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BIOSCIENCE ENGINEERING

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 N°57)
- 1970: Large breeding programs were started up:
  - CIMMYT
  - Poland
  - France
  - Canada
  - …

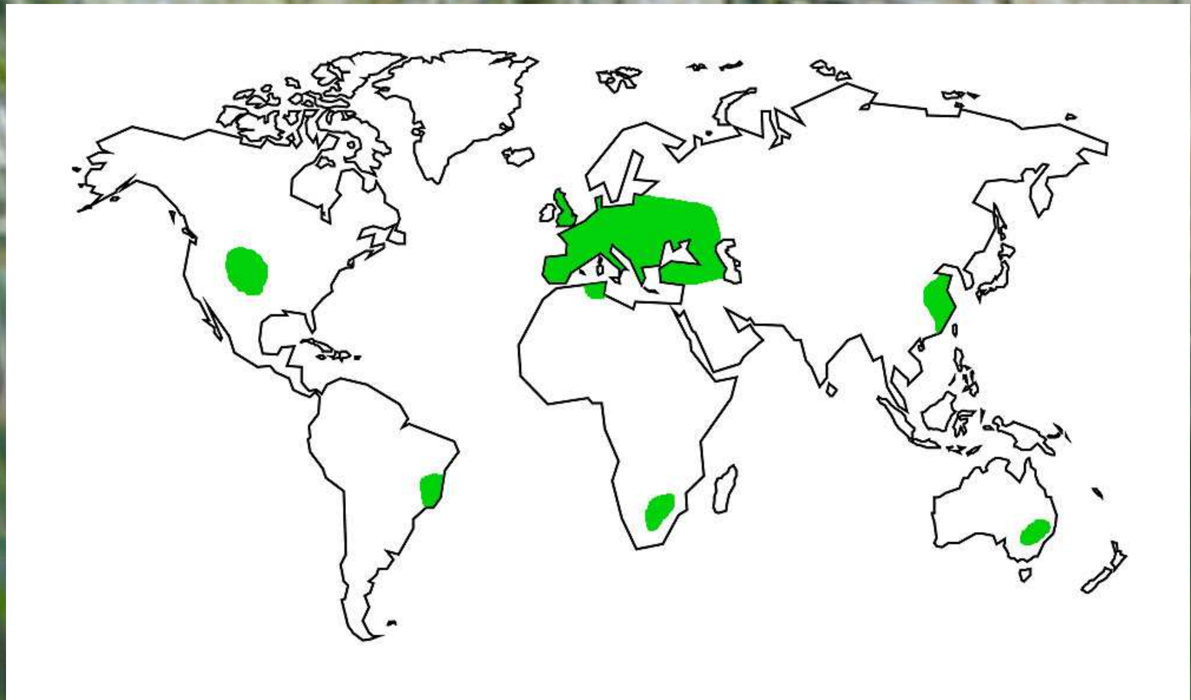
Why triticale?

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 **Δ: +18 %**

mean 2010-2016: 9865 kg/ha **Δ: + 73,6%**

CIMMYT: 1980s → 1990s: + 17 %

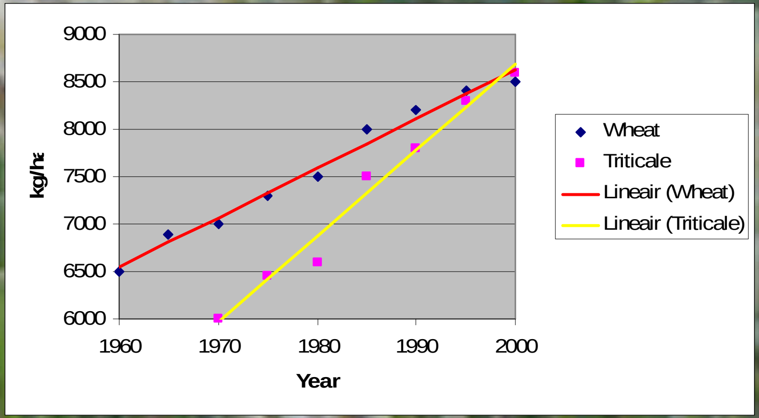
Major contributions resulted from:

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

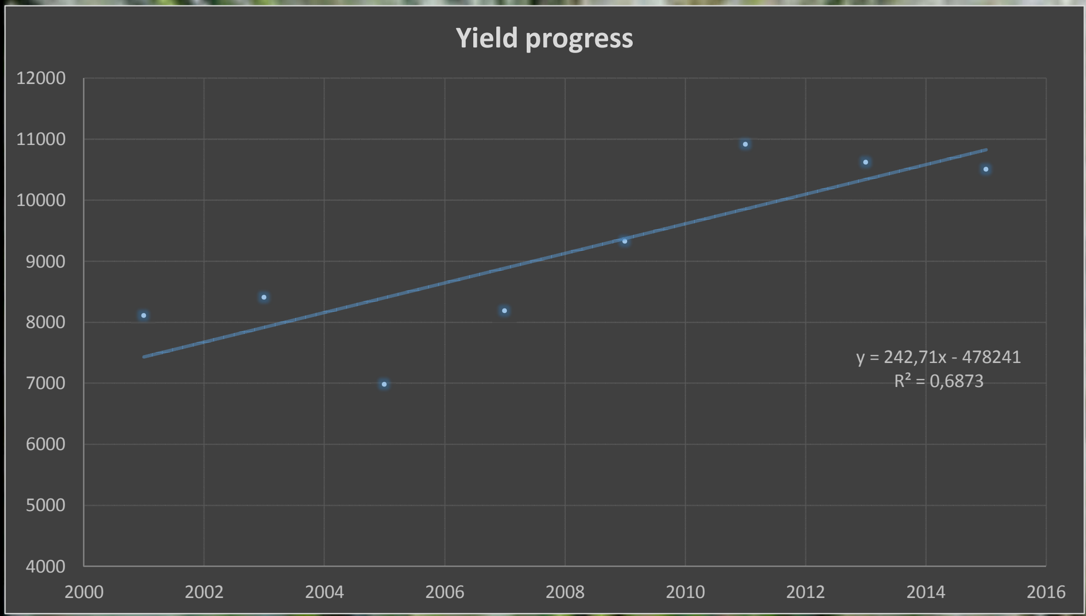
Table 2. Comparison of whole plant silage yield (t DM ha^{-1}) of triticale and wheat (1997–98 growing season)

Crop/variety	Dry matter content (%)	Digestibility[1] (%)	VEM[2]	Yield	
				t DM ha^{-1}	% of average[3]
Triticale					
Vision	36.2 b[4]	55 b	773 b	19.3	116.6 b
Ticino	38.8 b	54 b	763 b	19.3	116.6 b
Babor	37.9 b	54 b	763 b	21.2	128.1 a
Wheat					
Beaufort	36.8 b	52 b	730 b	13.8	83.4 c
Tremie	42.8 a	51 c	720 c	12.7	76.7 c
Isengrain	44.3 a	51 c	720 c	13.0	78.5 c

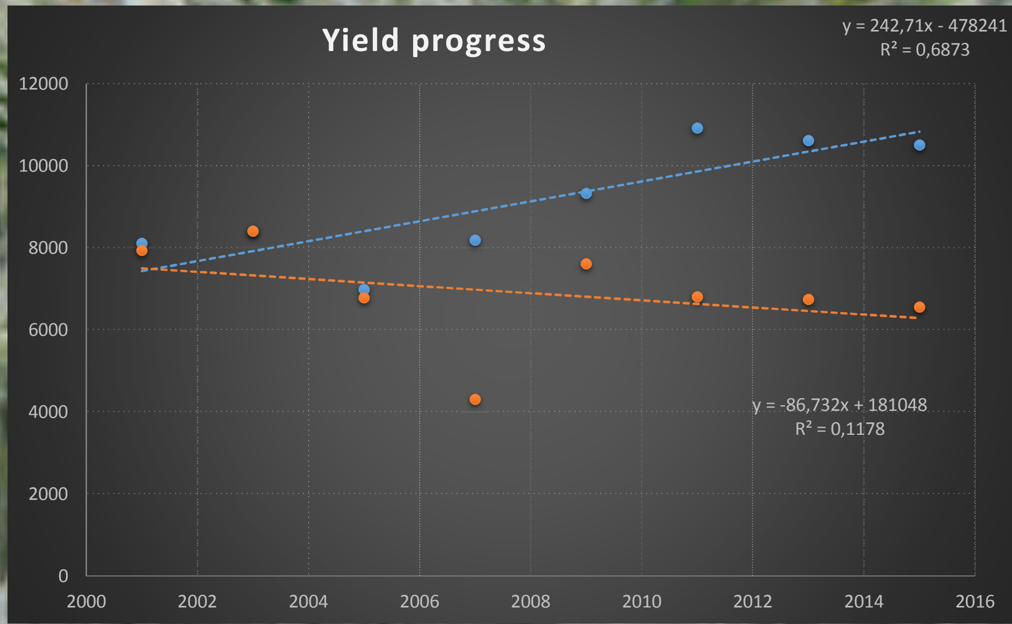
[1]Cellulase OM-digestibility;
[2]VEM (Net energy for lactation): 204 + 10.113 × Cellulase OM-digestibility (%);
[3]Average whole plant yield: 16.6 t ha^{-1};
[4]Means followed by the same letter are not significant different according to Duncan's multiple range test P>0.05

Triticale present status (4)

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

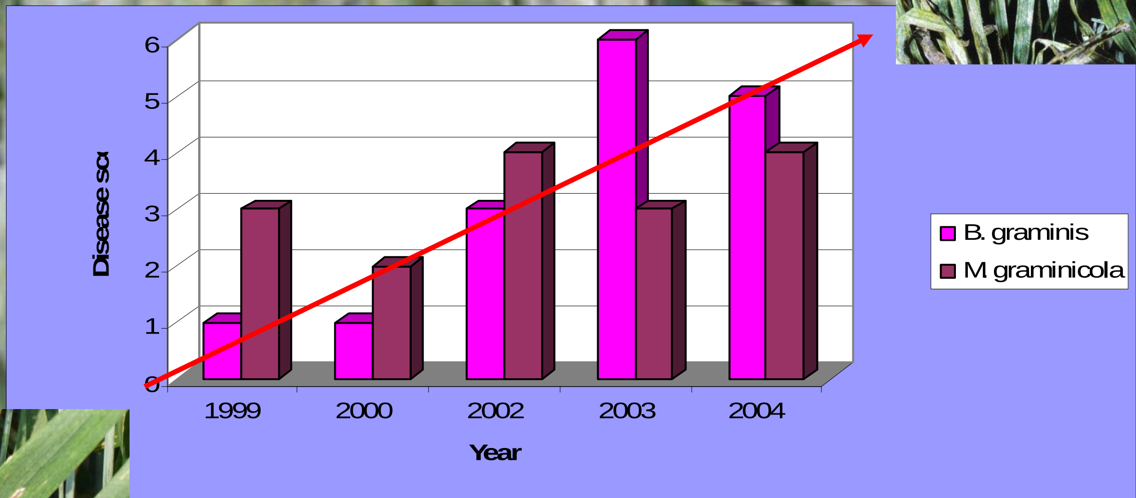


Crop management:
- Sowing October/350 kernels/m²
- 3 N fraction according to advice
- Herbicide/growth regulator/1or 2 Fungicide treatment

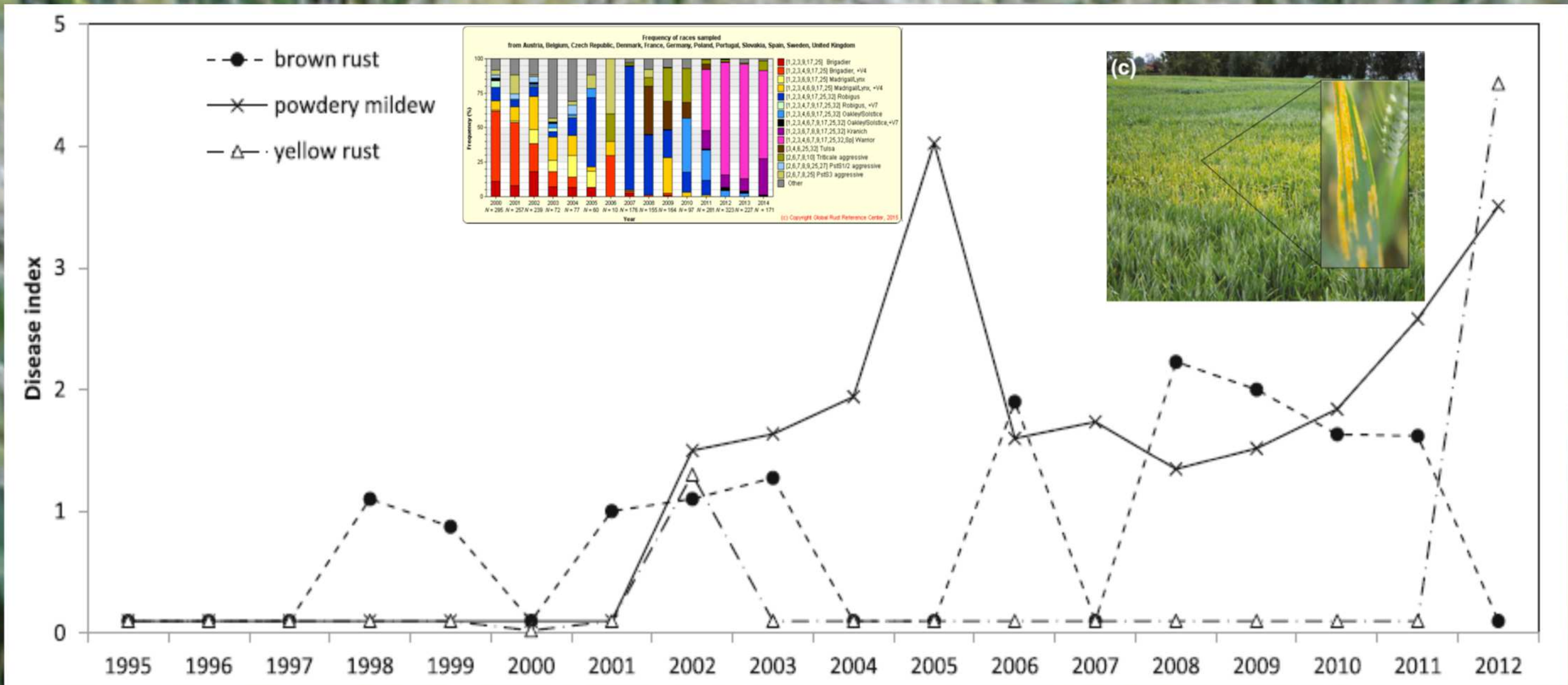


Crop management:
- Sowing October/350 kernels/m²
- 3 N fraction according to advice
- Herbicide/growth regulator/ NO Fungicide treatment

Powdery mildew



powdery mildew → stripe rust



K. Adenaert et al., Eur. J. Plant Pathol. (2014): 140:615-630

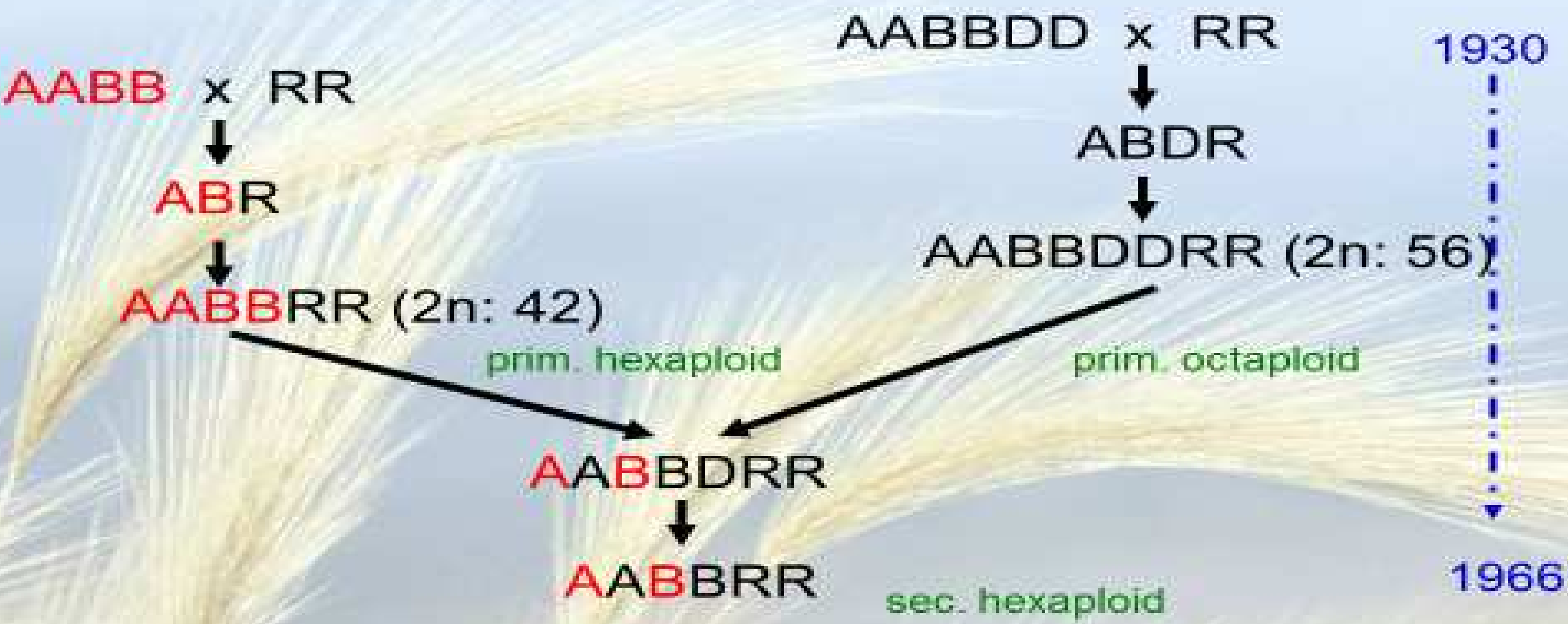
The challenge in triticale breeding

- 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



Expansion of triticale germplasm (1)

Production of primary triticales

- Primary triticales → new secondary hexaploid triticales
- Production:

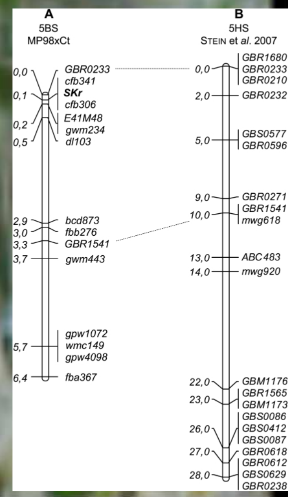
AABBDD x RR
↓
ABDR
↓ Colchicine
AABBDDRR

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

Kr1Kr1	Kr2Kr2 :	0 – 10 %
Kr1Kr1	kr2kr2 :	10 – 30 %
kr1kr1	Kr2Kr2 :	30 – 50 %
kr1kr1	kr2kr2 :	> 50 %

Strong QTL *SKr* on 5BS

Two SSR markers strongly linked to *SKR*



Crossability wheat x Rye

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

+ 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 x AABBRR

↓

AABBDRR

↓ 5-6 generations (self pollination)

AABBRR

- Polycross design is useful to combine octaploids with hexaploid
  - In progenies: % of heptaploids (49 chromosomes) varied from 10 to 95 %
  - Natural selection by sowing populations at different locations

Expansion of triticale germplasm (3)

- In hybrids between octaploids and hexaploid there will be a <u>comprehensive genetic recombination between A and B genome</u> 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.: $2R \rightarrow 2D$

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

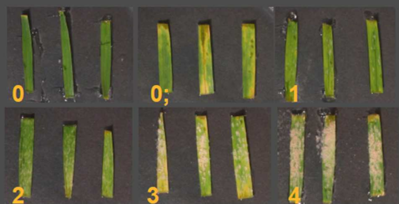
→ Improvement in bread making quality

Powdery mildew: wheat varieties as resistance sources

Virulence testing

Virulence determination

- 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



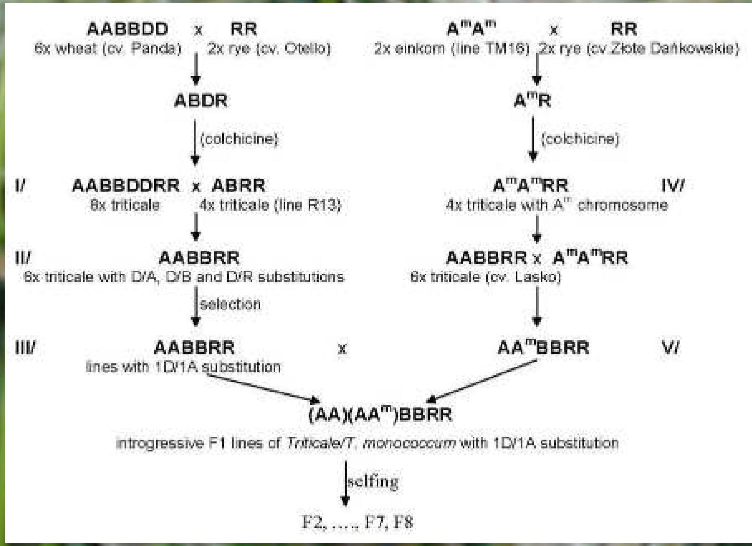
			Infection types to *Blumeria graminis* isolates																
			Blumeria graminis f. sp. *tritici*										*Blumeria graminis* f. sp. *triticale*						
Host	Cultivar	Resistance gene(s)	UK (1)	UK (2)	Switzerland (1)	Israel (1)	Poland	France	Belgium (1)	Belgium (4)	Belgium (7)	Belgium (8)	Poland (1)	France (1)	France (2)	Belgium (1)	Belgium (4)	Belgium (5)	Belgium (7)
Wheat	Kanzler	none	0;	3	4	0;	4	4	4	4	4	4	3	4	3	4	2	4	3
	Cerco	none	4	4	4	3	4	3	4	3	4	0;	2	4	2	4	3	4	2
	Anfield	*Pm1*	0;	0;	2	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;
	Galahad	*Pm2*	4	0	4	0	4	3	4	4	4	4	0	4	2	3	2	2	3
	Asosan	*Pm3a*	0;	0;	0;	0;	0;	0;	0;	0;	0;	1	0;	1	0;	0;	0;	0;	0;
	Chul	*Pm3b*	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;
	Sonora	*Pm3c*	4	3	4	0;	4	2	4	3	0;	4	0;	4	3	1	0;	0;	0;
	Broom	*Pm3d*	0;	0;	0;	0;	0;	0;	4	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;
	Michigan Amber	*Pm3f*	4	4	4	4	4	4	4	4	0;	4	0;	4	1	3	0;	4	1
	Khapli	*Pm4a*	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;
	Weihenste	*Pm4b*	4	0;	0;	0;	0;	0;	4	0;	0;	4	0;	4	0;	0;	0;	0;	0;
	Hope	*Pm5*	1	0;	3	2	3	0;	3	3	3	2	0;	0;	0;	0;	0;	0;	0;
	Holger	*Pm6*	0;	0;	0;	0;	3	1	4	2	3	3	2	1	0;	2	4	0;	1
	Transec	*Pm7*	3	1	2	1	1	0;	2	3	2	1	3	1	1	3	3	0;	0;
	Normandie	*Pm1,Pm2,Pm9,Pm12*	4	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;
	Sappo	*Pm1,Pm2,Pm4b,Pm9*	1	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;
	Amigo	*Pm17*	0;	0;	0;	0;	0;	0;	0;	0;	0;	1	0;	0;	0;	0;	0;	0;	0;
Triticale	Lamberto	*Unknown*	0;	0;	0;	0;	0;	4	0	0;	0	0	3	3	2	4	2	3	2
	Maximal	*Unknown*	0	0	0;	0;	0;	3	0;	0;	0;	0	4	4	4	4	3	4	1
	Borodine	*Unknown*	0;	0;	0;	0;	0;	4	0;	0;	0;	0;	2	1	4	3	1	4	1
Rye	CHD101	*Unknown*	0;	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dankowskie Zlote	*Unknown*	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)

- Tetraploid are cytogenetically instable and characterised by a high degree of sterility
- Possible practise:
  - Octaploid x tetraploid → hexaploid
    - D chromosomes can be introduced for A or B chromosomes in hexaploids, leaving the R genome complete



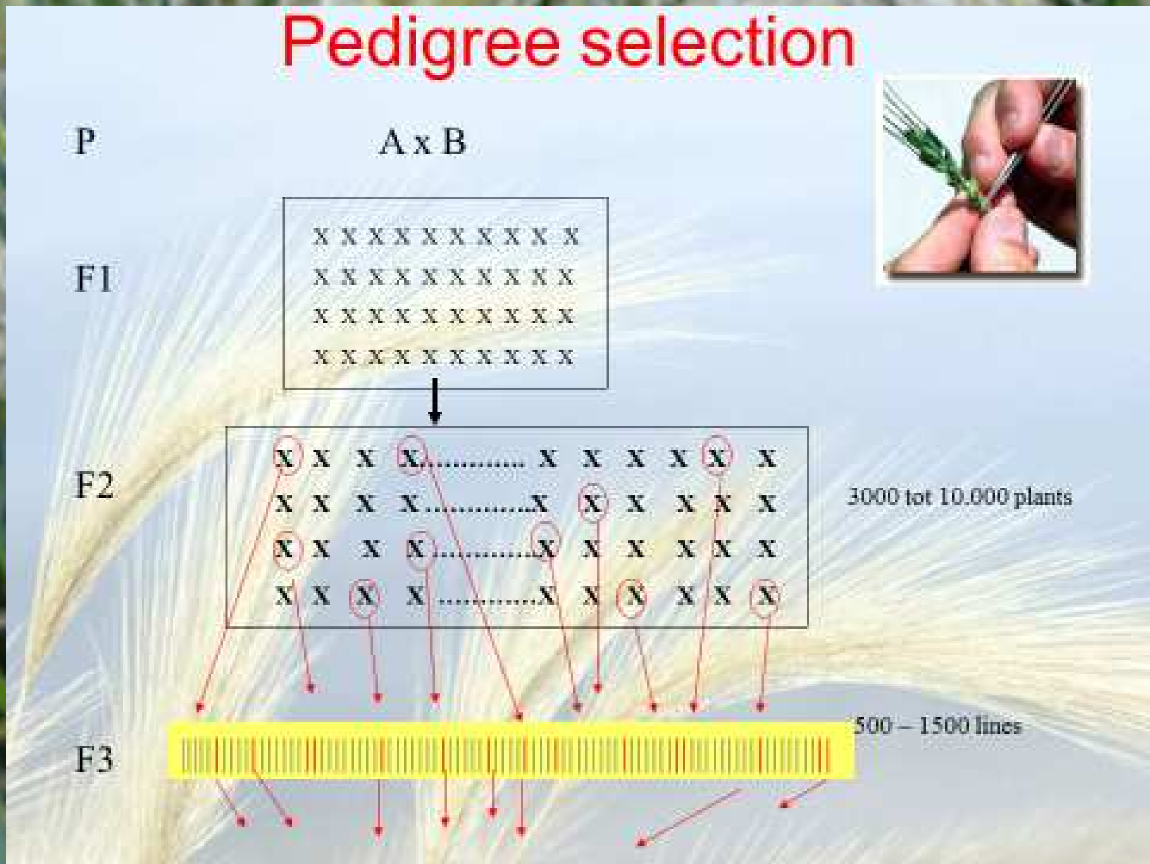
Breeding methodology (1)

- Breeding methods used for triticale must take into account some specific features:
  - Partial sterility of some crosses
    ⇒ Bulk method for several generation (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 generation
  - Important variation in plant height
    - An experimental design with guard plots must be used for avoiding inter plot competition

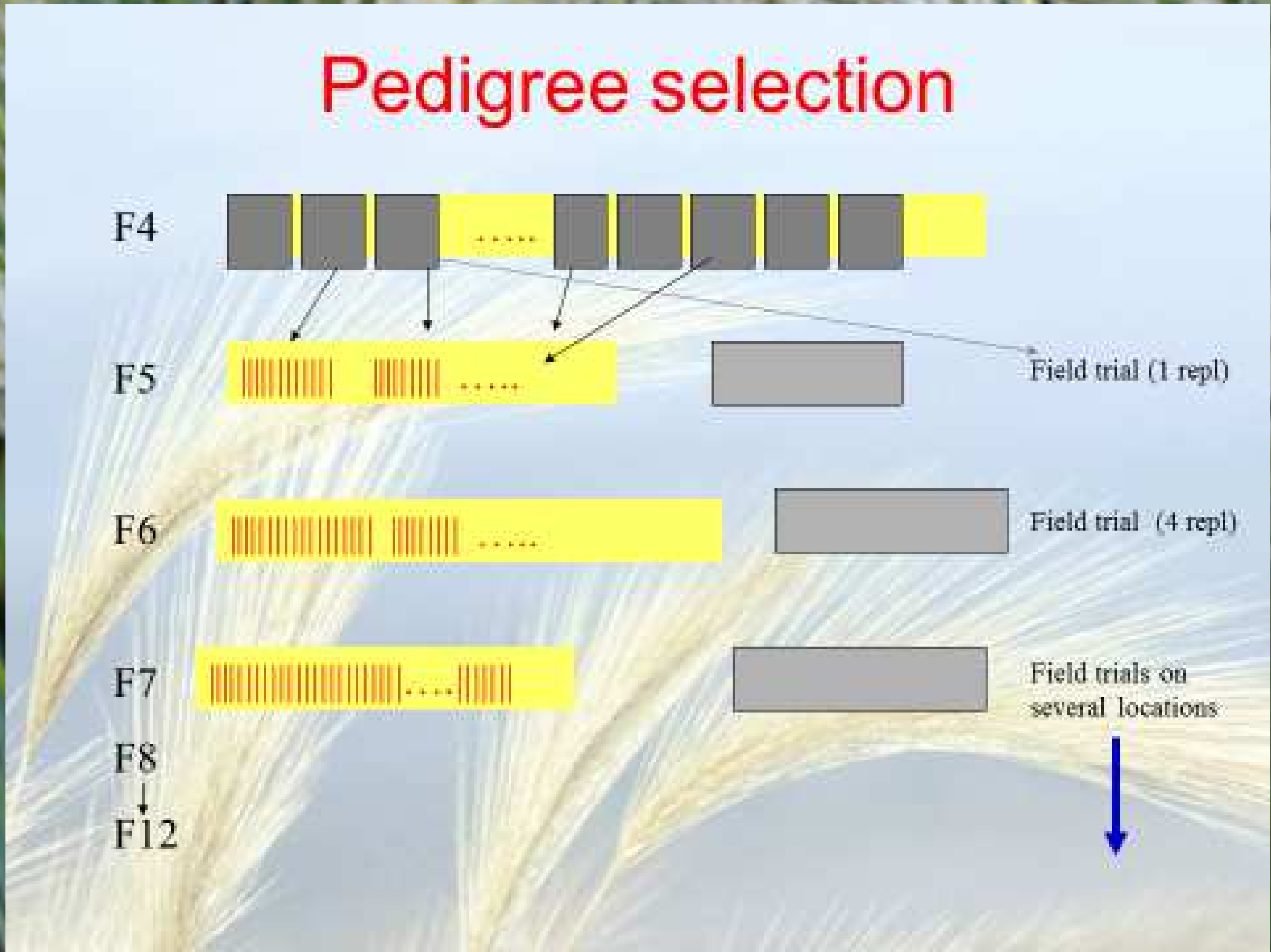
Breeding methodology (2)

- 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)

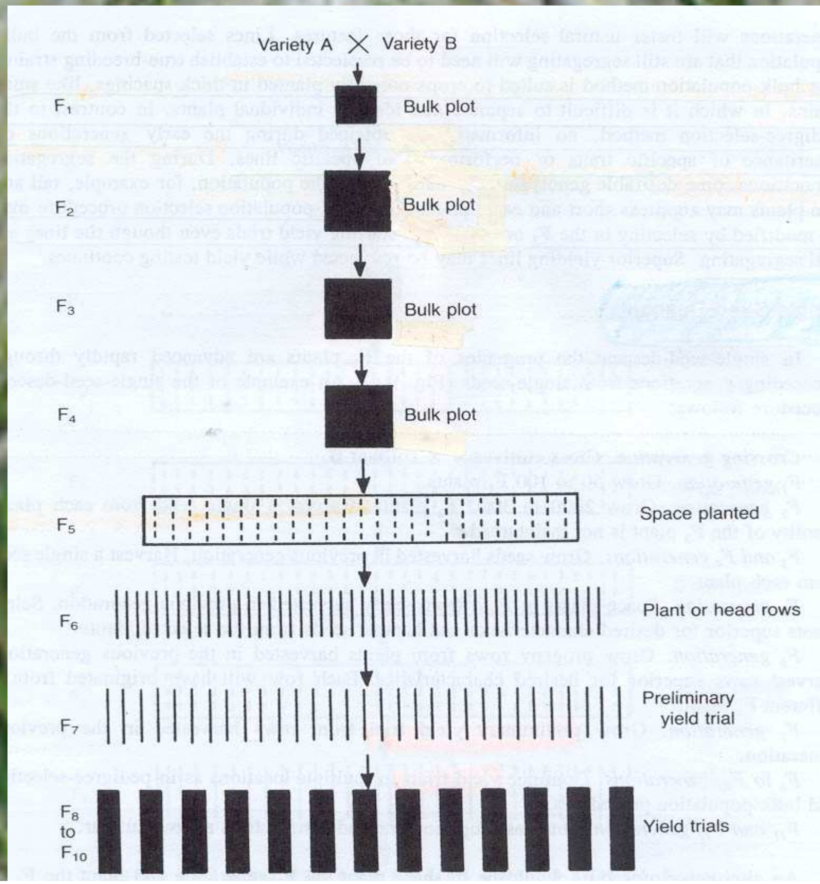


Breeding methodology (4)



Breeding methodology (5)

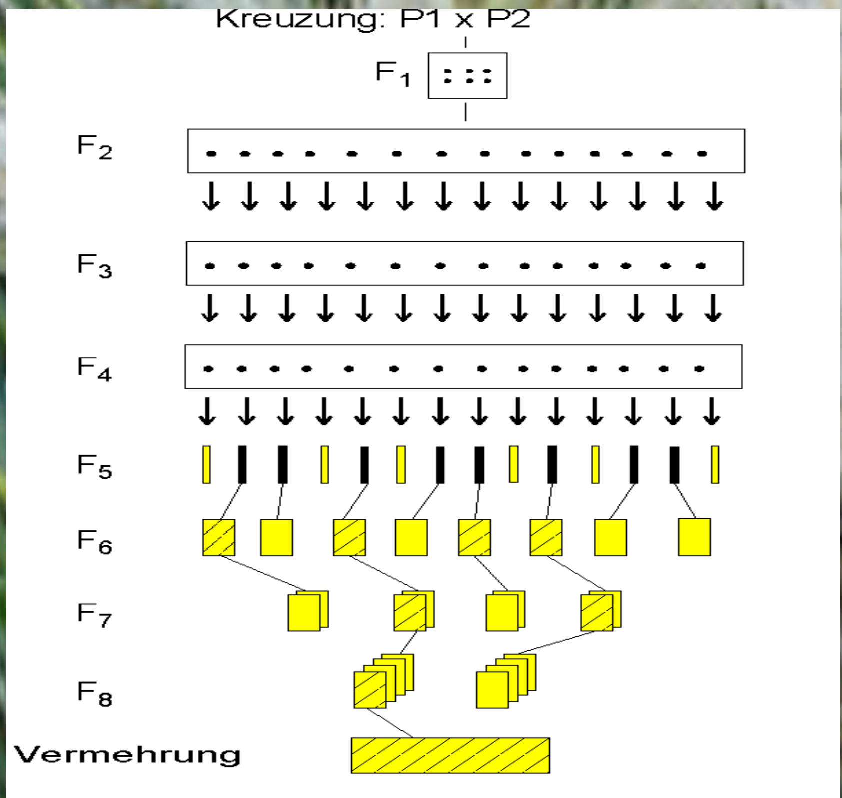
- Bulk method




triticale-infos
triticale-infos

Breeding methodology (6)

- Most companies are using dihaploids or single seed descend method to shorten the breeding cycle



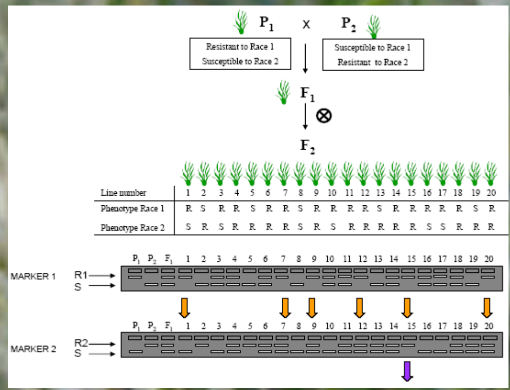
Single Seed Descent -Methode (Einkornramsch)

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)

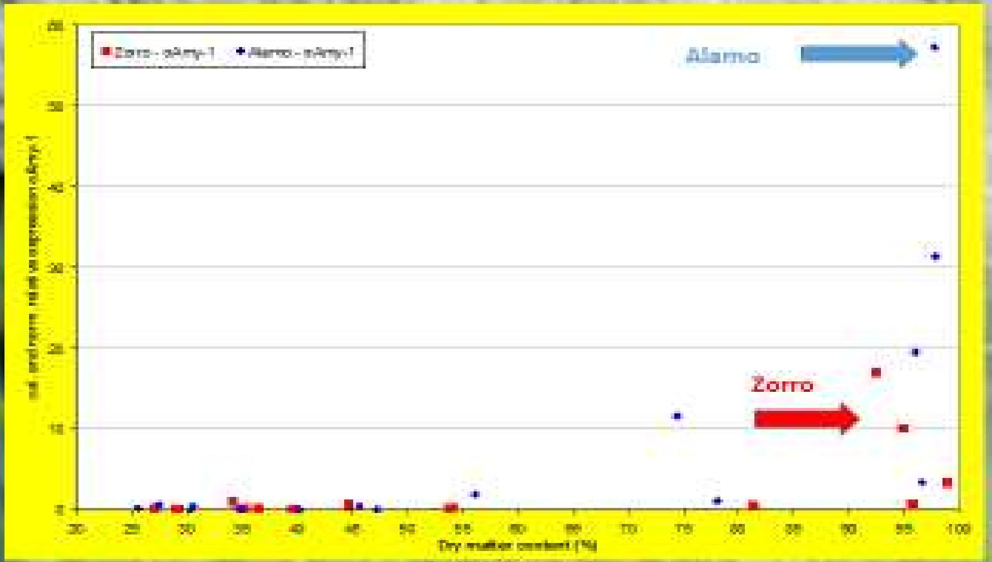
Breeding methodology (8)

- **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!



Breeding methodology (9)

Gene-expression profiles as breeding tool for Preharvest sprouting



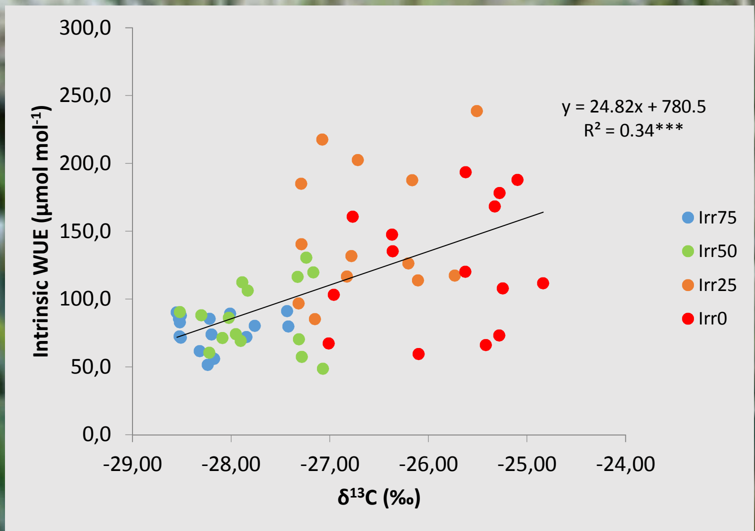
Expression of α-Amy1 gene in two triticale varieties during seed development

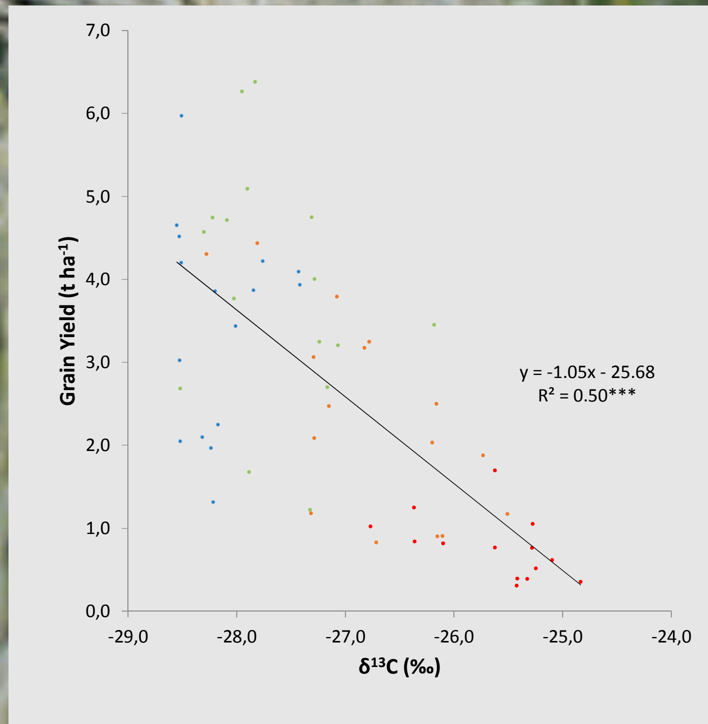
DE LAETHAUWER S. et al. (2013). Acta Physiologiae Plantarum. 35(10): 2927-2938.

Breeding methodology (10)

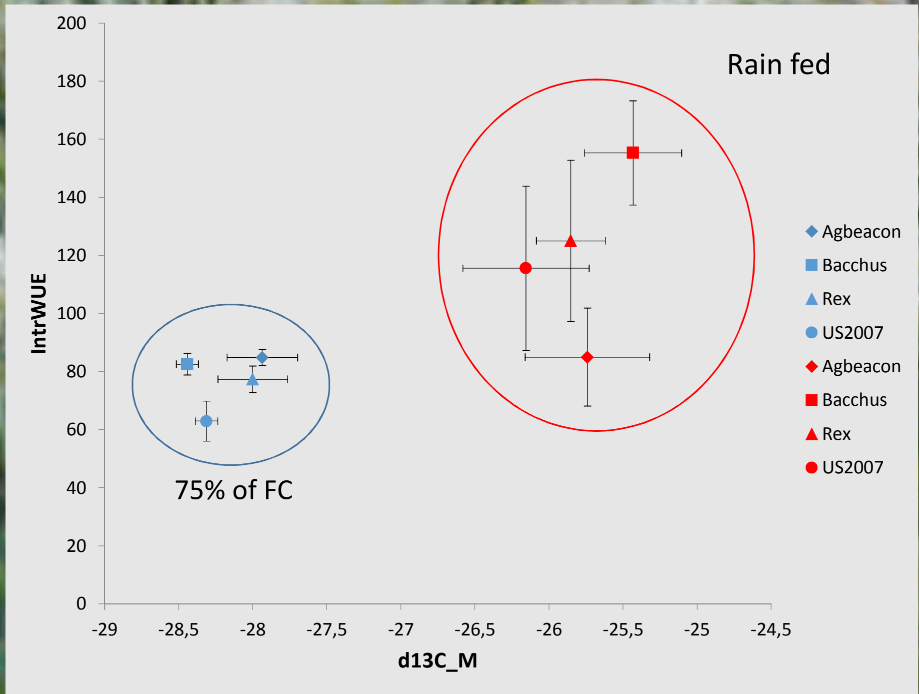
Physiological breeding

- 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} = C^{13}/C^{12}

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