TRITICALE: HOW TO BREED AN INTERGENERIC SPECIES?

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Outline

• Origin of triticale
• Why triticale?
• Present status
• The challenge of triticale breeding: genepool expansion
• Breeding methodology
Triticale: successful man-made crop

- Human-made crop developed by crossing wheat (Triticum) and rye (Secale) species
  - Intergeneric hybrid: X Triticosecale Wittmack

Also reverse cross exist but lack productivity
- X Secalotricum: Rye x wheat
Historical Milestones

• 1875: First crosses between wheat and rye by Scottish botanist Wilson: (F1 → sterile)
• 1884 – 1891: First fertile hybrids: Carman and Rimpau observed fertile sectors in ears of wheat-rye amphiploids (meiotic dihaploidisation?)
• 1921: Meister: breeding program on wheat-rye hybrids
• 1930: Intensive breeding: after discovery of characteristics of colchicine
• 1966: First commercial variety in Hungary (triticale №57)
• 1970: Large breeding programs were started up:
  • CIMMYT
  • Poland
  • France
  • Canada
  • …
Why triticale?

Combining the best of both of its parents:

1. Yield level and kernel quality of wheat
2. Tolerance to less favourable growing conditions (e.g. tolerance to cold, drought, Al-toxicities) and nutrient uptake efficiency of rye)
3. More disease resistance than wheat
Triticale present status (1)

- Worldwide: 4,135,952 ha
Triticale present status (2)

**Yield**

Since the beginning of triticale breeding yield potential was continuously improved:

- **UGent:** mean 1980s: 5684 kg/ha
  - mean 2000-2006: 6865 kg/ha \( \Delta: +18\% \)
  - mean 2010-2016: 9865 kg/ha \( \Delta: +73,6\% \)
- **CIMMYT:** 1980s → 1990s: + 17 %

Major contributions resulted from:

- Harvest index: +16 % (plant height: 140 cm → 125 cm)
- Spikes per m²: + 12 %
- Grains per m²: + 17 % and test weight: + 12 %

Especially under less optimal soil conditions triticale perform much better than wheat.

(CIMMYT yield trials CIANI, NW Mexico)
Triticale present status (3)

- Inferior bread making quality due to the absence of the D genome of wheat (*T. aestivum*)
- Feed:
  - Energy value is comparable with that of wheat
  - Protein content of triticale grain is higher than that of wheat
  - Amino acid composition of the protein is nearly similar to wheat, but may be slightly higher in lysine
  - Increasing area as silage crop (roughage)
Triticale as whole plant silage

<table>
<thead>
<tr>
<th>Crop/variety</th>
<th>Dry matter content (%)</th>
<th>Digestibility</th>
<th>VEM</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>t DM ha(^{-1})</td>
</tr>
<tr>
<td>Triticale</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vision</td>
<td>36.2 b (^4)</td>
<td>55 b</td>
<td>773 b</td>
<td>19.3</td>
</tr>
<tr>
<td>Ticino</td>
<td>38.8 b</td>
<td>54 b</td>
<td>763 b</td>
<td>19.3</td>
</tr>
<tr>
<td>Babor</td>
<td>37.9 b</td>
<td>54 b</td>
<td>763 b</td>
<td>21.2</td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beaufort</td>
<td>36.8 b</td>
<td>52 b</td>
<td>730 b</td>
<td>13.8</td>
</tr>
<tr>
<td>Tremie</td>
<td>42.8 a</td>
<td>51 c</td>
<td>720 c</td>
<td>12.7</td>
</tr>
<tr>
<td>Isengrain</td>
<td>44.3 a</td>
<td>51 c</td>
<td>720 c</td>
<td>13.0</td>
</tr>
</tbody>
</table>

\(^1\)Cellulase OM-digestibility;
\(^2\)VEM (Net energy for lactation): 204 + 10.113 \times \) Cellulase OM-digestibility (%);
\(^3\)Average whole plant yield: 16.6 t ha\(^{-1}\);
\(^4\)Means followed by the same letter are not significant different according to Duncan’s multiple range test P>0.05
Triticale present status (4)

- Yield winter triticale progress since 2000 (yearly varietal trials UGent)

Crop management:
- Sowing October/350 kernels/m²
- 3 N fraction according to advice
- Herbicide/growth regulator/1or 2 Fungicide treatment

Crop management:
- Sowing October/350 kernels/m²
- 3 N fraction according to advice
- Herbicide/growth regulator/ NO Fungicide treatment
Powdery mildew

![Graph showing disease scores over years for B. graminis and M. graminicola.](image)
powdery mildew ➔ stripe rust

The challenge in triticale breeding

- Sufficient genetic variation is necessary to obtain breeding goals but Triticale has no natural evolution

- What are the possibilities?

  genetic variation must be got from the parent species
Triticale: a cytogenetic labyrinth

AABBDD x RR → ABBR

ABR → ABBDDRR (2n: 56)

pr. octaploid

1930

AABBDDRR (2n: 56) → ABBDRR

prim. hexaploid

1966

AABBDDRR → ABBRR

sec. hexaploid
Expansion of triticale germplasm (1)

Production of primary triticales

- Primary triticales → new secondary hexaploid triticales
- Production:

  \[
  \text{AABBDD} \times \text{RR} \quad \downarrow \quad \text{ABDR} \quad \downarrow \quad \text{Colchicine} \\
  \quad \Downarrow \\
  \text{AABBDDRR}
  \]

Crossability of wheat and rye is under genetic control → two complementary genes KR1 and KR2 (on 5B and 5A, respectively):

- \( k1k1 \) vs. \( k2k2 \): 0–10%
- \( k1k1 \) vs. \( k2k1 \): 10–30%
- \( k1k1 \) vs. \( k2k2 \): 30–50%
- \( k1k1 \) vs. \( k2k2 \): > 50%

Strong QTL SKr on 5BS
Two SSR markers strongly linked to SKR
## Crossability wheat x Rye

<table>
<thead>
<tr>
<th>Year</th>
<th>N° wheat varieties</th>
<th>N° florets pollinated</th>
<th>Seed set (% of pollinated florets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>29</td>
<td>1160</td>
<td>0.7</td>
</tr>
<tr>
<td>1986</td>
<td>21</td>
<td>840</td>
<td>1.7</td>
</tr>
<tr>
<td>1987</td>
<td>27</td>
<td>1080</td>
<td>0.6</td>
</tr>
<tr>
<td>1988</td>
<td>36</td>
<td>1440</td>
<td>0.3</td>
</tr>
<tr>
<td>1989</td>
<td>17</td>
<td>680</td>
<td>2.2</td>
</tr>
<tr>
<td>1991</td>
<td>15</td>
<td>600</td>
<td>0.7</td>
</tr>
<tr>
<td>1992</td>
<td>4</td>
<td>160</td>
<td>7.5</td>
</tr>
</tbody>
</table>

+ UGent: W-European wheat varieties → poor crossability with rye

+ Chinese and South American genotypes → more than 50% seed setting after hybridisation

**Solution:** creating of genepool of crossable wheat genotypes with excellent genetic background

⇒ screening by using markers
Expansion of triticale germplasm (2)

Production of secondary triticales

AABBDDRR \( \times \) AABBRR

\[ \text{AABBDDRR} \]

5-6 generations (self pollination)

\[ \text{AABBRR} \]

- Polycross design is useful to combine octaploids with hexaploid
  - In progenies: % of heptaploids (49 chromosomes) varied from 10 to 85 %
  - Natural selection by sowing populations at different locations
Expansion of triticale germplasm (3)

- In hybrids between octaploids and hexaploid there will be a comprehensive genetic recombination between A and B genome of the tetraploid and hexaploid wheat parents
- D(A) and D(B) substitution may happen through pairing failure of the A or B homologous chromosomes during meiosis and the subsequent univalent swift
  - 6D(6A) substitution are frequently detected
- Use of ph1 mutans (Ph1 inhibits synapsis of homoeologous chromosomes in alloploids): more pairing in synapsis between D and B or A chromosomes will result in more new recombinations
Expansion of triticale germplasm (4)

Backcrosses with wheat

- Hybridization between hexaploid triticale and hexaploid wheat is becoming a routine procedure in triticale breeding
- Three way crosses: Triticale x wheat → F1 x triticale are very suitable at the beginning of a breeding cycle

- Crosses between hexaploid triticale and wheat may result in chromosome substitutions between R and D genome
- Natural selection that favours karyotypes in which the differences in chromosome size and DNA content between wheat and rye genomes have been reduced by substitution of the R chromosomes by their smaller D-Homoeologous chromosomes: e.g., 2R → 2D
Expansion of triticale germplasm (5)

- Wheat/rye translocation are in sufficient number present in triticale x wheat populations to be important for breeding;
- For example: cv. Presto: 1R is cytogenetically changed by wheat/rye translocations
  - Due to homoeologous pairing and recombination between 1R and 1D or 1B, secalin loci Sec-1 and Sec-3 of 1R are changed by interogation of the wheat storage protein loci Gli-1 and Glu1 fragments

  Improvement in bread making quality
**Powdery mildew: wheat varieties as resistance sources**

**Virulence testing**

- Reaction type produced by each differential and *B. graminis* isolate combination was scored 14 days after inoculation on a 0 to 4 scale (Torp et al. 1978)
- **Reaction type 0-2** → resistant
- **Reaction type 3-4** → virulent

| Host | Cultivar | Resistance gene(s) | UK (1) | UK (2) | Switzerland (1) | Sweden (1) | Poland (1) | France (1) | Belgium (1) | Belgium (2) | Belgium (3) | Belgium (4) | Belgium (5) | Belgium (6) | Belgium (7) | Belgium (8) | Belgium (9) | Belgium (10) | Belgium (11) | Belgium (12) | Belgium (13) | Belgium (14) | Belgium (15) | Belgium (16) | Belgium (17) |
|------|----------|-------------------|--------|--------|-----------------|-------------|------------|------------|------------|------------|------------|------------|-------------|-------------|-------------|------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|
| Wheat | Lancaster | none              | 3      | 4      | 0               | 4           | 4          | 4          | 4          | 4          | 4          | 4          | 4           | 4           | 4           | 4          | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           |
|       | Jaffari  | Pm13              | 5      | 5      | 5               | 5           | 5          | 5          | 5          | 5          | 5          | 5          | 5           | 5           | 5           | 5          | 5          | 5           | 5          | 5           | 5          | 5           | 5          | 5           | 5          | 5           |
|       | Galadad  | Pm2               | 4      | 0      | 4               | 4           | 4          | 4          | 4          | 4          | 4          | 4          | 4           | 4           | 4           | 4          | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           |
|       | Assian   | Pm30              | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
|       | Chul     | Pm36              | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
|       | Sonora   | Pm1c              | 4      | 3      | 4               | 2           | 4          | 3          | 4          | 4          | 4          | 4          | 4           | 4           | 4           | 4          | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           |
|       | Bloom    | Pm3d              | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
|       | Michigan | Amber             | Pm1f   | 4      | 4      | 4               | 4           | 4          | 4          | 4          | 4          | 4          | 4           | 4           | 4           | 4          | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           |
|       | Khapli   | Pm4d              | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
|       | Welkeene | Pm4d              | 4      | 4      | 4               | 4           | 4          | 4          | 4          | 4          | 4          | 4          | 4           | 4           | 4           | 4          | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           |
|       | Hope     | Pm16              | 4      | 4      | 4               | 4           | 4          | 4          | 4          | 4          | 4          | 4          | 4           | 4           | 4           | 4          | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           | 4          | 4           |
|       | Helger   | Pm16              | 5      | 5      | 5               | 5           | 5          | 5          | 5          | 5          | 5          | 5          | 5           | 5           | 5           | 5          | 5          | 5           | 5          | 5           | 5          | 5           | 5          | 5           | 5          | 5           |
|       | Trossac  | Pm7               | 3      | 3      | 3               | 3           | 3          | 3          | 3          | 3          | 3          | 3          | 3           | 3           | 3           | 3          | 3          | 3           | 3          | 3           | 3          | 3           | 3          | 3           | 3          | 3           |
|       | Normandie| Pm12              | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
|       | Sappho   | Pm3, Pm4          | 3      | 3      | 3               | 3           | 3          | 3          | 3          | 3          | 3          | 3          | 3           | 3           | 3           | 3          | 3          | 3           | 3          | 3           | 3          | 3           | 3          | 3           | 3          | 3           |
|       | Amigo    | Pm12              | 4      | 5      | 5               | 5           | 5          | 5          | 5          | 5          | 5          | 5          | 5           | 5           | 5           | 5          | 5          | 5           | 5          | 5           | 5          | 5           | 5          | 5           | 5          | 5           |
| Triticale | Landbergo | Unknown           | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
|       | Maximai  | Unknown           | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
|       | Borodina | Unknown           | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
|       | Rye     | WIDLO              | Unknown | 0      | 0      | 0               | 0           | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0          | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           | 0          | 0           |
Expansion of triticale germplasm (6)

- Three classes of multi-breakpoint translocation chromosomes of 1R are described in Presto:
  - **Chromosome Valdy**: 3-breakpoint translocation with loci *Gli-D1*, *Sec-1* and *Glu-D1*
  - **Chromosomes FC1 and FC2**: 5-breakpoint translocations with *Gli-D1* and *Glu-D1*
  - **Chromosome RM**: 6 breakpoint translocations with *Gli-B1* and *Glu-D1*
    - Increase of 230 to 250 % of SDS sedimentation value: better bread quality
Expansion of triticale germplasm (7)

- Tetraploids are cyto-genetically instable and characterised by a high degree of sterility
- Possible practice:
  - Octaploid x tetraploid → hexaploid
  - D chromosomes can be introduced for A or B chromosomes in hexaploids, leaving the R genome complete
Breeding methodology (1)

- Breeding methods used for triticale must take into account some specific features:
  - Partial sterility of some crosses
    → Bulk method for several generations (until F5 – F6)
  - A longer period of segregation
  - Open pollination and outcrossing (mostly less than 10% but sometimes more than 40%)
  - More attention must be paid to plant isolation in earlier generations
  - Important variation in plant height
  - An experimental design with guard plots must be used for avoiding inter plot competition
Breeding methodology (2)

• Two selection methods are frequently used:
  • For triticale x triticale crosses: Pedigree selection with selection of individual plants in the F2 generation
  • For octaploid x hexaploid crosses of triticale x wheat crosses: Bulk method during first generations and starting with individual plant selection in F5 or F6 generation
Breeding methodology (3)
Breeding methodology (4)

Pedigree selection

F4

F5

Field trial (1 repl)

F6

Field trial (4 repl)

F7

Field trials on several locations

F8

F12
Breeding methodology (5)

- Bulk method
Breeding methodology (6)

- Most companies are using dihaploids or single seed descend method to shorten the breeding cycle
Breeding methodology (7)

• Triticale hybrids
  • CMS-T based on *T. timopheevi* cytoplasm
  • Most triticale genotypes can used as restorer lines
  • Only a few maintainer lines have been described (e.g. LC427 of CIMMYT origin)
Breeding methodology (8)

• Marker assisted breeding
  • A lot of agronomic and economic important traits have been mapped in wheat and rye using molecular markers
  • Markers are available for a series of major disease resistance loci and loci for stress and quality traits;
• For triticale:
  • markers for Al tolerance Dart markers on 4R/6R and 7R
  • Preharvest sprouting: less than 10 % of the genotypes studied during the last two decades could be classified as more or less preharvest sprouting tolerant and are a potential genetic resource for breeding!
Gene-expression profiles as breeding tool for Preharvest sprouting.

Expression of α-Amy1 gene in two triticale varieties during seed development.

Physiological breeding

- Triticale: $\delta^{13}C$ (based on $C^{13}/C^{12}$) isotope signature at milking stage is a strong integrator of intrinsic water use efficiency.
Breeding methodology (8)

D13C = Discrimination $C^{13} = \frac{C^{13}}{C^{12}}$
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