Novel insights on the genetics of susceptibility to necrotrophic fungal pathogens of durum and bread wheat

Agnes Szabo-Hever

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Outline

- Introduction of the wheat populations
- Introduction of the wheat pathogens *Pyrenophora tritici-repentis* and *Parastagonospora nodorum*
- Methods
- Genetic mapping of tan spot resistance in durum wheat
- Genetic mapping of Septoria nodorum blotch resistance in durum and spring wheat
- Related studies

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Durum wheat

- *Triticum durum* L. ssp. *durum*
- 2n = 4*x* = 28
  AABB genomes
- Grown on ~13.5 million ha globally
  In the U.S. ~2 million ha
  Producing regions: Middle East
  North America
  Southern Europe
  North Africa
- Use: pasta
  couscous
  Mediterranean breads
  semolina-based products

Global Durum Wheat Panel (GDP)

- Initiated in 2015
- Identify beneficial alleles in durum wheat germplasm
- Make these alleles available for breeding programs
- Collection of 2,503 tetraploid wheat lines
- Included 987 *Triticum turgidum* spp.
- Selected 510 *Triticum turgidum* ssp. *durum*

  332 modern accessions

  178 landraces
- Represented lines from 41 countries, CIMMYT, and ICARDA

frontiers in Plant Science

ORIGINAL RESEARCH
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Check for updates

The Global Durum Wheat Panel (GDP): An International Platform to Identify and Exchange Beneficial Alleles

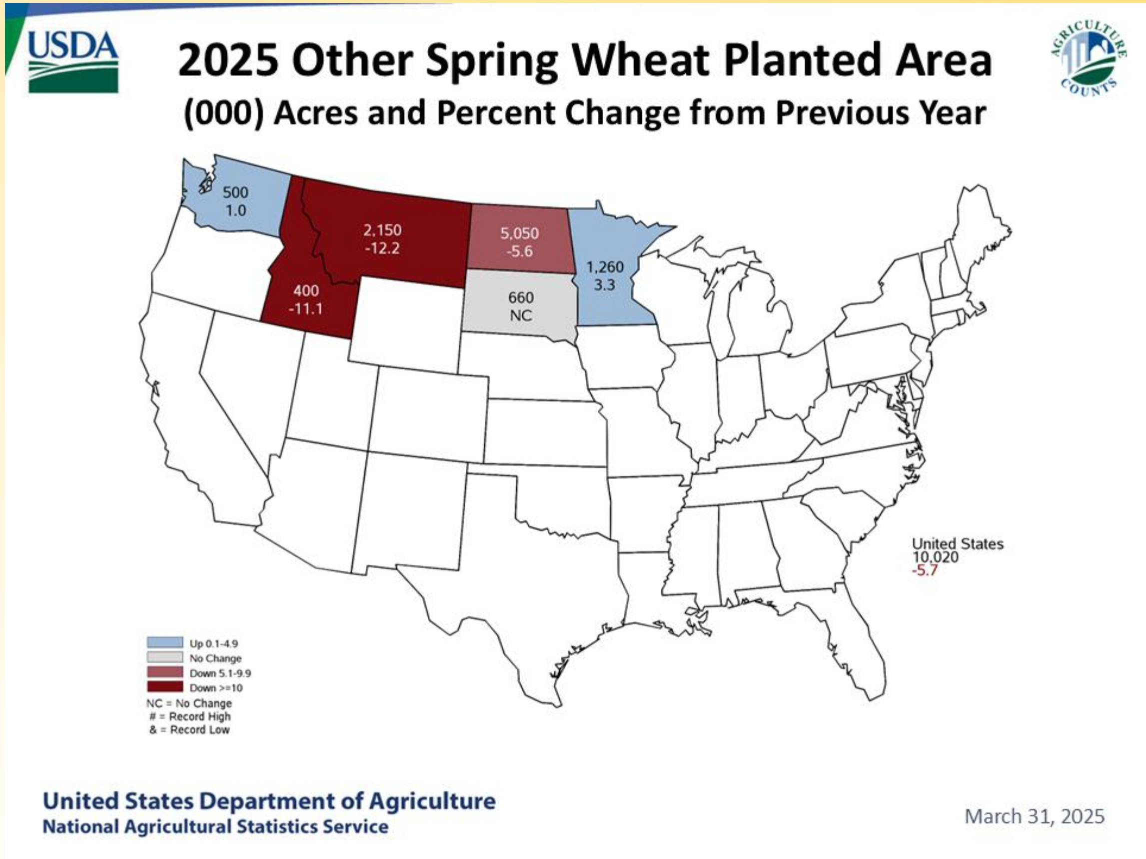
Elisabetta Mazzucotelli[1†], Giuseppe Sciara[2†], Anna M. Mastrangelo[3,4], Francesca Desiderio[1], Steven S. Xu[5], Justin Faris[5], Matthew J. Hayden[6,7], Penny J. Tricker[8], Hakan Ozkan[9], Viviana Echenique[10], Brian J. Steffenson[11], Ron Knox[12], Abdoul A. Niane[13], Sripada M. Udupa[13], Friedrich C. H. Longin[14], Daniela Marone[3], Giuseppe Petruzzino[3], Simona Corneti[2], Danara Ormanbekova[2], Curtis Pozniak[15], Pablo F. Roncallo[10], Diane Mather[8], Jason A. Able[8], Ahmed Amri[13], Hans Braun[15], Karim Ammar[16], Michael Baum[13], Luigi Cattivelli[1], Marco Maccaferri[2], Roberto Tuberosa[2] and Filippo M. Bassi[13]*

OPEN ACCESS

CIMMYT: International Maize and Wheat Improvement Center
ICARDA: International Center for Agricultural Research in the Dry Areas

Hard red spring wheat (HRSW)

- *Triticum aestivum*
- 2n = 6*x* = 42
  AABBDD genomes
- Grown on >200 million ha globally
  HRSW: ~10 million ha in the U.S.
  Producing regions: North Dakota
  Montana
  Minnesota
- Use: bagel
  artisan hearth breads
  pizza crust



Hard red spring wheat panel (HRSWP)

- USDA-ARS National Small Grains Collection
- Total of 812 accessions
  - cultivars
  - breeding lines
  - cultivated accessions
  - landraces
  - genetic stocks
- Lines from 88 countries

A Genome-Wide Association Study of Resistance to Stripe Rust (*Puccinia striiformis* f. sp. *tritici*) in a Worldwide Collection of Hexaploid Spring Wheat (*Triticum aestivum* L.)

Marco Maccaferri,[*,†,1] Junli Zhang,[*,1] Peter Bulli,[‡,1] Zewdie Abate,[*] Shiaoman Chao,[§] Dario Cantu,[**] Eligio Bossolini,[*] Xianming Chen,[††] Michael Pumphrey,[‡] and Jorge Dubcovsky[*,‡‡,2]
[*]Department of Plant Sciences, University of California, Davis, California 95616, [†]Department of Agricultural Sciences (DipSA), University of Bologna, Bologna 40127, Italy, [‡]Department of Crop and Soil Sciences, Washington State University, Pullman, Washington 99164-6420, [§]USDA-ARS, 1605 Albrecht Blvd, Fargo, North Dakota 58105, [**]Department of Viticulture and Enology, University of California, Davis, California 95616, [††]USDA-ARS, Wheat Genetics, Quality Physiology, and Disease Research Unit, and Department of Plant Pathology, Washington State University, Pullman, Washington 99164, and [‡‡]Howard Hughes Medical Institute, Chevy Chase, Maryland 20815

G3·Genes | Genomes | Genetics Volume 5 | March 2015 |

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Necrotrophic wheat pathogens

Classical gene-for-gene model
(effector-triggered immunity)
biotrophic plant–pathogen interactions

Pathogen Genotype	Host Genotype: ***R_***	Host Genotype: ***rr***
+Avr	Resistant	Susceptible
-Avr	Susceptible	Susceptible

Toxin-based inverse gene-for-gene model
(effector-triggered susceptibility)
necrotrophic plant–pathogen interactions

Pathogen Genotype	Host Genotype: ***S_***	Host Genotype: ***ss***
+NE	Sensitive	Insensitive
-NE	Insensitive	Insensitive

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Pyrenophora tritici-repentis

Tan spot

- Symptoms: necrotic lesions surrounded by chlorotic borders
- Yield loss up to 50%

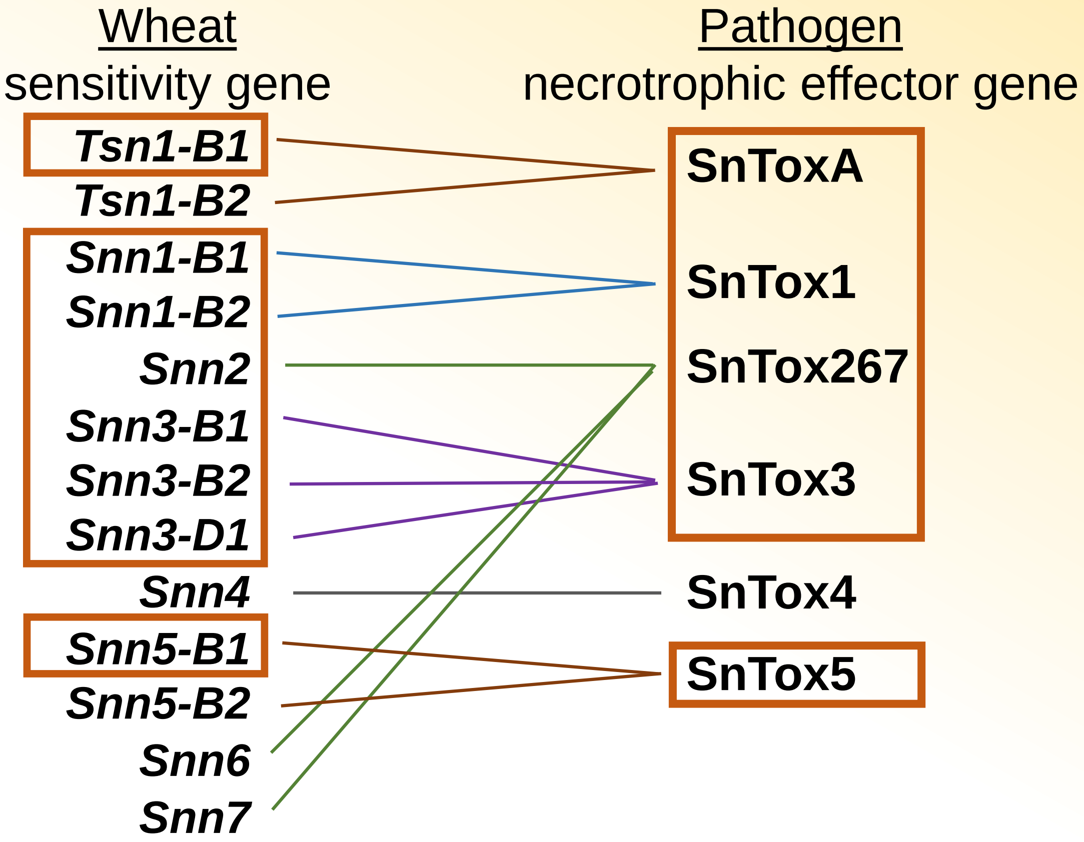
<u>Wheat</u> sensitivity gene	<u>Pathogen</u> necrotrophic effector gene	<u>Pathogen</u> races
Tsn1	Ptr ToxA	Race 1
Tsc2	Ptr ToxB	Race 2
Tsc1	Ptr ToxC	Race 3
		Race 4
		Race 5

https://plantwiseplusknowledgebank.org/

Parastagonospora nodorum

Septoria nodorum blotch (SNB)

- Symptoms: lens-shaped or elliptical necrotic lesions with pale yellow halo
- Yield losses: 30 - 50 %



https://cropprotectionnetwork.org

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Phenotyping

GDP

Tan spot

<u>Infiltration</u>
Ptr ToxA
Ptr ToxB

<u>Spray inoculation</u>
Pti2 (race 1)
86-124 (race 2)
331-9 (race 3)
L13-192 (race 4)
DW5 (race 5)

SNB

<u>Infiltration</u>
SnToxA
SnTox1
SnTox267
SnTox3
SnTox5

HRSWP

SNB

<u>Infiltration</u>
SnToxA
SnTox1
SnTox267
SnTox3
SnTox5

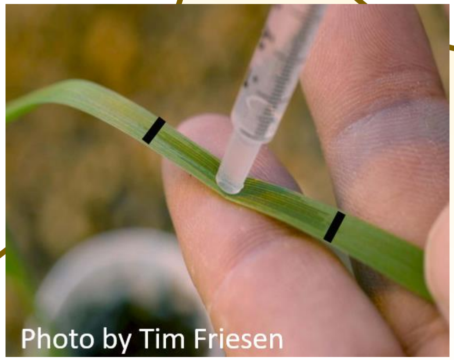
Photo by Tim Friesen

Genotyping

Illumina iSelect
90K SNP array

GWAS in R using
MLM method

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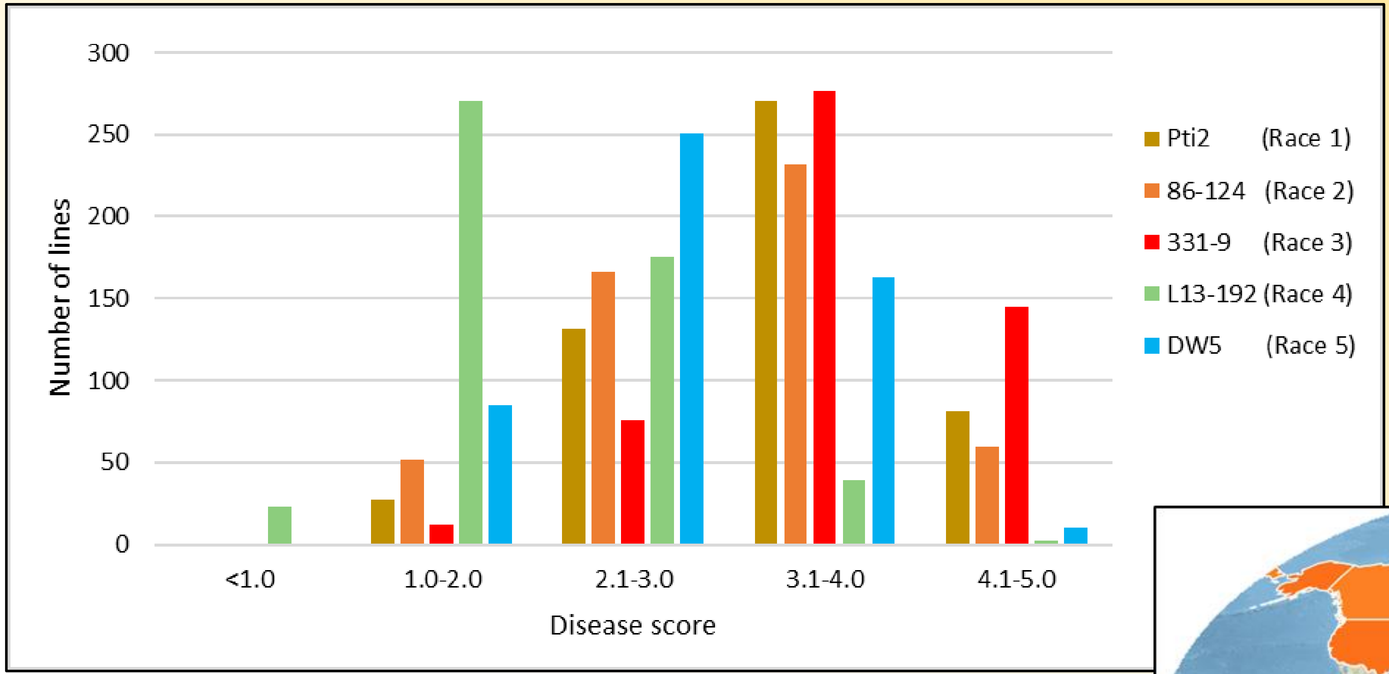
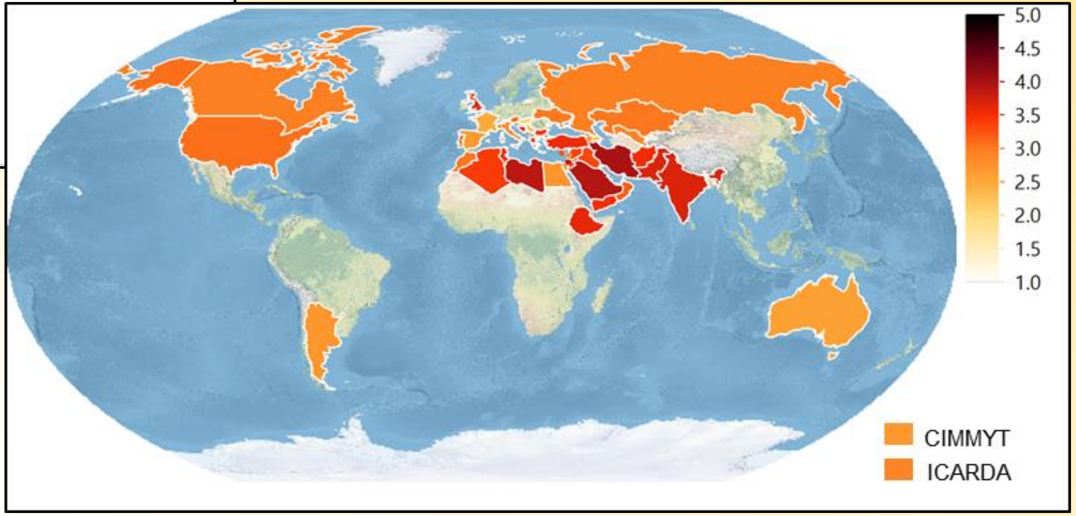
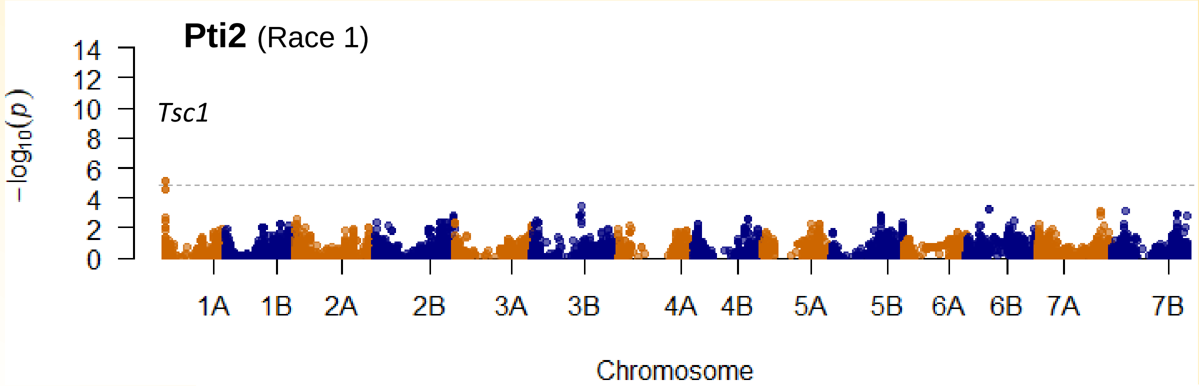
Global Durum Panel GWAS – tan spot





Average disease scores of races 1-5

Global Durum Panel GWAS results – tan spot



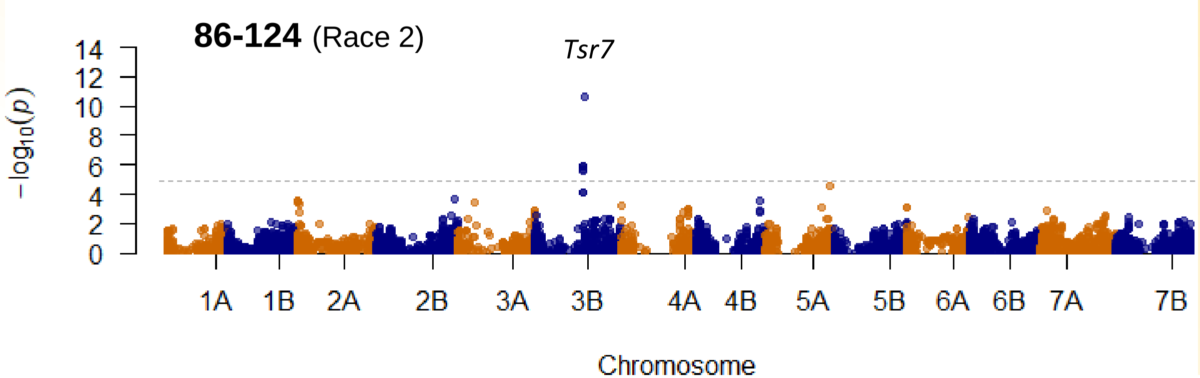
Produced effector:

Ptr ToxA + Ptr ToxC

G3 Genes | Genomes | Genetics Volume 6 | December 2016

New Insights into the Roles of Host Gene-Necrotrophic Effector Interactions in Governing Susceptibility of Durum Wheat to Tan Spot and Septoria nodorum Blotch

Simerjot K. Virdi,* Zhaohui Liu,† Megan E. Overlander,‡ Zengcui Zhang,‡ Steven S. Xu,‡ Timothy L. Friesen,†,‡ and Justin D. Faris‡,1



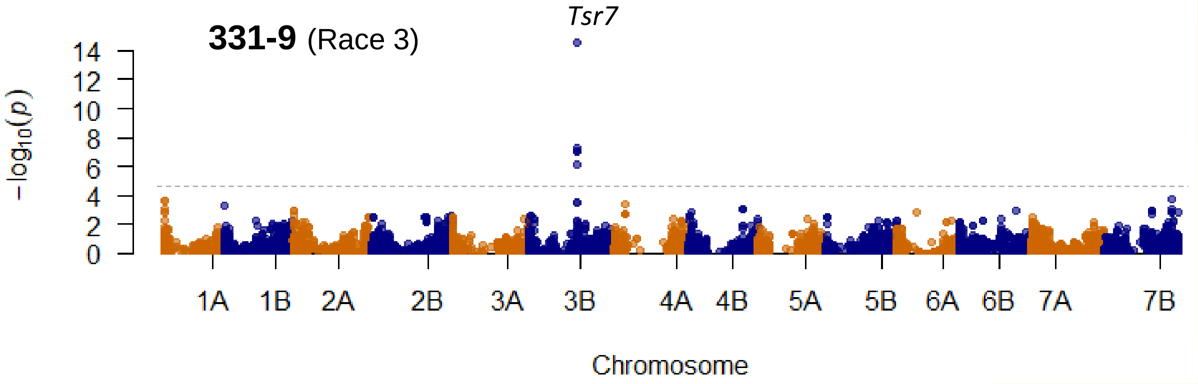
Produced effector:

Ptr ToxA

Theoretical and Applied Genetics (2020) 133:829–841

Identification of a major dominant gene for race-nonspecific tan spot resistance in wild emmer wheat

Justin D. Faris[1] · Megan E. Overlander[1] · Gayan K. Kariyawasam[2] · Arron Carter[3] · Steven S. Xu[1] · Zhaohui Liu[2]



Produced effector:

Ptr ToxC

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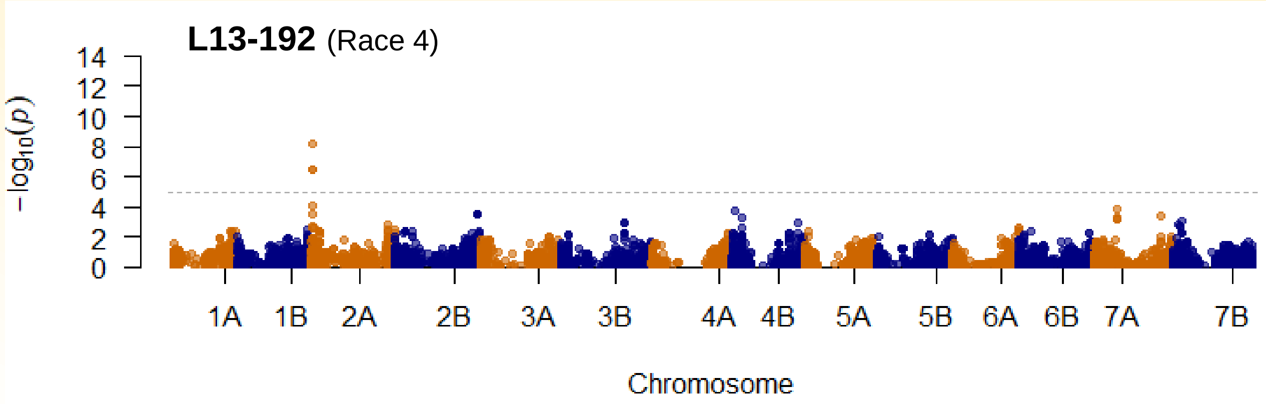
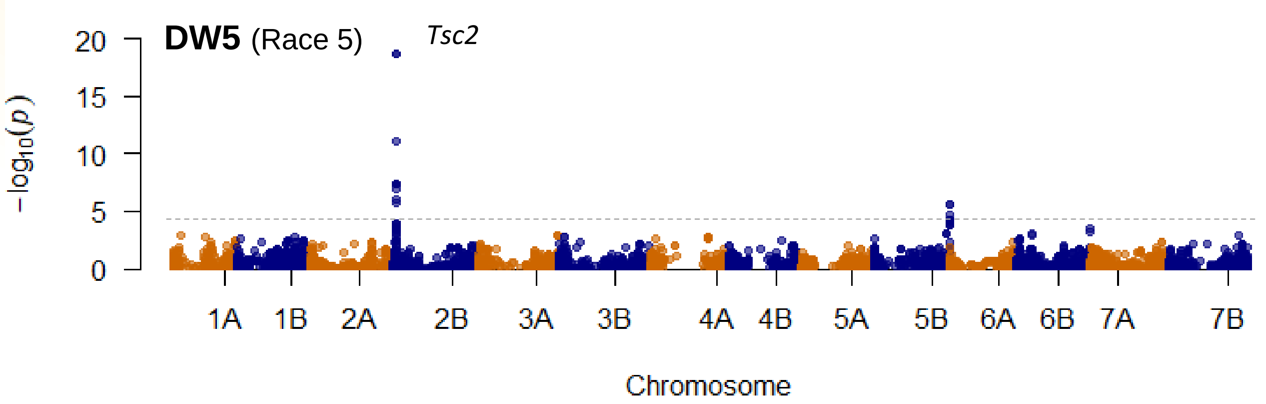
Global Durum Panel GWAS results – tan spot



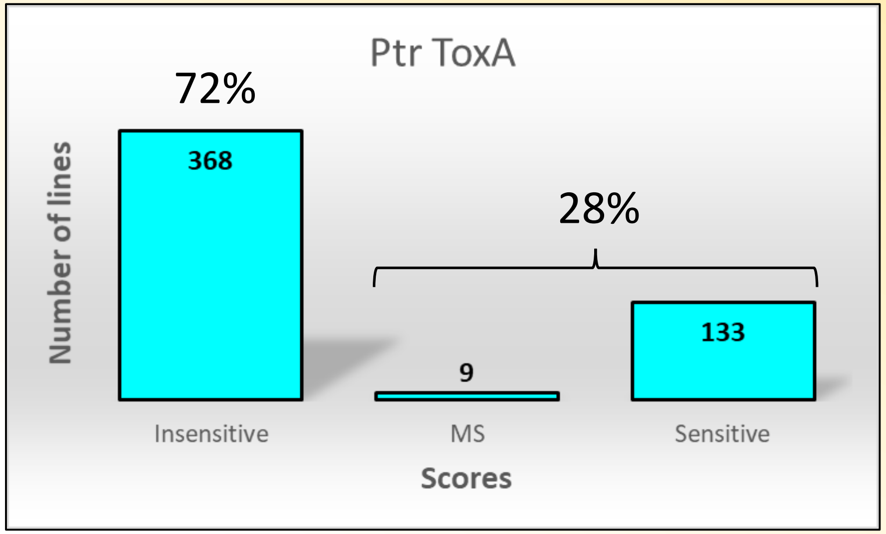
No known effector

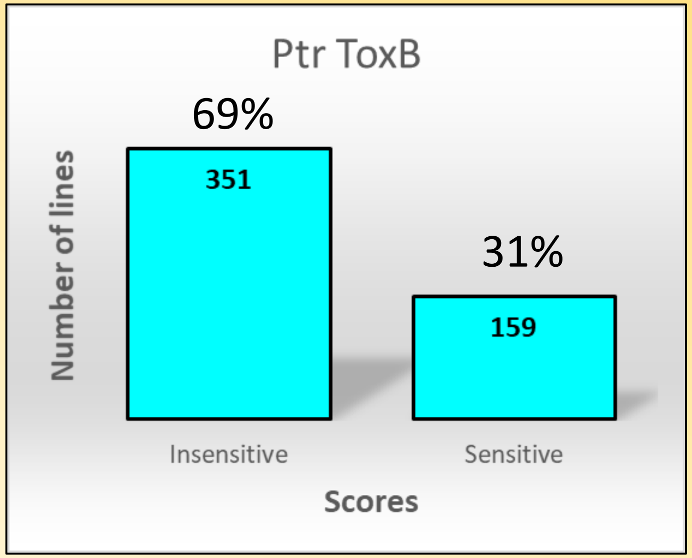


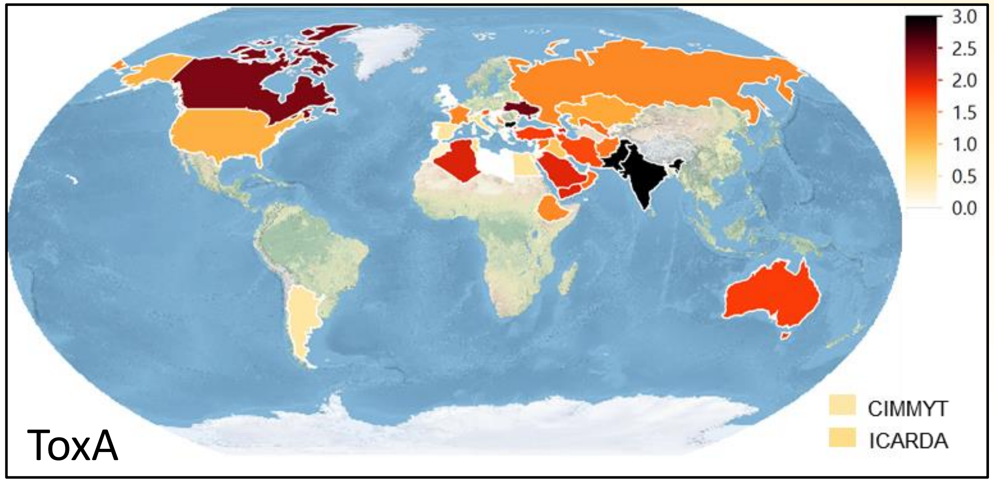
<u>Produced effector:</u>

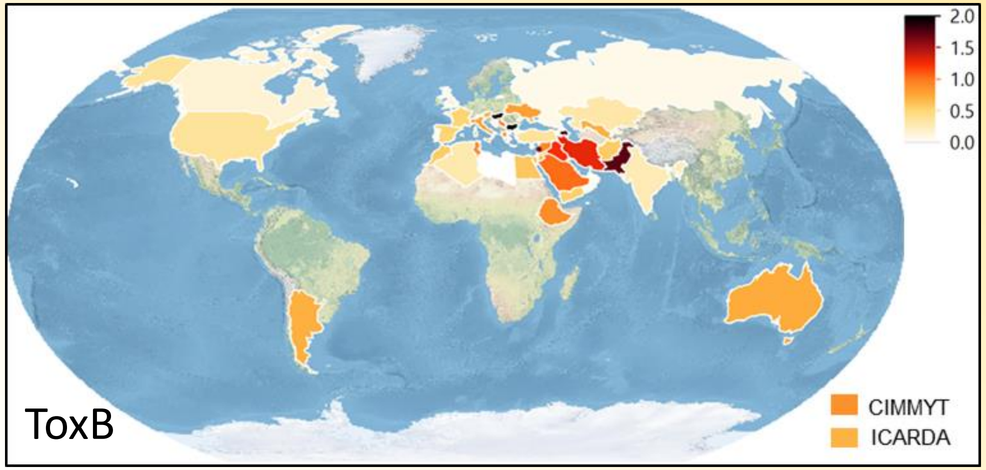
Ptr ToxB

Global Durum Panel GWAS – tan spot

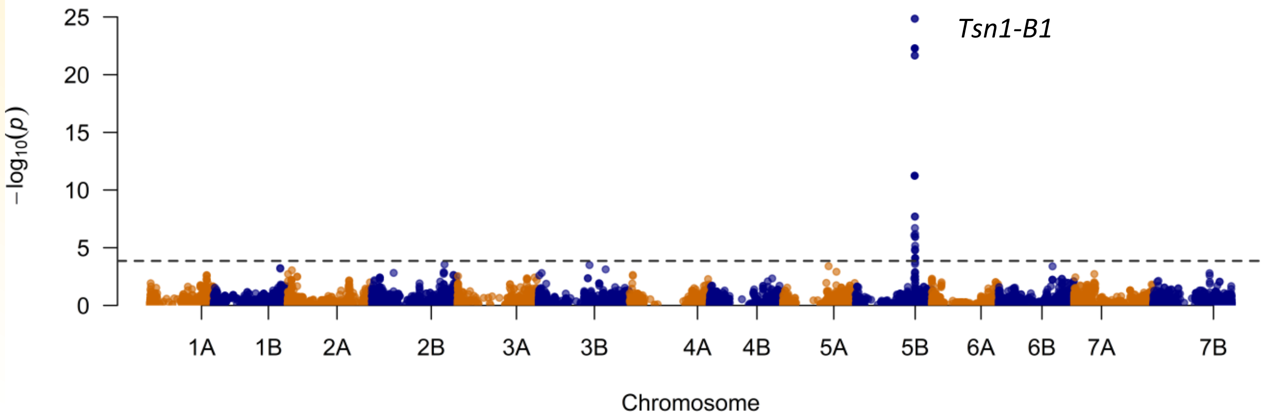




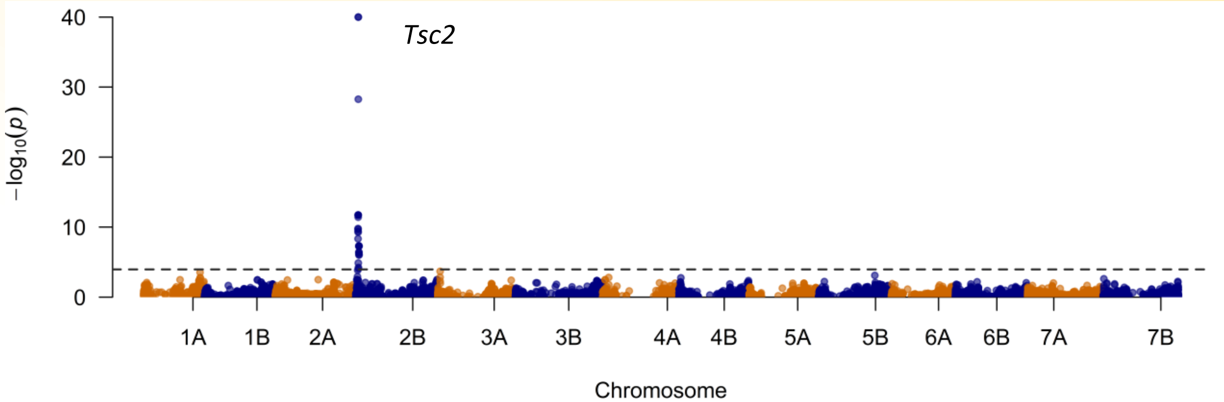




Global Durum Panel GWAS results – tan spot



Ptr ToxA

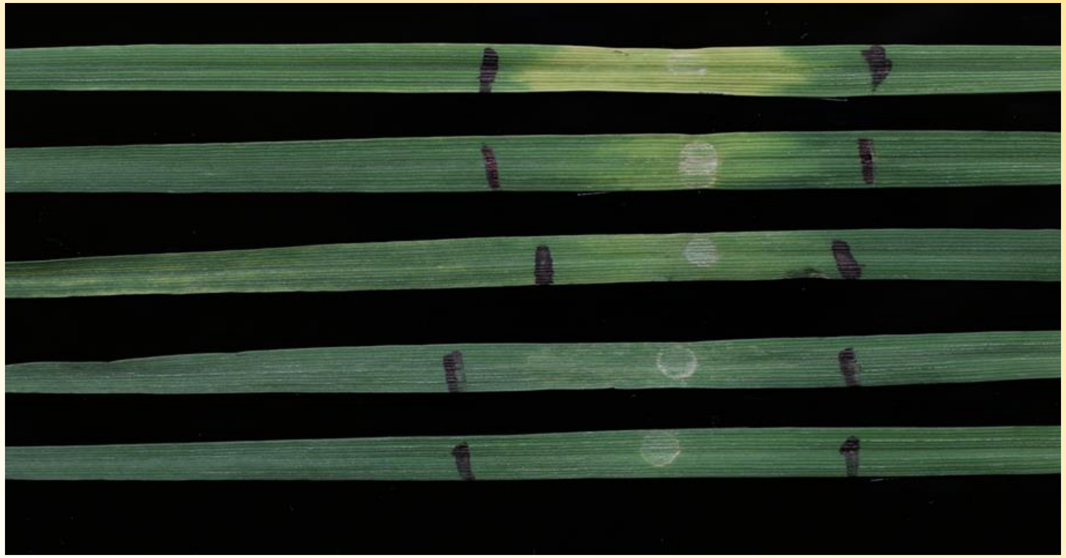


Ptr ToxB

Global Durum Panel GWAS results – tan spot

Sensitive

Insensitive



Infiltration area

2

1.5

1

0.5

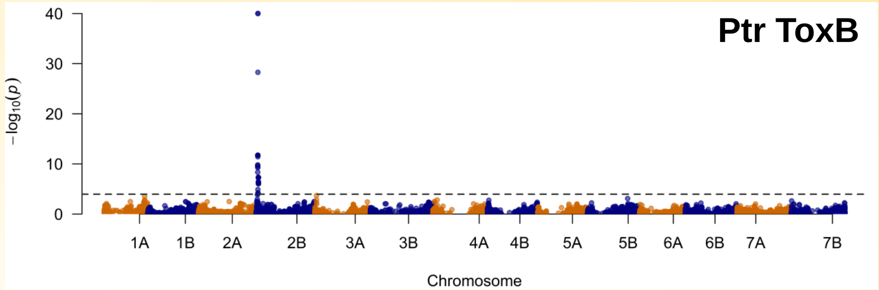
0

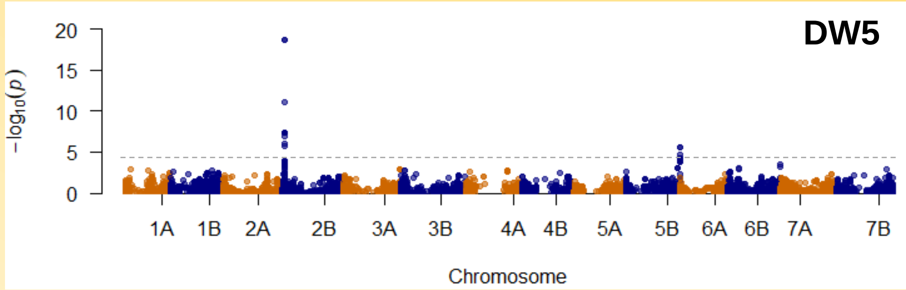
Gurminder Singh

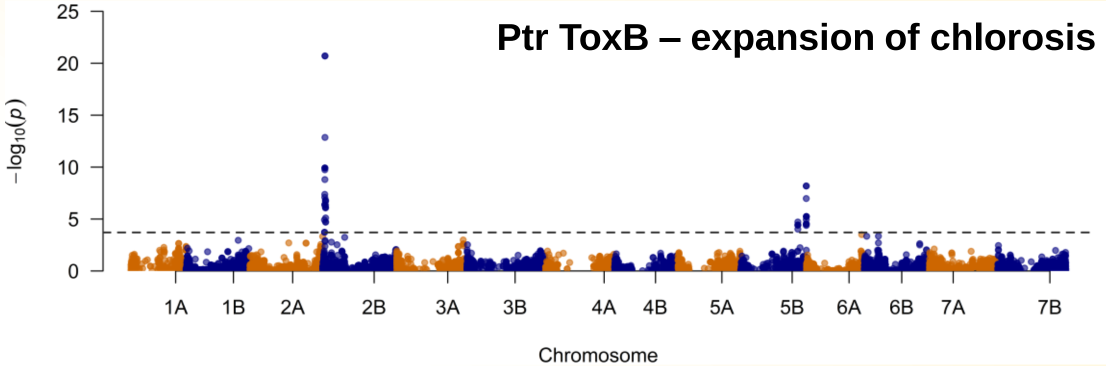
Chlorosis extended in 64% of the sensitive lines.

Infiltration area	Expansion of chlorosis
2	1
2	0
1.5	1

Global Durum Panel GWAS results – tan spot

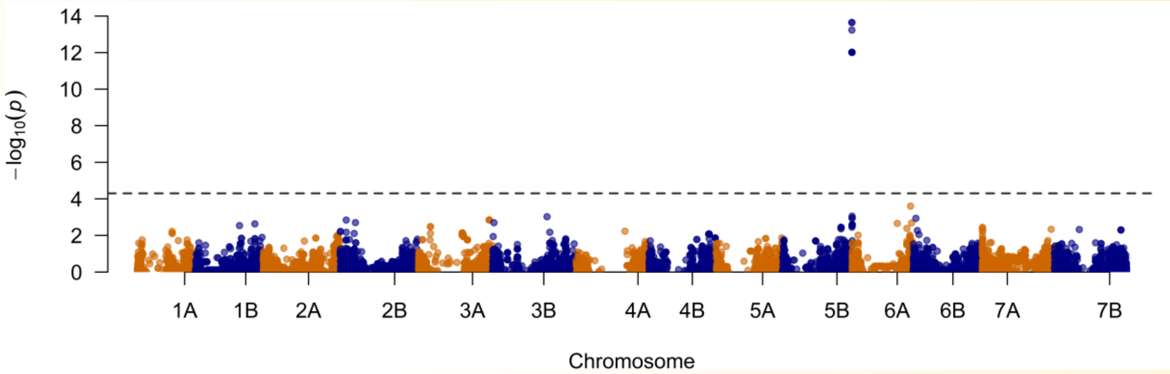






Expansion of chlorosis	DW5 score
1	3.54
0	2.86

Ptr ToxB – expansion of chlorosis
Sensitive lines



Global Durum Panel GWAS results – tan spot
Summary bullet points

- *Tsr7* is a major resistance factor in durum wheat.
- *Tsc1* and *Tsc2* play significant roles in conferring susceptibility.
- *Tsn1* is not a relevant factor in tan spot development in durum.
- New QTL on 2AS associated with race 4 isolate.
- Novel trait characterized by expanding chlorosis and increased disease severity. QTL on chromosome 5BL.
- Breeders are recommended to select for *Tsr7* and eliminate *Tsc1*, *Tsc2*, and ***Tsn1-B1***.
- 14 lines resistant to tan spot.

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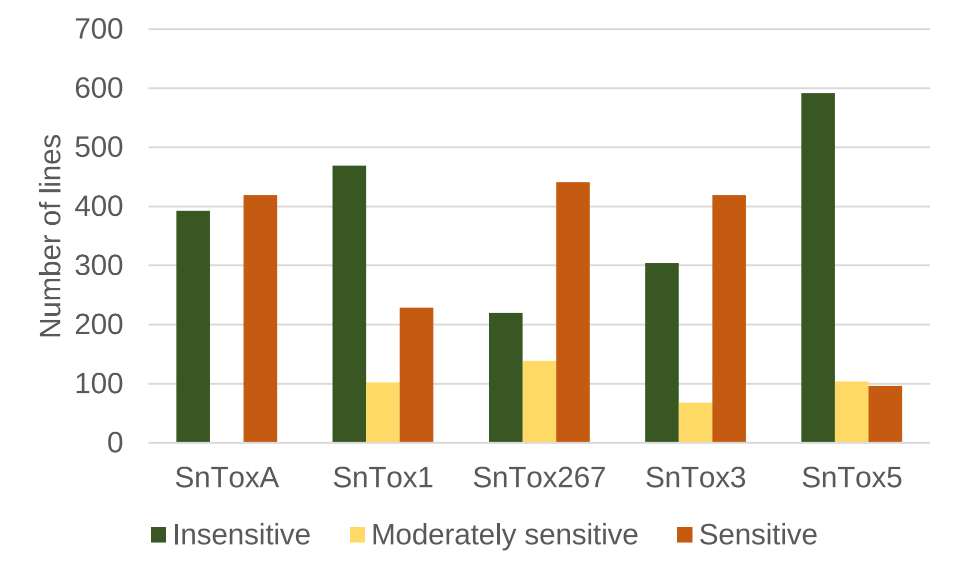
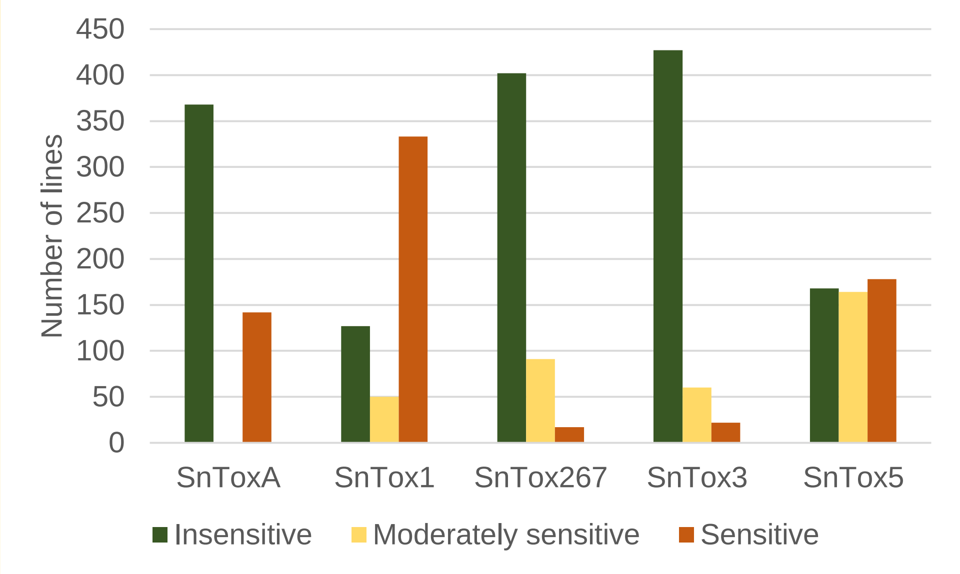
Disease scores – SNB

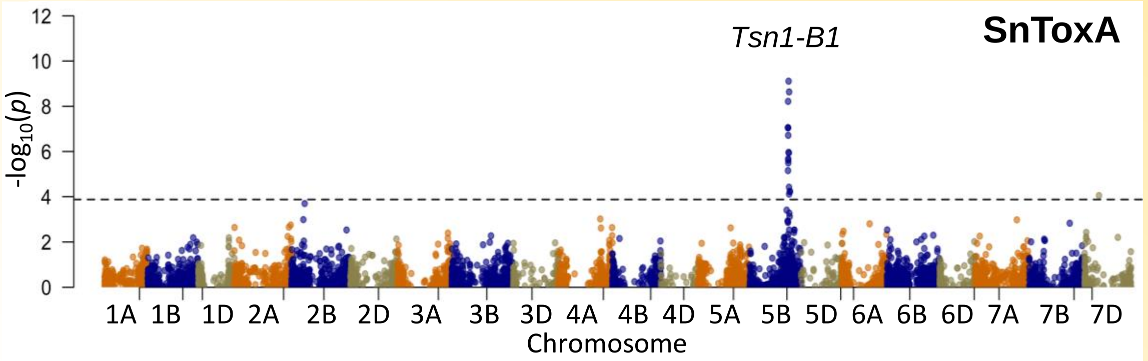
Spring wheat (HRSWP)

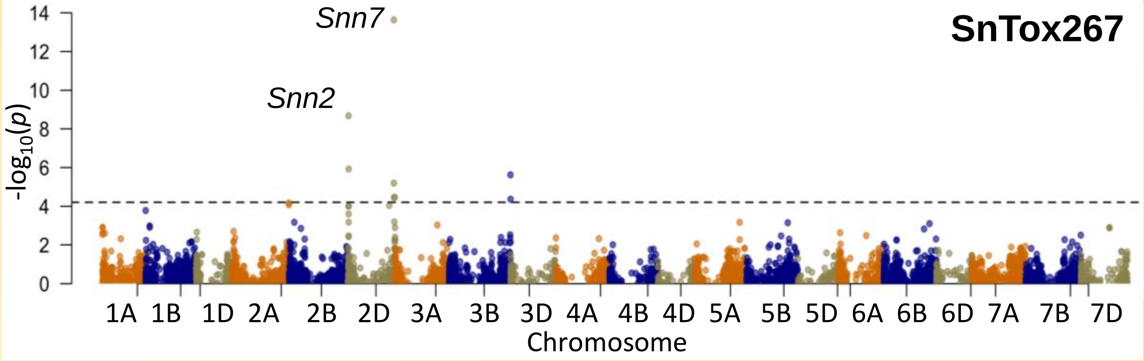


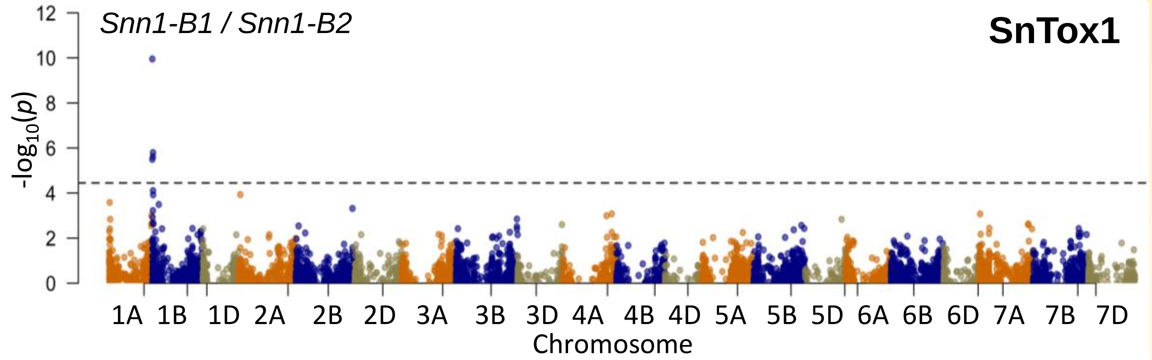
Durum wheat (GDP)

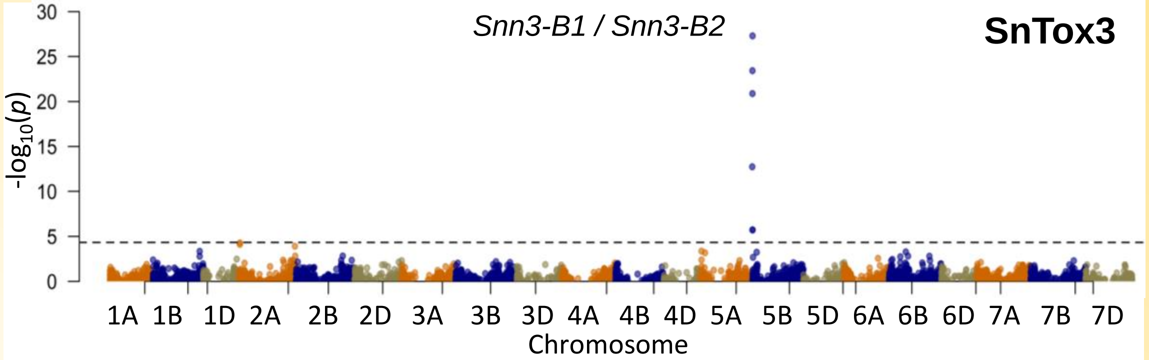


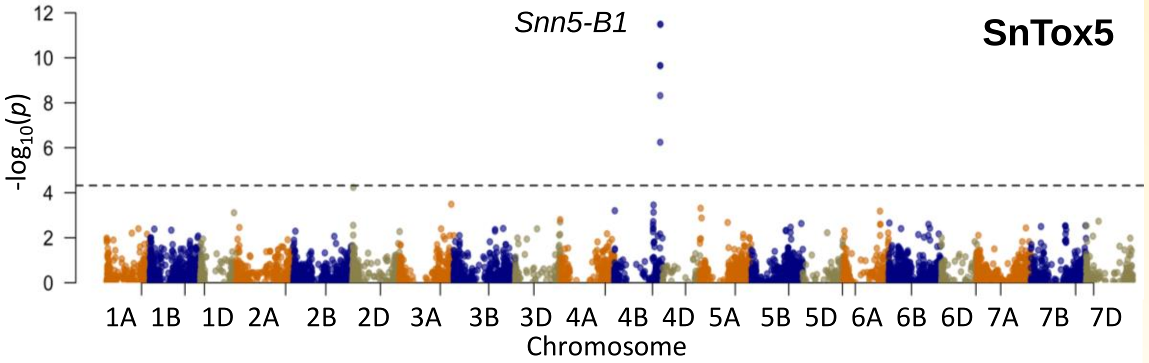
Hard Red Spring Wheat Panel GWAS results – SNB











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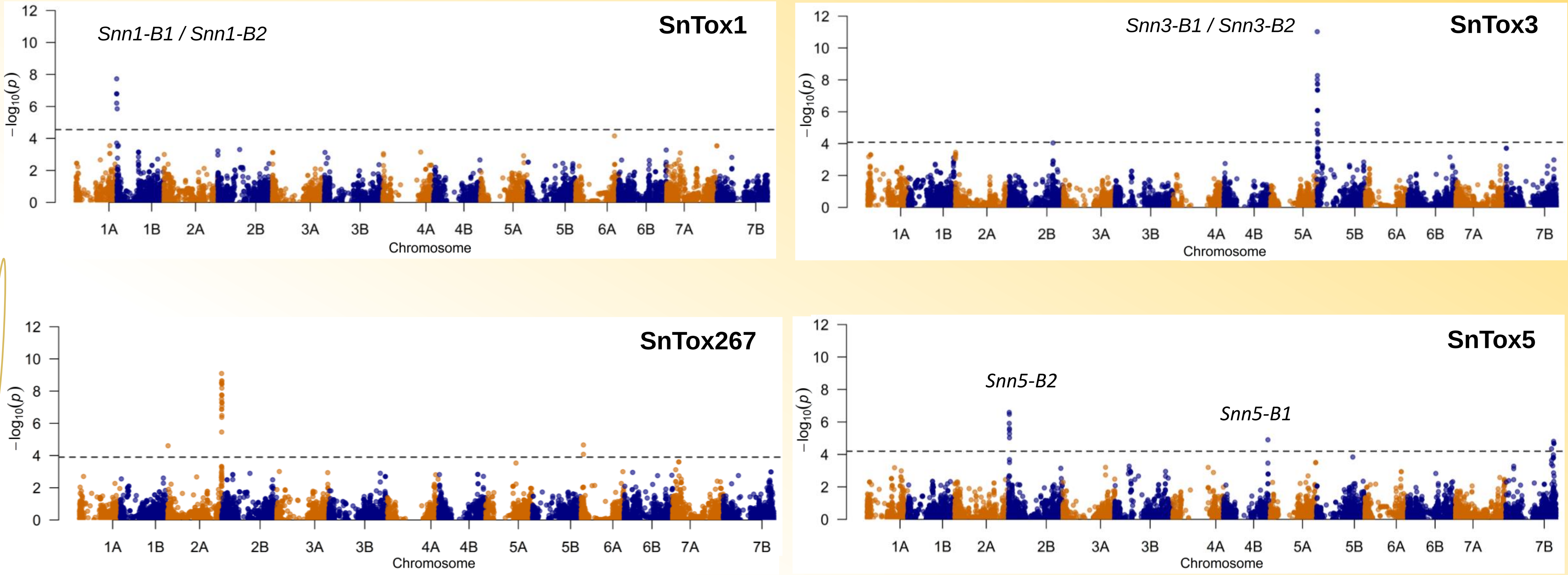
Global Durum Panel GWAS results – SNB



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SNB resistance in durum and spring wheat
Summary bullet points

HRSW breeders

- High frequency NEs: SnToxA, SnTox267, SnTox3
- Should eliminate *Tsn1-B1, Snn2*, *Snn3-B1, Snn3-B2*, and *Snn7*
- Select the resistant allele at 3BL QTL associated with SnTox267
- Identified 41 lines insensitive to all five NEs

Durum breeders

- High frequency NEs: SnToxA, SnTox1, SnTox5
- Should eliminate *Tsn1-B1, Snn1-B1, Snn1-B2*
- Select the resistant alleles at 2BS, 4BL and 7BL QTL associated with SnTox5
- Identified 32 lines insensitive to all five NEs

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The benefit of the GWAS projects in marker development and validation

- Identified two copies of *Snn1* (*Snn1-B1* and *Snn1-B2*).
- *Snn1-B2* evolved relatively recently compared to the paralog *Snn1-B1*.
- Developed KASP markers eliminating sensitive lines, and a *Snn1* null allele KASP marker, which shows the presence of the gene in durum and hexaploid wheat.

Sudeshi Seneviratne

the plant journal
S E B
SOCIETY FOR EXPERIMENTAL BIOLOGY

The Plant Journal (2024) **119**, 1720–1736 doi: 10.1111/tpj.16879

Evolution, diversity, and function of the disease susceptibility gene *Snn1* in wheat

Sudeshi Seneviratne[1], Gongjun Shi[2], Agnes Szabo-Hever[3], Zengcui Zhang[3], Amanda R. Peters Haugrud[3], Katherine L. D. Running[1], Gurminder Singh[1], Raja Sekhar Nandety[3], Jason D. Fiedler[3], Phillip E. McClean[1], Steven S. Xu[4], Timothy L. Friesen[3] and Justin D. Faris[3,*]

[1]*Department of Plant Sciences, North Dakota State University, Fargo, North Dakota 58102, USA,*
[2]*Department of Plant Pathology, North Dakota State University, Fargo, North Dakota 58102, USA,*
[3]*USDA-ARS Cereal Crops Research Unit, Edward T. Schafer Agricultural Research Center, Fargo, North Dakota 58102, USA, and*
[4]*USDA-ARS Crop Improvement and Genetics Research Unit, Western Regional Research Center, Albany, California 94710, USA*

The benefit of the GWAS projects in marker development and validation

- *Snn3-D1* (chromosome 5D) has been cloned from *Ae. tauschii*, and a candidate gene *Snn3-B1* (chromosome 5B) (homeolog) was identified to recognize SnTox3.
- While characterizing and validating *Snn3-B1*, *Snn3-B2* (paralog) was identified which also recognizes SnTox3 and leads to susceptibility.
- Developed diagnostic markers for showing the absence of *Snn3-B1* and *Snn3-B2*
- Evaluation of the HRSW panel showed that several alleles of each gene exist in germplasm.

Zengcui Zhang

MPMI Vol. 38, No. 2, 2025, pp. 315–327, https://doi.org/10.1094/MPMI-10-24-0125-FI

RESEARCH

Protein Kinase-Major Sperm Protein (PK-MSP) Genes Mediate Recognition of the Fungal Necrotrophic Effector SnTox3 to Cause Septoria nodorum Blotch in Wheat

Zengcui Zhang,[1] Katherine L. D. Running,[2] Sudeshi Seneviratne,[2] Amanda R. Peters Haugrud,[1] Agnes Szabo-Hever,[2] Gurminder Singh,[2] Kateřina Holušová,[3] István Molnár,[3,4] Jaroslav Doležel,[3] Timothy L. Friesen,[1] and Justin D. Faris[1,†]

[1] USDA-ARS, Cereal Crops Research Improvement Unit, Edward T. Schafer Agricultural Research Center, Fargo, ND 58102, U.S.A.
[2] Department of Plant Sciences, North Dakota State University, Fargo, ND 58108, U.S.A.
[3] Institute of Experimental Botany of the Czech Academy of Sciences, Centre of Plant Structural and Functional Genomics, Olomouc 77900, Czech Republic
[4] Hungarian Research Network (HUN-REN), Centre for Agricultural Research, Agricultural Institute, 2462 Martonvásár, Hungary

Accepted for publication 28 March 2025.

The benefit of the GWAS projects in marker development and validation

- Identified two loci controlling ToxA sensitivity (termed *Tsn1-B1* and *Tsn1-B2*).
- Developed breeder-friendly markers (KASP, STARP) to identify ToxA-insensitive lines.
- Markers were validated in the GDP and HRSW panels.

Katherine Running

Theoretical and Applied Genetics (2025) 138:164
https://doi.org/10.1007/s00122-025-04952-6

ORIGINAL ARTICLE

Check for updates

Development of diagnostic markers for the disease susceptibility gene *Tsn1* in wheat reveals novel resistance alleles and a new locus required for ToxA sensitivity

Katherine L. D. Running[1] · Krishna Acharya[1] · Tiana M. Roth[1] · Gurminder Singh[1] · Agnes Szabo-Hever[1] · Amanda R. Peters Haugrud[2] · Jason D. Fiedler[2] · Timothy L. Friesen[2] · Justin D. Faris[2]

The benefit of the GWAS projects in marker development and validation

- Molecular cloning and characterization of tan spot susceptibility gene *Tsc2* in wheat.
- Analyzed the allelic diversity of *Tsc2*.
- Developed a diagnostic genetic marker (KASP) for marker-assisted elimination of *Tsc2* in wheat.
- Marker successfully validated in the GDP and HRSW panels.

Gurminder Singh

UNDER PUBLICATION

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- Megan Overlander
- Cayley Steen
- Stephanie McCoy
- Heaven James
- **Timothy Friesen**
- Danielle Holmes

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- Jason Axtman
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- Marco Maccaferri
- Roberto Tuberosa

CREA Research Centre for Genomics and Bioinformatics, Italy

- Luigi Cattivelli

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USDA-ARS Research Participation Program

For more details…

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Genetics and Genomics of Resistance

Association Mapping of Resistance to Tan Spot in the Global Durum Panel

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Evaluation of Durum and Hard Red Spring Wheat Panels for Sensitivity to Necrotrophic Effectors Produced by *Parastagonospora nodorum*

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Thank you
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