Genetic gains for grain yield, disease resistance and other traits in CIMMYT spring wheat germplasm targeted for adaptation in diverse environments of Asia, Middle East, Africa and Latin America

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Global Wheat Program

13th IWGS, 23-28 April 2017
Tulln, Austria

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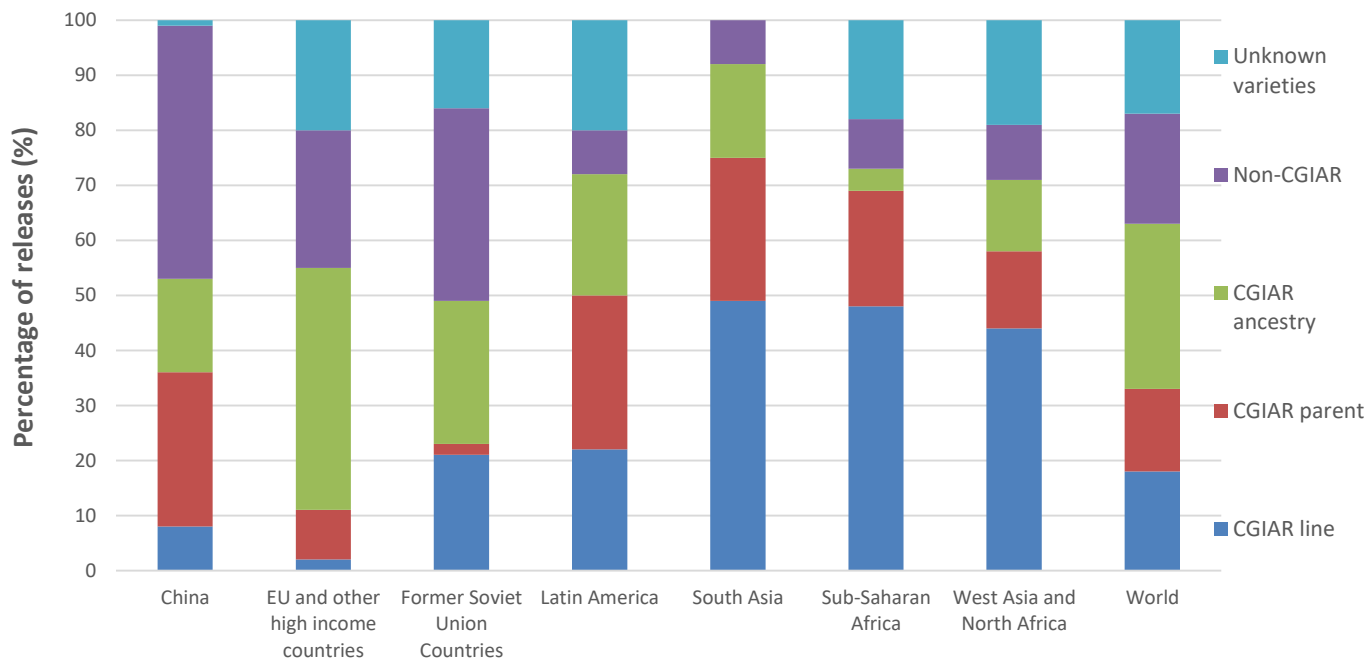
CIMMYT Wheat Improvement Program in Mexico-

Targeted area: 60 m ha in 4 mega-environments (40 m ha in South Asia)

- **Irrigated (ME 1):**
  30 m ha
- **High rainfall (ME 2):**
  5 m ha
- **Semiarid (ME 4):**
  15 m ha
- **Irrigated-Warmer (ME 5):**
  10 m ha

Spring bread wheat releases by region and origin 1994-2014
(Source: Lantican et al. 2016)



About half of the varieties released in South Asia, Sub-Saharan Africa and West Asia & North Africa are direct CGIAR derived; and >30% have at least one parent.

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Wheat Breeding Priorities

Core traits

- High and stable yield potential
- Durable resistance to Rusts- Stem (Ug99), Stripe and Leaf
- Water use efficiency/Drought tolerance
- Heat tolerance
- Appropriate end-use quality
- Enhanced Zn and Fe content for nutrition (currently South Asia, however mainstreaming plans underway)

Key diseases in specific mega-environments

- Durable resistance to diseases and pests
  - Septoria leaf blight (ME2)
  - Spot Blotch (ME5)
  - Tan Spot (ME4)
  - Fusarium – head scab and myco-toxins (ME2/4/5)
  - Karnal bunt (ME1)
  - Root rots and nematodes (ME4)
- *Wheat blast- new threat in South Asia (ME5)*

Packaging multiple traits together is essential under climate change scenario to benefit wheat farmers

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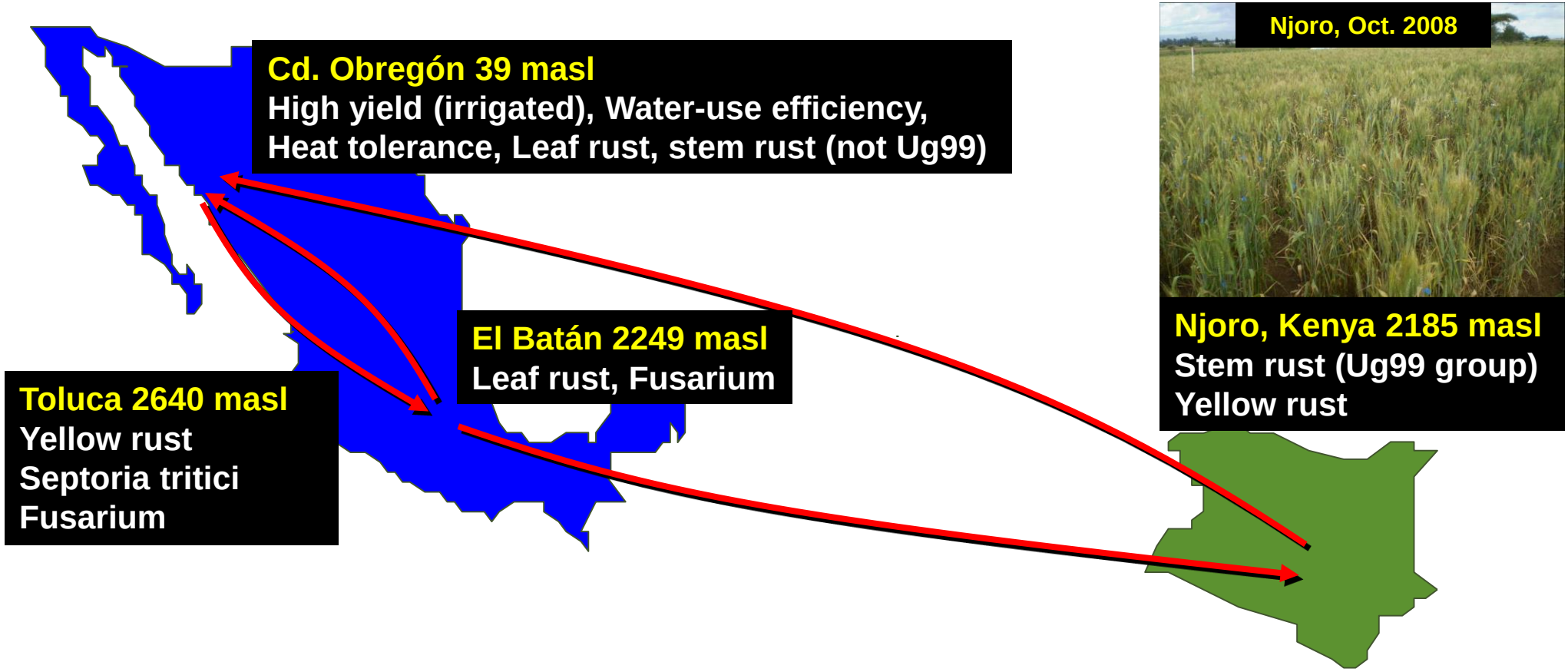
Rapid cycling of breeding materials

Mexico (Cd. Obregon-Toluca/El Batan)- Kenya International Shuttle Breeding

A five-year recurrent breeding cycle



- Phenotyping platform in partnership with KARI (now KALRO) established in 2006
- Mexico-Kenya Shuttle breeding initiated in 2008
- High yielding, resistant lines from shuttle breeding distributed worldwide since 2011

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Grain yield potential in CIMMYT wheat

1% annual increase during the last decade

- Increased investments in breeding
- Integrating breeding for yield potential, stress (heat and drought) tolerance and disease resistance
- Better targeting of crosses using phenotypic and marker data
- Expanded phenotyping for yield, stress tolerance & disease resistance

Validating & applying new approaches for enhancing genetic gains

- High-throughput phenotyping based selection
- Genomic selection
- Predicting winning cross combinations

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Grain yield performance testing of advanced lines
Cd. Obregon, Mexico (2016-17)

- 1st year yield trials Irrigated (9940 entries + Checks): 30 entries/trial, 2 reps, alpha-lattice design
  - Raised bed-5 irrigations
- 2nd year yield trials or EYT (1092 entries + Checks): 30 entries/trial, 3 reps, alpha-lattice design
  - Flat-Drip-5 irrigations (8-9 t/ha)
  - Raised bed-5 irrigations (8-9 t/ha)
  - Raised bed-2 irrigations (3-4 t/ha)
  - Flat- Drip irrigation- high drought stress (2-2.5 t/ha)
  - Raised bed-Late (85 days) sown- (3-4 t/ha)
  - Raised bed-Early sown (20 days) (8-9 t/ha)

Yield potential phenotyping- Flat

Yield potential phenotyping- Bed

Drought tolerance phenotyping: Drip irrigation

Heat tolerance phenotyping: Late sowing

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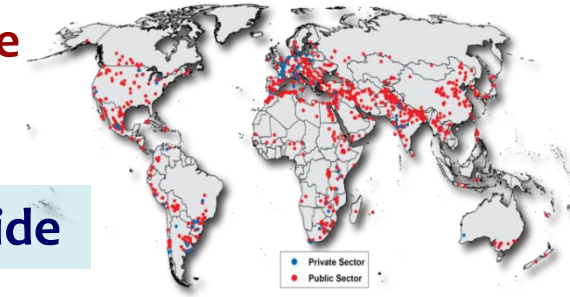
Phenotyping for other traits

- Diseases:
  - Leaf rust- seedling and field (El Batan and Cd. Obregon)
  - Yellow rust- seedling and field (Toluca and Ecuador)
  - Stem rust- seedling and field: off- and main-seasons (Kenya)
  - Septoria tritici- Toluca
  - Fusarium- El Batan
  - Karnal Bunt- Cd. Obregon
  - Tan (yellow) spot- seedling, El Batan greenhouse
  - Stagnospora nodorum blotch- seedling, El Batan greenhouse
  - Spot blotch- Aguas Frias
- Grain weight, test weight and processing quality traits
- Agronomic traits: height, heading, maturity, lodging

International partnership: distribution & phenotyping of new diverse high yielding wheat germplasm through Trials and Nurseries-



50-150 sets of each trials/nurseries distributed annually worldwide

Trial/Nursery	Abbreviation	Entries (No.)	Target Environment	Grain
Yield Trials (Replicated):				
Elite Spring Wheat Yield Trial	ESWYT	50	ME1, ME2, ME5	White
Semi Arid Wheat Yield Trial	SAWYT	50	ME4	White
High Rainfall Wheat Yield Trial	HRWYT	50	ME2, ME4	Red
Heat Tolerance Wheat Yield Trial	HTWYT	50	ME1, ME4, ME5	White
Harvest Plus Yield Trial	HPYT	50	ME1	White
Screening nurseries:				
Int. Bread Wheat Screening Nursery	IBWSN	250-300	ME1, ME2, ME5	White
Semi Arid Wheat Screening Nursery	SAWSN	150-200	ME4	White
High Rainfall Wheat Screening Nursery	HRWSN	150-200	ME2, ME4	Red
Harvest Plus Advanced Nursery	HPAN	100-150	ME1	White
Disease based nurseries:				
International Septoria Observation Nursery	ISEPTON	100-150	ME2, ME4	White/Red
Leaf Blight Resistance Screening Nursery	LBRSN	100-150	ME4, ME5	White/Red
Stem Rust Resistance Screening Nursery	SRRSN	100-150	All MEs	White/Red
Fusarium Head Blight Screening Nursery	FHBSN	50-100	ME2, ME4	White/Red
Karnal Bunt Resistance Screening Nursery	KBRSN	50-100	ME1	White/Red

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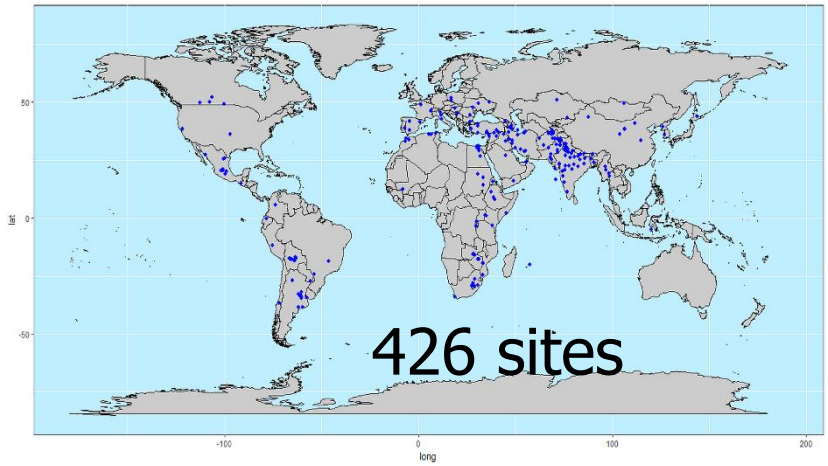
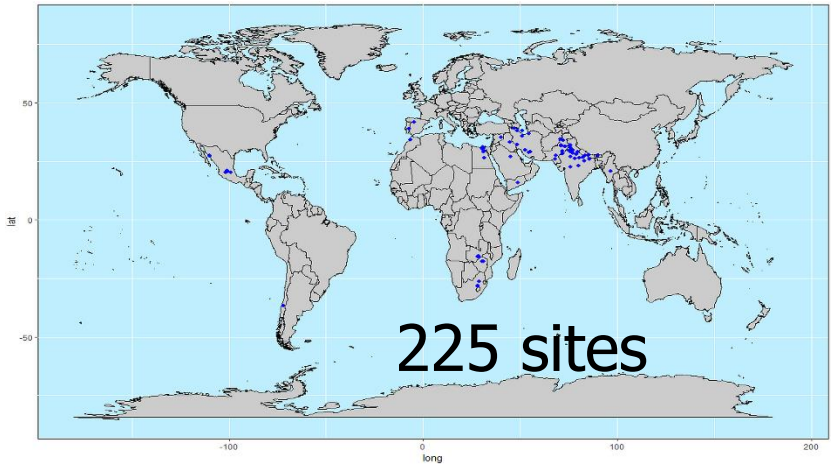
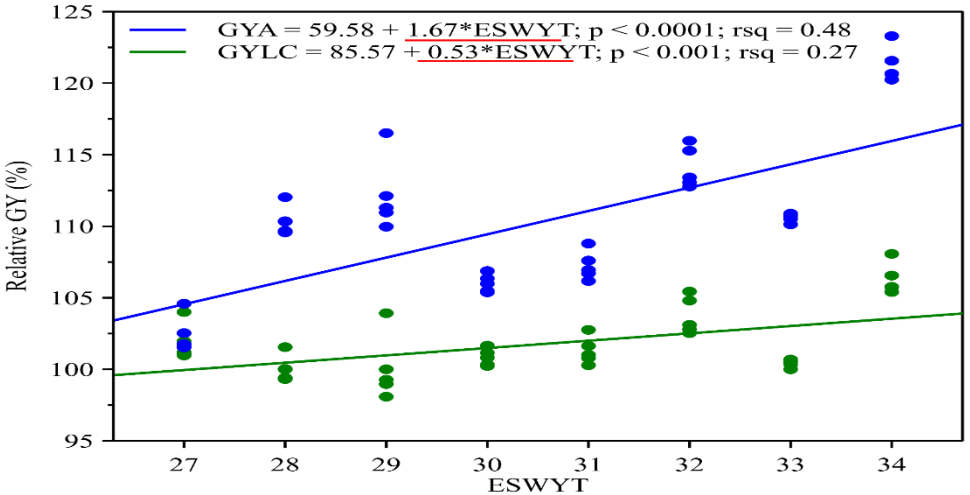
Genetic gains for grain yield in 27th-34th ESWYT (grown during 2006/07 to 2014/15 crop seasons) worldwide & in optimum environments (ME1)

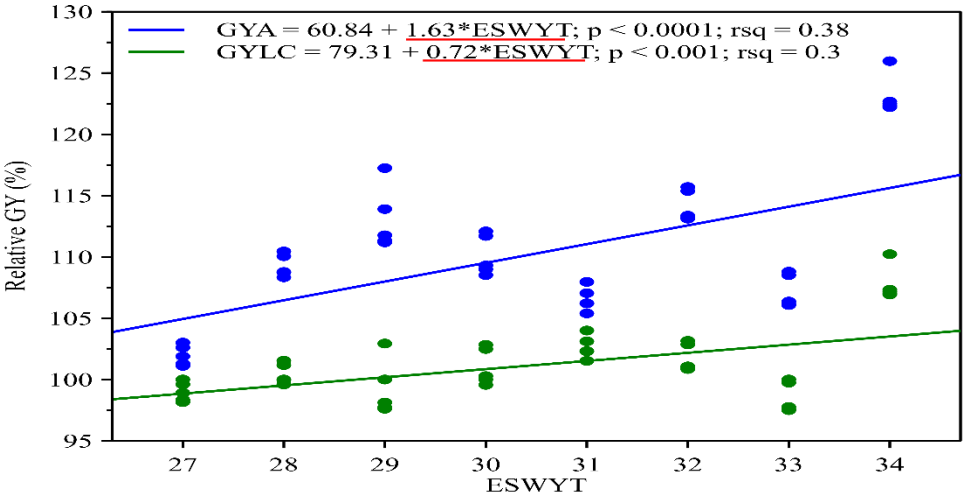




Annual gain (all sites): **1.67%** (Attila check) and **0.53%** (Local Checks)

Annual gain (ME1 sites): **1.63%** (Attila check) and **0.72%** (Local Checks)





Crespo et al. Crop Sci. (2017)

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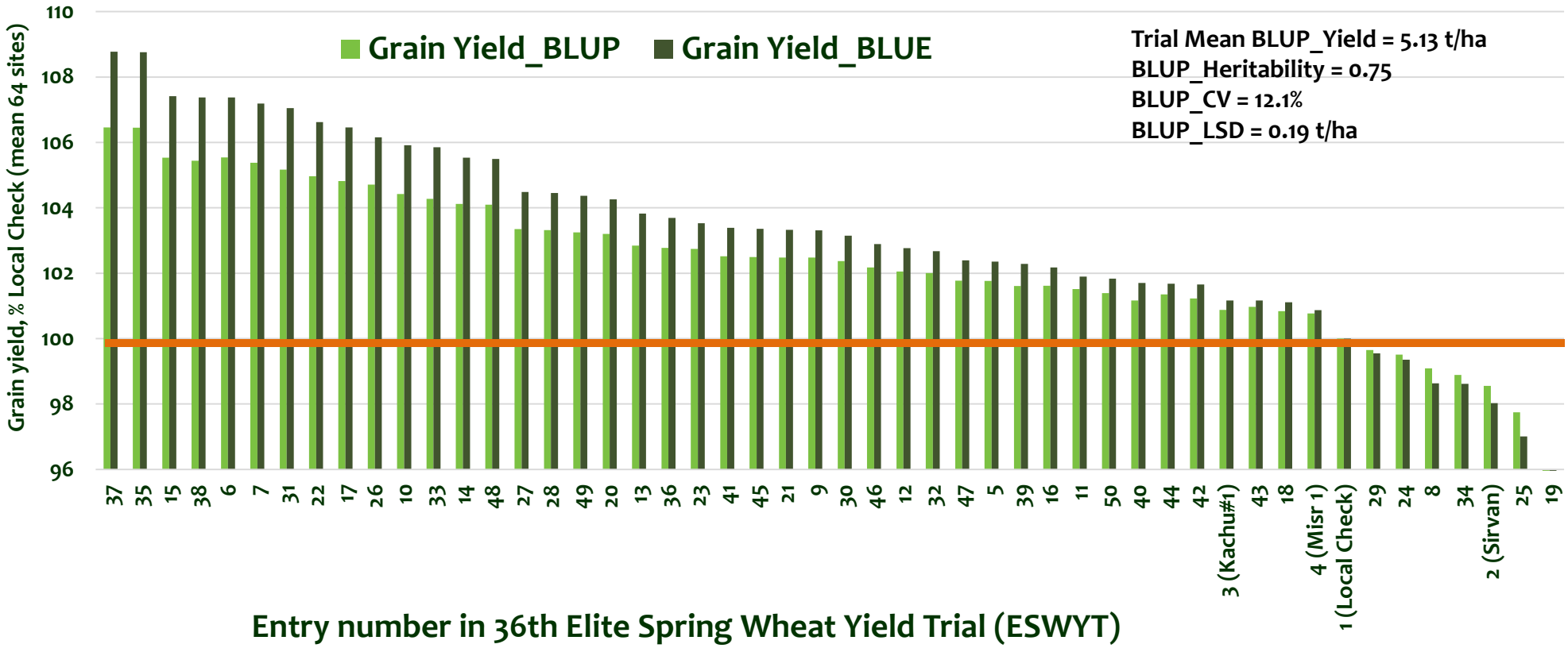
Grain yield performance of 50 entries in 36th Elite Spring Wheat Yield Trial (ESWYT) tested at 64 locations in diverse environments by National partners during 2015-16 season



14 (30%) entries with +5% (BLUE) or +4% (BLUP) yields than the mean of local checks across 64 diverse environments

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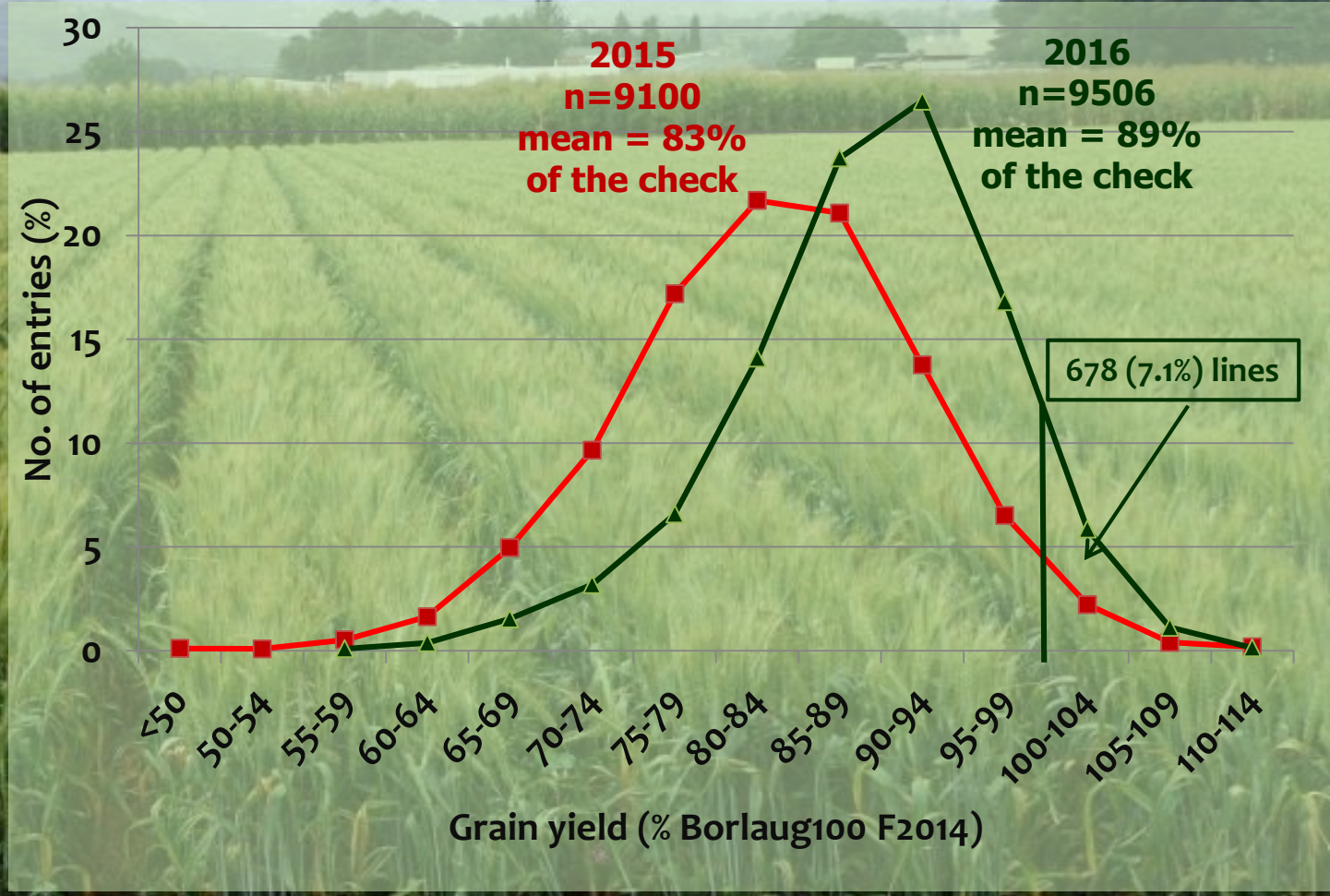
Grain yield enhancement:

Distribution of grain yields of new cohorts of bread wheat lines in 1st year yield trials (2 reps) at Cd. Obregon (2015 and 2016) under optimum irrigation management

- Truly quantitative- many minor genes
- Diversity within improved breeding materials
- Small portion of new lines show superior yields
  - *Various derivatives of Borlaug100 showing further yield gains*

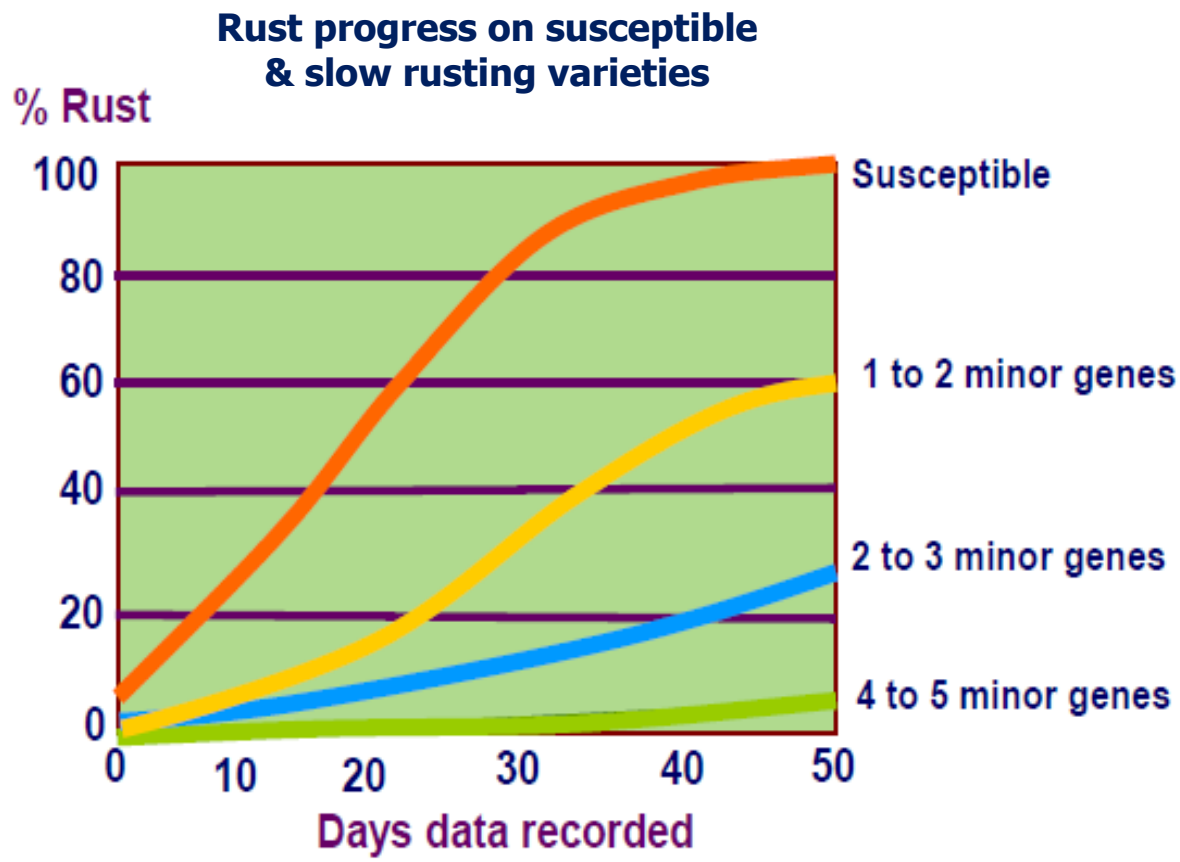


Bread wheat variety Borlaug 100 released in 2014 in Mexico with 9% grain yield superiority over Roelfs released in 2007 in Mrxico & DPW621-50 in India

Breeding for Resistance in Wheat to Rusts

Preferred Strategy: Utilizing Partial or Slow Rusting Resistance Genes

- **Small to intermediate effects**
- **Effective in post seedling stages**
- **Susceptible reactions for LR & SR uredinia (chlorosis & necrosis in stripes for YR)**
- **Confer slow disease progress**
- **Near-immunity (trace to 5% severity) achieved by combining 4-5 genes (a similar genetics for Spot Blotch & other leaf spotting diseases)**



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Pleiotropic multi-pathogen & other slow rusting genes

- *Lr34* [Syn. =*Yr18*=*Sr57*=*Pm38*=*Sb1*=*Bdv1*=*Fhb?*=*Ltn1*] chromosome 7DS

(leaf rust, yellow rust, stem rust, powdery mildew, spot blotch, barley yellow dwarf virus, leaf tip necrosis)

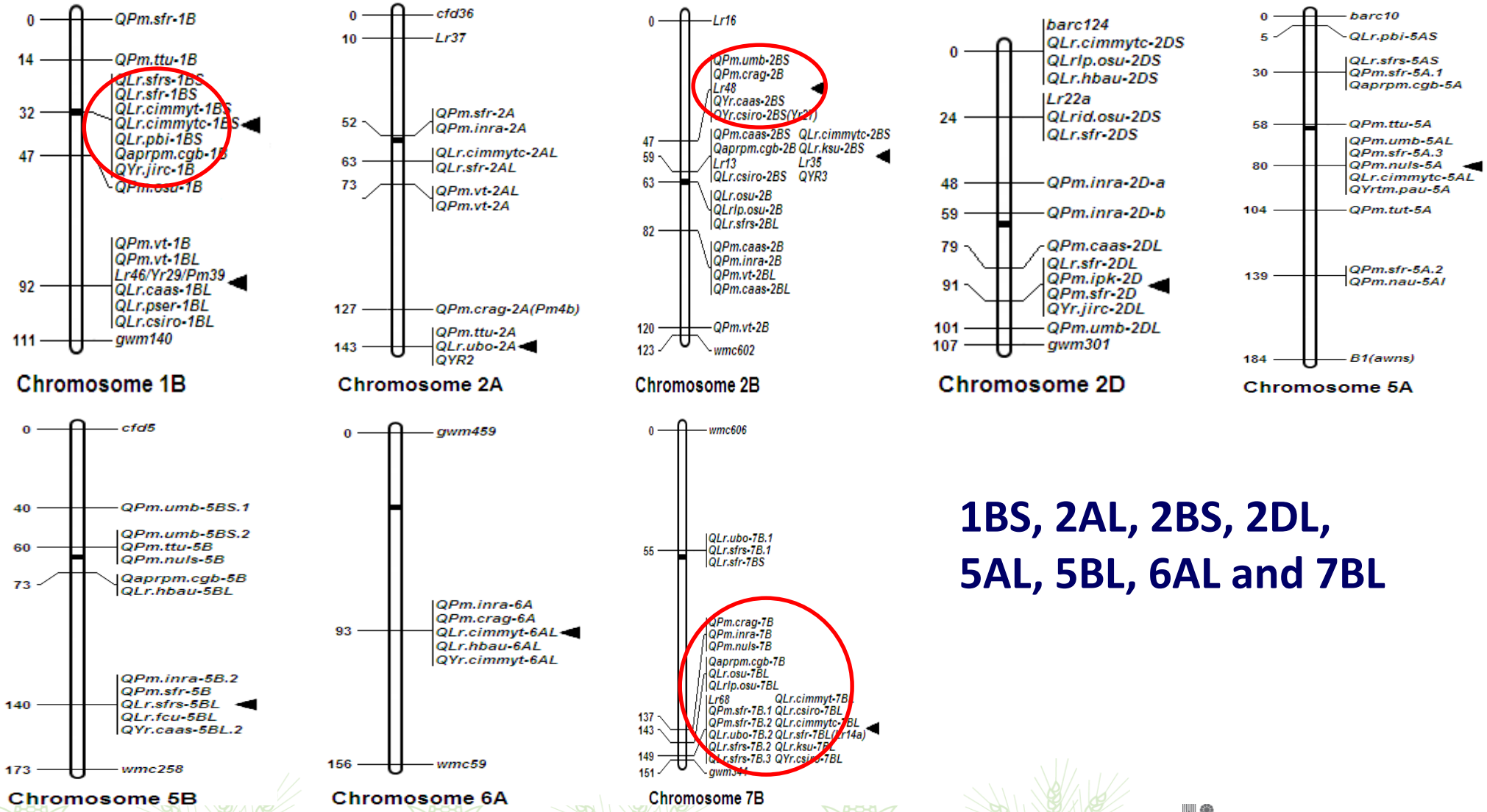
- *Lr46* [Syn.=*Yr29*=*Sr58*=*Pm39*=*Ts?*=*Ltn2*] chromosome 1BL
- *Lr67* [Syn.= *Yr46*=*Sr55*=*Pm46*=*Ltn3*] chromosome 4DL

- *Sr2/Yr30/Lr* chromosome 3BS
- *Lr68* chromosome 7BL

- Various consistent APR QTLs, some with effects on multiple pathogens

Potential PAPR QTLs for leaf rust, yellow rust and powdery mildew

(Li et al. 2014 Crop Sci. 54:1907-1925)



1BS, 2AL, 2BS, 2DL, 5AL, 5BL, 6AL and 7BL

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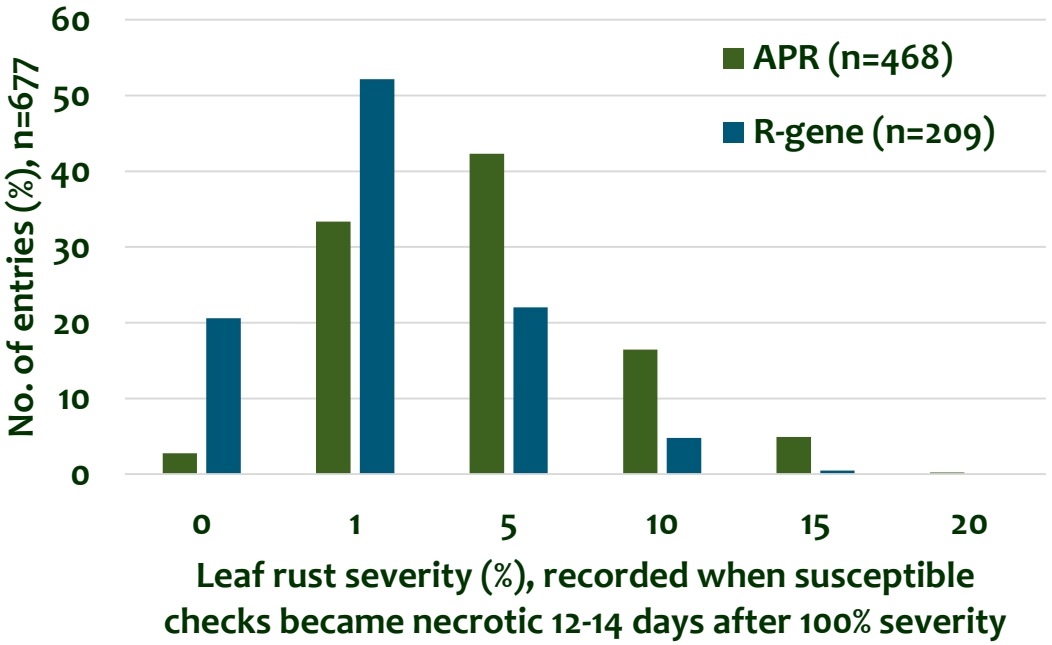
Status of leaf rust in Asia, Africa and Latin America

- Major problem in South America due to utilization of single race-specific resistance genes
- CIMMYT-derived varieties and breeding materials possess adequate to high levels of resistance mostly based on slow rusting APR genes

Leaf rust resistance in wheat entries distributed through international trials and nurseries for 2016-17 season



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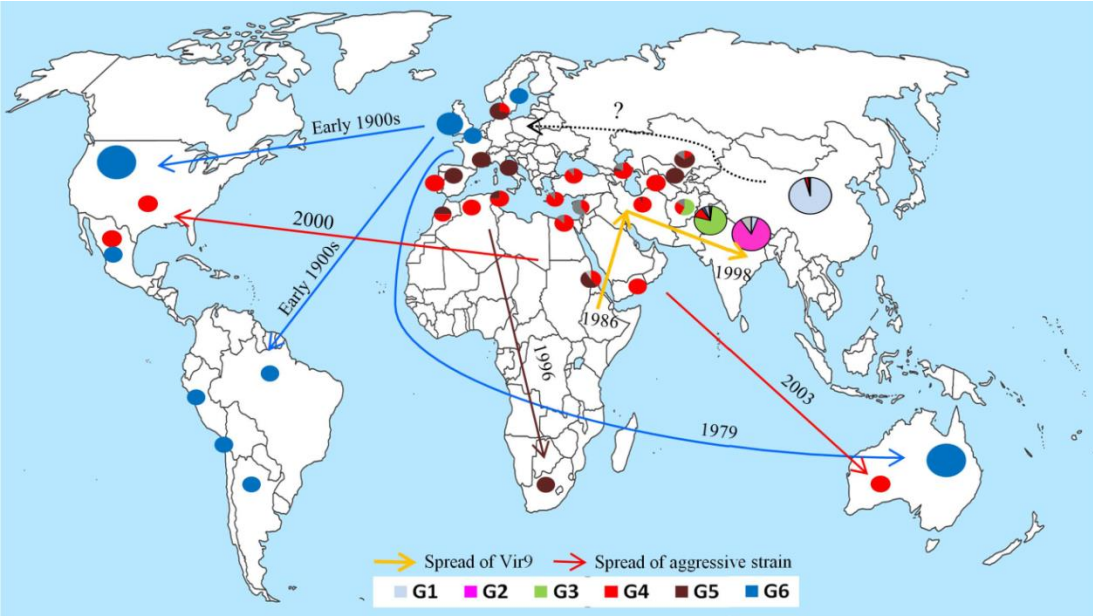
Spread of aggressive *Puccinia striiformis* (yellow rust) races (e.g. Pst1/Pst2 & Warrior) adapted to higher temperature



Countries with red dots with confirmed presence of Pst1/Pst2 race group

Source: Ali et al. (2014) PLoS Pathog 10(1): e1003903. doi:10.1371/journal.ppat.1003903

- Early infection initiation
- Faster disease build up
- Disease progression even when temperatures are warmer
- New areas of adaptation
- Faster evolution for new virulences
- Reduced effectiveness of resistance

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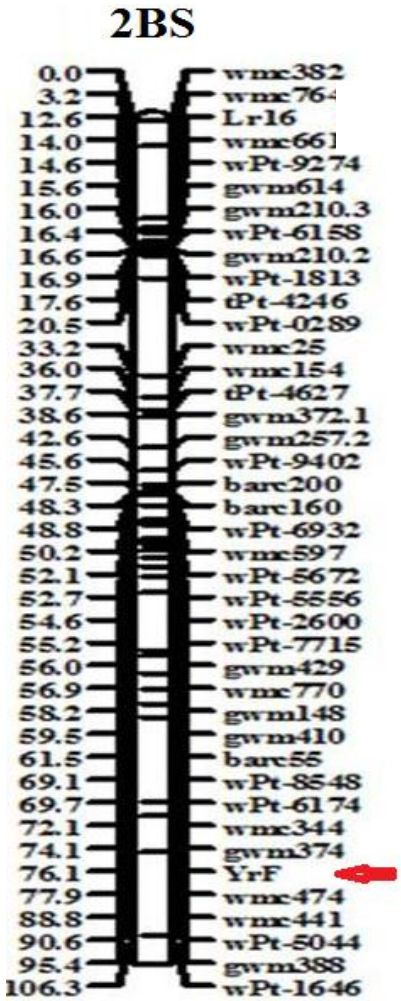
Achieving near-immune resistance to yellow rust at all growth stages

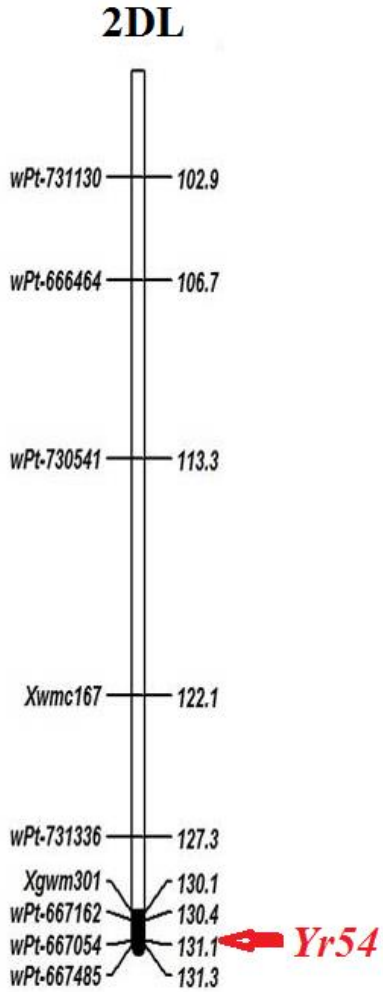
- 4-5 slow rusting genes based APR is effective in most areas where yellow rust infection begins at post stem elongation stages
- In some areas aggressive races initiate infection as early as tillering causing juvenile susceptibility
- Slow rusting APR genes interact with small/intermediate effect race-specific genes, resulting in high levels of all-stage resistance
- Simultaneous field based selection for resistance with other agronomic traits for increases genetic gains

Examples of small/moderate effect race-specific resistance genes

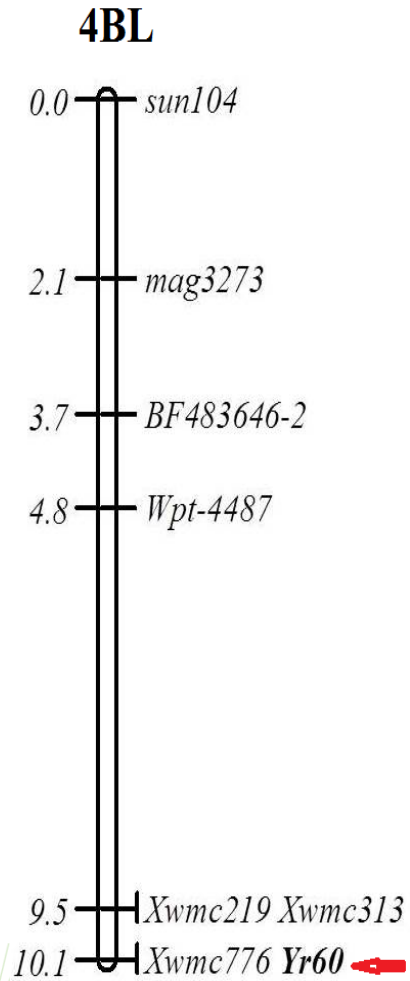
YrF in Francolin



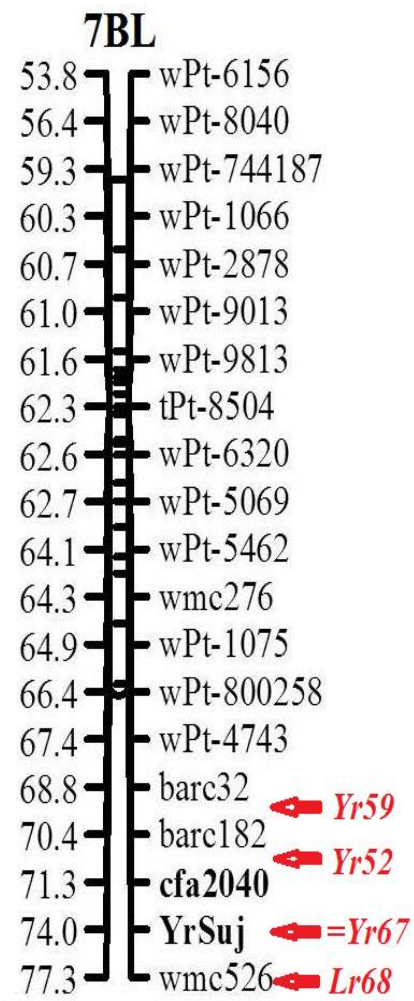
Yr54 in Quaiu3



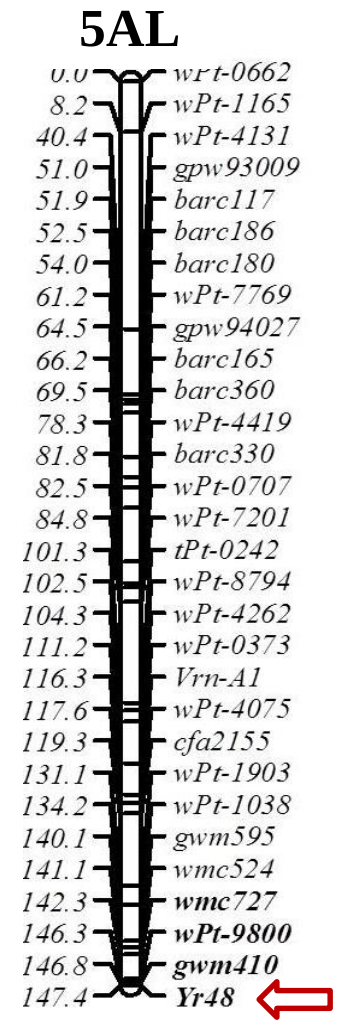
Yr60 in Lalbahadur



Yr67 in Sujata - pleiotropic effect on LR



Yr48 in PI610750



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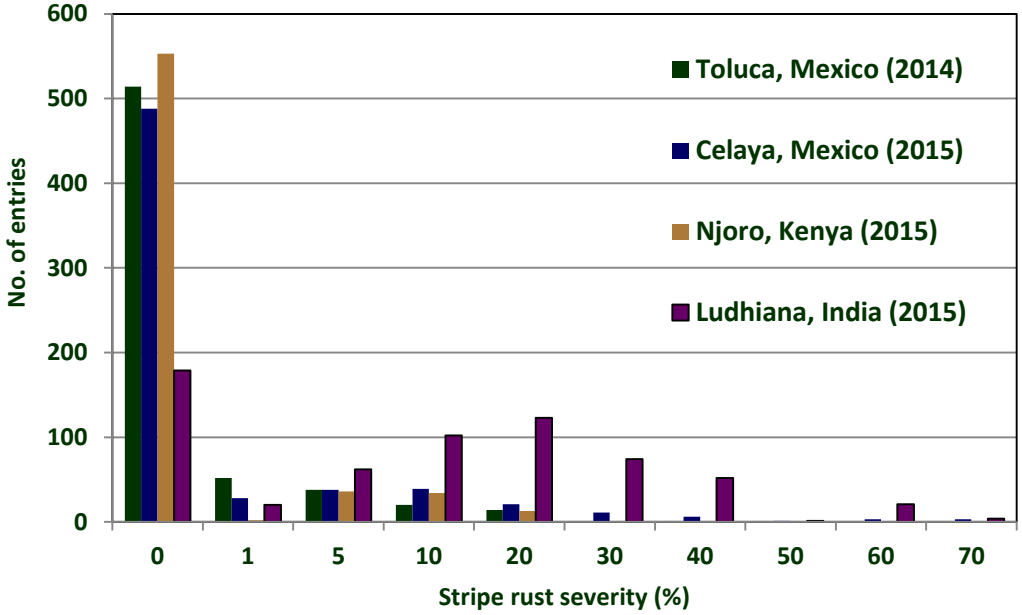
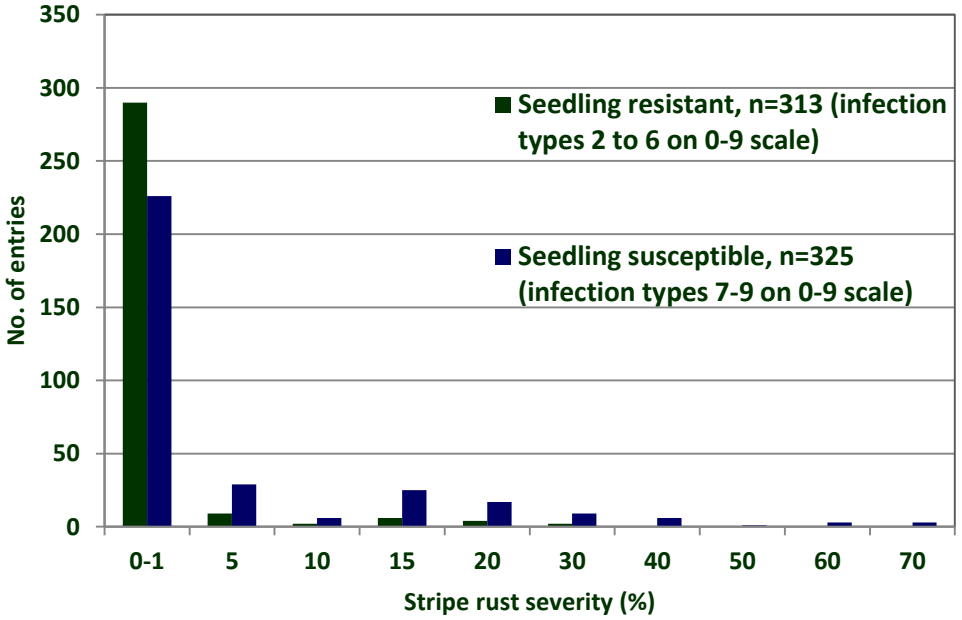
Stripe rust resistance in 638 wheat entries distributed through international trials and nurseries for 2016-17 season





Phenotyping at Toluca, Celaya (Mexico), Njoro (Kenya) and Ludhiana (India) helping in identifying highly resistant lines in field. ***Increased severity in Ludhiana compared to other sites.***

High levels of resistance in the field despite susceptible seedling reactions with the same race in Mexico trials

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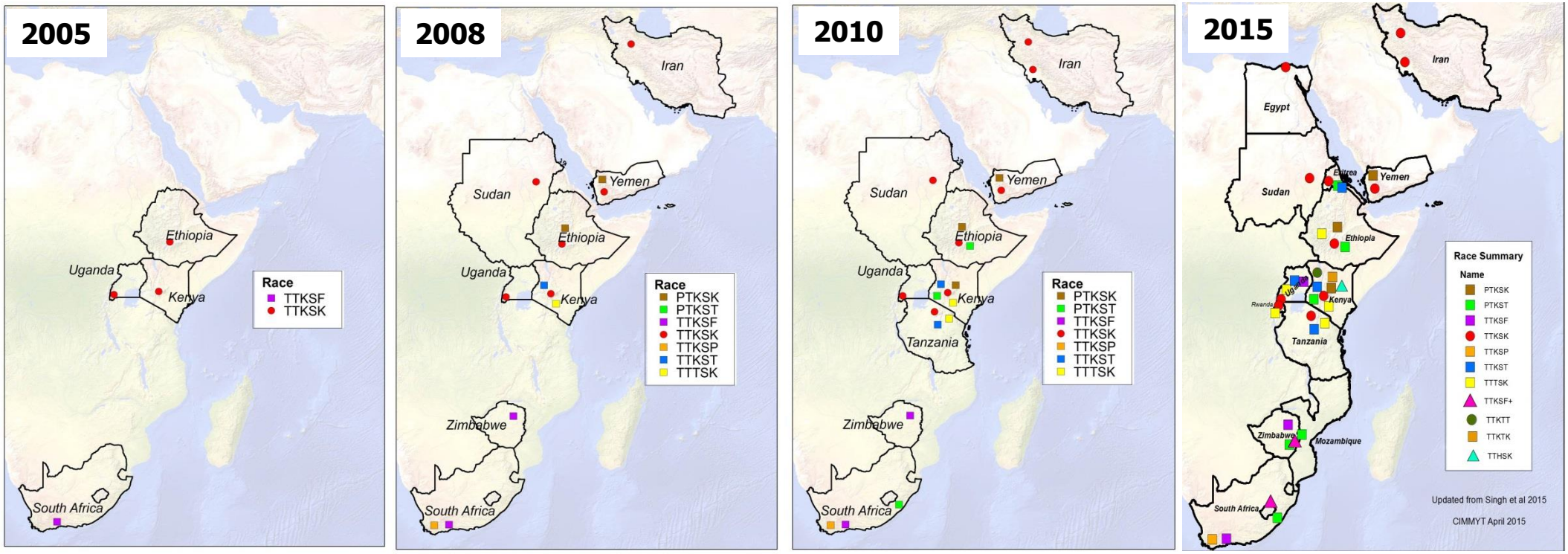
Status of Ug99 lineage of stem (black) rust fungus



- 13 races now known
- Presence in 13 countries confirmed
- Localized epidemics in Ethiopia, Kenya & other east African countries

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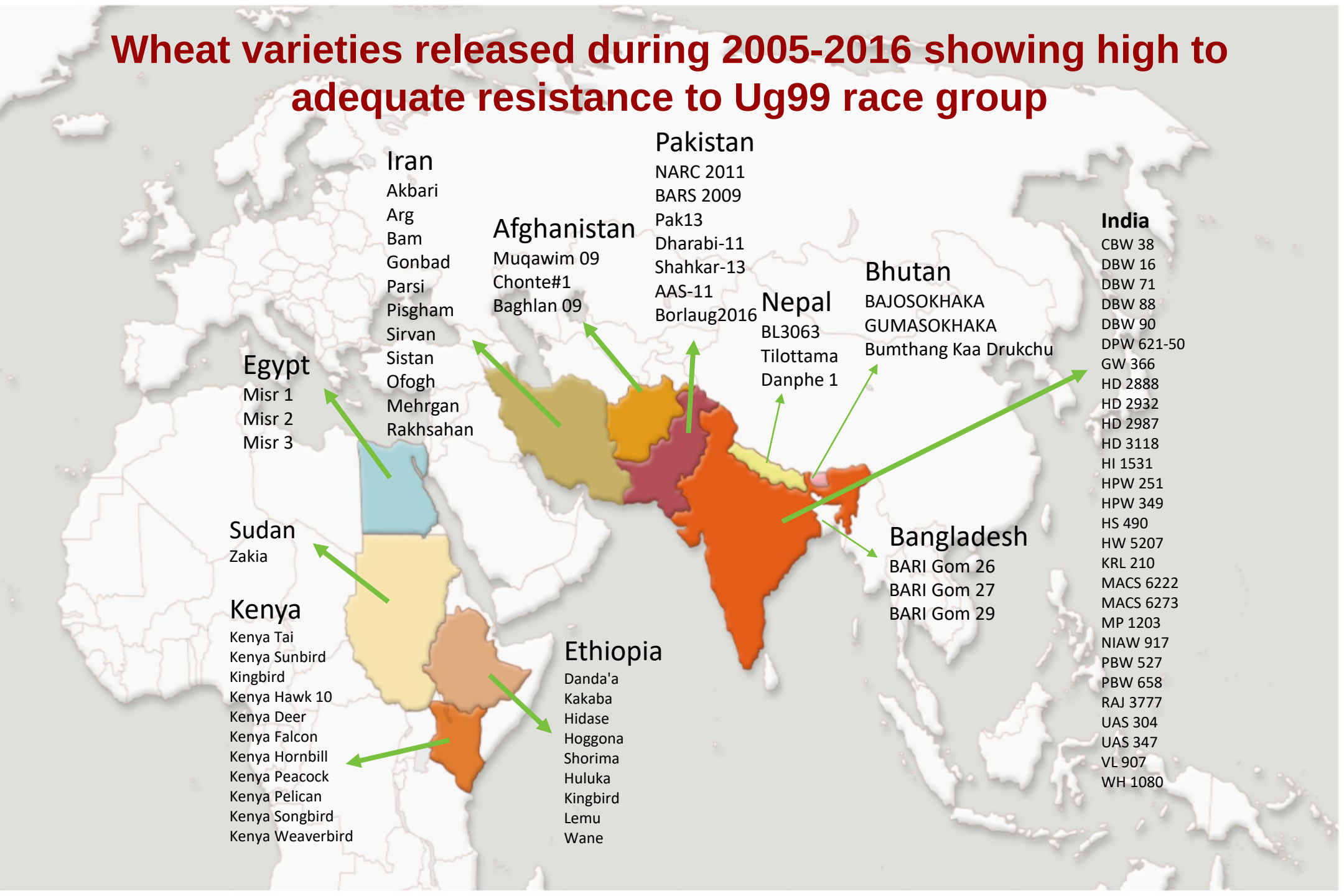
Wheat varieties released during 2005-2016 showing high to adequate resistance to Ug99 race group



Progress in breeding Ug99 stem rust resistance in CIMMYT wheats: resistance in current international trials and nurseries

- **10-15% lines with high levels of adult plant resistance**
- **40-50% lines with adequate adult plant resistance**
- **20-30% lines with 5-6 race-specific resistance genes**
- **20-30% lines with inadequate resistance**

New lines with high yields and high levels of complex adult-plant resistance to stem rust (Njoro, Kenya 2016)

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Resistance to Septoria tritici blotch

- **Near-immunity possible:**
  - **e.g. *synthetic wheat derivatives***
- **APR genes *Lr34* and *Lr46* implicated in enhanced susceptibility, however resistant lines possessing these genes also known**
  - **Genetic background effects**
  - **Presence of other resistance genes compensating the negative effects**

Toluca, Mexico 2014

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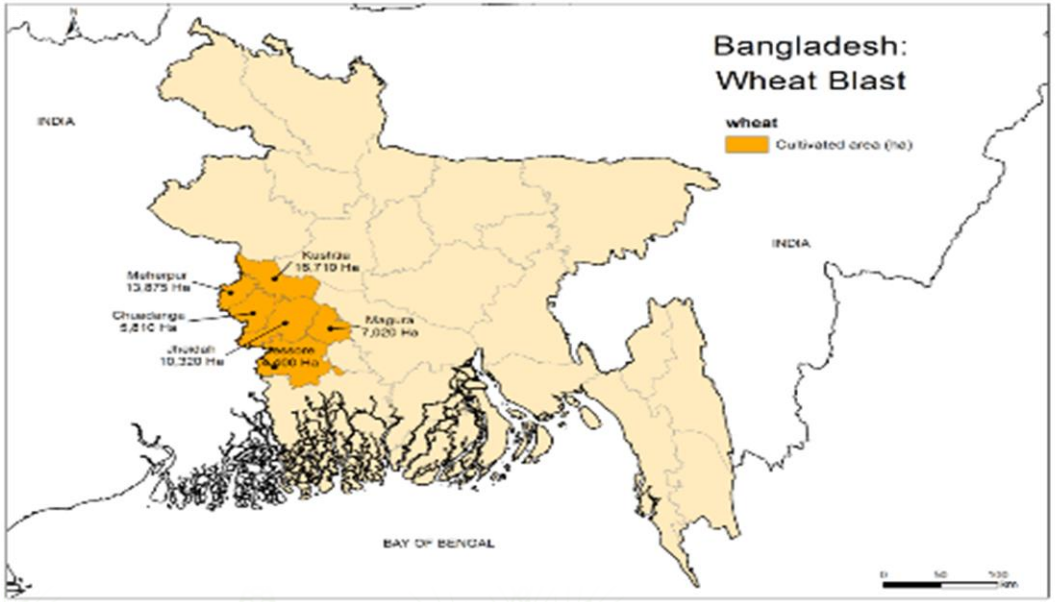
Wheat Blast (caused by *Magnaporthe oryzae*): new challenge for South Asia

- Moved from South America to South Asia
- Localized epidemic in Bangladesh in 2016, presence in 2017
- Translocation 2NS (*Yr17/Lr37/Sr38*) associated with moderate resistance
- Moderately resistant varieties released in South America



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Bread making quality- glutenins alleles

Bread volumes from 100 g of flour (Straight-dough method)

550 mL | 650 mL | 800 mL | 900 ml

Fixing desired glutenins alleles in parents to obtain higher frequency of progenies with superior quality

Extremely poor		Poor		Acceptable		Excellent	
Glu -A1	0	Glu -A1	0	Glu -A1	1	Glu -A1	2*
Glu-A3	e	Glu-A3	c	Glu-A3	b	Glu-A3	d
Glu-B1	20	Glu-B1	7	Glu-B1	7+8	Glu-B1	7+9
Glu-B3	c	Glu-B3	c	Glu-B3	b	Glu-B3	b
Glu-D1	2+12	Glu-D1	2+12	Glu-D1	5+10	Glu-D1	5+10
Glu-D3	c	Glu-D3	b	Glu-D3	d	Glu-D3	a

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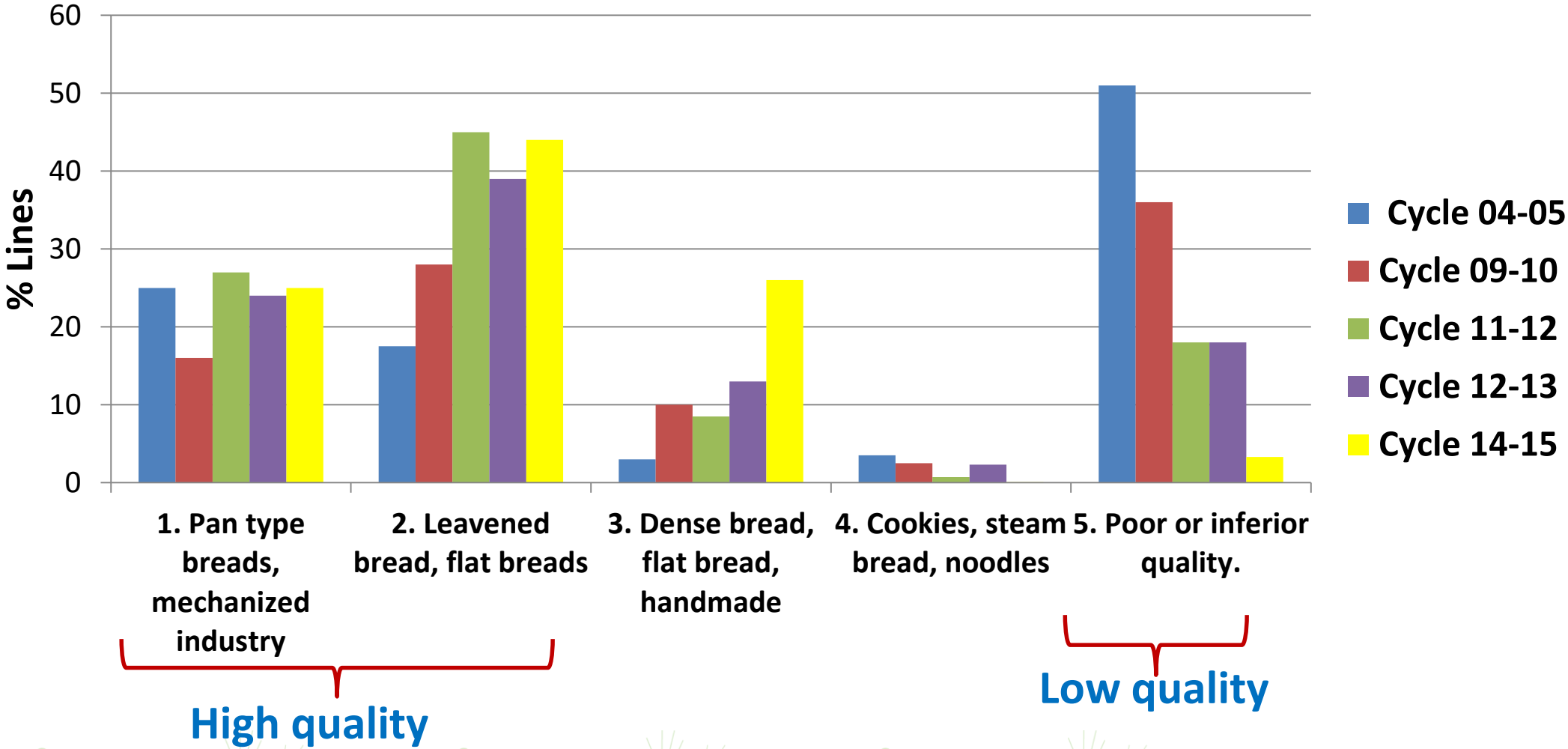
Bread wheat quality improvement progress

Data for candidate lines (>1000) for international distribution



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Conclusions and future outlook

- 25-30 varieties are released each year in various countries & under diverse environments from improved germplasm distributed by CIMMYT

- Yield potential continues to increase, however expanded breeding and utilization of new approaches are necessary to maintain/enhance genetic gains.

- Resistance durability can be achieved by releasing and growing new varieties that possess complex adult plant resistance.

- Packaging of yield potential with tolerance/resistance to multiple abiotic/biotic stress and processing/nutritional quality is the way forward to enhance productivity, nutrition and profitability.

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Acknowledgements

Bill and Melinda Gates Foundation & DFID through:

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ICAR, India
SAGARPA, Mexico
USAID, USA

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Agrovegetal, Spain
GRDC, Australia (ACRCP & CAIGE Projects)
Patronato-Sonora, Mexico

CRP Wheat

Thank you