Application of molecular markers in cereals breeding

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Worldwide development of food supply

**World population**
(in Mrd)

- 1950
- 1975
- 2000
- 2025
- 2050

**Cultivated area**
(in Mrd ha)

- 1950
- 1975
- 2000
- 2025
- 2050

**Arable land per-capita**
(in ha)

- 1950
- 1975
- 2000
- 2025
- 2050

Breeding of high yielding and resistance to abiotic and biotic stress cultivars will play a key role
Conventional Plant Breeding

Yield
- Grain yield

Quality
- Nutrition
- Processing

Resistance
- Diseases

Agronomic traits
- Yield Stability

Nutrient use efficiency
- Nitrogen
Conventional Plant Breeding

GENETIC RESOURCES

Evaluation of plants
↓
Crossing
↓
Evaluation

Selection

years, places, replications

resistances, yield, quality

Official testing
↓
Variety

2 to 4 years

6 to >8 years

8 to >12 years, 5 to 6 mn €, release rate < 10%
State of the art in plant breeding technologies

Breeding speed-up and add-on technologies
- Genomic research
- Gene technology
- DNA diagnostics
- Cell- and tissue culture

Yield improvement
- Hybrid breeding
- Cross breeding and selection

Timeline:
- 1856
- 1910
- 1940
- 1970
- Today
Molecular markers

Advantages of molecular markers:

- environment independent detection of trait(s)
- application in early generations
- possibility for HT automatisation

Disadvantages of molecular markers:

- relatively high cost of application
- limited application on quantitative trait(s)
Seed Production of Hybrid Rye

- Pre-basic seed (1st year)
- Basic seed (2nd year)
- Certified seed (3rd year)
- Hybrid rye, commercially grown (4th year)

General formula of a hybrid rye variety: \((A\text{-cms} \times B\text{-N}) \times R\text{-Syn}\)
Fertility restoration in rye

Germinating sclerotia

Ergot

Ergot intoxification in the middle ages (fire of St. Anton)
Altar of Isenheim (Alsassia, France)

Pollen grains germinating on pistils
Fertility restoration in rye
Fertility restoration in rye
Fertility restoration in rye

"old" assay

"modern" assay
A = 87,5 % RP

B = 64,5 % RP
Fertility restoration in rye

Hybrid Rye with PollenPlus

increased pollen shedding = less ergot
tolerant of stress

medium hybrid rye

high · ergot infection level · low

medium conventional rye

PollenPlus hybrid rye

An additional information about POLLEN+ strategy see on www.pollenplus.de
WHEAT
Fusarium Head Blight (FHB) in cereals

- Winter wheat is most prominent in Germany, followed by barley, rye and triticale

- Complex of *Fusarium* species: *Fusarium graminearum*, *F. culmorum*, *F. avenaceum*, *F. poae*

- Main focus on deoxynivalenol (DON), but nivalenol (NIV) occurs also

- Epidemics do not occur regularly (1998 and 2002 in Germany), however, mycotoxins can be found every year

- Mycotoxin contamination is of greater concern than yield loss (food safety)
**Mycotoxins in cereals**

**Commission Regulation (EC) No 856/2005**

<table>
<thead>
<tr>
<th>DON in unprocessed cereals:</th>
<th>1250 µg kg(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>DON in bread and bakeries:</td>
<td>500 µg kg(^{-1})</td>
</tr>
<tr>
<td>DON in baby food:</td>
<td>200 µg kg(^{-1})</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Germany(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durum products</td>
</tr>
<tr>
<td>Cereals for human consumption</td>
</tr>
<tr>
<td>except Bread, pastries, beer</td>
</tr>
<tr>
<td>Baby food</td>
</tr>
</tbody>
</table>

\(^1\) Since February 2004 valid
Selection success by resistances breeding

Note 1-9, (1 is full resistant)

Resistance to

- FHB
- Powdery mildew

BSL 1986-2005
Strategies towards improving resistance to Fusarium Head Blight

Molecular breeding
- Marker development
  - QTL-Mapping
  - QTL-Validation
- Recurrent selection
  - Phenotypic selection
- Marker-based selection

Genetic engineering

LfL/IFA  LfL/HOH/LP  HOH/LP/LfL  PLT/MPI/LP
1. Resistance level of Sumai 3 is much higher
2. Low number of QTL with high effects that are less dependent on environment
FHB resistance of parents

Spring wheat

- CM 82036 (CHINA)
- Frontana (BRAS)
- Munk (D)

Winter wheat

- G16-92
- Brando
- Dream
- LP 235.1
A. Spring wheat

2000

\((A^R \cdot B) \times (C^R \cdot D)\)

- Phenotyp. Sel.
- Marker-based Sel.

2001

- Test 1
- Test 2
- Recomb.
- S0
- MBS
- S+MBS
- xS

2002

- Test 1'
- Recomb.
- S0
- S+MBS
- xS

2003

- Test 1'
- xS

2004

- C0
- CP1
- CP1'
- CM
- unsel.
- sel.

2005

Data analysis, use of selected lines in breeding programmes

B. Winter wheat

2000

\((E^R \cdot F) \times (G^R \cdot H)\)

- Phenotyp. Sel.
- Marker-based Sel.

2001

- Test 1
- MBS
- S0
- S+MBS
- xS

2002

- Test 1
- Recomb.
- S0
- S+MBS
- xS

2003

- C0
- C1
- CM

2004

- Data analysis, use of selected lines in breeding programmes
Effect of exotic QTL on DON content in spring wheat
# Mean realised selection gain

<table>
<thead>
<tr>
<th>Variant</th>
<th>Spring wheat</th>
<th>Winter wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Total</td>
</tr>
<tr>
<td>Phenotypic selection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP1</td>
<td>40</td>
<td>9.6 (2)</td>
</tr>
<tr>
<td>CP1'</td>
<td>135</td>
<td>12.6 (3)</td>
</tr>
<tr>
<td>Marker-based selection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CM</td>
<td>26</td>
<td>8.8 (1)</td>
</tr>
</tbody>
</table>

EUREKA – 2004, 4 locations
Canadian-German Collaboration on Plant Genomics Research
Reducing Fusarium Toxins in Wheat Through Genomics - Guided Strategies

Duration: 4 Years 1.04.2006 - 31.03.2010

Project coordination (Canada):
Dr. Daryl Somers /Christof Rampitsch

Project coordination (Germany):
scientific: Prof. Dr. Gerhard Wenzel / Dr. M. Schmolke (TUM)
industrial: Dr. E. Ebmeyer (KWS-L)

Cooperating Partners in Germany:
University of Hohenheim (UHOH)
Bavarian State Research Center for Agriculture (LfL)
Technical University of Munich (TUM)
Federal Centre for Breeding Research on Cultivated Plants (JKI)
Institute of Plant Genetics and Crop Plant Research (IPK)
KWS LOCHOW GMBH
Saaten-Union Resistenzlabor GmbH
Module 1: Molecular characterization of resistance sources adapted to Central Europe

Partners: LfL, Saaten Union, TUM

Module 2: Introgression breeding of resistance from exotic sources

Partners: KWS, Julius Kühn Institut

Module 3: Functional genomics

Partners: IPK, TUM
FHB resistance from exotic sources
FHB resistance tests – spray inoculation
GABI Canada: Aims of our part (module 2) of the project

1. **Marker based transfer** of the exotic resistance QTL 3B and 5A into elite winter wheat

2. **Linkage drag**: Evaluation of possible negative effects of the exotic resistance loci on yield and other characters

3. **Dissection of QTL**: Diminution of the exotic chromosome segment by retaining the FHB resistance
## Development of material for Dissection and Linkage Drag

<table>
<thead>
<tr>
<th>Generation</th>
<th>Sowing</th>
<th>Marker Analysis</th>
<th>Dissection (Opus)</th>
<th>Linkage Drag (Opus/Anthus)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opus x Donor</td>
<td>Nov. 2002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthus x Donor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1 x Opus/Anthus</td>
<td>Aug. 2003</td>
<td>1.940 GT</td>
<td></td>
<td>Marker assisted background selection</td>
</tr>
<tr>
<td>BC1 x Opus/Anthus</td>
<td>Feb. 2004</td>
<td>2.500 GT</td>
<td></td>
<td>Marker assisted background selection</td>
</tr>
<tr>
<td>BC2 x Opus/Anthus</td>
<td>Oct. 2004</td>
<td>3.300 GT</td>
<td></td>
<td>Marker assisted background selection</td>
</tr>
<tr>
<td>BC3 F1</td>
<td>July 2005</td>
<td>3.600 GT</td>
<td>Selection: Bbaa, bbAa</td>
<td>Selection: aaBb, bbAa, AaBb</td>
</tr>
<tr>
<td>BC3 F3</td>
<td>Aug. 2006</td>
<td>7.700 GT (3.000 GT)</td>
<td>B_aa: 402 GT with recomb. bbA_: 300 GT with recomb.</td>
<td>BC3 F2:3</td>
</tr>
<tr>
<td>BC3 F4</td>
<td>Jan. 2007</td>
<td></td>
<td>Homozygous sub-NILs</td>
<td>BC3 F2:4</td>
</tr>
<tr>
<td>BC3 F4:5</td>
<td></td>
<td>Propagation 2008</td>
<td></td>
<td>BC3 F2:5</td>
</tr>
</tbody>
</table>

- **GT**: Genotypes
- **Resistance Donor**: SW1-91 (CM 82036 x Nandu) x (Frontana x Munk)

- **Yield and resistance trial 2008**
  - T=180, P=5, R=2

- **Yield and resistance trial 2009**
  - (P=4)
  - 3B: 165 GT, 5A: 183 GT
  - T=180, P=5, R=2
Exotic resistance loci in elite winter wheat
Susceptibility for FHB in different marker classes
**GABI-Wheat:** Establishment of a platform for genome-wide association mapping in wheat
BARLEY
Malting quality
Virus resistance in barley

- ym4/ym5

+ ym4/ym5
Magic triangle

- Plant Genetics
- Ressources
- Breeding
- Genomics
- TriGen COST action
- ITMI
Thank you for your attention!