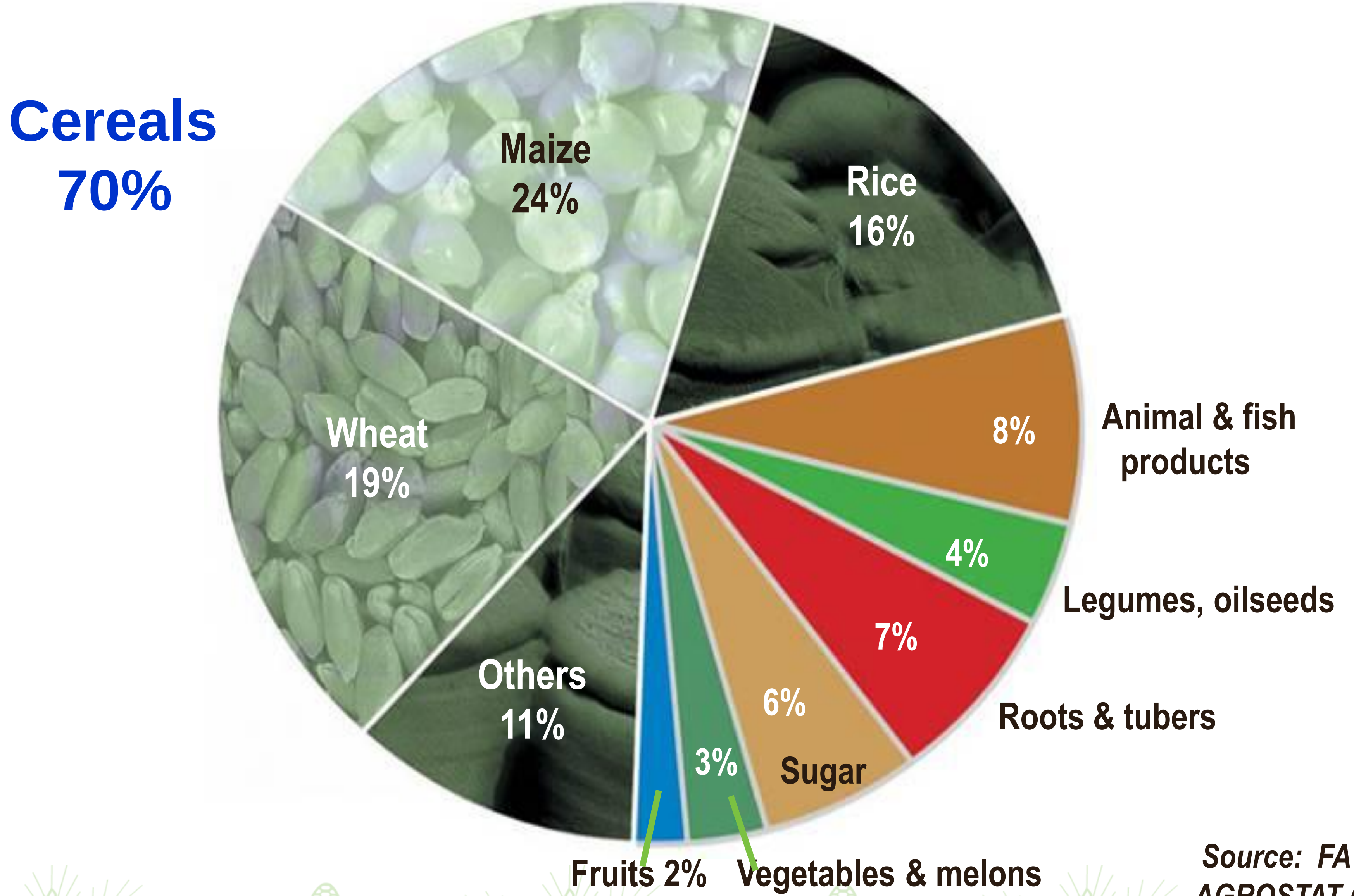
Breeder Friendly Phenotyping

Matthew Reynolds & colleagues

The 6th Annual - Nordic Plant Phenotyping Network Workshop

Virtual meeting – Friday 27 November 2020

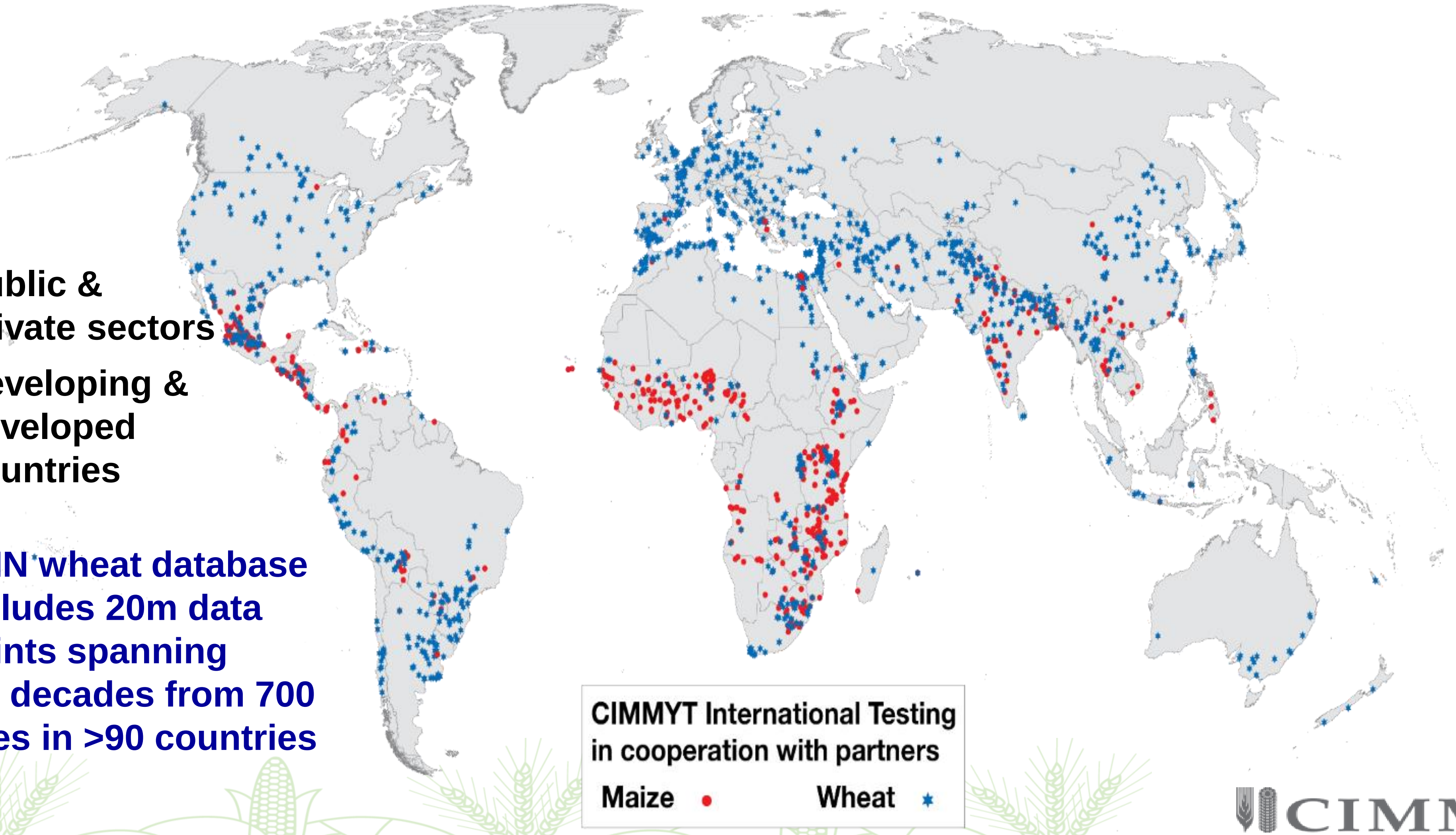
World food supply: ~3 b tonnes (dry wt)



Source: FAO AGROSTAT (2012)

CIMMYT

CIMMYT Maize & Wheat Improvement Networks:
in the post Green-Revolution period, emphasis on yield stability, biotic stresses & nutritional quality

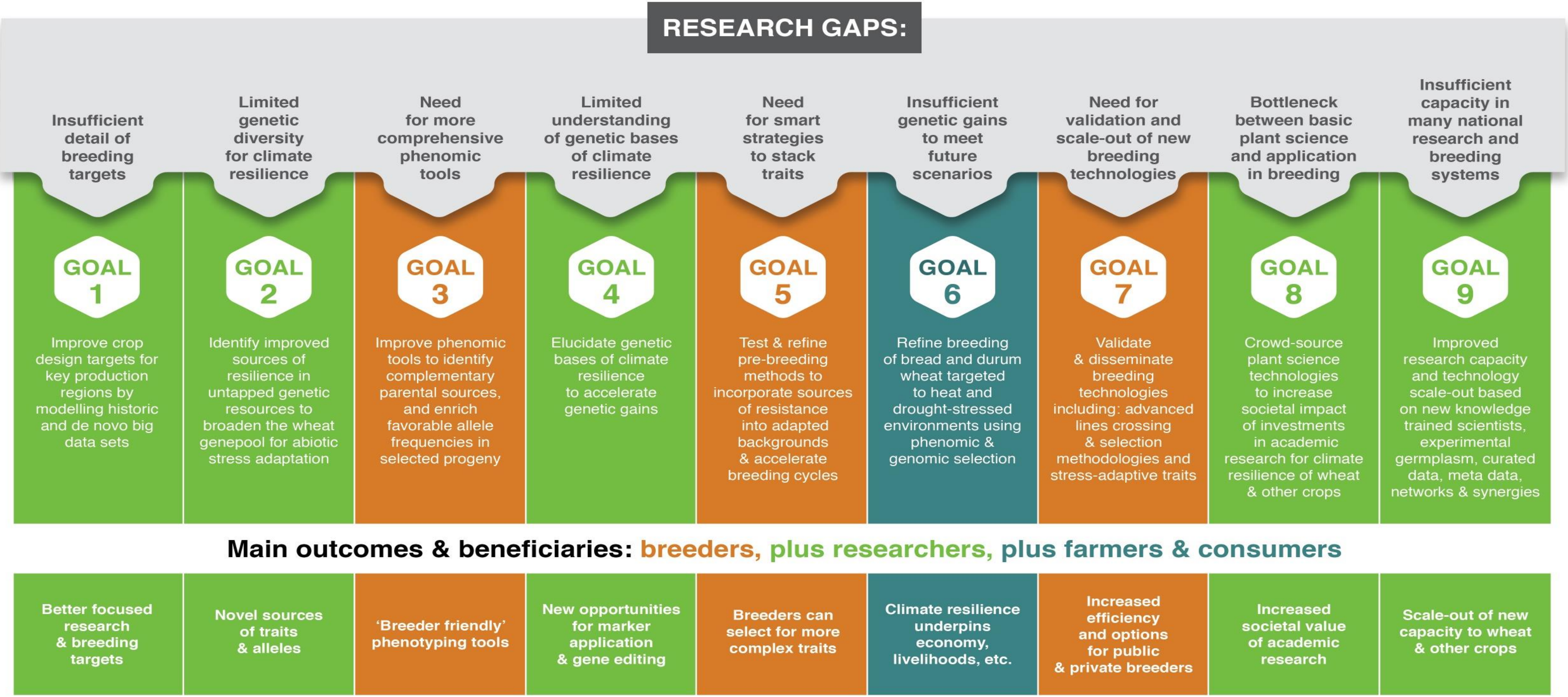


- Public & private sectors
- Developing & developed countries

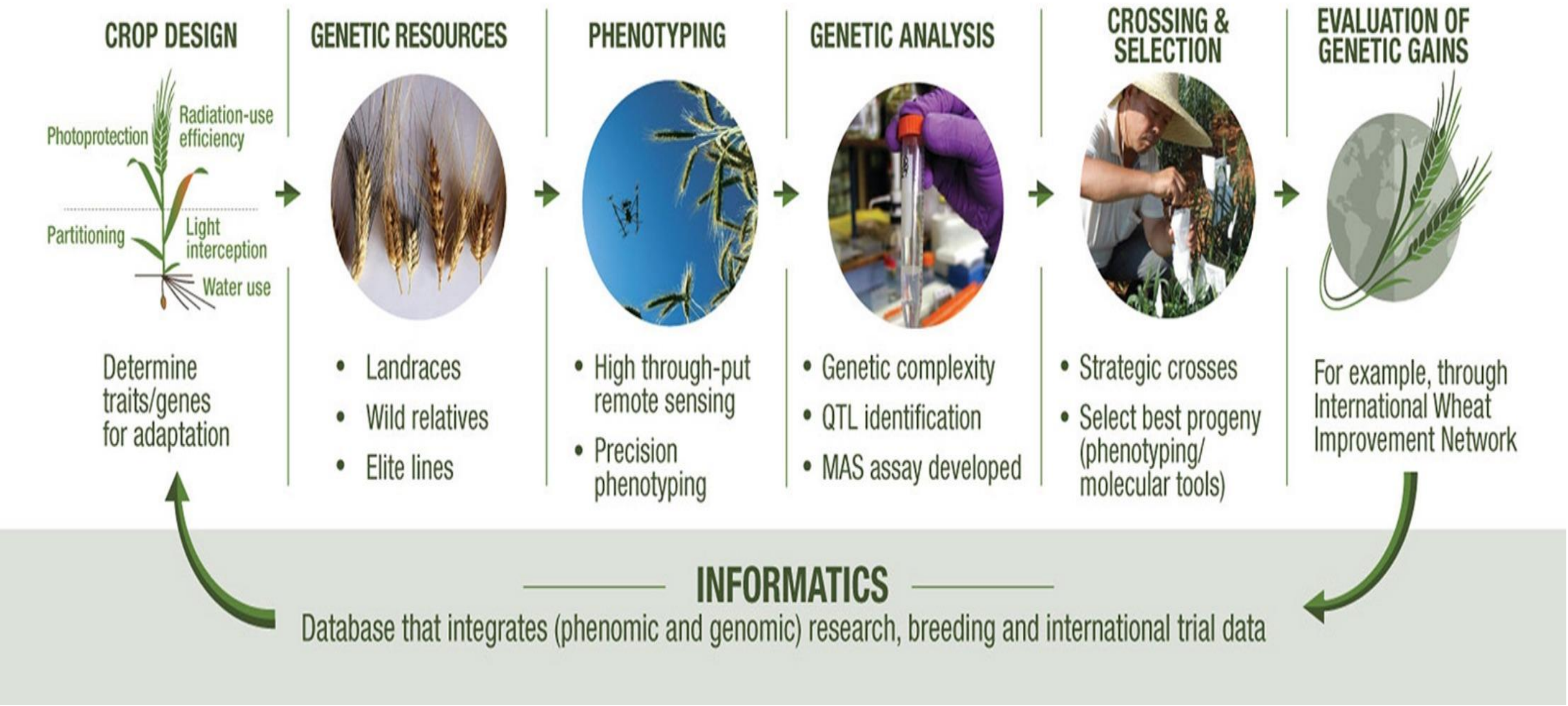
IWIN wheat database includes 20m data points spanning > 4 decades from 700 sites in >90 countries

CIMMYT

Harnessing translational research across a global wheat improvement network for climate resilience: Research gaps, interactive goals and outcomes



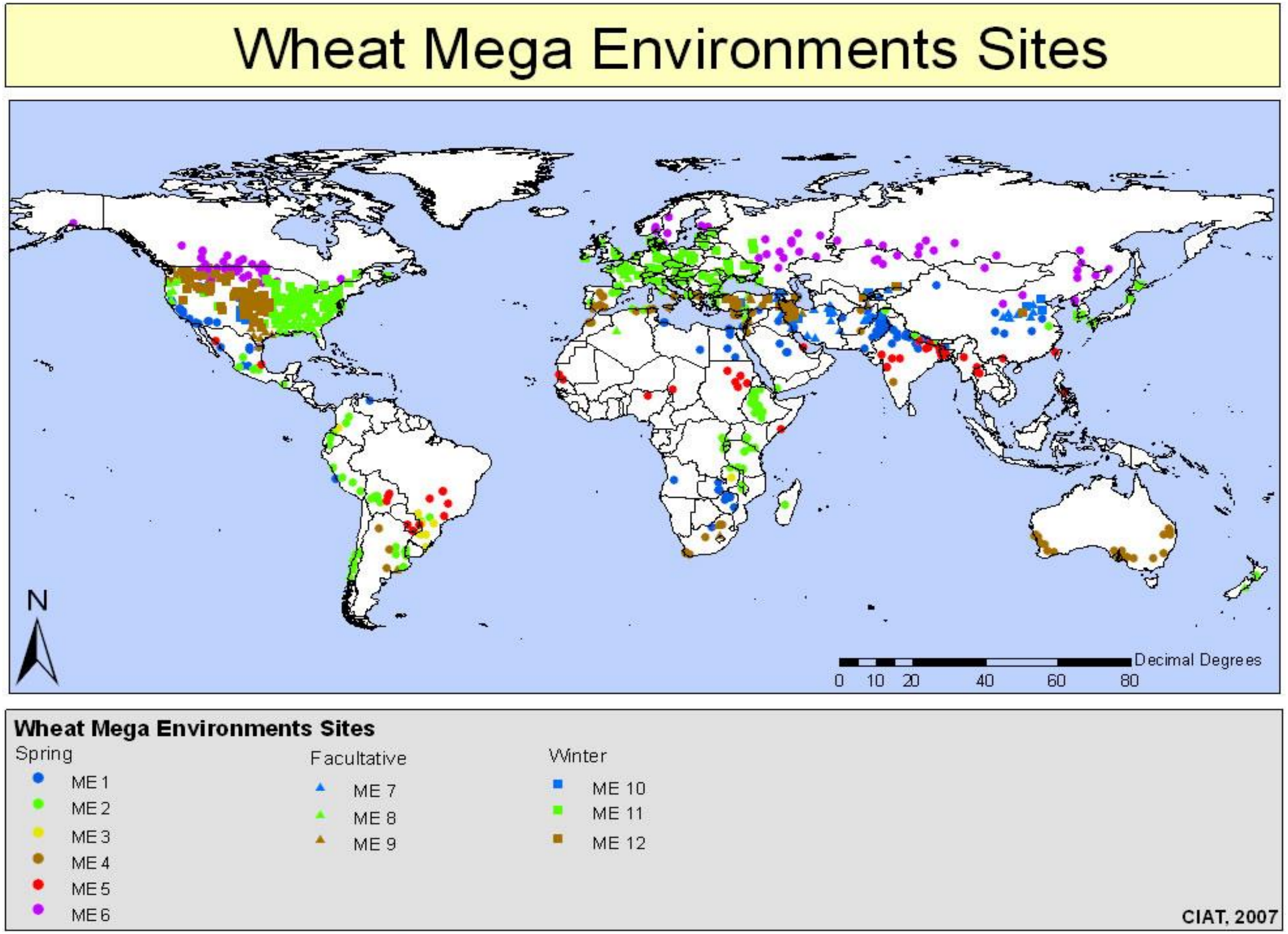
PHYSIOLOGICAL PRE-BREEDING PIPELINE



Reynolds MP and Langridge P, (2016). Physiological Breeding.
Current Opinions in Plant Biology 31: 162–171

Goal 1: Improve crop design using modeling and IWIN big data sets

- ~1000 new lines sent annually to a network of public & provate breeders globally
- Common set of germplasm grown under a diverse conditions
- Generated millions of data points over 4 decades



河南農業大學
Henan Agricultural University

CIMMYT

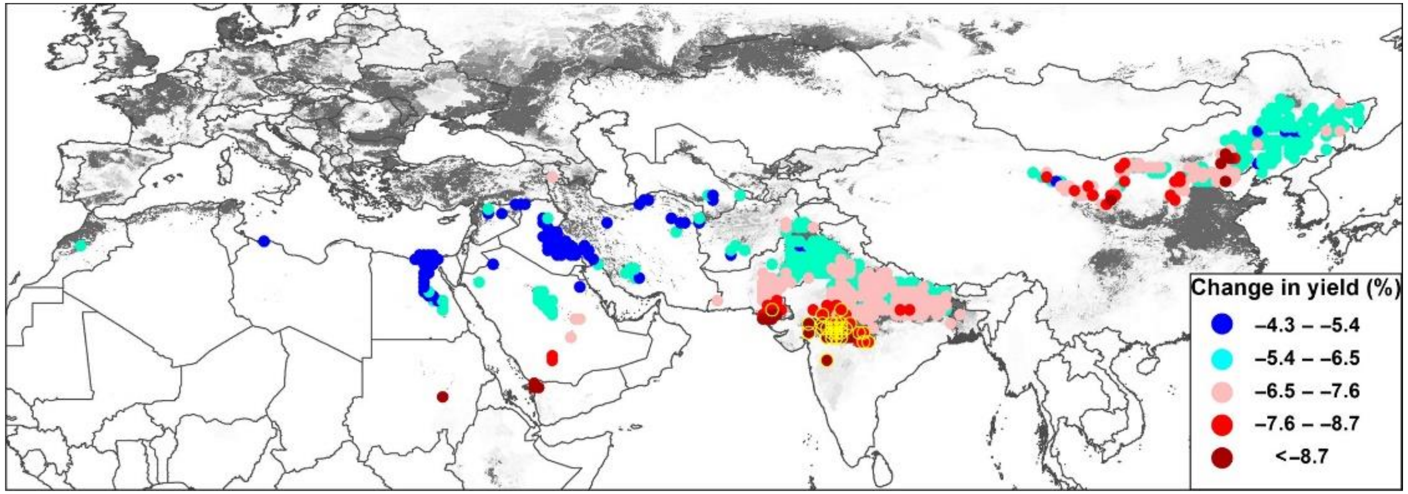
Builds on Previous Research Using IWIN

Global Change Biology

Global Change Biology (2016), doi: 10.1111/gcb.13530

Hot spots of wheat yield decline with rising temperatures

SENTHOLD ASSENG[1], DAVIDE CAMMARANO[1,a], BRUNO BASSO[2], URAN CHUNG[3,b], PHILLIP D. ALDERMAN[3,C], KAI SONDER[3], MATTHEW REYNOLDS[3] and DAVID B. LOBELL[4,5]



Estimated average yield change for 2030–2041 (compared to baseline 2000–2011) across main global irrigated spring wheat areas with >13.0 °C mean seasonal temperature.

Gourdji, S. M., et al. 2013. An assessment of wheat yield sensitivity and breeding gains in hot environments. Proceedings of The Royal Society B, 280: 20122190

Crespo-Herrera, L. A., et al. 2017. Genetic Yield Gains In CIMMYT's International Elite Spring Wheat Yield Trials By Modeling. Crop Science, 57:789–801

Crespo-Herrera, L. A., et al. 2018. Genetic gains for grain yield in CIMMYT's Semi-Arid wheat yield trials grown in suboptimal environments. Crop Science, 58:1890–1898

Juliana, P., et al. 2020. Retrospective quantitative genetic analysis and genomic prediction of global wheat yields. Frontiers in Plant Science, 11

CIMMYT

DESIGN: conceptual model of heat-adaptive traits

YIELD = LI x RUE x HI

Photo-Protection (RUE)

•Leaf morphology (display
wax)
•Down regulation
•Pigment compos
 • Chl a:b
 • Caroteno
•Antioxidants

Efficient metabolism (RUE)

 tion
 • 2 conductance
 •Rubsico (>>)
•Ca hotosynthesis
 •s e photosynthesis
 ion

G x G

Partitioning (HI)

•Spike fertility (r sis, pollen, etc)
•Stress signaling . eth egulating
 •senescenc te
 •floret abort
•Grain filling (starch synthase)
•Stem carbohydrate storage & remobilization

Light interception (LI)

 ground cover
•Functional stay-green

Water Use (RUE)

•Roots match evaporative demand
•Regulation of transpiration (VPD; ABA)

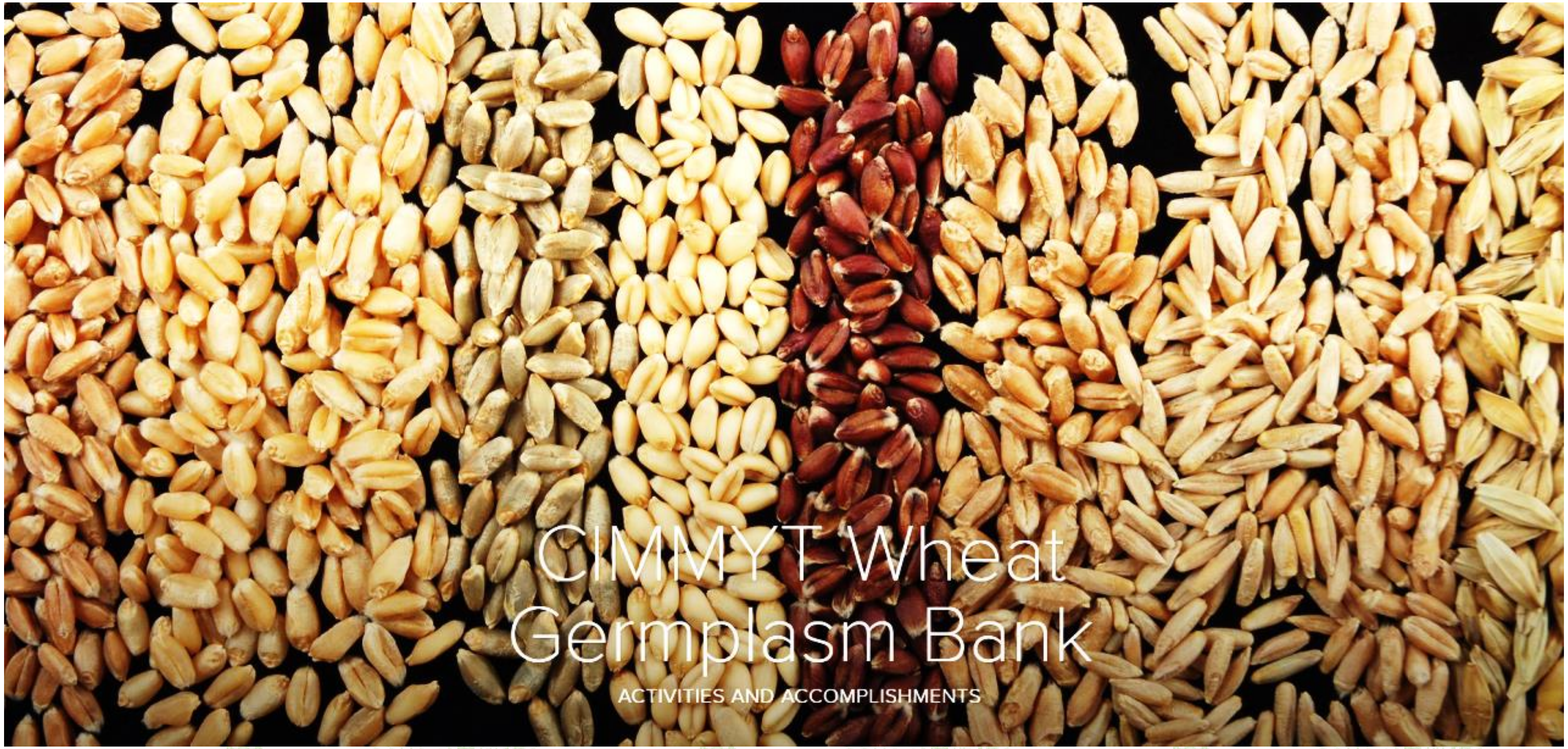
G x E

Cossani CM, Reynolds, MP. 2012.
Physiological traits for improving heat tolerance in wheat.
Plant Physiology 160: 1710-18

CIMMYT

Goal 2: Explore untapped genetic resources

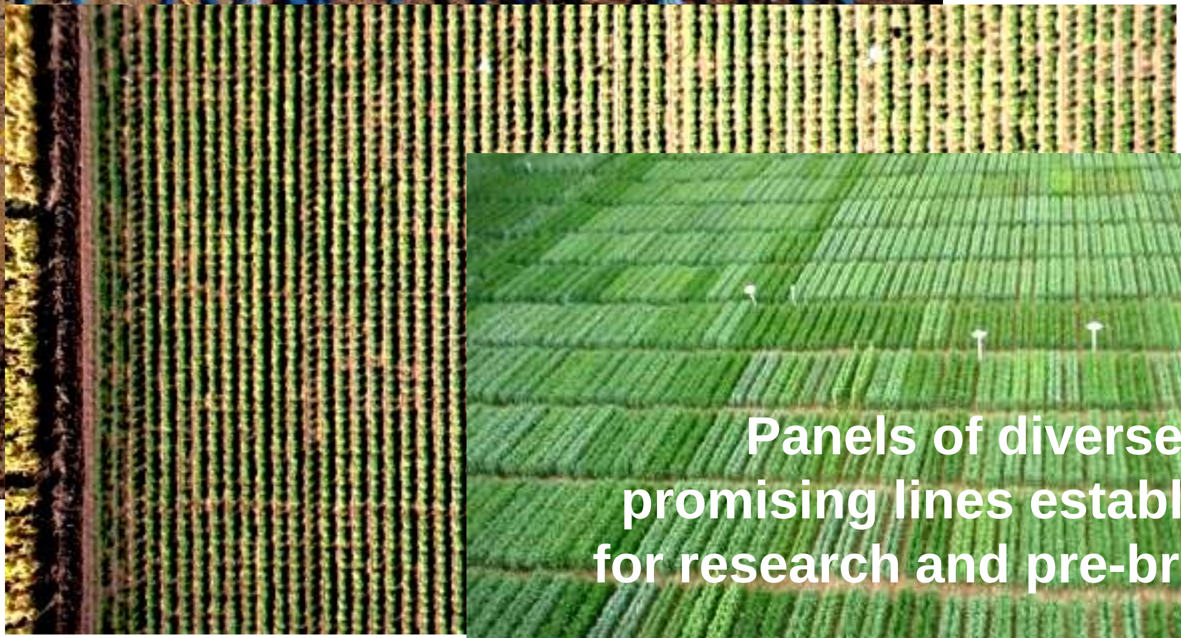
World Wheat Collection at CIMMYT comprise >150,000 genotypes from more than 100 countries; the largest unified collection in the world for a single crop.

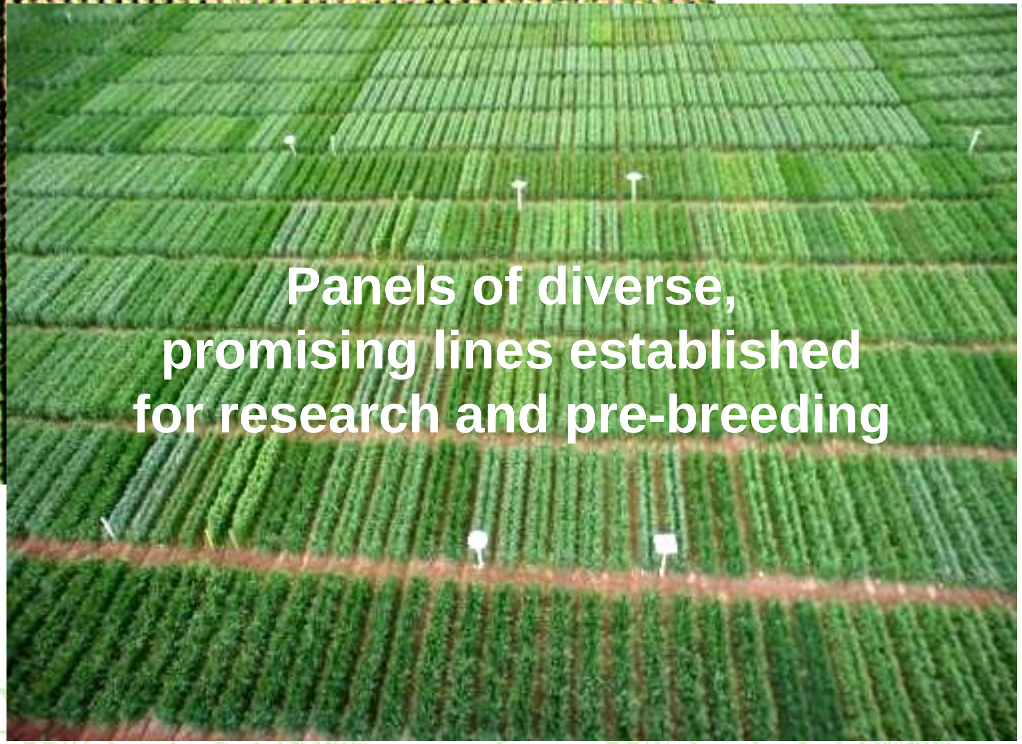


70,000 wheat genetic resource samples

Screened under drought and heat, Sonora, Mexico, 2011-2013

Funded by MasAgro-SeeD





There are ~0.8 m samples of wheat genetic resources in global collections

Reynolds et al (2015): Exploring genetic resources to increase adaptation of wheat to climate change. In Advances in Wheat Genetics: From Genome to Field. Eds Ogihara Y, Takumi S, Handa H. Springer Japan; 2015

Bread wheat diversity panel (n=370)

Includes best performing lines from:

- International nurseries
- Landraces/FIGS panels
- Lines derived from inter-specific hybridization

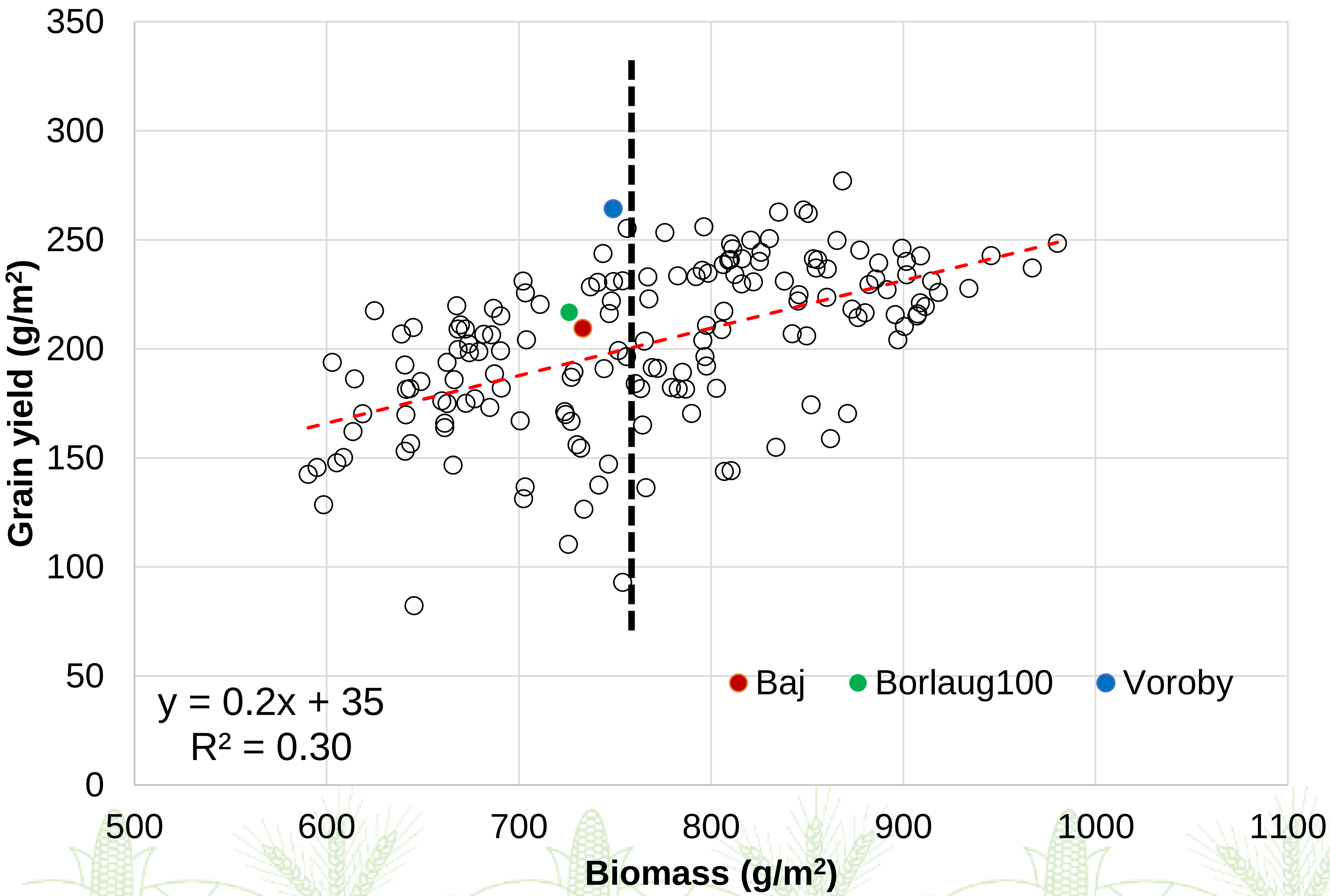
Spike diversity in BW panel

Primary synthetic panel (n=160)

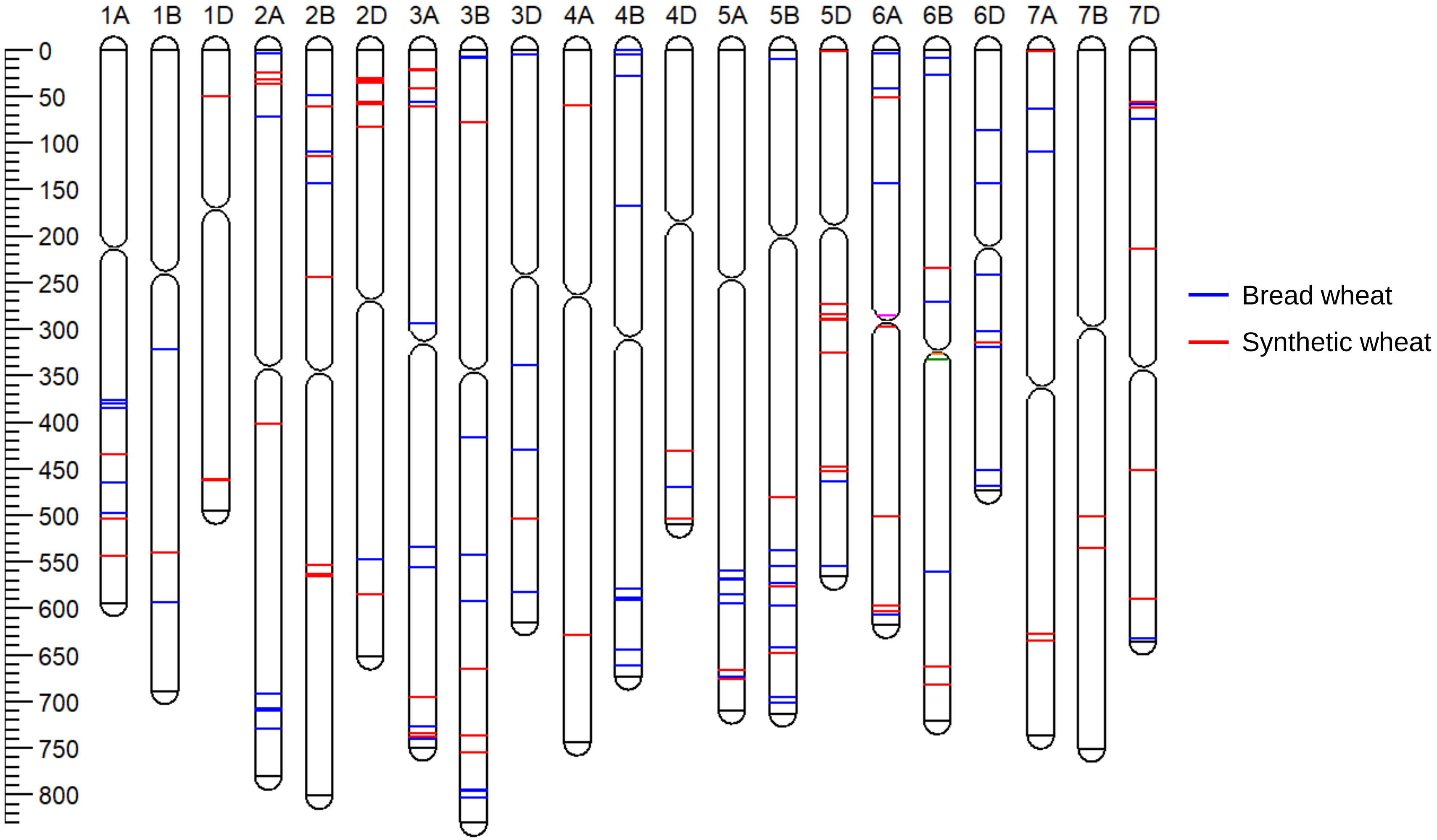
Selected from 2,000 lines (i.e. with brand new hexaploid genomes) for adaptation to heat, drought and favorable conditions

Genetic variation in synthetic hexaploid wheat (heat stress)

NW Mexico, 2016 & 2017



Chromosome regions for drought tolerance

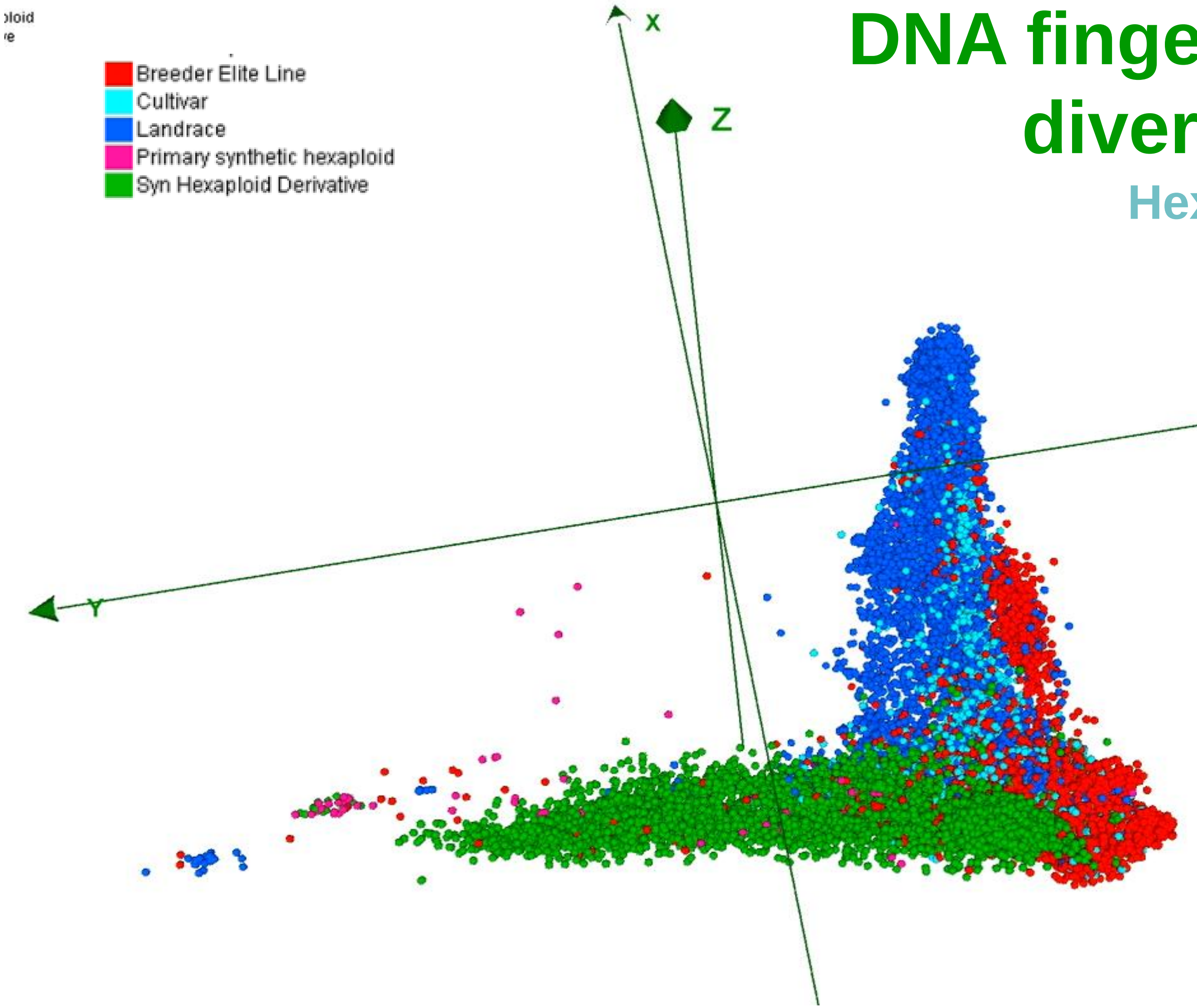


Sukumaran et al., unpublished…

CIMMYT

DNA fingerprinting for diversity subsets

Hexaploid diversity



Modified Roger distance of 60,000 hexaploid accessions displayed in a multidimentional scaling plot.

60,000 accessions,

8 domesticated species:

T. aestivum subs. aestivum,
T. aestivum subs. spelta,
T. aestivum subs. campactum,
T. aestivum subs. sphaerococcum,
T. aestivum subs. macha,
Tritucum hybrid,
x Aegilotriticum
x Triticosecale

ABD genomes,

105 countries

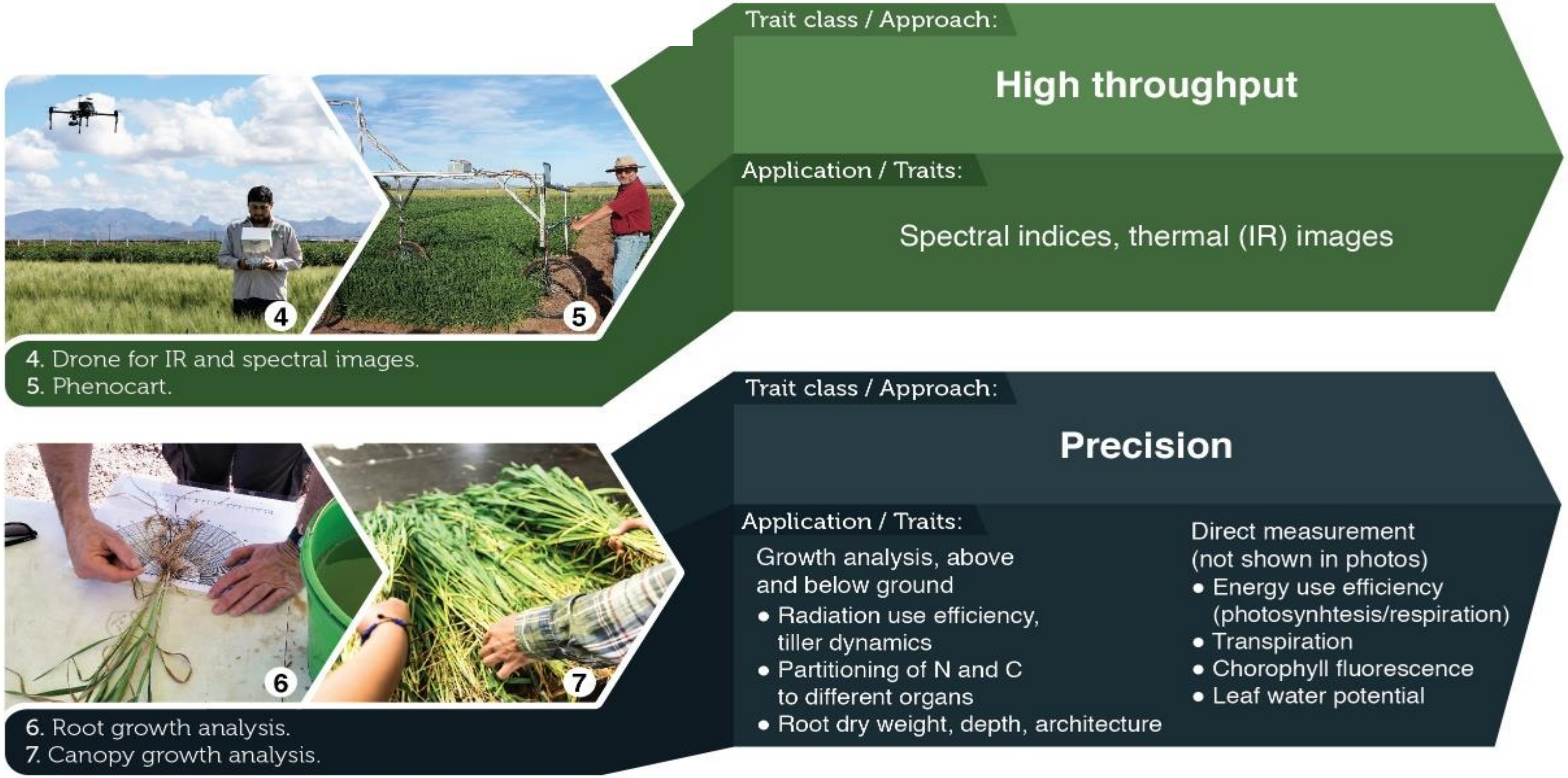
26,500 SilicoDArT

85,500 SNP's

Sansolini et al., 2020. Diversity analysis of 80,000 wheat accessions reveals consequences and opportunities of selection footprints. Nature Communications

CIMMYT

Goal 3 Phenotyping



BREEDER FRIENDLY
PHENOTYPING

1. Low resolution stereoscopic spectral radiometer (eyes) + supercomputer (brain).

Trait class / Approach:

Handy-visual

Application / Traits:

Phenology, canopy architecture, disease, pests

2. Greenseeker for NDVI.
3. IR thermometer for canopy temperature.

Trait class / Approach:

Handy-physiological

- NDVI/SPAD
- IR thermometer

Application / Traits:

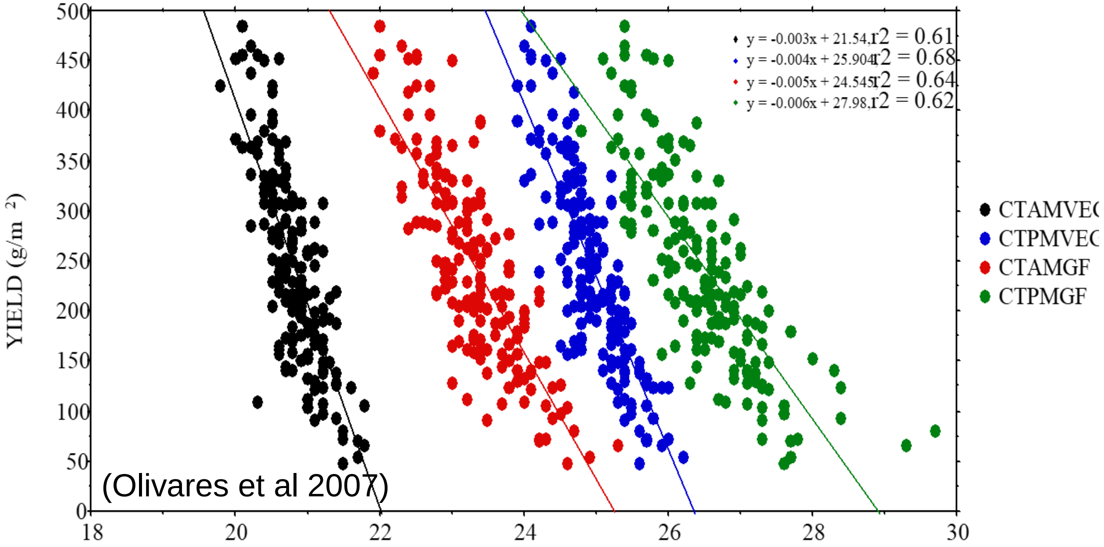
Ground cover, green area, biomass, leaf greenness

Canopy temp: fitness, root depth/capacity

Canopy temperature (CT)

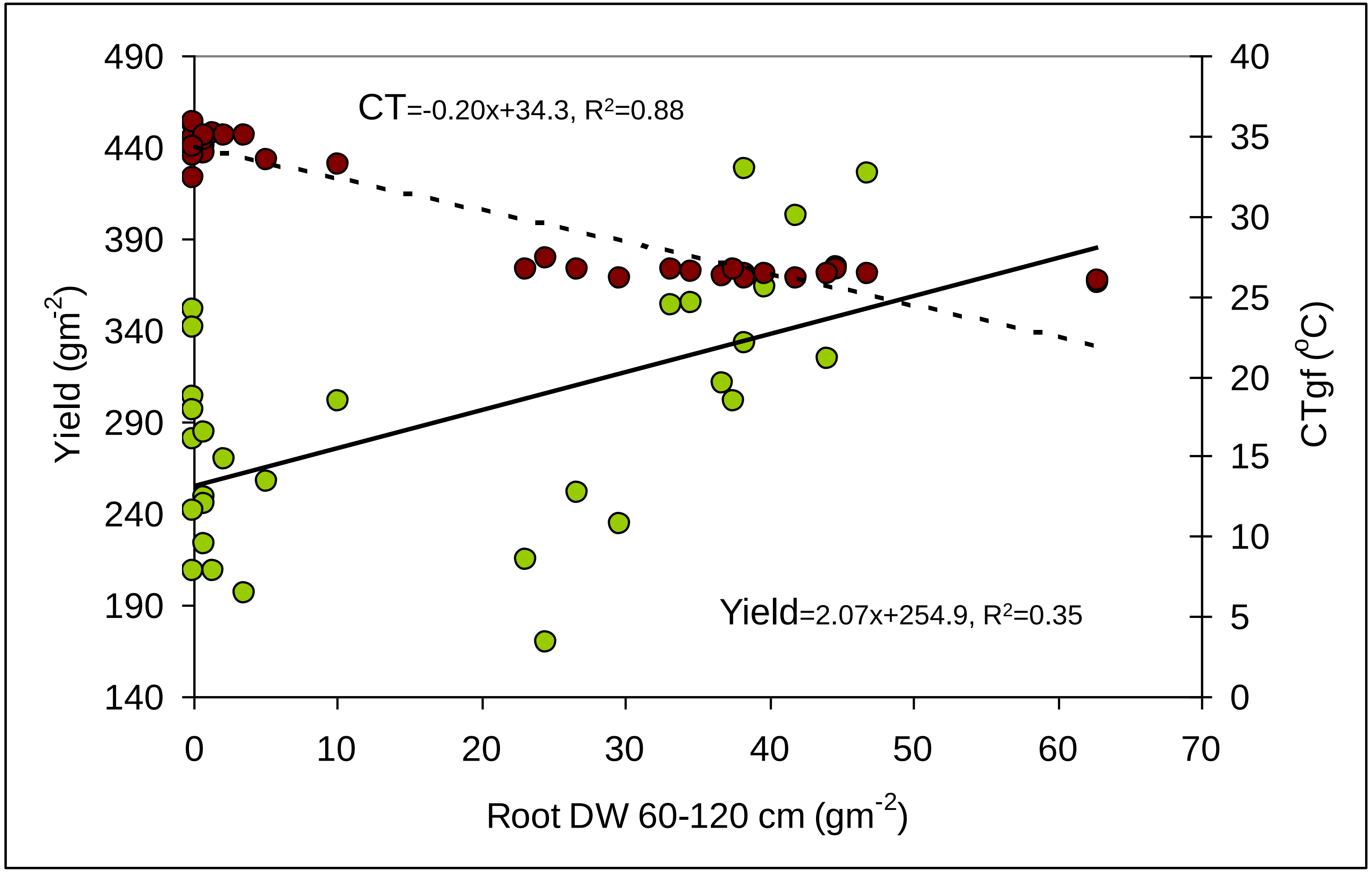
correlated with yield under drought & heat stress

Seri/Babax RILs



CT under drought, at different growth stages and times of day

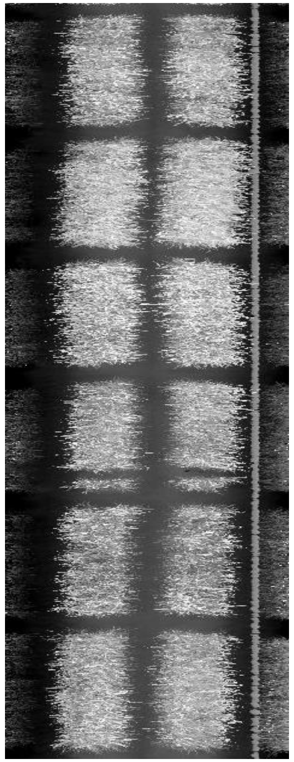
Deep root profiles under drought stress

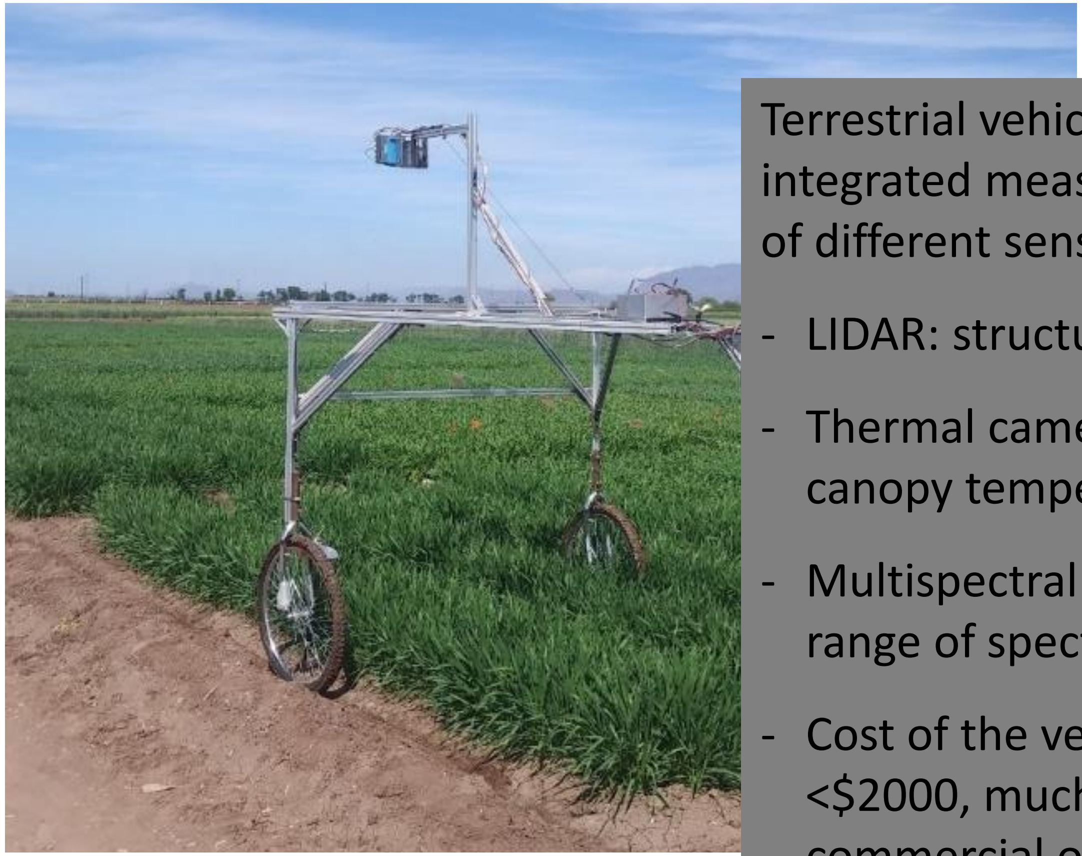


Lopes MS and Reynolds MP, 2010. Partitioning of assimilates to deeper roots is associated with cooler canopies and increased yield under drought in wheat. *Functional Plant Biology* 37:147-156

Root phenotyping under drought

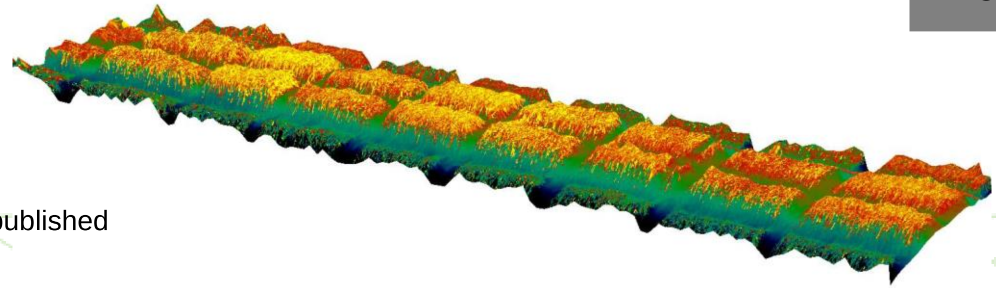
Versatile platform for ground based phenotyping





Terrestrial vehicle for integrated measurements of different sensors:

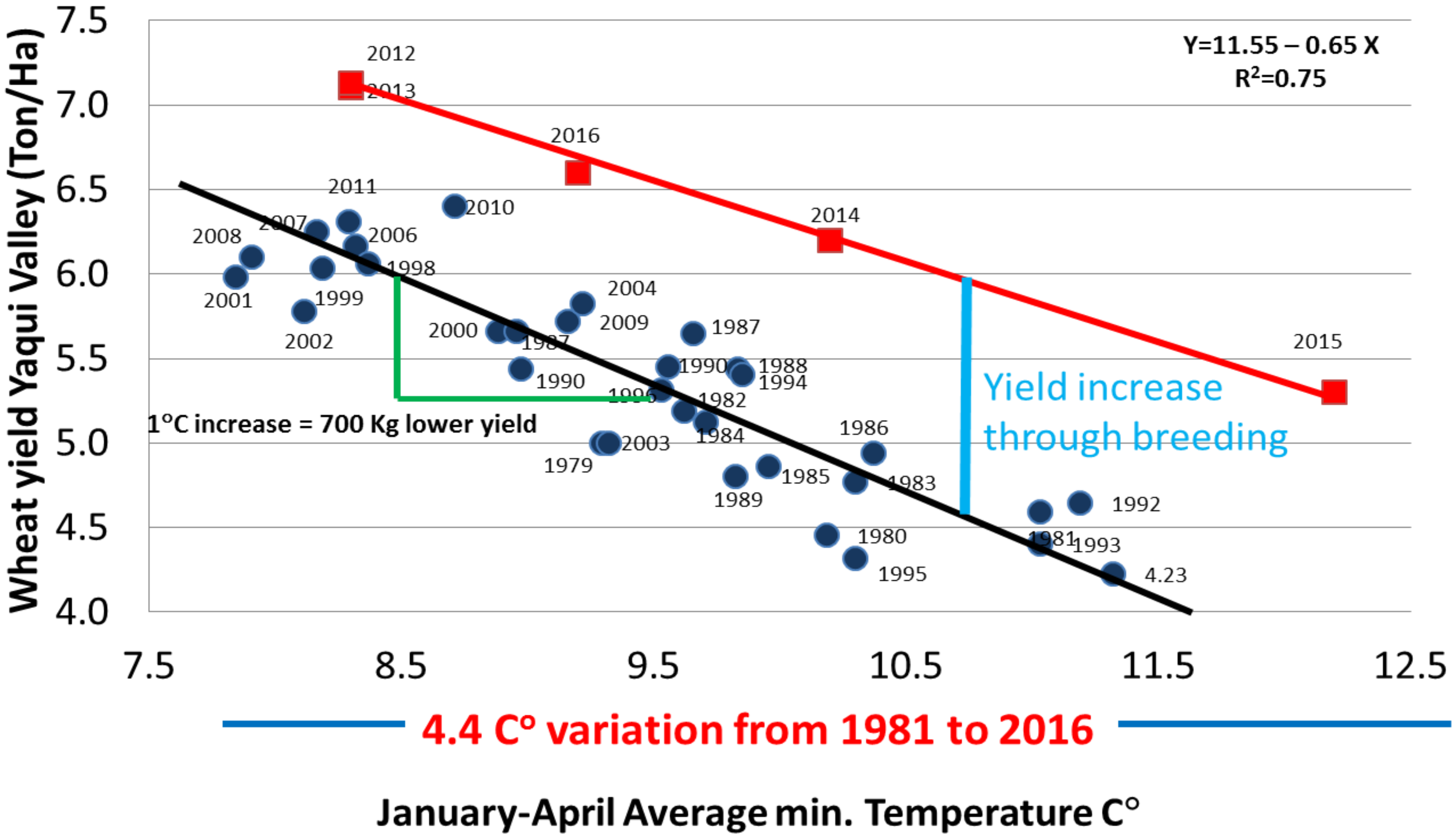
- LIDAR: structural traits
- Thermal camera: leaf & canopy temperature
- Multispectral cameras: range of spectral indices.
- Cost of the vehicle <$2000, much less than commercial options



F. Pinto et al., unpublished

Goal 4: Genetic Dissection

Response of farm yield to mínimum temperature, NW Mexico



Source: H.-J. Braun and I. Ortiz-Monasterio, CIMMYT

Partial least square analysis of traits and weather parameters

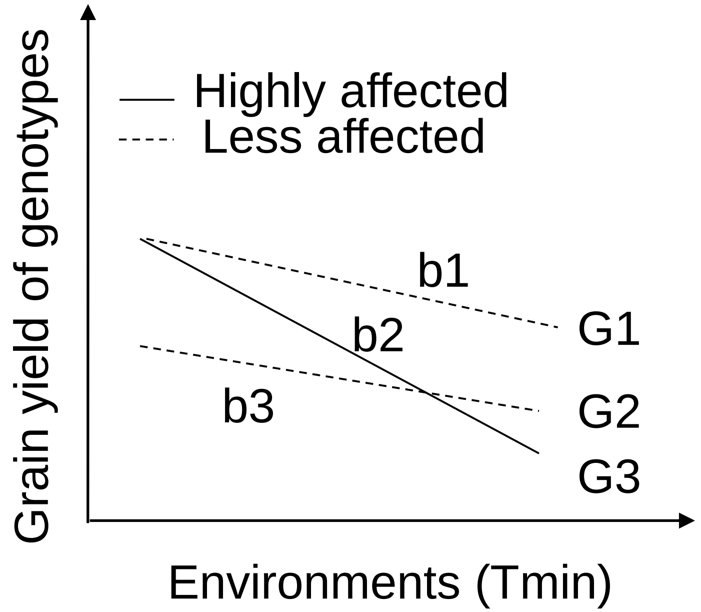
	Grain yield		Thousand-grain weight	
Weather	Variance	x.loading	Variance	x.loading
RH-v	0.20	-0.25	0.01	0.05
RH-h	0.05	-0.12	0.18	0.17
RH-gf	0.13	-0.20	0.12	0.14
T_{max}-v	0.02	0.07	0.02	-0.06
T_{max}-h	0.17	-0.23	0.91	-0.39
T_{max}-gf	0.33	-0.32	0.67	-0.33
T_{max35}	0.07	-0.14	0.48	-0.28
T_{min}-v	0.59	-0.42	0.65	-0.33
T_{min}-h	0.91	-0.53	0.85	-0.37
T_{min}-gf	0.78	-0.49	0.81	-0.36

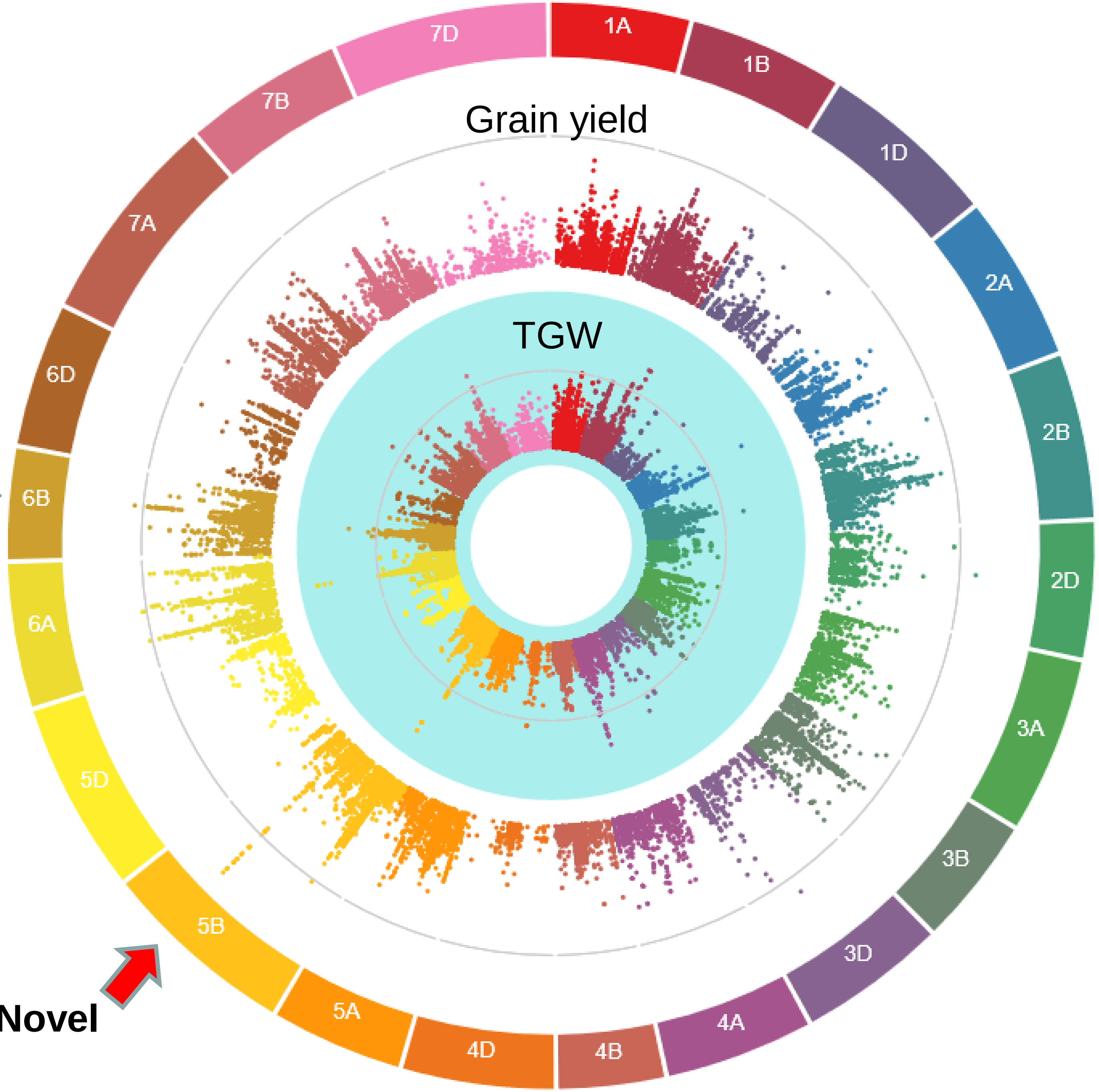
V, vegetative stage; h, heading; gf, grain filling

Sukumaran et al. (unpublished)

CIMMYT

Slope of reaction norms





Novel

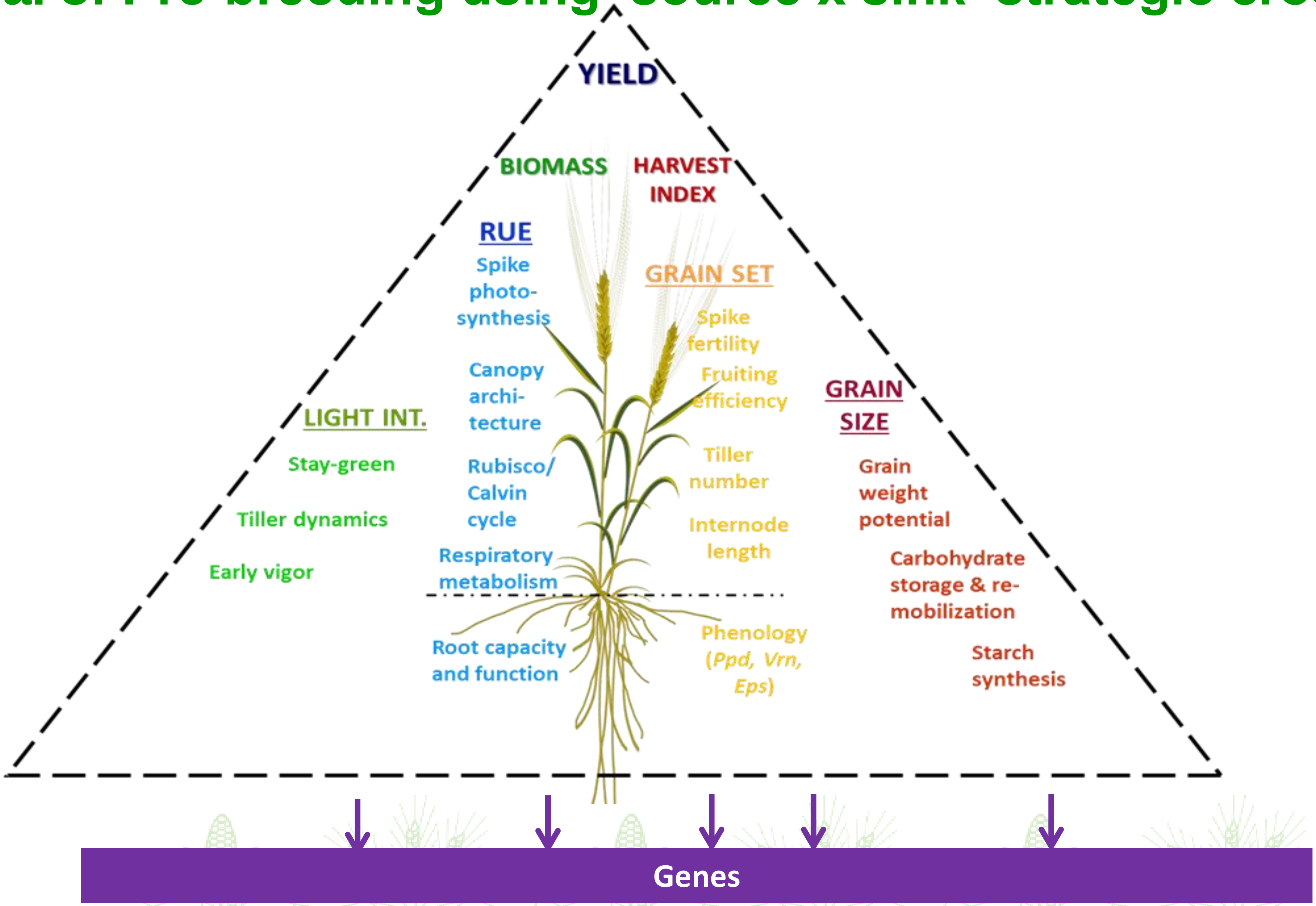
TaGW2 gene

Novel

TaGW2 gene is involved in trait variation, response to night time temperature, and phenotypic plasticity

Sukumaran et al. (unpublished)

Goal 5: Pre-breeding using 'source x sink' strategic crossing



Pre-breeding pipeline

Diversity panels

Trait panels

Marker donors

Gene bank

PT lines

Crossing

Generation advancement

International nurseries

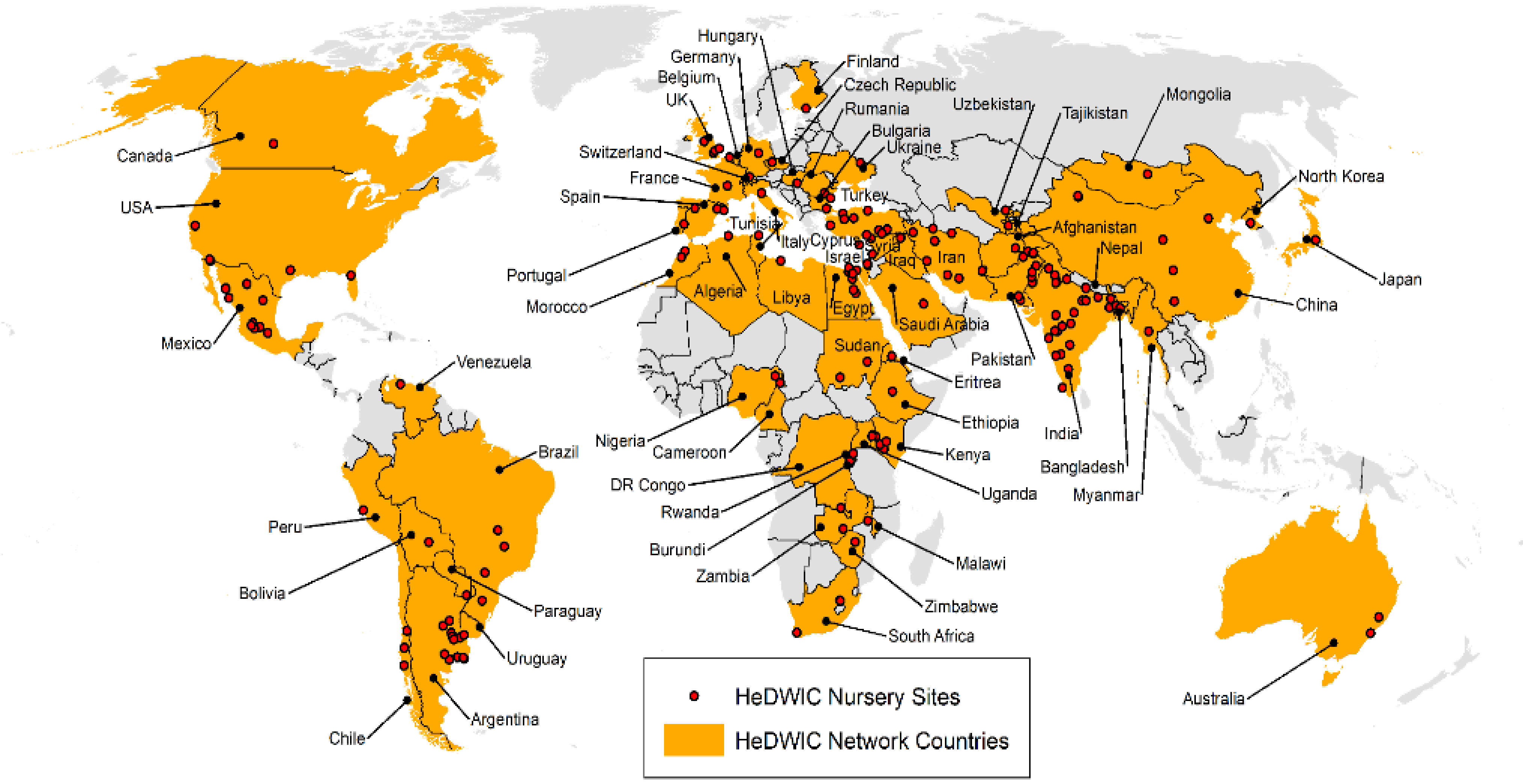
- Conceptual models
- Source-sink traits (Grain yield, Biomass, CT, NDVI, adaptation to density, spikes)
- Genetic diversity/Pedigree
- Validated Markers/GEBV (GS)

- Yield based selection
- Genomic selection/MAS/MABC
- HTP (NDVI)
- Rust resistance (YR/BR)
- Multi-environmental testing

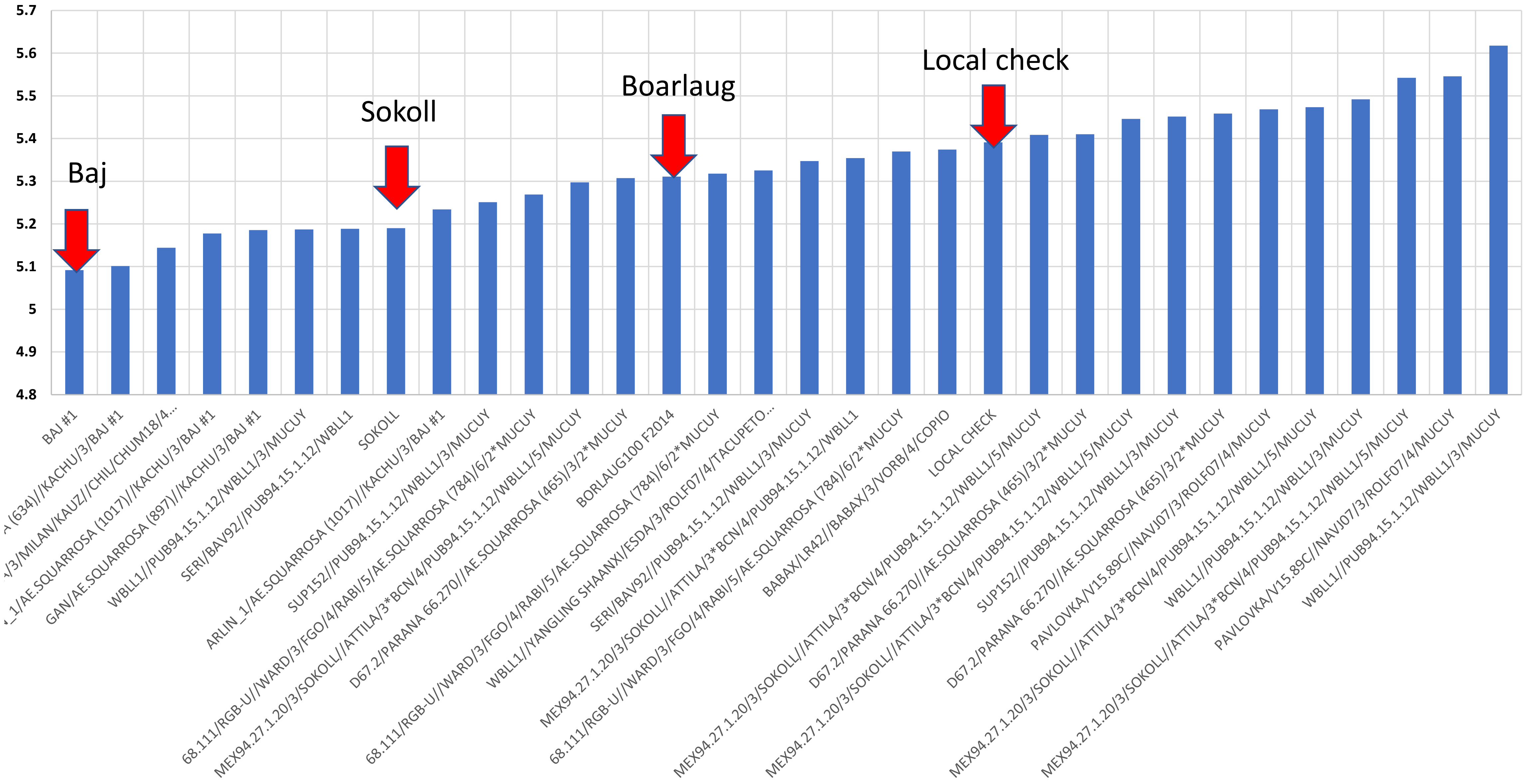
WYCYTs & SATYNs

CIMMYT

HeDWIC international collaboration including SATYN nursery sites



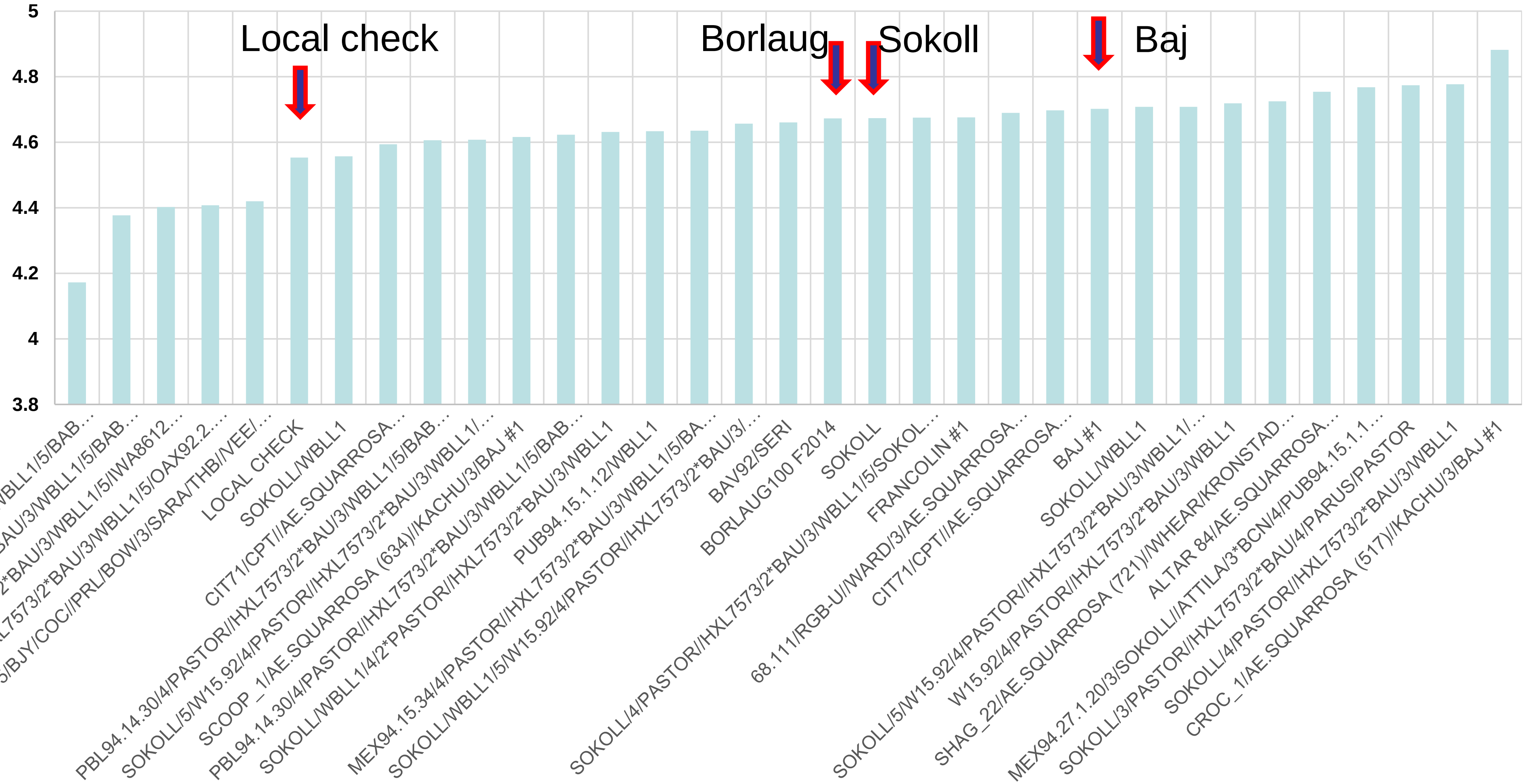
Avg. yield of 6th WYCYT lines (BLUPs) across 32 environments



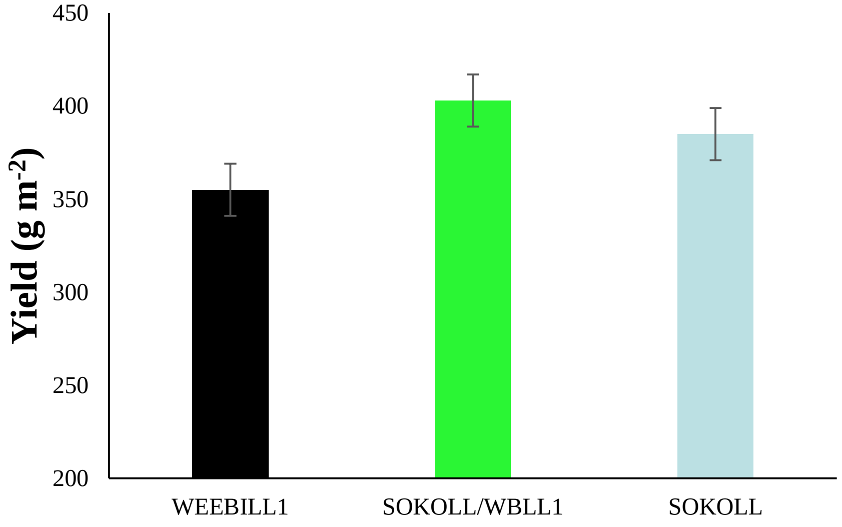
8th SATYN lines in 33 environments, 2018/19

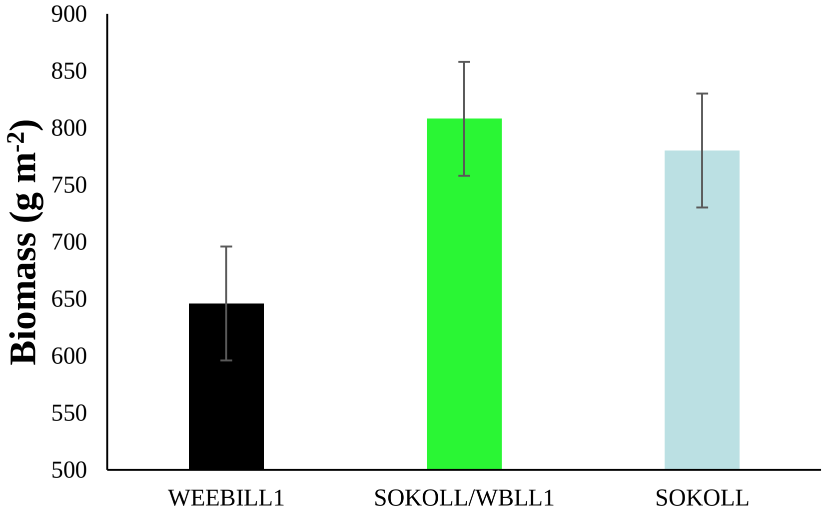
Best 3 lines 7% above local checks

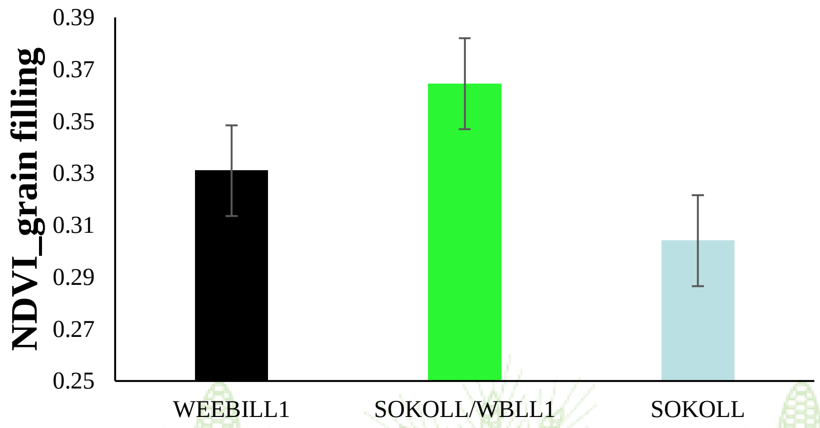
Best line 4% above elite CIMMYT Check Baj

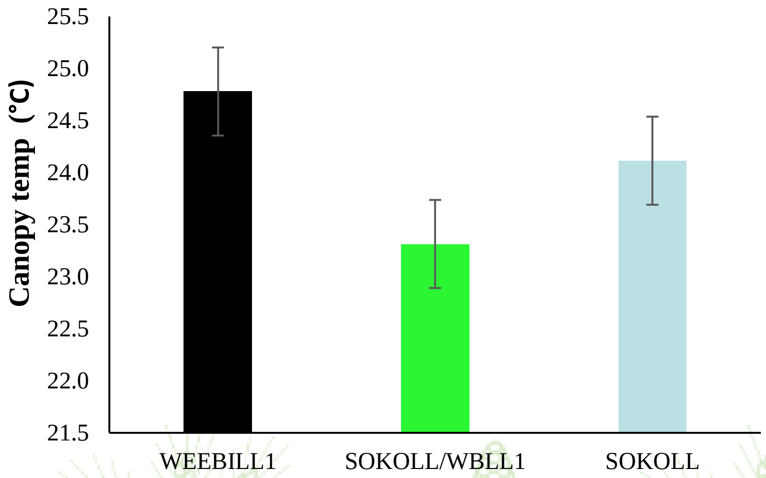


TESTING: Sokoll/Weebil cross (Mexico data under drought stress)

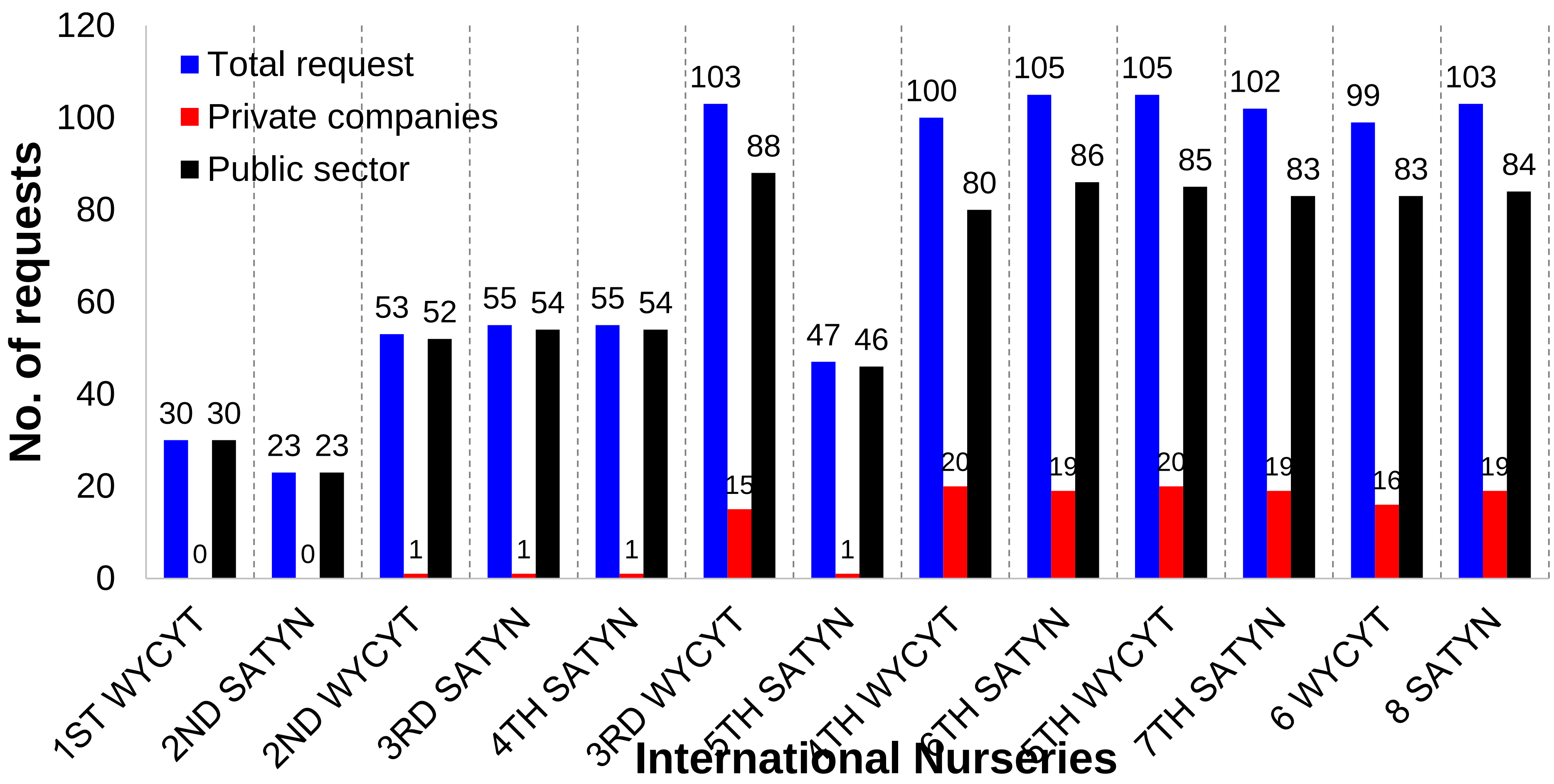








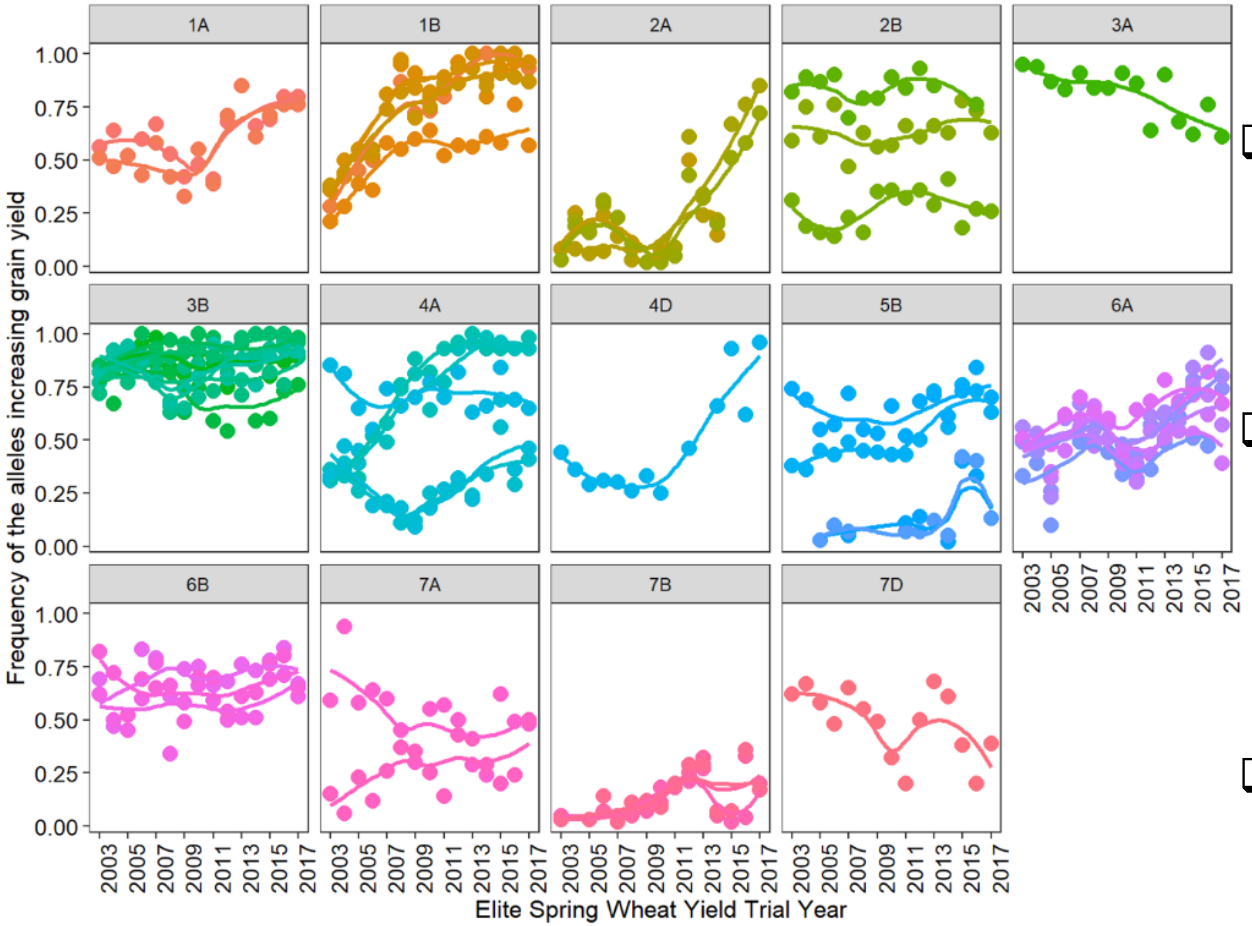
Requests for international nurseries



Goal 6: Continuous improvement in breeding

- Predict breeding value & select parents using pedigree and genomic data
- Rapid generation advancement
- Genomic selection assisted rapid-cycle recurrent selection
- Practical haplotype graph and utilization for predicting breeding values.
- Integrate new traits sources through mainline breeding pipelines

Molecular tracking of favorable allele frequencies over 15 years of breeding



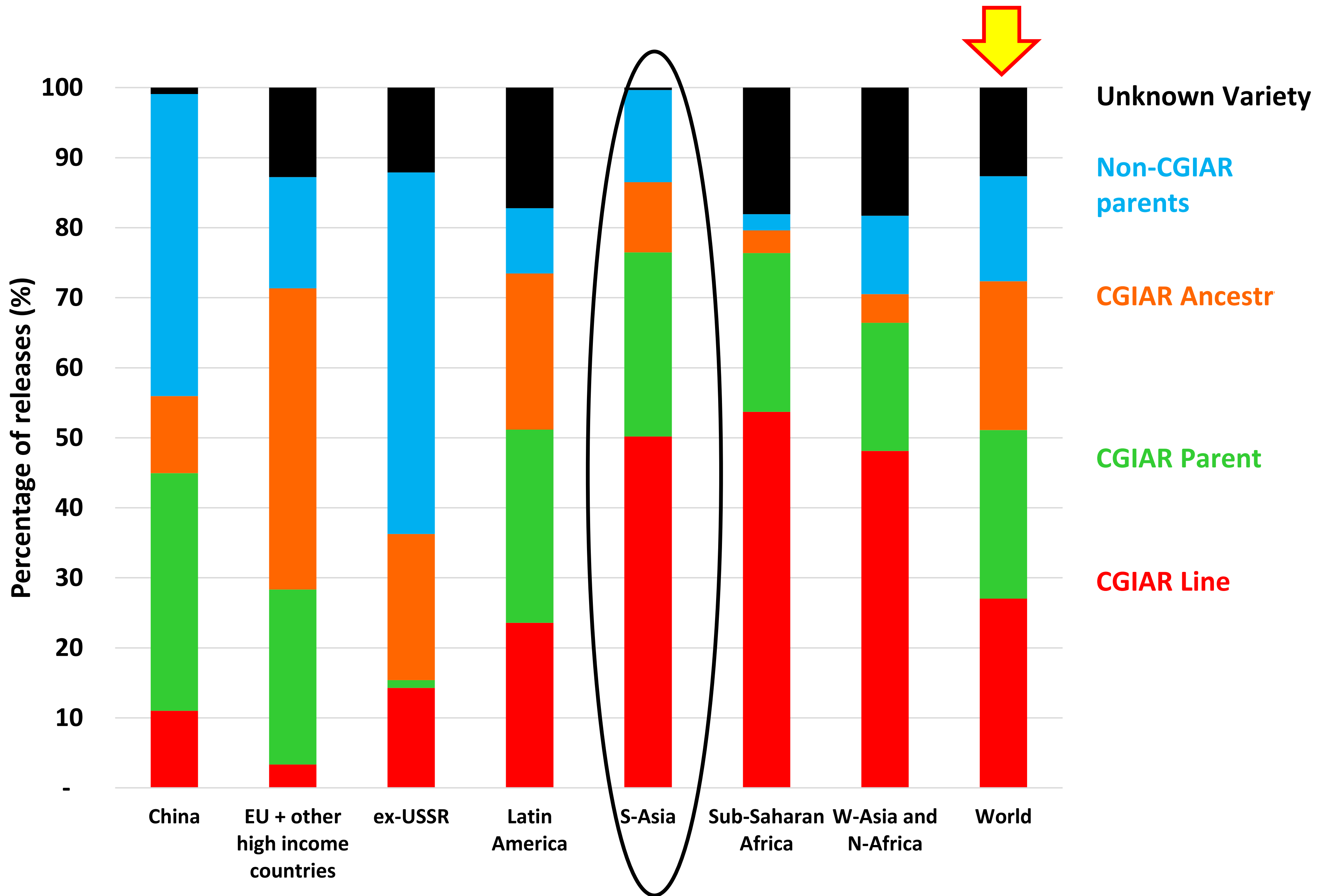
Trends in the grain yield favorable allele frequencies in the globally distributed Elite Spring Wheat Yield Trials

- **CIMMYT's Elite Spring Wheat Yield Trials (2003–2017) using 47 markers associated with yield**
- **Several favorable alleles have reached near-fixation indicating the effectiveness of phenotypic selection in Mexico**
- **Illustrates importance of integrating genomic data in achieving accelerated allele enrichment.**

Juliana, P., Poland, J., Huerta-Espino, J. *et al.* Improving grain yield, stress resilience and quality of bread wheat using large-scale genomics. *Nat Genet* **51**, 1530–1539 (2019)

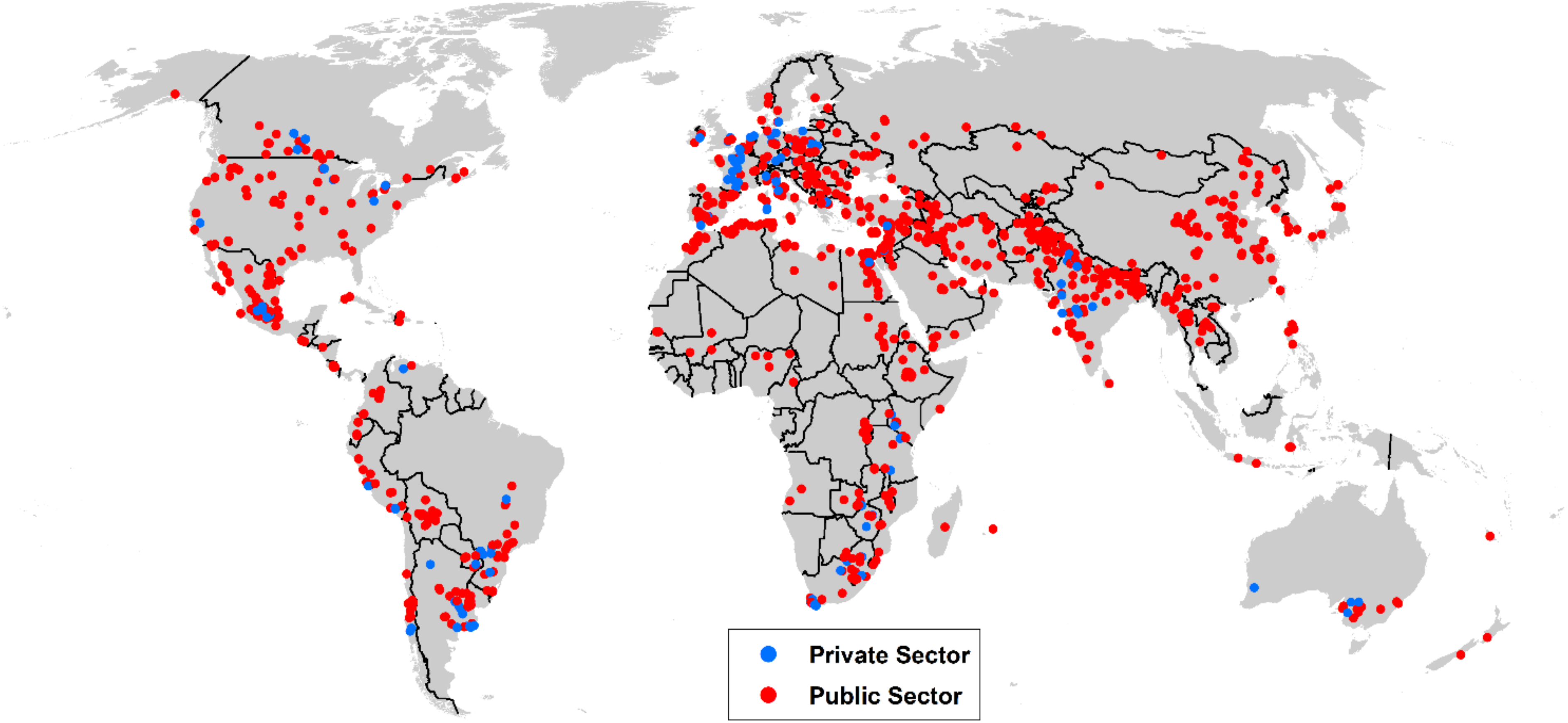
CIMMYT

Spring bread wheat releases by region and origin 1994-2014



Goal 7: Dissemination of technology

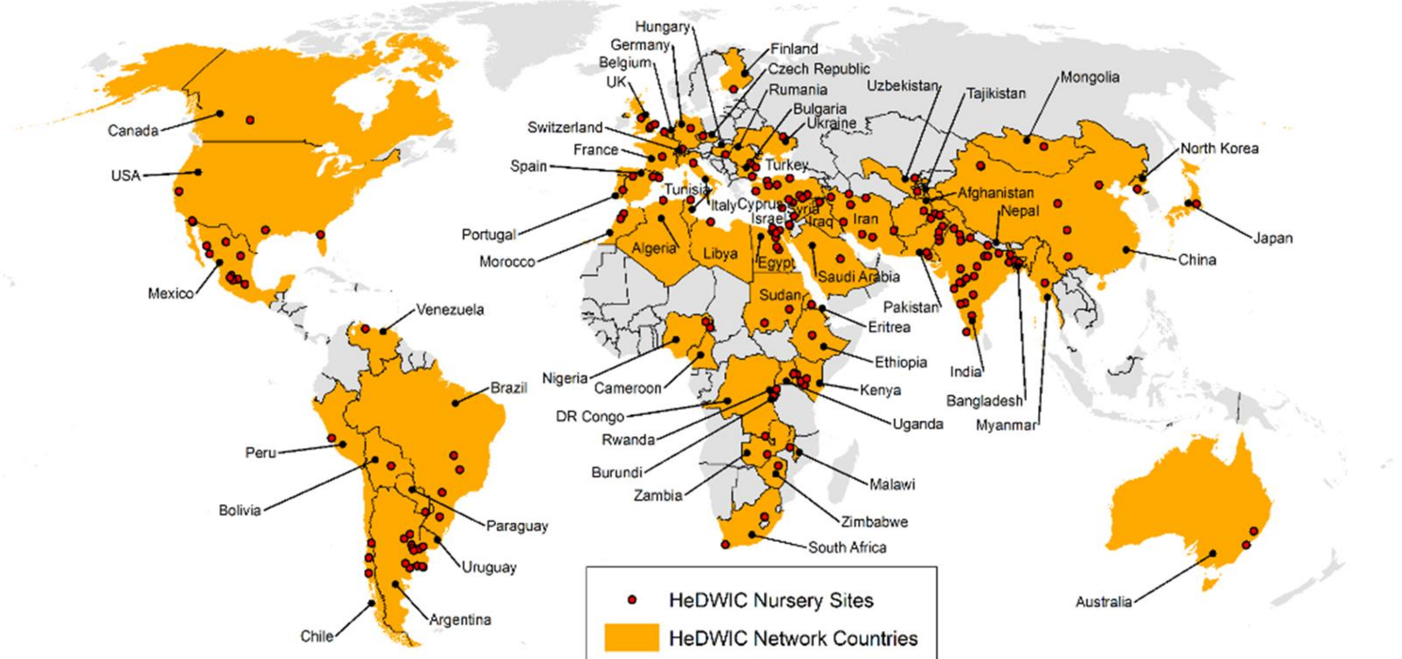
International Wheat Improvement Network (IWIN)



Public and private breeding programs and other partners that have received germplasm through the International Wheat Improvement Network (IWIN)

CIMMYT

GOAL 8:
Crowd-source novel plant science technologies to increase societal impact of investments in academic research on climate resilience of wheat and other crops.

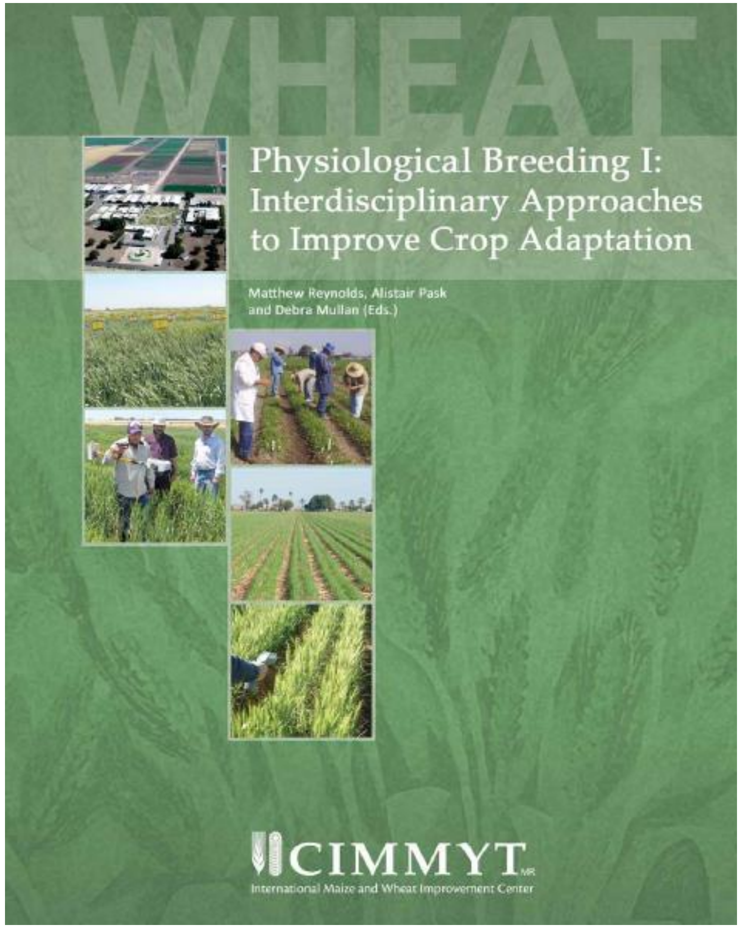


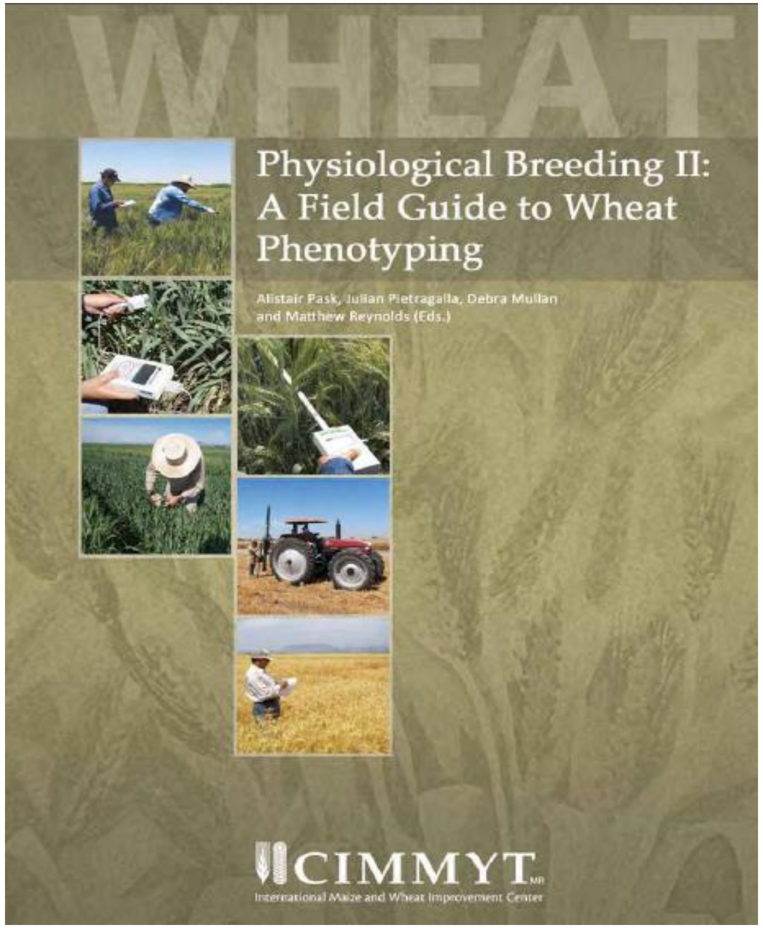
CIMMYT

GOAL 9:
Improved research capacity and technology scale-out based on new knowledge, trained scientists, experimental germplasm, curated data and metadata sets, and networks involving expertise, infrastructure and synergistic collaboration.

CIMMYT

Shared protocols:





http://libcatalog.cimmyt.org/download/cim/96140.pdf libcatalog.cimmyt.org/download/cim/96144.pdf

- Reynolds MP and Langridge P, (2016). **Physiological Breeding**. Current Opinions in Plant Biology 31: 162–171.
- Reynolds et al. 2017. **Strategic crossing of biomass and harvest index—source and sink—achieves genetic gains in wheat.** Euphytica 213:257-80

Take home points

- Climate is becoming warmer and less predictable
- Many opportunities exist to improve wheat's adaptation:
  - Advances in genomics and phenomics
  - Exploring untapped genetic resources
  - Physiological and molecular breeding
- Impacts will reach farmers and consumers sooner if efforts are coordinated through collaboration and technology sharing platforms such as HeDWIC and the Wheat Initiatives (AHEAD)

CIMMYT

CIMMYT
Matthew Reynolds (PI)
Karim Ammar (Co-PI)
Bhoja Basnet
Hans Braun
Fatima Camarillo Castillo
Leonardo Crespo-Herrera
José Crossa (Co-PI)
Kanwarpal Dhugga
Kate Dreher
Susanne Dreisigacker (Co-PI)
Philomin Juliana
Hannes Karawat
Masahiro Kishii (Co-PI)
Margaret Krause
Janet Lewis (Project Manager)
Suchismita Mondal
Tom Payne (Co-PI)

CIMMYT cont
Diego Pequeno
Francisco Pinera
Francisco Pinto
Carolina Rivera
Carolina Saint-Pierre
Carolina Sansaloni
Urs Schulthess (Co-PI)
Deepmala Sehgal
Rosemary Shrestha
Ravi Singh (Co-PI)
Kai Sonder (Co-PI)
Siva Sukumaran (Co-PI)
Wei Xiong (Co-PI)

External collaborators
Jesse Poland, Kansas State (Co-PI)
Jorge Dubcovsky, UC Davis
Jason Cook, Phil Bruckner, Montana State
Bernd Hackauf, Das Julius Kühn-Institut
Malcolm Bennett, Lucia Nevescanin, Univ Nottingham
Azam Lashkari, Henan Agricultural University
Edward Buckler, Sara Miller, Cornell University
Simon Griffiths, John Innes Center
Andreas Hund, ETH Zurich