Evidence for Recombination of Sr2 and Fhb1

#bgri2014    #Borlaug100

• Background on genes Sr2 and Fhb1
• Objective: to generate evidence of recombination of Sr2 and Fhb1 resistance from repulsion to coupling
• Genetic Materials: Carberry/AC Cadillac
• Evidence:
  – Pedigree
  – Phenotype
  – FHB resistance with PBC and stem rust resistance
  – Haplotype
Background: Sr2

- Durable adult plant stem rust resistant gene
- Partial resistance
- Enhances expression of other Lr and Yr rust resistance genes
- 3BS (Yaroslav emmer to Hope and H.44-24 etc)
- QTL analysis of stem rust co-segregation with (microsatellite) markers in the region of gwm533 and gwm493
- SNP marker XcsSr2 co-segregated with Sr2 which is closest reported marker to date (Mago et al. 2011)
- Tightly linked to PBC (Kota et al. 2006)
- Fine mapping studies have identified recombinants in the region of gwm533 and gwm493 (Kota et al. 2006, McNeil et al. 2008)
Background: Fhb1

- Confers resistance to FHB, a major fungal disease causing loss of yield and grain quality (mycotoxins harmful to human and animal health).
- Resistance on 3BS (from landrace Taiwan wheat to Sumai 3).
- QTL analysis of FHB detected co-segregation with (microsatellite) markers in the region of gwm533 and gwm493.
- Current most tightly linked markers are Xsnp7 and Xsnp11, Xsts256, and Xsts3B-138 (Bernardo et al. 2012)
- Fine mapping studies have identified recombinants in the region of gwm533 and gwm493 (Cuthbert et al. 2006, Bernardo et al. 2012).
Background:

- *Sr2* and *Fhb1* are linked with QTL in the *Sr2/Fhb1* region of *gwm533* and *gwm493* on 3BS.
- ~5 cM apart (Bernardo et al. 2012)
- *Sr2* and *Fhb1* are currently reported only in repulsion.
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<th>End (bp)</th>
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<td>cfb6061</td>
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<td>gwm493</td>
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Combine Sr2 and FHB

Norman Borlaug,
Objective:

- To identify a recombinant of $Sr2$ and $Fhb1$ in coupling from the doubled haploid population of Carberry/AC Cadillac

- Null Hypothesis: PBC($Sr2$) and low FHB will not be expressed together in a DH line

- Evidence for recombination: a DH line which expresses both PBC and low FHB symptoms
Parental Materials

• AC Cadillac
  – resistant to stem rust
  – moderately susceptible to FHB
  – expresses molecular marker products linked to Sr2 but not to \textit{Fhb1} resistance

• Carberry
  – resistant to stem rust
  – moderately resistant to FHB
  – displays molecular marker products linked to \textit{Fhb1} but not to \textit{Sr2} resistance

• Both parents have gene \textit{Lr34/Yr18/Sr57/Pm38/Ltn1} (7DS)
Genotyping of the population

• Carberry/AC Cadillac
  – Phenotyped 261 DH line subset of doubled haploid population of 812 lines

• Genotyped with DArT® (578), SSR (54), BAC-derived (3), CAPS (3), and STS (3) molecular markers including:
  • SSR marker \textit{Xumn10} (SNP: \textit{Xsnp3BS-11}) is reported to be most diagnostic for \textit{Fhb1} (Bernardo et al. 2012)
  • \textit{XcsSr2} is reported to be most diagnostic for \textit{Sr2} (Mago et al. 2011)
Evidence: Pedigree

<table>
<thead>
<tr>
<th></th>
<th>AC Cadillac</th>
<th>Carberry</th>
<th>Thatcher</th>
<th>Hope</th>
<th>H44-24</th>
<th>Marquis</th>
<th>Yaroslav Emmer</th>
<th>Sumai #3</th>
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<td>Thatcher</td>
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<td>1.00</td>
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<td>0.25</td>
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<td>H44-24</td>
<td>0.16</td>
<td>0.12</td>
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<td>1.00</td>
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<td>Marquis</td>
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<td>0.18</td>
<td>0.50</td>
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<tr>
<td>Yaroslav Emmer</td>
<td>0.01</td>
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<td>0.00</td>
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<td>Sumai #3</td>
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<td>0.03</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

- Both AC Cadillac and Carberry have Yaroslav emmer in their genealogy
- Only Carberry has Sumai #3 in genealogy
Sr2 potential sources

94468 CT934/NEP
94390 ERA/PARK
94349 CT615
2314 NEEPAWA
199114 SELN 70.3524/7*NEP
1982 TOBARI F 66
2328 MANITOU

94391 RL 4353
3541384 BW40
94384 BW38
199063 BW 553
5414988 BW 15

193045 RL4359/RL4353
193044 RL4302/RL4356

193046 PACIFIC

5809130 BW 90/BW 553
5809659 BW90*/2/BW553

3825962 AC CADILLAC
Fhb1 potential source

Diagram showing genetic relationships involving terms such as BUTTE*2/ND507, LEN, ND-601, LEN/BUTTE*2/ND507, ND593, BW 83, ND585, GRANDIN/GLUPRO, SUMAI #3/WHEATON, GRANDIN, AC DOMAIN, ND-674, ND-2710, GRANDIN/AC DOMAIN, ND 688, ND674/ND2710, SUPERB, ALSEN, and CARBERRY.
Evidence: Stem Rust and Genetic analysis

Stem rust field nurseries:
- Njoro, Kenya: 2010, 11, 12, 13
- Swift Current, Canada: 2011 and 2012, and 2013

Stem Rust QTL (Singh et al. TAG 2013)
- AC Cadillac contributed stem rust resistance QTL on chromosomes 2B, 3B, 5B, 6D, 7B and 7D
- Carberry contributed resistance QTL on 4B and 5A.
- Epistatic interactions were observed between loci on 6D and 3B
Yellow Rust

• Swift Current, Canada in 2011
• Lincoln, NZ: 2012, 2013
• Njoro, Kenya: 2009, 2011

Yellow Rust QTL

• AC Cadillac was a source of yellow rust resistance QTL on chromosomes 2A, 2B, 3A, 3B, 5B, and 7B
• Carberry was a source of resistance on chromosomes 2B, 4B, and 7A. (Singh et al. 2014)
Evidence: Genetic analysis

Co-location:

- Yellow rust resistance QTL co-localized with stem rust resistance QTL on 2B, 3B, and 7B.
- *Sr2* and *Yr30* reported in same region 3BS
Epistatic Interactions:

- Several epistatic interactions were identified both for yellow and leaf rust resistance QTL.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Environment</th>
<th>QTL&lt;sub&gt;a&lt;/sub&gt;&lt;sup&gt;1&lt;/sup&gt;</th>
<th>QTL&lt;sub&gt;b&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</th>
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<td>Yr severity</td>
<td>Kenya</td>
<td>QYr.spa-3B.1</td>
<td>QYr.spa-2B</td>
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<td>Lr severity</td>
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<td>QLr.spa-3B</td>
<td>QLr.spa-4B</td>
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<td>Yr infection response</td>
<td>New Zealand</td>
<td>QYr.spa-3B.1</td>
<td>QYr.spa-2A</td>
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<td>Yr infection response</td>
<td>New Zealand</td>
<td>QYr.spa-3B.1</td>
<td>QYr.spa-7B.2</td>
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First QTL<sub>1</sub>
Second QTL<sub>2</sub>
Source: Singh et al. TAG 2014 (in press)
Evidence: Fusarium Head Blight

- FHB nurseries
- Variables: Incidence, Severity:
  \[
  \text{Disease Index} = \frac{\text{Incidence} \times \text{Severity}}{100}
  \]
- QTL in AC Cadillac 4B
- QTL in Carberry 3B, 5A, 6D
Evidence: Pseudo Black Chaff

- PBC is a dark pigmentation that may occur on the glumes, peduncle and below stem internodes, but its level of expression varies with genetic background and environment.
- Linkage of Sr2 and PBC has not been broken in about 90 yrs
- PBC scoring: an expression in 6 nurseries out of 12
- QTL for pseudo-black chaff:
  - AC Cadillac 2B and 3B
  - Carberry 6A
Pseudo Black Chaff

Carberry/AC Cadillac
DH line B0767&AB019
B0767&: Scatter plot of 261 DH lines

- AC Cadillac
- Carberry

Color code: 
- No. of lines: 1 2 3 4 5 6 7 8 9 11 12

FHB Index

Pseudo black chaff (#Environment)
Pseudo Black Chaff and low FHB
### Carberry/AC Cadillac: Haplotpye + Phenotype

#### Genotypic Data

<table>
<thead>
<tr>
<th></th>
<th>gwm389</th>
<th>csSr2</th>
<th>3B028F08</th>
<th>3B042G11</th>
<th>gwm533</th>
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</table>

#### Phenotyping

- **Sr2/Pbc**
- **Fhb1**

<table>
<thead>
<tr>
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<th>PBC (#Environment)</th>
<th>Severity Sr</th>
<th>Infection type Sr</th>
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<tr>
<td>AC Cadillac</td>
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<td>3</td>
</tr>
<tr>
<td>Carberry</td>
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<td>5</td>
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<tr>
<td>B0767&amp;AT073</td>
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<td>3</td>
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<td>B0767&amp;BF115</td>
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Summary of evidence

- Carberry/AC Cadillac: 261 DH phenotyped
- Evidence provided for Sr2 and FHB1: pedigree, phenotype, genotype
- DH lines expressed variation for: FHB; Stem, Yellow, & Leaf rust resistance; PBC
- QTL on 3B detected for FHB; Stem, Yellow, & Leaf rust resistance; PBC
- Co-location of QTL for Sr and Yr and Epistatic interactions Sr and Yr, and Sr and Lr
- Recovered recombinants with PBC and FHB resistance
- Haplotype recombination in Sr2/Fbh1 region based on markers reported to be closest linked
Acknowledgements

- Colleagues and Support Staff at:
  - AAFC, Swift Current, Lethbridge and Winnipeg, Canada
  - CIMMYT, Kenya
  - KARI, Njoro, Kenya
  - Plant and Food Research, Lincoln, New Zealand

- Funders:
  - Levy by Farmers of western Canada administered by Western Grains Research Foundation
  - AAFC: Growing Forward and core funding
Yield trial plots, KARI, Njoro, Kenya, 1971

Photo Credit: R. M. DePauw