flint-Garcia[2,6], Michael D McMullen[2,6], James B Holland[2,7], Edward S Buckler[1,2,5*] and Candice A Gardner[2,3*]

# Validating these SNPs in three bi-parental linkage populations

| Population | $F_{2:4}$ N= | SNP1 | SNP2 | SNP3 |
|---|---|---|---|---|
| LH82 X (LAMA2002-12-1-B-B-B-B/LAMA2002-1-5-B-B-B-B)-3-2-B-1-B3-B) | 178 | X | X | |
| Tx740 x NC356 | 110 (55) | X | X | |
| Ki3 x NC356 | 239 (72) | X | X | X |

**SNP2 Ear height P < 0.03**

| Level | LS Means | N = |
|---|---|---|
| X:X | **22.5** | 156 |
| X:Y | **21.5** | 144 |
| Y:Y | **21.2** | 182 |
| Pop effect | P < 0.0001 | 482 (45 missing) |

**Pop. 3 SNP1 Plant height P < 0.01**

| Level | LS Means | N = |
|---|---|---|
| X:X | **62.5** | 56 |
| X:Y | **61.2** | 64 |
| Y:Y | **59.2** | 86 |
| Pop. 3 only | | 206 (33 missing) |

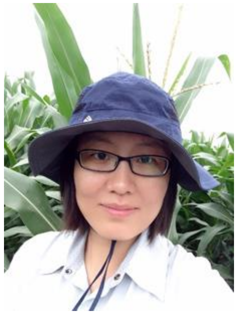
**Pop. 3 SNP3 Plant height P < 0.003**

| Level | LS Means | N = |
|---|---|---|
| X:X | **59.0** | 70 |
| X:Y | **63.2** | 60 |
| Y:Y | **61.4** | 87 |
| Pop3 only | | 217 (22 missing) |

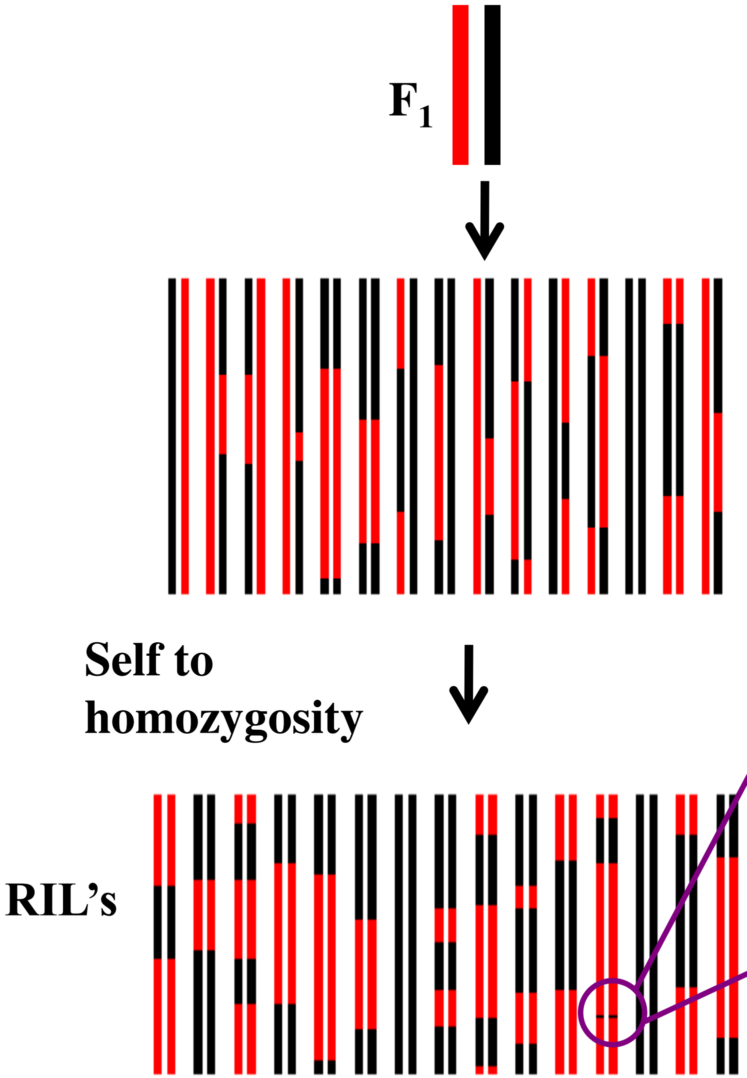
Good results considering
- Off season nursery
- Lines per se and not hybrids
- Not yield

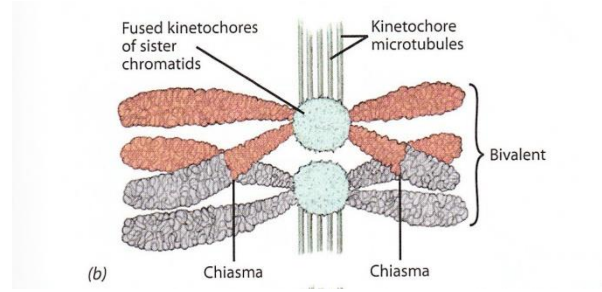
Genotyped with KASPAR assay's

Ms. Yuanyuan Chen PhD student



# In Plant Breeding and Genetic Linkage Mapping effective recombination is more often becoming the limiting factor



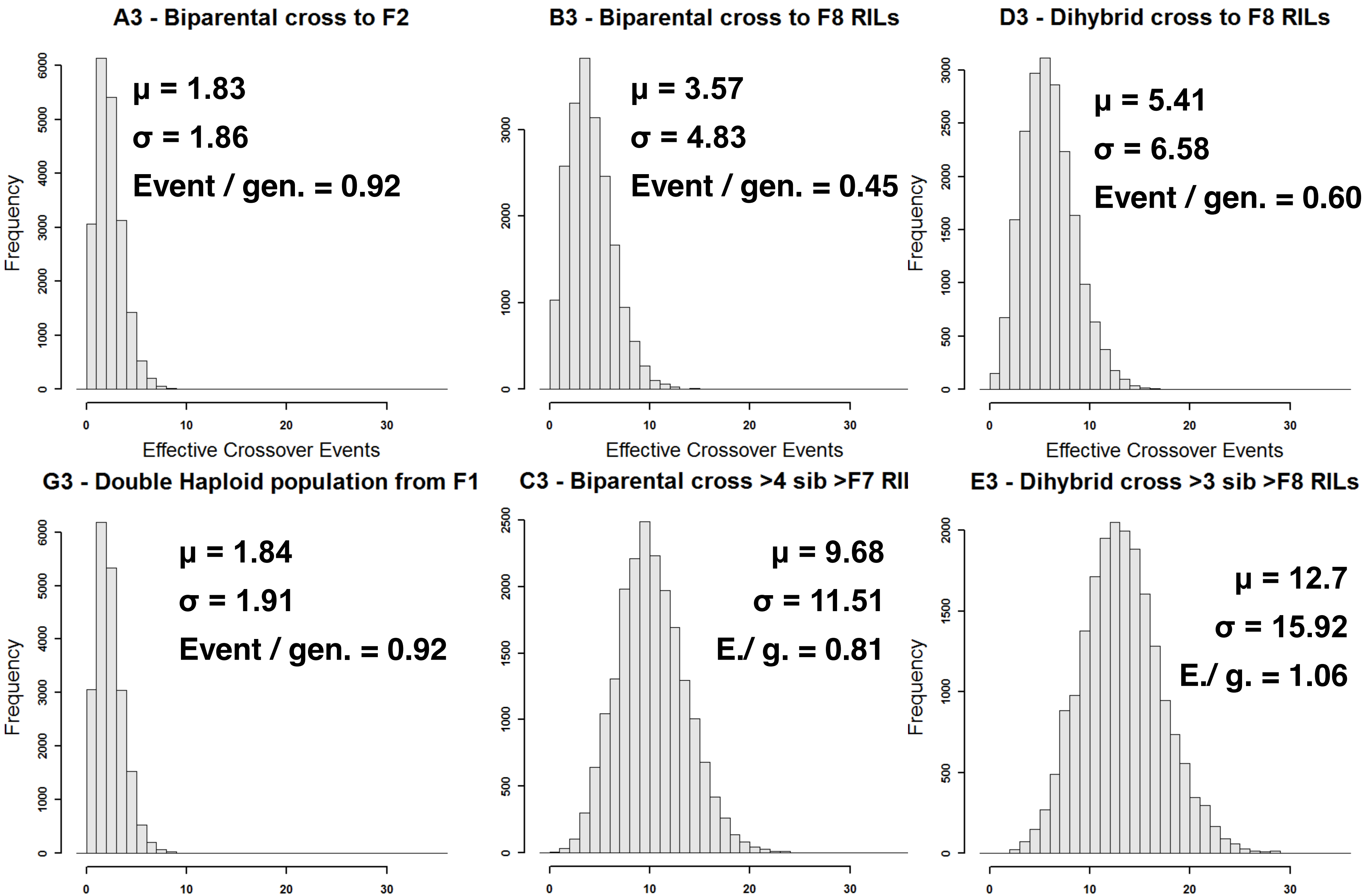

Raven, 1999.

**Effective recombination < Total recombination**

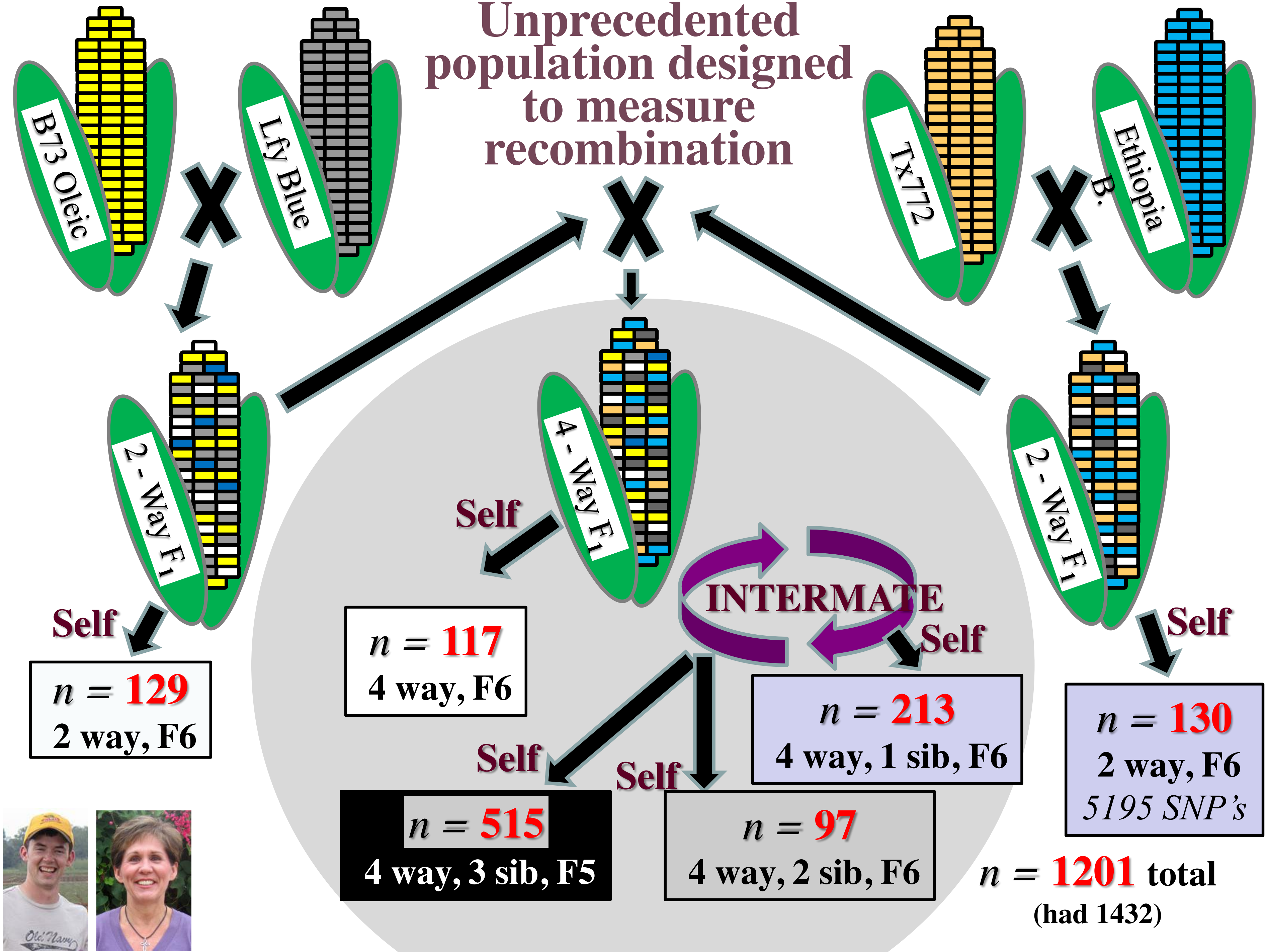
**Introgression of gene we would still expect linkage drag.**

**Not near "gene" resolution for map based cloning**

# Predicted distributions of effective recombination events under different population development scenarios



# Unprecedented population designed to measure recombination



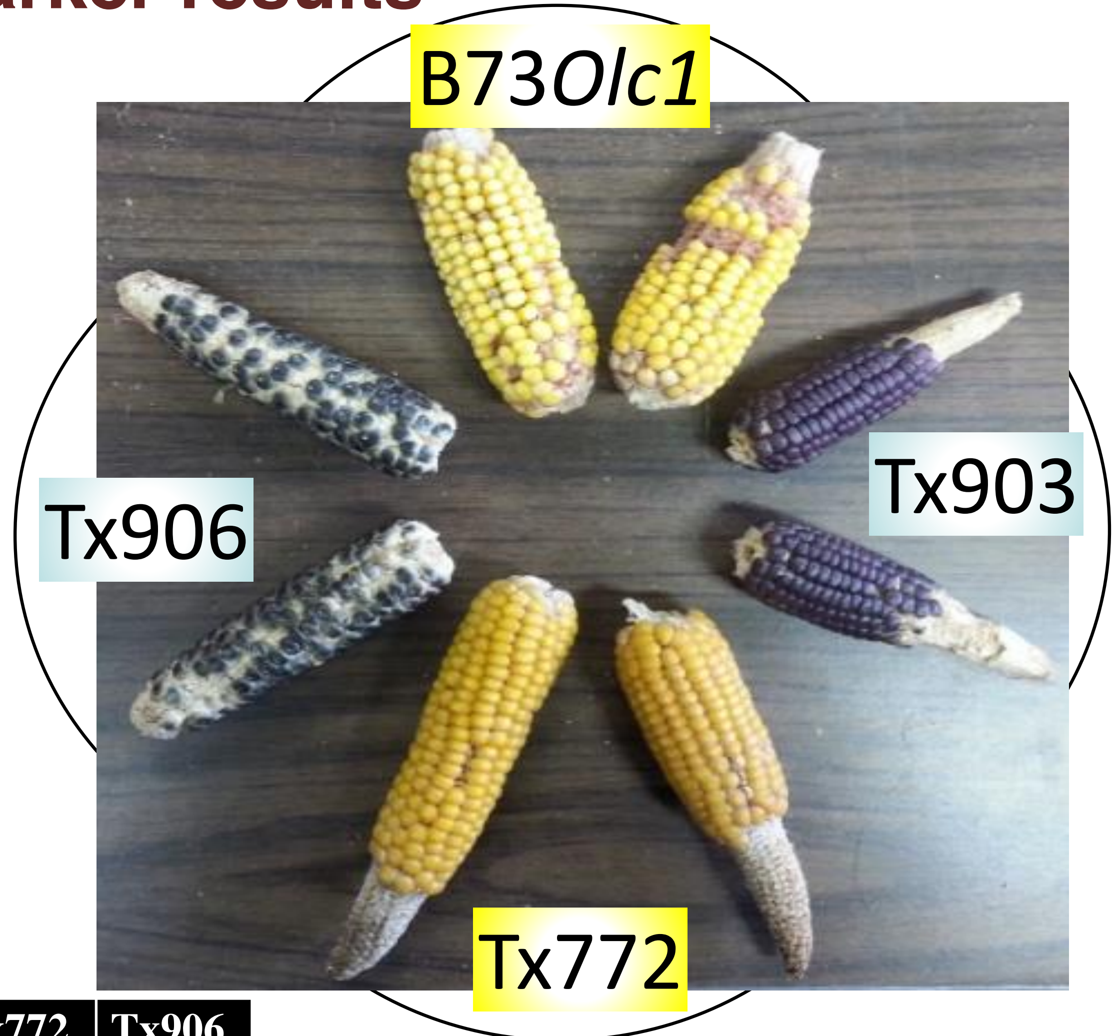
# Marker results

107,308 total markers

<u>B73 x Tx903</u>
44,581 markers

<u>Tx772 x Tx906</u>
73,717 markers

<u>Polymorphic in both</u>
11,149 markers

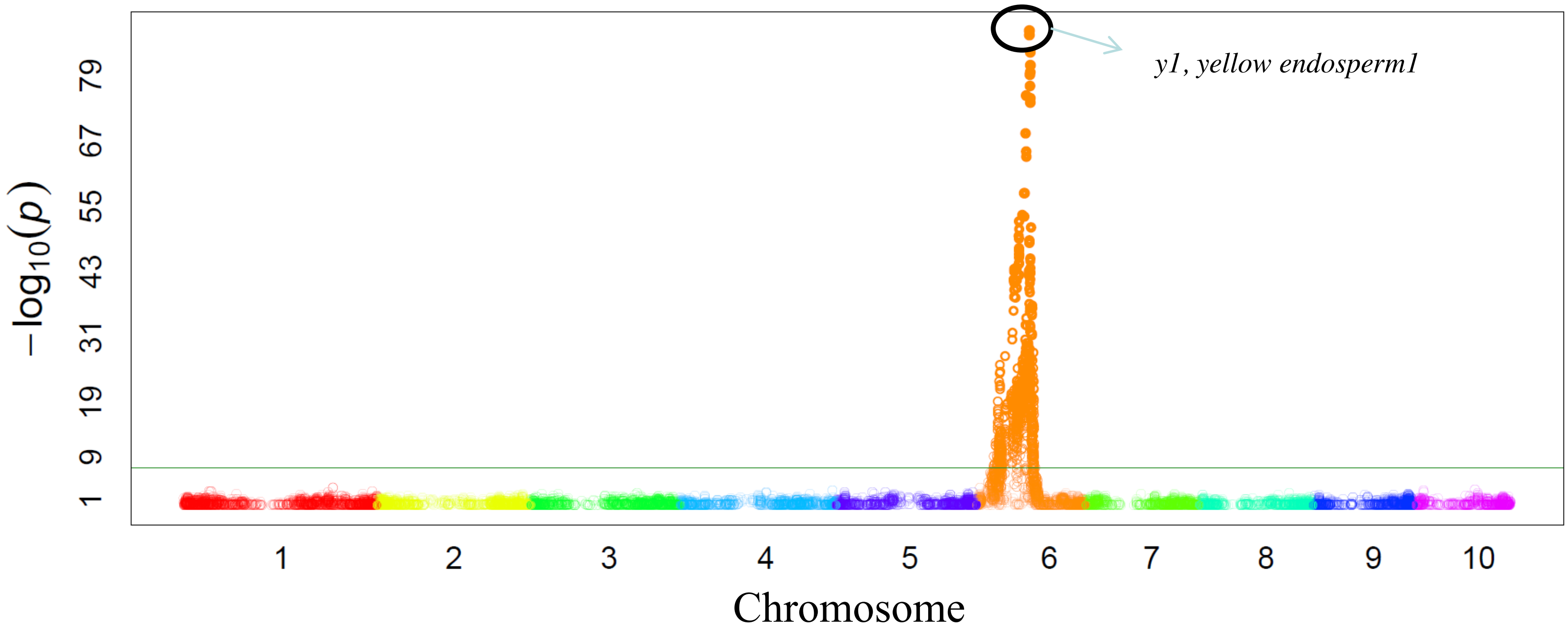



| | Ref. | B73*Olc1* | Tx903 | Tx772 | Tx906 |
|---|---|---|---|---|---|
| Reference | 100% | 98.5% | 64.7% | 40% | 44.9% |
| B73olc | | 100% | 64.7% | 40.1% | 44.9% |
| Tx903 | | | 100% | 40.9% | 42.9% |
| Tx772 | | | | 100% | 40.7% |
| Tx906 | | | | | 100% |

107,308 markers *1207 lines
= 129,000,000 marker data points
@ $0.0004 per data point

# Huge power to detect QTLs with high resolution

Manhattan plot of all 4-parent individuals (899 observations); ~130,000 SNPs




- Gene region of 3,731 bp: 82,017,148 – 82,020,879
- Yellow endosperm detection was very strong, and in correct place.
- Peak logarithm of odds (LOD) value of 87.20.

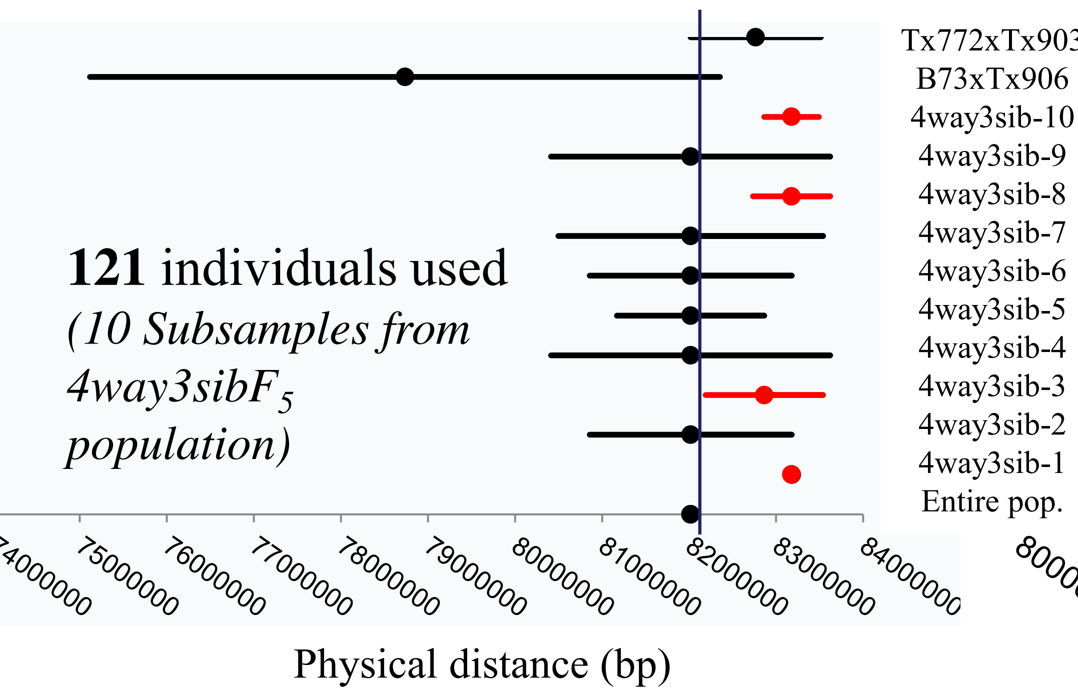
**Kernel color distribution**

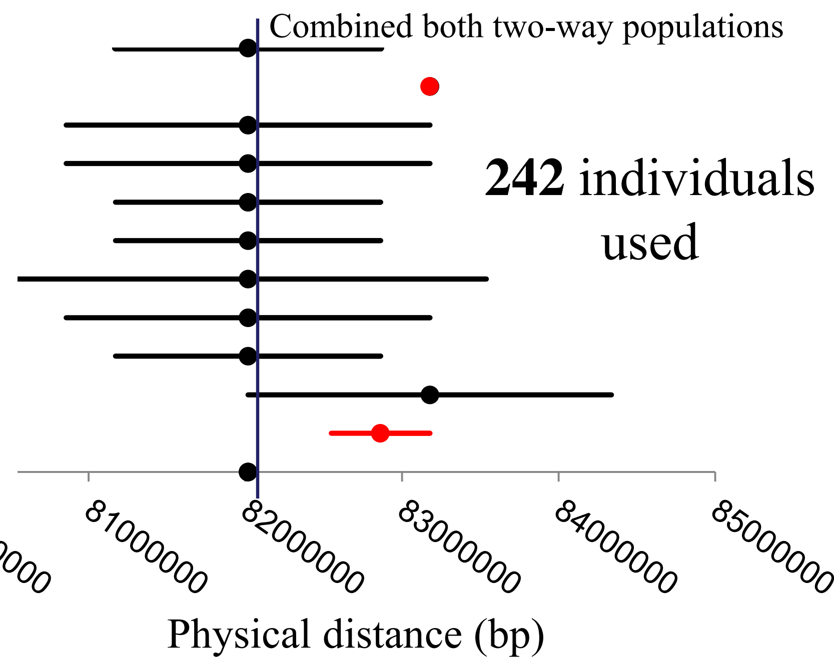
| % blue | % white | % yellow | % seg. |
|---|---|---|---|
| **23.1** | **31.3** | **33.0** | **12.6** |

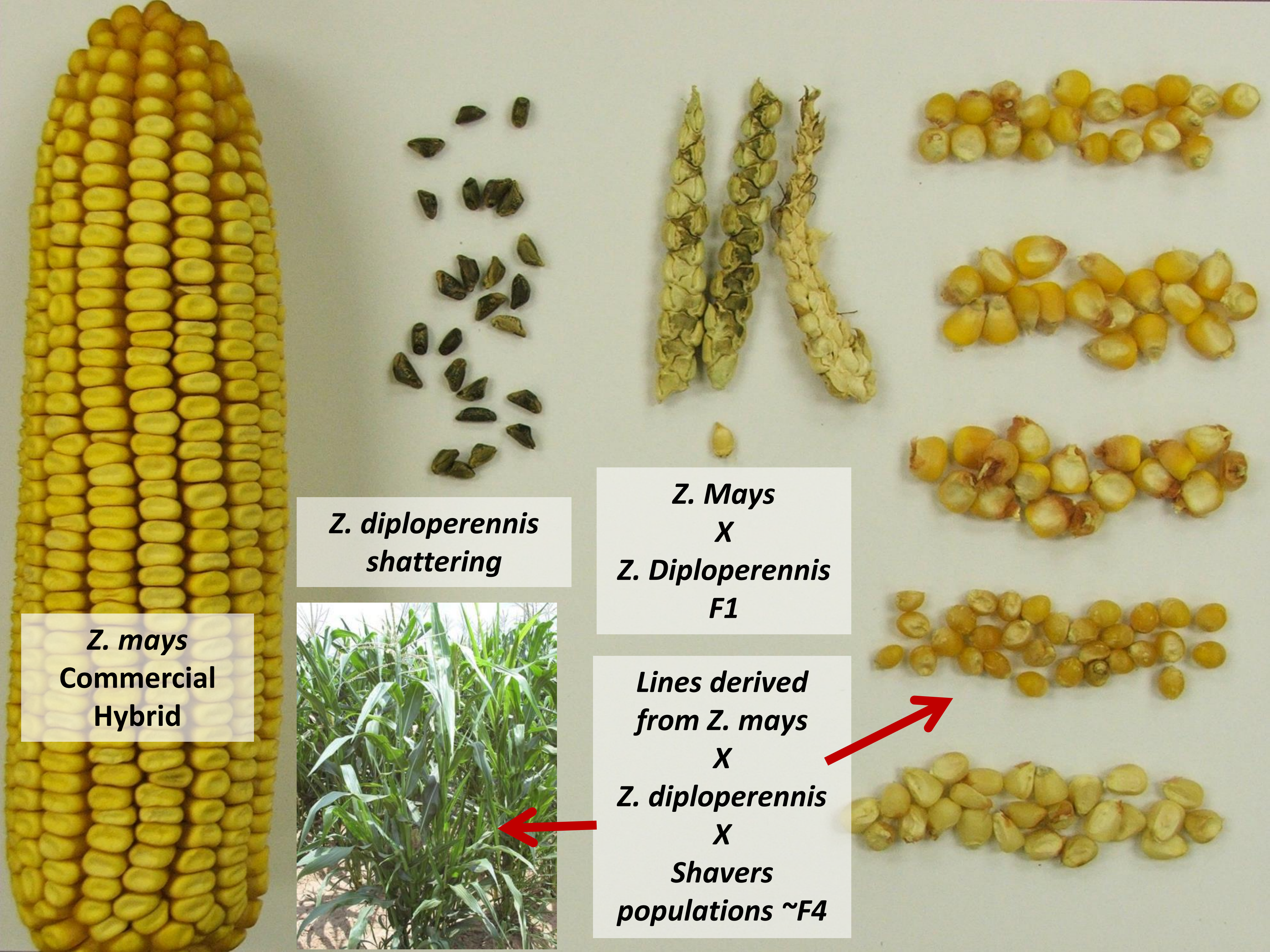

Blue kernels were dissected to determine endosperm color

# *yellow endosperm1* (*y1*) on Chromosome 6

| Group | n | Chr. | Peak position (bp) | LOD | Confidence interval distance (bp) |
|---|---|---|---|---|---|
| all subpops | 1141 | 6 | 82,017,348 | 107.08 | 54 |
| all4ways | 899 | 6 | 82,017,348 | 87.2 | 54 |
| 4way3sib | 488 | 6 | 82,017,402 | 48.95 | 54 |
| 4way2sib | 89 | 6 | 83,621,389 | 11.89 | 2,712,138 |
| 4way1sib | 203 | 6 | 82,017,348 | 26.85 | 7,303,989 |
| 4way0sib | 109 | 6 | 83,621,056 | 14.74 | 757,405 |
| B73xTx903 | 121 | 6 | 78,735,091 | 16.90 | 3,618,539 |
| Tx772xTx906 | 121 | 6 | 82,764,656 | 14.81 | 747,254 |
| all2ways | 242 | 6 | 82,017,348 | 29.41 | 845,669 |



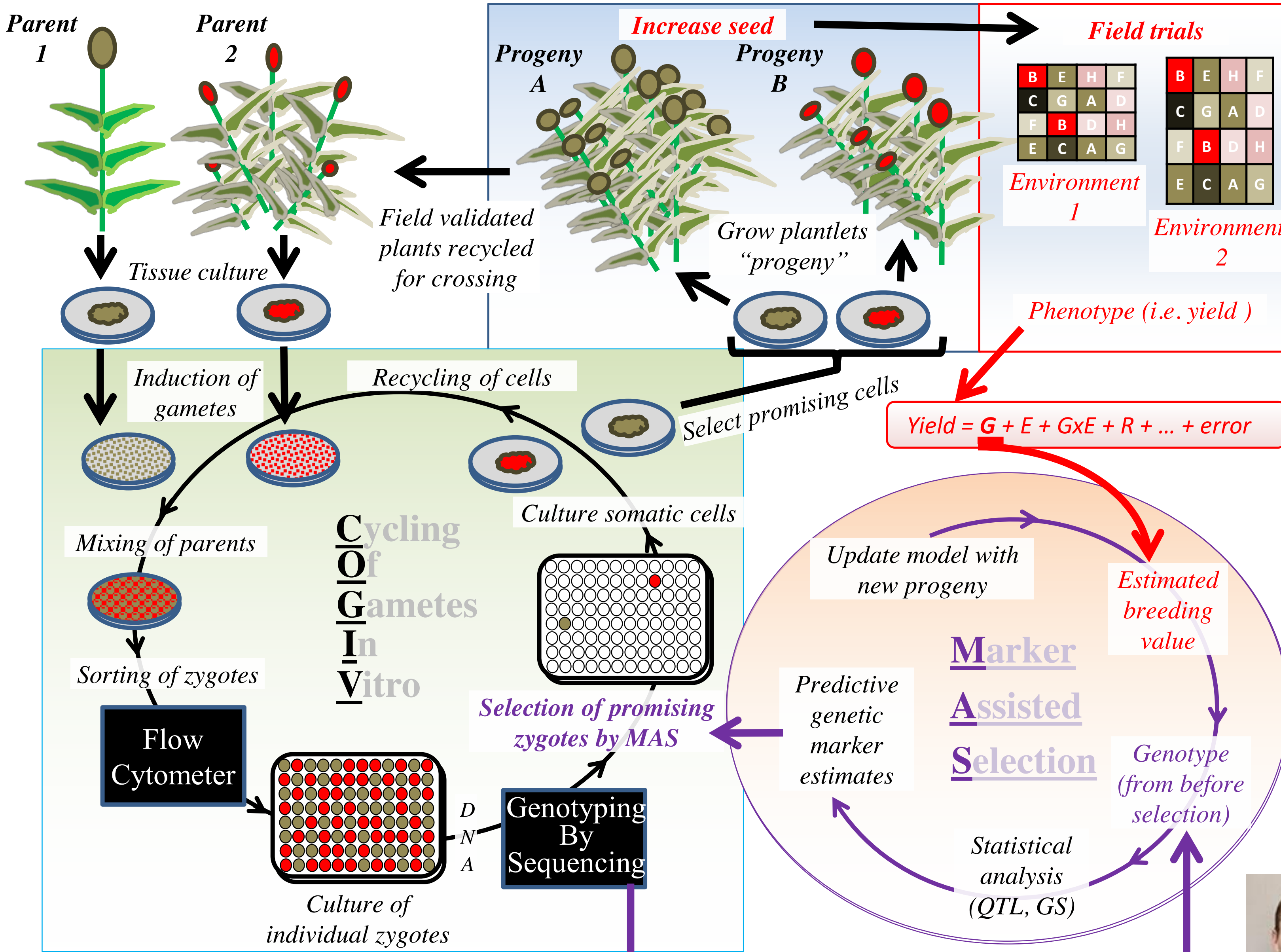

Z. mays
Commercial
Hybrid
Z. diploperennis
shattering
Z. Mays
X
Z. Diploperennis
F1
Lines derived
from Z. mays
X
Z. diploperennis
X
Shavers
populations ~F4

**Weslaco, December 2013**

***Note differences in roots***




# Cycling of gamete in vitro (COGIV)




Murray et al. 2013, Nature Biotechnology

De La Fuente, Frei & Lübberstedt 2013, Trends in Plant Science

- **Undergraduates & high school students**


- **Graduate students, technical support, and visiting professors**

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