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Genetics-based breeding in winter wheat has lead to modern elite varieties with broad resistance to major diseases – A success story

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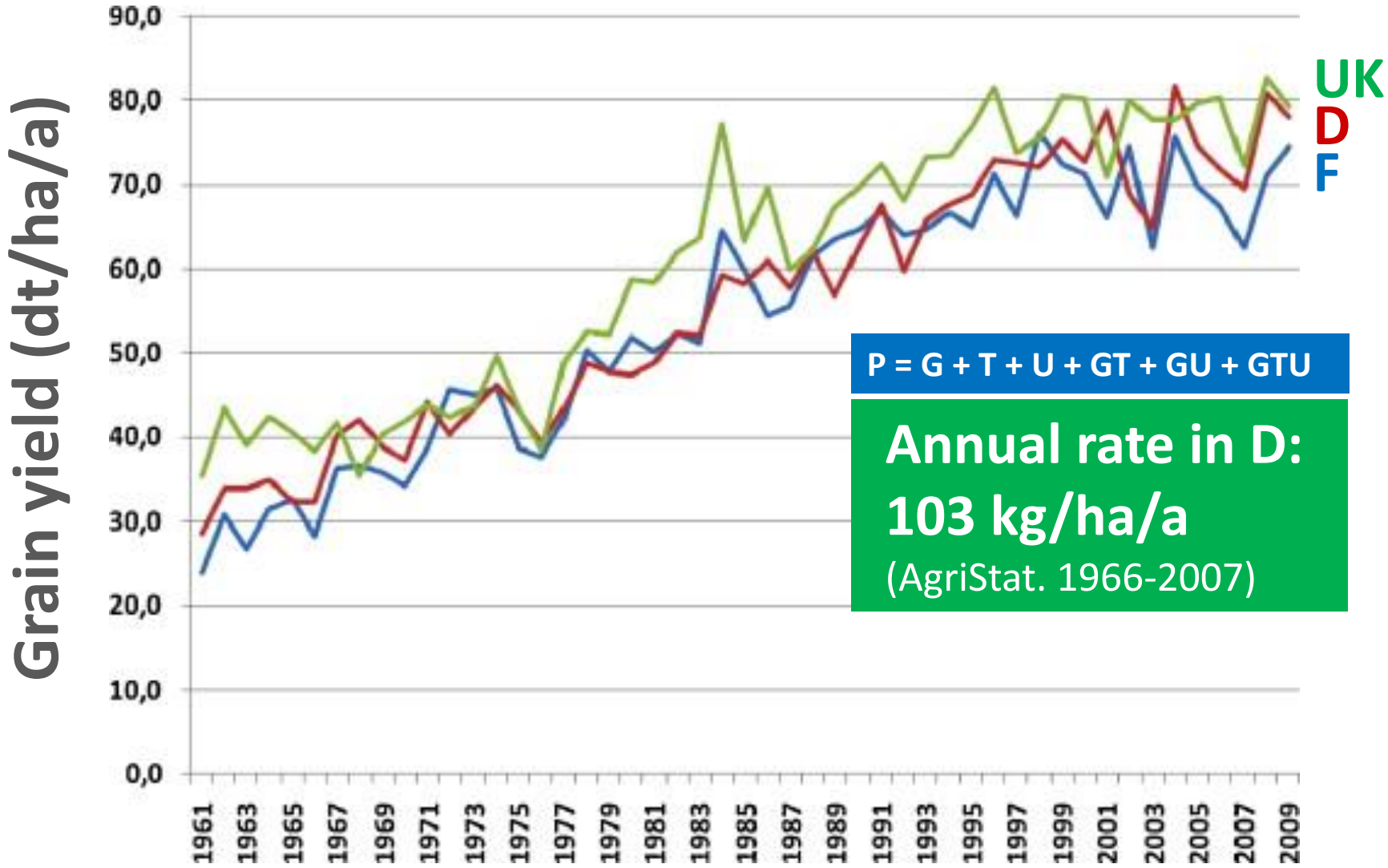
Wheat yield in Europe in the last 5 decades



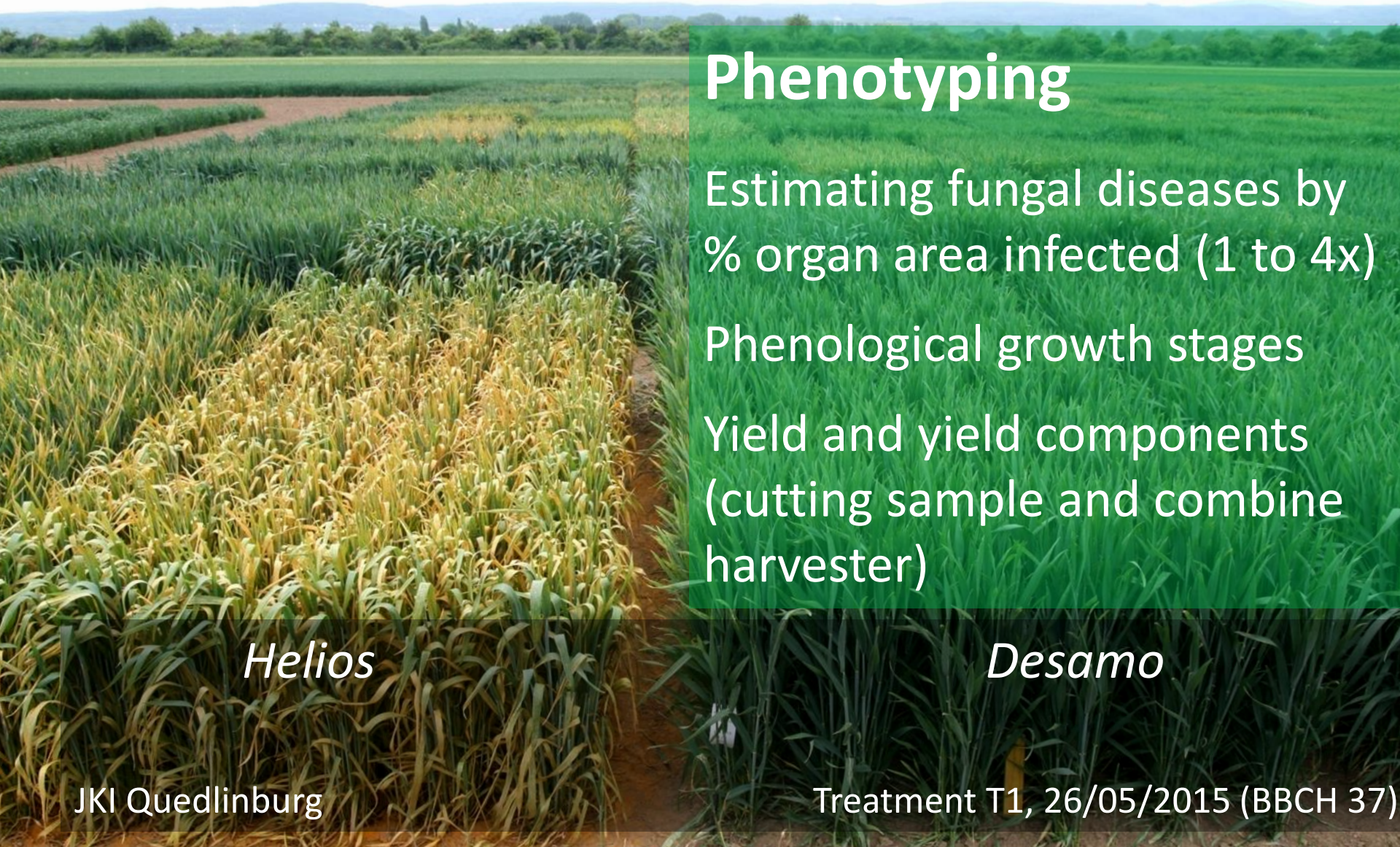
Development of annual average grain yield (dt/ha) in major wheat producing countries of Europe

Major fungal diseases and causal pathogens of wheat

Disease	Pathogen
CAUSED BY BIOTROPHIC FUNGI	
Powdery Mildew	*Blumeria graminis*
Leaf (Brown) Rust	*Puccinia triticina*
Stripe (Yellow) Rust	*Puccinia striiformis*
Stem (Black) Rust	*Puccinia graminis*
Septoria tritici blotch (STB)	*Septoria tritici*
CAUSED BY NECROTROPHIC FUNGI	
Fusarium Head Blight (FHB)	*Fusarium* ssp.

Field experiments, 6 locations (BRIWECS project)

Aim: Understanding innovation decisions for cereal breeding



Phenotyping

Estimating fungal diseases by % organ area infected (1 to 4x)

Phenological growth stages

Yield and yield components (cutting sample and combine harvester)

Field phenotyping of reaction to major diseases

JKI Quedlinburg, 2 years (2015 & 2016)

Stripe and leaf rust inoculation

220 varieties

4 treats, 2 reps = 1,760 plots

Incomplete block design

Fusarium inoculation

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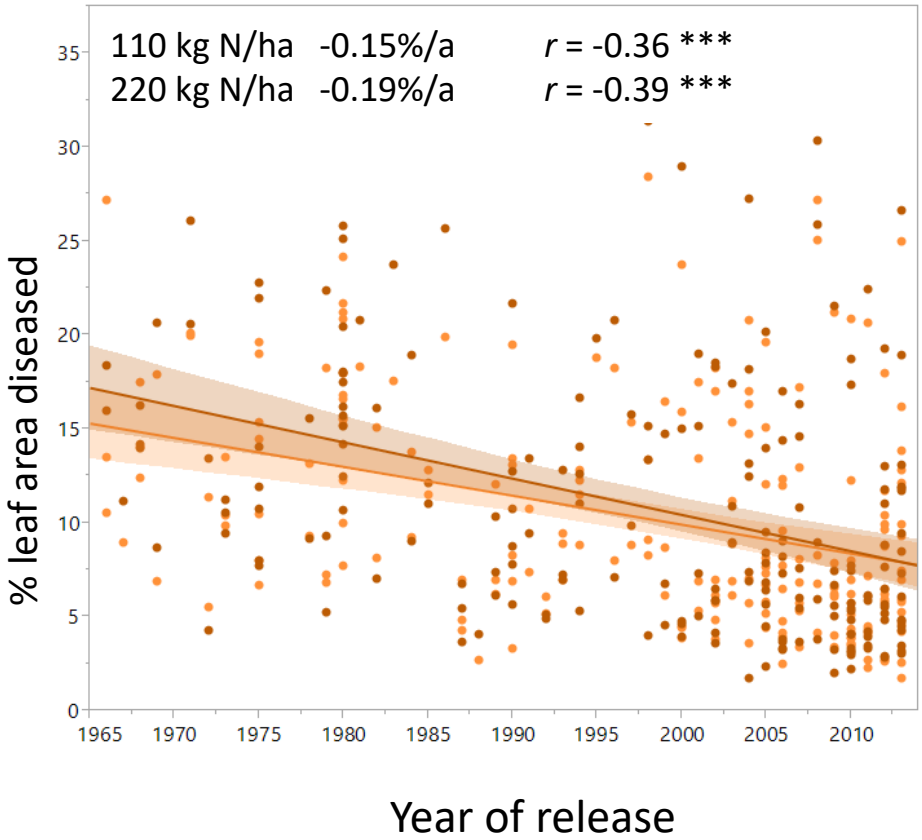
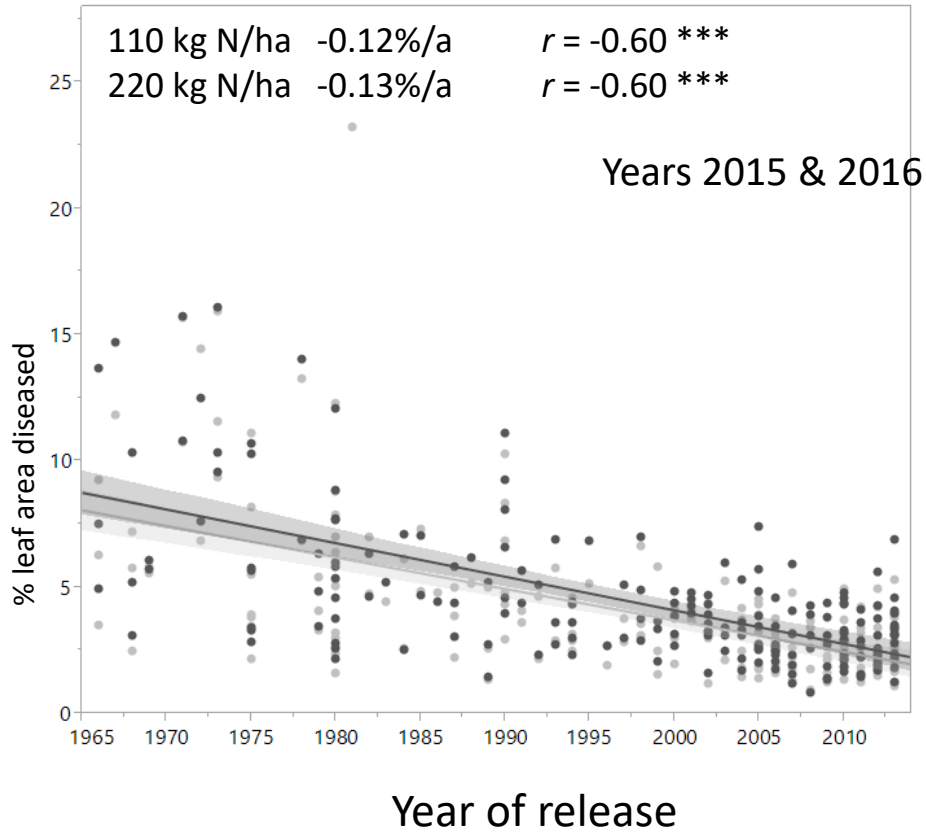
Breeding innovation – resistance by year of release

Stripe rust



Powdery mildew



r correlation coefficient
*** significant with p<0.001

Holger Zetzsche, JKI

Sources of resistance of wheat against powdery mildew

Pm1	Triticum aestivum, Normandie
Pm2	**Triticum aestivum, Ulka**
Pm3a	**Triticum aestivum, Asosan**
Pm3b	Triticum aestivum, Chul
Pm3c	Triticum aestivum, Sonora
Pm3d (syn. Mlk)	Triticum aestivum, Kolibri
Pm4a	Triticum dicoccum, Khapli
Pm4b	**Triticum carthlicum, Armada**
Pm5	**Triticum dicoccum, Hope**
Pm6	**Triticum timopheevi, TP 114**
Pm8	Secale cereale, Disponent
Pm9	Triticum aestivum, Normandie
Pm17	**Secale cereale, Amigo**
Pm46	**Triticum aestivum, Tabasco** (5DS)
Mld	Triticum durum, Maris Dove
MlAx	Triticum aestivum, Axona
MICo3	Triticum aestivum, Cornett (=Kadett)
MIHa2	Triticum aestivum, Haven
MITa2	Triticum aestivum, Talent
U	unbekannt, unterschiedlicher Herkunft

46 identified powdery mildew resistance genes (loci)

Red = present in current resistant cultivars (rating 1)

[German Descript. Variety List 2016]

Pm3 together with its multiple alleles, Pm38, Pm8 and a key member of Pm21 have been cloned

Mildew Resistant Winter Wheat Cultivars, Germany 2016 (Rating 1)

Wheat variety	Source	Breeder
Apostel *	U	4046
Bosporus *	U	8887
Dekan	Pm4b, Pm5, Pm6	129
Design *	U (Pm17?)	1410
Edward	Pm46	25
Gustav	U	25
Halvar	Pm2, Pm4b, Pm6	6918
Hyland +	U	9056
Moschus *	Pm3a, Pm5	214
Nordcap *	Pm2, Pm3a	9056
Sheriff *	U	9925
Tabasco	Pm46	25

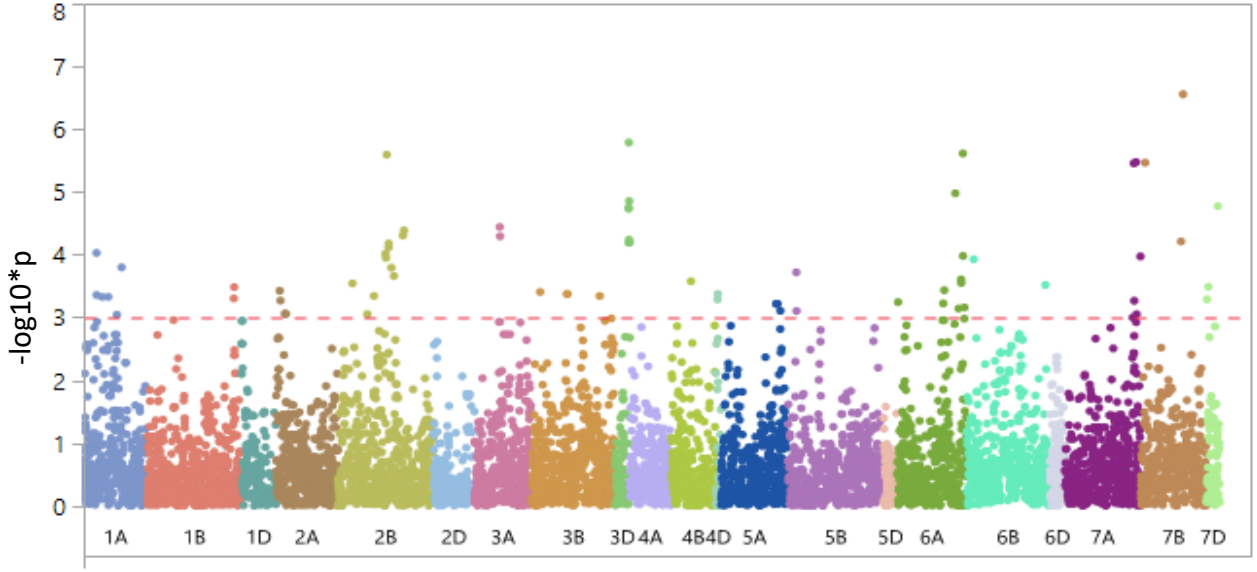
_Pm3_ with its multiple alleles, _Pm38_, _Pm8_ and a key member of _Pm21_ have been cloned

+ = hybrid cultivar, *) new registration, U = unknown (*Triticum dicoccoides*?)

25= BE, 129= KWS, 214= STR, 1410= SEC, 4046= Streng, 6918= Sejet, 8887= Breun, 9056= NORD, 9925= Intersz

GWAS - Manhattan-Plot : Stripe rust (2015, 2016)

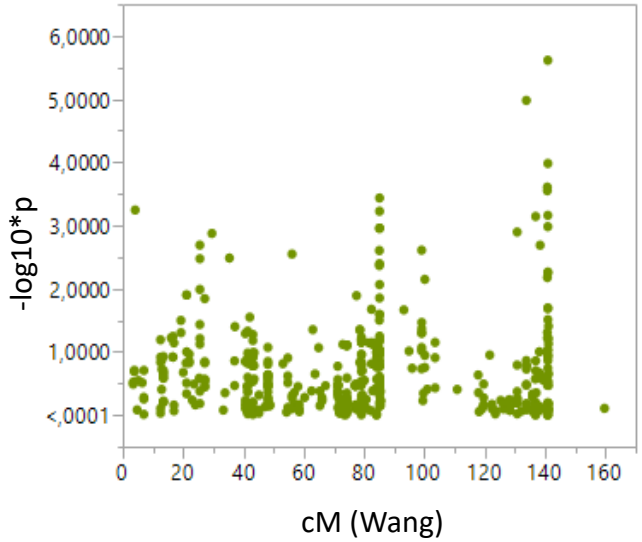
JMP Genomics 8 (SAS 9.4): Q-K Mixed model, P <0.001



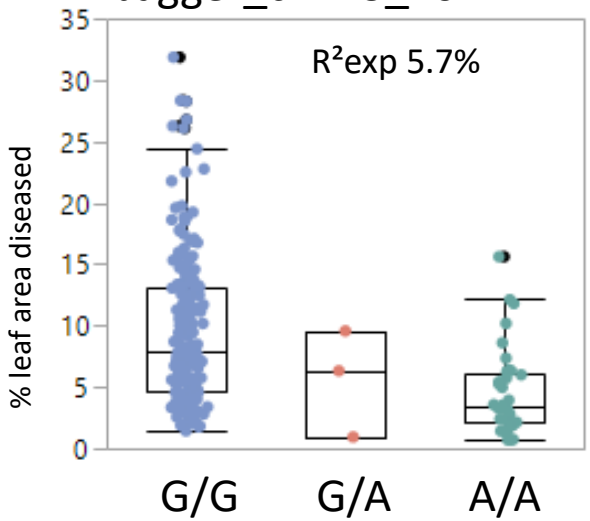
Ref. WANG map

New QTL on 6A, 2A, 3D?

6A



Jagger_c1423_102



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GWAS - Manhattan-Plot: Powdery mildew (2015, 2016)

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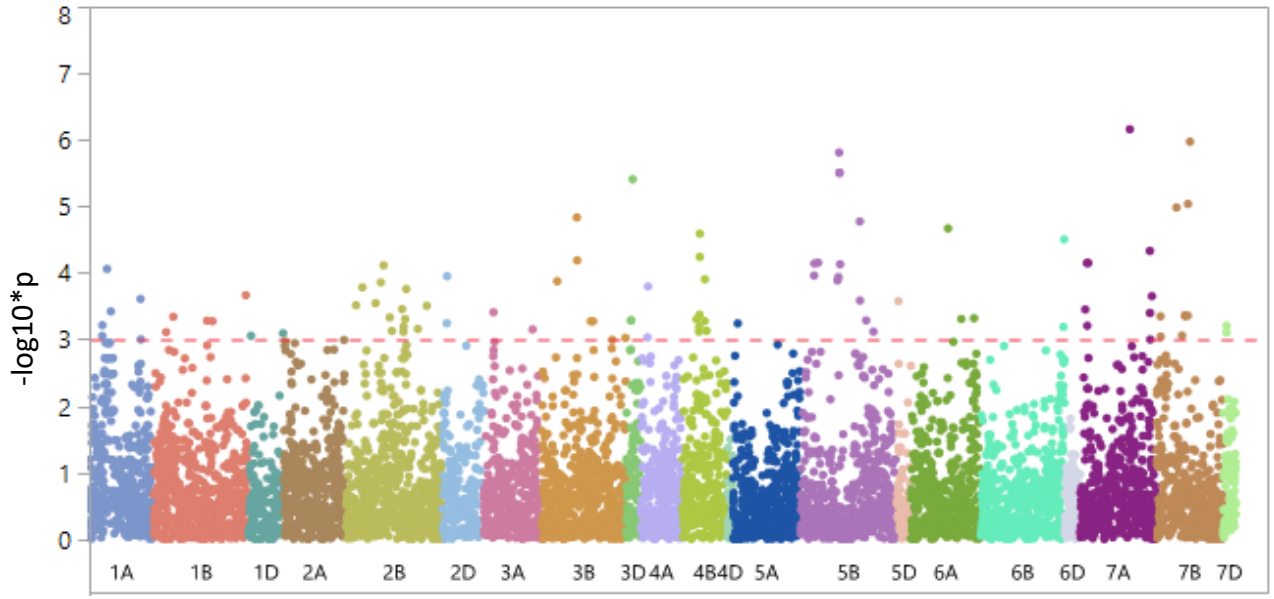
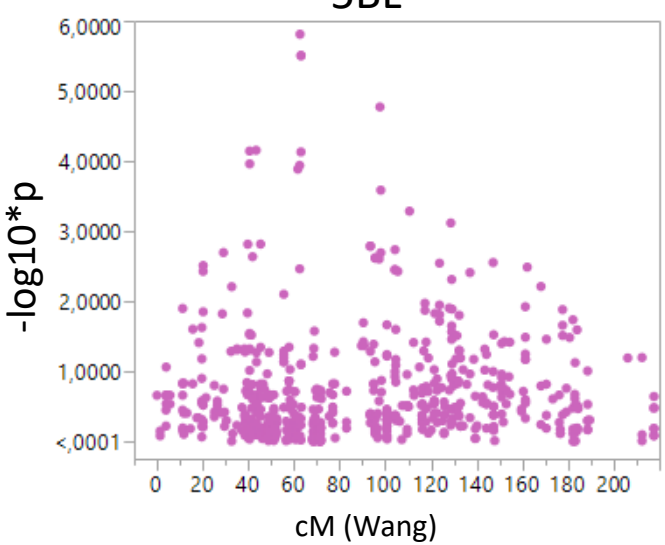


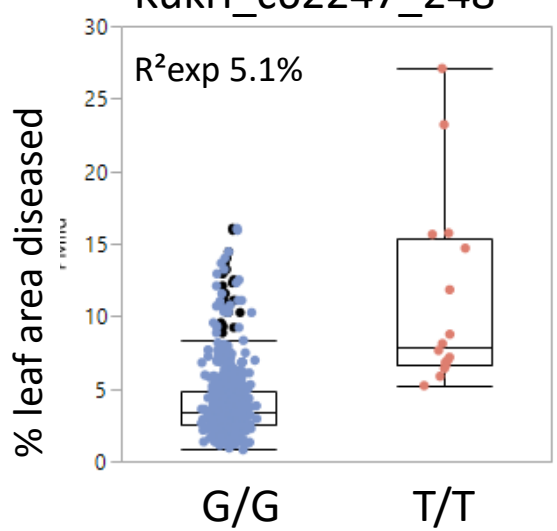
Known QTL on 2A, 2B and 7A, 7B

QTL on 5BL close to Pm36?

5BL



Kukri_c62247_248



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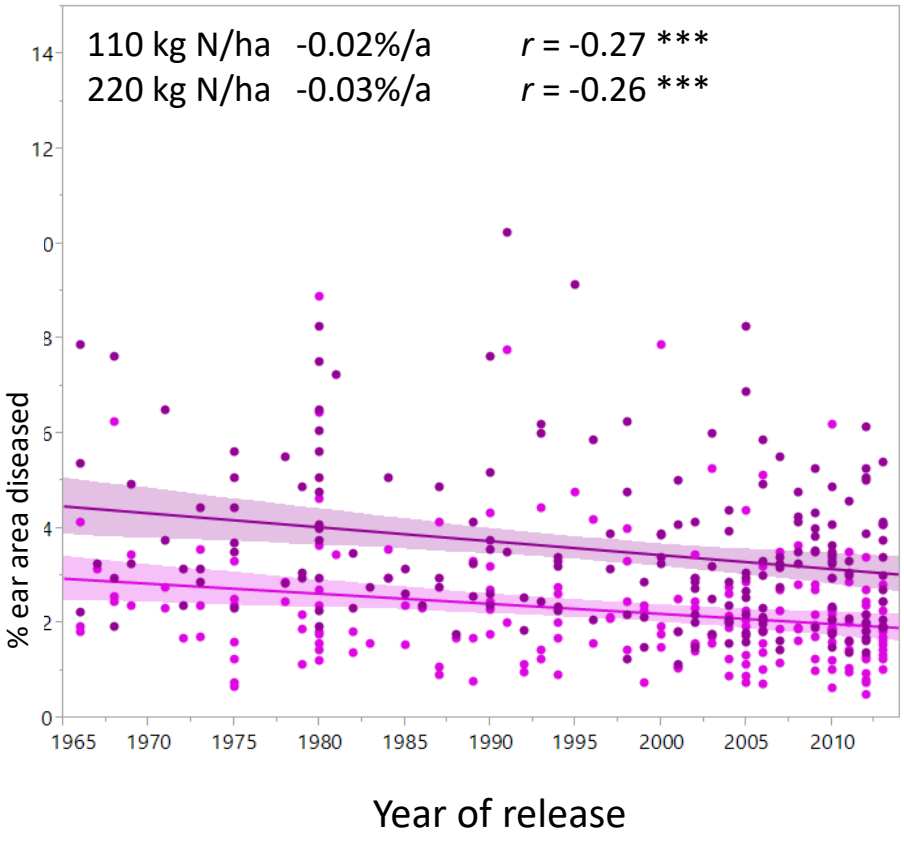
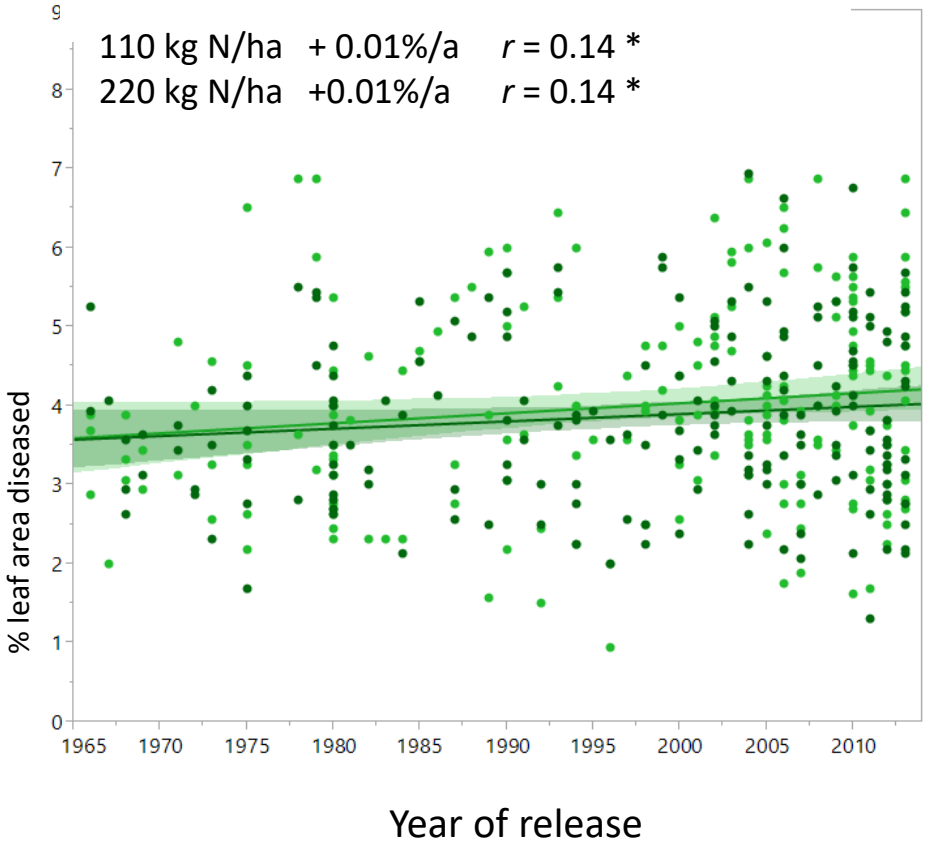
Breeding innovation – resistance by year of release

Fusarium head blight (FHB)



Septoria tritici blotch (STB)



r correlation coefficient
***, * significant with p<0.001, <0.05

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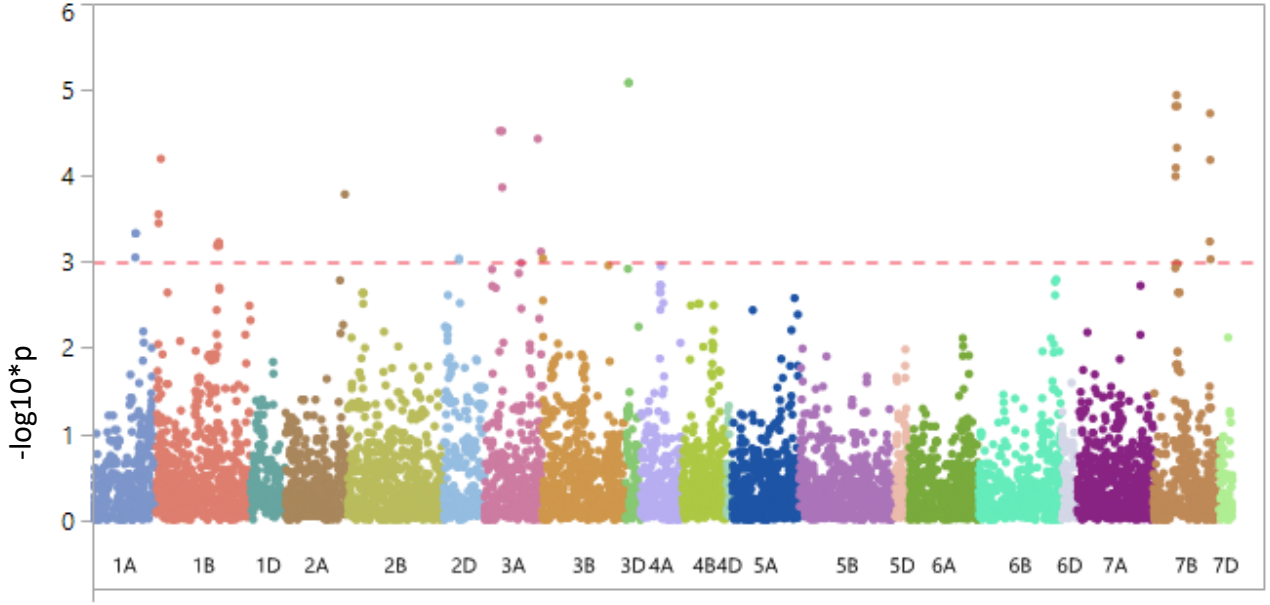
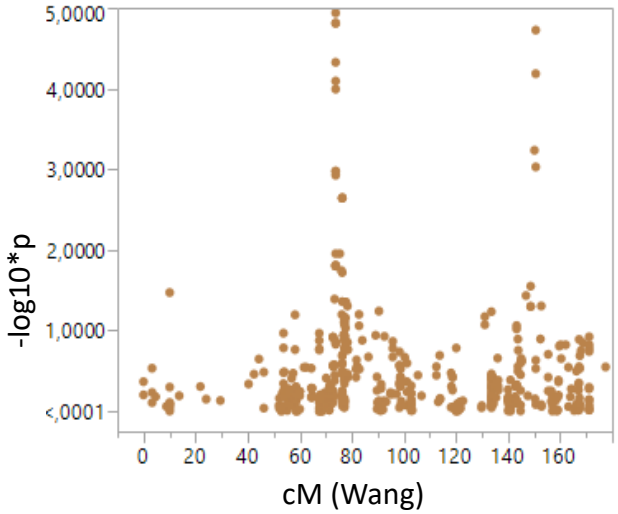
GWAS - Manhattan-Plot – FHB (years 2015, 2016)

JMP Genomics 8 (SAS 9.4): Q-K Mixed model, P <0.001



7BL



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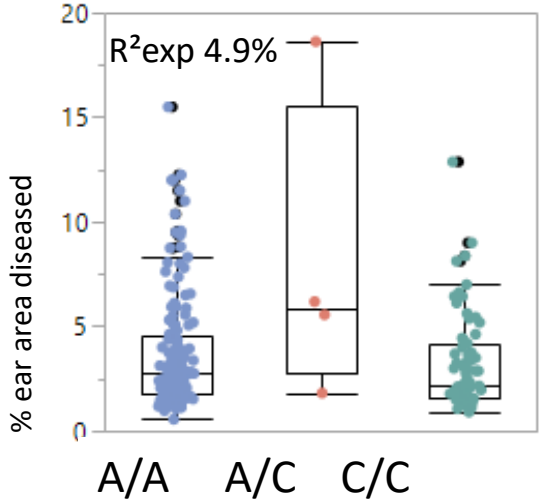

FHB resistance QTL:

- Known on 7BL
- New QTL on 3A?

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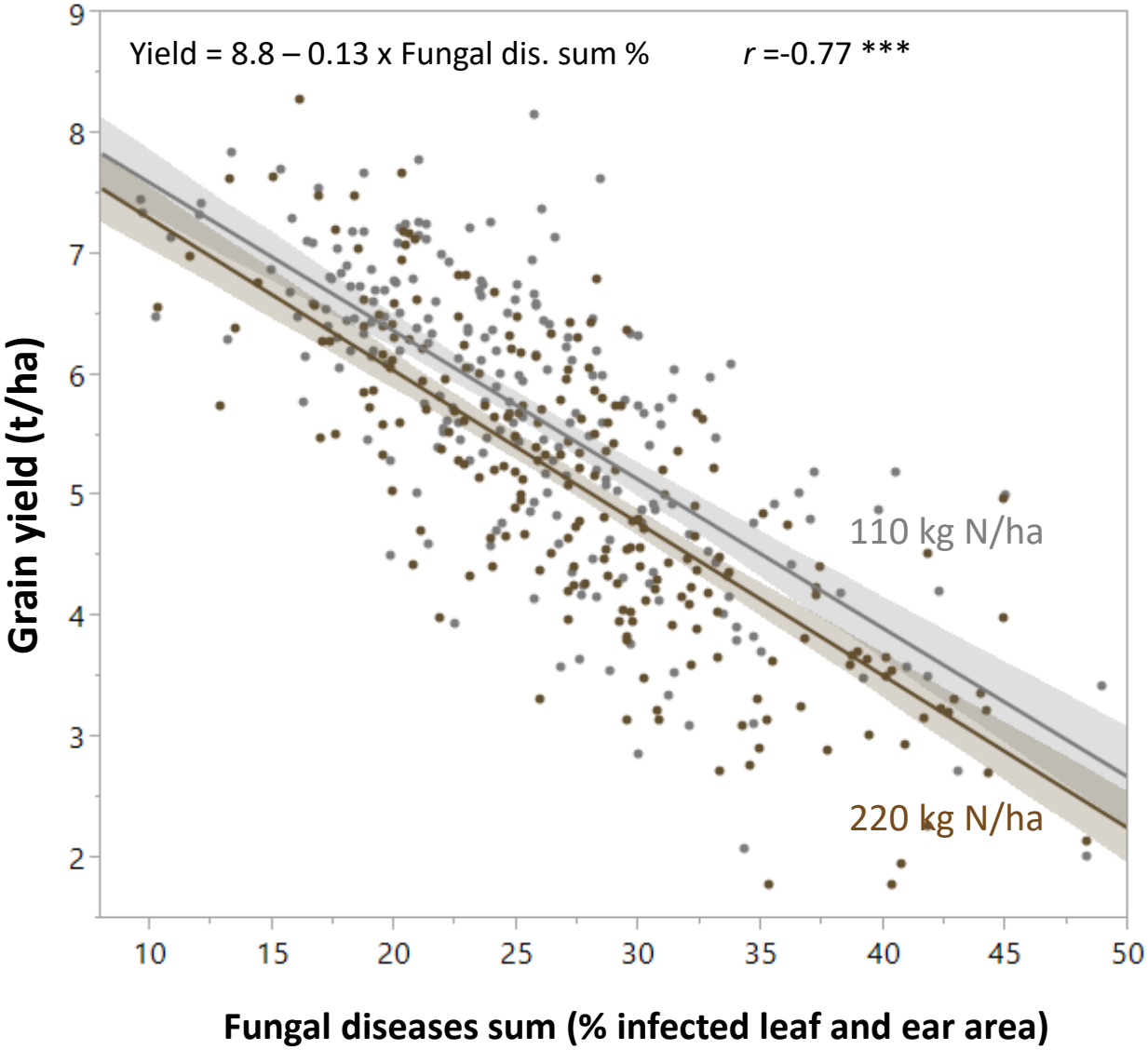
Impact of fungal diseases on grain yield



1% fungal disease* ~ 130 kg/ha grain yield

***) Powdery mildew + Leaf rust + Stripe rust + FHB + STB**

r correlation coefficient
*** significant at p<0.001

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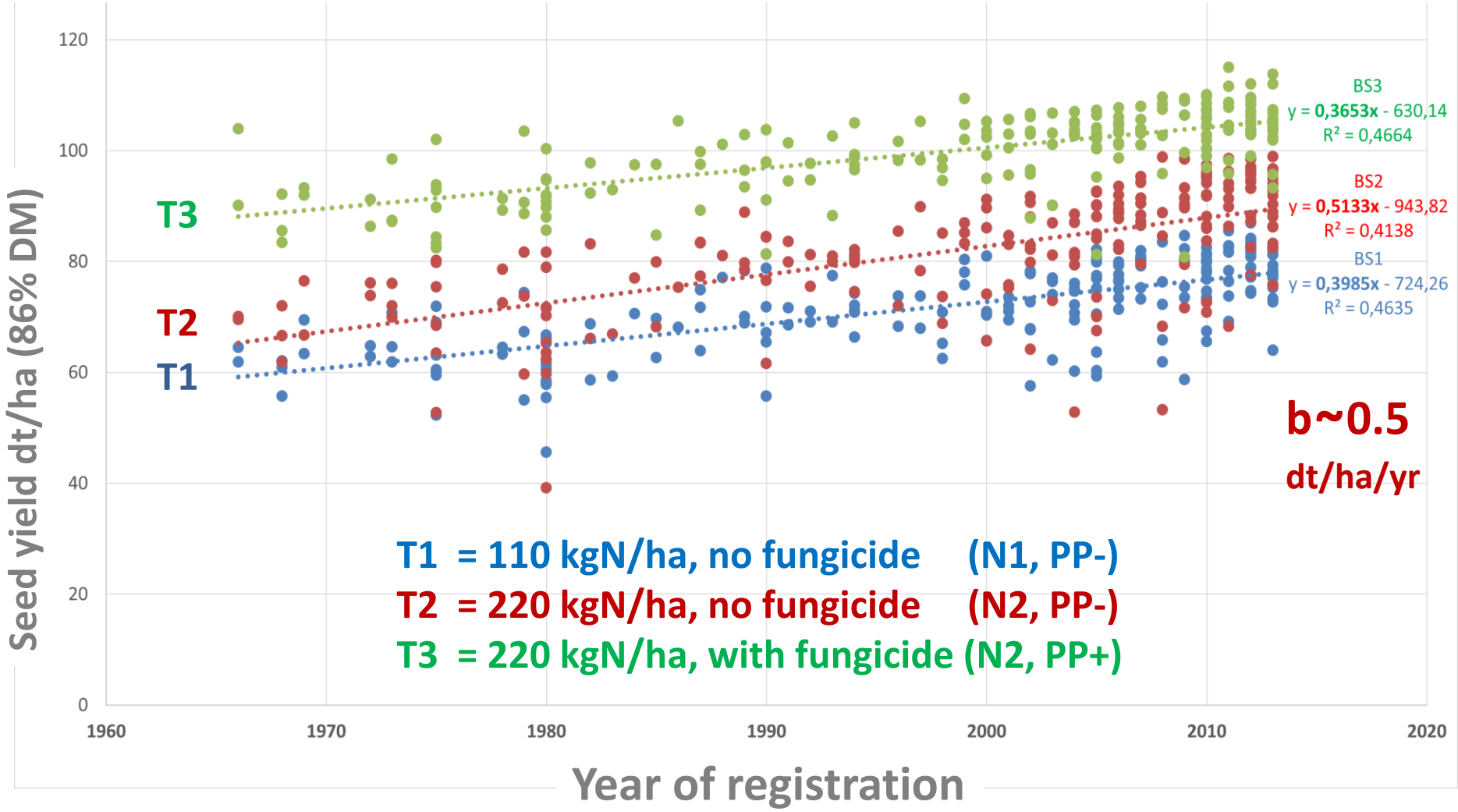
Yield stability of varieties released since the 1960s

193 varieties, 10 environments (2 years: 2015, 2016, 5 locations in Germany)

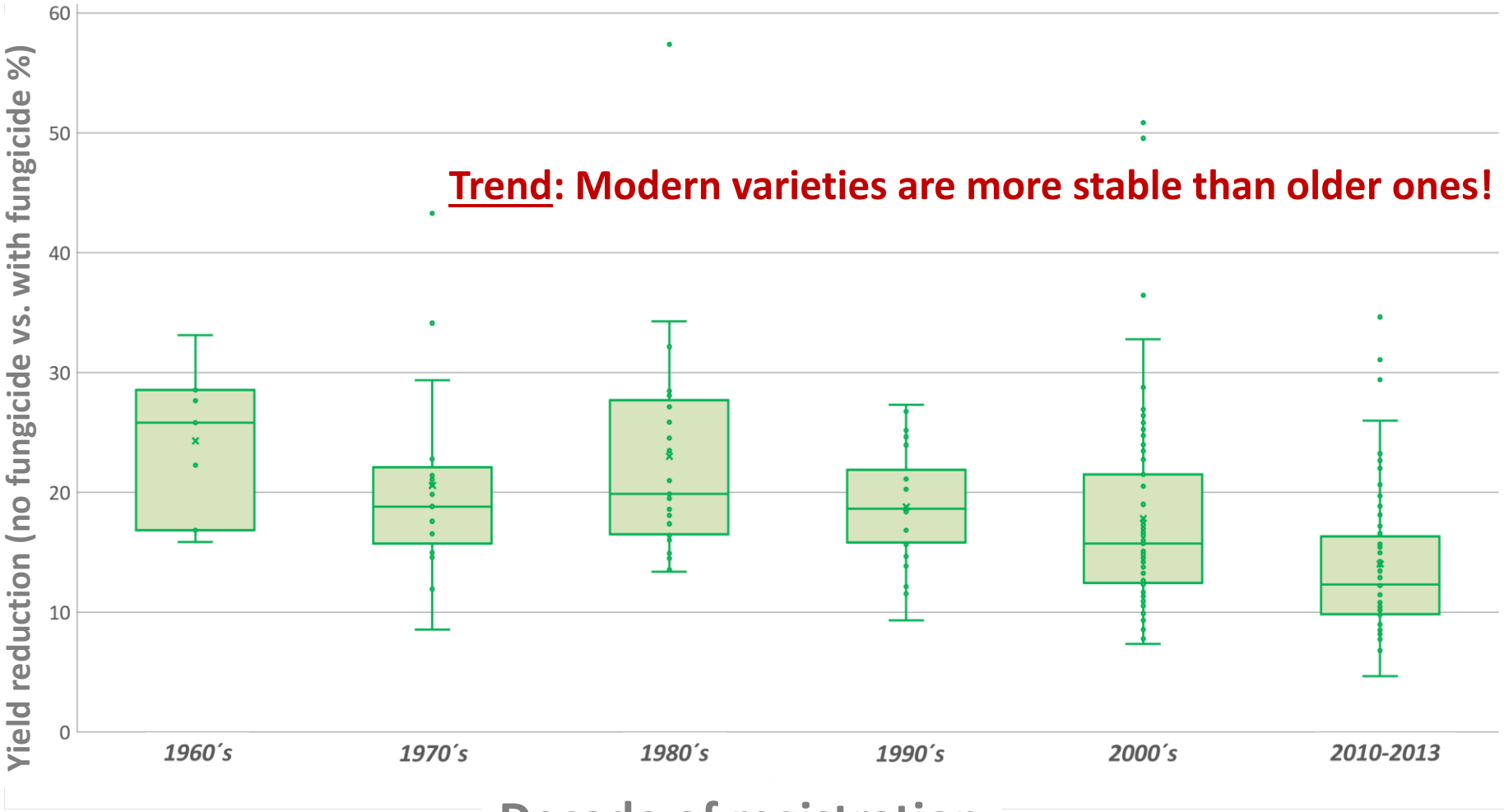


BRIWECS

Benny Wittkop, UGi

Fungicide effect on yield stability of varieties released since the 1960s

193 varieties, 10 environments (2 years: 2015, 2016, 5 locations in Germany)



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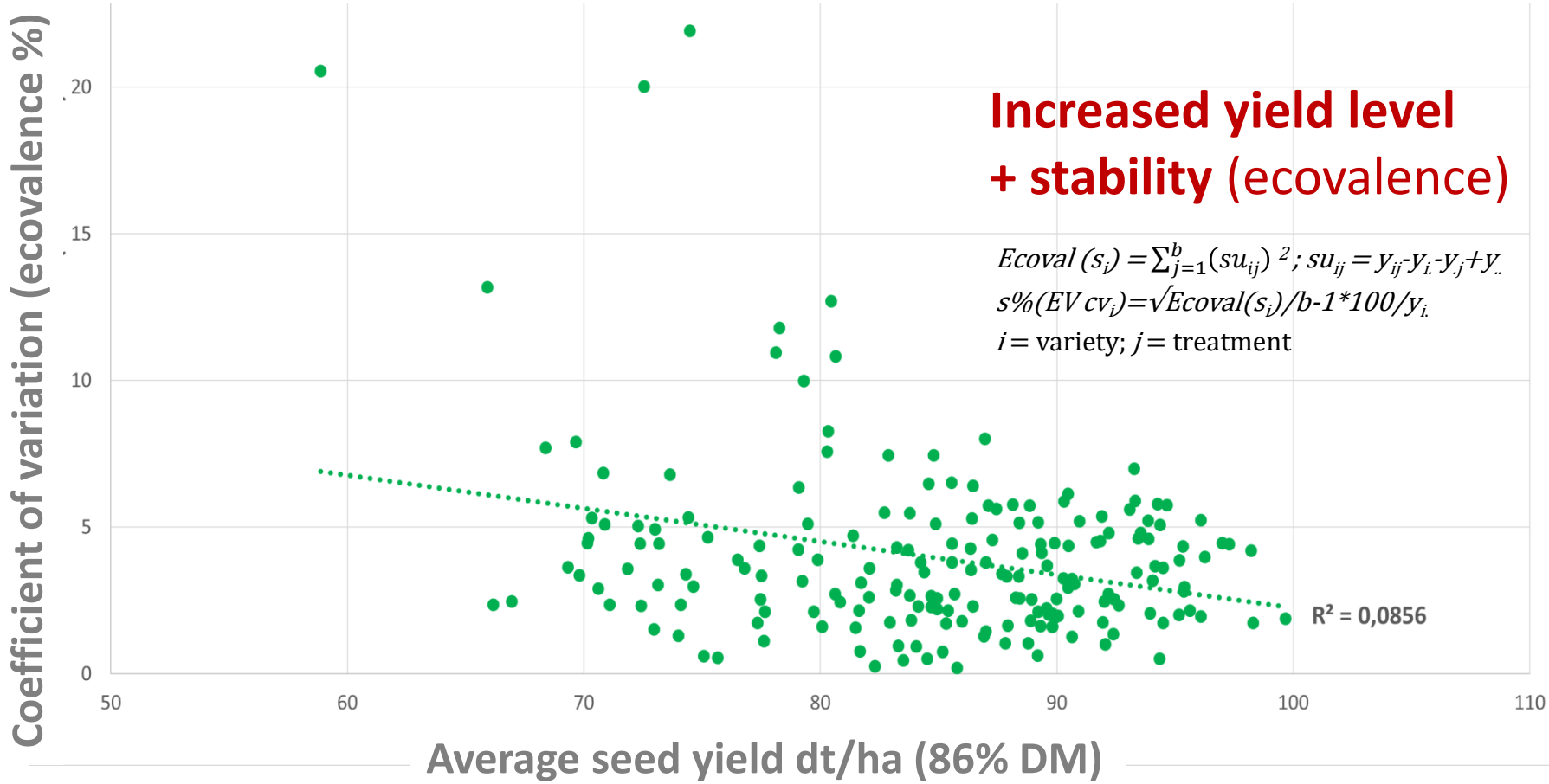

Benny Wittkop, UGi

Consequences for resistance breeding

1. Great improvement of wheat by **phenotypic selection**: powdery mildew > rusts > FHB
2. **Pyramiding** (combination) of functional loci by MAS
3. **Isolation and characterization** of resistance genes (e.g. mildew, rusts), allowing transfer and direct selection
4. Direct mutations in isolated genes by **gene editing** (e.g. CRISPR-Cas)
5. **Genomic selection** for oligo- or polygenic (quantitative) and potentially durable resistance
6. **Future: Resistance/tolerance to abiotic stresses!**

Thanks

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BRIWECS wheat for tomorrow **Consortium**

to Hermann Bürstmayr and the whole team!