Breeder Friendly Phenotyping

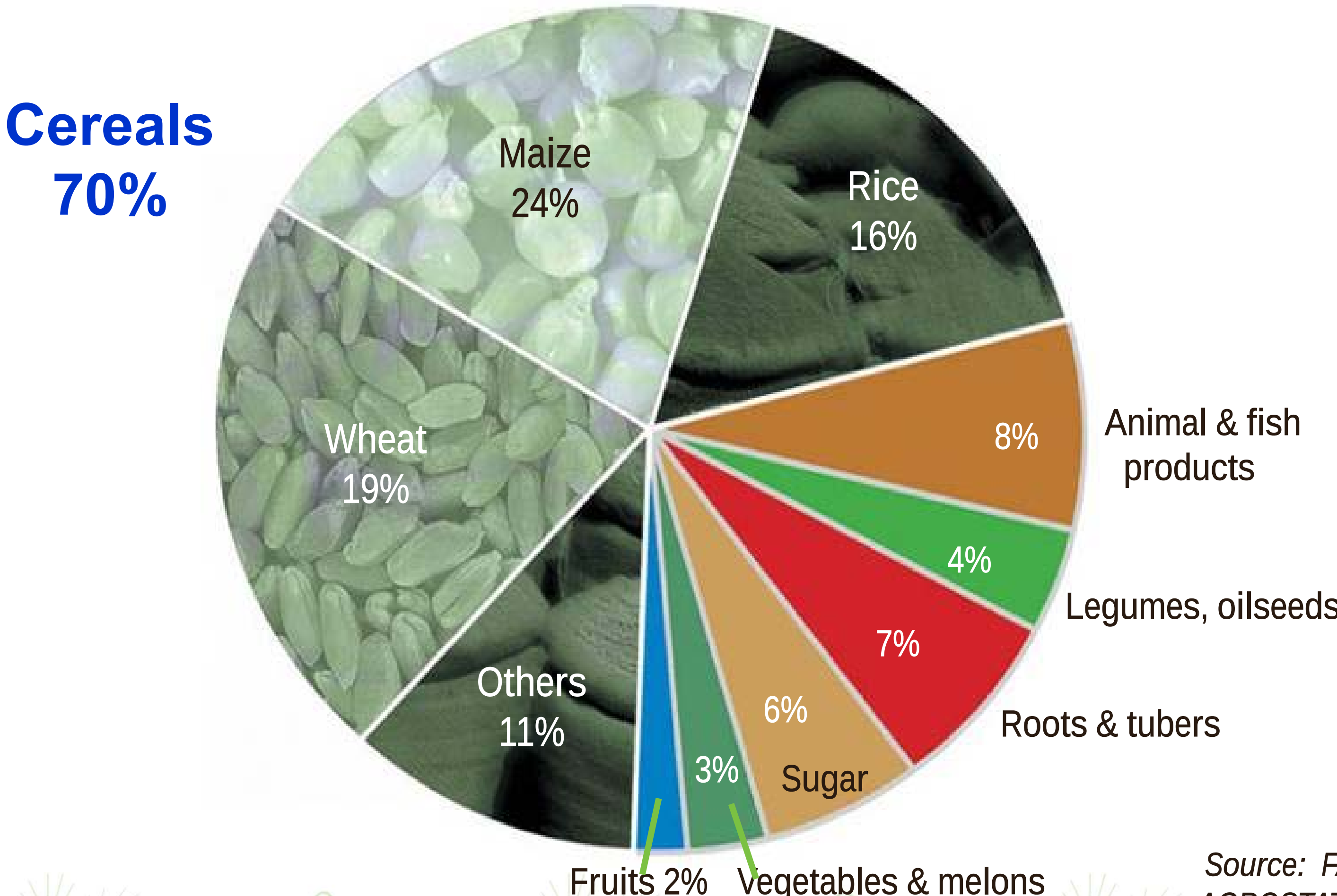
Matthew Reynolds & colleagues

The 6th Annual - Nordic Plant Phenotyping Network Workshop

Virtual meeting – January 20th2021

HeDWIC

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



Source: FAO AGROSTAT (2012)

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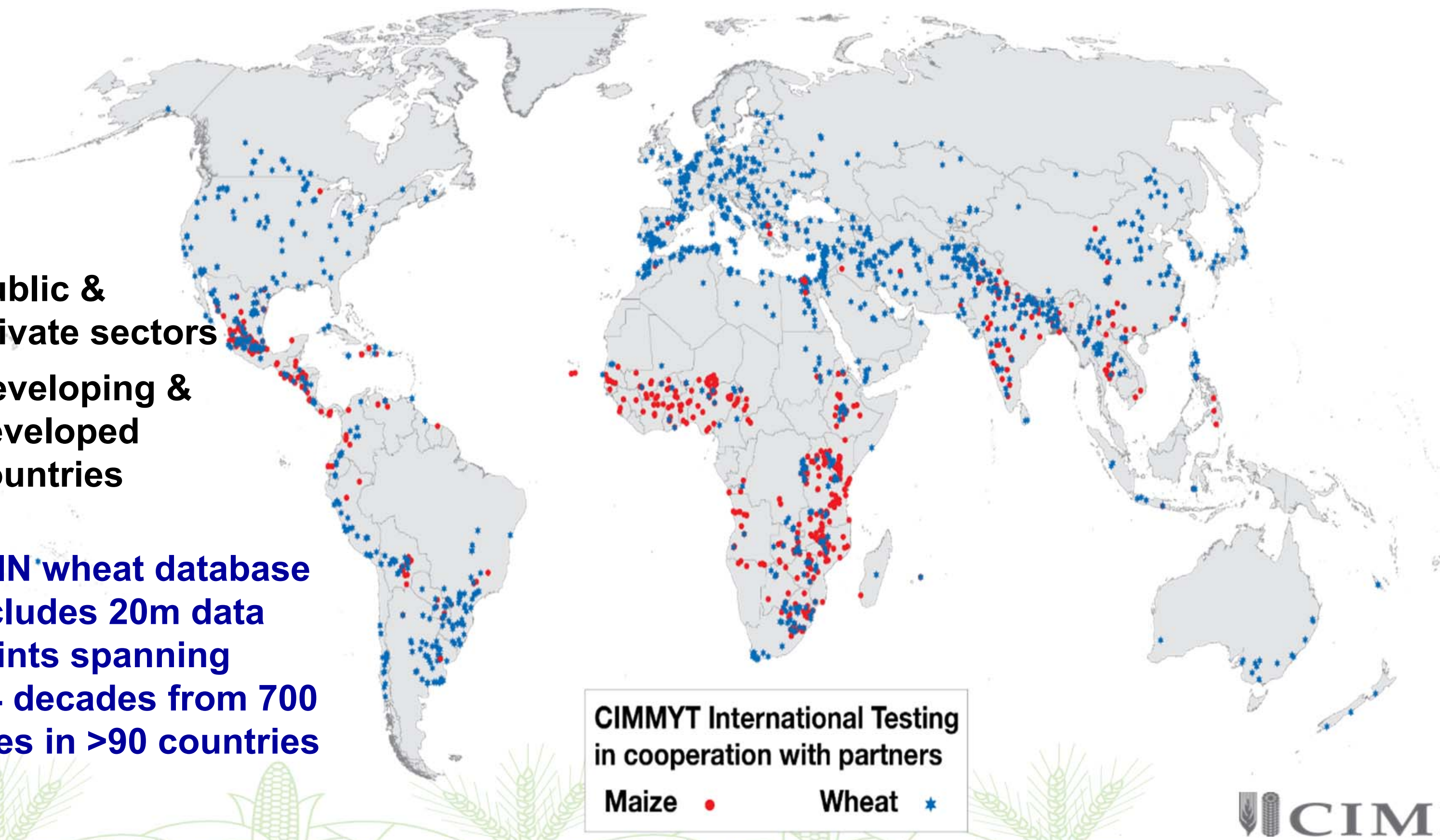
CIMMYT Maize & Wheat Improvement Networks:
in the post Green-Revolution period, emphasis on yield stability, biotic stresses & nutritional quality

- **Public & private sectors**
- **Developing & developed countries**

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



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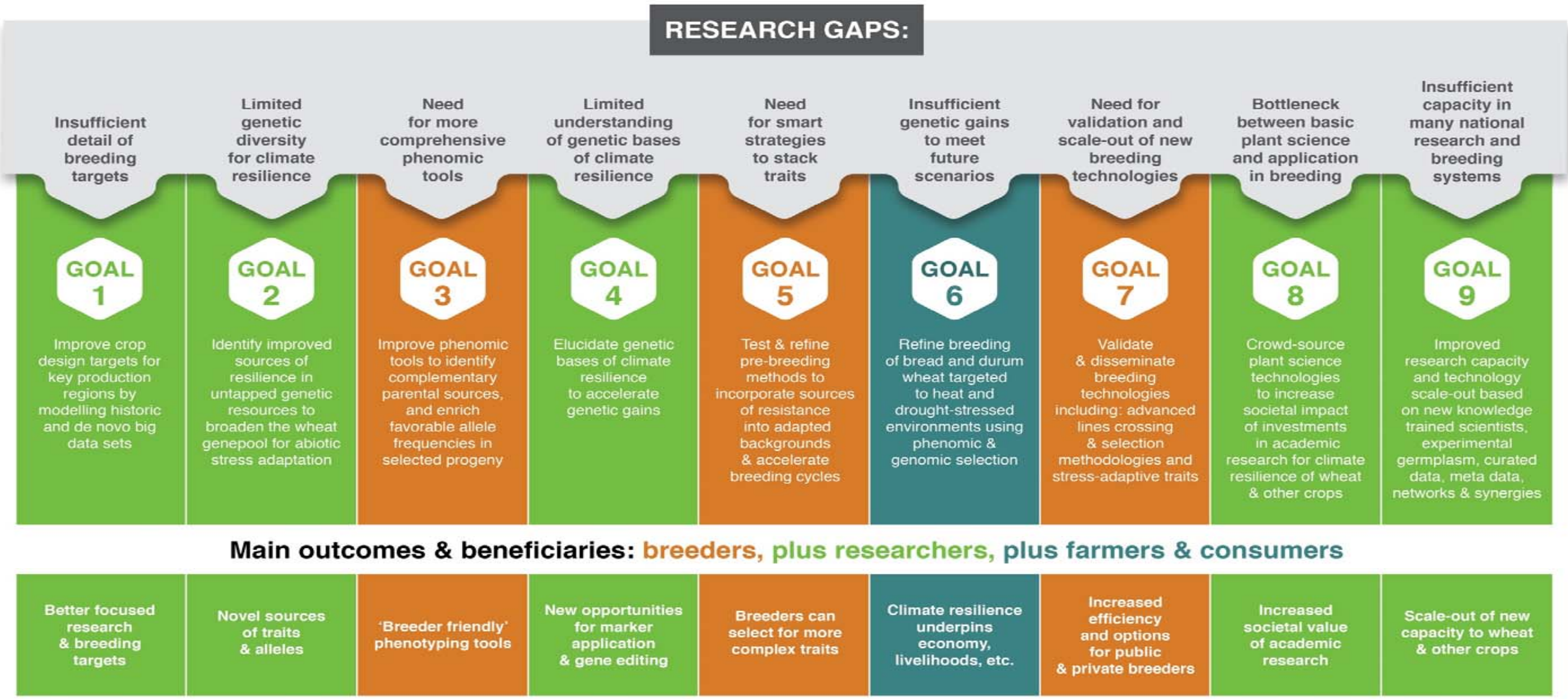
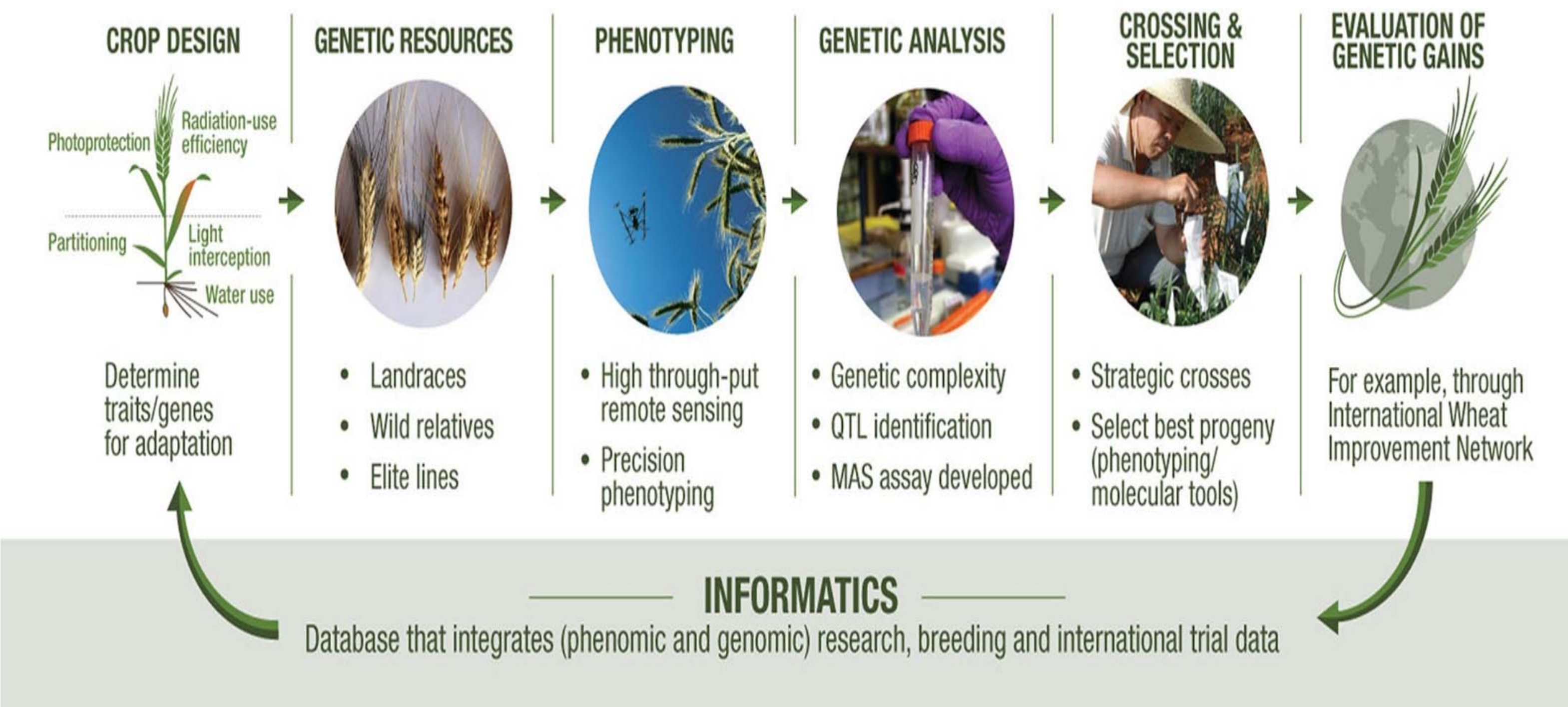
Harnessing translational research across a global wheat improvement network for climate resilience: Research gaps, interactive goals and outcomes



PHYSIOLOGICAL PRE-BREEDING PIPELINE



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

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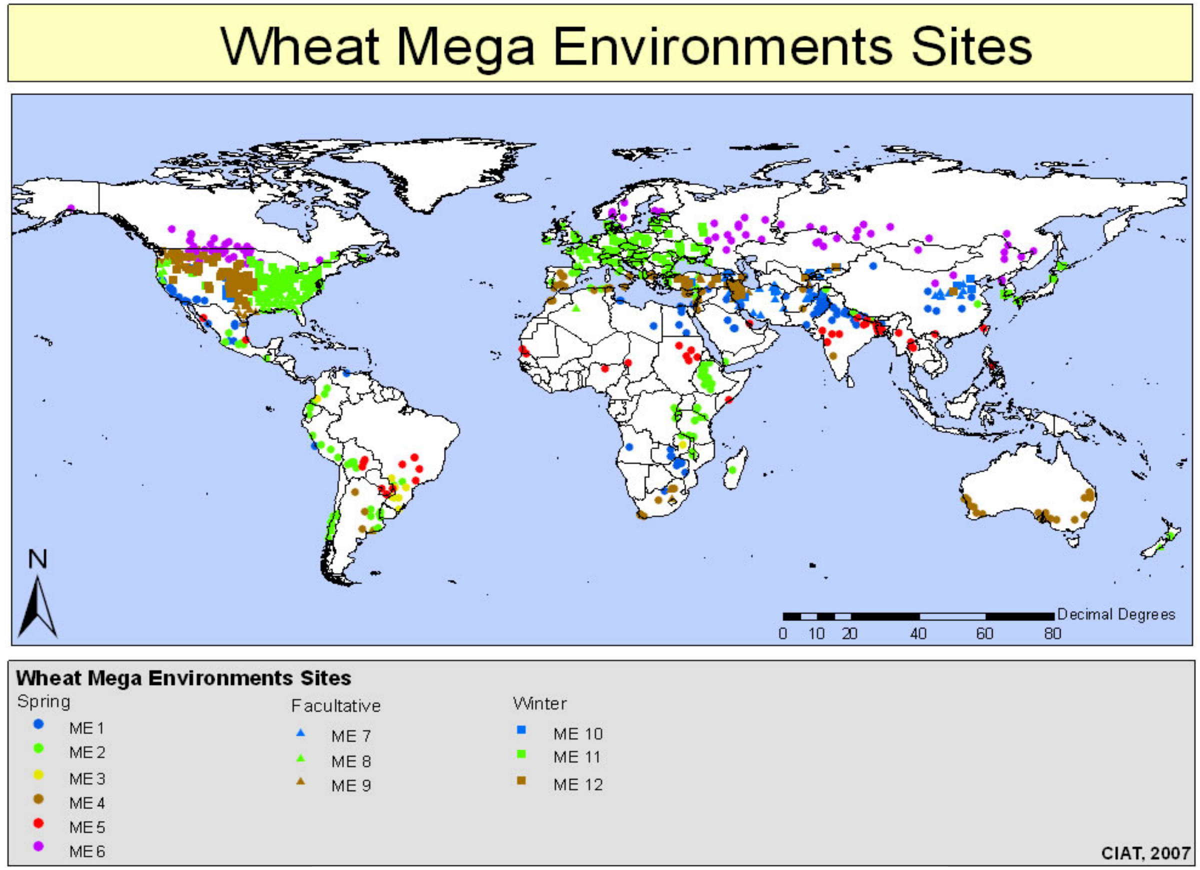
Goal 1: Improve crop design using modeling and IWIN big data sets

- ~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

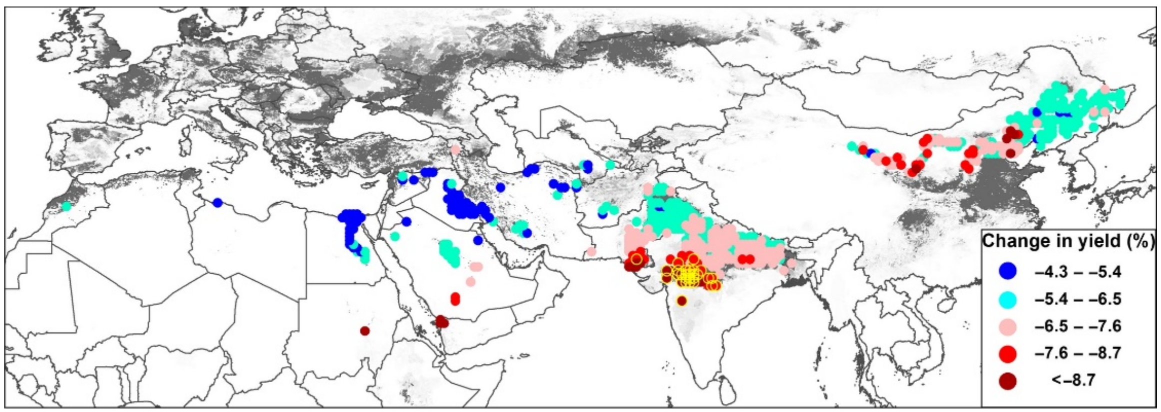
Builds on Previous Research Using IWIN

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

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DESIGN: conceptual model of heat-adaptive traits

YIELD = LI x RUE x HI

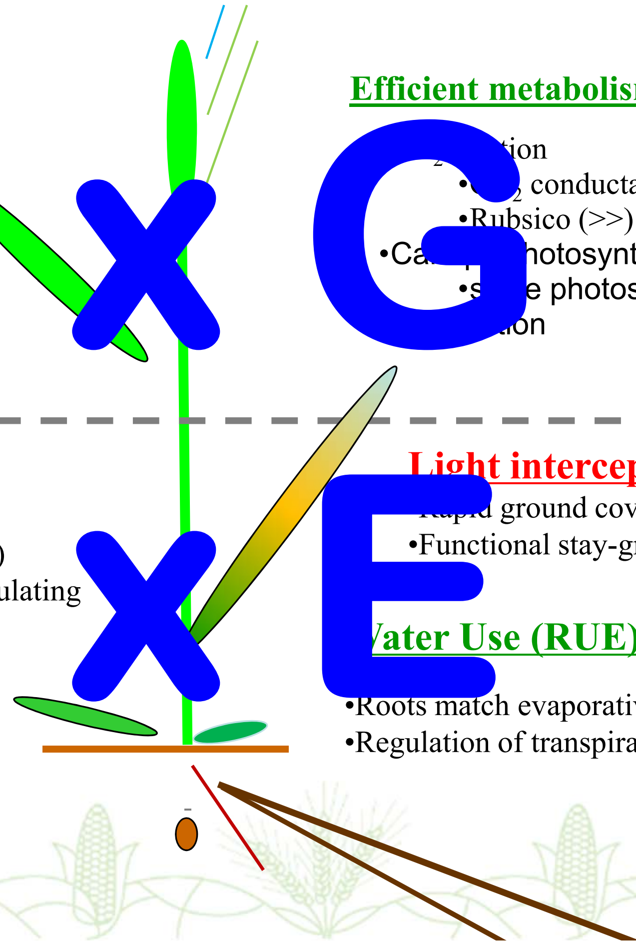
Photo-Protection (RUE)

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

Efficient metabolism (RUE)

- tion
  - conductance
  - Rubsico (>>)
- Ca hotosynthesis
  - e photosynthesis
- ion

G x G



G x E

Partitioning (HI)

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

Light interception (LI)

- Rapid ground cover
- Functional stay-green

Water Use (RUE)

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

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

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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.

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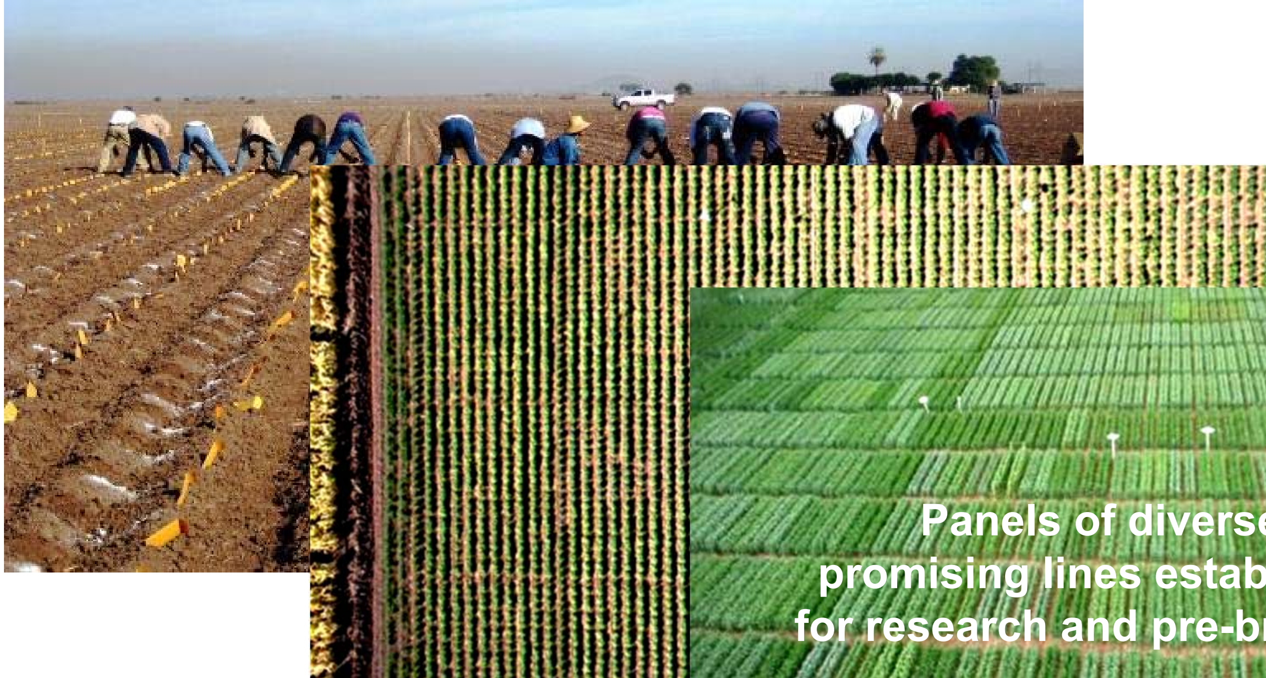
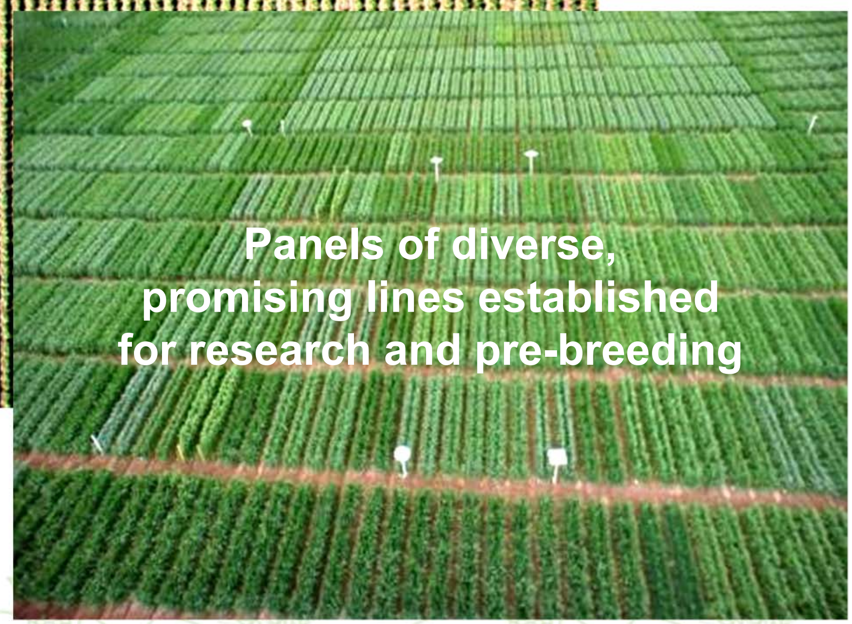
70,000 wheat genetic resource samples

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

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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

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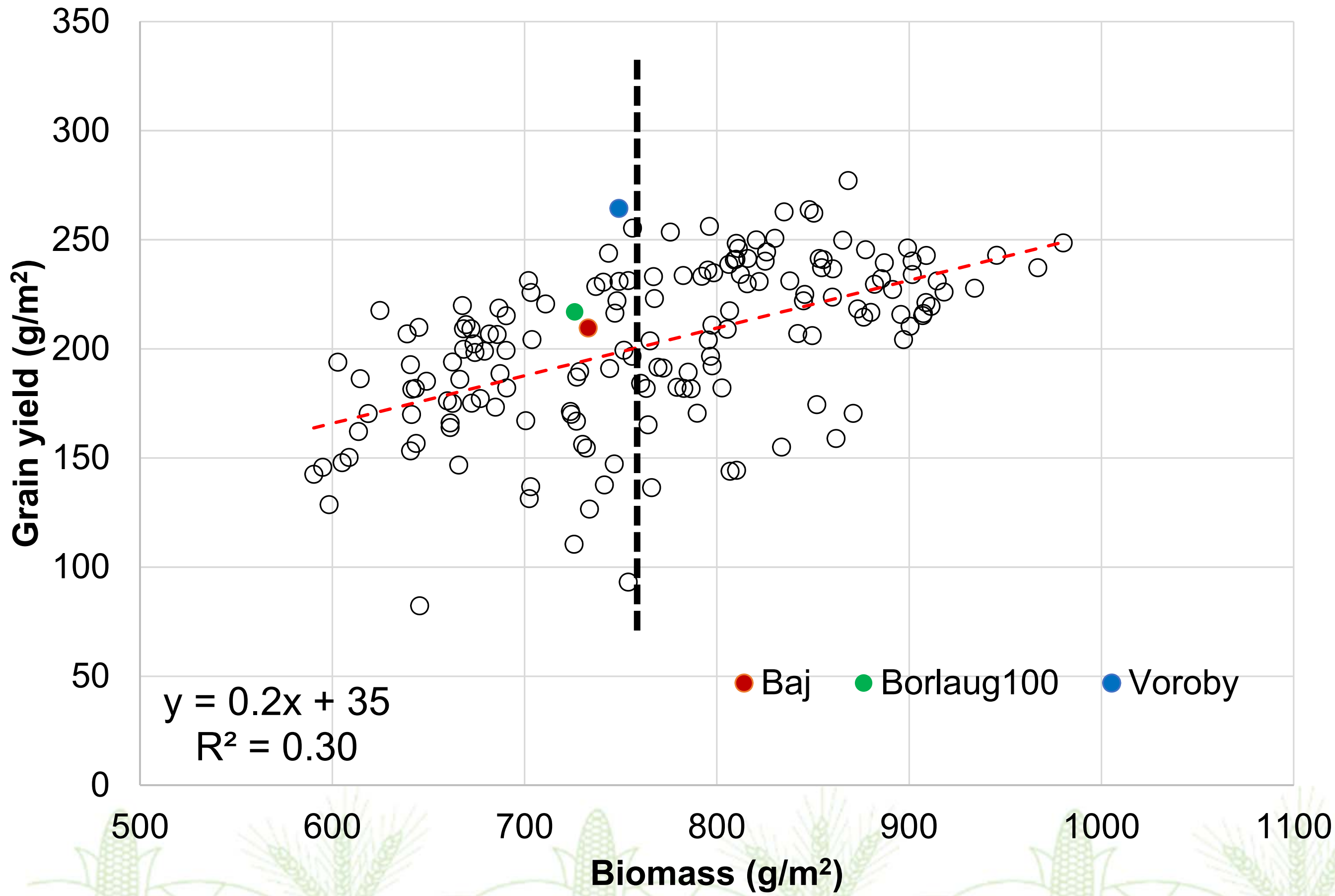
Primary synthetic panel (n=160)

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



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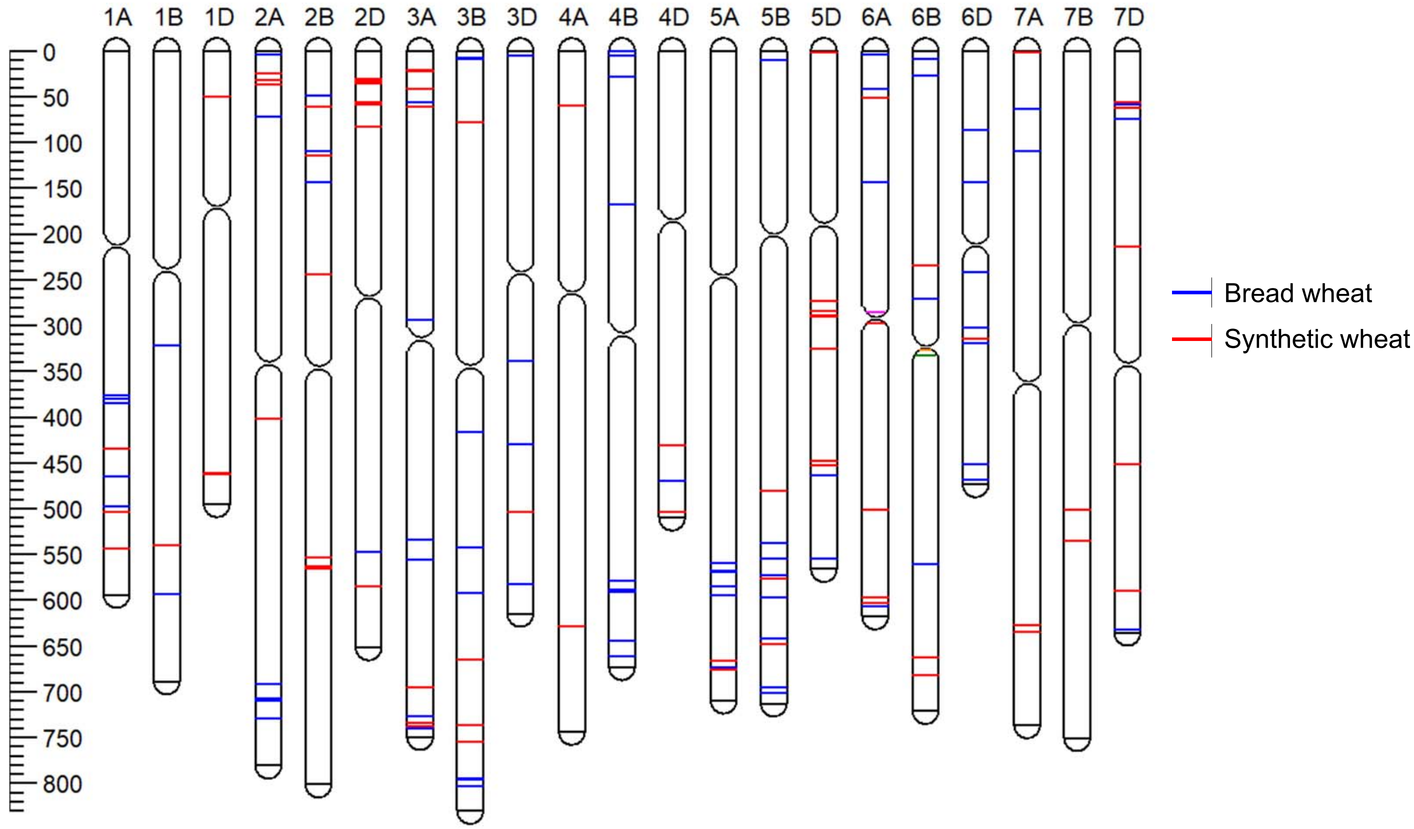
Chromosome regions for drought tolerance



Sukumaran et al., unpublished…

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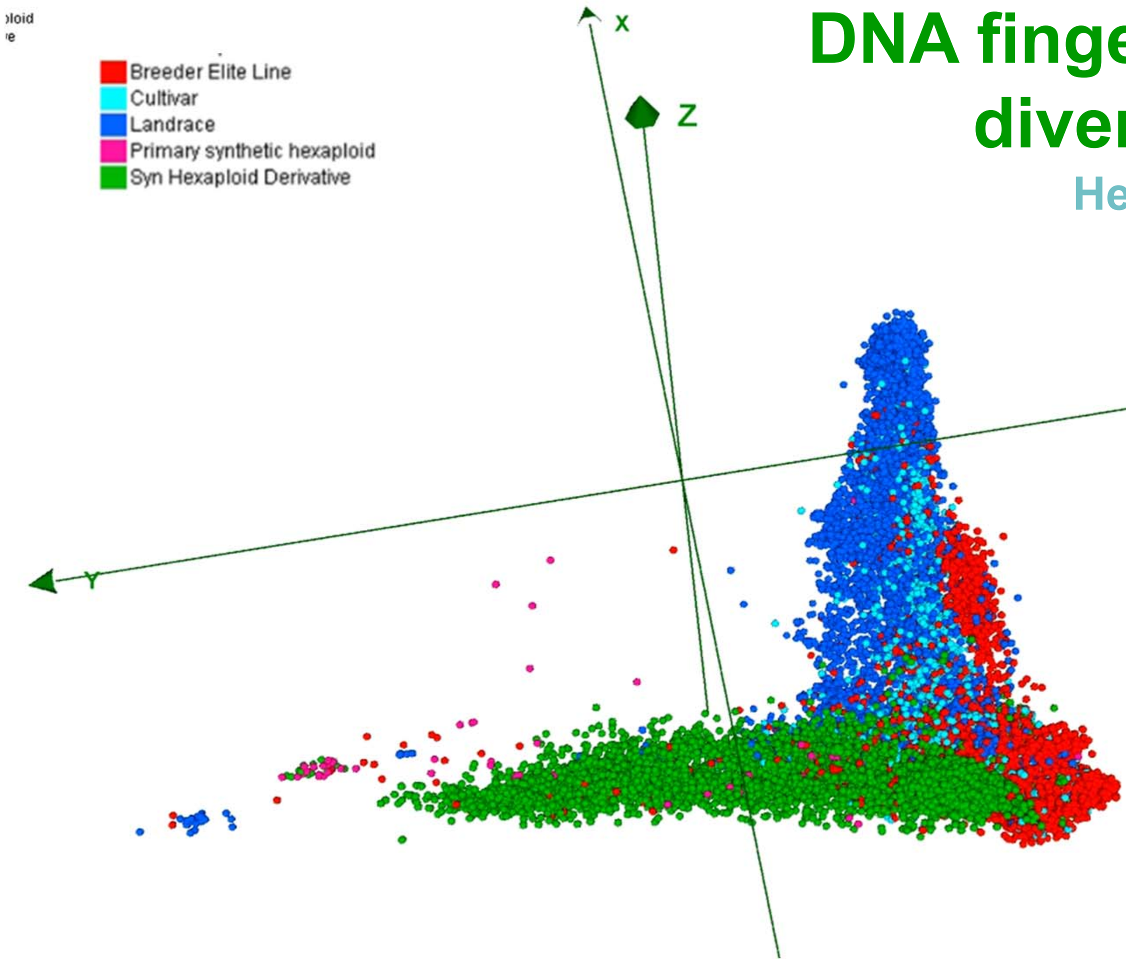
DNA fingerprinting for diversity subsets

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

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Goal 3 Phenotyping

4. Drone for IR and spectral images.
5. Phenocart.

Trait class / Approach:

High throughput

Application / Traits:

Spectral indices, thermal (IR) images

6. Root growth analysis.
7. Canopy growth analysis.

Trait class / Approach:

Precision

Application / Traits:

Growth analysis, above and below ground

- Radiation use efficiency, tiller dynamics
- Partitioning of N and C to different organs
- Root dry weight, depth, architecture

Direct measurement (not shown in photos)

- Energy use efficiency (photosynhtesis/respiration)
- Transpiration
- Chorophyll fluorescence
- Leaf water potential

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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:

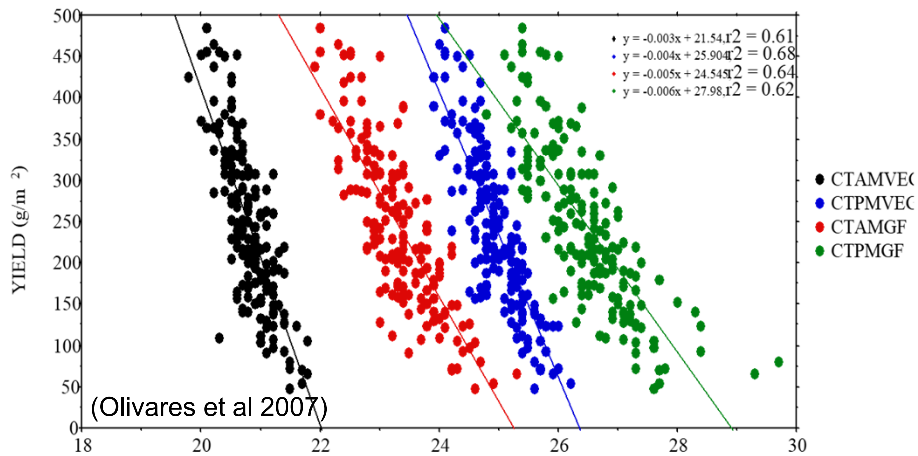
Ground cover, green area, biomass, leaf greenness

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

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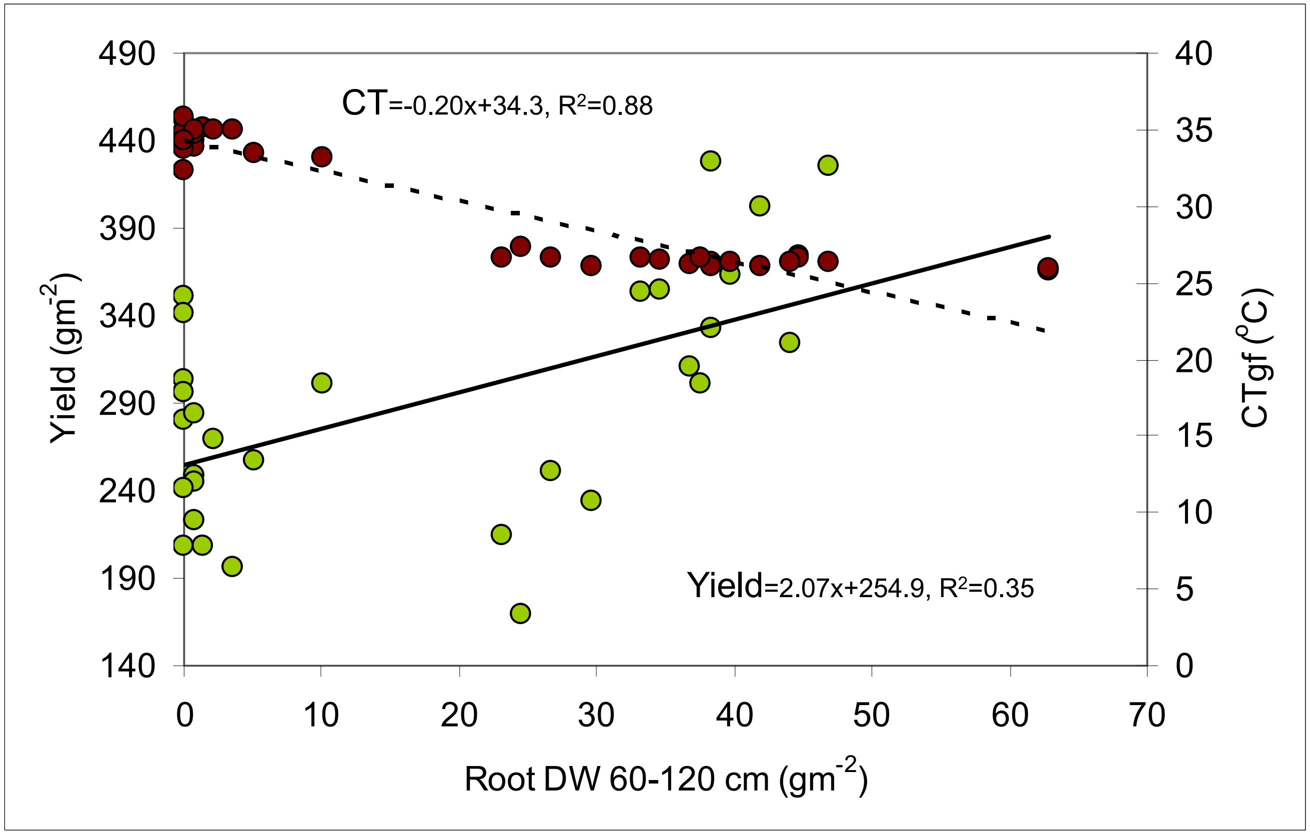
Deep root profiles under drought stress



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

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Root phenotyping under drought

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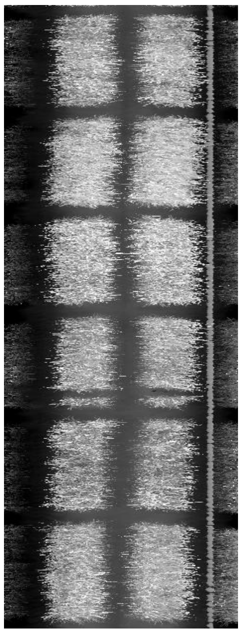
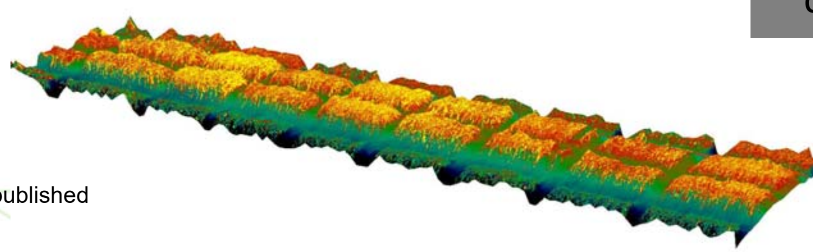
Versatile platform for ground based phenotyping



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

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Goal 4: Genetic Dissection

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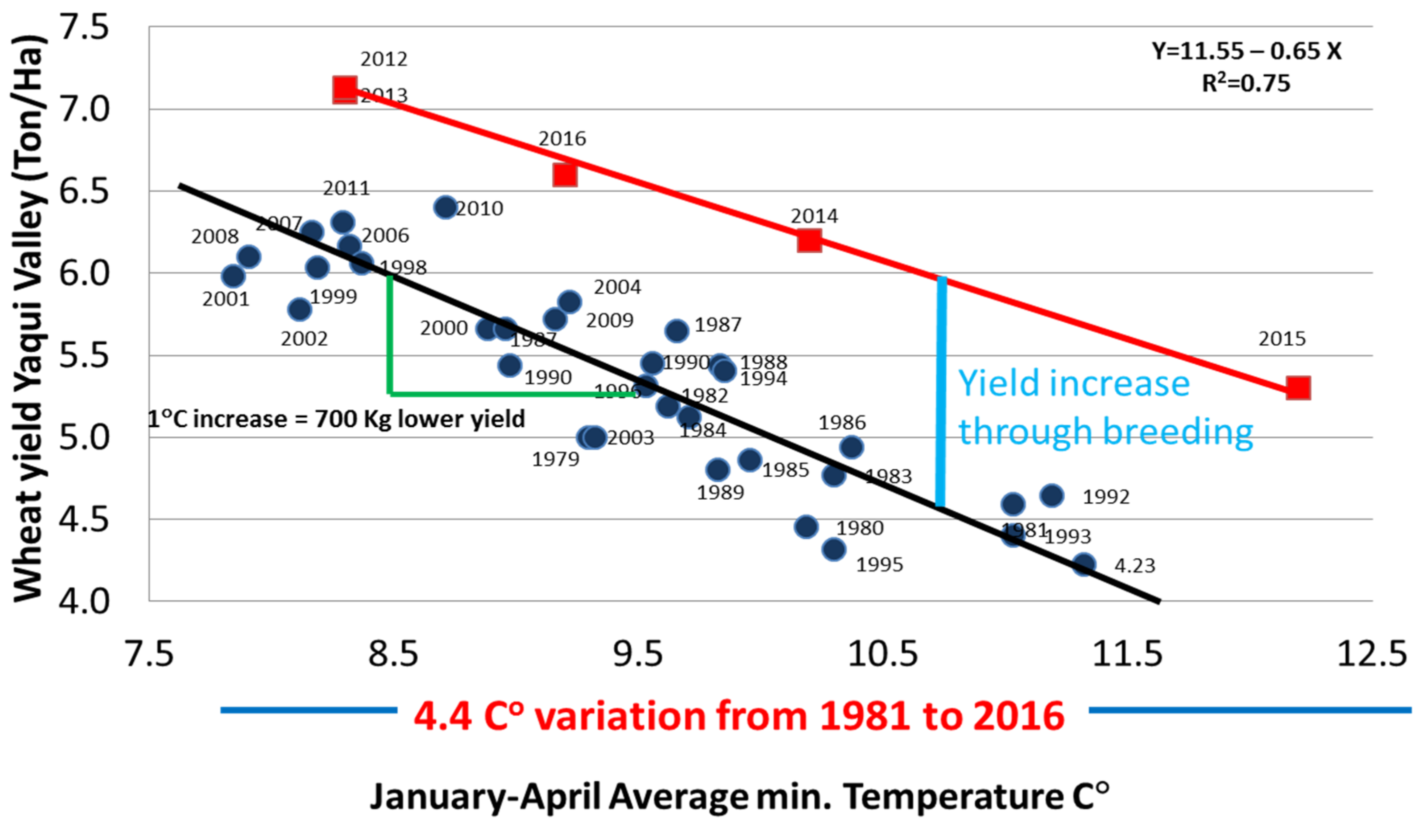
Response of farm yield to mínimum temperature, NW Mexico



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

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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)

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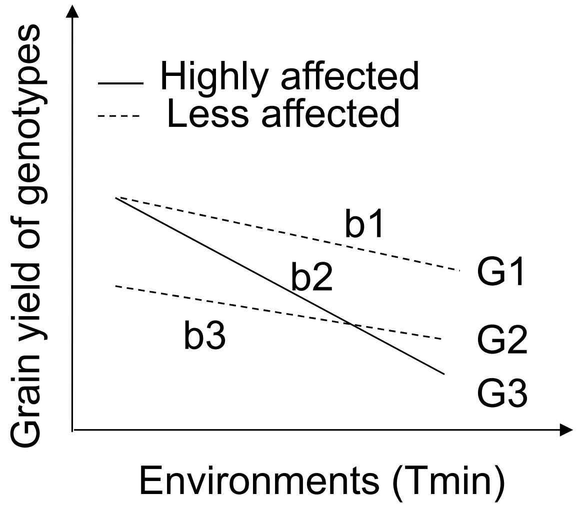
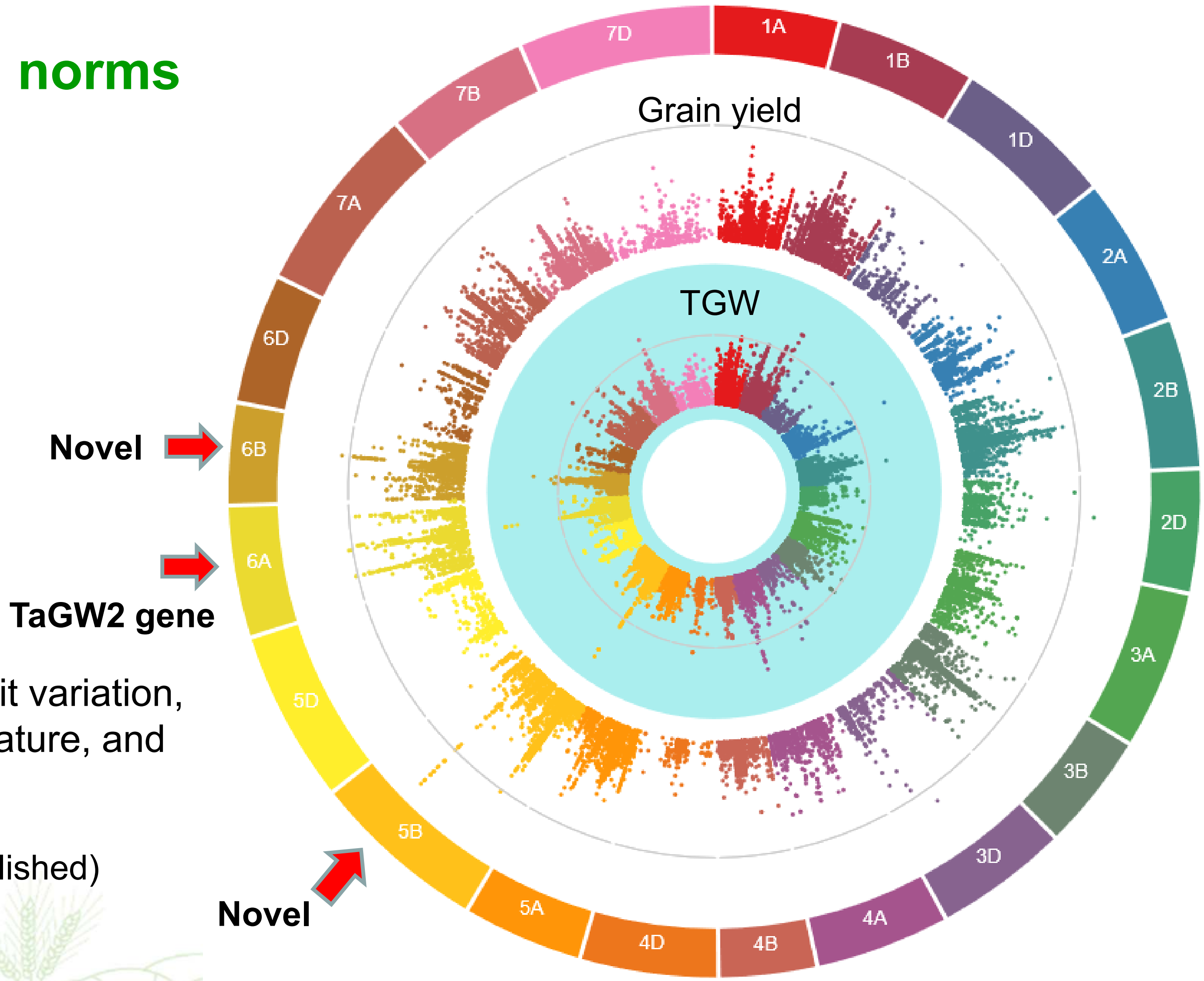
Slope of reaction norms

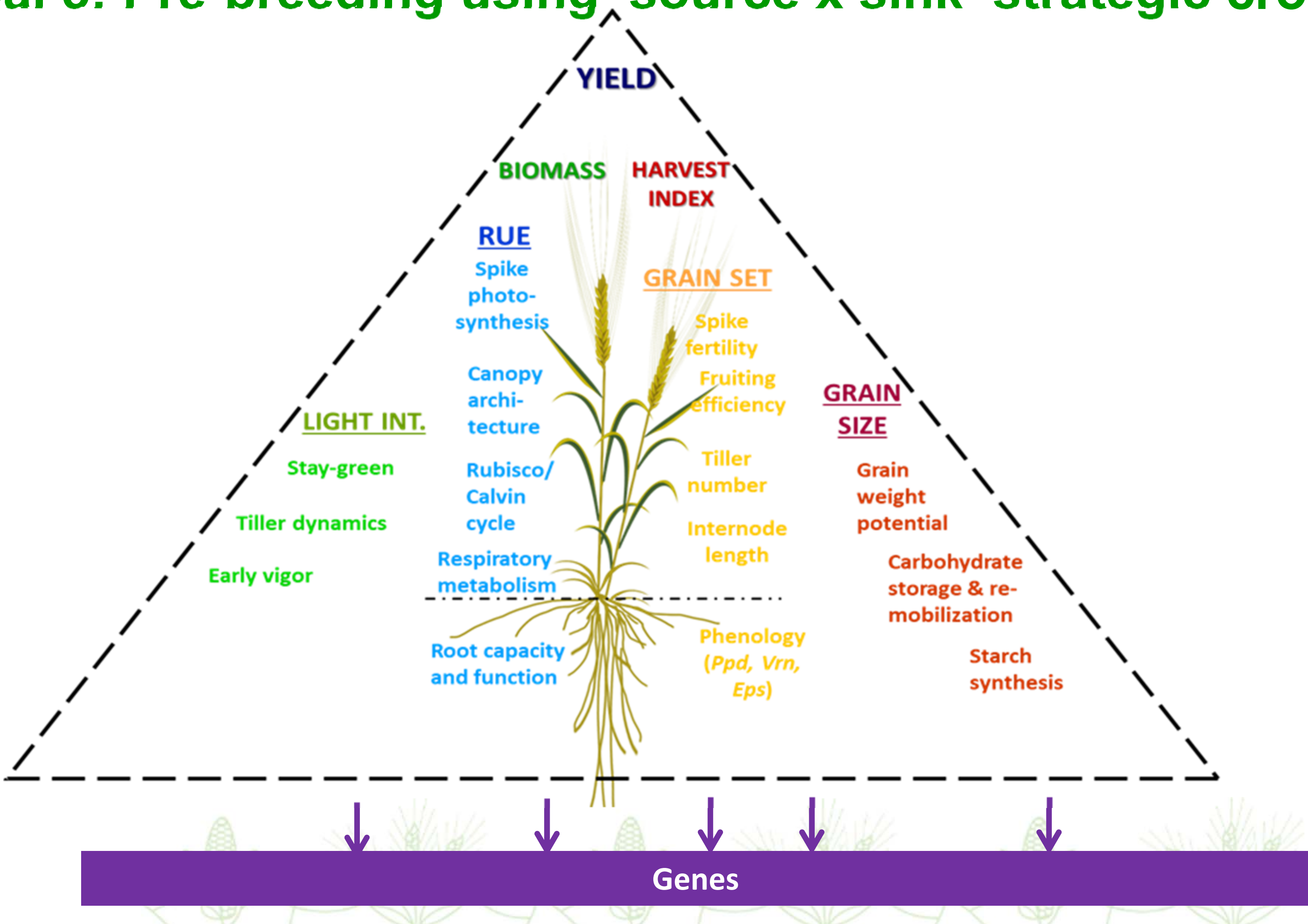




TaGW2 gene is involved in trait variation, response to night time temperature, and phenotypic plasticity

Sukumaran et al. (unpublished)

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



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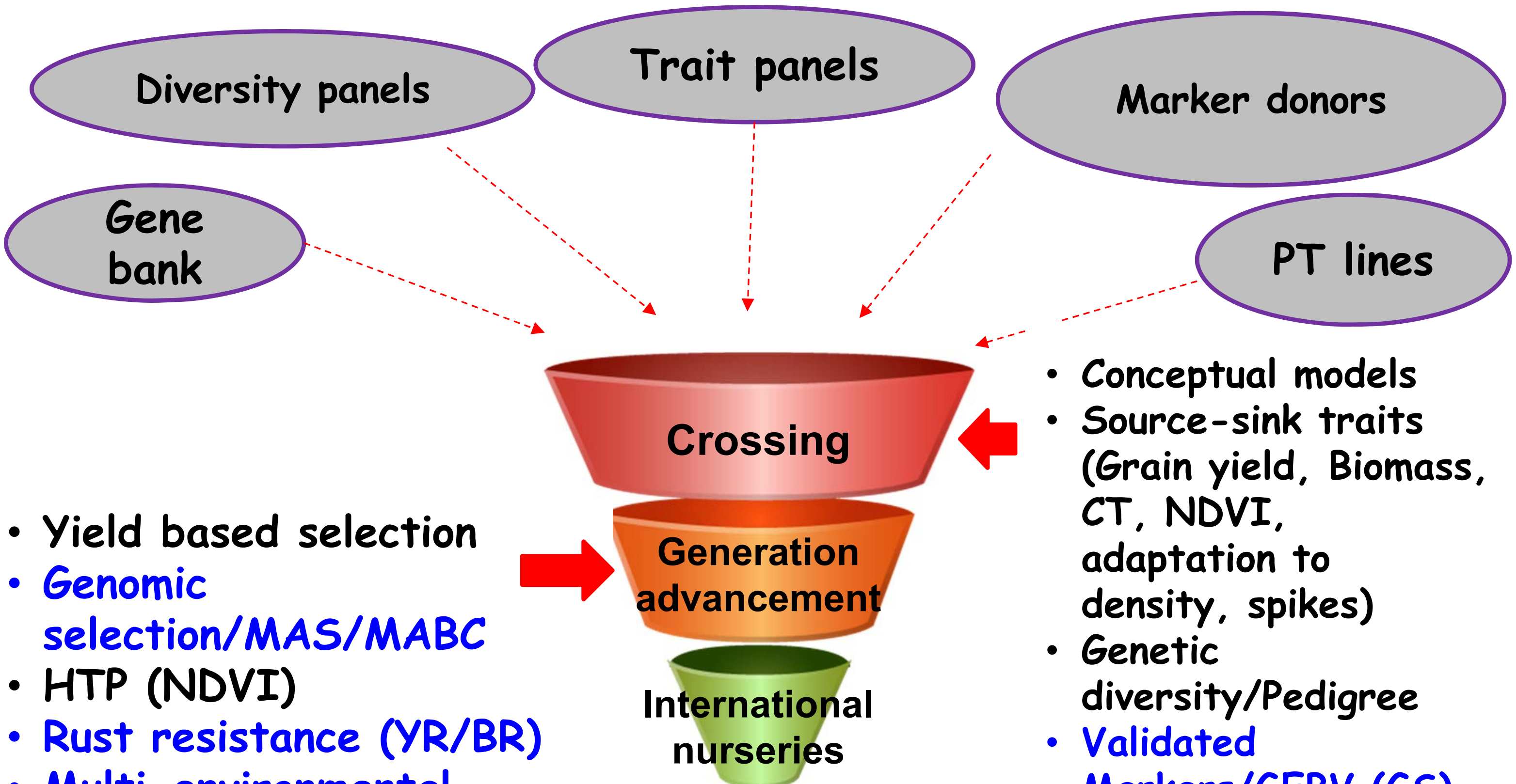
Pre-breeding pipeline



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

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

WYCYTs & SATYNs

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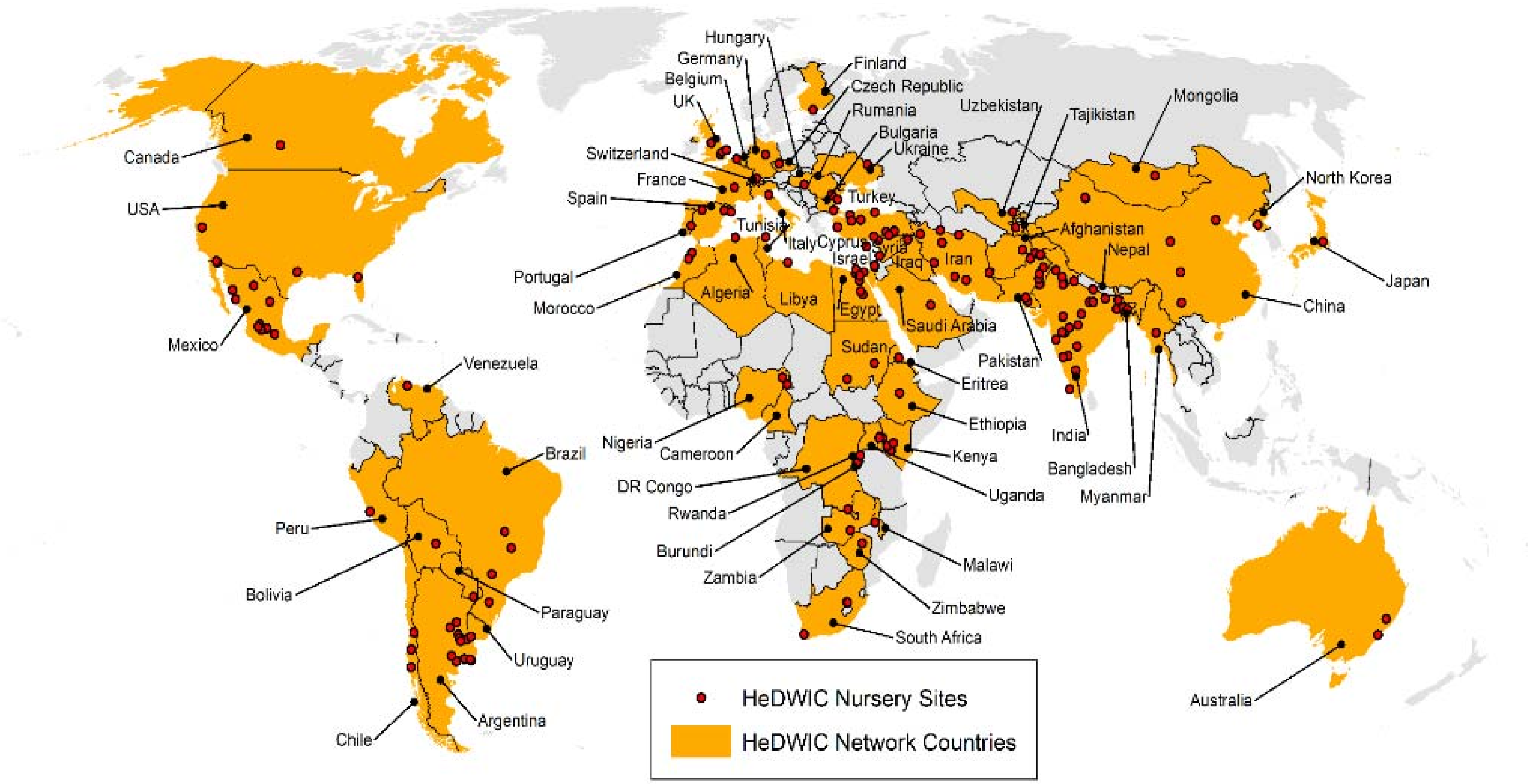
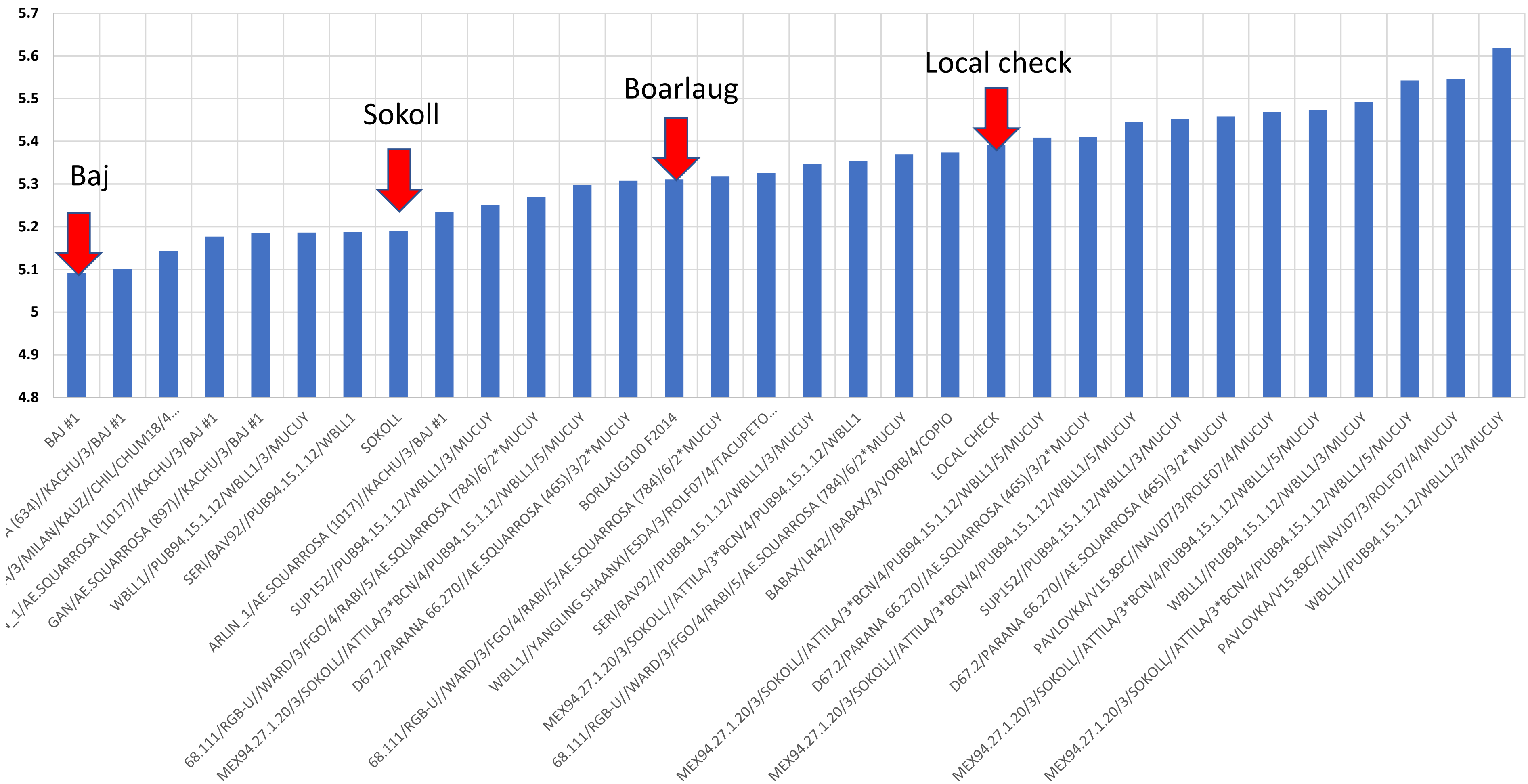
HeDWIC international collaboration including SATYN nursery sites



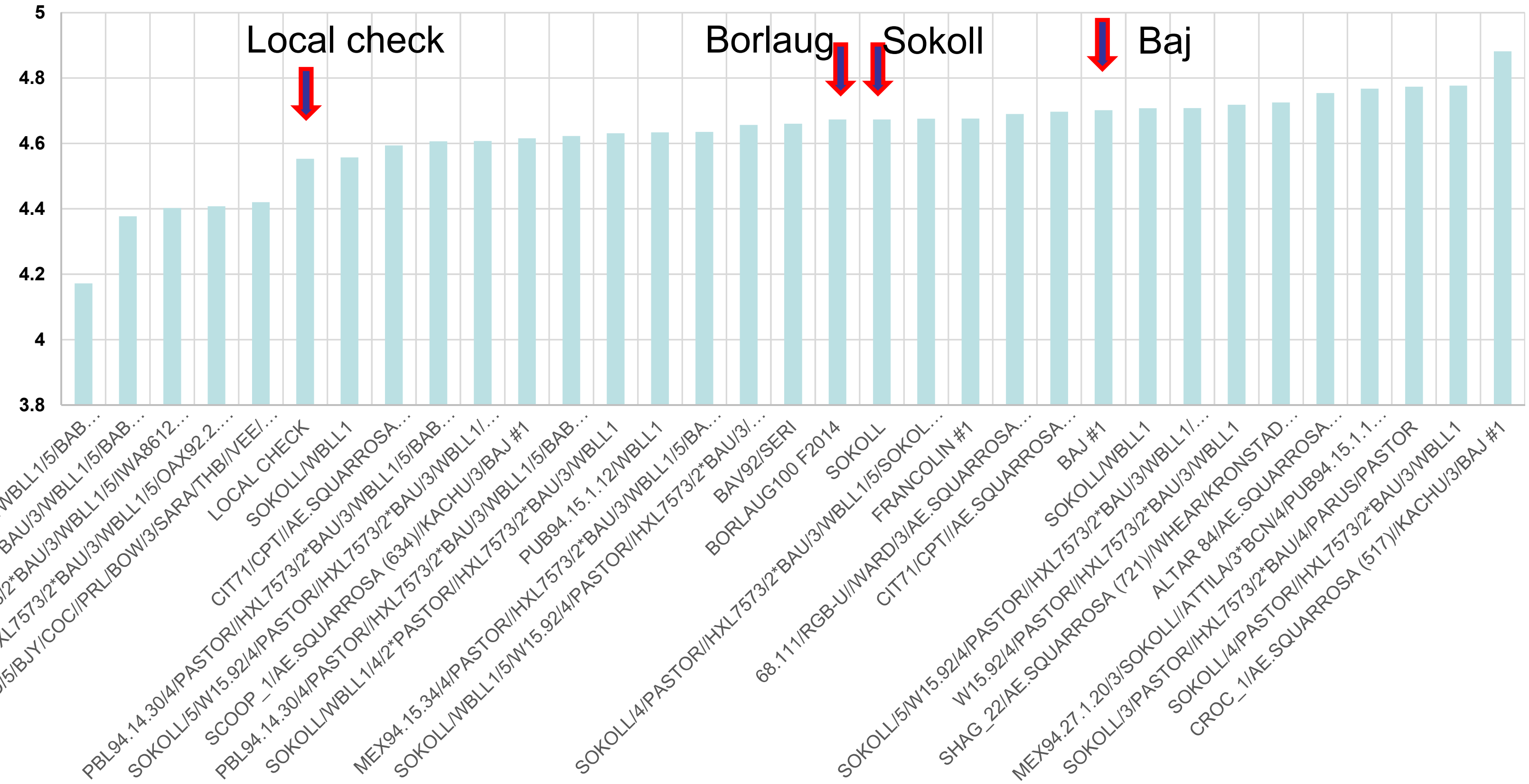
Avg. yield of 6th WYCYT lines (BLUPs) across 32 environments



8th SATYN lines in 33 environments, 2018/19

Best 3 lines 7% above local checks

Best line 4% above elite CIMMYT Check Baj



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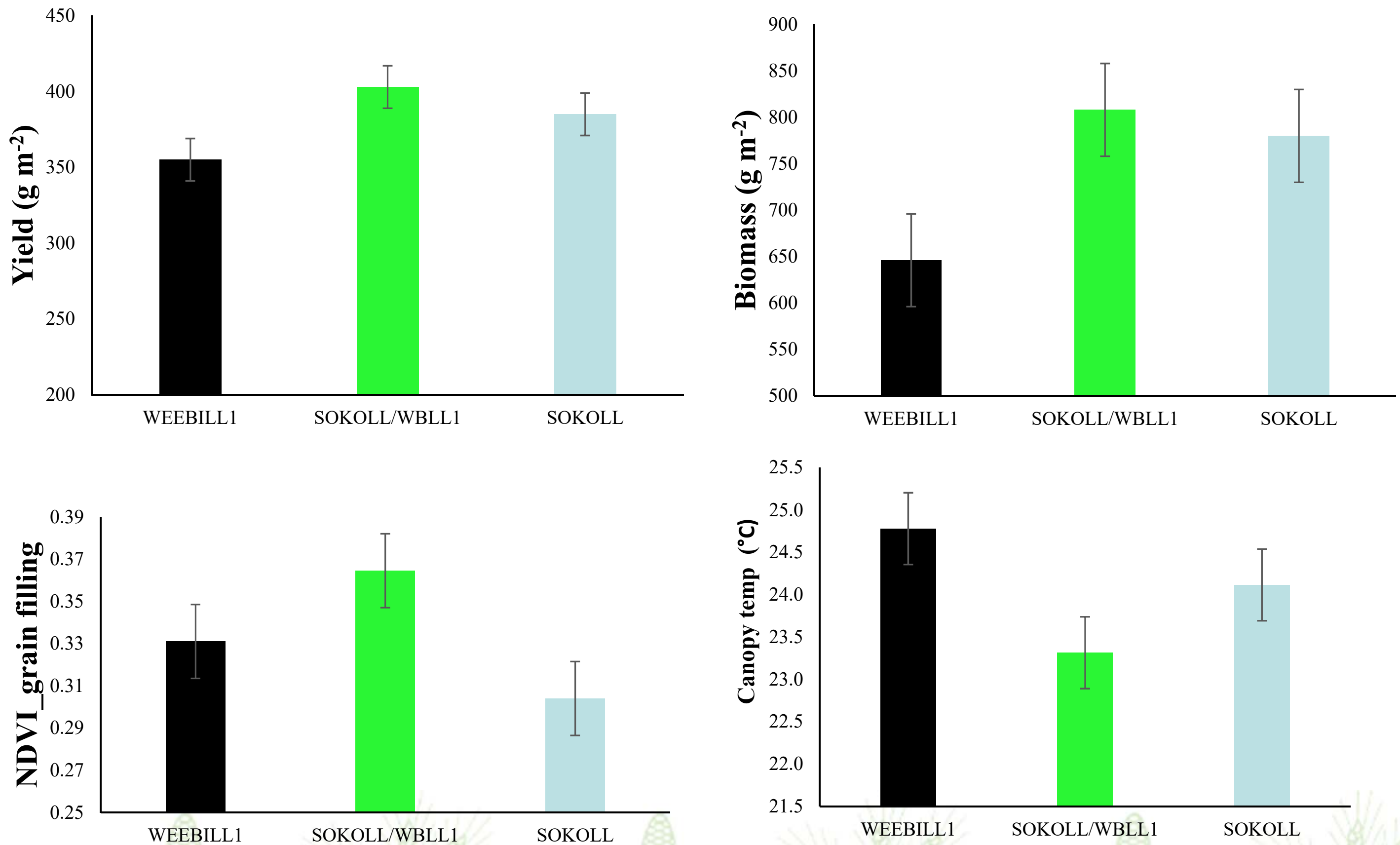
TESTING: Sokoll/Weebil cross
(Mexico data under drought stress)



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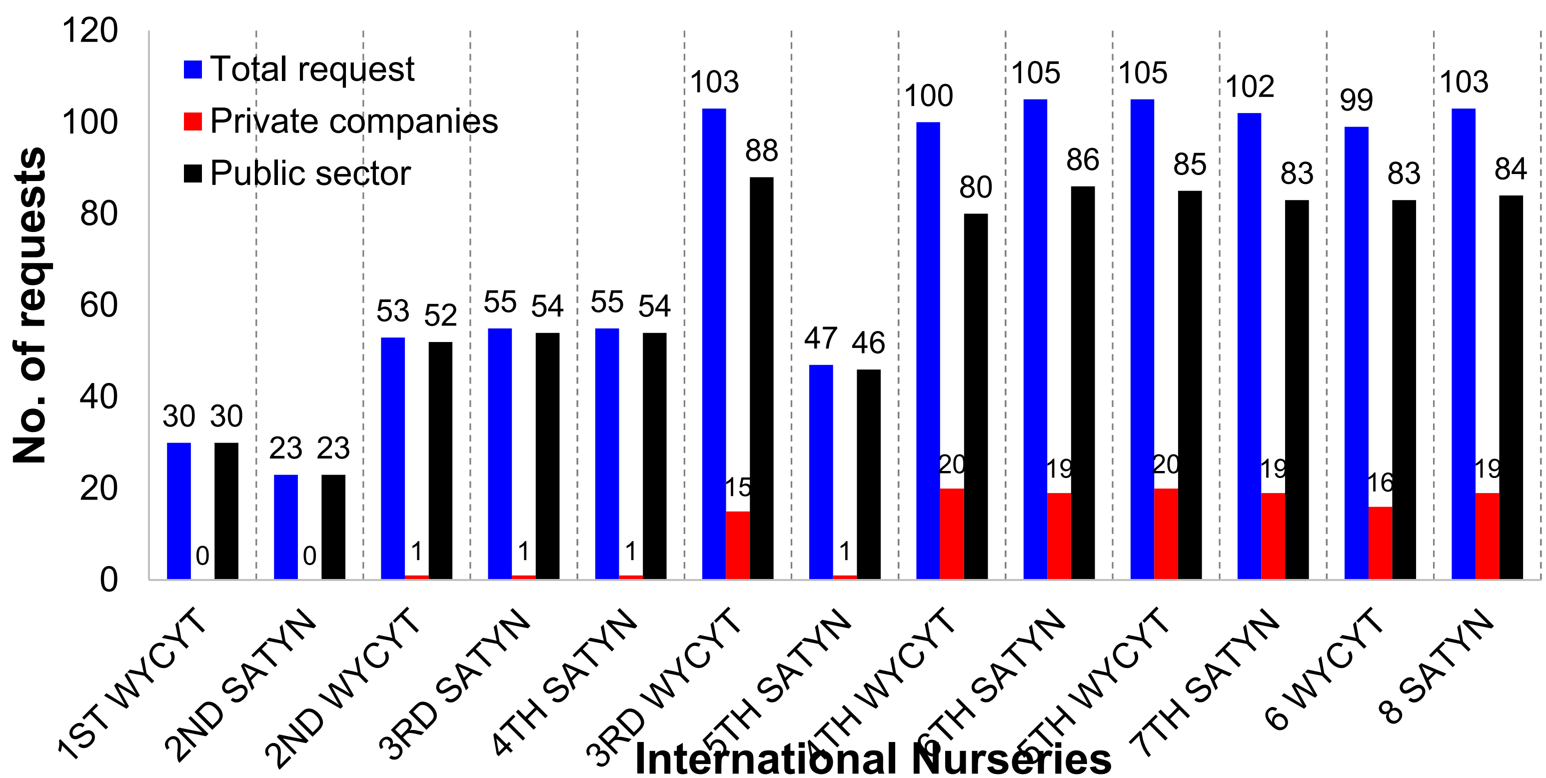
Requests for international nurseries



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

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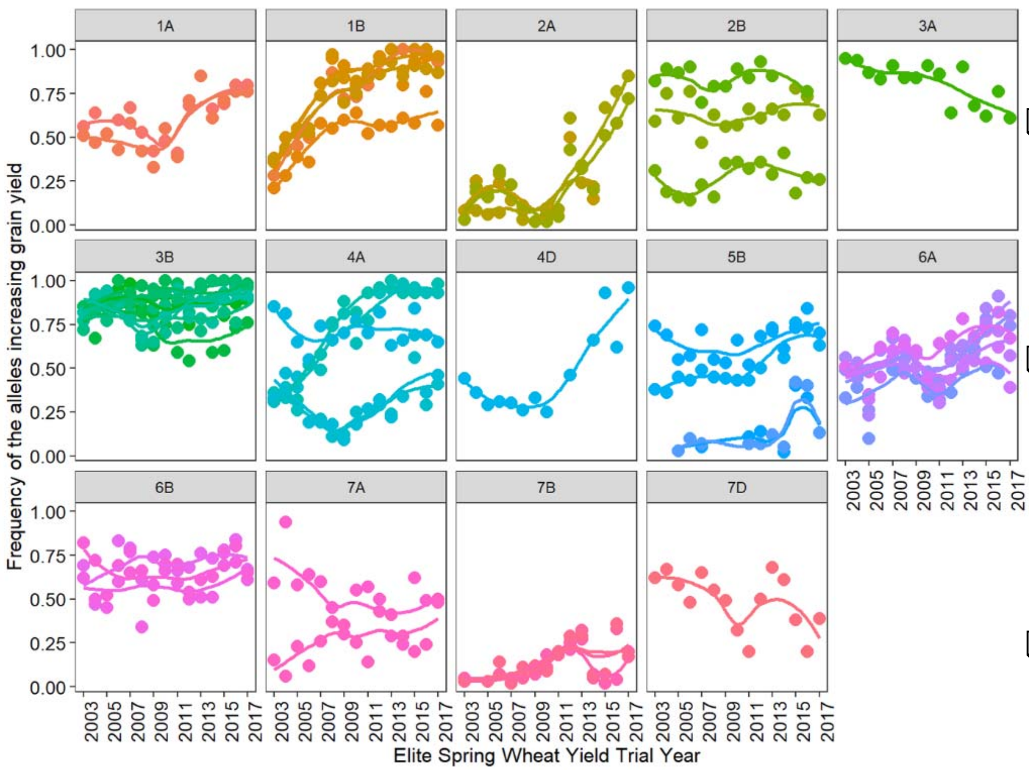
Molecular tracking of favorable allele frequencies over 15 years of breeding



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)

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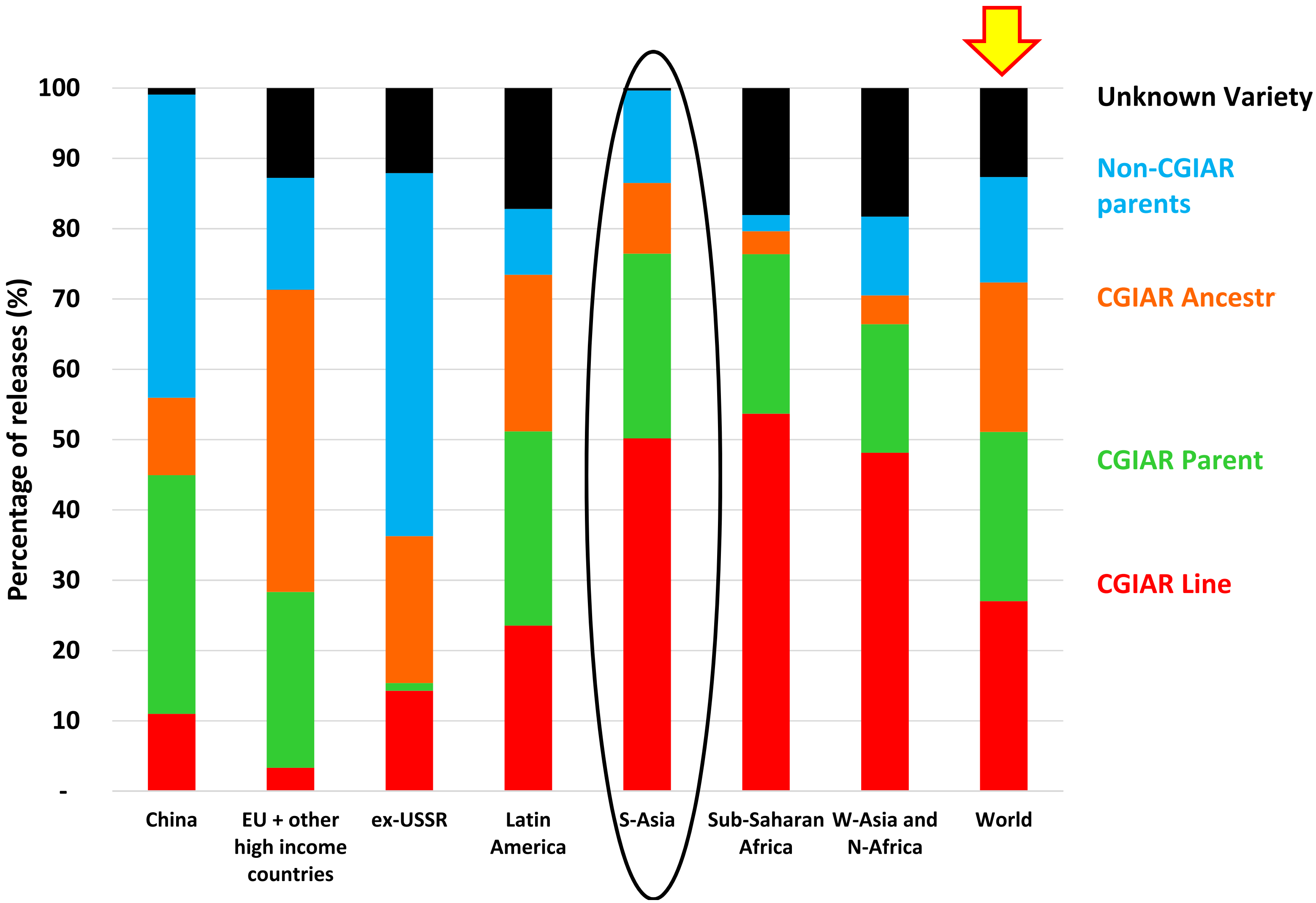
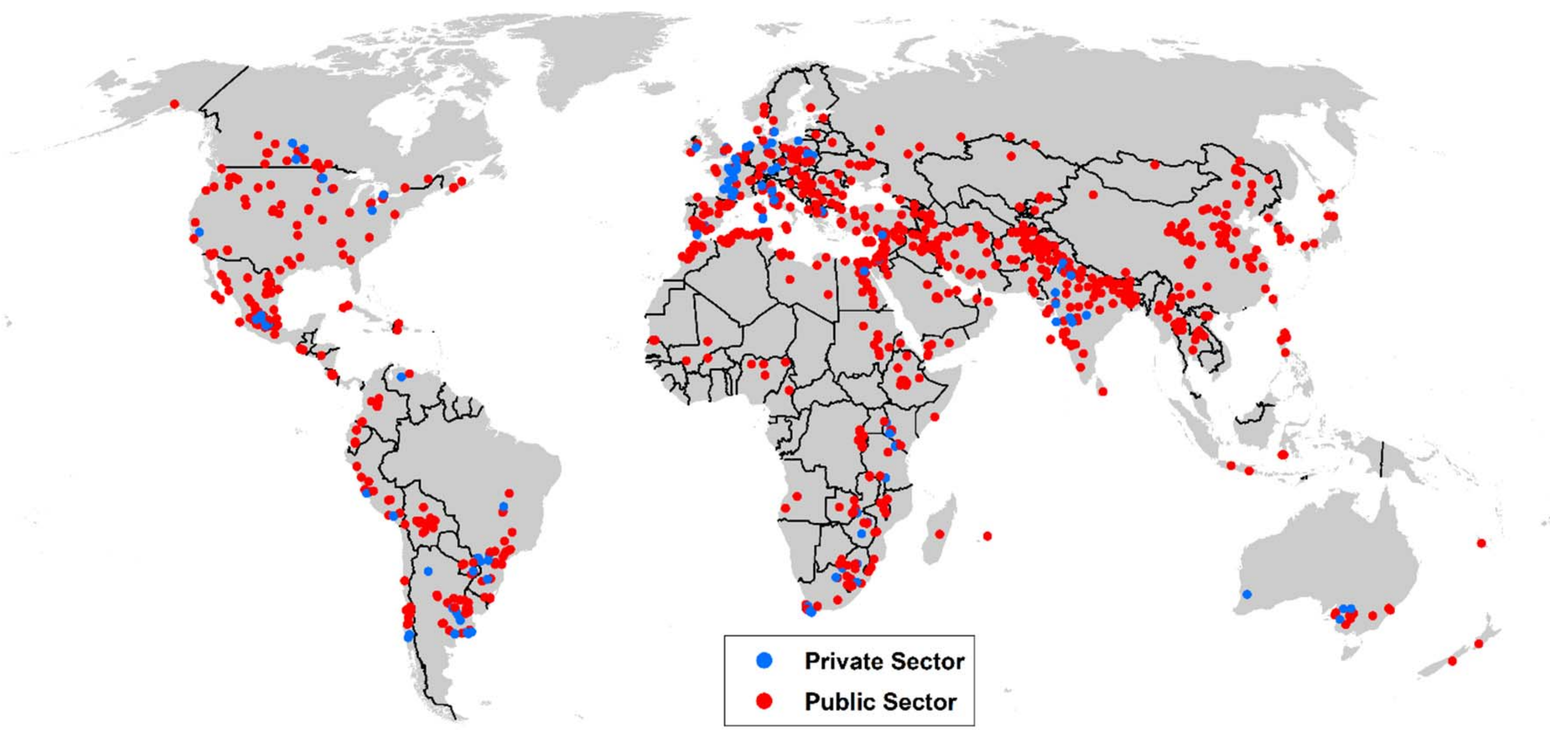
Spring bread wheat releases by region and origin 1994-2014



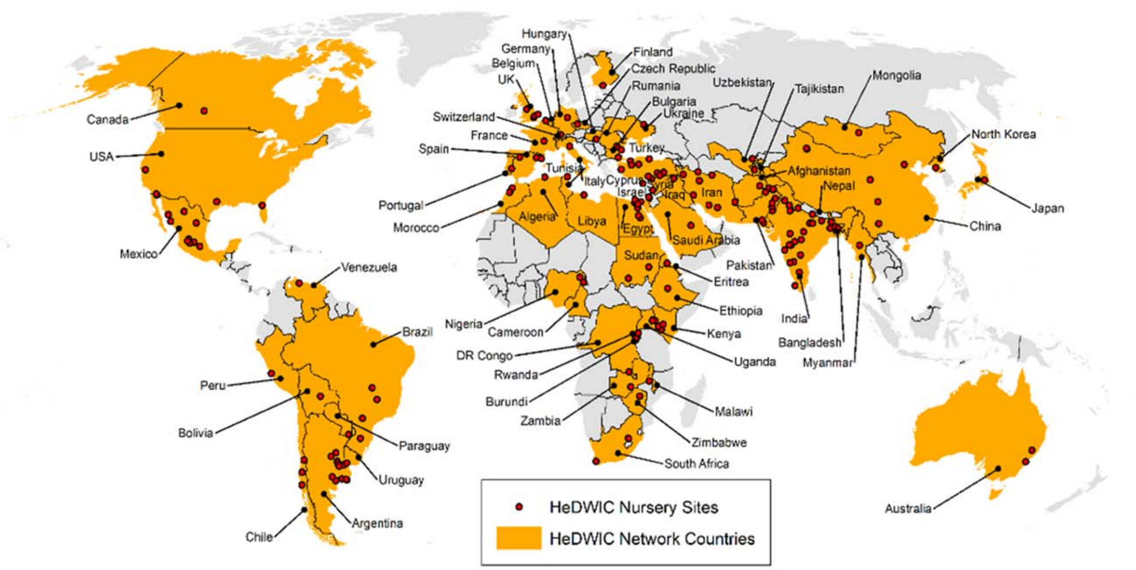
Goal 7: Dissemination of technology

International Wheat Improvement Network (IWIN)



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

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.



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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.

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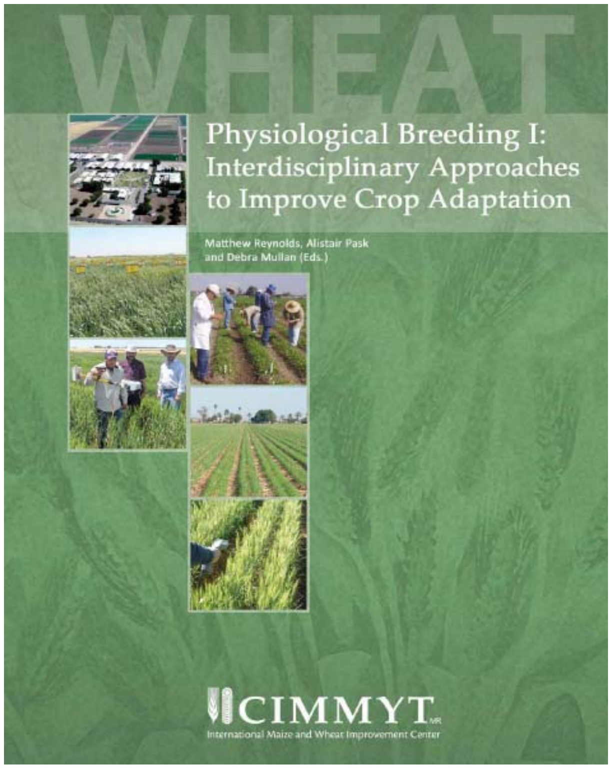
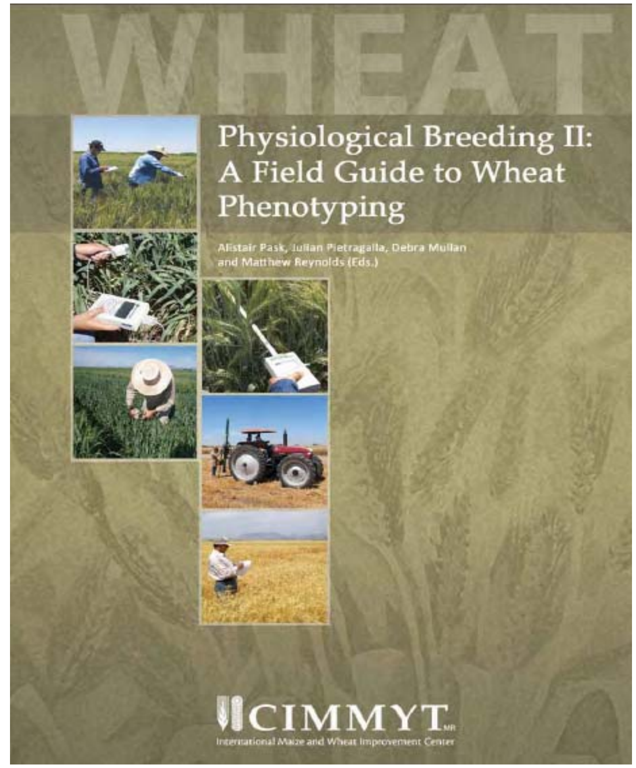
Shared protocols:





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)

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