International Wheat Yield Partnership

Research to Deliver Wheat for the Future

Combining complex traits to improve yield potential, climate-resilience and input-use-efficiency of wheat.

IWYP, HeDWIC, CIMMYT

IWYP AGM, 10,12 September, 2025

Big data analyses predicts stagnation of wheat yield gains if complex traits to match growing demand and & climate instability are not tackled

The International Wheat Improvement Network

- ***GWP focuses on traits of trans-national (strategic) value:***
  - Yield & wide adaptation.
  - **Biotic stress resistance ****
  - End-use quality/nutrition

- ***Productivity gains worth $11b p.a.***
  (to consumers in Global South alone)

****1b litres fungicide saved since 2000**

nature climate change

Article https://doi.org/10.1038/s41558-024-02069-0

New wheat breeding paradigms for a warming climate

Received: 16 January 2024
Accepted: 19 June 2024
Published online: 16 July 2024

Wei Xiong[1,2], Matthew P. Reynolds[2], Carlo Montes[2], Jose Crossa[2], Sieglinde Snapp[2], Beyhan Akin[3], Keser Mesut[4], Fatih Ozdemir[5], Huihui Li[2,6], Zhonghu He[2,6], Daowen Wang[1] & Feng Chen[1]

nature plants

LETTERS

https://doi.org/10.1038/s41477-021-00988-w

Check for updates

Increased ranking change in wheat breeding under climate change

Wei Xiong[1,2], Matthew P. Reynolds[3], Jose Crossa[4], Urs Schulthess[1,2], Kai Sonder[5], Carlo Montes[2], Nicoletta Addimando[6], Ravi P. Singh[3], Karim Ammar[3], Bruno Gerard[2] and Thomas Payne[3]

The International Maize and Wheat Improvement Center develops and annually distributes elite wheat lines to public and private breeders worldwide. Trials have been created in multiple sites over many years to assess the lines' performance for use in breeding and release as varieties, and to provide iterative feedback on refining breeding strategies[1].

strategies[11]. GEIs impact the overall genetic gains and efficiency of breeding programmes by influencing how well target growing environments are identified and resources are allocated to different breeding objectives. GEIs can be grouped into two categories: cross-over interactions, which represent differences in genotype rankings, and non-crossover interactions, which are associated with changes

Received: 23 January 2024 | Revised: 29 May 2024 | Accepted: 3 June 2024
DOI: 10.1111/gcb.17440

Global Change Biology WILEY

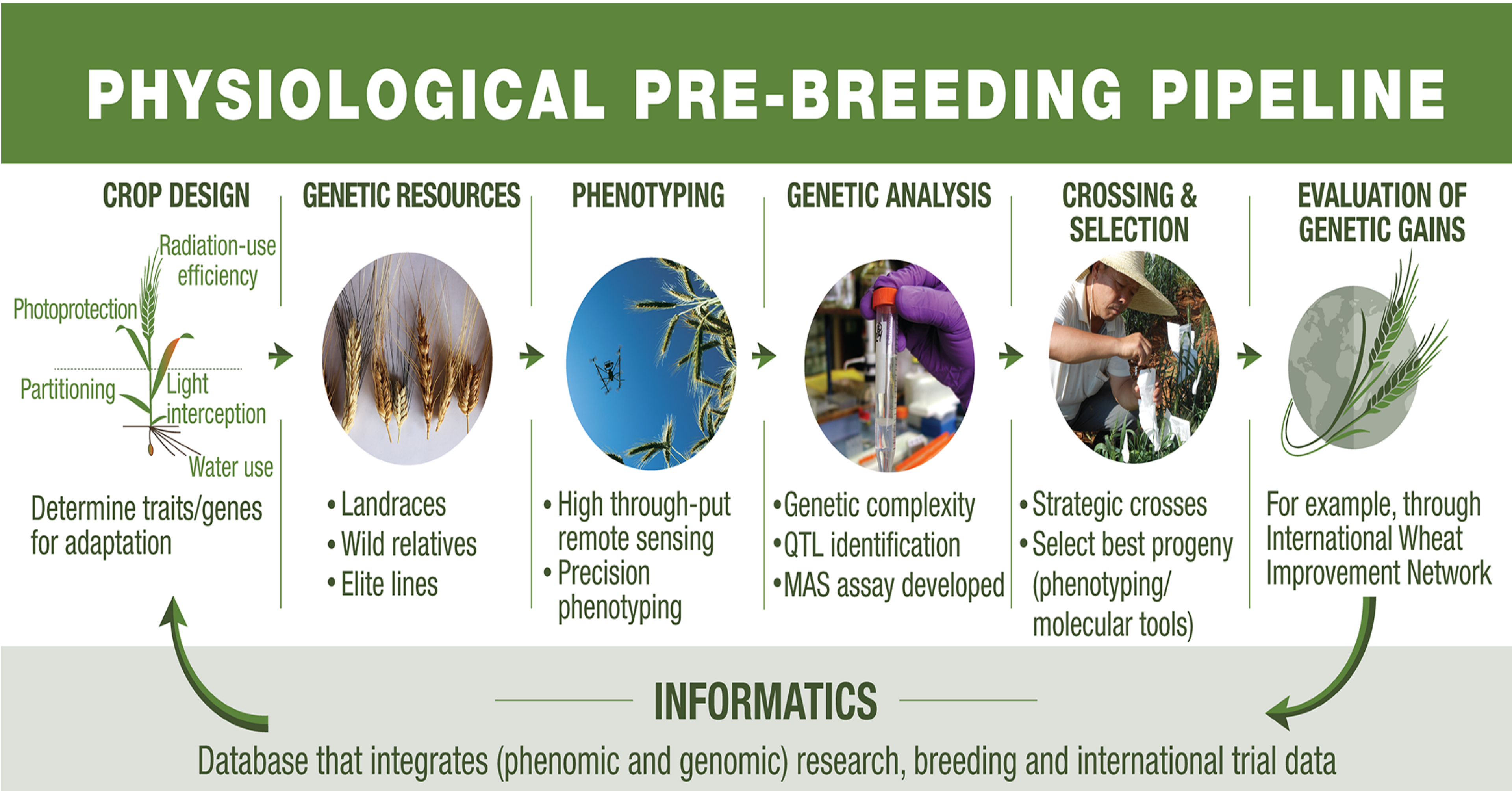
GCB REVIEW

Wheat genetic resources have avoided disease pandemics, improved food security, and reduced environmental footprints: A review of historical impacts and future opportunities

Julie King[1] | Susanne Dreisigacker[2] | Matthew Reynolds[2] | Anindya Bandyopadhyay[2] |

HeDWIC

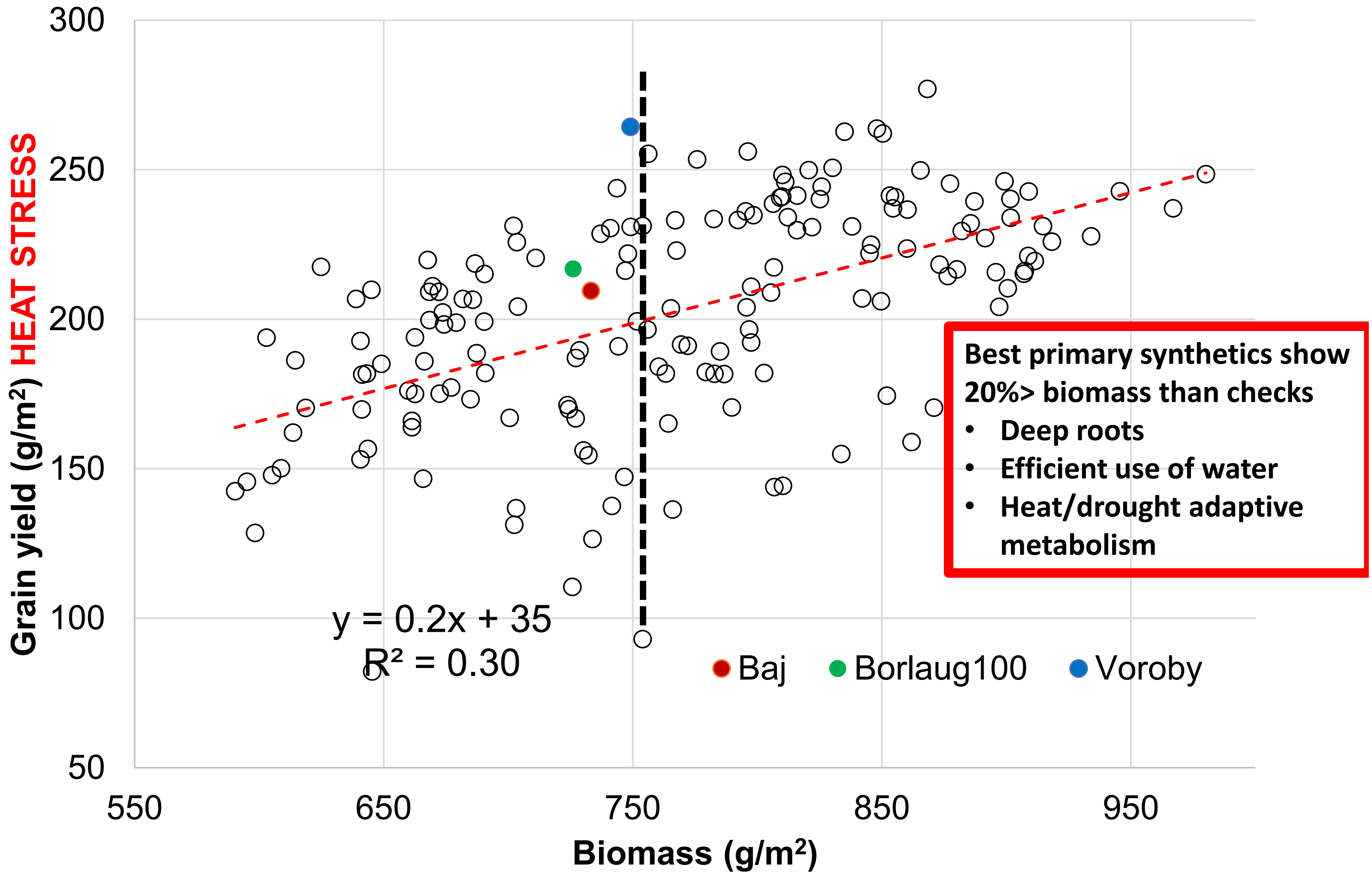
The IWYP approach to "blend" complex traits capitalizes on models of yield, genetic resources, phenomics, genomics and validation via IWIN



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

Novel alleles from wild-relatives are accessed via crossing with amphiploids like 'synthetic wheat'

NW Mexico, 2016 & 2017 (Late sown)



Evolution of high-throughput field-phenomics at CIMMYT Hub applied in BW breeding nurseries since 2016

(Francisco Pinto et al)

Multispectral and thermal cameras:

- NDVI
- MCARI
- Leaf angle
- Chlorophyll Index (green)
- Chlorophyll Index (Red-Edge)
- Vegetation cover (PROSAIL)
- LAI (PROSAIL)
- Clhorophyll a + b (PROSAIL)
- FIPAR (PROSAIL)
- Canopy Temperature
- Biomass index*
- Plant height*
- Yield predictions*

hiphen

2016

- NDVI
- CT (uncalibrated)

3 Experiments
Pre-breeding: WYCYT, CandWYCYT

1 Ha in 30 min for CT at a resolution of 5 cm/pix aprox

2017-2018

- NDVI
- CT
- Plant height

>10 Experiments
Pre-breeding: WYCYT, CandWYCYT, SATYN, CandSATYN

1 Ha in 30 min for CT at a resolution of 5 cm/pix aprox

2019 to date

Airplane

- NDVI
- SR
- MCARI
- Chl index red_edge
- Chl index green Index
- LAI
- Chl ab
- Fcover
- FIPAR
- Average Leaf Angle
- CT

Available for all trials, nurseries and experiments, including candidates for WYCYT and IYPTE

12 Ha in 30 min for CT at a resolution of 5 cm/pix aprox

LIDAR

- Growth analysis
- In-season biomass
- Plant height

At experimental stage for fitting models

Tests in experiment : BestPT, HiBAP, BDP.
Available for candidates in 2024

400 plots (large)/h

Multi-sensor

- NDVI
- PRI
- CT
- Hyperspectral
- High resol RGB

Test and calibration phase in 2023

Tests in BestPT and BDP.
Available for candidates in 2024

400 plots (large)/h

Rover

- Heading date
- Spike/spikelet count
- Canopy cover
- Stay green
- Spike morphology

- Private partner
- DL models developed.
- Outputs available

Not available until new funds.

200 plots (large)/h

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Genetic Analysis & Gene Discovery

Gene-sequencing of progeny from crosses with amphiploids reveals heat tolerance haplotypes without yield penalty

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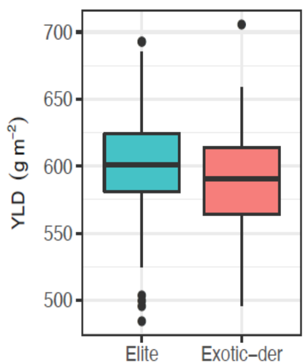
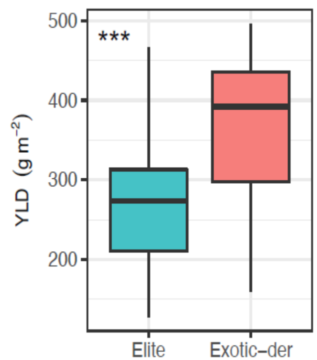
Research to Deliver Wheat for the Future

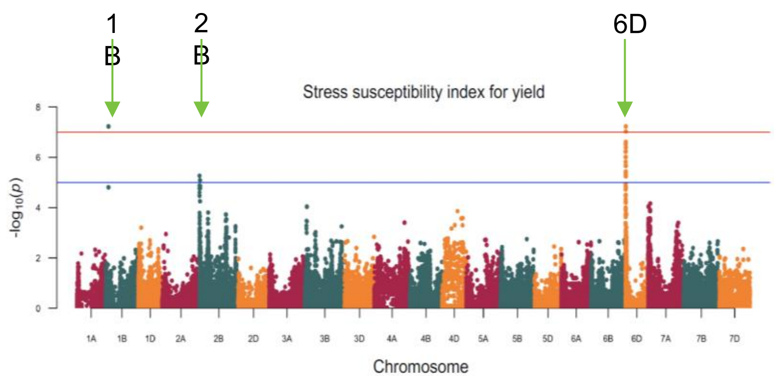
Sequenced IWYP & HeDWIC panels -by AGIS- leverages the vast phenotypic data sets for gene & haplotype discovery

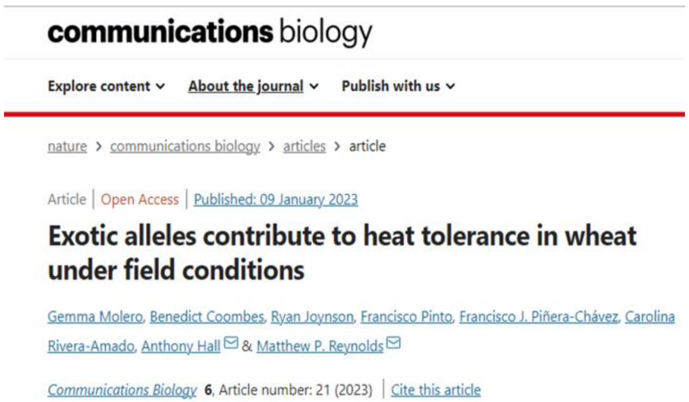


Check yield



Heat stressed yield





communications biology

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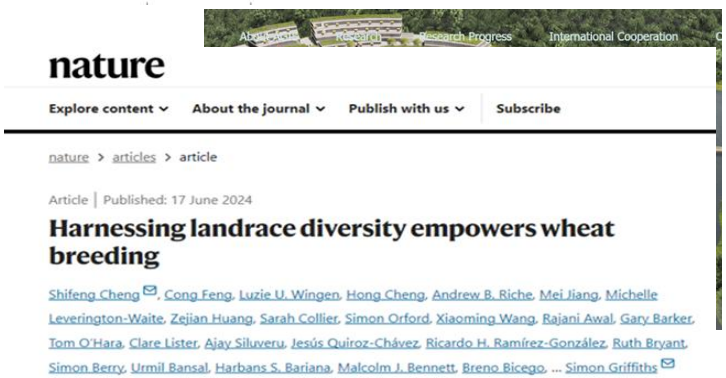
Article | Open Access | Published: 09 January 2023

Exotic alleles contribute to heat tolerance in wheat under field conditions

Gemma Molero, Benedict Coombes, Ryan Joynson, Francisco Pinto, Francisco J. Piñera-Chávez, Carolina Rivera-Amado, Anthony Hall & Matthew P. Reynolds

Communications Biology **6**, Article number: 21 (2023) | Cite this article



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Article | Published: 17 June 2024

Harnessing landrace diversity empowers wheat breeding

Shifeng Cheng, Cong Feng, Luzie U. Wingen, Hong Cheng, Andrew B. Riche, Mei Jiang, Michelle Leverington-Waite, Zejian Huang, Sarah Collier, Simon Orford, Xiaoming Wang, Rajani Awal, Gary Barker, Tom O'Hara, Clare Lister, Ajay Siluveru, Jesús Quiroz-Chávez, Ricardo H. Ramírez-González, Ruth Bryant, Simon Berry, Urmil Bansal, Harbans S. Bariana, Malcolm J. Bennett, Breno Bicego, ... Simon Griffiths

HeDWIC
CIMMYT

Gene discovery in novel amphiploid genomes (Xu et al)

- ▪

	Environments CENEB, Mexico	Marr	Chromo-some	PVE all sig SNPs	Novel markers	PVE all novel SNPs
SYNPAN II	Irrigation	AX-94907052	1A	40%	Y	**23%**
		AX-158621657	5B		Y	
		AX-94951542	5B		Y	
	Heat	Excalibur_c32608_500	1B	47%	Y	**20%**
		Ex_c525_1401	2B		Y	
	Drought	AX-94537209	4D	15%	Y	**6%**
		AX-158587956	6B		Y	
	Combined	AX-158570322	1B	55%	Y	**24%**
		Tdurum_contig777_260	3A		Y	
		AX-158541430	3B		Y	
		D_contig59199_227	3D		Y	
		AX-158534283	5B		Y	
		Ex_c101666_634	7B		Y	
ISO-D RILs (Family 2)	Irrigation	5D@20.2	5D	21%	Y	**8%**
	Drought	1D@42.2	1D	24%	Y	**24%**
		5D@0.2	5D		Y	

Gene discovery in diversity panels originating from the World Wheat Collection (large subset) at CIMMYT
(Xu et al)

- .

MOLPAN (selected to maximize molecular diversity)	Environment	Chromo-some	P value adjusted	PVE per SNP	PVE all sig SNPs	Novel MTA	PVE all novel SNPs
					%		%
MOLPAN	Yield Potential	3A	0.0000181	8%	30.7	Y	20
	CENEB, Mexico	3B	0.0004115	10%		Y	
MOLPAN	Heat	3B	0.0000006	6%	21.5	Y	9
	CENEB, Mexico	4A	0.0064573	3%		Y	
MOLPAN	Drought	3B	0.0065973	7%	37	Y	17
	CENEB, Mexico	6A	0.0050185	7%		Y	
		7D	0.0020624	5%		Y	
MOLPAN	Combined	1A	0.0083901	NS	32	Y	9
	CENEB, Mexico	1A	0.0003131	7%		Y	
		3B	0.0000004	10%		Y	

EDPIE-MEX selected elite lines with highly diverse pedigrees	Heat	1A	0.0070	6%	43	Y	4
	Drought	5A	0.0004	13%	22	Y	22
	CENEB, Mexico	7A	0.0065	10%		Y	

EDPIE-International	Comb (22 sites)	4B	0.0039	8%	42	Y	18

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Physiological or Predictive Pre-Breeding (PPB)

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Source x sink crosses to stack complementary physiological traits

Sink Traits

Source Traits

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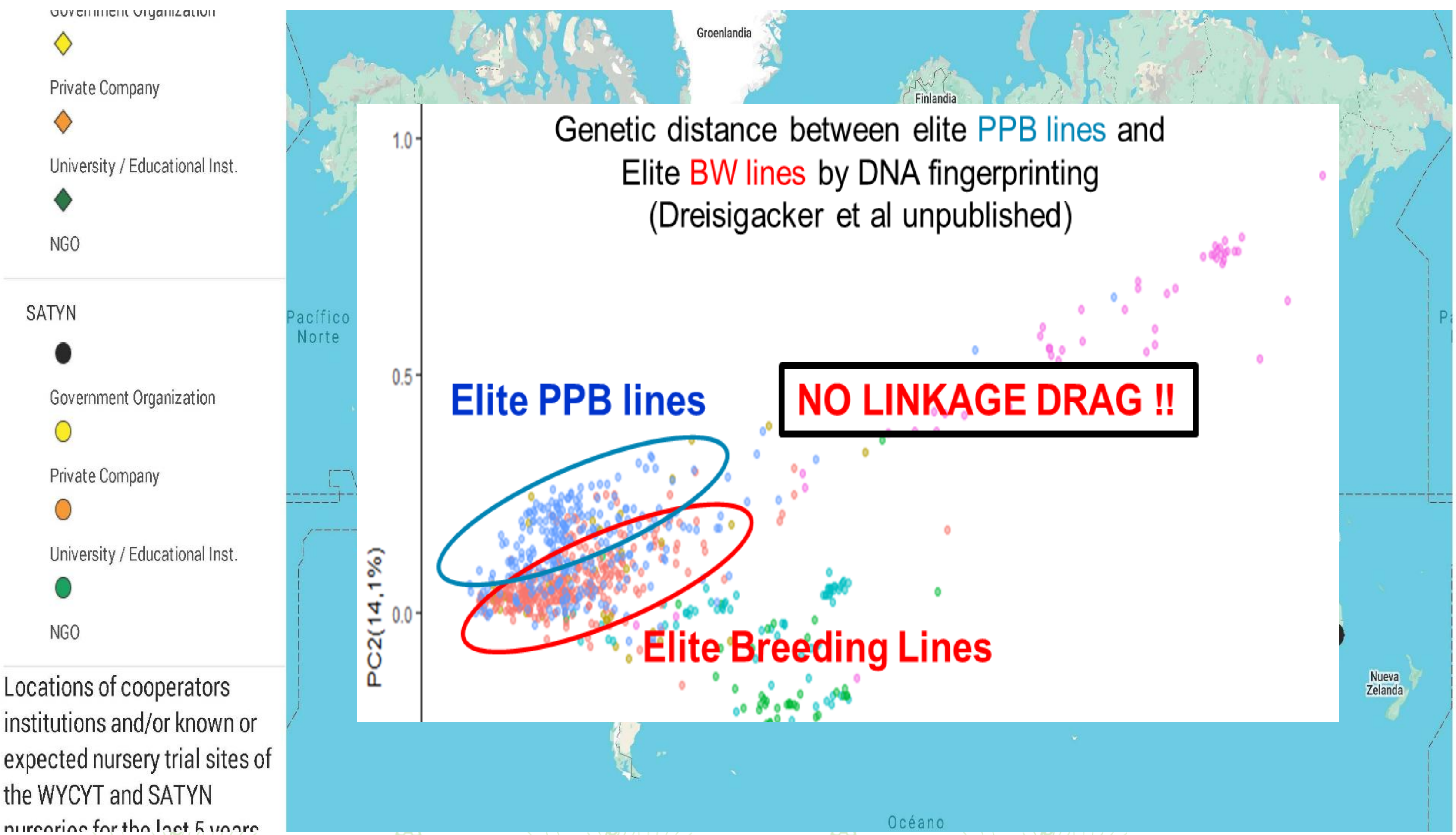
WYCYT & SATYN trial sites (>200 request p.a.)

Best lines locally/regionally used as parents

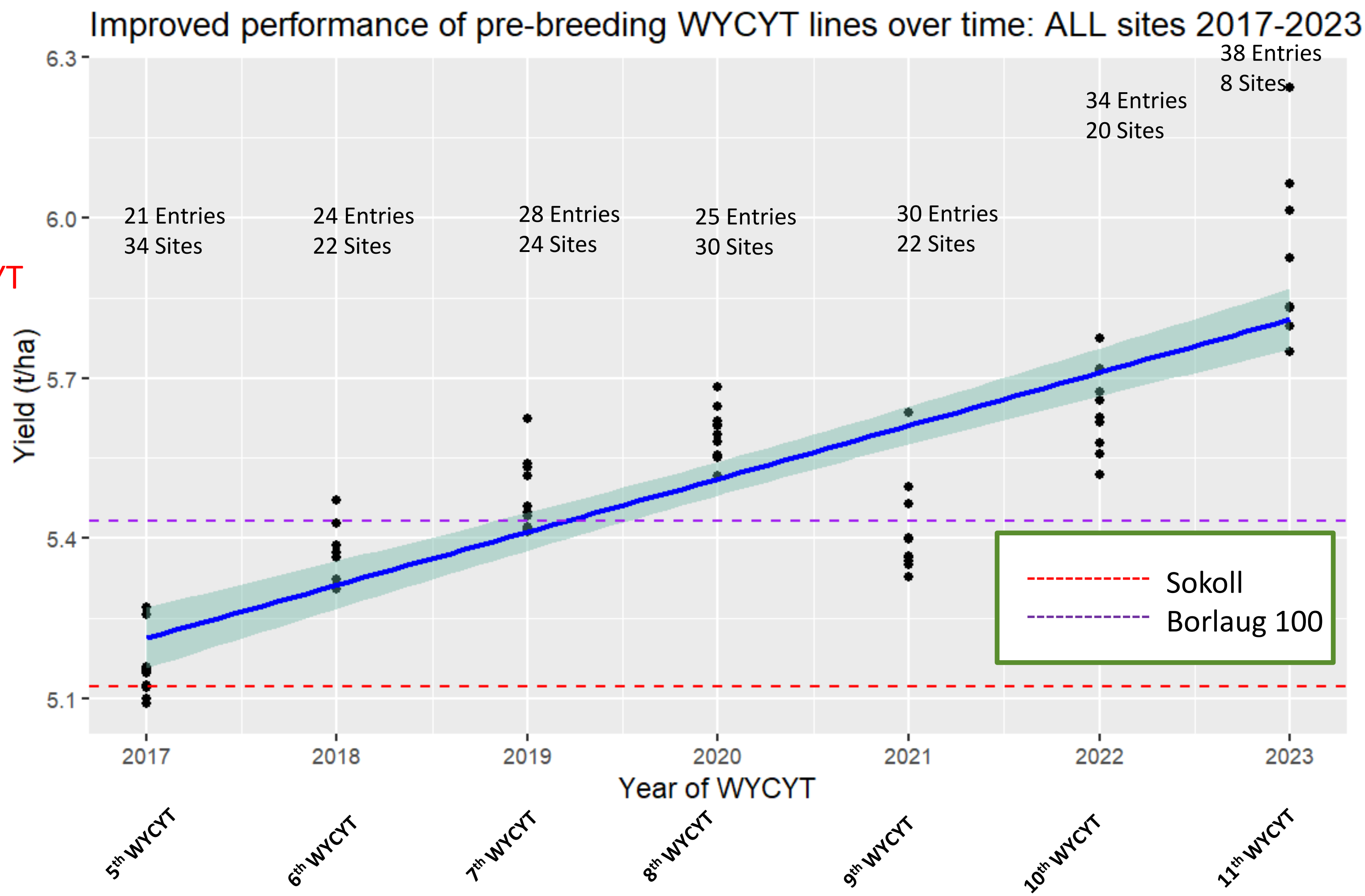


Top 10 WYCYT lines (averaged across all IWIN sites) on-track to deliver 50% yield gains -over Borlaug 2014- by 2034.

TOP 10 lines/WYCYT
SImprovement, **1.80% per year,** relative to average yield (Slope 99 kg/ha/yr)

p-value = 2.19E-19

R^2adj = 0.69



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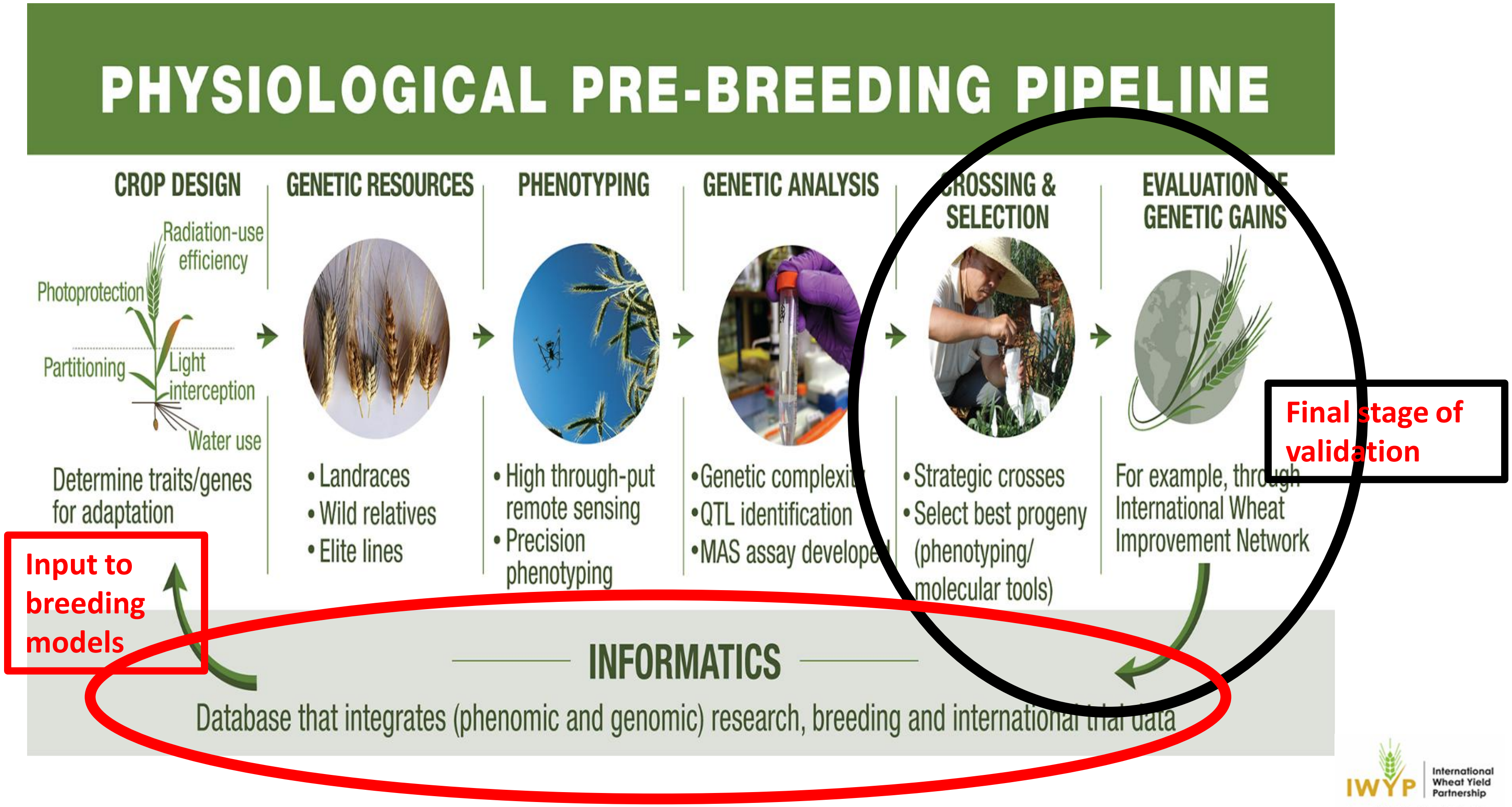
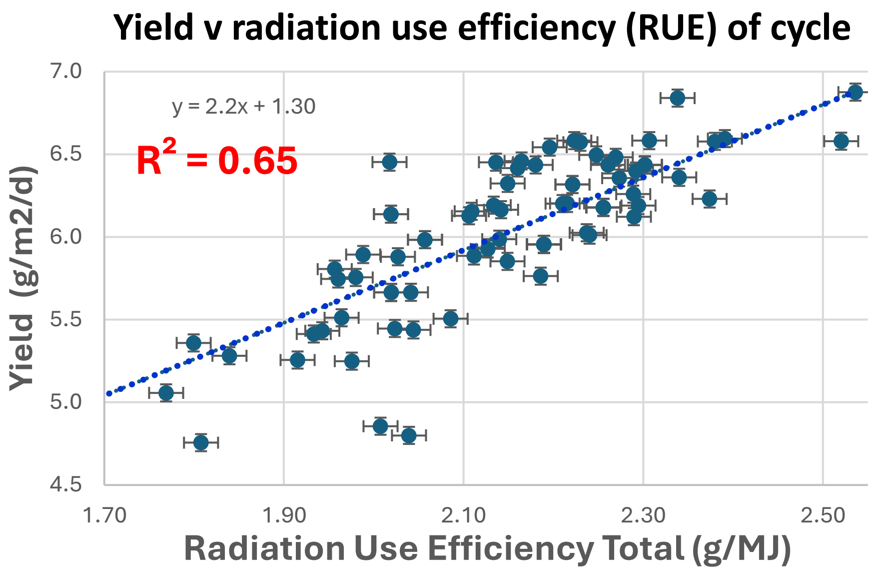
Understanding yield potential and trait targets



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

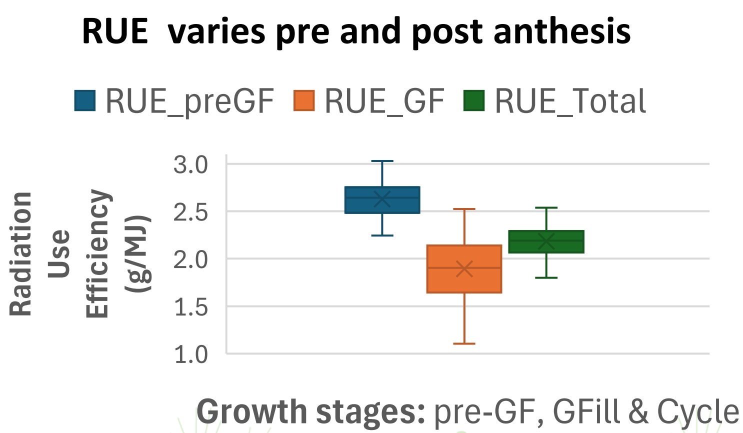
Physiological bases of yield potential: Source Traits

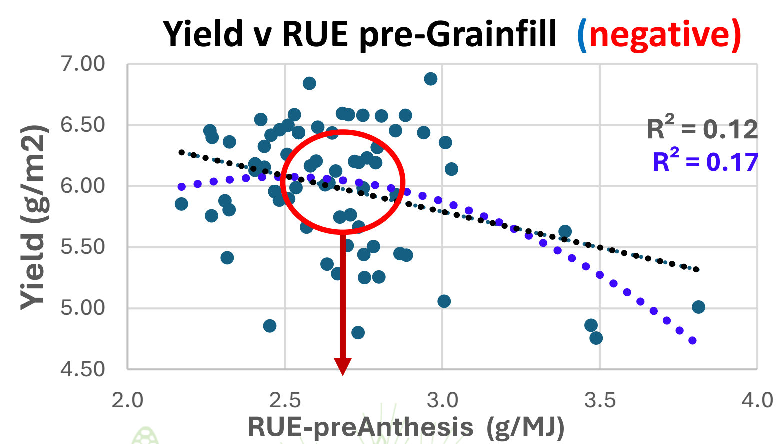
Yield shows linearity with radiation use efficiency over the total cycle



Nonetheless, RUE pre-Anthesis, while avg 30% higher than in grain-filling is not associated with yield.

To capture the benefits of RUE pre-Anthesis, requires discovery.





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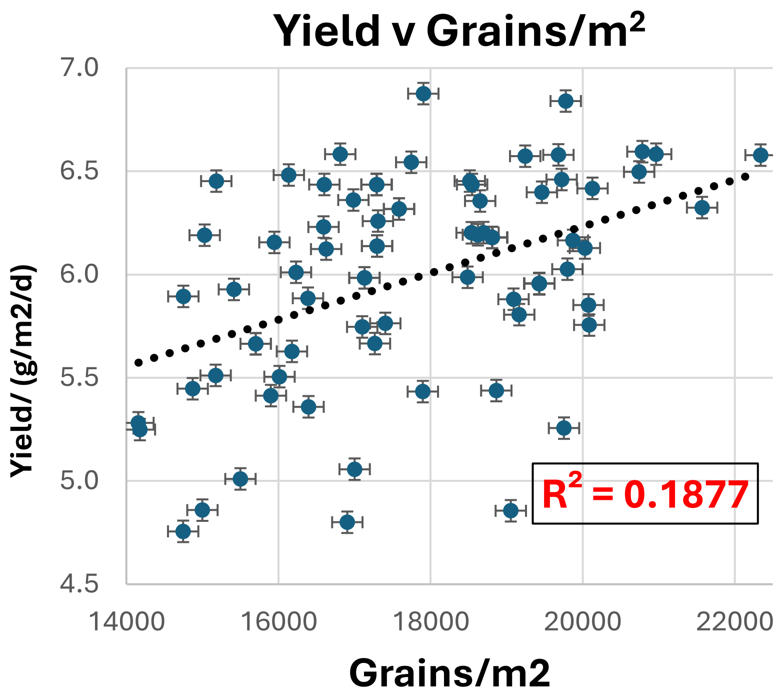
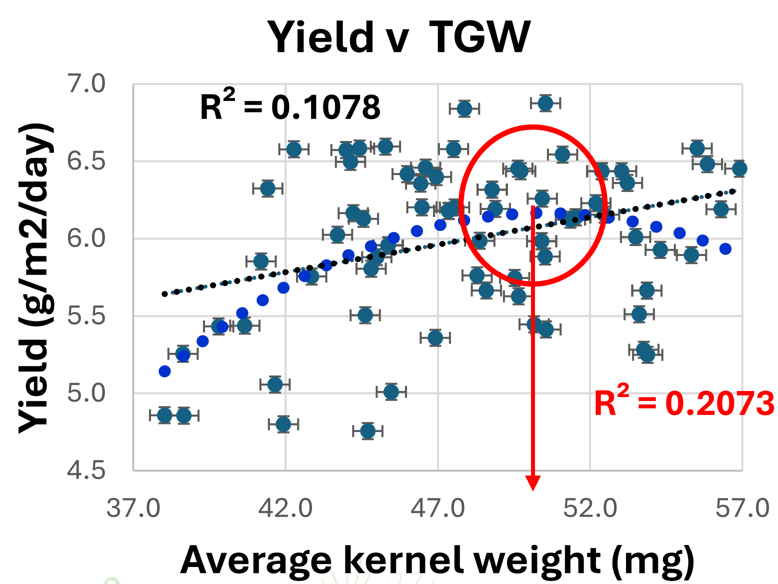
Physiological bases of yield potential: Sink Traits I

Yield shows a linear relationship with Grains/m2



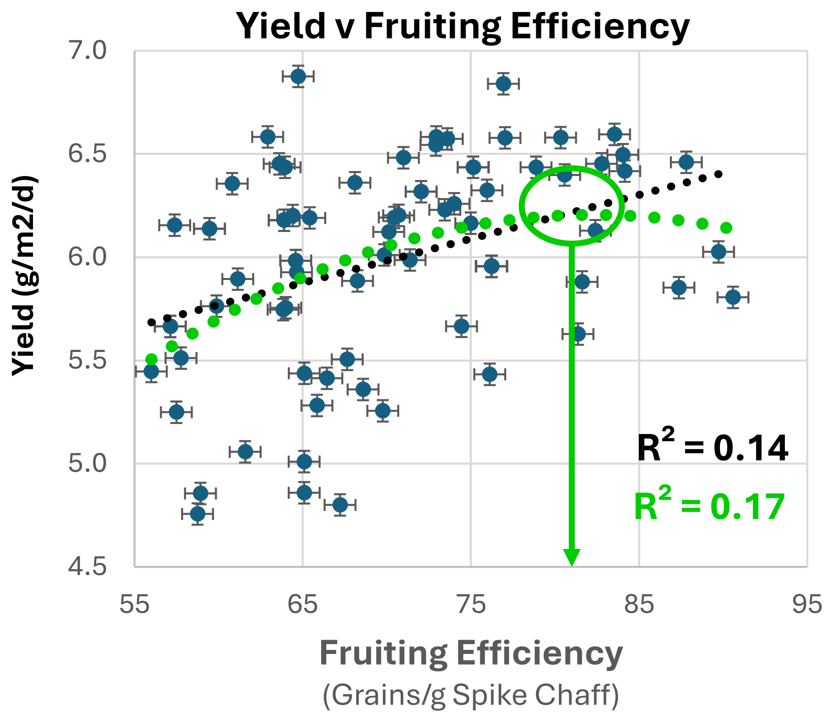
However, kernel weight (TGW) indicated non-linear association with yield

A polynomial model suggest a value of ~50mg to be optimal in this situation.



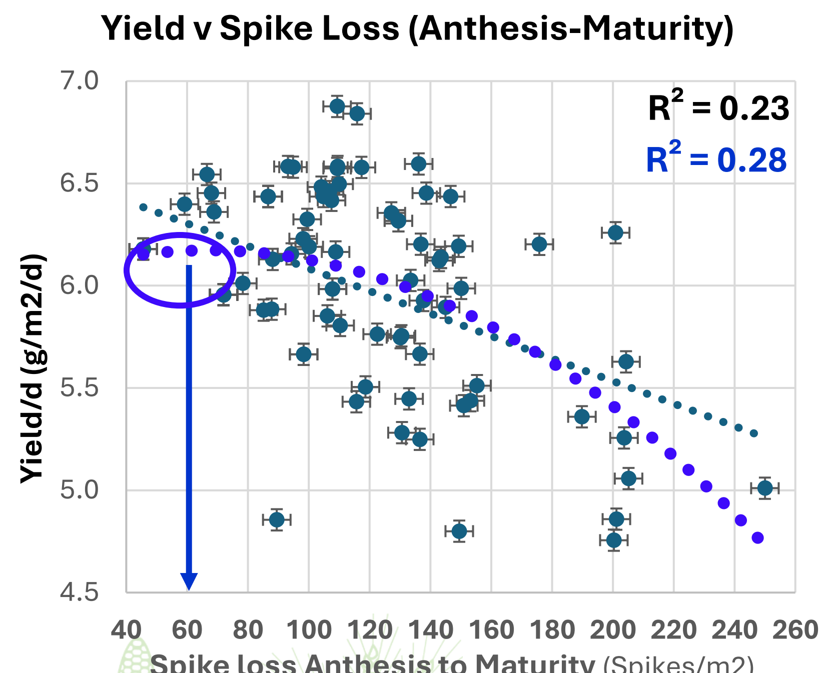
Physiological bases of yield potential: Sink Traits II

Fruiting Efficiency (FE) is positive with yield



Tiller & spike dynamics indicate opportunities to improve RUE & harvest index

They also point to alternative 'Trait-Paths' to yield:



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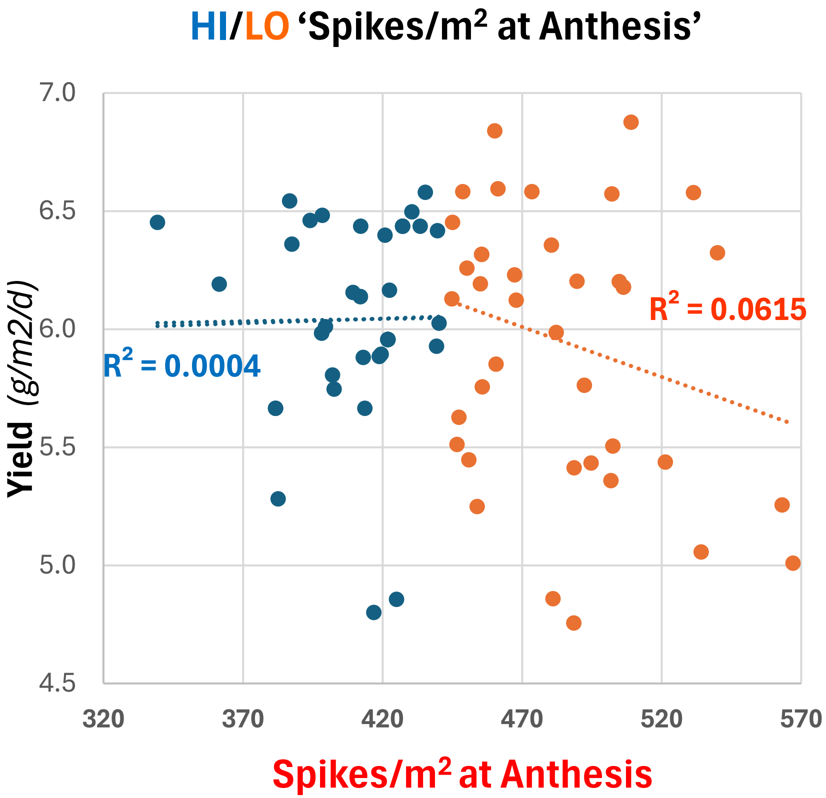
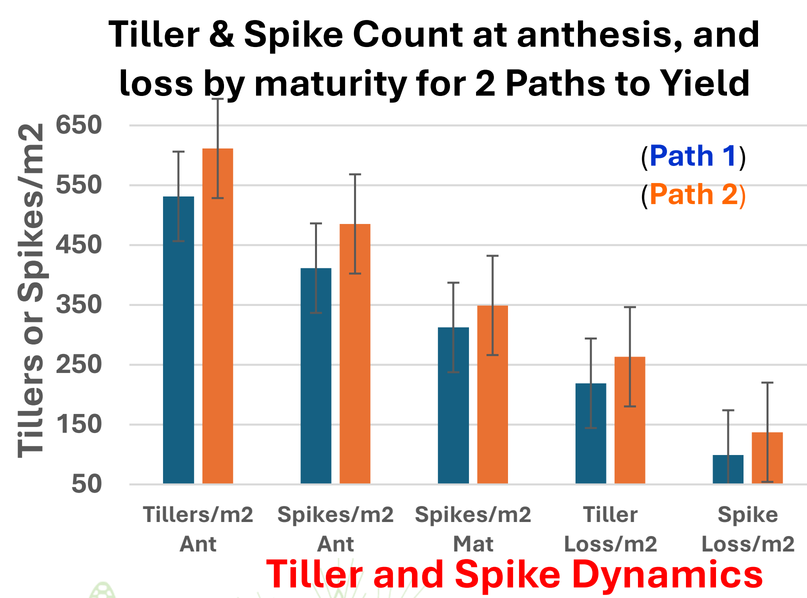
Paths to Yield

Two 'Trait-Paths' to yield are illustrated by large variation in Spikes/m² at anthesis



The 2 Paths to yield show a consistent main effect of tiller & spike dynamics (below).

The 2 paths are associated with other specific trait profiles.



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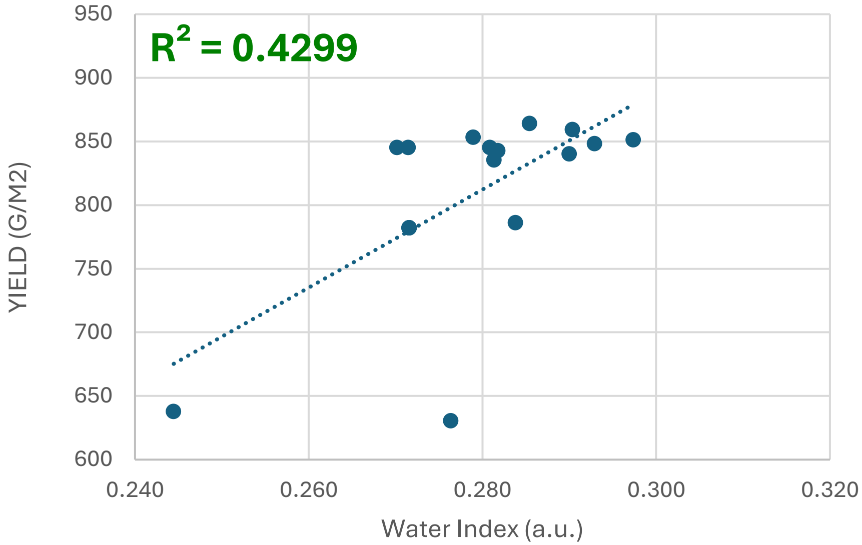
Paths to Yield

Trait Paths 1 & 2 differ in association of **Yield with Water Index (WI)**

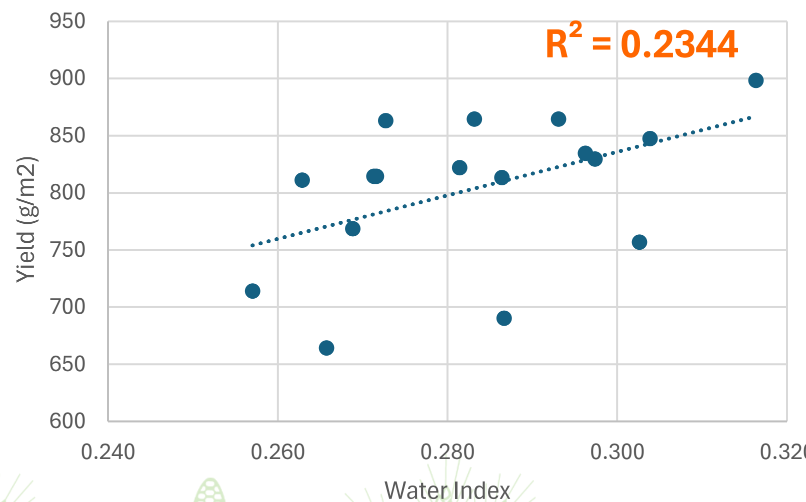
Yield v Water Index: Trait-Path 1



Lines in trait Path 1 express lower 'apparent RUE' pre-anthesis.

Water Index (WI) data support the hypothesis that Path-1 lines invest in root mass (not factored into RUE pre-Anthesis) making yield more tightly coupled to WI.

Yield v Water Index Trait-Path 2



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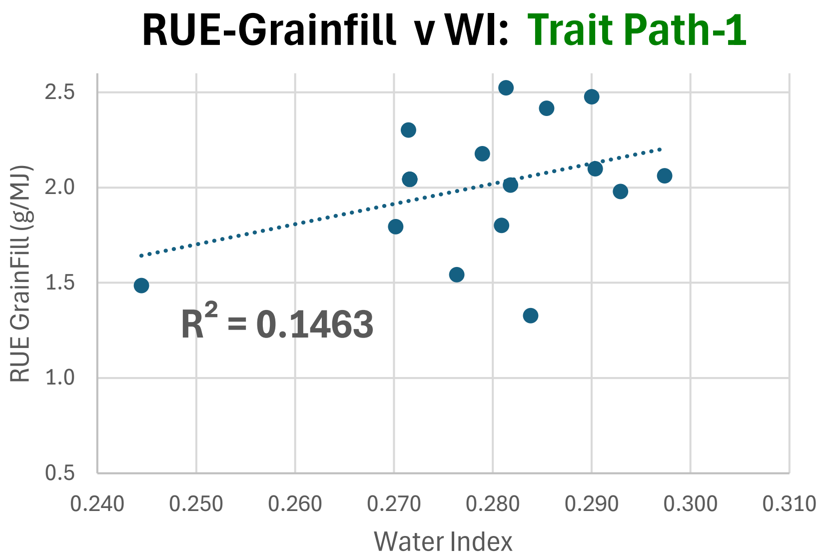
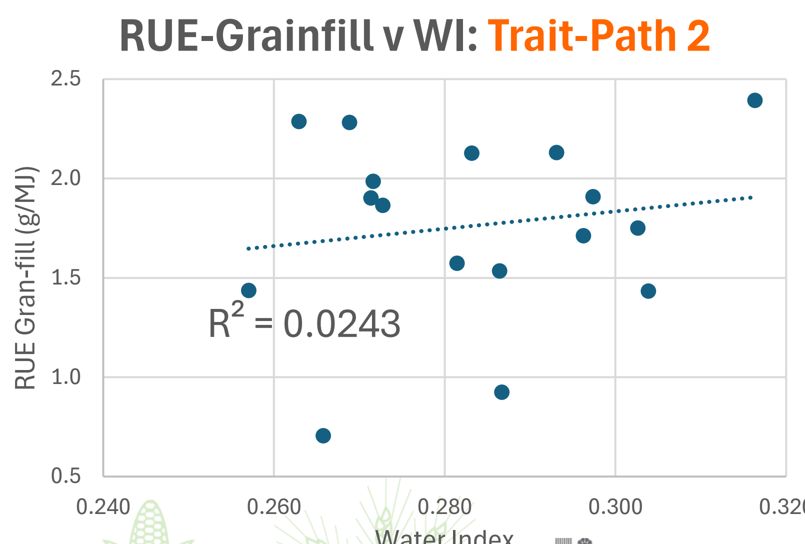
Paths to Yield

Trait Paths 1 & 2 differ in association of **RUE-Grainfill v Water Index**



Lines in Trait-Path 1 express coupling of RUE-Grainfill to WI, while Path 2 lines do not.

The data further support the hypothesis of increased investment in roots (pre-Anthesis) in Path-1



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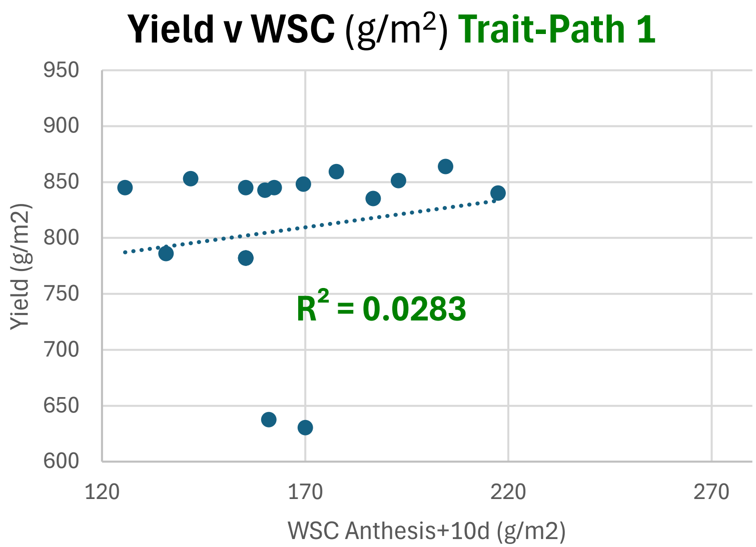
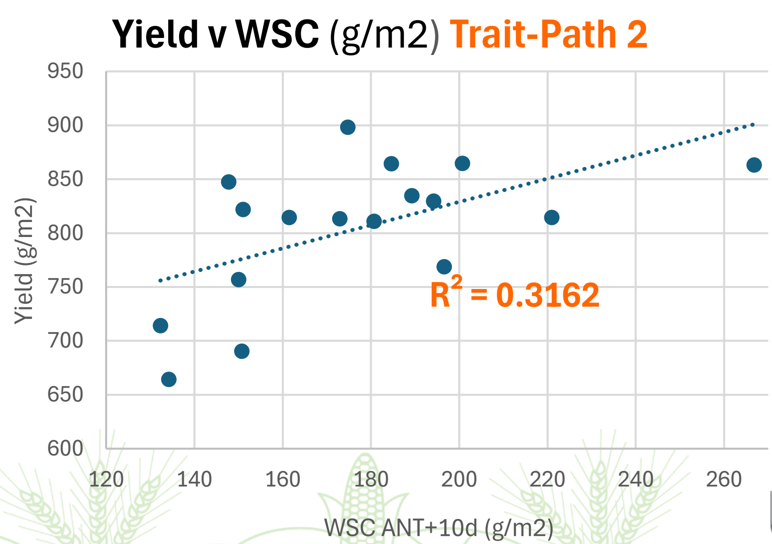
Paths to Yield

Trait-Paths 1v2 differ in association of **Water Soluble Carbohydrates (WSC) v Yield**



Lines in Trait-Path 2 show increased storage of WSCs at anthesis, associated with 32% of yield, while Path-1 lines show no association.

The data illustrate the strategy of a high tiller number to store WSCs and their subsequent loss as WSCs are remobilized to the grain.



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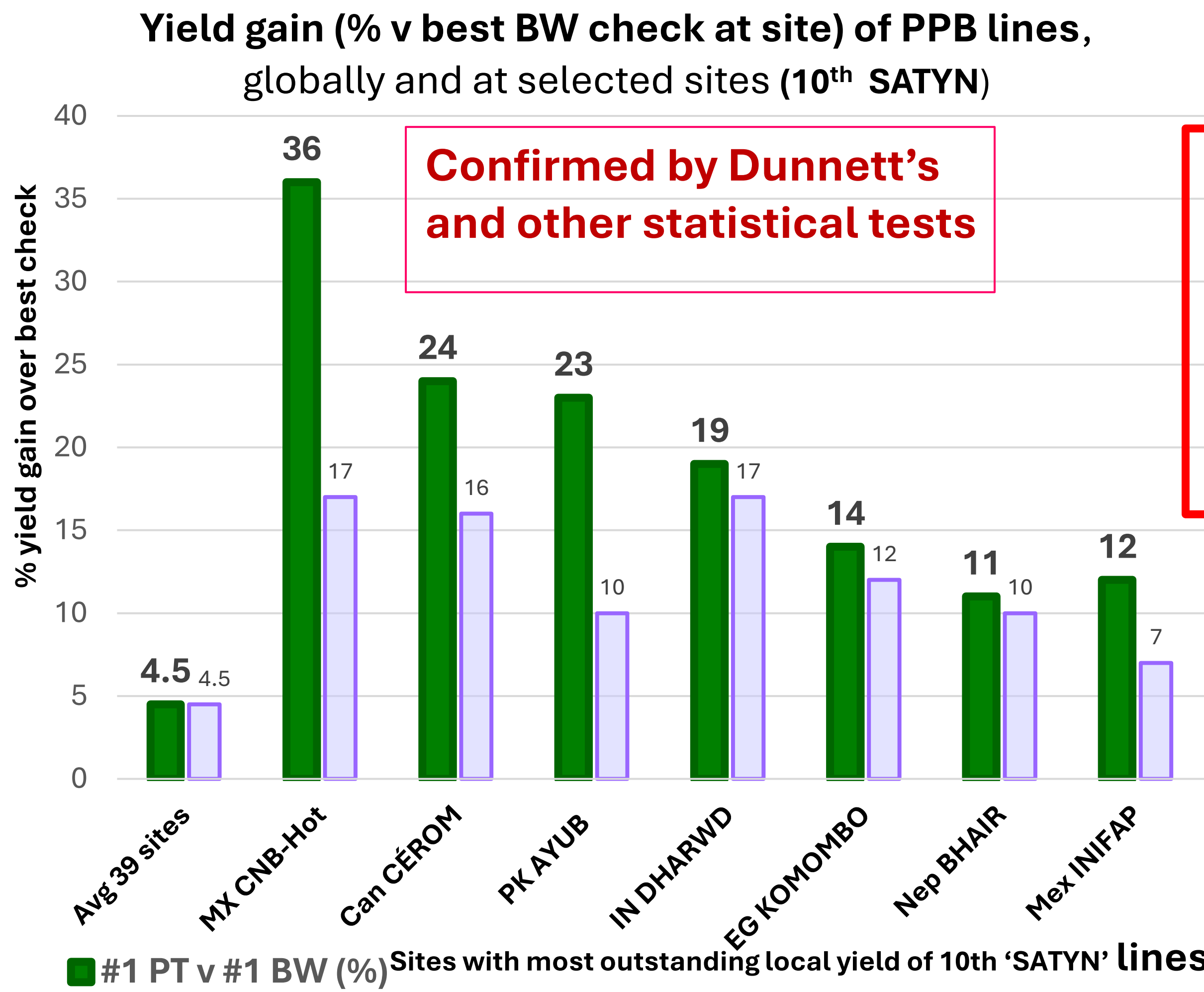
Outstanding Yields from Predictive Pre-Breeding lines

Mainly observed at local or regional level at ~40% of IWIN sites.



All WYCYT and SATYN nurseries have included lines with outstanding yields at between 3-7 sites, and typically mirrored in sister lines

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Reported released PT cultivars

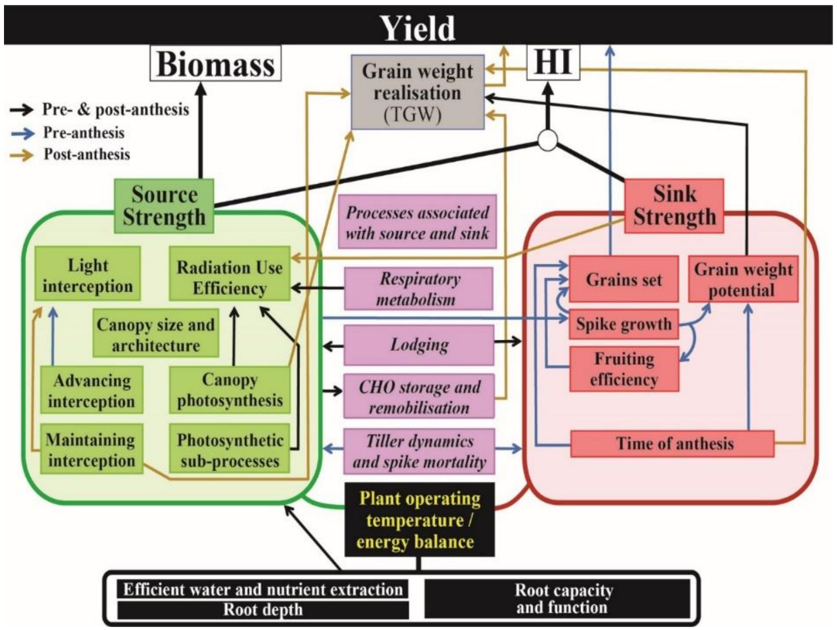
Year	Name	Country	Cross / pedigree
2013	Pakistan-13	Pakistan	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN
2016	Borlaug-16	Pakistan	SOKOLL/3/PASTOR//HXL7573/2*BAU
2017	Kohat 17	Pakistan	SOKOLL/WEEBIL
2018	CASCABEL (for SB)	S Asia (humid)	SOKOLL//W15.92/WBLL1 (SQWA or SUGA)
2020	Kunar 20	Afghanistan	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1
2022	Misr 7	Egypt	WBLL1//PUB94.15.1.12/WBLL1/3/MUCUY
2023	Misr 9	Egypt	BCN/WBLL1//PUB94.15.1.12/WBLL1/3/MUCUY
2024	WGE000006939945	Pakistan	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SERI/BAV92//WBLL1
2025		Iran	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1

CIMMYT

Breeding for complex traits is enabled by a confluence of new technologies:

- **Satellite** resolution enables a *de facto* 'global laboratory' of field trials.
- **Phenomics** is opening former "*black-boxes*" like estimation of root-depth profiles at breeding scale with HTP.
- **Gene-sequencing** ushers in the true age of molecular breeding for complex traits
- **AI** vastly accelerates analysis of multidimensional data

Conclusions



Reynolds, Slafer, Foulkes, Griffiths, Murchie, Carmo-Silva, Asseng, Chapman et al. 2022. A wiring diagram to integrate physiological traits of wheat yield potential. Nat Food 3, 318-22

Yield gains ~2% p.a. put IWYP-Hub on-track to deliver its original objective: 50% yield gain.

Source & sink traits from discovery have been improved and show association with yield gains.

Different 'Trait Paths' to high yield were shown

Results support the efficiency of the IWYP-Hub approach, using relatively low numbers of strategic crosses combining yield potential traits.

IWYP's WD is accepted as a valuable 'prior' in the AI & crop modelling communities

A proposal has been developed -with AI and modelling experts- to build a trait/allele-based crossing model to simulate crosses *in silico* at a scale unimaginable without machine leaning, to suggest 'best-bets' strategic crosses

IWYP International Wheat Yield Partnership

Research to Deliver Wheat for the Future

CIMMYT

Acknowledgements

Scientists, students, support staff

- **IWYP & HeDWIC collaborators globally**
- **CIMMYT Colleagues (other units)**
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  - Lucia Nevescanin Moreno
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CONACYT
SADER
GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION
IWIN The International Wheat Improvement Network

IWYP International Wheat Yield Partnership
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