Advances in Breeding for Resistance to Stem Rust Caused by Ug99 and Ethiopian *Pgt* Races in Durum Wheat

Karim Ammar, Abeyo Bekele, Alexandro Loladze, Susanne Dreisigacker, Roberto-Javier Peña & Masahiro Kishii
Global Wheat Program - CIMMYT

Ayele Badebo
DZARC – EARO, Ethiopia
Stem Rust on Durum Wheat
Specificity of the pathogen and current presence

- **Ug99+variants**
  - Present in Kenya, Ethiopia, Yemen, Iran
  - Widespread resistance in most durum germplasm groups

- **Ethiopian races, pre-dating Ug99**
  - Not as well characterized
  - *Sr13+Sr9e combined virulence* (Olivera et al. 2010)
  - Very little resistance (5%) in all germplasm groups worldwide (Olivera et al. 2010)
  - Confined to Ethiopia?, *Sr13* virulence present in Turkey
Stem Rust on Durum Wheat
Durum areas threatened by the “Ethiopian” races:

- Durum areas of Central India (1.0-1.5 million ha)
  - Through Yemen, most likely path as confirmed by migration of Ug99
  - Stem rust (less virulent races) already endemic in the region

- Turkey, North-Africa, Middle-East (>5 million ha)
  - Less likely dissemination path, but cannot be ignored
  - Sr13-virulence present in Turkey
  - Durum critical in these areas
  - Historically favorable climatic conditions for the development of stem rust epidemics

- Threat likely to increase with warming temperatures earlier in the cropping seasons as predicted by climate change scenarios
Breeding for Stem Rust Resistance in Durum Wheat

Screening in Njoro-Kenya vs. Debre Zeit-Ethiopia

\[ y = 0.9729x + 22.67 \]

\[ R^2 = 0.223 \]
Breeding for Stem Rust Resistance in Durum Wheat

The basis of our strategy

- Establishment of bi-annual screening program in Ethiopian “hot-spot”
  - Hosted by the Debre Zeit Ag. Res. Center
  - Artificial inoculation with mixture of relevant races (Ethiopian races + Ug99)
  - Screening of 1000s of lines annually:
    - Resistance sources discovery for crossing
    - Resistance confirmation in new advanced lines
    - Genetic studies for resistance characterization

Photos: Dr. Ayele Badebo
Breeding for Stem Rust Resistance in Durum Wheat
Rare resistance to start with in 2009… but enough to work with

<table>
<thead>
<tr>
<th>Reaction Class</th>
<th>Number of Lines</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 MR – 20 MRMS</td>
<td>12</td>
<td>3.1</td>
</tr>
<tr>
<td>30 MR – 40 MSS</td>
<td>36</td>
<td>9.3</td>
</tr>
<tr>
<td>50 – 70 S</td>
<td>278</td>
<td>71.3</td>
</tr>
<tr>
<td>80 – 100s</td>
<td>64</td>
<td>16.4</td>
</tr>
</tbody>
</table>

390 Elite Lines

Data from Debre Zeit, off-season 2009
Breeding for Stem Rust Resistance in Durum Wheat

Emphasis in CIMMYT crossing program

Crosses made for Stem Rust Resistance 2009 - 2012

- **Resistance Sources**
  - CIMMYT Elite
  - European germplasm
  - North-American germplasm
  - ICARDA germplasm
  - Genetic resources
  - Stocks with marked genes (MAS)

20 – 46% of program’s crossing effort
Breeding for Stem Rust Resistance in Durum Wheat
Selection stream: parallel selection Ethiopia/Mexico of new fixed lines

- **F2** Obregon
- **F3** Toluca
- **F4** Obregon
- **F5** Toluca/Batan

Selection for LR, YR, agronomic type, earliness and grain-fill

**MEXICO:** Selection for yield, drought tolerance, quality

- **F8** Rep YT Obregon
- **F7** HR Batan
- **F6** PYT Obregon

**ETHIOPIA:** Selection for Stem Rust resistance

- **F8** Off season Debre Zeit
- **F7** Main season Debre Zeit
- **F6** Off season Debre Zeit

Distribution Globally

Release Ethiopia

Globally

Ethiopia
Breeding for Stem Rust Resistance in Durum Wheat

Significant increase in resistant germplasm distributed globally

<table>
<thead>
<tr>
<th>Reaction Group</th>
<th>43 IDYN+IDSN Distributed 2011 (N = 152)</th>
<th>44 IDYN+IDSN Distributed 2012 (N = 150)</th>
<th>45 IDYN+IDSN Distributed 2013 (N = 159)</th>
<th>46 IDYN+IDSN Distributed 2014 (N = 216)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Lines</td>
<td>% Total</td>
<td>Number of Lines</td>
<td>% Total</td>
</tr>
<tr>
<td>Resistant</td>
<td>20</td>
<td>13.2</td>
<td>5</td>
<td>3.3</td>
</tr>
<tr>
<td>Moderately Resistant</td>
<td>5</td>
<td>3.3</td>
<td>17</td>
<td>11.3</td>
</tr>
<tr>
<td>Useful for Stem Rust</td>
<td>25</td>
<td>16.4</td>
<td>22</td>
<td>14.6</td>
</tr>
<tr>
<td>Moderately Susceptible</td>
<td>12</td>
<td>7.9</td>
<td>19</td>
<td>12.7</td>
</tr>
<tr>
<td>Susceptible</td>
<td>115</td>
<td>75.7</td>
<td>109</td>
<td>72.7</td>
</tr>
</tbody>
</table>

2009: 3.1%
Breeding for Stem Rust Resistance in Durum Wheat

Significant increase in resistant germplasm distributed globally while maintaining agronomic performance

- Stem Rust Resistant lines have similar distribution than other lines
  - Yield Potential
  - Drought Tolerance
  - Quality attributes (gluten strength & yellow color)
### Breeding for Stem Rust Resistance in Durum Wheat

**Stacking alien genes of resistance via MAS**

<table>
<thead>
<tr>
<th>Gene</th>
<th>Location</th>
<th>Origin</th>
<th>Source Originally Used</th>
<th>Marker Designation</th>
<th>Inheritance</th>
<th>Phenotypic Validation and use in program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr25/Lr19</td>
<td>7AL</td>
<td><em>L. ponticum</em></td>
<td>Durum w heat (^1)</td>
<td><em>PsyA1+PsyER4</em></td>
<td>Co-dominant</td>
<td>Full phenotypic expression, routine use in parent characterization and MAS</td>
</tr>
<tr>
<td>Sr22</td>
<td>7AL</td>
<td><em>T. boeticum</em></td>
<td>Bread w heat</td>
<td><em>cfa2123</em></td>
<td>Co-dominant</td>
<td>Full phenotypic expression, routine use in parent characterization and MAS</td>
</tr>
</tbody>
</table>

\(^1\): Transferred to durum by Dr. Adam Lukashewski, U.C. Riverside

Photos: Susanne Dreisigacker

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**Sr25**

*PSY1-EF2_ER4*

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**Sr22**

*(cfa2123, cfa2019)*
Breeding for Stem Rust Resistance in Durum Wheat

Sr22 and Sr25 loci tightly linked, essentially inherited together, attempt at better gene stewardship...

 Chr. 7A  
(Courtot x C.S.)

<table>
<thead>
<tr>
<th>Chromosome Segment</th>
<th>Genes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7AL-1.0</td>
<td>Xgpw2242, Xfba423, Xfba17, Xgpw4130</td>
</tr>
<tr>
<td>7AL-1.039</td>
<td>Xfba132, Xfba201, Xgpw3234</td>
</tr>
<tr>
<td>7AL-7.7</td>
<td>Xfba171, Xfba71, Xfba222</td>
</tr>
<tr>
<td>7AL-7.9</td>
<td>Xfba127, Xfba109, Xbcd1438</td>
</tr>
<tr>
<td>7AL-8.2</td>
<td>Xfba127, Xfba109, Xbcd1438</td>
</tr>
</tbody>
</table>

**Double-Cross Population**

- **F1<sub>Sr22</sub>**
  - **MAS**
  - **F6**
    - **F8**
      - Testing SR Yield, Drought Quality

- **F1<sub>Sr25</sub>**
  - **Double-Cross Population**
  - **F6**
    - **F8**
      - Testing SR Yield, Drought Quality
Breeding for Stem Rust Resistance in Durum Wheat
Advanced lines with linked Sr22+Sr25

- GISH of *L. Ponticum* segment
  - Telomeric

- GISH of *T. Boeticum* segment
  - Not yet available

Photos: Masahiro Kishii
Breeding for Stem Rust Resistance in Durum Wheat

Advanced lines with linked Sr22+Sr25: Characteristics

- **Confirmed homozygocity for both genes**
  - Markers stably homozygous in F$_6$ – F$_8$ head-rows
  - Stably resistant over 2-3 seasons at Debre Zeit

- ** Improved quality parameters**
  - Better gluten strength than most local cultivars
  - Significantly higher yellow color than local cultivars

- **Variable yield performance and drought tolerance**
  - Obregon: some yield penalty due to lower kernel size
  - Ethiopia: under evaluation
  - Second round breeding started!!
CIMMYT – DZARC Joint Breeding Effort for Stem Rust Resistance in Durum Wheat: Conclusions

- **Debre Zeit phenotyping platform has been key!**
  - Testing facilities have been enhanced, effort needs sustaining

- **Strategy of parallel Selection Mexico/Ethiopia has been successful**
  - Significant progress in frequency of SR resistant or moderately resistant lines in CIMMYT outgoing germplasm
  - Useful variability for yield potential, drought tolerance and quality maintained in new resistant germplasm

- **MAS with gene stewardship in mind provided valuable germplasm**
  - If not usable for cultivar release, provides useful parental stocks for further breeding
Stem Rust Resistance in Durum Wheat
Research efforts to provide information and markers for breeding

- **Association Mapping of Stem Rusts resistance**
  - Beachell-Borlaug scholar Tesfaye Dugo Letta
  - Led y Prof. Tuberosa team, Univ. Bologna, Italy
  - Results from adult plant reaction and seedling published *(Letta et al., TAG, 2013; Letta et al., Plant Genome, 2014)*

- **Mapping of Stem Rust Resistance from Boohai**
  - Beachell-Borlaug scholar Tesfaye Dugo Letta
  - Led y Prof. Tuberosa team, Univ. Bologna, Italy
  - Phenotyping done, mapping in process

- **Mapping of Stem Rust Resistance from COCORIT**
  - Collaboration with Dr. Curtis Pozniak, Univ. Saskatchewan
  - Preliminary results presented, manuscript in progress