Use of Identity by Descent Mapping Approaches for FHB Resistance

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SOUTH DAKOTA STATE UNIVERSITY

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- J.T. Eckard, J.L. Gonzalez-Hernandez*, S. Chao, P. St Amand, G. Bai. 2014. Construction Of Dense Linkage Maps "On The Fly" Using Early Generation Wheat Breeding Populations. ***Molecular Breeding 34:1281-1300***
- Yuba R. Kandel, Karl D. Glover, Lawrence E. Osborne And Jose L. Gonzalez-Hernandez*. 2014. Mapping Quantitative Resistance Loci For Bacterial Leaf Streak Disease In Hard Red Spring Wheat Using An Identity By Descent Mapping Approach. ***Euphytica 201:53-65***
- Eckard JT, Glover KD, Mergoum M, Aderson J, Gonzalez-Hernandez JL*. 2015. Multiple *Fusarium* Head Blight Resistance Loci Mapped And Pyramided Onto Elite Spring Wheat *Fhb1* Backgrounds Using An IBD-based Linkage Approach. ***Euphytica*. 204 (1), 63-79**
- Eckard JT, Gonzalez-Hernandez JL*, Caffe M, Berzonsky, W, Bockus WW, Marais GF, Baenziger PS. 2015. Native *Fusarium* Head Blight Resistance From Winter Wheat Cultivars 'Lyman,' 'Overland,' 'Ernie,' And 'Freedom' Mapped And Pyramided Onto 'Wesley'-*fhb1* Backgrounds. ***Molecular Breeding*. 35 (1), 1-16**
- SOUTH DAKOTA STATE UNIVERSITY –**PHD DISSERTATIONS: UMESH ROSYARA, MUNA KADARIA, YUBA KANDEL, JONATHAN E. TYLER,**

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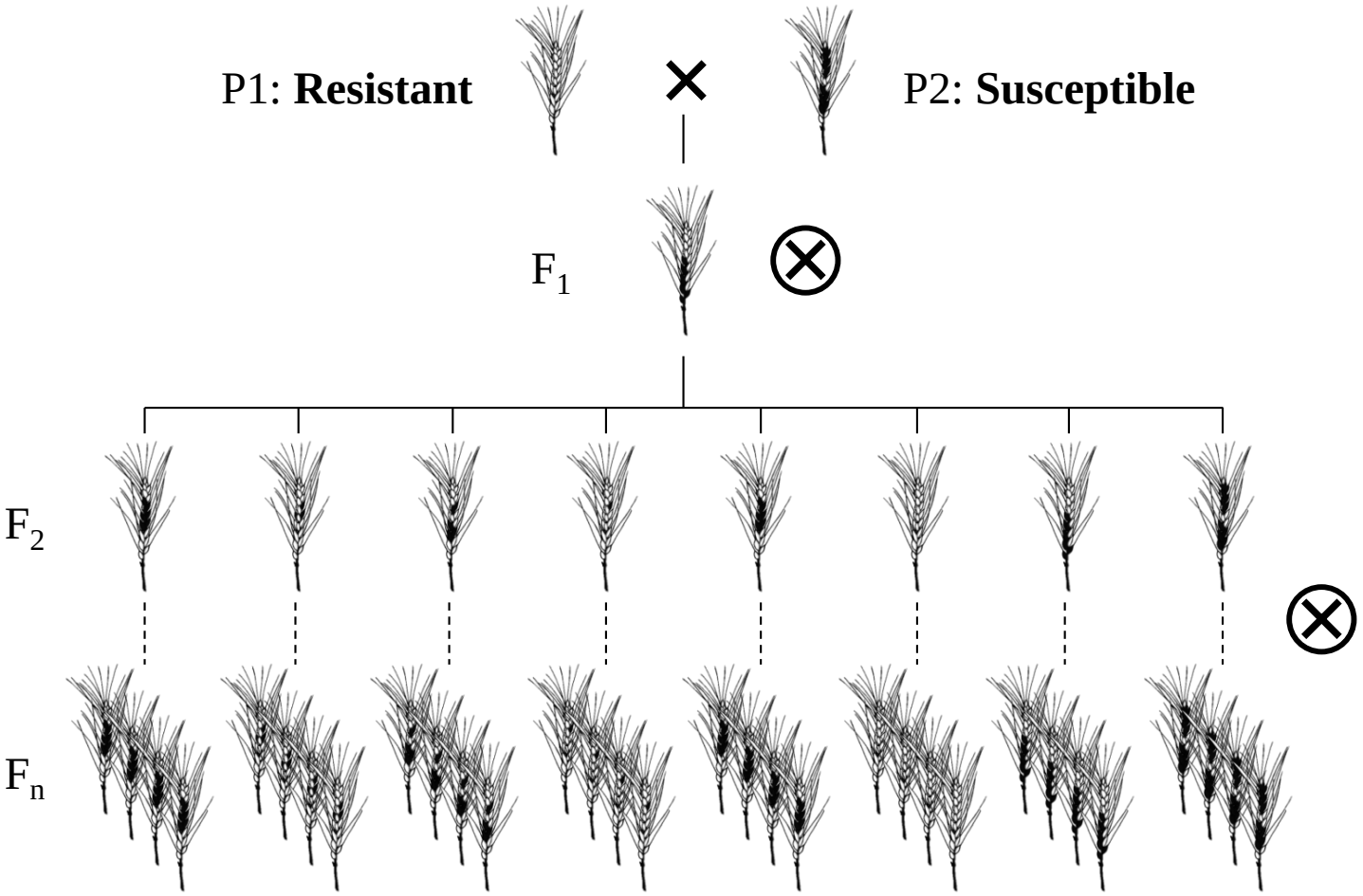
Experimental Paradigm For QTL Mapping



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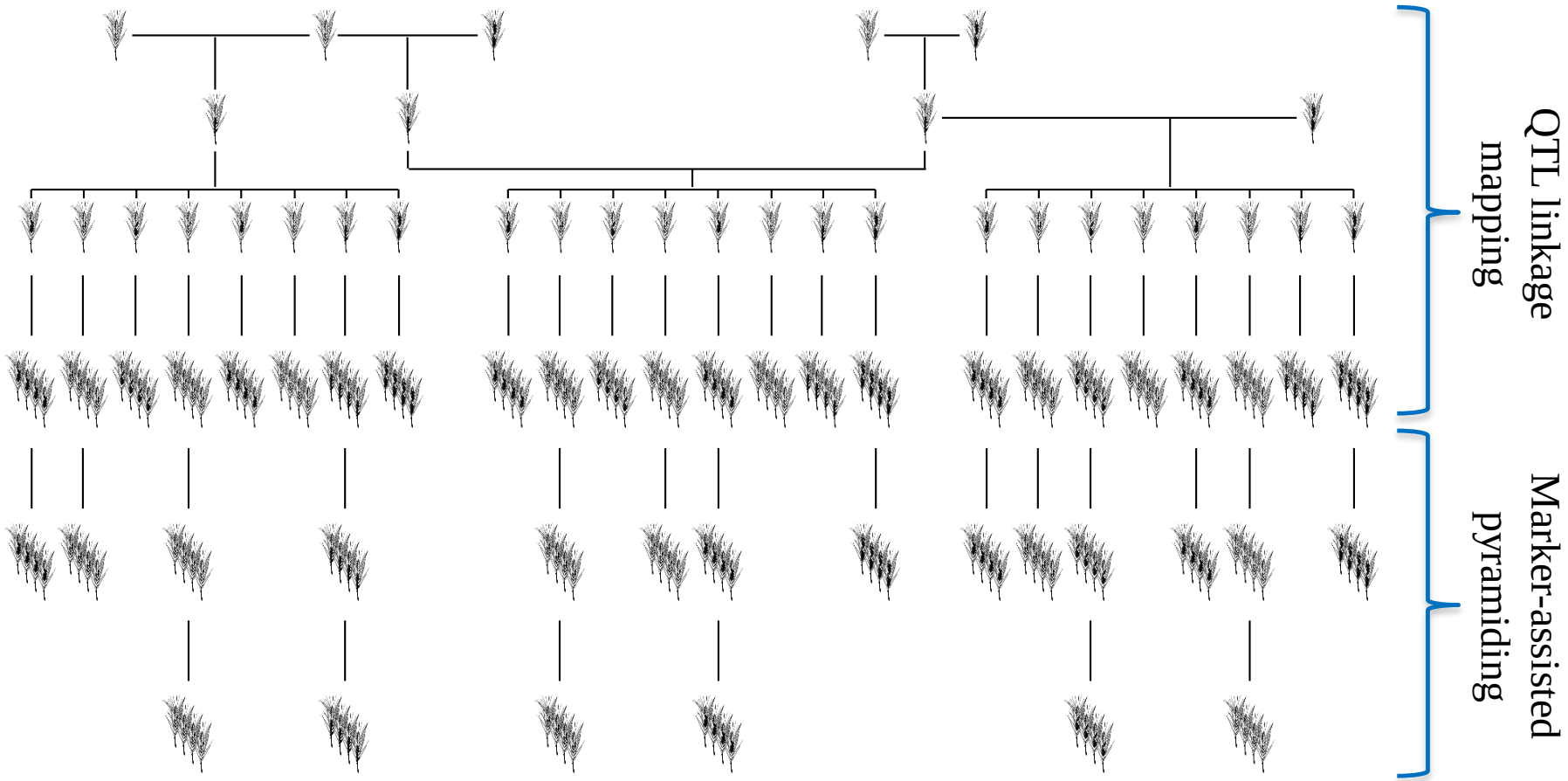
Integrated Molecular Breeding Approach



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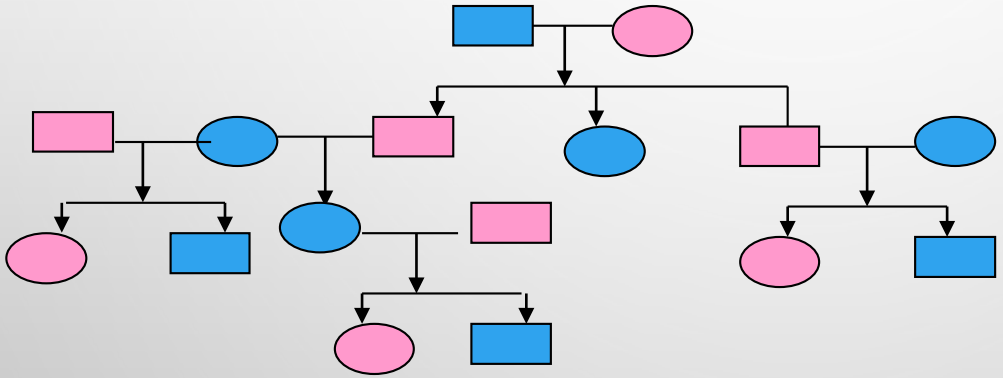
Test case. *Fhb1*

- ✓ The resistant genotypes Sumai 3 derivatives (SD3851, Freyr, SD3776) crossed with other 46 susceptible wheat genotypes
- ✓ 82 families, average family size = 9



- ✓ Variance component analysis (MERLIN), Pedigree-wide regression (MERLIN-Regress) and Linkage disequilibrium analysis for quantitative traits (QTDT)

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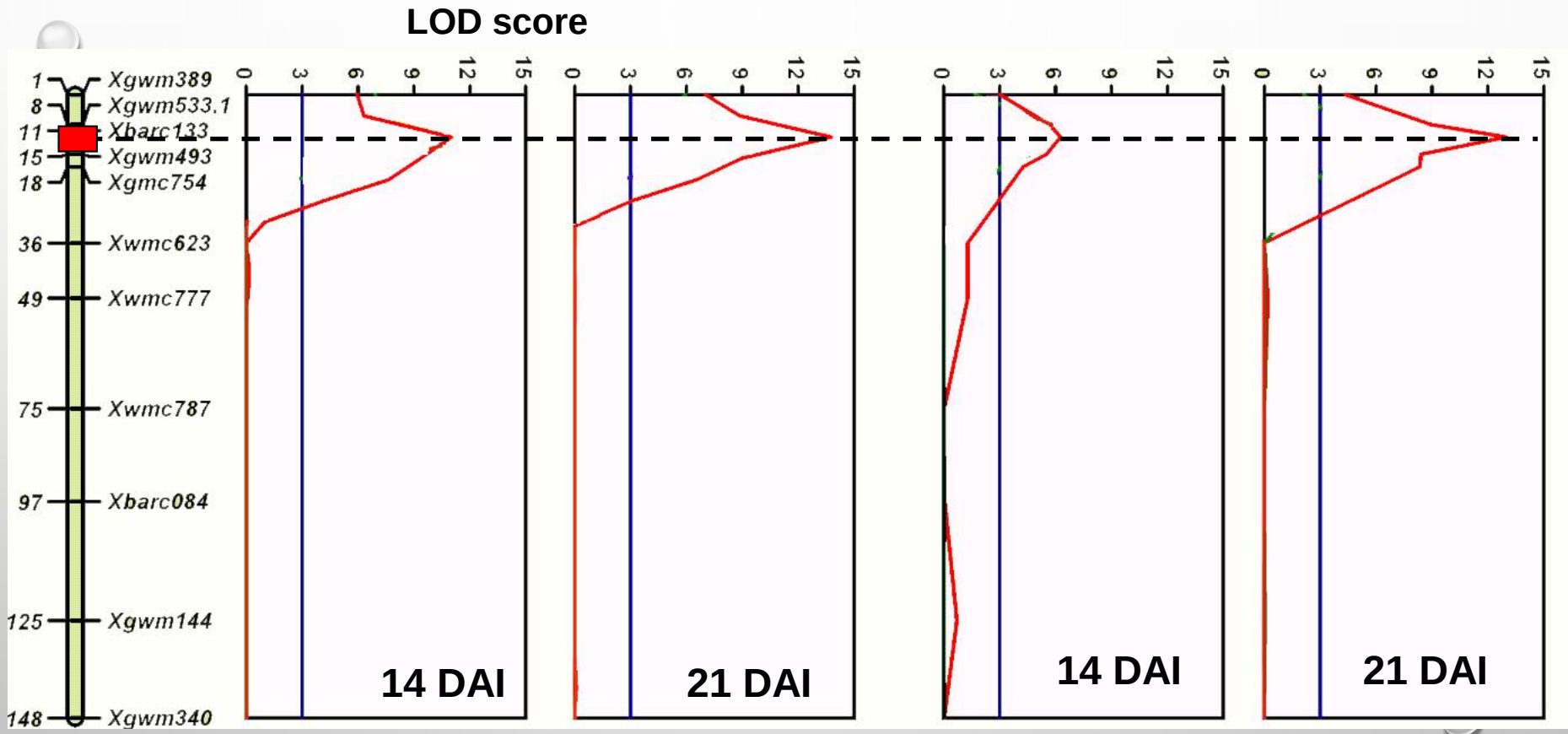
Results: Linkage Analysis



Variance component – linkage

Pedigree-wide regression

DAI: Days after inoculation

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Linkage disequilibrium

Marker	AS*	14 DAI χ^2TDT	14 DAI P-value	21 DAI χ^2TDT	21 DAI P-value
Xgwm389-3B	131	0.4	>0.05	0.04	>0.05
	135	0.34	>0.05	0.03	>0.05
Xgwm533.1-3B	114	6.4	0.01	8.25	0.004
	158	**15.5**	**8×10^{-5}**	**25.5**	**4×10^{-7}**
	155	8.5	0.003	15.1	0.0001
Xbarc133-3B	88	7.3	0.06	5.3	0.02
	120	11.2	0.006	11.1	0.0008
	118	**8.0**	**0.0008**	**17.9**	**2×10^{-5}**
Xgwm493-3B	137		0.004	8.7	0.003
	157	10.7	0.001	14.2	0.0002
	192	**18.6**	**2×10^{-5}**	**18.6**	**4×10^{-7}**

***AS- allele size**

Alleles from resistant parent are labeled blue

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After successfully mapping mapping two more lines we learned:

- **We need to be able to make linkage maps for the materials in question**
- **Additional phenotyping opportunities**
- **Computational challenges**

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Linkage Maps With Multiple Populations

Consensus mapping:

Plant studies, few large populations

Pop. 1 (n = 150) → Map 1

Pop. 2 (n = 200) → Map 2

Pop. 3 (n = 100) → Map 3

Consensus map

Joint mapping:

Animal studies, many small populations

Pop. 1 (n = 3)

Pop. 2 (n = 10)

Pop. 3 (n = 6)

Pop. 4 (n = 5)

⋮

Pop. p (n = 2)

Joint map

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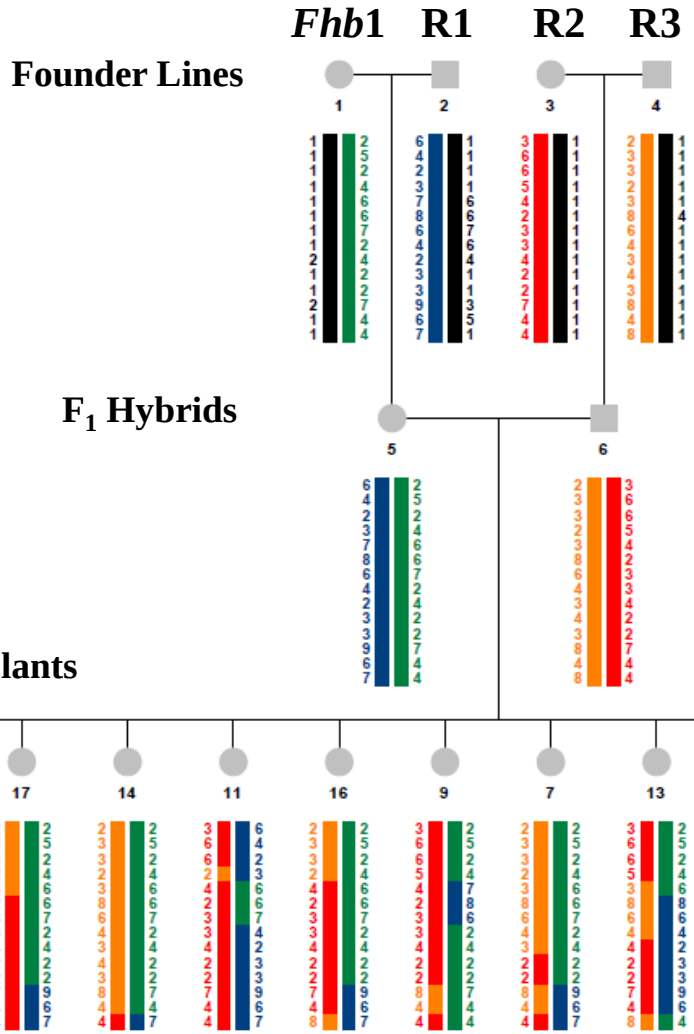
Four-way Crosses To Pyramid Resistance



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Building Linkage Maps in Winter Wheat Breeding Populations

Population	Pedigree	SSR genotyped	SNP genotyped
01	Wesley-Fhb1-BC56 / NE06545 // Ernie / Overland	20	19
02	Ernie / Wesley-Fhb1-BC06 // Ernie / NE06545	26	-
03	Ernie / Wesley-Fhb1-BC06 // Lyman / AL-107-6106	22	16
04	Ernie / Wesley-Fhb1-BC56 // Ernie / Lyman	40	37
05	Ernie / Wesley-Fhb1-BC56 // NI08708 / Lyman	40	38
06	Ernie / Lyman // Ernie / Wesley-Fhb1-BC06	12	-
07	Ernie / Overland // Freedom / Wesley-Fhb1-BC56	5	-
08	Ernie / Overland // Overland / Wesley-Fhb1-BC56	24	23
09	Ernie / Overland // NI08708 / Wesley-Fhb1-BC06	33	30
10	Ernie / NE06545 // McGill / Wesley-Fhb1-BC56	28	-
11	Ernie / McGill // Lyman / Wesley-Fhb1-BC06	12	9
12	Freedom / Wesley-Fhb1-BC06 // Ernie / Overland	12	9
13	Freedom / Wesley-Fhb1-BC06 // Lyman / AL-107-6106	7	7
14	Freedom / Wesley-Fhb1-BC06 // Overland / Wesley-Fhb1-BC56	11	9
15	Freedom / Wesley-Fhb1-BC56 // Ernie / NE06545	4	-
16	Freedom / Ernie // Overland / Wesley-Fhb1-BC56	34	30
17	Freedom / Ernie // NI08708 / Wesley-Fhb1-BC06	29	-
18	Freedom / Overland // Lyman / AL-107-6106	8	8
19	Freedom / NI08708 // Wesley-Fhb1-BC56 / NE06545	7	-
20	AL-107-6106 / Overland // Lyman / Wesley-Fhb1-BC06	11	10
21	AL-107-6106 / Overland // NI08708 / Lyman	14	14
22	Lyman / Wesley-Fhb1-BC56 // Ernie / Lyman	37	35
23	Lyman / Wesley-Fhb1-BC56 // NI08708 / Lyman	31	-
24	Overland / Wesley-Fhb1-BC56 // Ernie / Lyman	44	41
25	Overland / Wesley-Fhb1-BC56 // Ernie / NE06545	5	-
26	Overland / McGill // Lyman / Wesley-Fhb1-BC06	12	9
27	NI08708 / Wesley-Fhb1-BC06 // Ernie / NE06545	8	-
28	NI08708 / Lyman // Overland / Wesley-Fhb1-BC56	29	28
	Total population	**565**	**372**
	Genotypic data points	**15 M**	**3.3 MM**

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Methodology For Map Development

CRI-MAP – Provides multipoint maximum likelihood estimation in general pedigrees.

Recombination fractions (CRI-MAP) → **SNP thinning** (R) → **Linkage grouping** (JoinMap) → **Ordered loci** → **Set threshold** → (CRI-MAP) → **Extend map** → **Permutate orders** → **Ordered loci**

www.animalgenome.org

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Map Development

Polymorphic loci

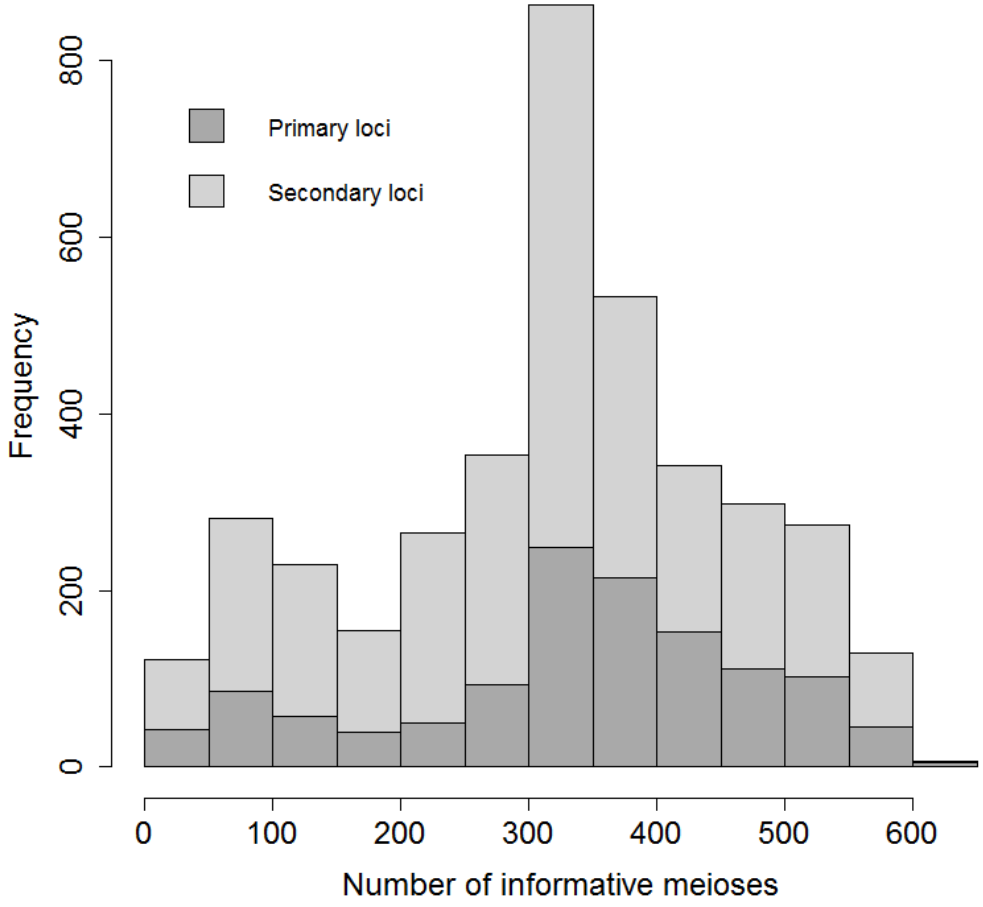
- 4,000

Genetic bins ($\theta < 0.001$)

- 1,269

Linkage groups

- 31 (consolidated to 21)



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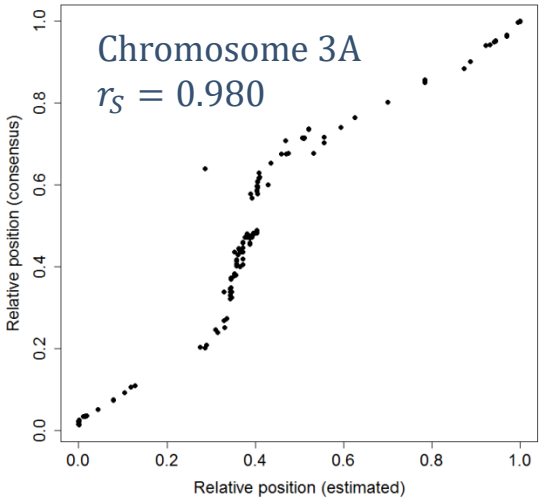
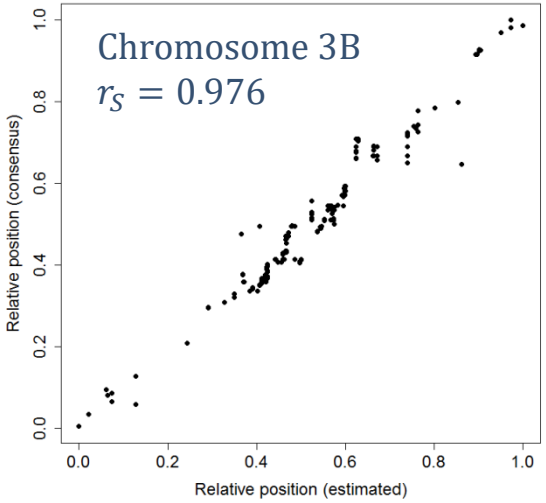
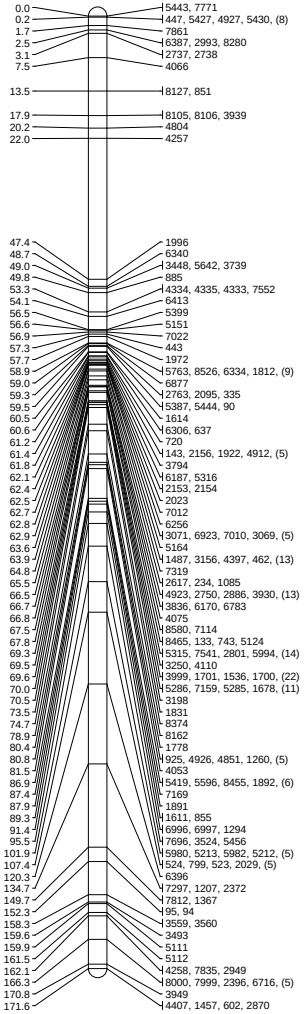
Linkage maps

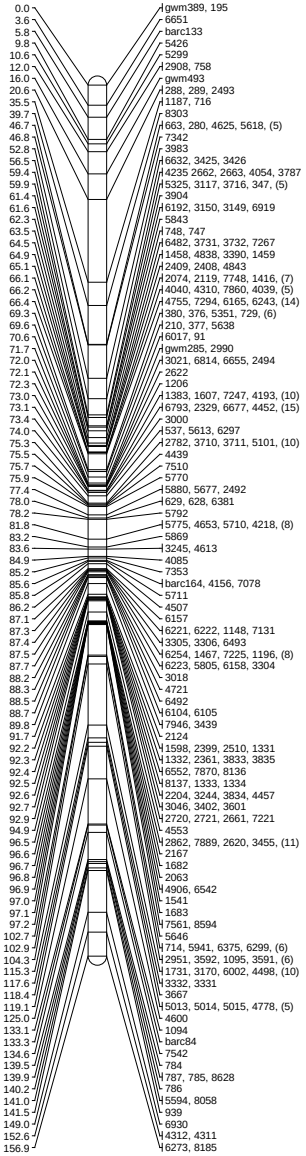




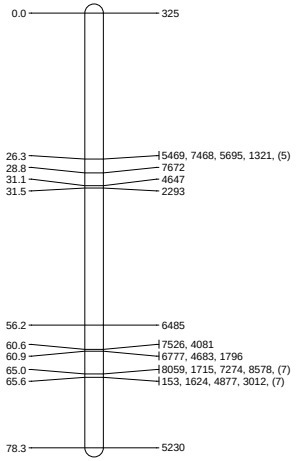
3A



3B



3D



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Summary of Linkage Maps

Chrom	Mapped loci	Genetic bins	Total cM distance	Mean interval	Rank-order correlation	Observed crossovers
1A	350	88	174	2.0	**0.953**	1,074
1B	193	59	160	2.8	**0.990**	919
1D	110	30	92	3.2	-	464
2A	214	92	225	2.5	**0.992**	1,450
2B	364	72	142	2.0	**0.640**	917
2D	50	25	103	4.3	-	596
3A	231	76	171	2.3	**0.980**	1,107
3B	288	116	156	1.4	**0.976**	1,245
3D	30	11	78	7.8	-	205
4A	104	56	151	2.8	**0.992**	994
4B	104	47	140	3.1	**0.969**	901
4D	9	7	39	6.6	-	58
5A	296	104	255	2.5	**0.997**	1,750
5B	335	113	212	1.9	**0.986**	1,284
5D	39	22	190	9.1	-	747
6A	242	72	176	2.5	**0.976**	926
6B	338	85	133	1.6	**0.519**	840
6D	44	16	45	3.0	-	104
7A	316	105	206	1.9	**0.993**	1,263
7B	189	58	186	3.3	**0.928**	1,161
7D	29	15	36	2.7	-	189
Overall	**3,875**	**1,269**	**3,080**	**2.5**	**0.921**	**18,194**

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Founders of Spring Wheat Breeding Populations

Founder	Pedigree	Class	*Xumn10*	Resistance loci
AZ10-1859	SD3934 / Granger // Granger	HRSW	238	***Fhb1***
AZ10-1876	SD3934 / SD4101 // HW010	HRSW	238	***Fhb1***
AZ10-1913	SD3934 / SD4027 // Sonalika	HRSW	238	***Fhb1***
AZ10-1941	SD3934 / SD4101 // SD3997	HRSW	238	***Fhb1***
AZ10-1973	SD3934 / SD3948 // Oxen	HRSW	238	***Fhb1***
AZ10-2029	SD3934 / SD4011 // Granger	HRSW	238	***Fhb1***
AZ10-2158	SD3934 / SD3948 // SD3934 / SD4102	HRSW	238	***Fhb1***
NZ10-3716	SD3746 / SD3776 // SD4032	HRSW	238	***Fhb1***
NZ10-3750	MN01197 / SD3851 // SD4070	HRSW	238	***Fhb1***
NZ10-3785	MN01057-3-1 / SD3851 // SD4032	HRSW	null	.
NZ10-3772	FN1504-124 / SD3851 // Glenn	HRSW	238	***Fhb1***
NZ10-3773	FN1504-124 / SD3851 // Glenn	HRSW	238	***Fhb1***
NZ10-3789	WEAVERCOMPLEX / SD3851 // Glenn	HRSW	238	***Fhb1***
NZ10-3790	WEAVERCOMPLEX / SD3851 // Glenn	HRSW	238	***Fhb1***
NZ10-3794	WEAVERCOMPLEX / SD3851 // Glenn	HRSW	238	***Fhb1***
MN99112-10-2-4	MN93377 / MN94350	HRSW	235	.
MN99126-1-3-7-5	MN94053 / MN2514	HRSW	235	.
RIL35	Wheaton / PI 81791	HRSW	235	2B, 3B, 3D
RIL59	Wheaton / PI 81791	HRSW	235	2B, 3B, 3D
MULT 757	PI 271127	HRSW	235	7B

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Founders of Winter Wheat Breeding Populations

Founder	Pedigree	Class	Loci
Wesley-Fhb1-BC06	Wesley / 2*ND2928	HWW	***FHB1***
Wesley-Fhb1-BC56	Wesley / 2*ND2928	HWW	***FHB1***
AL-107-6106	Alsen / NE00403 // NE02583-107	HWW	***FHB1***
Ernie	Pike / MO9965	SWW	5A, 3B, 4B, 2B
Freedom	GR876 / OH217	SWW	2AS
Lyman	KS93U134 / Arapahoe	HWW	.
Overland	Millennium sib // Seward / Archer	HWW	.
NE06545	KS92-946-B-I5-1 / Alliance	HWW	.
NI08708	CO980829 / Wesley	HWW	.
McGill	NE92458 / Ike	HWW	.

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Spring Wheat Breeding Populations

Cross	Four-way F_1 sibs
AZ10-1859 / MN99126 // **NZ10-3785** / MULT757	24
AZ10-1859 / MN99126 // **NZ10-3794** / RIL35	12
AZ10-1859 / RIL59 // **NZ10-3716** / MN99112	20
AZ10-1859 / RIL59 // MN99126 / **NZ10-3772**	23
AZ10-1876 / RIL59 // **AZ10-1859** / MN99112	23
AZ10-1876 / RIL59 // MULT757 / **NZ10-3750**	21
AZ10-1913 / MULT757 // **NZ10-3772** / RIL35	24
AZ10-1913 / MULT757 // MULT757 / MN99112	9
AZ10-1941 / MULT757 // MN99126 / **NZ10-3772**	19
NZ10-3750 / MN99112 // **NZ10-3785** / MULT757	20
NZ10-3785 / MULT757 // **NZ10-3716** / MN99112	22
NZ10-3785 / MULT757 // RIL35 / **AZ10-2158**	18
NZ10-3772 / RIL35 // MN99126 / MULT757	20
NZ10-3790 / MN99112 // RIL35 / **NZ10-3772**	25
NZ10-3790 / RIL35 // MN99126 / MULT757	18
NZ10-3794 / RIL35 // MULT757 / MN99112	18
MN99112 / MN99126 // **NZ10-3716** / MN99112	18
MN99112 / MN99126 // RIL35 / **NZ10-3716**	21
MN99112 / MN99126 // MULT757 / **NZ10-3773**	15
MN99112 / RIL59 // MN99126 / **NZ10-3785**	20
MN99112 / RIL59 // RIL59 / **NZ10-3750**	20
MN99126 / **AZ10-1941** // **AZ10-2029** / MN99112	22

Cross	Four-way F_1 sibs
MN99126 / **AZ10-1941** // MULT757 / **NZ10-3772**	23
MN99126 / **NZ10-3785** // MN99112 / MN99126	15
MN99126 / **NZ10-3785** // RIL35 / MN99112	20
MN99126 / MULT757 // **NZ10-3750** / MN99112	21
MN99126 / MULT757 // RIL59 / **NZ10-3750**	14
RIL35 / **AZ10-2158** // **NZ10-3789** / MN99126	21
RIL35 / **AZ10-2158** // RIL35 / MULT757	19
RIL35 / **AZ10-2158** // MULT757 / **NZ10-3772**	18
RIL35 / **NZ10-3772** // MN99112 / **NZ10-3789**	26
RIL35 / **NZ10-3789** // **AZ10-2029** / MN99112	19
RIL35 / MN99112 // **NZ10-3785** / MULT757	22
RIL35 / MN99112 // MULT757 / **AZ10-1859**	17
RIL35 / MULT757 // MN99126 / **NZ10-3772**	22
RIL59 / **NZ10-3750** // MN99126 / **NZ10-3750**	17
MULT757 / **NZ10-3750** // **AZ10-1859** / MN99112	15
MULT757 / **NZ10-3750** // RIL35 / **NZ10-3772**	20
MULT757 / **NZ10-3750** // RIL59 / **NZ10-3794**	26
MULT757 / MN99112 // **AZ10-1859** / RIL59	17
MULT757 / MN99112 // MN99126 / **NZ10-3750**	25
MULT757 / RIL59 // **AZ10-1859** / MN99126	15
MULT757 / RIL59 // MN99126 / **AZ10-1941**	2
Total population:	**826**

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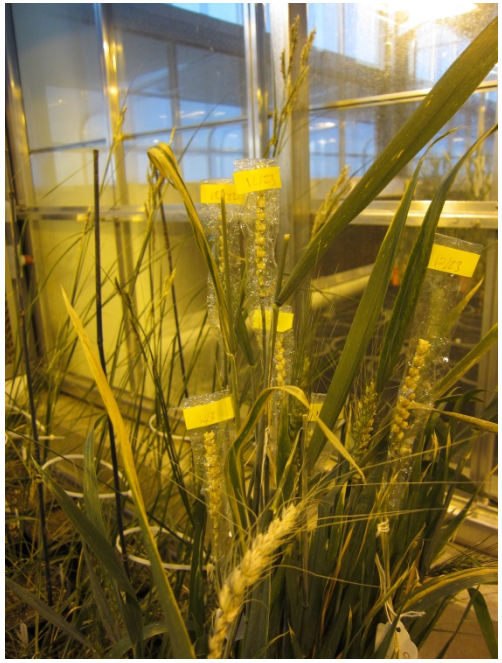
Winter Wheat Breeding Populations

Cross	Four-way F_1 sibs
Wesley-Fhb1-BC56 / NE06545 // Ernie / Overland	20
Ernie / **Wesley-Fhb1-BC06** // Ernie / NE06545	26
Ernie / **Wesley-Fhb1-BC06** // Lyman / **AL-107-6106**	22
Ernie / **Wesley-Fhb1-BC56** // Ernie / Lyman	40
Ernie / **Wesley-Fhb1-BC56** // NI08708 / Lyman	40
Ernie / Lyman // Ernie / **Wesley-Fhb1-BC06**	12
Ernie / Overland // Freedom / **Wesley-Fhb1-BC56**	5
Ernie / Overland // Overland / **Wesley-Fhb1-BC56**	24
Ernie / Overland // NI08708 / **Wesley-Fhb1-BC06**	33
Ernie / NE06545 // McGill / **Wesley-Fhb1-BC56**	28
Ernie / McGill // Lyman / **Wesley-Fhb1-BC06**	12
Freedom / **Wesley-Fhb1-BC06** // Ernie / Overland	12
Freedom / **Wesley-Fhb1-BC06** // Lyman / **AL-107-6106**	7
Freedom / **Wesley-Fhb1-BC06** // Overland / **Wesley-Fhb1-BC56**	11
Freedom / **Wesley-Fhb1-BC56** // Ernie / NE06545	4
Freedom / Ernie // Overland / **Wesley-Fhb1-BC56**	34
Freedom / Ernie // NI08708 / **Wesley-Fhb1-BC06**	29
Freedom / Overland // Lyman / **AL-107-6106**	8
Freedom / NI08708 // **Wesley-Fhb1-BC56** / NE06545	7
AL-107-6106 / Overland // Lyman / **Wesley-Fhb1-BC06**	11
AL-107-6106 / Overland // NI08708 / Lyman	14
Lyman / **Wesley-Fhb1-BC56** // Ernie / Lyman	37

Cross	Four-way F_1 sibs
Lyman / **Wesley-Fhb1-BC56** // NI08708 / Lyman	31
Overland / **Wesley-Fhb1-BC56** // Ernie / Lyman	44
Overland / **Wesley-Fhb1-BC56** // Ernie / NE06545	5
Overland / McGill // Lyman / **Wesley-Fhb1-BC06**	12
NI08708 / **Wesley-Fhb1-BC06** // Ernie / NE06545	8
NI08708 / Lyman // Overland / **Wesley-Fhb1-BC56**	29
Total population:	**565**



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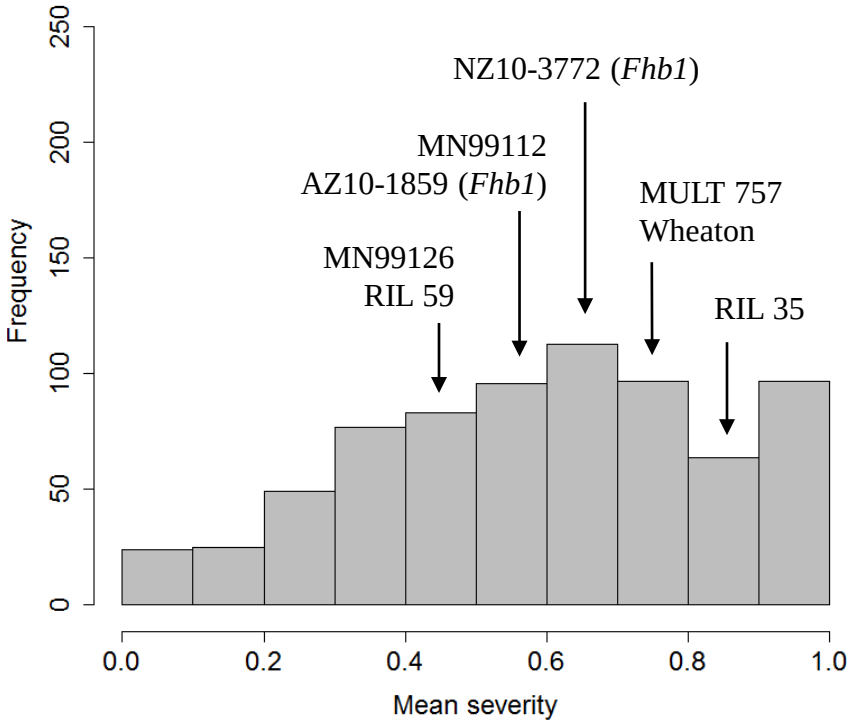
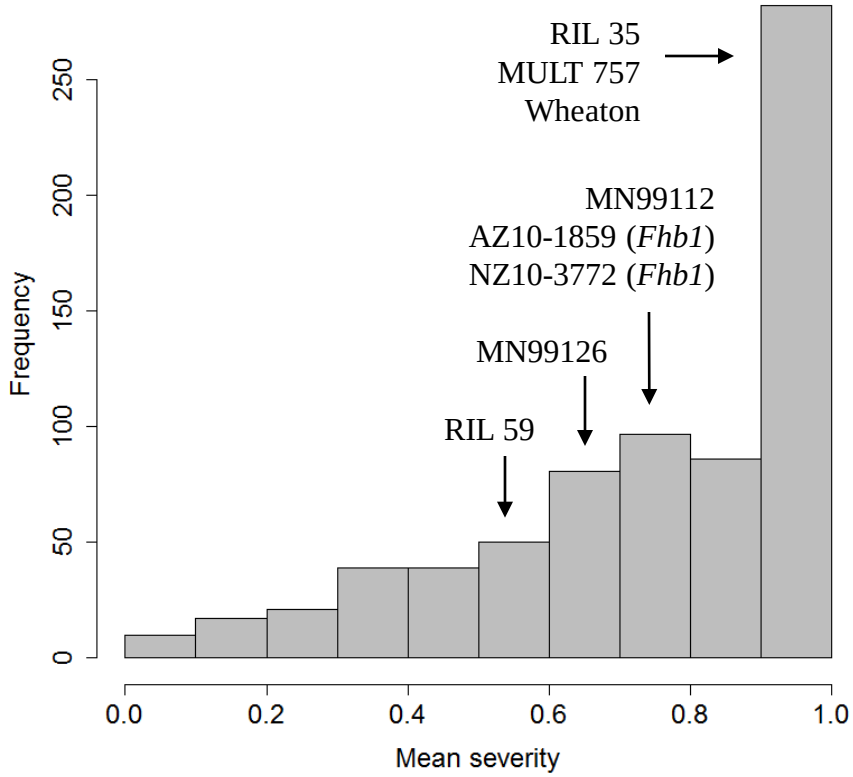
Greenhouse Evaluations of FHB Severity in Spring Wheat Populations

14 days after inoculation



21 days after inoculation



BLUPs

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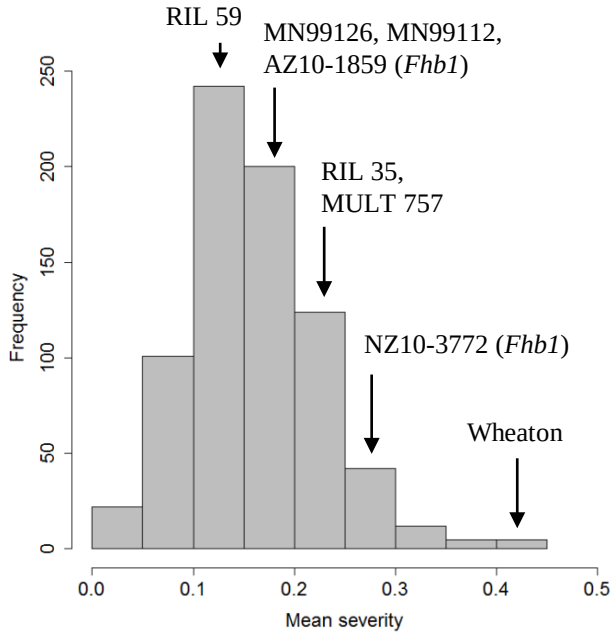
Spring Wheat Self-progeny Testing Four-way F_1 Plants



Evaluation	Inoculation method	F_1 plants evaluated	Biological replicates	Spikes evaluated	Ave. FHB severity
Brookings, SD	Spawn / spray	388	1	20	0.15
Volga, SD	Spawn / spray	485	1	20	0.10
St. Paul, MN	Spawn / spray	346	1	20	0.24
Prosper, ND	Spawn	341	3	60	0.18
Combined	**Mixed**	**744**	**1-6**	**20-120**	**0.17**

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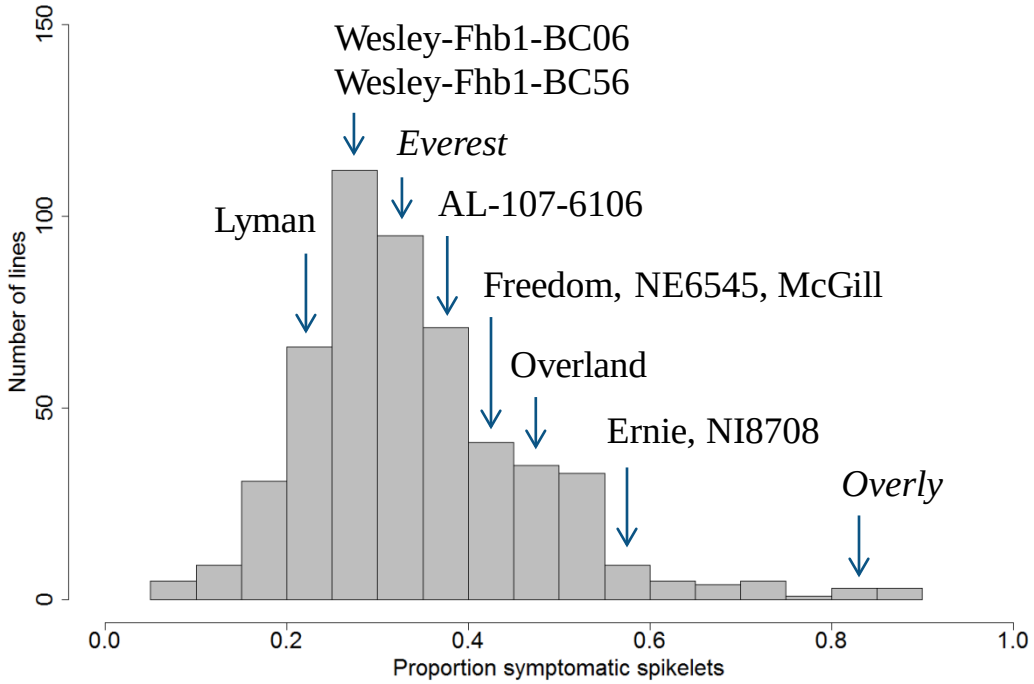
Winter Wheat Selfed-progeny Testing Four-way F_1 Plants

Evaluation	Inoculation method	F_1 plants evaluated	Biological replicates	Spikes evaluated
Volga, SD	Spawn / spray	501	1	20
Manhattan, KS	Spawn / spray	380	1	20
Carrington, ND	Spawn	201	1	20
Combined	**Mixed**	**531**	**1-3**	**20-60**



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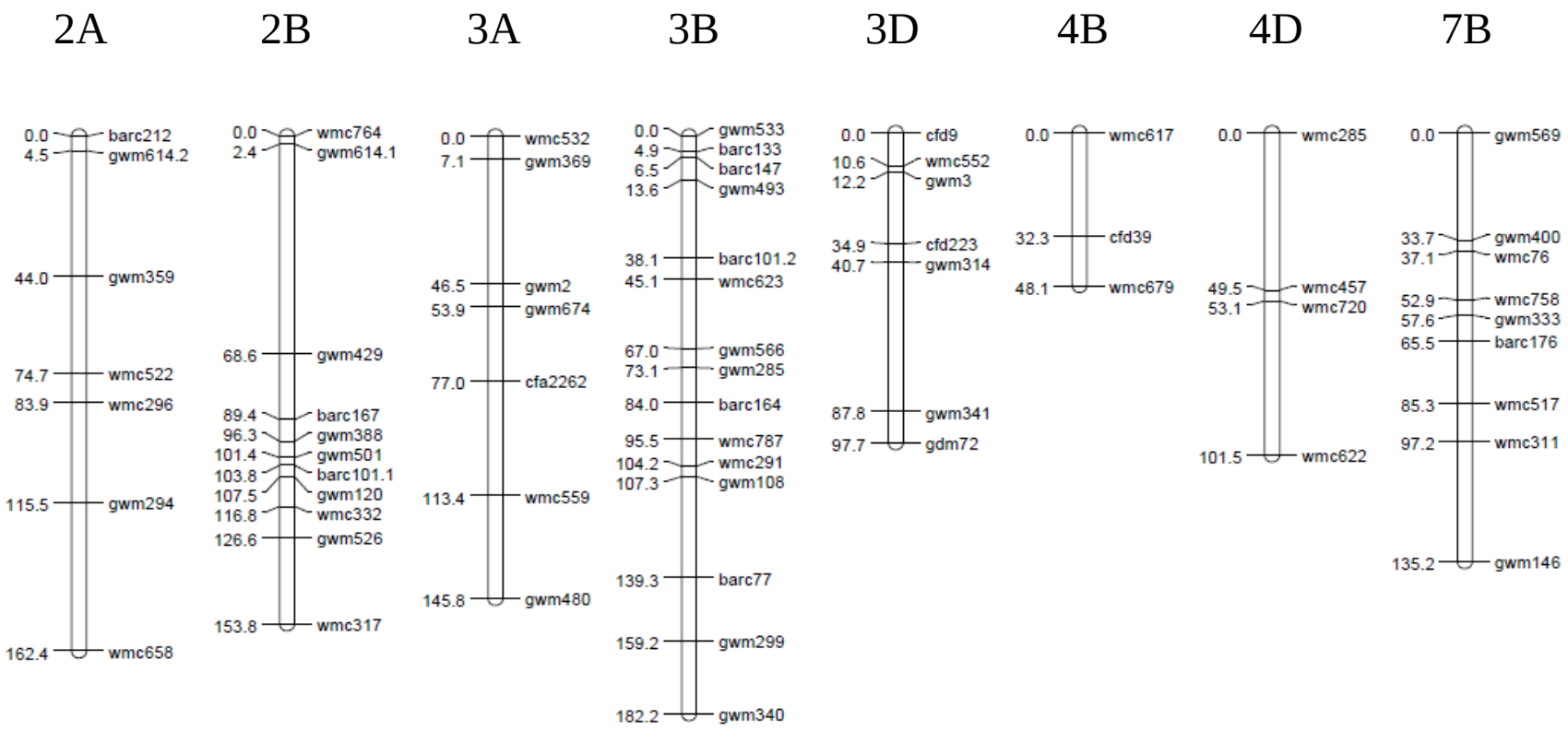
Targeted Genotyping For 72 SSR Markers in Spring Wheat Breeding Populations



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Genome Wide Genotyping for 3,875 SNPs and 22 SSR Loci in Winter Wheat Populations

Chrom	Mapped loci	Genetic bins	Total cM distance	Mean interval
1A	350	88	174	2.0
1B	193	59	160	2.8
1D	110	30	92	3.2
2A	214	92	225	2.5
2B	364	72	142	2.0
2D	50	25	103	4.3
3A	231	76	171	2.3
3B	288	116	156	1.4
3D	30	11	78	7.8
4A	104	56	151	2.8
4B	104	47	140	3.1
4D	9	7	39	6.6
5A	296	104	255	2.5
5B	335	113	212	1.9
5D	39	22	190	9.1
6A	242	72	176	2.5
6B	338	85	133	1.6
6D	44	16	45	3.0
7A	316	105	206	1.9
7B	189	58	186	3.3
7D	29	15	36	2.7
Overall	**3,875**	**1,269**	**3,080**	**2.5**

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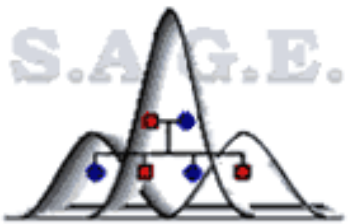
Methods For Linkage Analysis

- **Statistical Analysis for Genetic Epidemiology (S.A.G.E)**

  1. **Pedigree error checking** – ‘PEDINFO’
  2. **Mendelian error checking** – ‘MARKERINFO’
  3. **Allele frequency estimation** – ‘FREQ’
  4. **Multipoint IBD estimation** – ‘GENIBD’
  5. **IBD-based linkage analysis** – ‘RELPAL’



http://darwin.cwru.edu/sage/

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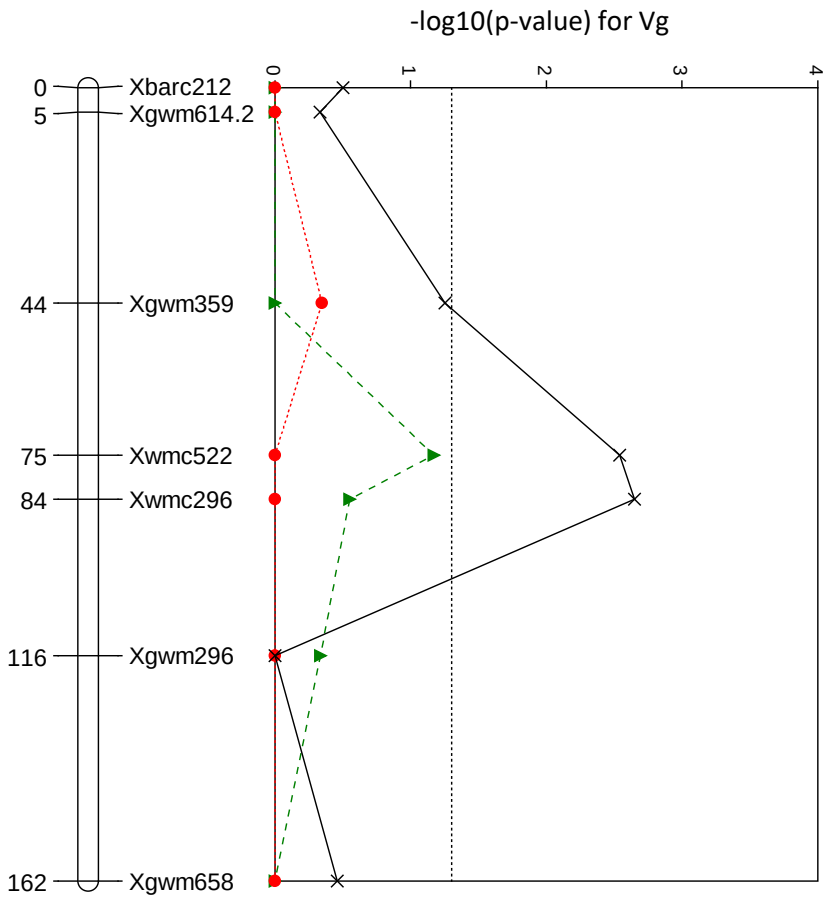
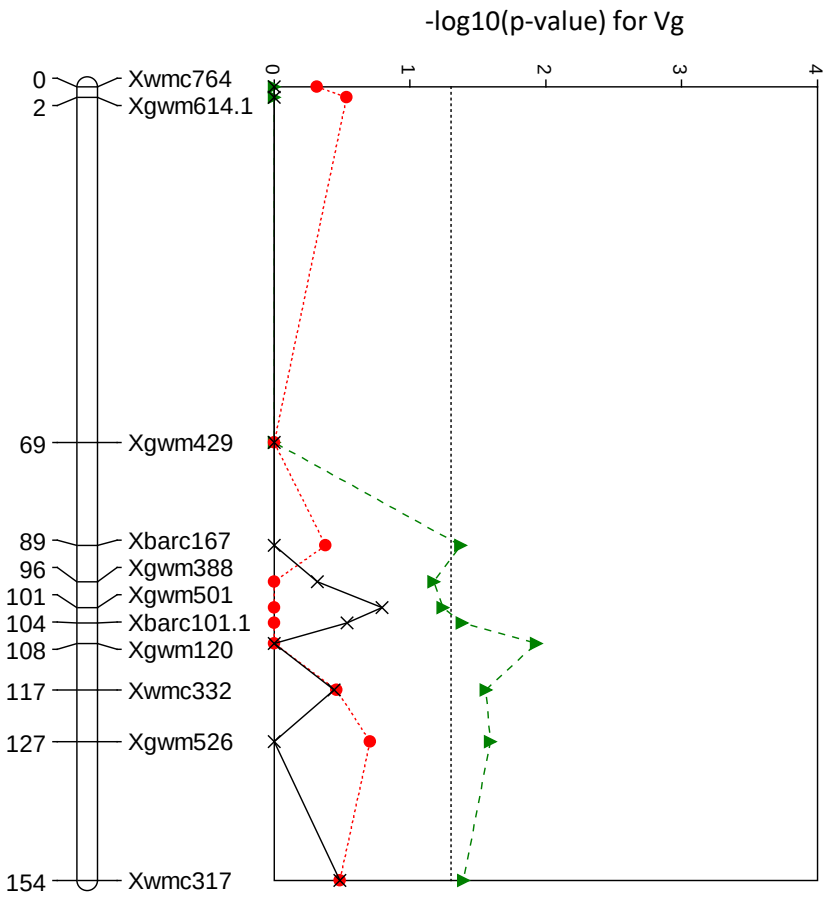
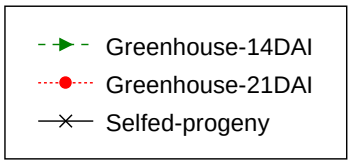
Results From IBD-based Linkage Analysis



Chr.2A



Chr.2B



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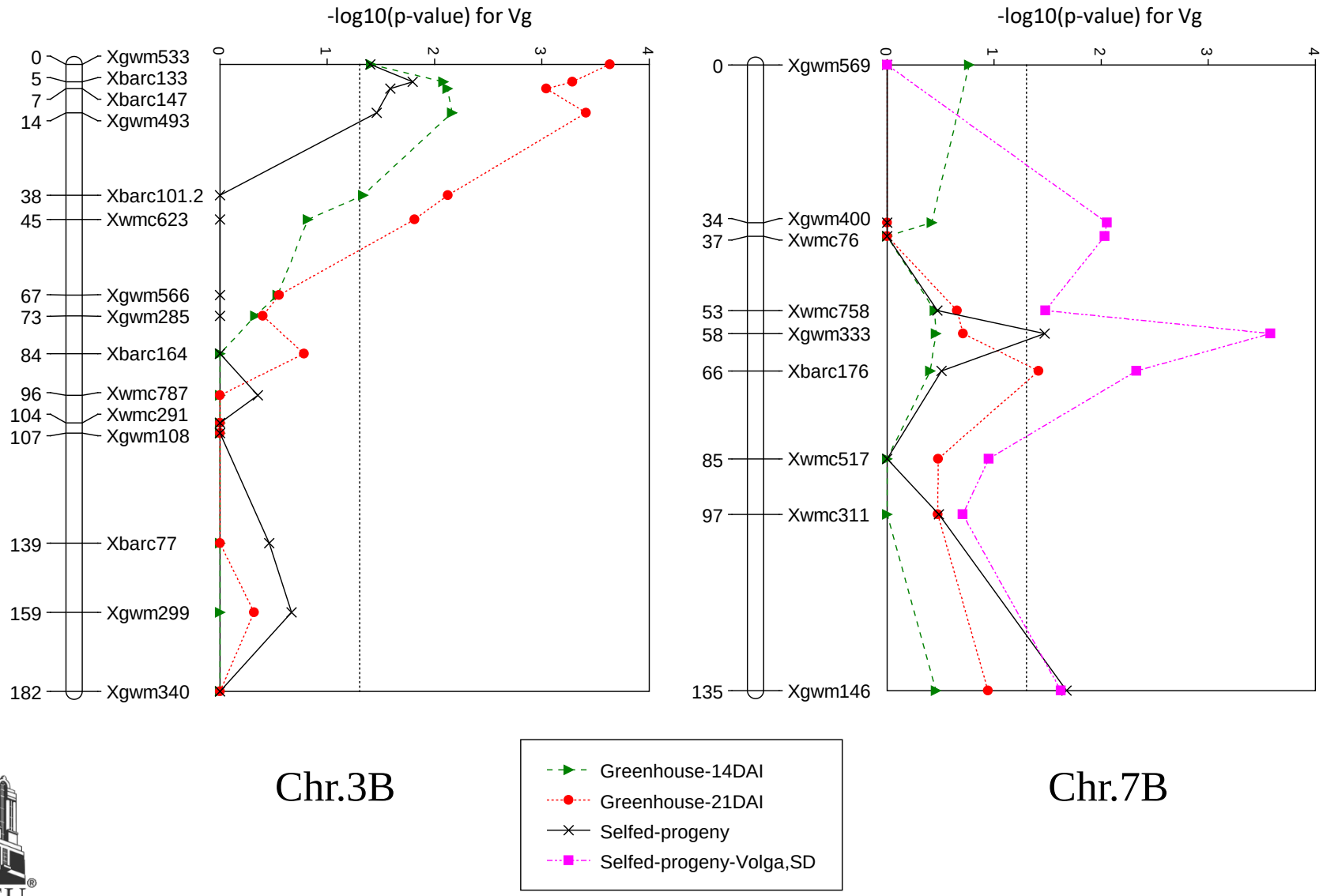
Results From IBD-based Linkage Analysis



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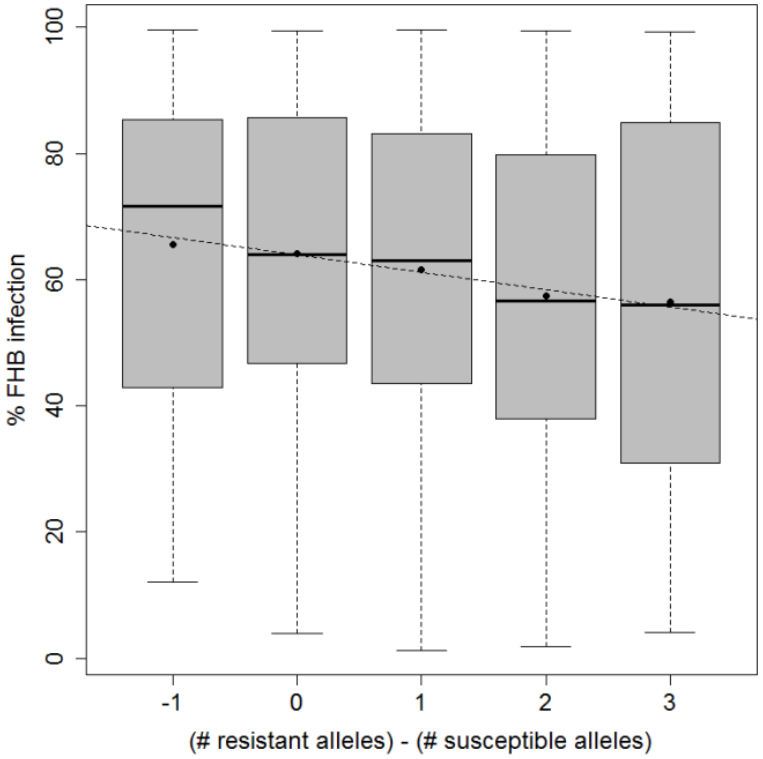
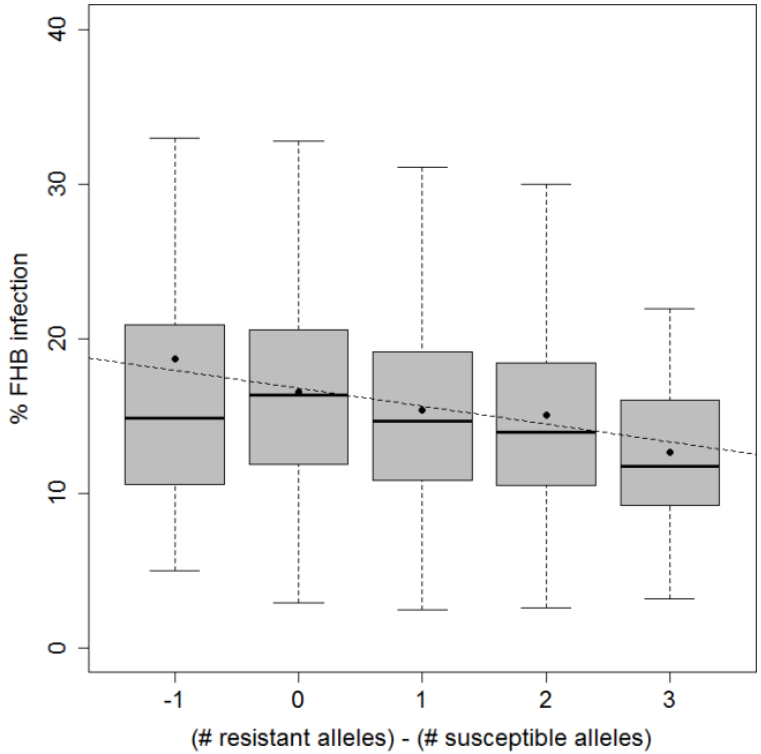
Cumulative Effects of QTL Alleles in Spring Wheat Populations

Greenhouse 14 DAI



Selfed progeny



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Qfhb-sdsu-1AS (5-10%) Lyman, Overland

Qfhb-sdsu-1BS (5-12%) Lyman, Overland

Fhb1 (5-10%)

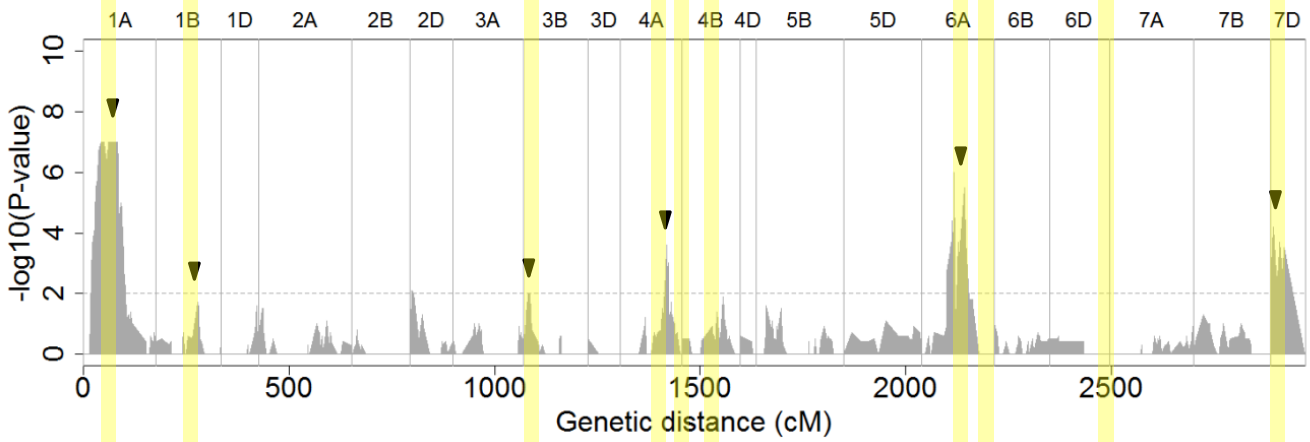
Qfhb-sdsu-4AC (5-10%) Lyman, *Qfhb-sdsu-4AL* (7%) Wfhb1 *Qfhb-sdsu-4B* (7%)Wfhb1

Qfhb-sdsu-6AC (5-15%)Wfhb1, Overland *Qfhb-sdsu-6AS* (10%) Overland,

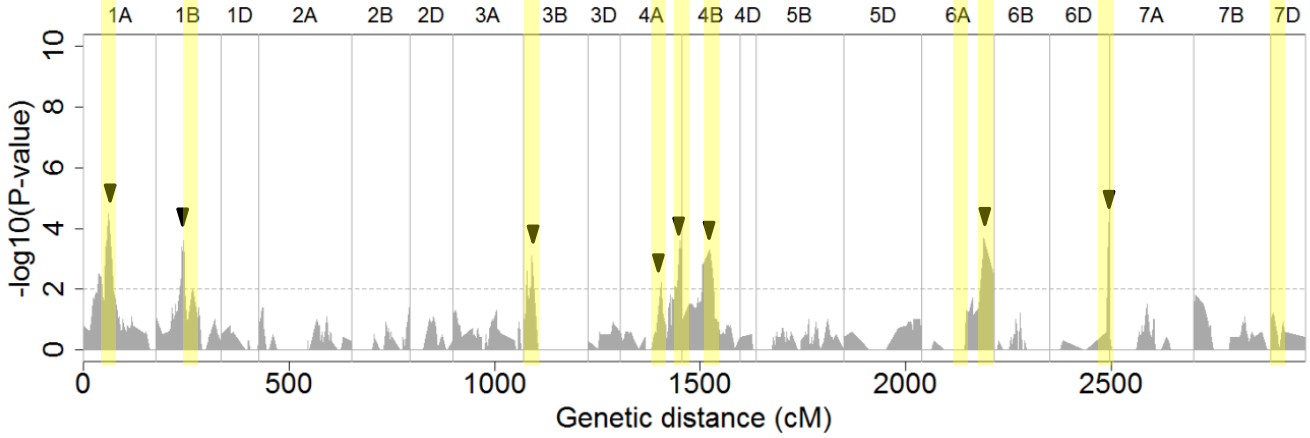
Qfhb-sdsu-6D (12%) Wfhb1, Overland

Qfhb-sdsu-7D (3-5%) Wfhb1,AL

Greenhouse AUDPC



Selfed progeny



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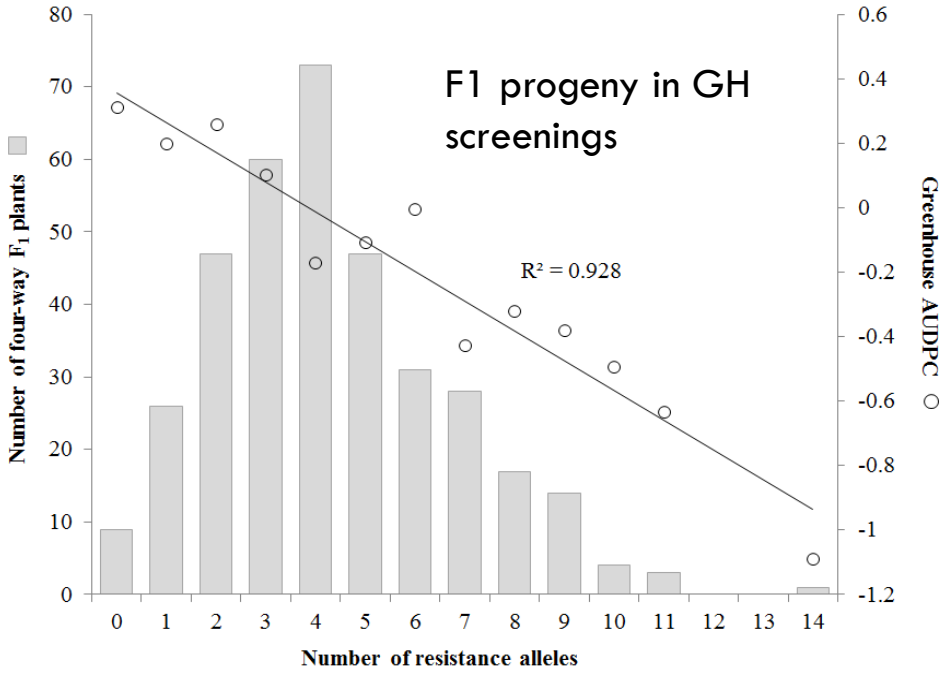
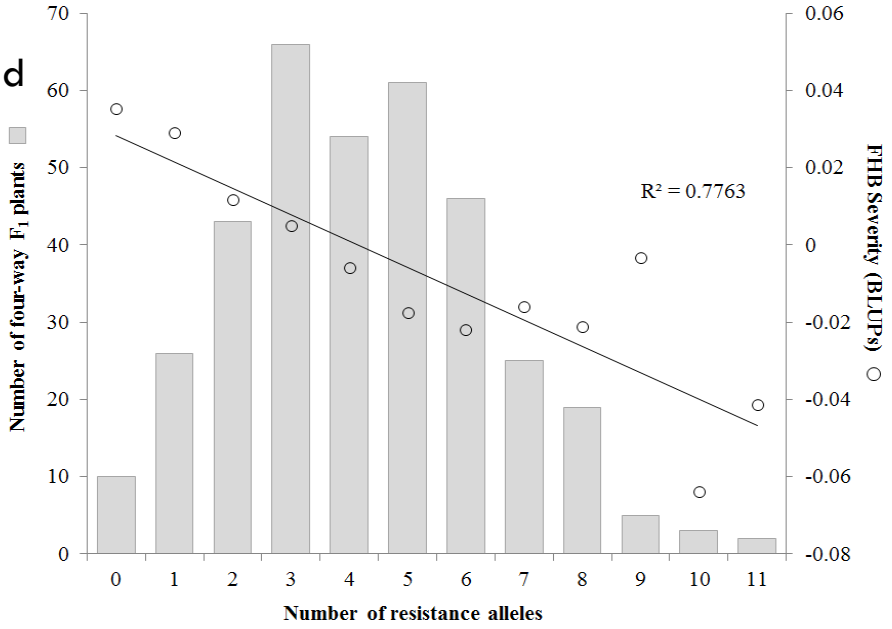
Pyramiding Resistance Alleles Reduces FHB in Winter Wheat Populations



Self progeny in field screenings



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SUMMARY

1. **We can develop reliable dense genetic maps** using early generation breeding populations.

2. **We can detect multiple resistance QTL** using generation breeding populations**.**

3. **At the same time we generated breeding material;** ~3,000 early generation lines and ~500-600 DHs

4. **We need to address assumptions** underlying existing implementations of linkage analysis for general pedigrees:
    1. Related pedigrees, Hermaphroditic mating systems, Inbred founders and Simplifying MCMC algorithm

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2016 USWBSI Annual Meeting
December 4-6; St Louis, MO