CHALLENGES FOR DISEASE AND INSECT PEST RESISTANCE BREEDING IN WINTER WHEAT

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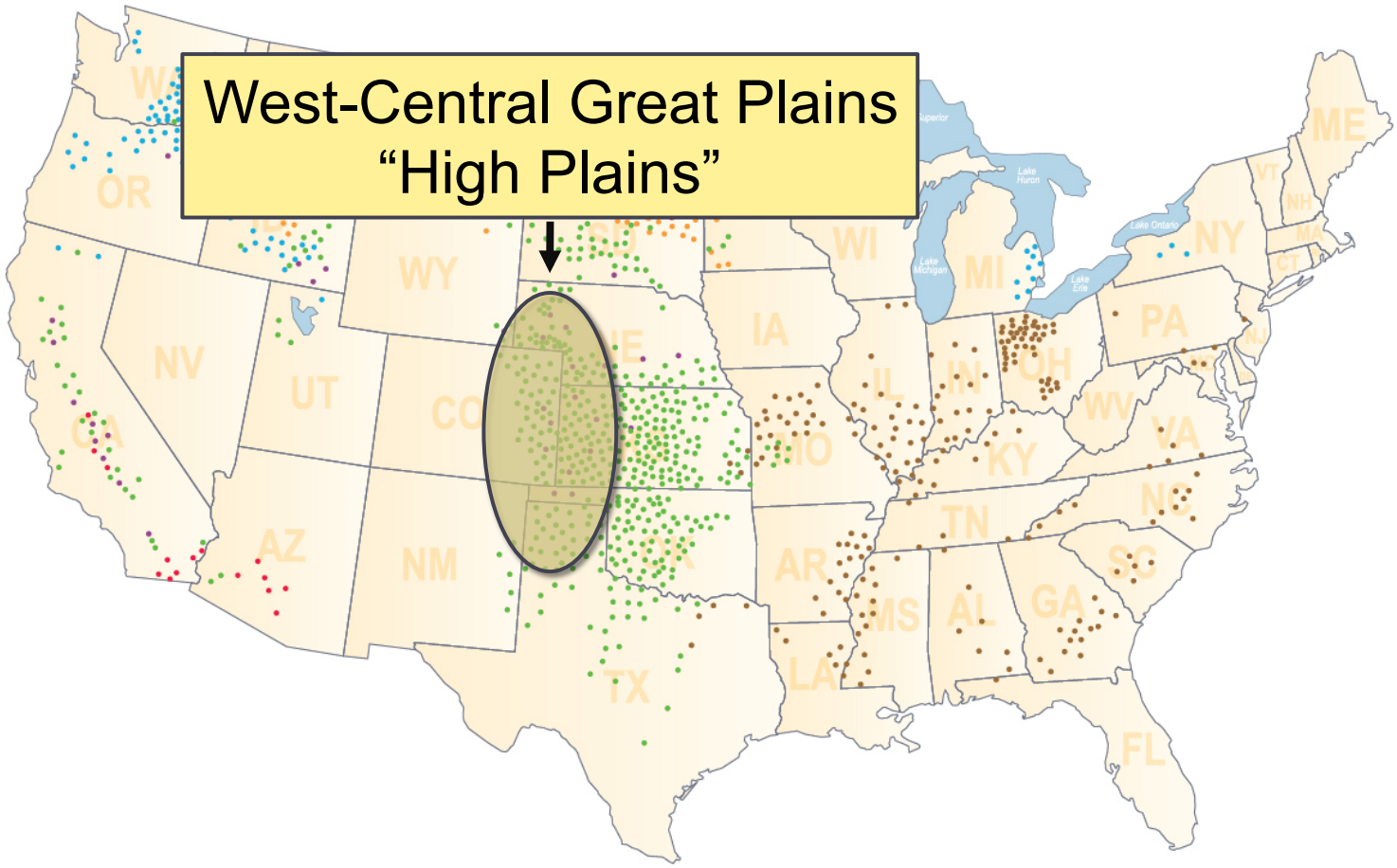
Outline

- US High Plains winter wheat production
- Stripe (yellow) rust
  - Evaluation of resistance in breeding
  - Genotyping by sequencing (GBS)
  - Use of GBS for association studies
  - Use of GBS for genomic selection
- Wheat stem sawfly
  - Breeding approaches for solid-stem trait
  - Field evaluations with hollow stem breeding lines
  - Multi-trait genomic selection
- Breeder perspectives on “durability”

US Wheat Production Regions



Courtesy of US Wheat Associates

HARD RED WINTER · HARD RED SPRING · SOFT RED WINTER · SOFT WHITE · HARD WHITE · DURUM

High Plains Winter Wheat

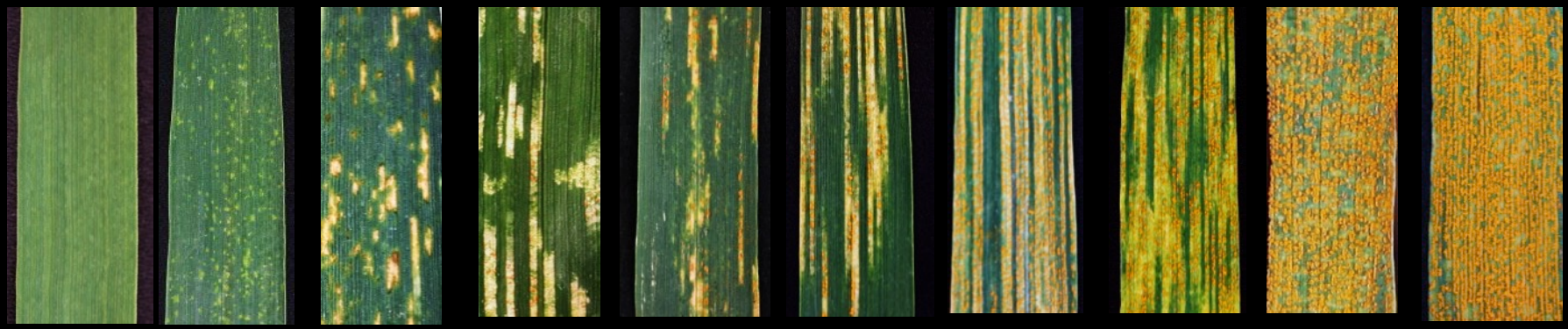
- High elevation, semi-arid
  - Fort Collins ~ 1600 masl
  - Mean precip ~ 375 mm/year
  - Strong N-S ET gradient
- Crop cycle
  - September planting
  - July harvest
- Rainfed production – 90% area
  - Avg yield – 1.5 to 3.2 MT
  - Drought stress common
- *Relatively* few critical diseases and insect pests
  - Russian wheat aphid
  - Aphids/mite-vectored viruses
  - Stripe rust, wheat stem sawfly

Stripe Rust (aka Yellow Rust)

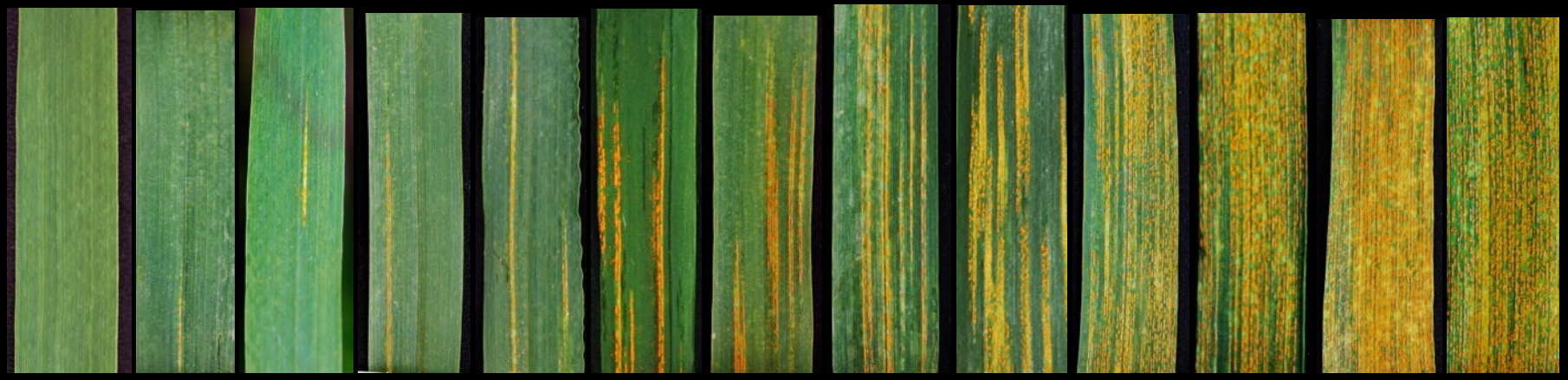
Puccinia striiformis

- Breeding objective only since 2001
- Cool night-time High Plains temperatures favor stripe rust more than other rusts
- Important race changes in 2010 and 2012 following original race change in 2000-2001
- Keys for problems in Colorado are moisture in Texas and Oklahoma, May precipitation

Infection Type (IT)

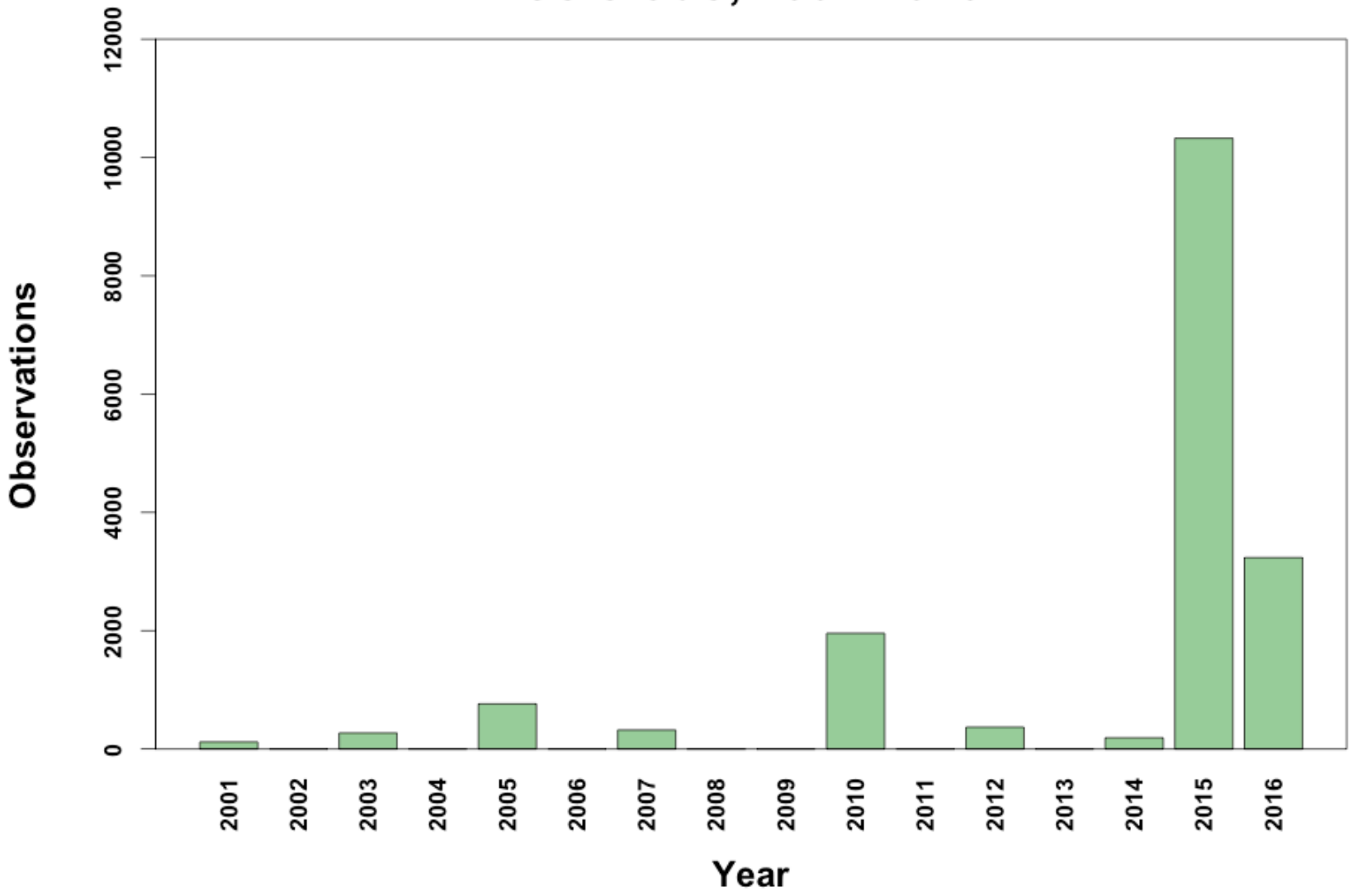


Severity (%)



Slide courtesy of Xianming Chen, USDA-ARS


Stripe Rust Susceptibility
score 7-9
Stripe Rust Resistance
score 1-3

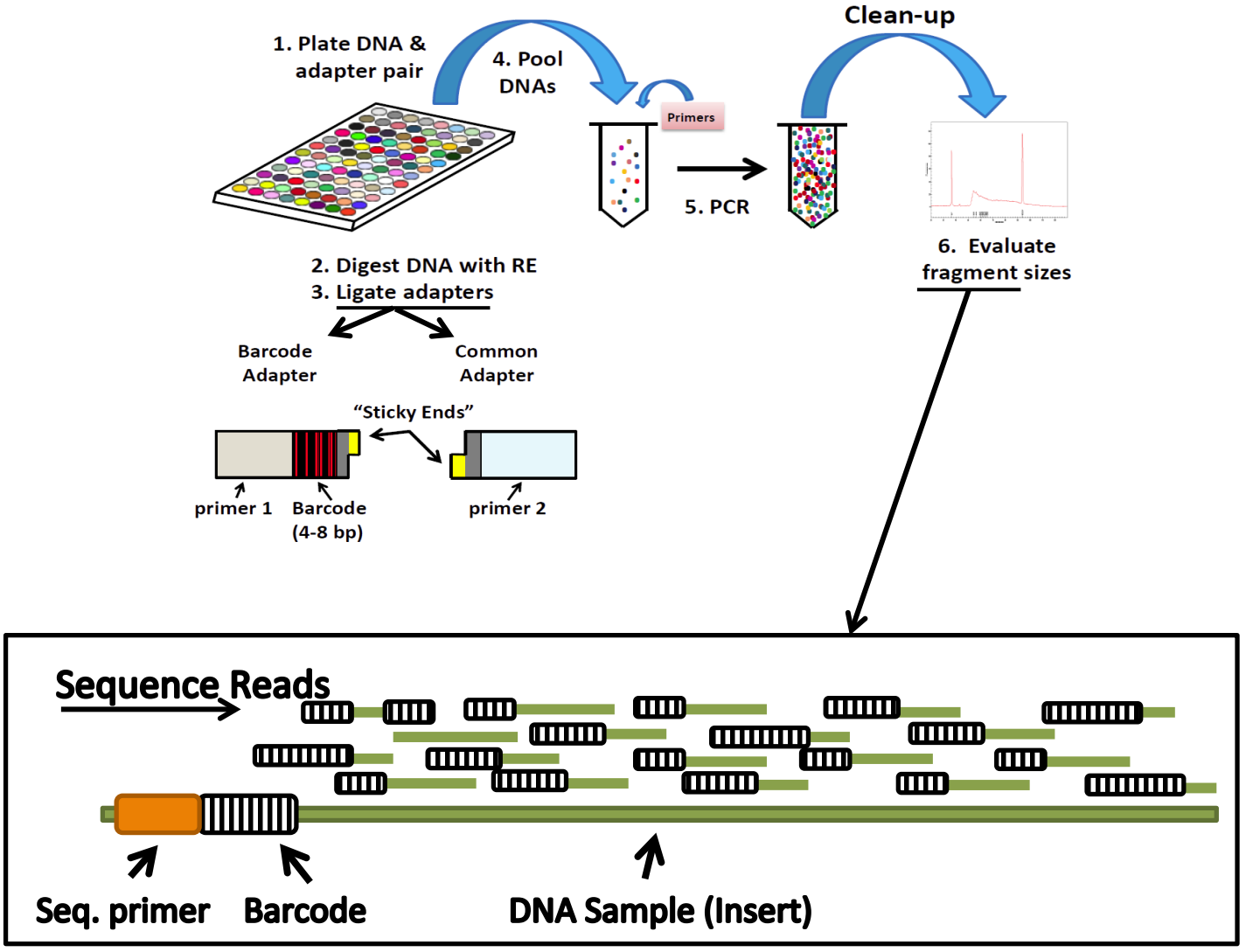

Stripe Rust Notes Collected in Yield Trials
Colorado, 2001-2016
Observations
0
2000
4000
6000
8000
10000
12000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Year

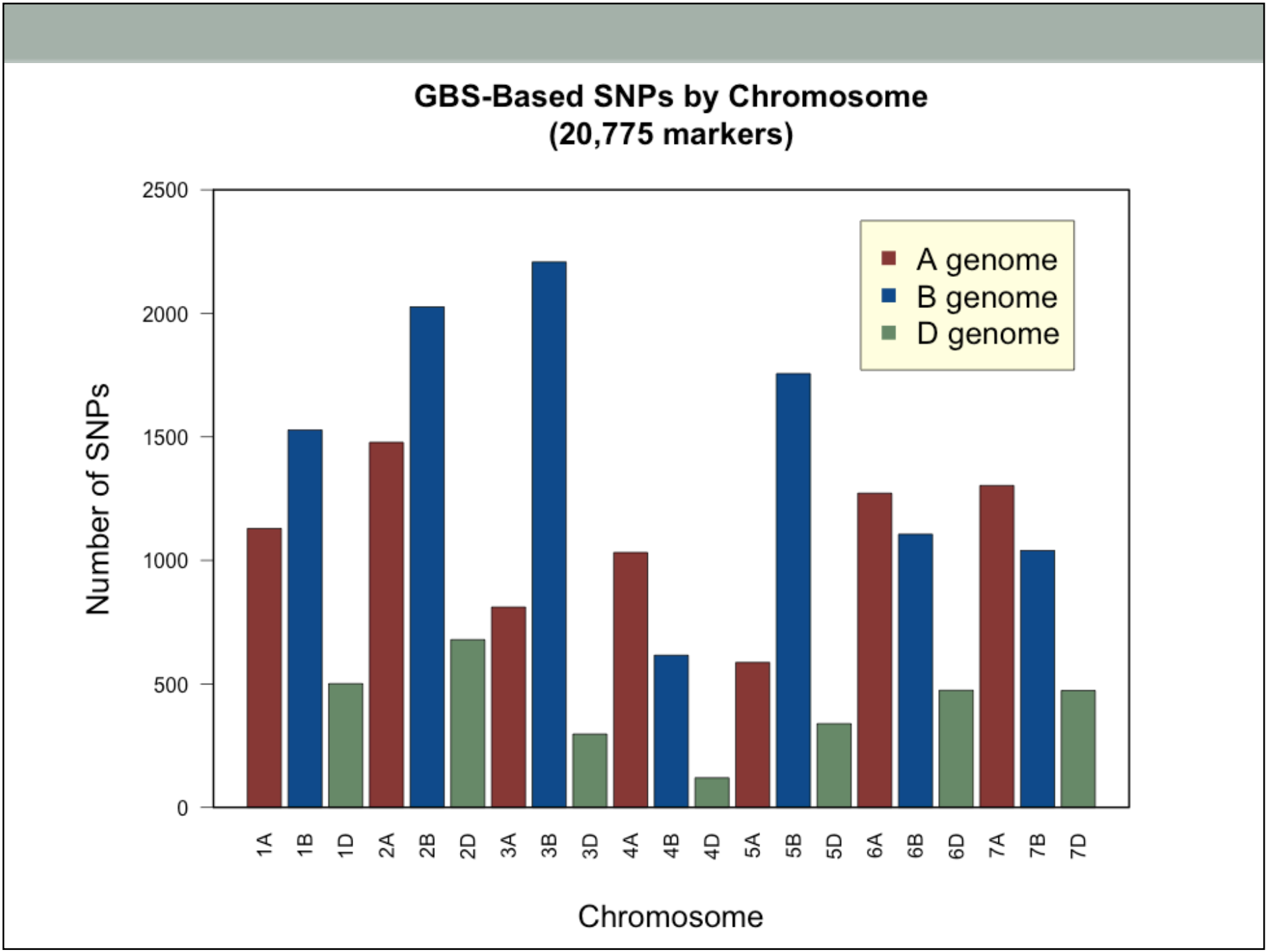
Breeding Approaches for Stripe Rust

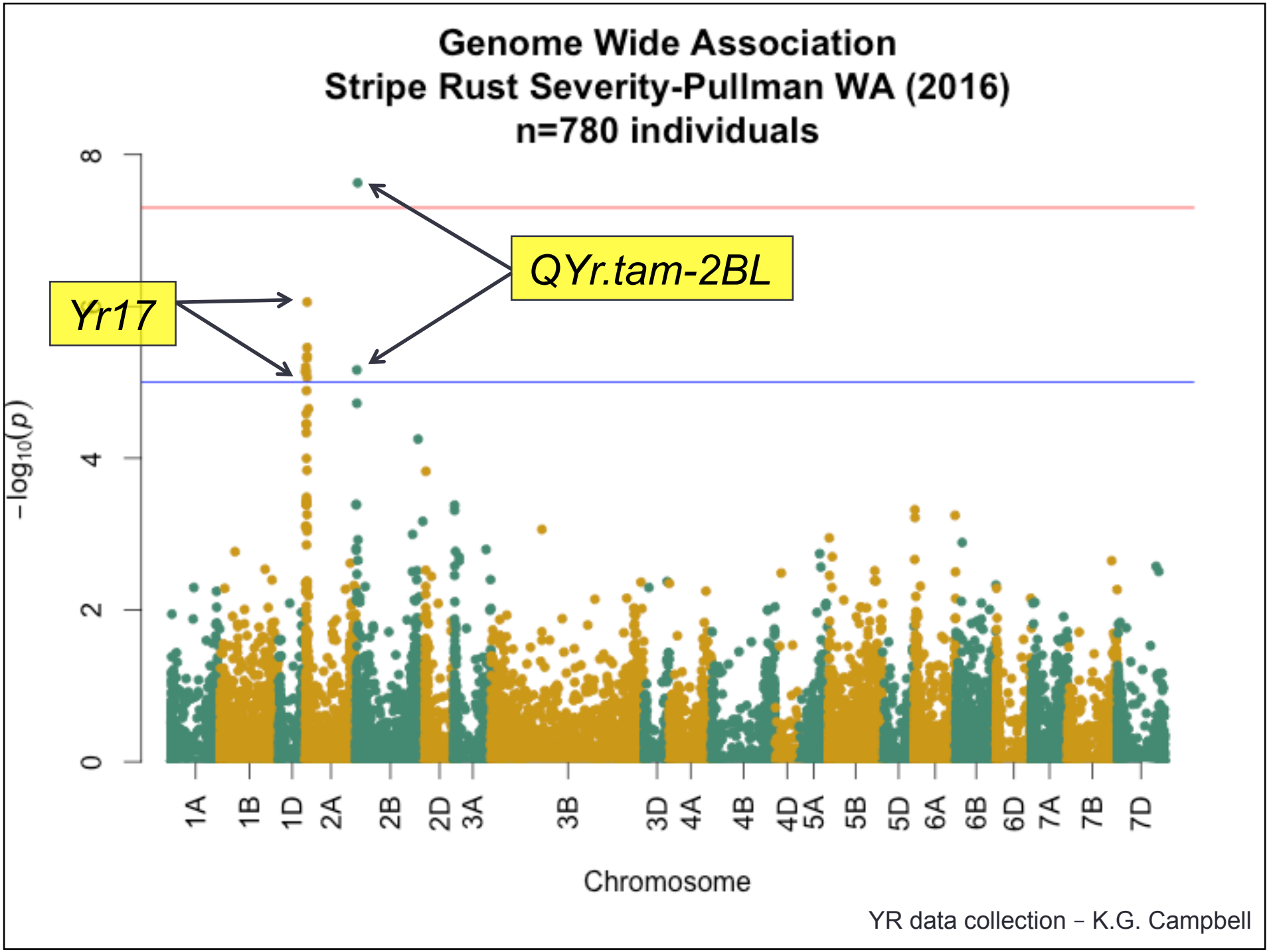
- Crossing – monitor regional/international nurseries
- Field selection for resistance
  - Has worked well – when we get the opportunity!
  - Cooperative nurseries: Castroville TX (Amir Ibrahim)
    Rossville KS (Bob Bowden)
    Pullman WA (Kim Campbell)
- Marker-assisted selection for known genes
  - Marker-assisted backcrossing (parent building)
  - Preliminary line and doubled haploid screening
- Newer tools – genomewide association (GWAS)
  genomic selection (GS)

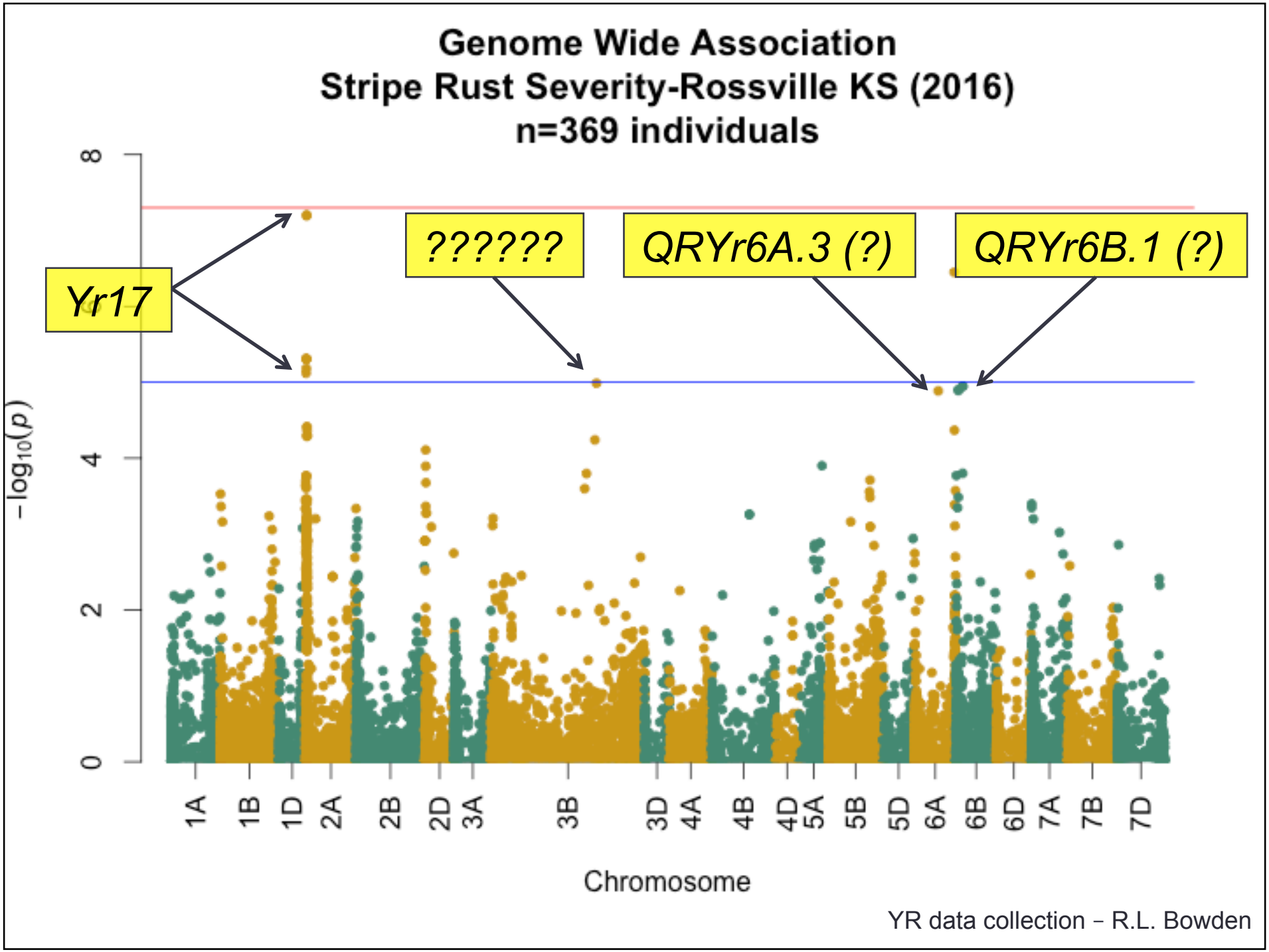
Genotyping by Sequencing

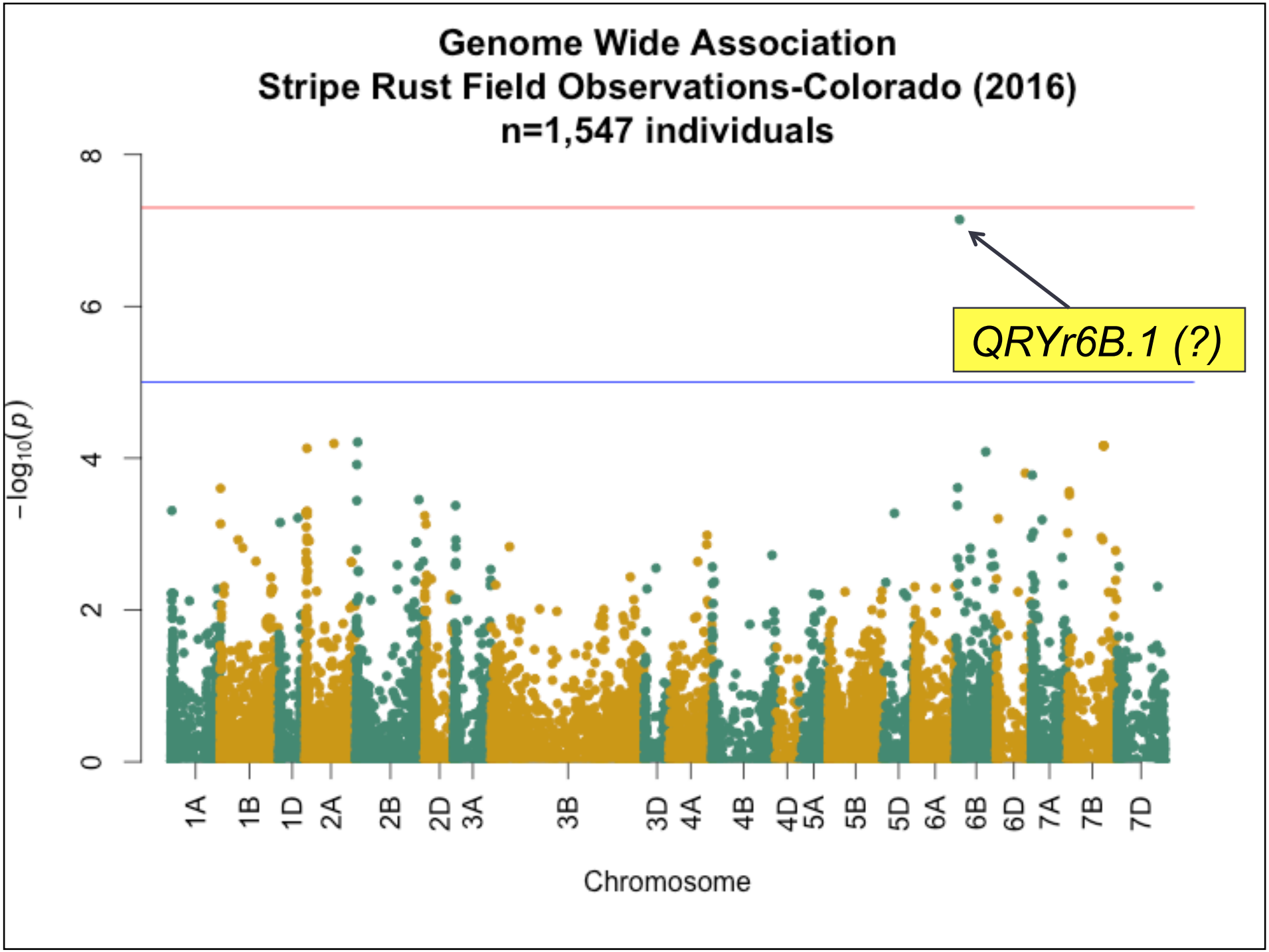
Elshire et al. (2011) PLoS One 6(5): e19379




GBS-Based SNPs by Chromosome
(20,775 markers)
Number of SNPs
2500
2000
1500
1000
500
0
A genome
B genome
D genome
1A
1B
1D
2A
2B
2D
3A
3B
3D
4A
4B
4D
5A
5B
5D
6A
6B
6D
7A
7B
7D
Chromosome


Genome Wide Association
Stripe Rust Severity-Pullman WA (2016)
n=780 individuals
Yr17
QYr.tam-2BL
−log10(p)
0
2
4
8
1A
1B
1D
2A
2B
2D
3A
3B
3D
4A
4B
4D
5A
5B
5D
6A
6B
6D
7A
7B
7D
Chromosome
YR data collection – K.G. Campbell


Genome Wide Association
Stripe Rust Severity-Rossville KS (2016)
n=369 individuals
Yr17
??????
QRYr6A.3 (?)
QRYr6B.1 (?)
−log10(p)
0
2
4
8
1A
1B
1D
2A
2B
2D
3A
3B
3D
4A
4B
4D
5A
5B
5D
6A
6B
6D
7A
7B
7D
Chromosome
YR data collection – R.L. Bowden


Genome Wide Association
Stripe Rust Field Observations-Colorado (2016)
n=1,547 individuals
QRYr6B.1 (?)
−log10(p)
0
2
4
6
8
1A
1B
1D
2A
2B
2D
3A
3B
3D
4A
4B
4D
5A
5B
5D
6A
6B
6D
7A
7B
7D
Chromosome

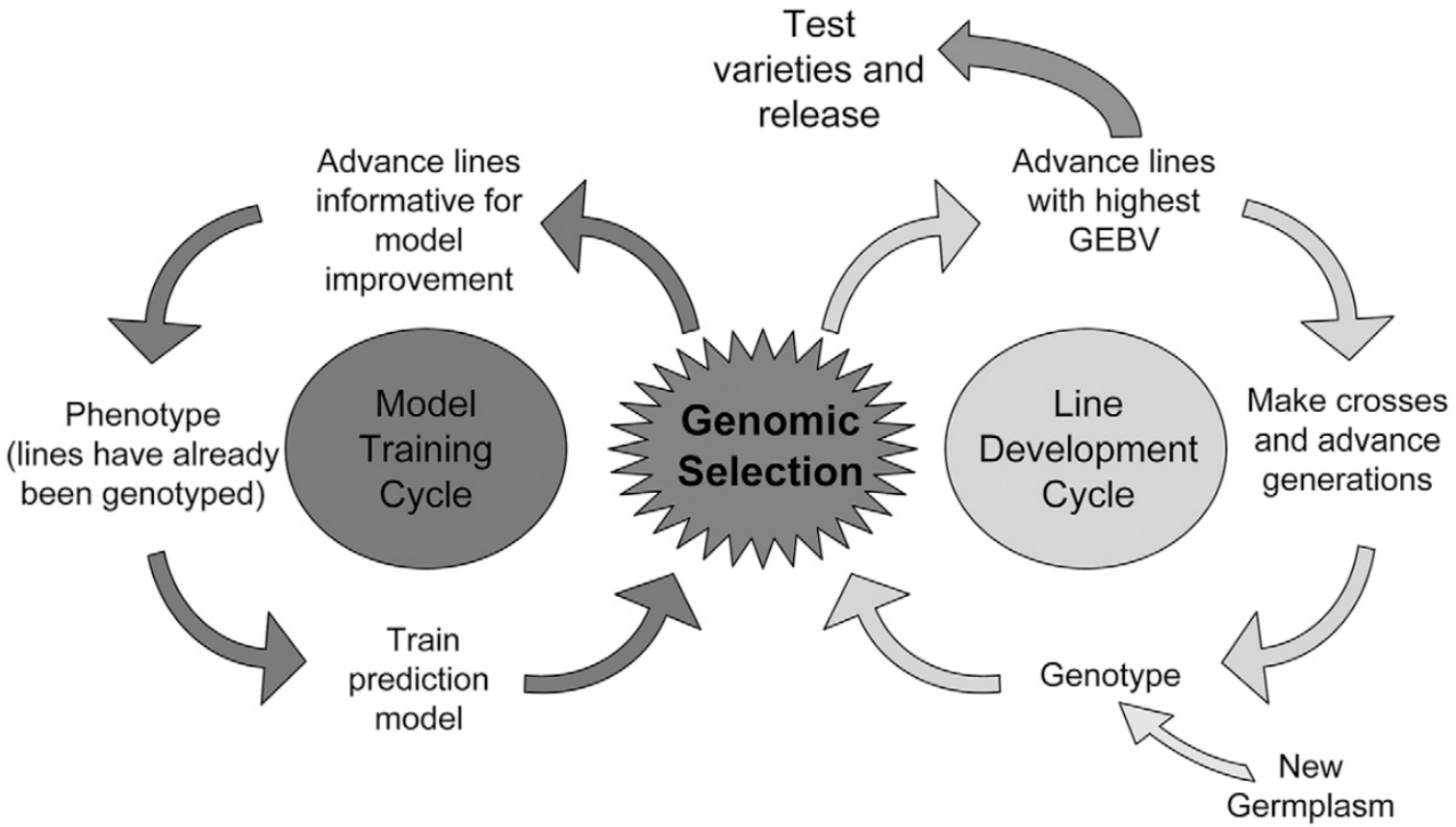
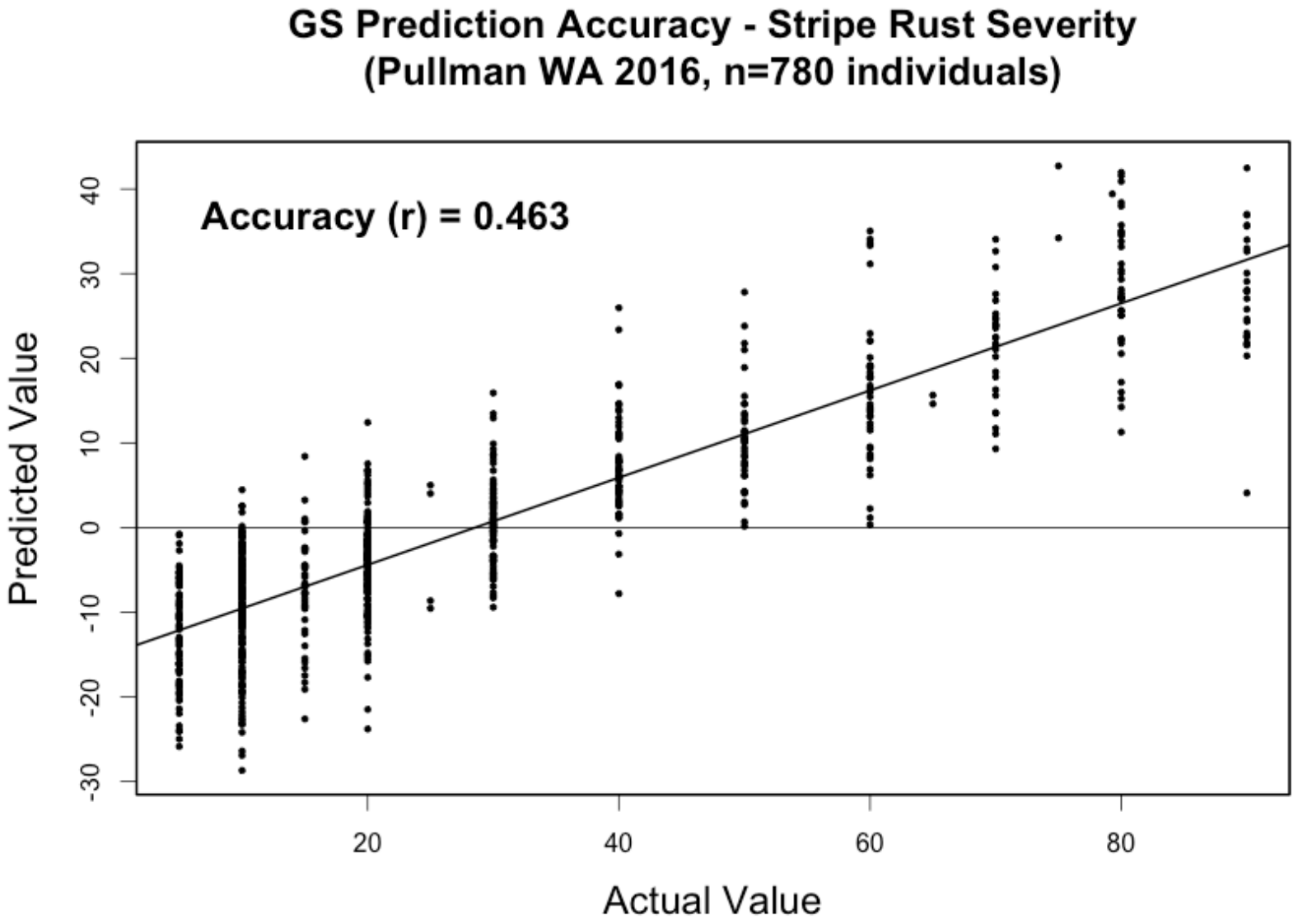
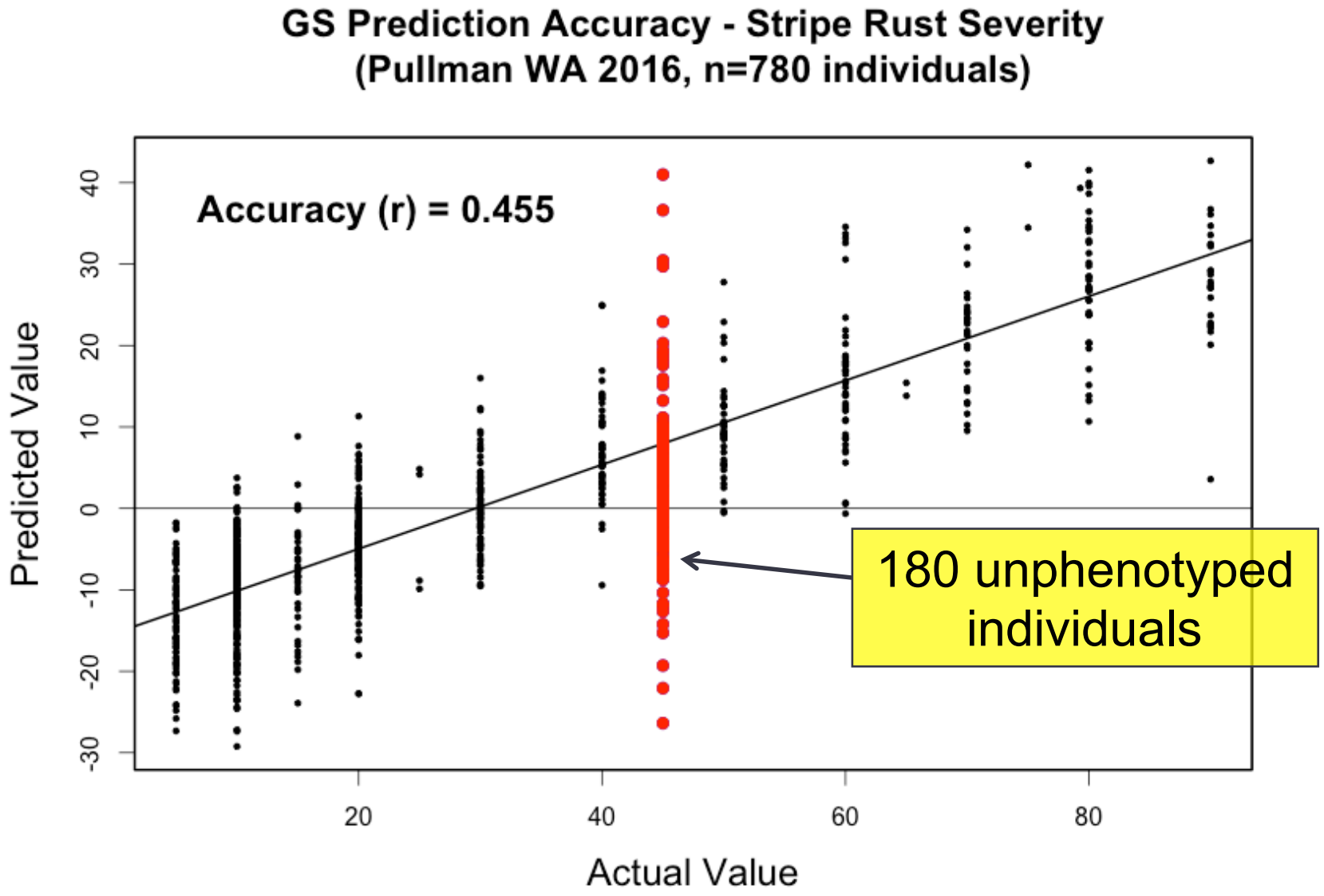


Figure 2. Flow diagram of a genomic selection breeding program. Breeding cycle time is shortened by removing phenotypic evaluation of lines before selection as parents for the next cycle. Model training and line development cycle length will be crop and breeding program specific. (GEBV = genomic estimated breeding value.)

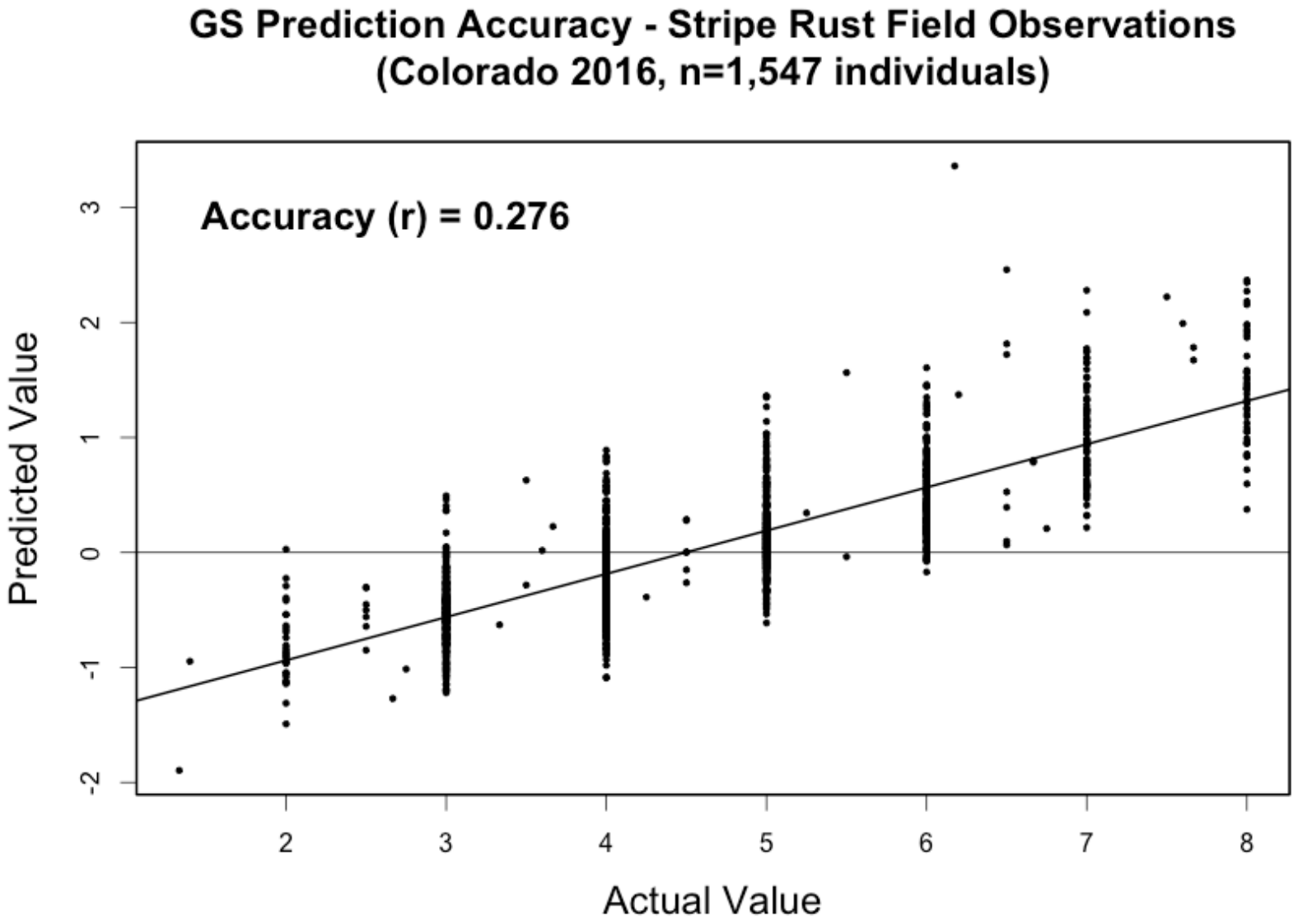
Elliot L. Heffner, Mark E. Sorrells, and Jean-Luc Jannink
Genomic Selection for Crop Improvement
Crop Science 49:1-12 (2009)

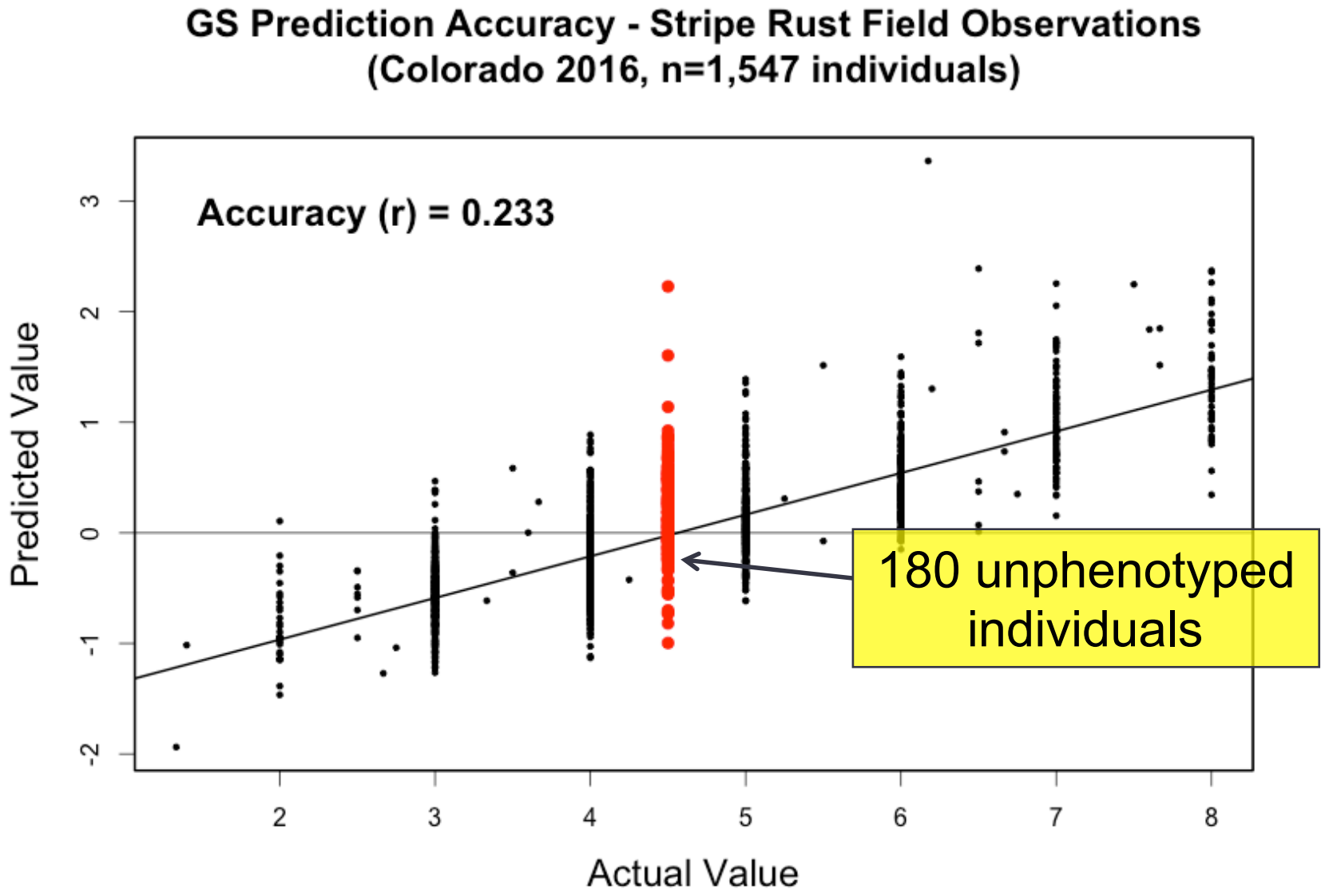


YR data collection – K.G. Campbell



YR data collection – K.G. Campbell


GS Prediction Accuracy - Stripe Rust Field Observations
(Colorado 2016, n=1,547 individuals)
Accuracy (r) = 0.276
Predicted Value
Actual Value
-2
-1
0
1
2
3
2
3
4
5
6
7
8


GS Prediction Accuracy - Stripe Rust Field Observations
(Colorado 2016, n=1,547 individuals)
Accuracy (r) = 0.233
Predicted Value
Actual Value
180 unphenotyped individuals

Wheat Stem Sawfly

Photo - R.K.D. Peterson, MT State

Cephus cinctus

- Serious and expanding US wheat production problem
  - Early 1900s – spring wheat region
  - 1980s – Montana winter wheat
  - 2000s – Wyoming winter wheat
  - 2011 – Colorado winter wheat
- Nature of the damage
  - Inhibits translocation and cuts stem
  - Affects crop residue persistence
- Management
  - Insecticides – not effective
  - Cropping – partially effective
  - Host plant resistance – solid stem trait, host-plant “attractiveness”/etc

Selected-Bulk Breeding for Stem Solidness

Image - Phil Bruckner, MT State

- Solid stem assessment
  - Cut individual stems at soil surface
  - Assess solidness (1-5 scale), sum over 5 internodes (5-25 scale)
- Solid stem parents – MT
  - Judee
  - Bearpaw, Warhorse, MTS1024
- Adapted parents – CSU

2011-12	Single backcross (SS source/Byrd//Byrd)
2013	Increase and bulk harvest BC_1F_1 plants
2014	Space-plant in bulk single plant selection SS score >15 bulked
2015	Space-plant in bulk single plant selection SS score >20 advanced
2016 800 rows	Line Selection (headrows)
2017 56 lines	Preliminary Line Testing

Doubled Haploid (DH) Breeding

Make cross, grow F1
Pollinate with maize
Treat with hormones

↓

Collect immature seeds
excise embryos
transfer to tissue culture

↓

Regenerate haploid
plants in tissue culture

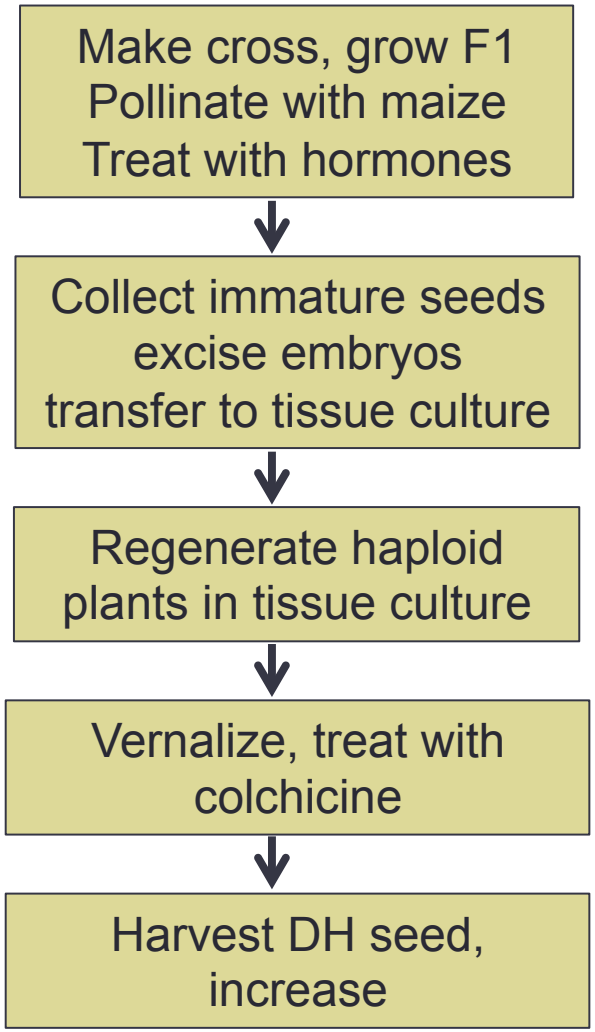
↓

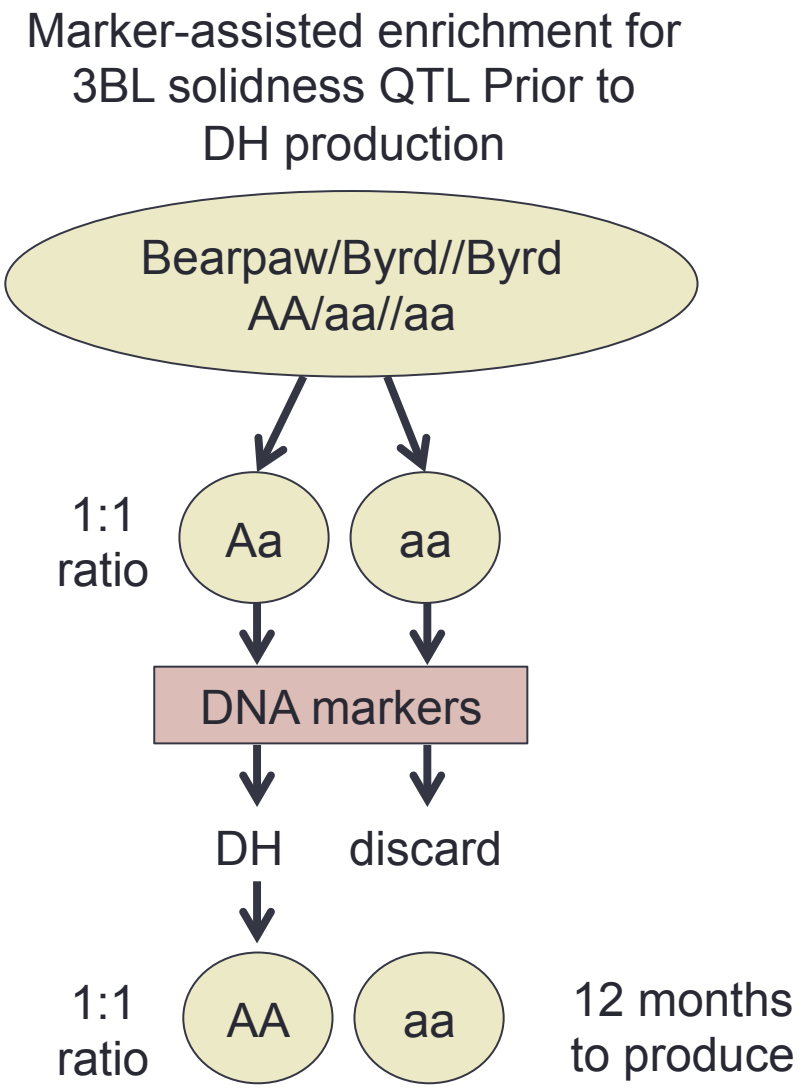
Vernalize, treat with
colchicine

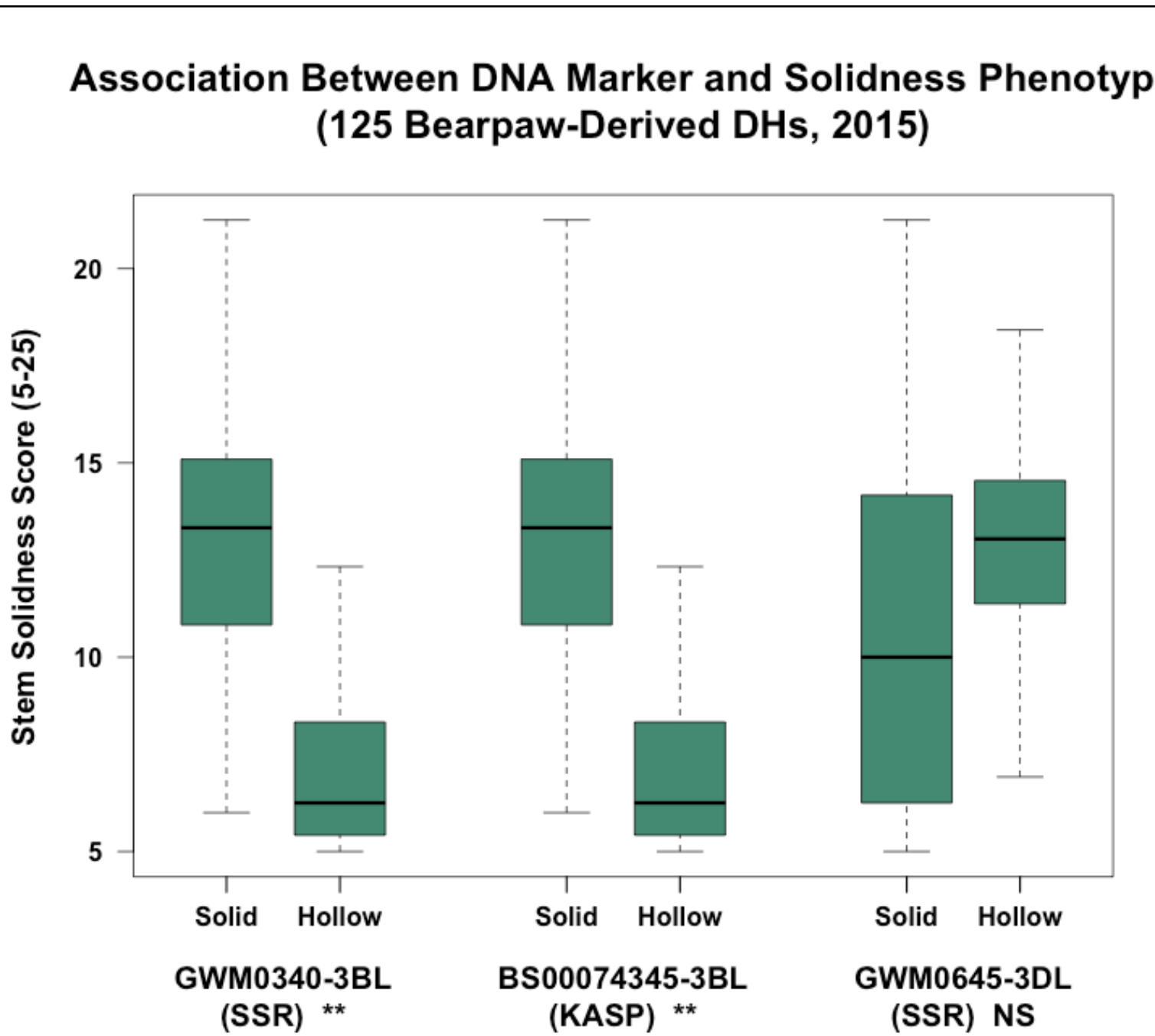
↓

Harvest DH seed,
increase

Doubled Haploid (DH) Breeding

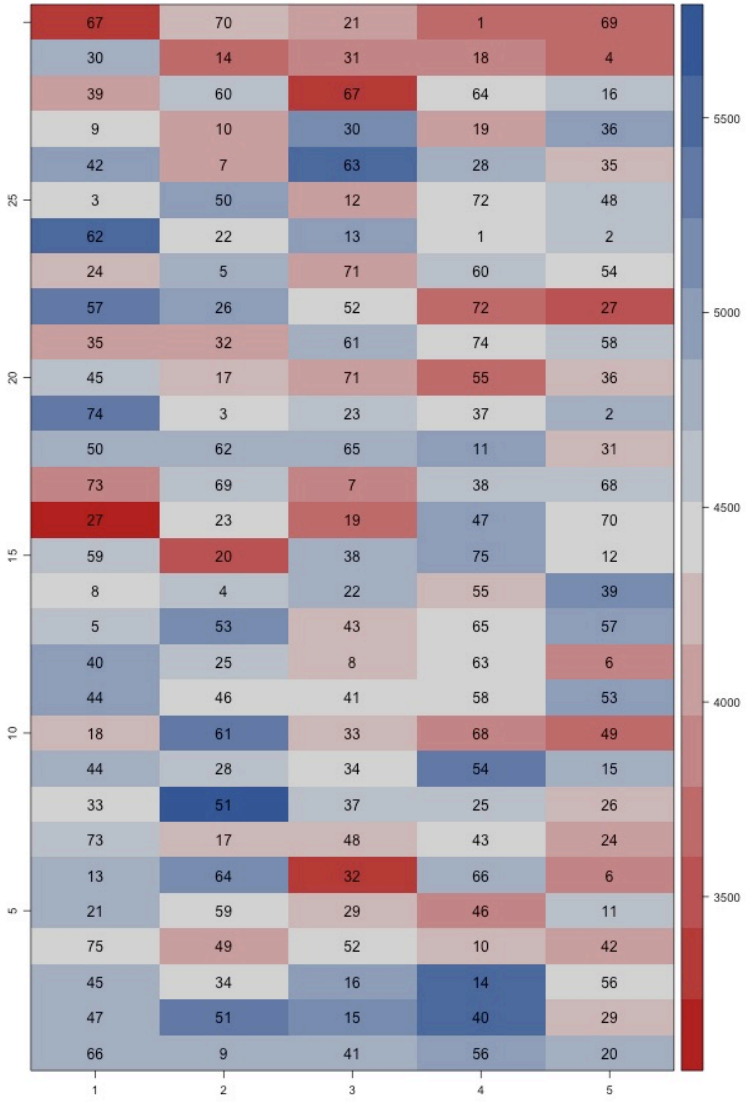





Association Between DNA Marker and Solidness Phenotype
(125 Bearpaw-Derived DHs, 2015)
Stem Solidness Score (5-25)
20
15
10
5
Solid
Hollow
Solid
Hollow
Solid
Hollow
GWM0340-3BL
(SSR) **
BS00074345-3BL
(KASP) **
GWM0645-3DL
(SSR) NS

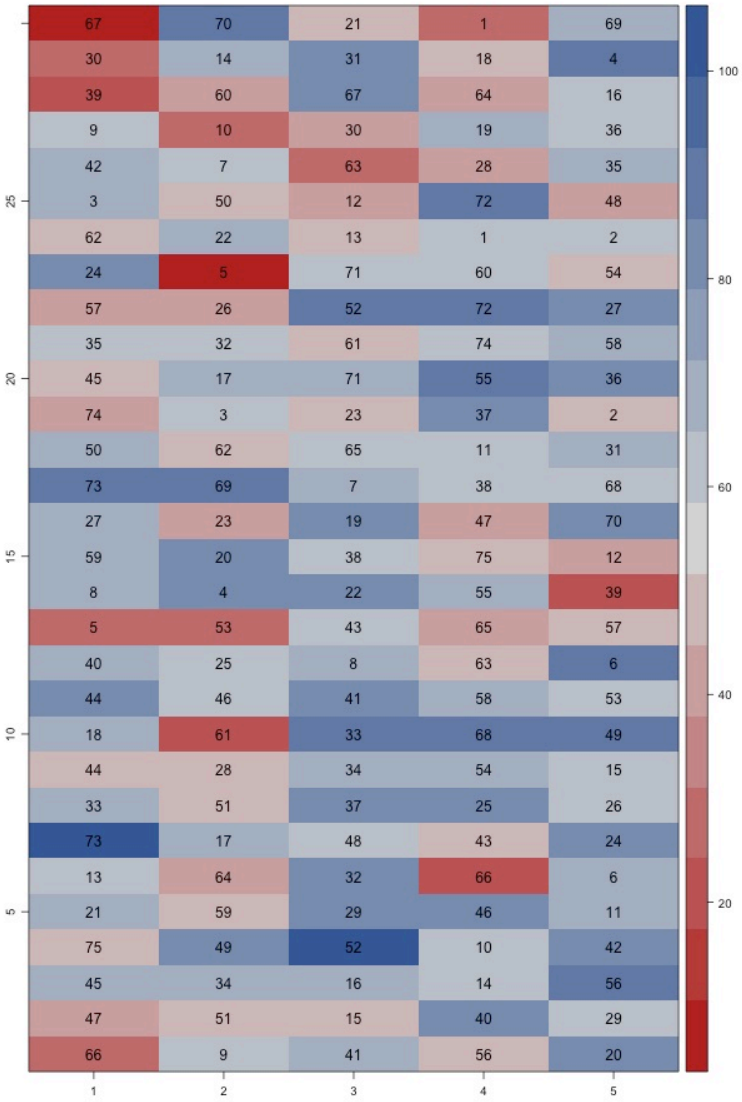
Field Evaluations at New Raymer CO

New Raymer, Colorado
CSU Elite Trial (2014-2016)

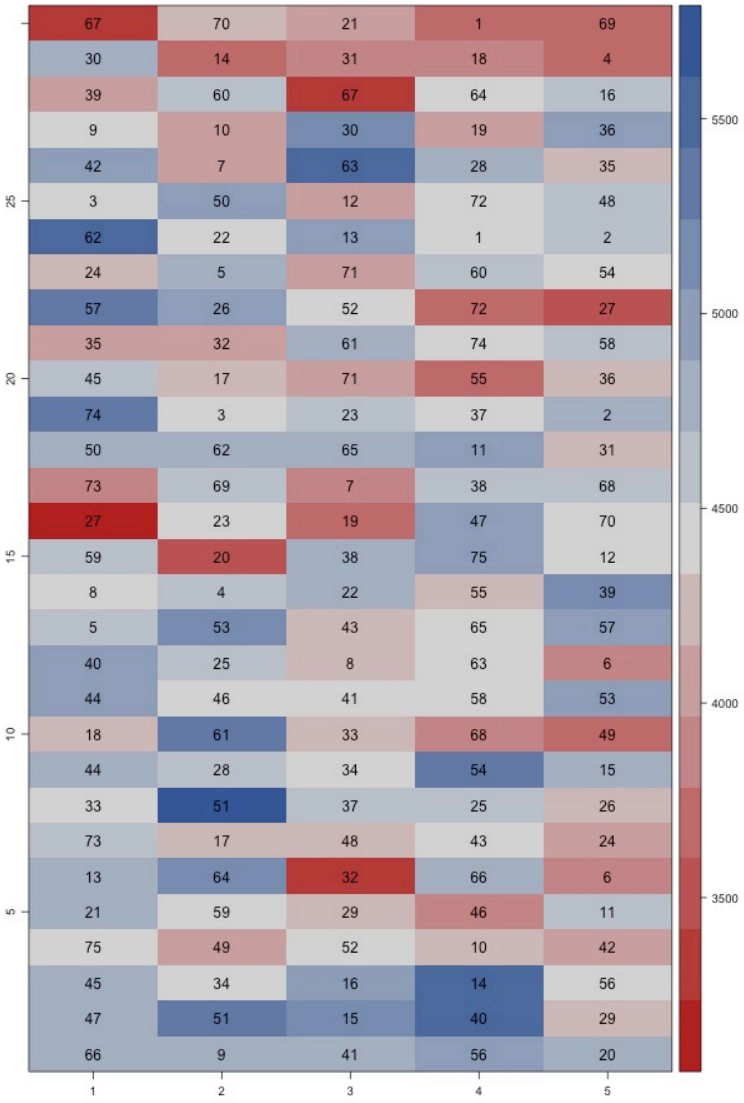


Grain Yield Heat Map

Field Evaluations at New Raymer CO



Stem Cutting Heat Map

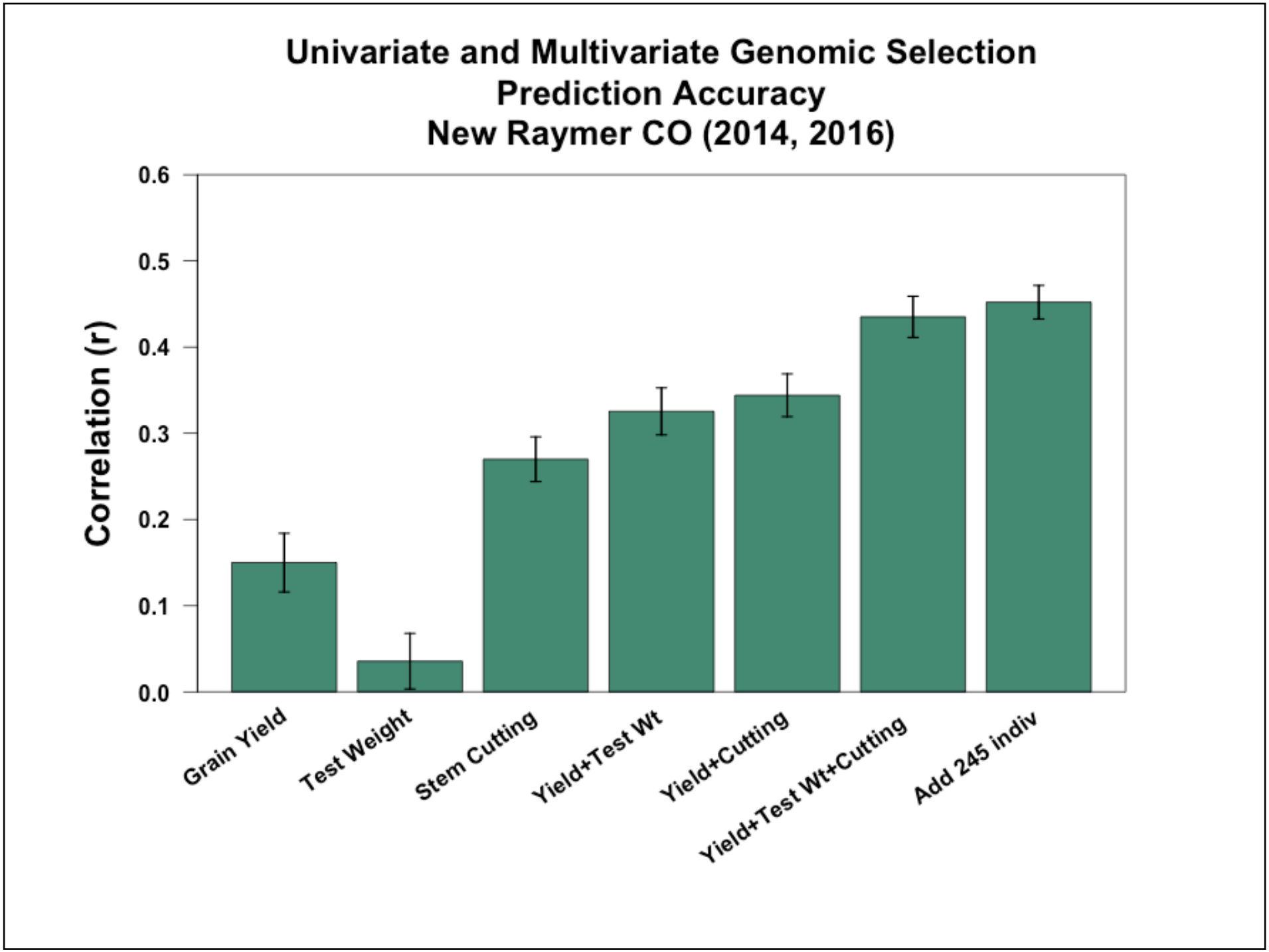


Grain Yield Heat Map

Field Evaluations at New Raymer CO

BLUPS	2014 Grain Yield (kg/ha)	2014 Test Weight (kg/hl)	2014 Cutting (percent)	2016 Grain Yield (kg/ha)	2016 Test Weight (kg/hl)	2016 Cutting (percent)
Avg	4466	748	61	4278	714	43
Max	5005	780	85	4893	763	67
Min	3851	706	32	3532	648	19
H2	0.73	0.82	0.85	0.81	0.87	0.79

Correlations	Test Weight	Cutting
2014		
Yield	0.28	-0.50
Test Wt	--	-0.21
2016		
Yield	0.59	-0.02
Test Wt	--	0.16
Combined		
Yield	0.41	-0.34
Test Wt	--	-0.06


Univariate and Multivariate Genomic Selection
Prediction Accuracy
New Raymer CO (2014, 2016)
Correlation (r)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Grain Yield
Test Weight
Stem Cutting
Yield+Test Wt
Yield+Cutting
Yield+Test Wt+Cutting
Add 245 indiv

Durability of Resistance

- Stripe Rust
  - Multiple race changes, key sources/varieties “defeated”
  - “The 2016 Colorado wheat crop was the most expensive crop we’ve ever produced” (trial producer/cooperator)
  - Inconsistency in incidence addressed through use of DNA markers and cooperative evaluations (KS, WA, TX)
- Wheat stem sawfly
  - No evidence for biotypic differences among populations, aside from “host shift” that has already occurred
  - Solid stem trait – inconsistent expression, “yield drag”
  - Non solid-stem based resistance may be useful to complement solid-stem trait

Durability of Resistance

- Recent technological advancements very useful in an applied breeding context
  - Ability to pyramid multiple resistance sources
  - Ability to dissect phenotypes in breeding populations
  - Shift in the “phenotype-selection” model of plant breeding
  - Capacity for trait prediction and cross prediction
- Challenges
  - Maintenance of genetic diversity (“breeder’s equation”)
  - Maintenance of “pyramids” for yield, drought tolerance, sprouting tolerance, herbicide resistance, quality, etc.
  - Mendelian segregation (we need “cassette gifts”!)
  - Multiple disease and insect resistances to address

Acknowledgements

- Bob Bowden
  (USDA-ARS Manhattan KS)
- Kim Garland-Campbell
  (USDA-ARS Pullman WA)
- Xianming Chen
  (USDA-ARS Pullman WA)
- Luther Talbert
  (MT State Univ)
- Phil Bruckner
  (MT State Univ)
- Mertens Family Farms
  (New Raymer CO)


Questions?