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CIMMYT Wheat Breeding: Continuing genetic gains through the development of high yielding and nutritious varieties

Suchismita Mondal

Bread Wheat Improvement Team

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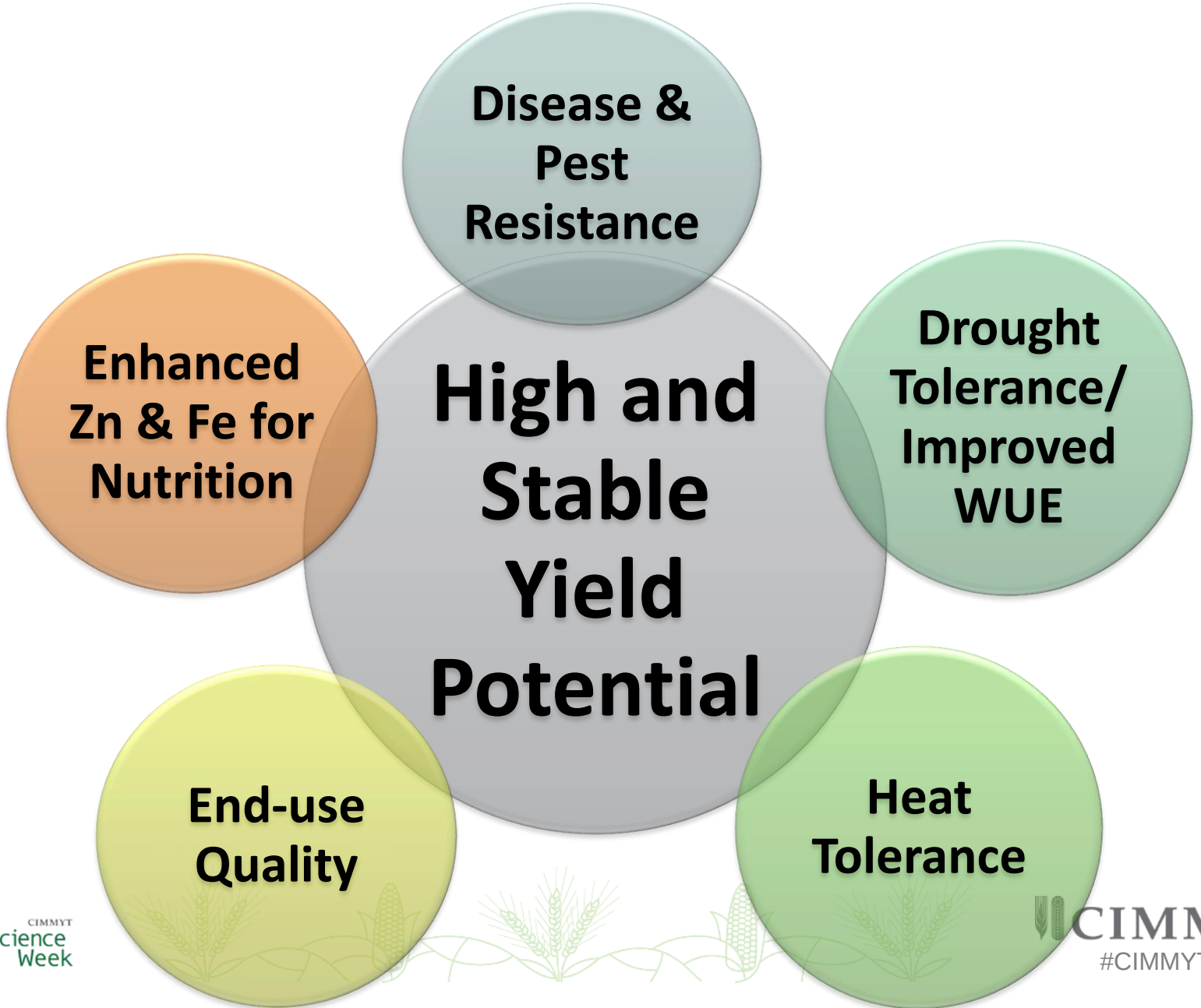
Wheat breeding priorities



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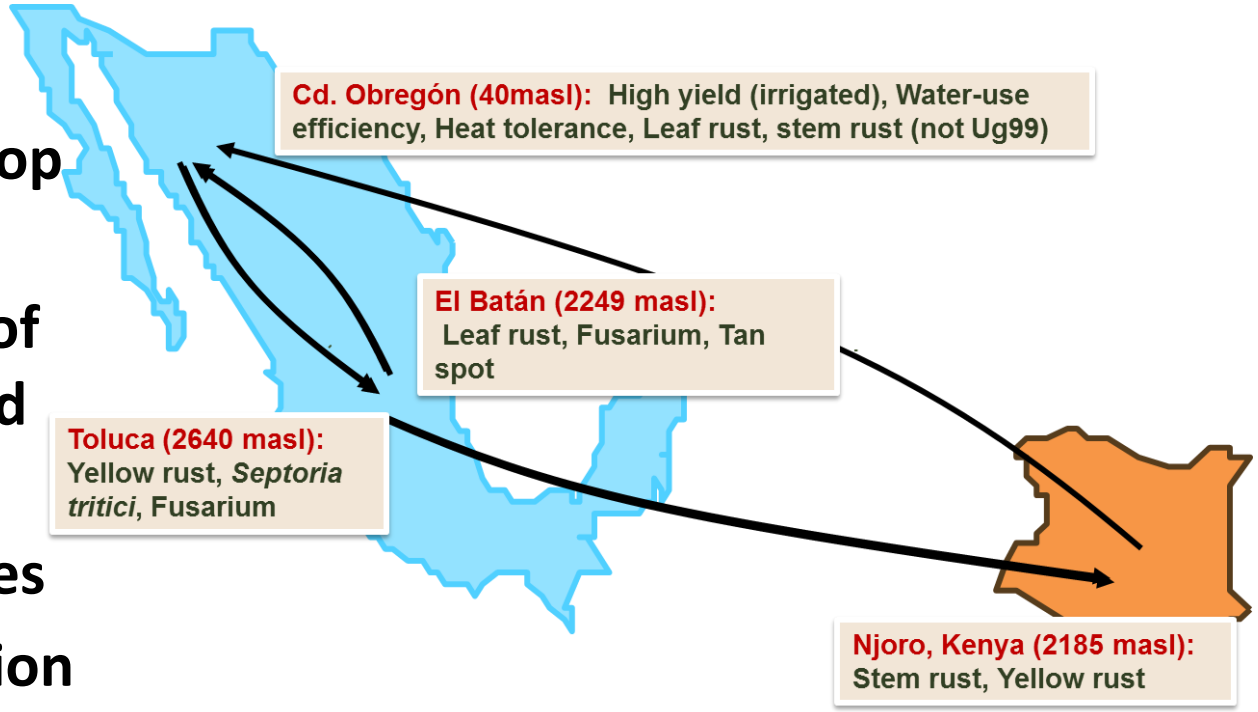
Up-scaled breeding and testing to deliver genetic gain (5 years breeding cycle)

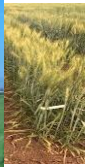
- Parental diversity
- ~1500 Simple, 600 top and 600 BC1
- Targeted utilization of new genes, traits and germplasm
- Large population sizes
- Selected-bulk selection scheme



Each selection in field adds to genetic gain for more than one trait

Grain yield evaluations advanced lines Cd. Obregon, Mexico

Bed sowing normal irrigation



1st year Yield Trial, 9044 lines, 323 trials, 2 reps

Late heat sowing in beds

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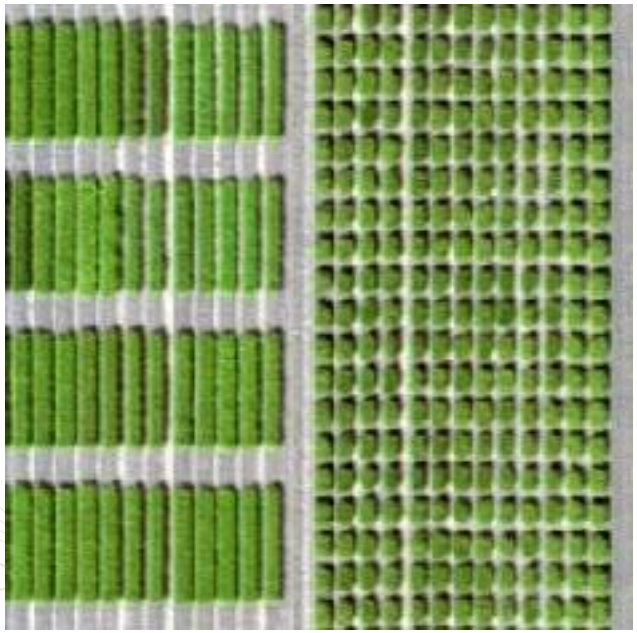
Possibilities with high throughput phenotyping in wheat breeding

- Aerial and UAV based HTP implemented
- CT and NDVI highly correlates with grain yield (r =0.5-0.7)
- However, CT has strong G x Y and G x E effect

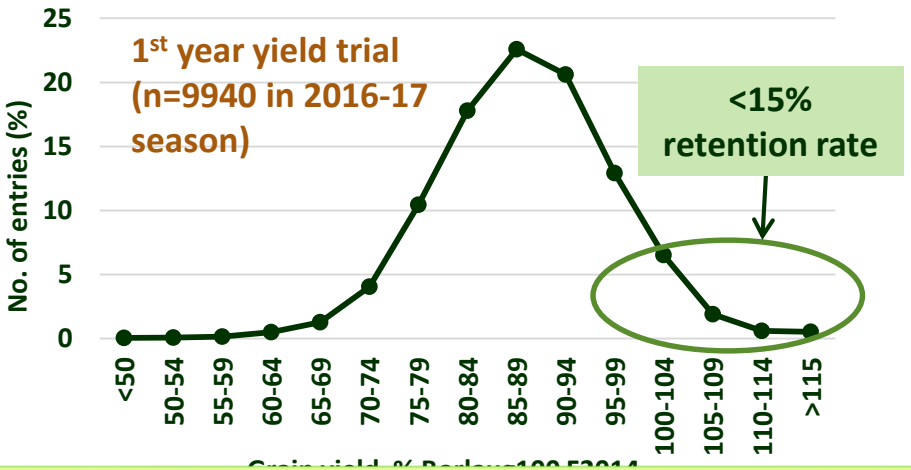
Looking forward:

- Complementing early generation selections with HTP
- Algorithms to estimate other agronomic traits, e.g. heading (days) and plant height
- Evaluating feasibility of assessing certain foliar disease



Potentials of genomic selection

- USAID Feed the Future Innovation Lab at KSU and DGGW focus on implementing GS and HTP at different stages of breeding program
- GBS, phenotypic, yield data for about 46,000 lines (2013-14 to 2017-18) utilized



Genomic predictions are very promising for some diseases & quality traits. Challenges: G x E and G x Y interactions need extensive research to improve predictions for grain yields

1st year yield trials

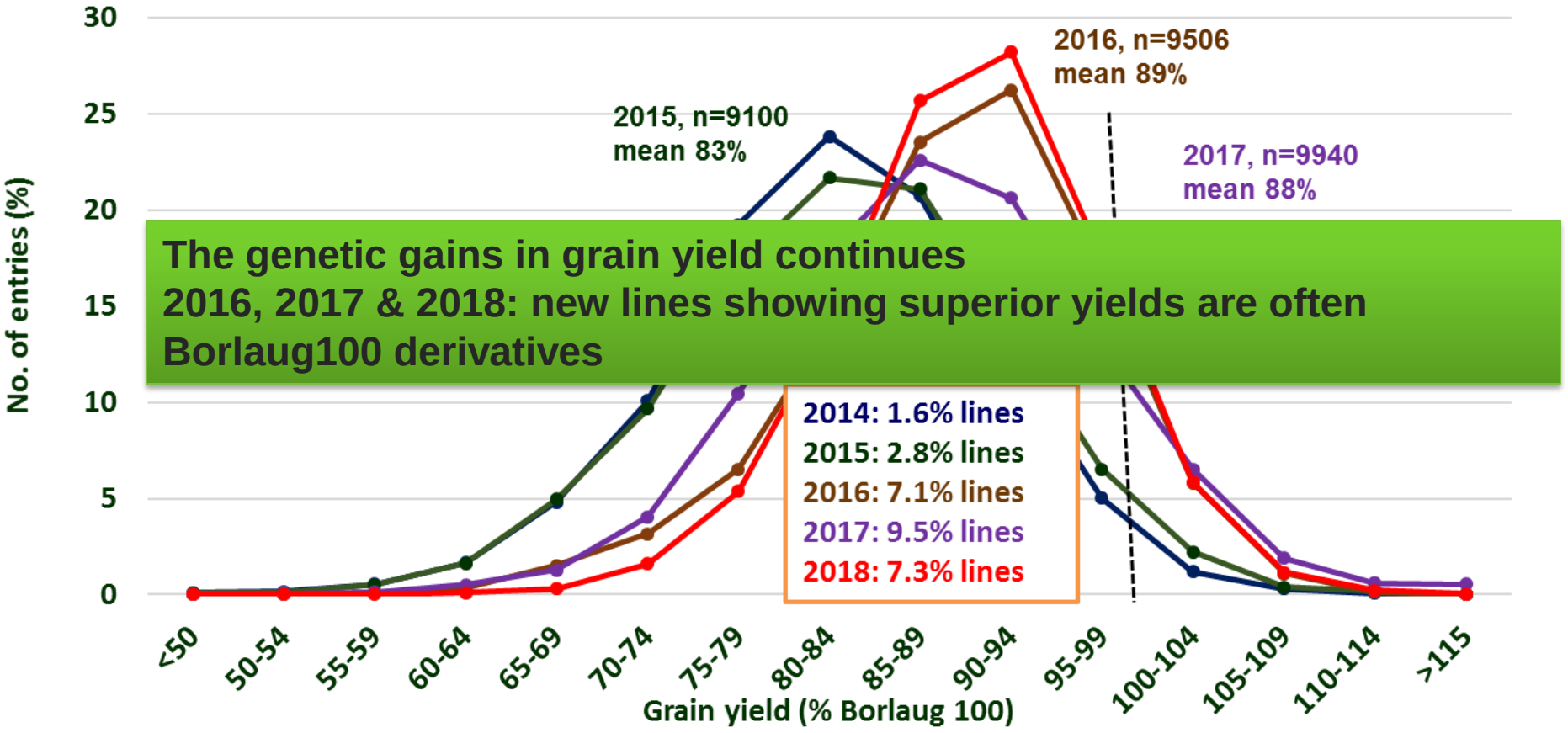
- Average within-nursery prediction accuracy Yield= 0.67, Stem rust=0.60
- Average across-nursery prediction accuracy Yield= 0.42, Stem rust=0.50

2nd year yield trials, prediction accuracy (r)

	Within	Across	Within	Across	Within	Across	Within	Across	Within	Across
Grain yield	Bed 5IR		Flat 5IR		Bed 2IR		Flat drip		Late heat	
	0.59	0.15	0.60	0.05	0.59	0.14	0.59	0.09	0.60	0.17
Disease	Stem rust		FHB		S. tritici blotch		Spot blotch			
	0.79	0.60	0.38	0.11	0.57	0.17	0.55	0.24		
Quality	Alveogram W		Flour protein		Flour yield		Loaf volume		Mixing time	
	0.72	0.52	0.73	0.5	0.61	0.43	0.72	0.5	0.76	0.48

Grain yield enhancement:

Distribution of 1st year yield trials at Cd. Obregon under optimum irrigation (2014, 2015, 2016, 2017 and 2018)



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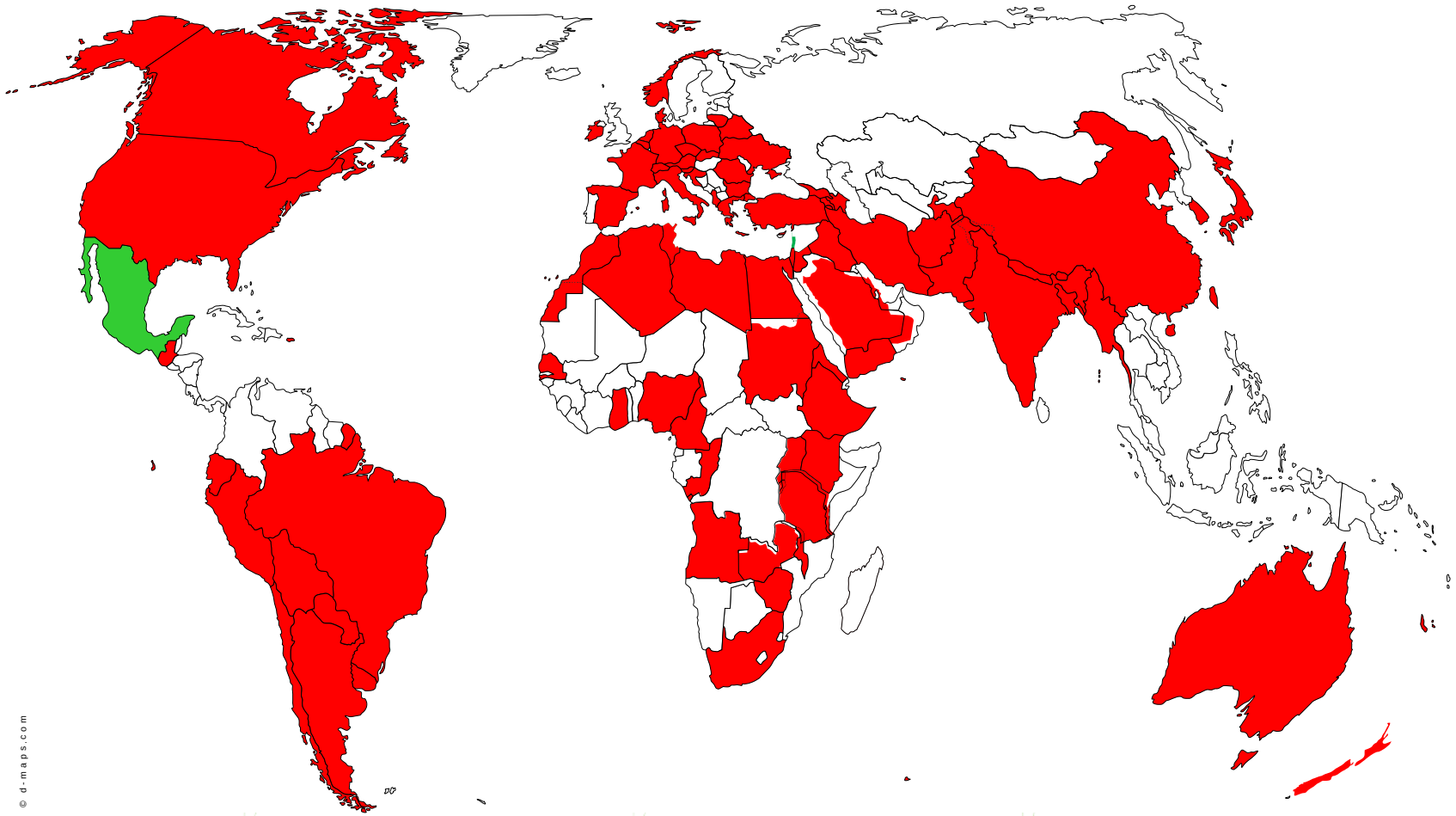
81 Countries receiving CIMMYT Spring Wheat nurseries 2016/17



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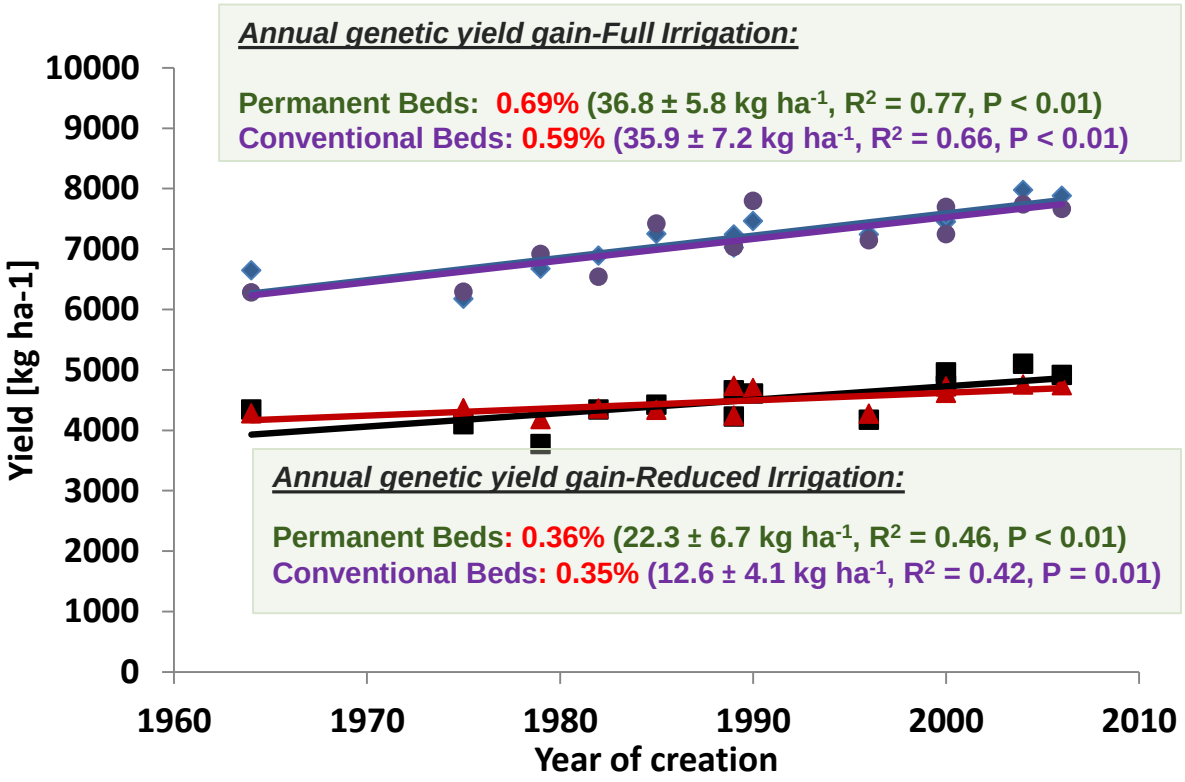
Genetic gains in grain yield for CIMMYT derived bread wheat varieties created between 1964-2009 (CENEB, Cd. Obregon, Sonora, Mexico)

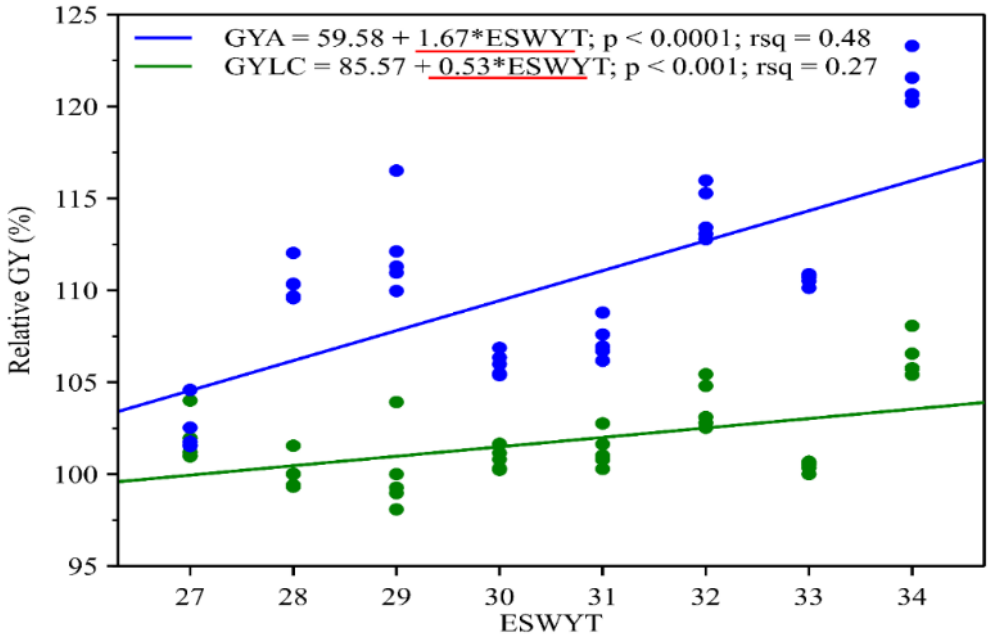
- Trials conducted (2009-10 to 2014-15)
- Conservation agriculture on permanent beds & conventional tillage on beds
- Full and reduced irrigation management
- Semidwarf varieties, adapted for full irrigation, oldest “Siete Cerros”

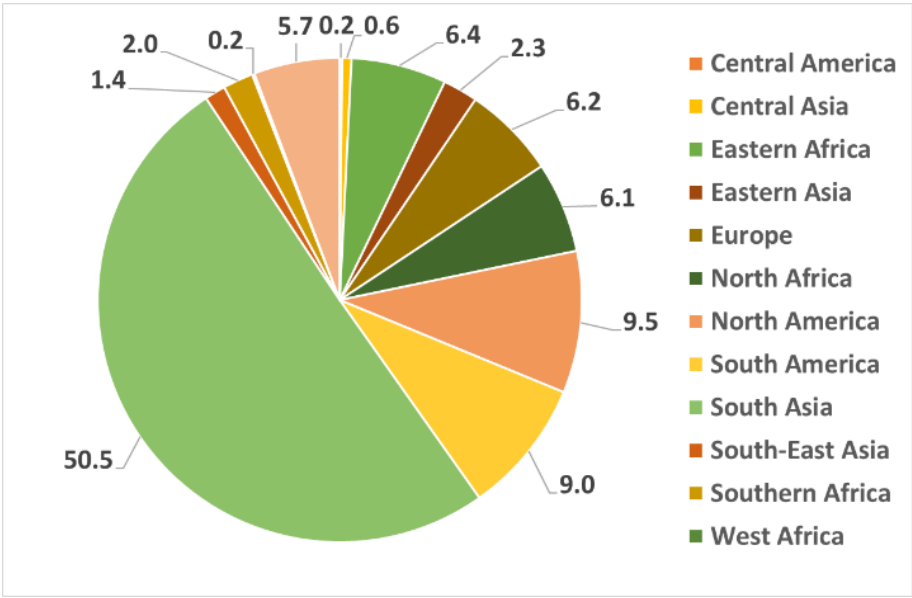


Source: Honsdorf et al. (2018) Field Crops Research 2016:42-52 (doi: 10.1016/j.fcr.2017.11.011)

Genetic gains in Elite Spring Wheat Yield Trial (ESWYT, 2006-07 to 2014-15)

Geographical distribution of 426 sites

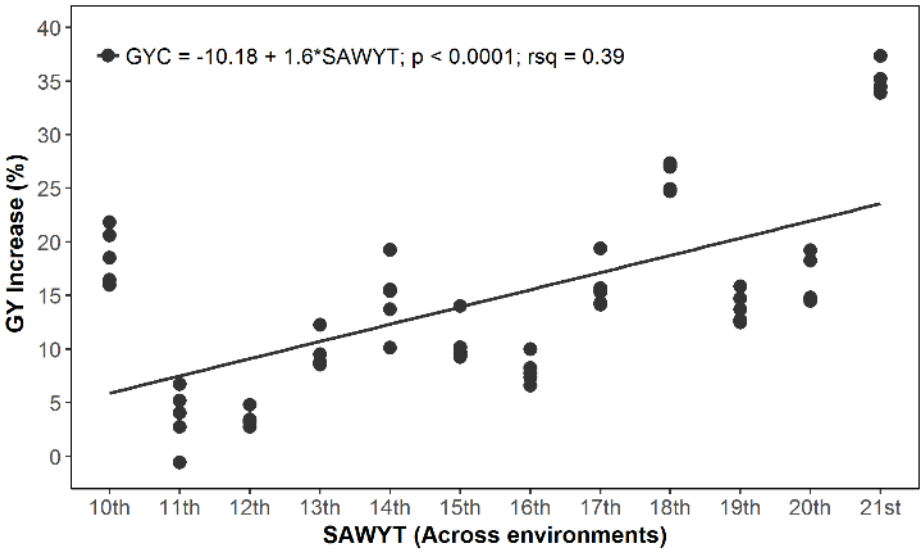


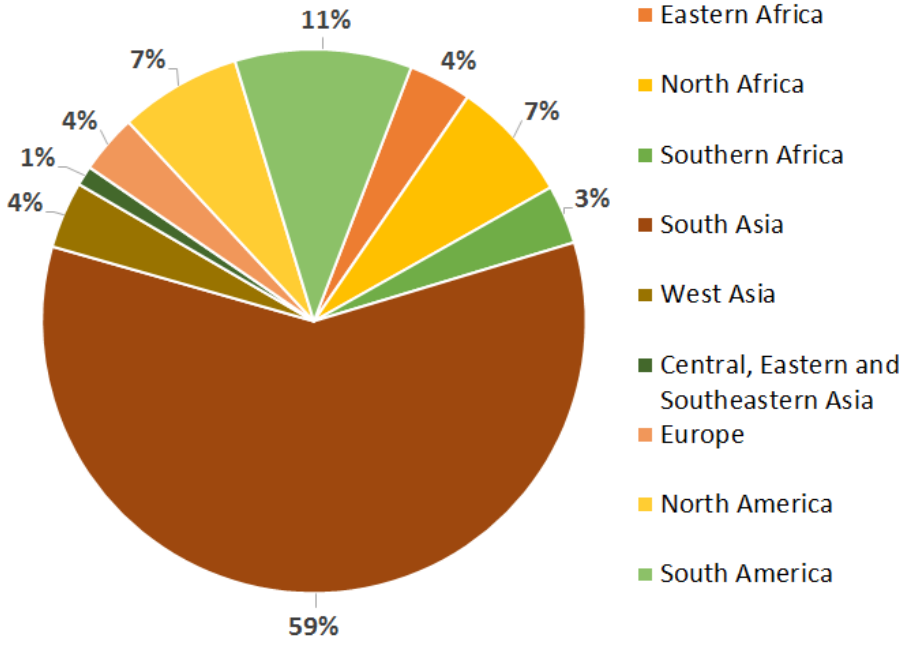


1.6 % increase/year in grain yield compared to long-term CIMMYT checks
0.5 % increase/year in grain yield compared to local check/new varieties

Genetic gains in Semi-Arid Wheat Yield Trial (SAWYT, 2003-04 to 2013-14)

Geographical distribution (216 sites)





1.6 % increase/year in grain yield compared to long term CIMMYT checks

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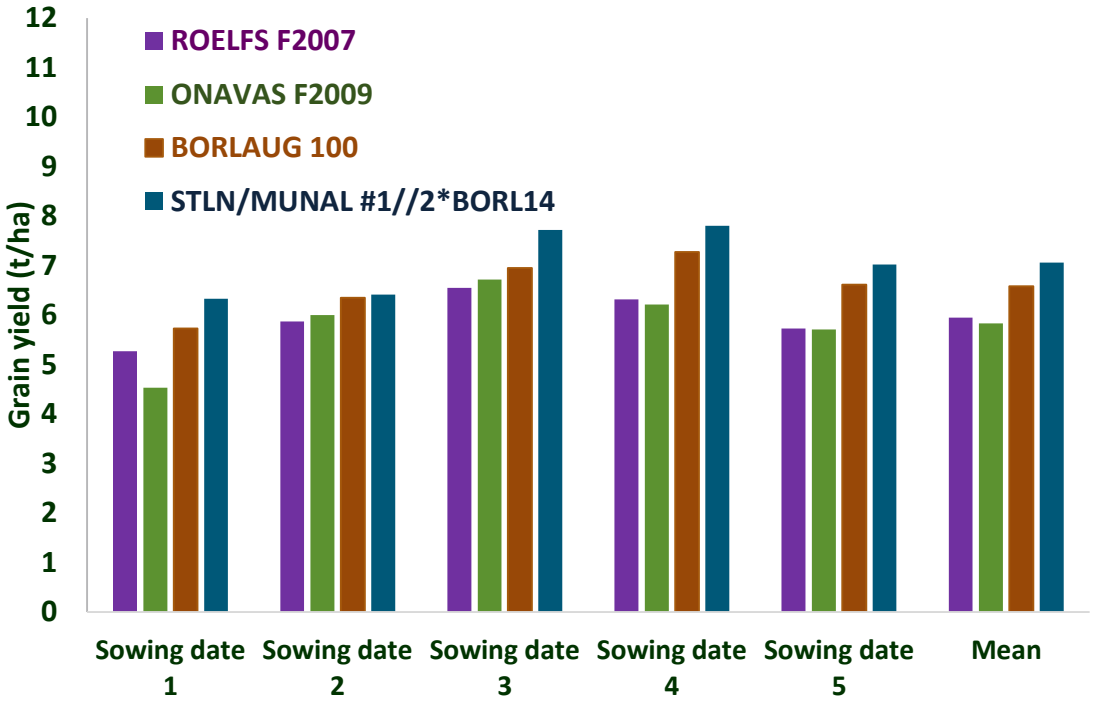
Variety registration trials in Northwestern Mexico under optimum irrigation

CENEB, INIFAP, Cd. Obregon, 2017-18



Variety/ breeding line	Year of release	Mean grain yield (t/ha)	Grain yield (% Roelfs)
ROELFS F2007	2007	5.947	100
ONAVAS F2009	2009	5.833	98
BORLAUG 100	2014	6.583	111
STLN/MUNAL#1// 2*BORL14	2019?	7.057**	119

**P<0.001

Performance similar to CIMMYT breeding trials (3 years) & yield potential trial (1 year)

~ 1.5% annual genetic gain during 2007-2019 compared to 0.7% during 1966-2007

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Data source: Miguel Camacho, CENEB, INIFAP, Cd. Obregon, Sonora, Mexico

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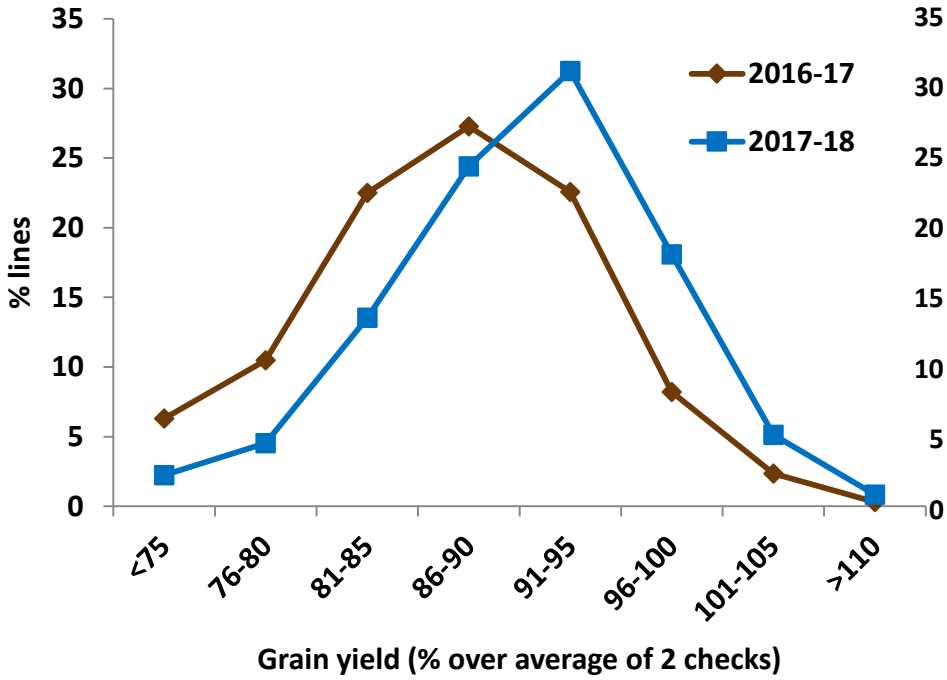
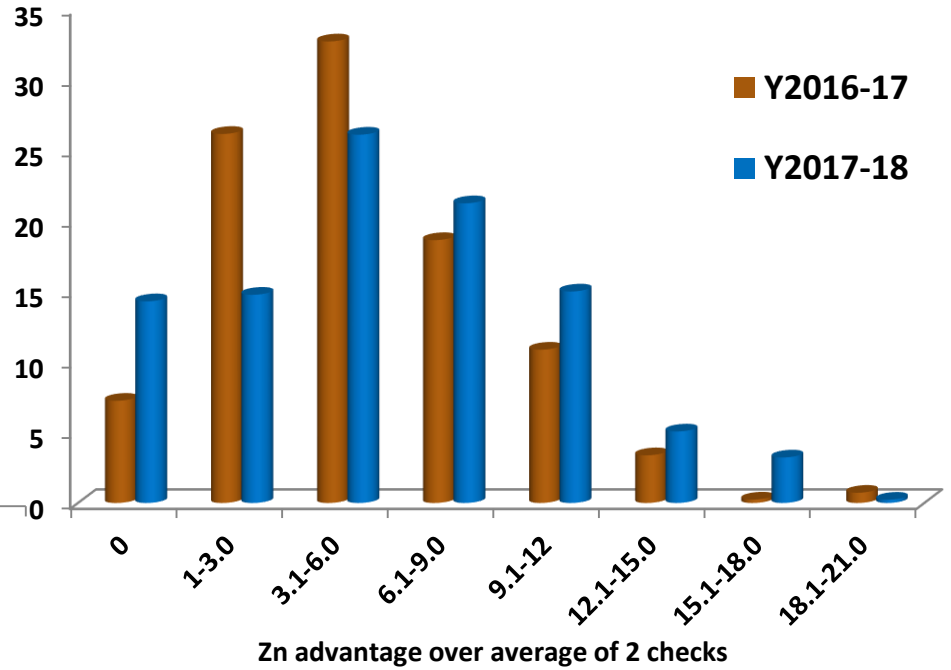
Keeping pace: Grain yield & Zinc enhancement (Y16-17 & Y17-18)





Average grain yield: 6.2 t/ha (Y16-17) vs 6.8 t/ha (Y17-18)

Frequency of lines with + 10 ppm Zn 15% (Y16-17) vs 23.5% (Y17-18)

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From genetic resources to High zinc wheat in farmers' fields of South Asia in less than 10 years

Progenitors:

T. durum based SHW

=

Zn-Shakti' PVS variety: Extra-early with +14 ppm Zn (40% increase) adopted by >40000 farmers in NEPZ

CROC1_/AE.SQUARROSA(210)// INQALAB 91*2/KUKUNA/3/ PBW343*2/KUKUNA

T. spelta

=

Zincol 2016: 1st high zinc wheat in Pakistan with +6 ppm Zn = 2000 tons of seed to be sown in 2016-17

OASIS/SKAUZ//4*BCN/3/2*PASTOR /4/**T.SPELTA PI348449**/5/BACEU #1/6/WBLL1*2/CHAPIO

T. Dicoccon based SHW

WB02/HPPW-01 = T.DICOCCONCI9309/AE.SQUARROSA (409)//MUTUS/3/2*MUTUS

Two sister lines (+6 ppm Zn) released for NWPZ of India

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Country	Name of variety
Afghanistan	Daima-17, Lalmi-17, Shamal-17
Argentina	BIOCERES 1008, MS INTA 815
Australia	Borlaug100, SEA Condamine
Bangladesh	BARI Gom 31, BARI Gom 33
Bhutan	Bumthang kaa Drukchu
Bolivia	Cupesi CIAT, INIAF Tropical
Egypt	Misr 3
Ethiopia	Amibara 2, Kingbird, Lemu, Wane
	Songbird, Kenya Weaverbird
Mexico	Bacorehuis F2015, Conatrigo F2015, Ñipal F2016, Ciro NL F2016
Nepal	Chyakhura, Danphe, Munal, Tilottama
Nigeria	Lacriwhit 9, Lacriwhit 10
Pakistan	Anaaj-17, Barani-17, Ihsan-16, Israr-shaheed-2017, Khaista-17, NIFA-Aman, Pakhtunkhwa-15, Pasina-2017, Pirsabak-15, Shahid-2017, Sindhu-16, Ujala-16, Wadaan-2017, Zincol 2016
Rwanda	Cyumba, Gihundo, Keza, Kibatsi, Majyambere, Mizero, Nyangufi, Nyaruka, Reberaho, Rengerabana
Spain	Tujena
Sudan	Ageeb, Akasha
Tajikistan	Haydari, Roghun
Turkey	Altinoz, Ekinoks, Kayra, Koc 2015, Nisrat

Outcome: **95 direct CIMMYT-derived varieties released by 20 partner countries (2015-2018)**

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Pre-breeding in GWP: Developing proof of concept for trait(s) that add value and broadening the genepool

Gemma Molero

Wheat Physiology

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Global Wheat Program Pre-breeding activities

Genetic resources

Multiple Teams in GWP & Partners

Use of Wild relatives

Quality traits

Heat and Drought

Yield Potential

Crossing with wild relatives:
Example Leymus for biological nitrification inhibition (BNI)

Improving quality traits
- Bread Wheat
- Durum Wheat

Expoiting diversity based on:
- genomics (SeeD)
- phenomics (Trigo)

IWYP and Trigo:
- MAS for HI using major genes
- HTP
- GS
- Balancing S:S

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Wide Crosses with Wild Relatives:
Biological nitrification inhibition from *Leymus racemosus*

Has the potential to radically increase NUE by preventing losses of available soil N

Wheat parents CS (-BNI)

Yield: 972 Kg/ha
Biomass: 3,606 Kg/ha

N short arm translocation (+BNI)

Yield: 831 Kg/ha
Biomass: 5,536 Kg/ha

50% higher biomass

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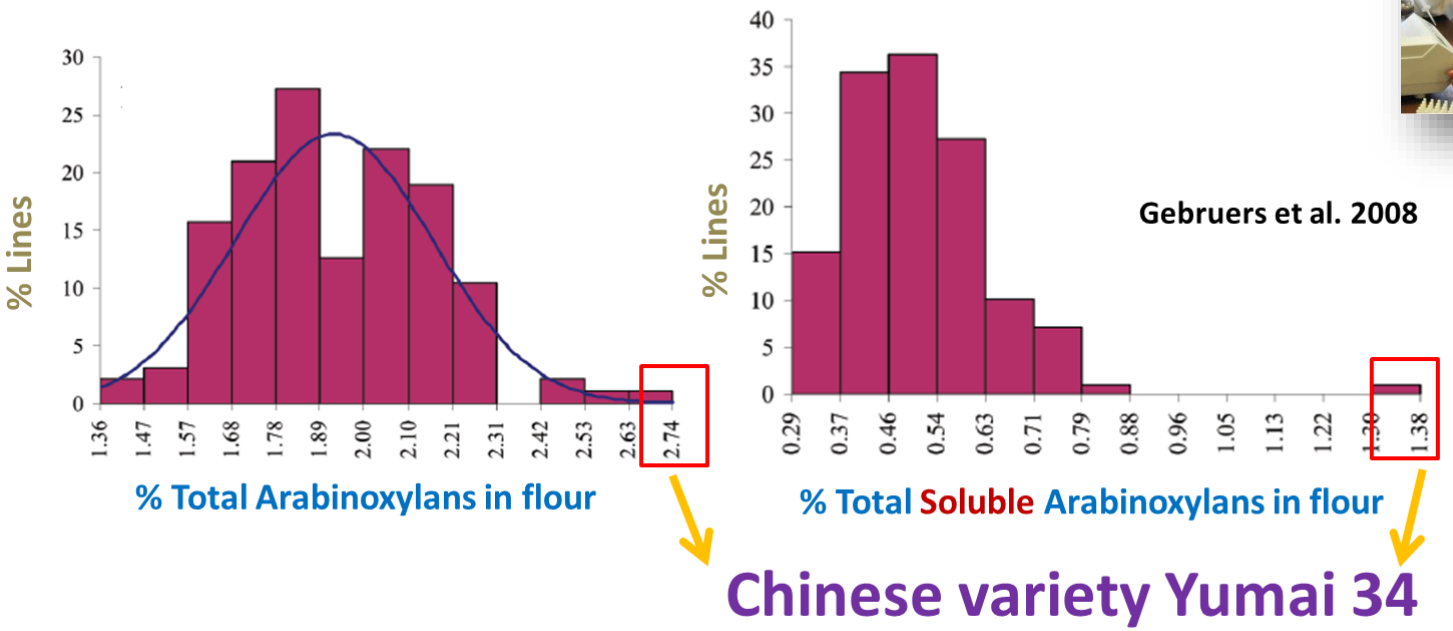
Pre-Breeding for Quality in Bread Wheat

- **Introgression of genes** associated to high content of endosperm soluble fiber (arabinoxylan)



- **Objective**: increase soluble fiber content in white refined flours
- **Progress**: starting crosses in this cycle

Pre-Breeding in Durum Wheat Improvement

Quality enhancing/diversifying genes transferred to elite durum backgrounds

Grain Protein Content
GPC-B1 (*T. dicocoides*)

Source: durum stock from UC Davis

Glutenin Sub-units
Glu-D1 (*bread wheat*)

Source: durum stocks from UC Riverside + CIMMYT

Starch Modification
SBEII (*Mutations*)

Source: durum stocks from UC Davis

Soft Texture
Pin A+B (*bread wheat*)

Source: durum stocks from USDA-WA

Durum Program
GWP Marker Lab
GWP Quality Lab

Marker-Assisted Selection or
Marker-Assisted Backcrossing
+
Phenotypic/Quality Selection

Several elite lines with
novel industrial quality attributes:

- Phenotypically confirmed
- Evaluation of industrial potential started
- Evaluation of agronomic value ongoing

Exploiting diversity based on genomics (SeeD)

Pre-breeding lines as trait donors for heat-drought

Grain yield under heat

GID	Exotic parent type	2015-16	2016-17
		------ kg ha^{-1} ------	
7641495	**Synthetic**	2261	2346
7644075	**Synthetic**	2325*	2418**
7645422	**Synthetic**	2338*	2488**
7645970	**Synthetic**	2214	2407*
7689940	**Landrace**	2415*	2362
BAJ #1	**Check**	2144	2216
VOROBEY	**Check**	1769	1985
SOKOLL	**Check**	NA	2023

Grain yield under drought

GID	Exotic parent type	2015-16	2016-17
		------- kg ha^{-1} -------	
7643084	**Synthetic**	3587	4510*
7642492	**Synthetic**	3480	4574*
7688508	**Landrace**	3360	4787*
7687479	**Synthetic**	3167	5198**
7642491	**Synthetic**	2766	5151**
VOROBEY	**Check**	3346	4613
BAJ #1	**Check**	3111	4858
SOKOLL	**Check**	NA	3968

Up to 11% yield increase under **heat** & **5%** under **drought**

Exploiting diversity based on phenomics (Trigo)

Lines derived from strategic crosses for Heat Tolerance

NW Mexico, Combined analysis 2015-2016 & 2016-2017

PT Line	Type	Yield (g m^{-2})	%vs. Best check
C80.1/3*QT4118//KAUZ/RAYON/3/2*TRCH/4/BERKUT/KRICHAUFF	Elite-Introgression	496	**27.6***
WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA (205)//…	Synthetic+Landrace derivative	494	**26.9***
BCN/WBLL1//PUB94.15.1.12/WBLL1	Landrace derivative	472	**21.2***
SOKOLL//PUB94.15.1.12/WBLL1	Synthetic+Landrace derivative	471	**20.9***
SOKOLL/WBLL1	Synthetic derivative	462	**18.8***
PUB94.15.1.12/FRTL/5/CROC_1/AE.SQUARROSA (205)//…	Synthetic+Landrace derivative	459	**18.0***
SOKOLL//PUB94.15.1.12/WBLL1	Synthetic+Landrace derivative	455	**17.0***
MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1	Synthetic+Landrace derivative	451	**16.0***
VOROBEY	**Check**	**389**	
SOKOLL	**Check**	**370**	
BORLAUG100 F2014	**Check**	**357**	

Up to 28% yield increase under **heat**

New Pre-breeding lines with improved adaptation to heat stress (introgression, synthetics and landrace background)

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IWYP and Trigo pre-breeding pipeline

Landraces

Elite lines

FIGs (ICARDA)

Gene bank

Synthetics

Crossing

Generation advancement

International nurseries

- Yield based selection
- Genomic selection
- Physiological traits (NDVI and CT)

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

WYCYTs and SATYNs

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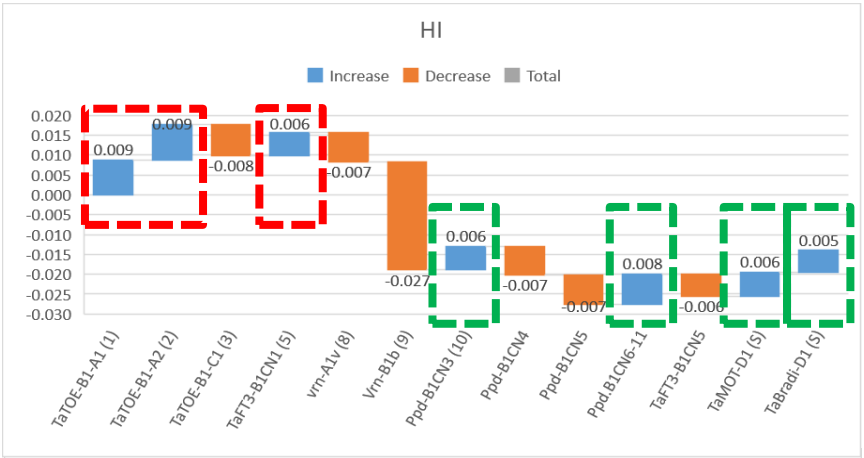
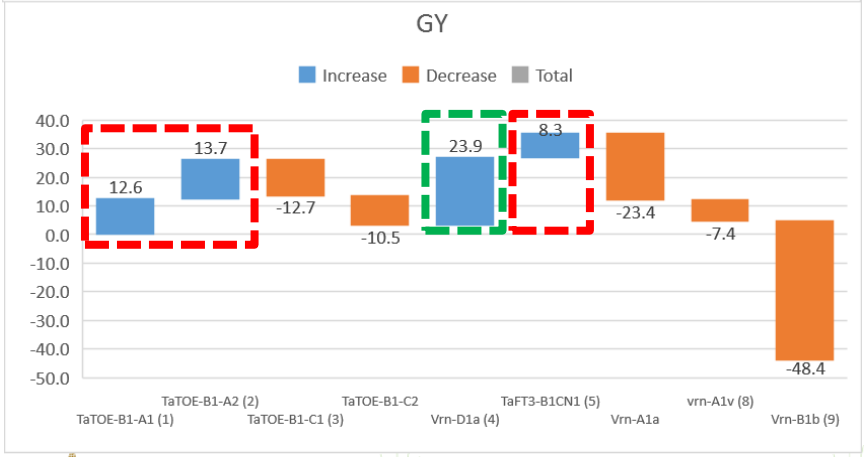
Major genes associated with HI & Grain Yield





Gene positively effecting HI

TARGET of EAT (TaToe1-B1)

FLOWERING LOCUS T3 (TaFT3-B1- 1 copy)

Eps-D1

Ppd-B1 (6 to 11 copies)

Gene positively effecting GY

TARGET of EAT (TaToe1-B1)

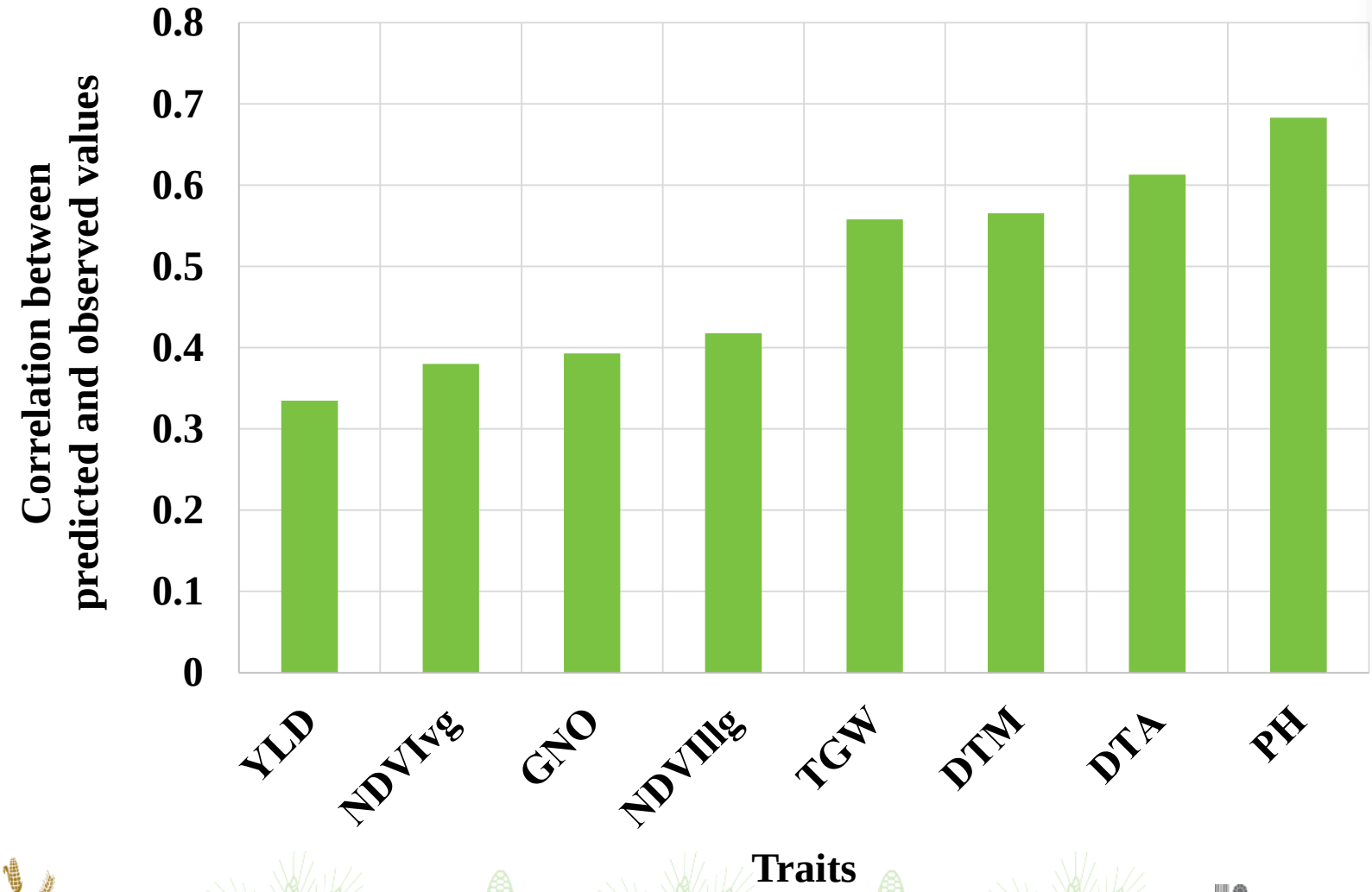
FLOWERING LOCUS T3 (TaFT3-B1- 1 copy)

Vrn-D1a

Complex traits: Aerial remote sensing for HTP

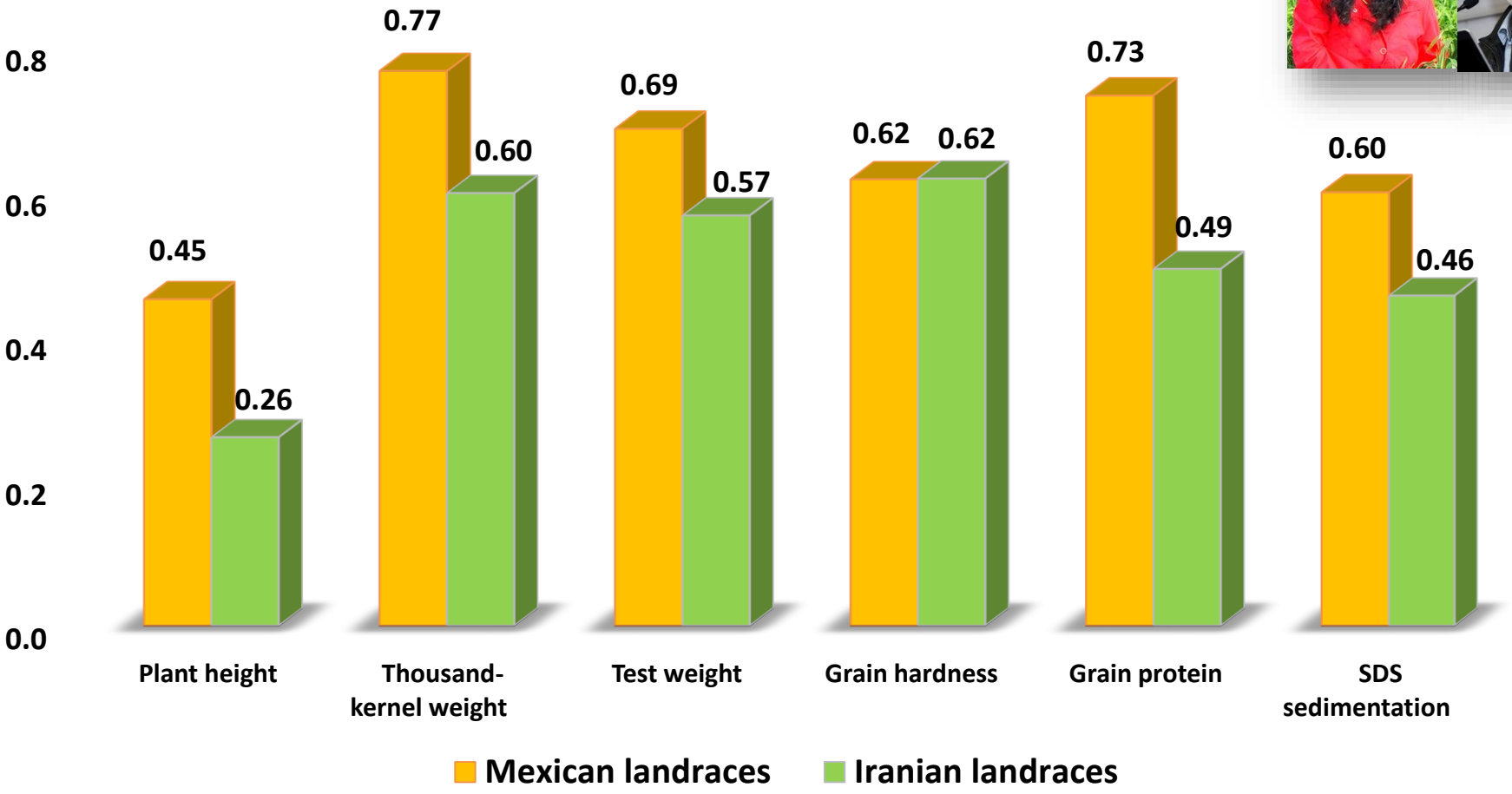
Tattaris M, Reynolds MP, Chapman SC, 2016.
A direct comparison of remote sensing approaches for high-throughput phenotyping in plant breeding.
Front. Plant Sci. 7: 1131.

Genomic and pedigree based prediction models durum wheat



Sukumaran et al., 2018. The Plant Genome

Genomic selection also a valuable tool for pre-breeding with genetic resources



Crossa J. et al (2016) Genomic Prediction of Gene Bank Wheat Landraces. G3 6:1819–1834.

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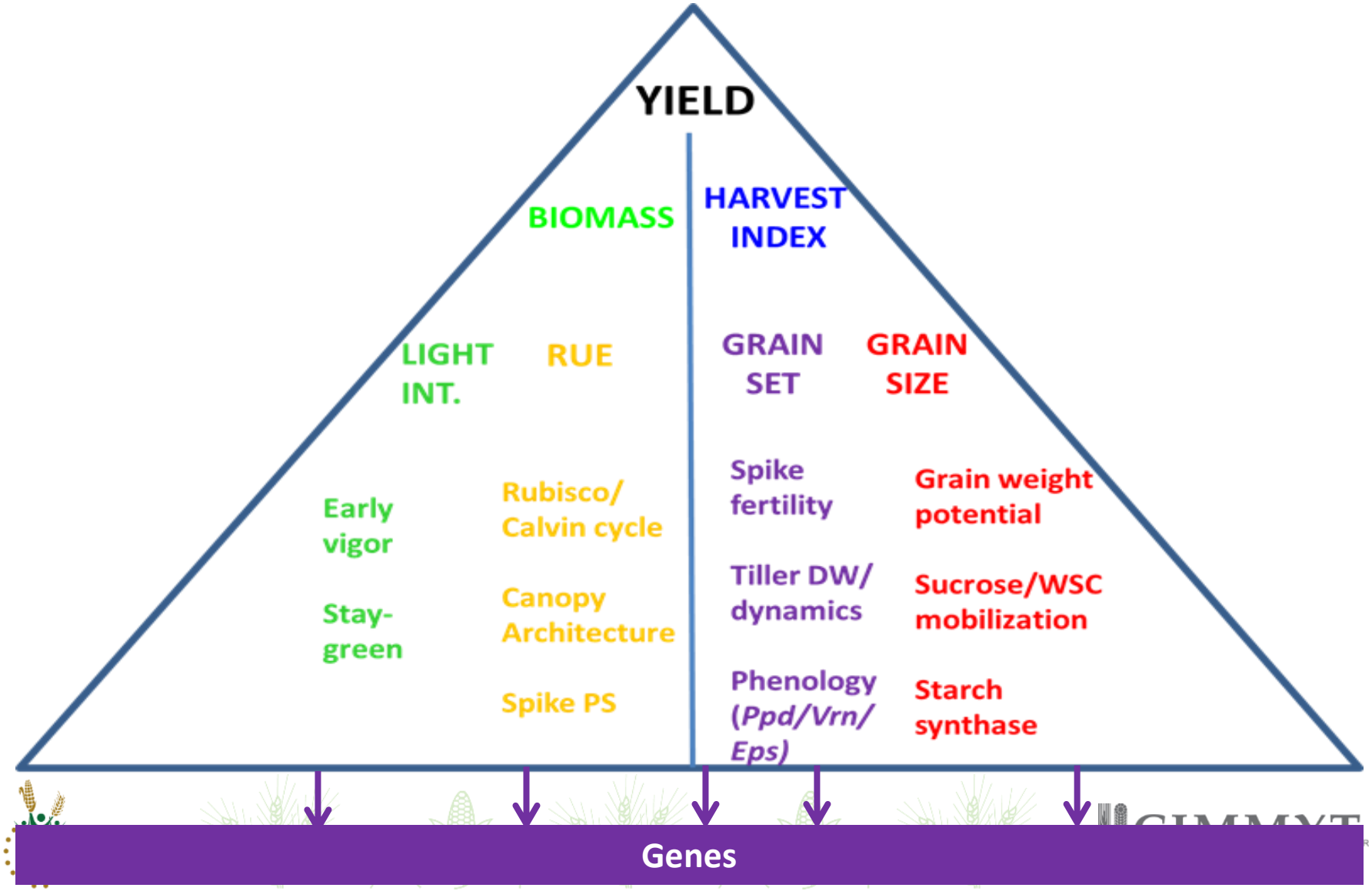
Basis for ‘source’ x ‘sink’ strategic crossing

Trait hierarchy (in relation to their degree of integration) depicting the main drivers of yield (biomass and harvest index), and sub-components



International yield trials data
4th WYCYT (2016/17)

	Clusters based on G x E for yield					
Cluster of sites	C1	C2	C3	C4	C5	**Combined**
Best PT line (t/ha)	4.96^{ns}	5.45*	7.41*	5.89^{ns}	8.05*	**5.44***
Borlaug (t/ha)	5.29	4.46	5.45	5.65	7.28	**5.09**
% over Borlaug	-6.2%	22.3%	36.0%	4.2%	10.6%	**6.9%***

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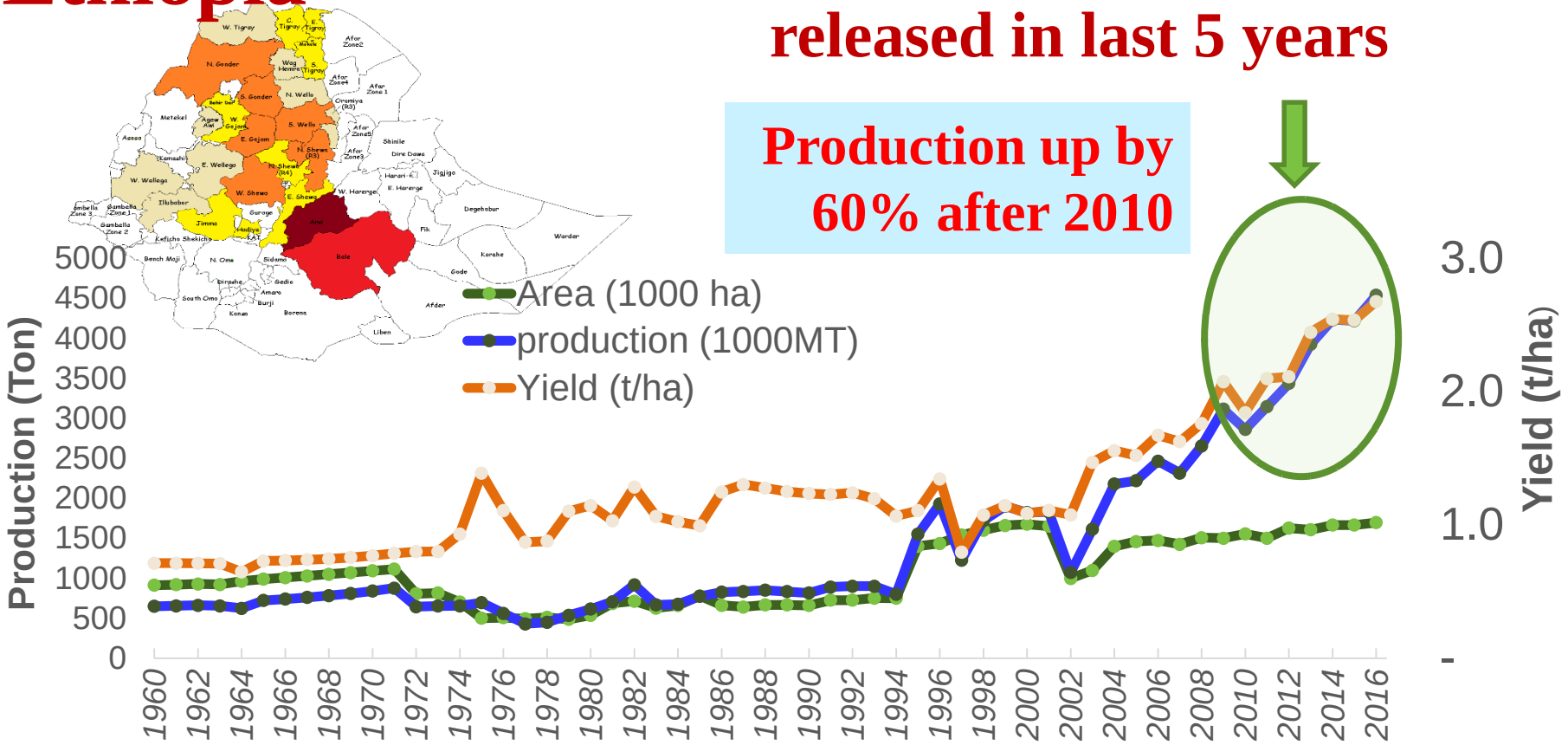
Global Wheat Program
“Regional Offices”

Ethiopia

14 CIMMYT wheat varieties released in last 5 years

Production up by 60% after 2010



- **Excellent emergency support and scaling up in 2017**
- **1082 tons of maize and wheat distributed to 72,371 households (434,226 individuals) in 55 districts**

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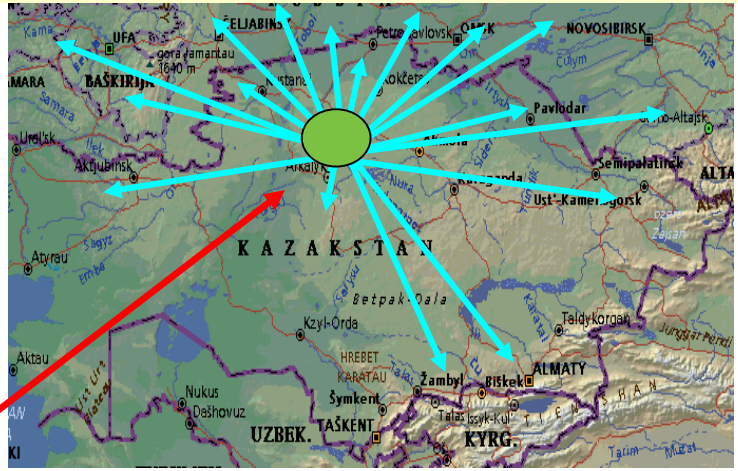
Kazakhstan: Kazakhstan-Siberia Network on Wheat Improvement (KASIB) & Shuttle Breeding "Mexico-KASIB" Program:

- 21 Breeding programs of Kazakhstan and Russia united in year 2000
- By 2018:
  - >25,000 advanced lines developed and evaluated
  - >70 varieties released



KASIB is one of the best examples of regional and Int. cooperation

In 2016-17:

- ✓ ***Russia: 1st in the world for wheat grain export;***
- ✓ ***Kazakhstan: 1st in the world for wheat flour export***

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CIMMYT wheat in China

- 20,000 accessions stored in Chinese gene bank
- Over 300 cultivars developed from CIMMYT wheat, covering 10% area, worth US $ 3.4 billion
- Received eight awards from State Council since 1998

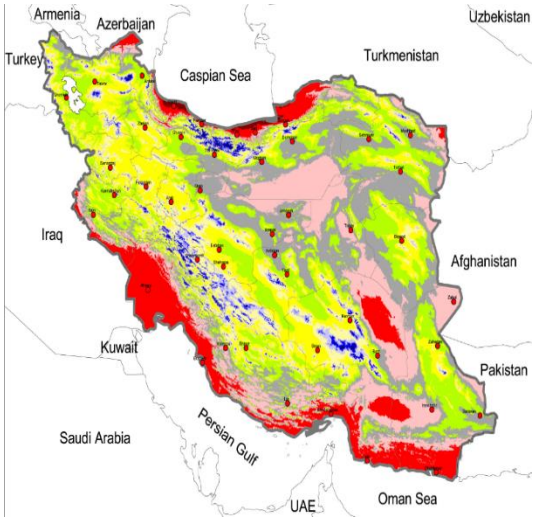
CAAS-CIMMYT wheat team

Ten scientists, 10 support staff, and 20 postgraduates

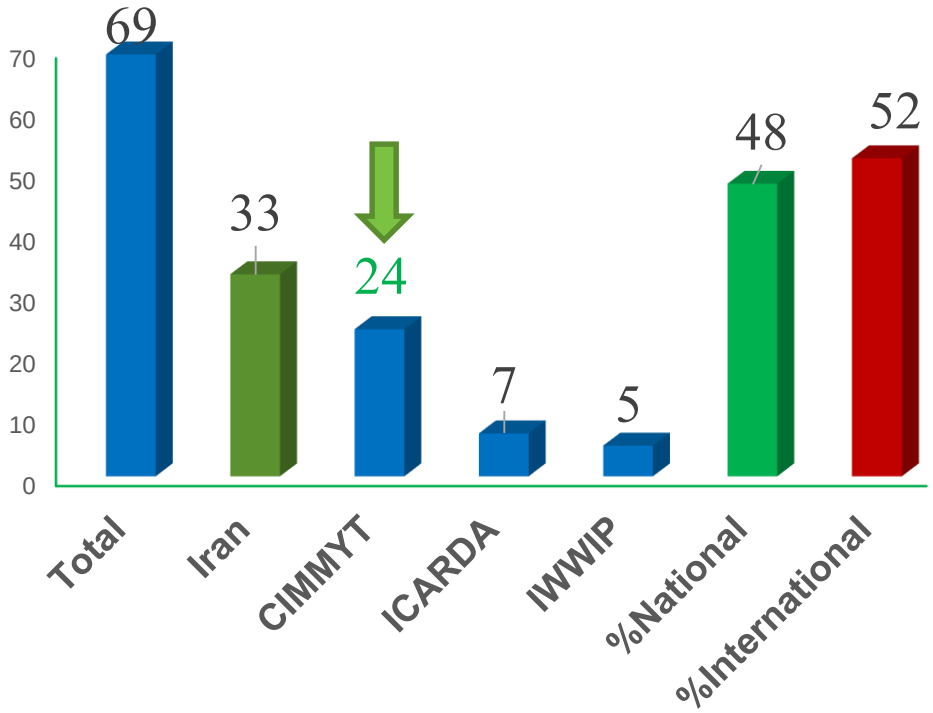
Quality and molecular labs, three breeding stations

IRAN

5.4 million ha wheat



24 of 69 wheat/ triticale varieties released during 2001-18 were from CIMMYT



Iran-CIMMYT Joint Project (20 m USD)

"Increasing the Productivity of Wheat and Wheat-based Systems in Iran"

Turkey: Int. Winter Wheat Improvement Program

Objectives:

- Develop winter wheat germplasm for Central and West Asia
- Winter wheat germplasm exchange
- Maintain wheat landraces
- Research on priority topics

Country	Varieties released
Afghanistan	5
Armenia	4
Azerbaijan	4
Georgia	6
Iran	7
Kazakhstan	2
Kyrgyzstan	9
Tajikistan	6
Turkey	32
Turkmenistan	3
Uzbekistan	2
Total	**80**

7 varieties in 2017:

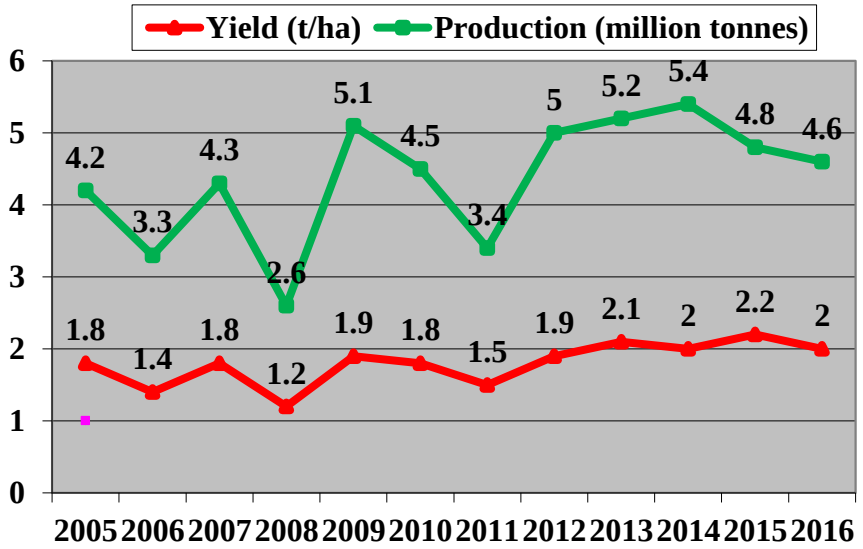
- **Turkey (2)**
- **Iran (1)**
- **Kyrgyzstan (2)**
- **Turkmenistan (2)**

Afghanistan

Wheat yields sustained despite serious issues.
17 CIMMYT varieties released in last 5 years (2013-17)

441 farmers cleaned 200 MT seed at their door step in 2017

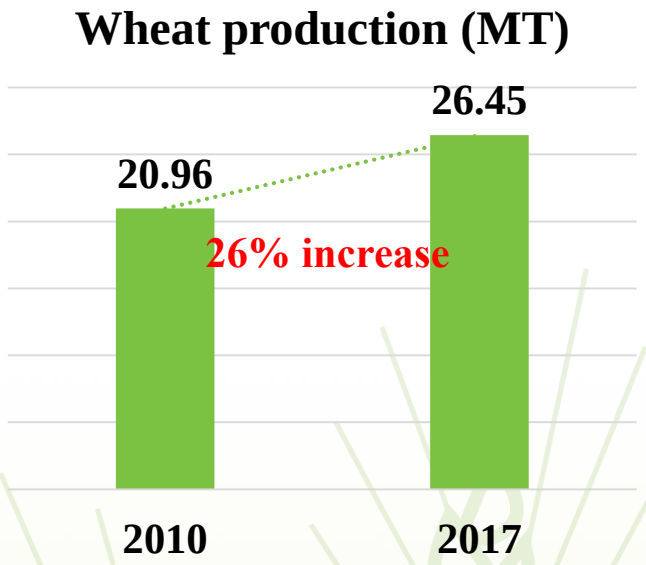
Wheat production & yield in Afghanistan, 2005-2016



Improved seed is the major limitation. Hence, 8 Mobile Seed cleaners were introduced to empower farmers to multiply new varieties on their own and share among themselves.

Pakistan

- **10** varieties, **9 direct CIMMYT**, released in a single year **2017**
- **54** CIMMYT varieties released in last 10 years
- One biofortified - Zincol 2016



DNA-based 2-D digital barcodes for Wheat Varietal Identification and digital repository use – 130 Pakistan wheat cultivars

Pak-81

Mexipak-65

Inqalab-91

CIMMYT

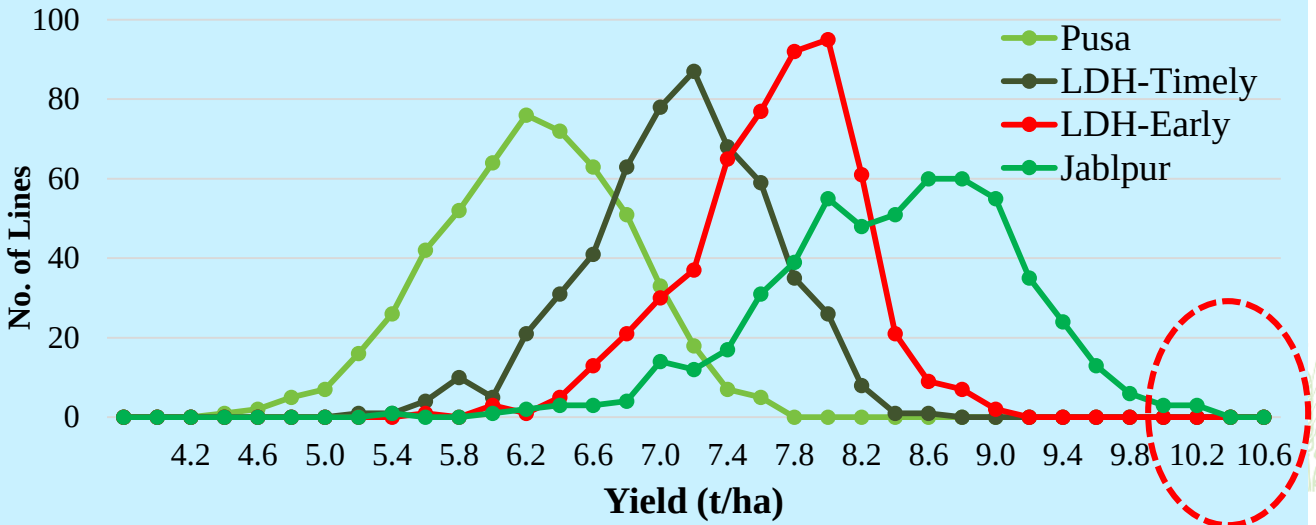
India, Nepal & Bangladesh

35 CIMMYT varieties released since 2010

1st biofortified wheat released in India and Bangladesh

1st durum wheat variety released in Nepal

For the first time in South Asia, 10 t/ha grain yield achieved (location: BISA, India)



CIMMYT

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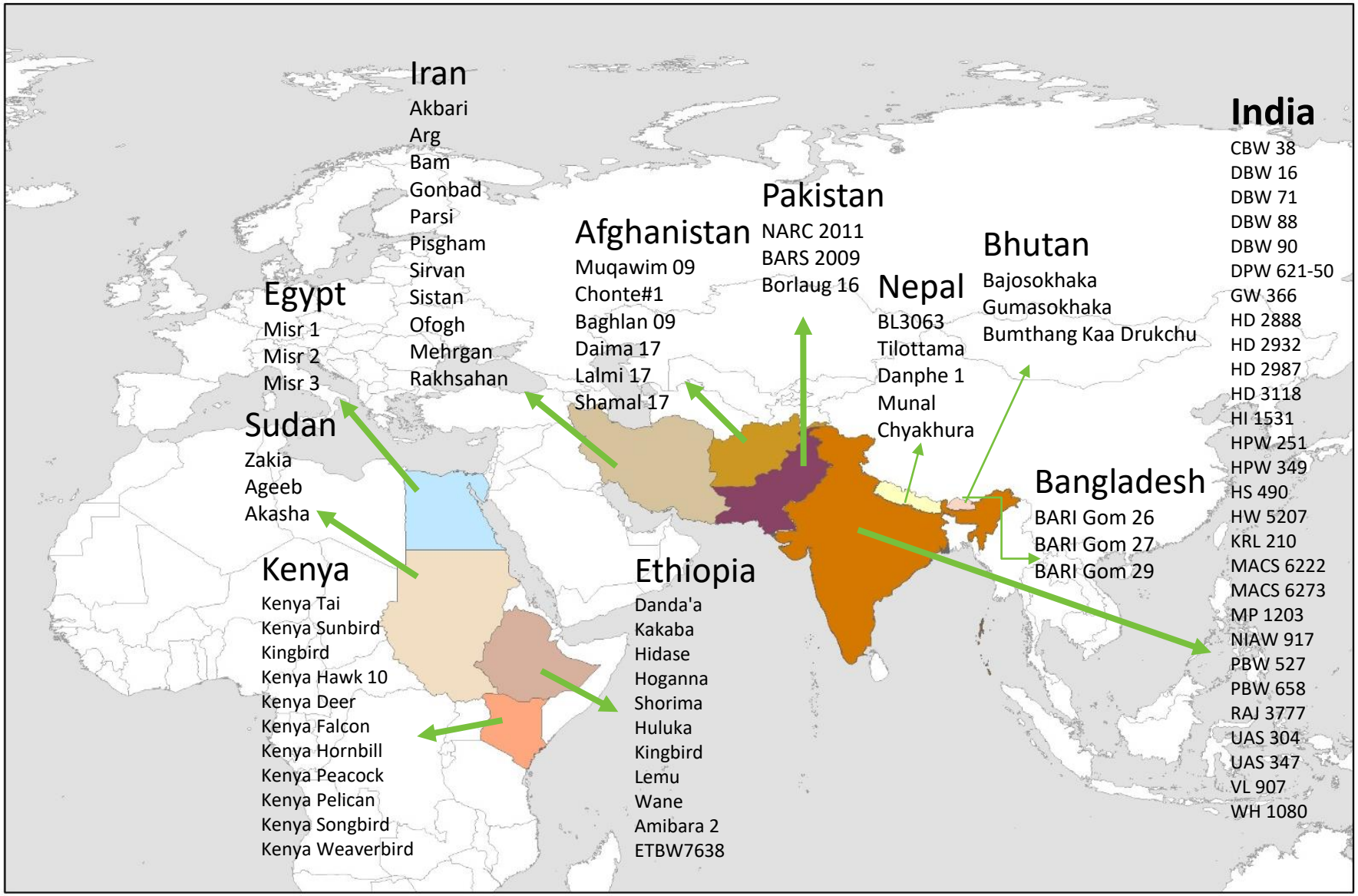
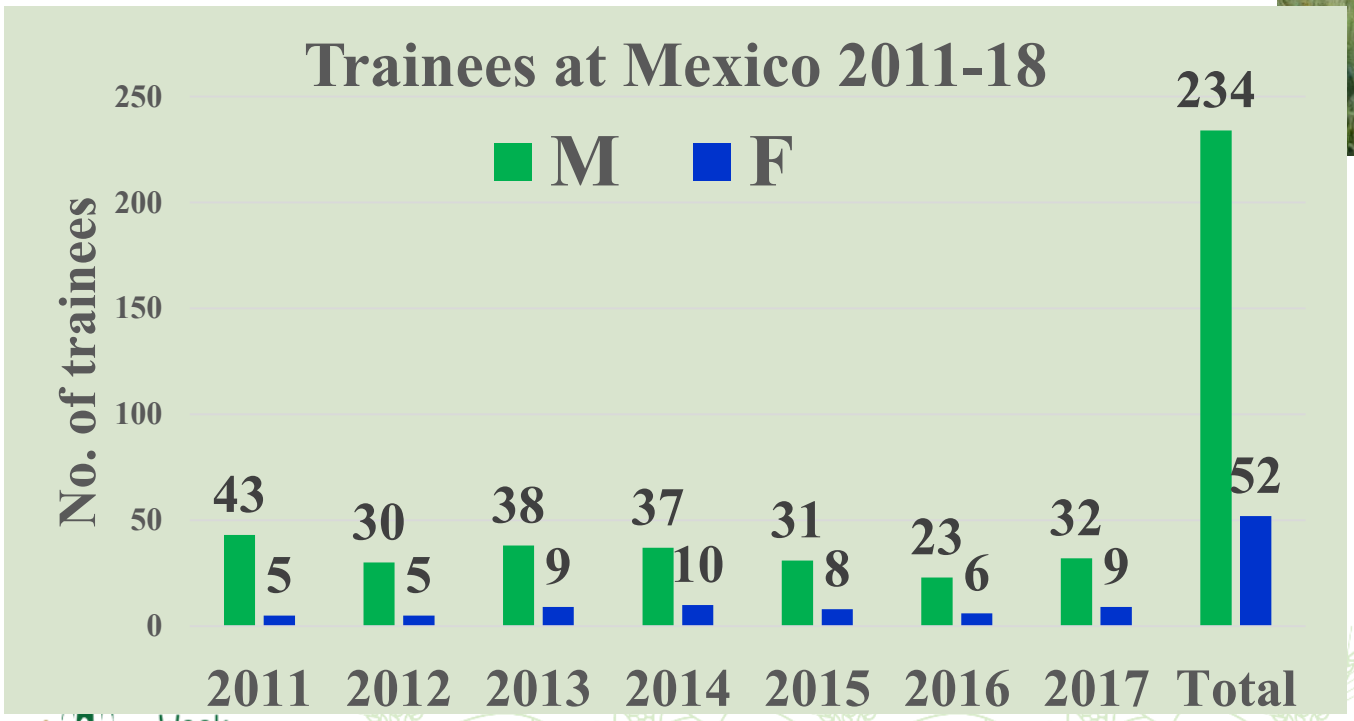
Kenya

The Ug99 threat mitigated through Kenya phenotyping: identification, release and cultivation of resistant varieties during the last decade



Capacity building

- 287 scientists of 30 countries trained during 2011-18 at Mexico
- Around 350 participated in meetings, symposiums



CIMMYT Science Week

There was a significant progress in wheat research

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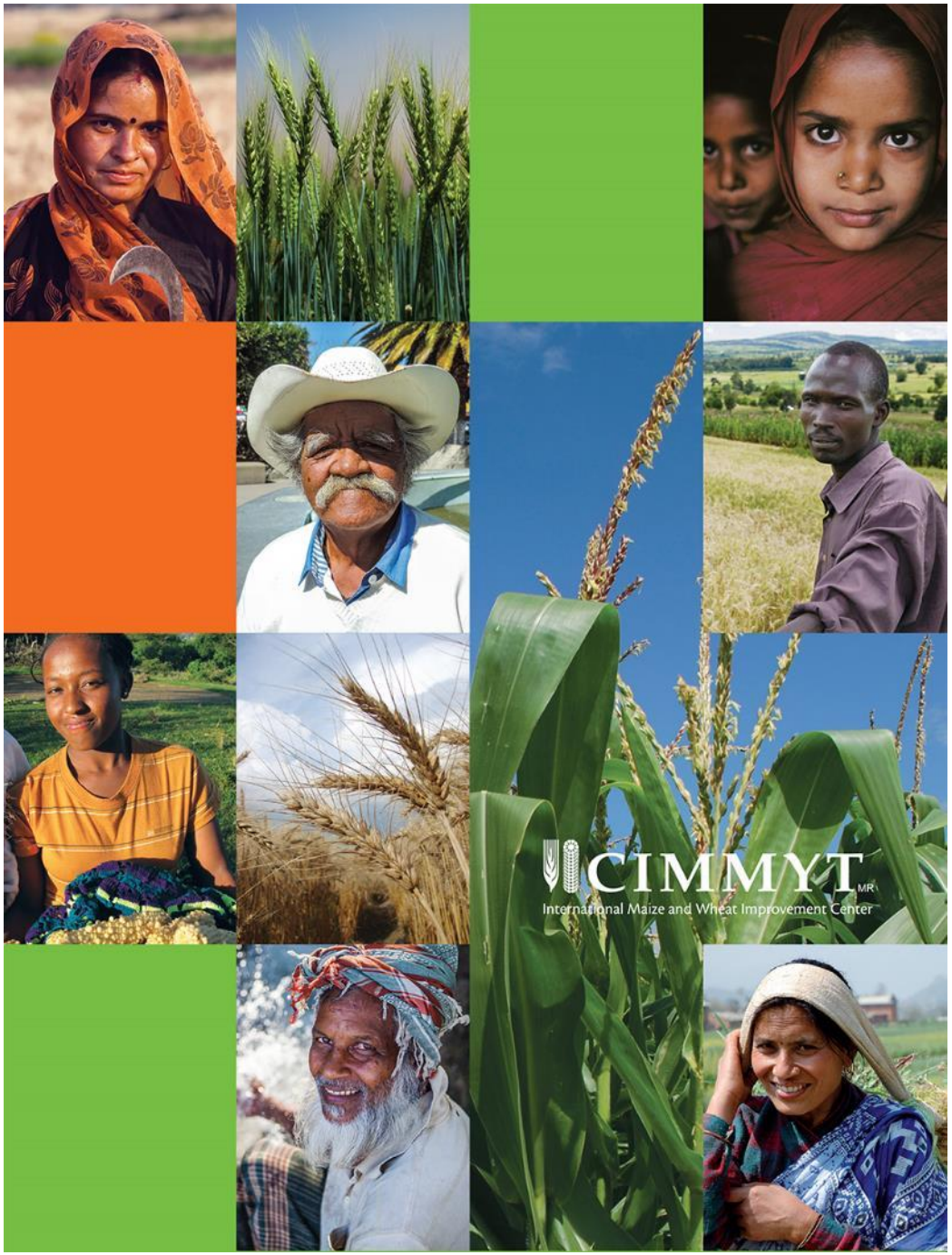

Thank you for your interest!

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Pre-Breeding Outputs

- Crossing with wild relatives: recent outputs
  - *Example: Leymus* for biological nitrification inhibition
- Improving quality traits
  - Bread Wheat
  - Durum Wheat
- Pre-breeding outputs for heat and drought
  - Exploiting diversity based on genomics (SeeD)
  - Exploiting diversity based on phenomics (Trigo)
- The international Wheat Yield Partnership
  - MAS for harvest index using major genes
  - High throughput phenotyping
  - Genomic selection
  - Balancing source and sink