Important wheat diseases in E. Africa and strategies to enhance durable resistance

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CIMMYT

Mission

Maize and wheat science for improved livelihoods.

Vision

CIMMYT contributes to the development of a world with healthier and more prosperous people – free from the threat of global food crises – and with more resilient agri-food systems.

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The big impact

Annual benefits of $3.5-4 billion.

50% of maize and wheat in the developing world are based on CIMMYT varieties.

Trained over 10,000 agricultural experts and scientists.

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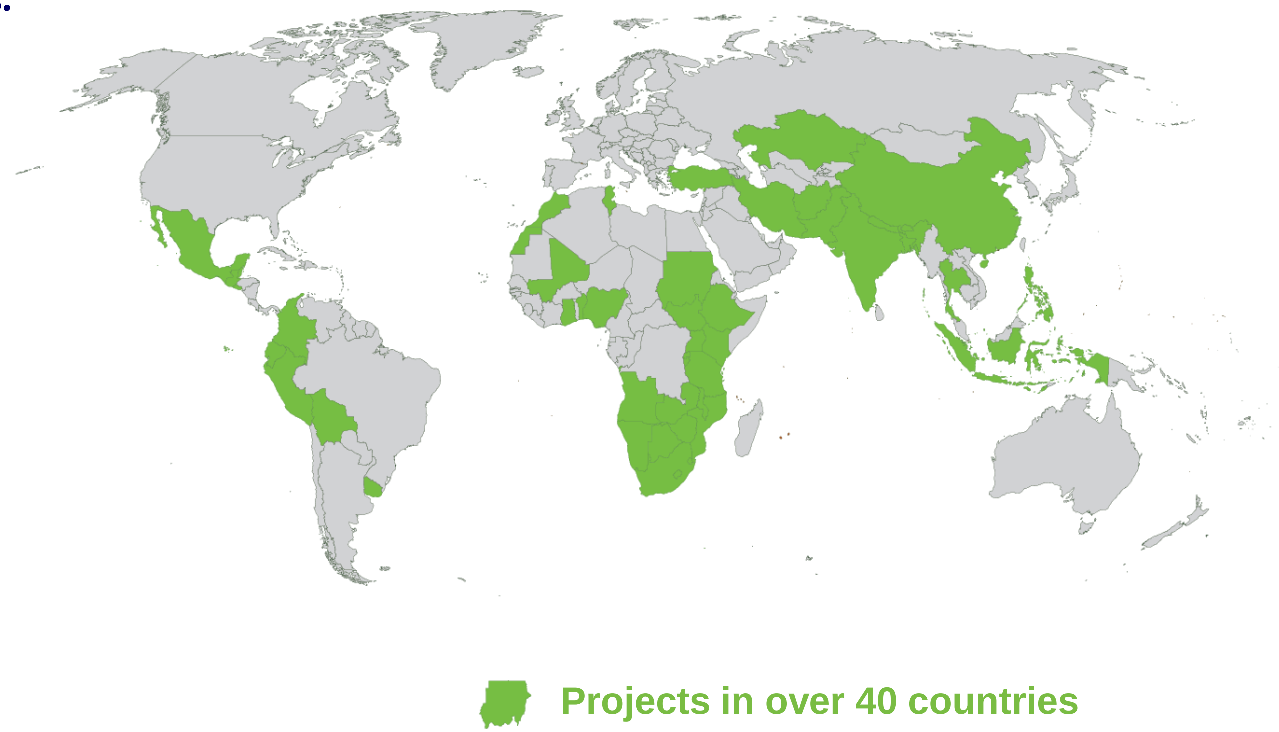
CIMMYT around the world

1,200 staff from over 50 countries!

Countries with offices:

Afghanistan
Bangladesh
China
Colombia
Ethiopia
Guatemala
India
Iran
Kazakhstan
Kenya
Mexico
Nepal
Pakistan
Turkey
Zimbabwe



Integrated research agenda

Genetic diversity

- Conserve and use diverse maize and wheat collections
- Seed health
- Unlocking genetic potential

Develop and improve access to varieties

- Stress, disease and pest resilience
- Molecular tools
- Developing seed sectors
- Nutritional and end-use quality

Farming systems

- Crop management practices
- Mechanization
- Participatory research

Increasing impact

- Big data
- Gender and youth
- Foresight and impact assessments

CROSS CUTTING

Capacity development – Partnership

Wheat

WHEAT IS THE LARGEST PRIMARY COMMODITY

GLOBAL PRODUCTION IS OVER

700 million tons

2.5 billion people in **89** countries

GROWN ON

215mm

HECTARES

$50 billion

IN TRADE EACH YEAR

WHEAT PROVIDES **19%** OF OUR TOTAL AVAILABLE CALORIES

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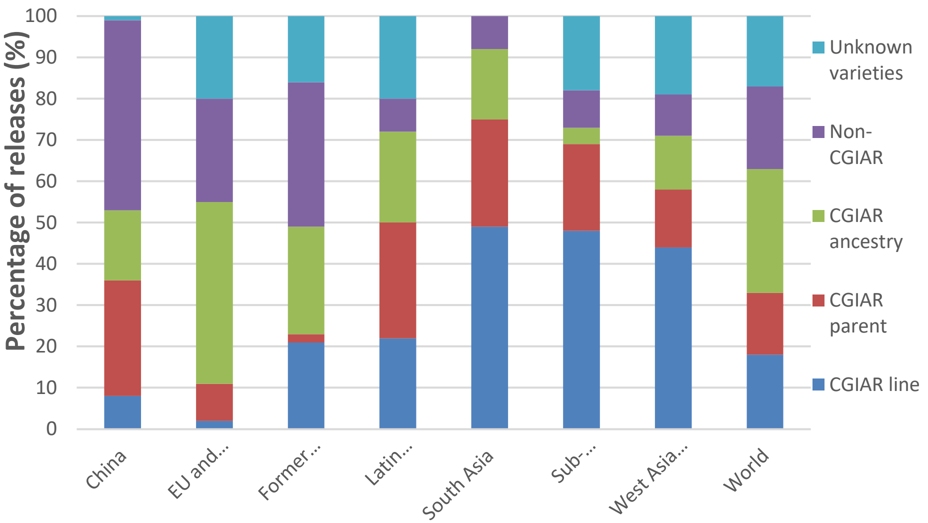
CIMMYT Wheat Improvement Program in Mexico-
Targeted area: 60 million hectare (150 million acre)

- **Irrigated (Mega-environment 1):**
  30 million hectare
- **High rainfall (Mega-environment 2):**
  5 million hectare
- **Semiarid (Mega-environment 4):**
  15 million hectare
- **Irrigated-Warmer (Mega-environment 5):**
  10 million hectare

Wheat varieties 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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Priority Traits in Spring Bread Wheat Product Profiles

	Product Profile/Market Segment					
	Breeding Program 1		Breeding Program 2			
	1. Hard White-Optimum Environment	2. Hard White-Heat Tolerant Early Maturity	3. Hard White-Drought Tolerant Normal Maturity	4. Hard White-Drought Tolerant Early Maturity	5. Hard White-High Rainfall	6. Hard Red – High Rainfall
	HW-OE	HW-HTEM	HW-DTNM	HW-DTEM	HW-HR	HR-HR
Trait	2x	2x	1x	1x	0.75x	0.25x
High and stable yield potential	XXX	XXX	XXX	XXX	XXX	XXX
Water use efficiency/Drought tolerance	X	X	XXX	XXX	XX	XX
Heat tolerance	XX	XXX	XX	XXX	X	X
End-use quality	XXX	XXX	XXX	XXX	XXX	XXX
Enhanced grain Zn (and Fe) content (new mainstreaming trait)	XXX	XXX	XXX	XXX	XXX	XXX
Stem rust (Ug99 & other)	XX	XX	XX	XXX	XXX	XXX
Stripe rust	XXX	XX	XXX	XX	XXX	XXX
Leaf rust	XXX	XXX	XXX	XXX	XX	XX
Septoria tritici blotch	-	-	XXX	-	XXX	XXX
Spot blotch	X	XXX	-	X	-	-
Fusarium – head scab and myco-toxins	-	-	-	-	XX	XX
Wheat blast- new threat in South Asia	X	XXX	X	X	X	X
Maturity	Normal-late	Early	Normal	Early	Normal	Normal

Importance: X= low, XX= moderate, XXX= high

Regional Priorities for Wheat Diseases

Biotic stress	East Asia	South Asia	West Asia	M-East+ N-Africa	C-Asia+ Caucasus	S-Saharan Africa	L-America + Mexico	Developed countries
Yellow rust	+++	+++	+++	+++	+++	+++	+	+++
Stem rust	+++	+++	+++	+++	+++	+++	+++	+++
Leaf rust	++	+++	+++	+++	+++	++	+++	++
FHB	+++	0	+	+	0	++	++	+++
Septoria	+	0	++	+++	++	++	++	+++
Spot blotch	+	+++	0	0	0	+	++	+
Tan spot	0	+	+	+	+++	0	++	+++
Nematodes	++	++	+++	++	0	0	+	+
Root diseases	++	+	++	++	+	0	+	+
Wheat blast	0	+	0	0	0	++	++	0
Powderymildew	++	+	0	0	0	0	+	++
Smuts/bunts	+	++	++	++	+	+	+	+

0=not present, +=present, ++=concern, +++=very important

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Disease symptoms - Stem rust "Ug99"

Infected stems

Infected leaves

Infected glumes

Infected awns

Black rust- Teliospores

Reduced photosynthetic area

Reduced nutrient and water translocation

Lodging of stems

Impact on stem rust disease on wheat yield and quality

Impact of stem rust damage in farmers fields

Stem Rust (Black Rust)

Puccinia graminis f.sp. *tritici*

Symptoms: Pustules (containing masses of urediospores) are **dark reddish brown**, and may occur on **both sides of the leaves**, on the stems, and on the spikes. With light infections the pustules are usually separate and scattered, but with **heavy infections they may coalesce**. Prior to pustule formation, "flecks" may appear. Before the spore masses break through the epidermis, the infection sites feel rough to the touch; as the spore masses break through, the surface tissues take on a **ragged and torn appearance**.

Development: Primary infections are usually light and develop from wind-borne urediospores that may have travelled long distances. The disease can develop rapidly when free moisture (rain or dew) and moderate temperatures prevail. If temperatures average about 20C or more, the first generation of urediospores will be produced in 10-15 days. As plants mature, masses of black teliospores may be produced.

Hosts/Distribution: Stem rust can affect wheat, barley, triticale, and many other related grasses; it is found wherever temperate cereals are grown. The alternate hosts are *Berberis* and *Mahonia* spp.

Importance: If infection occurs during the early crop stages, the effects can be severe: reductions in tillering and losses in grain weight and quality. Under favorable conditions, complete crop loss can occur.

Control:
1. The use of resistant cultivars.
2. Control of volunteer wheat and seeding dates.
3. The use of fungicide sprays

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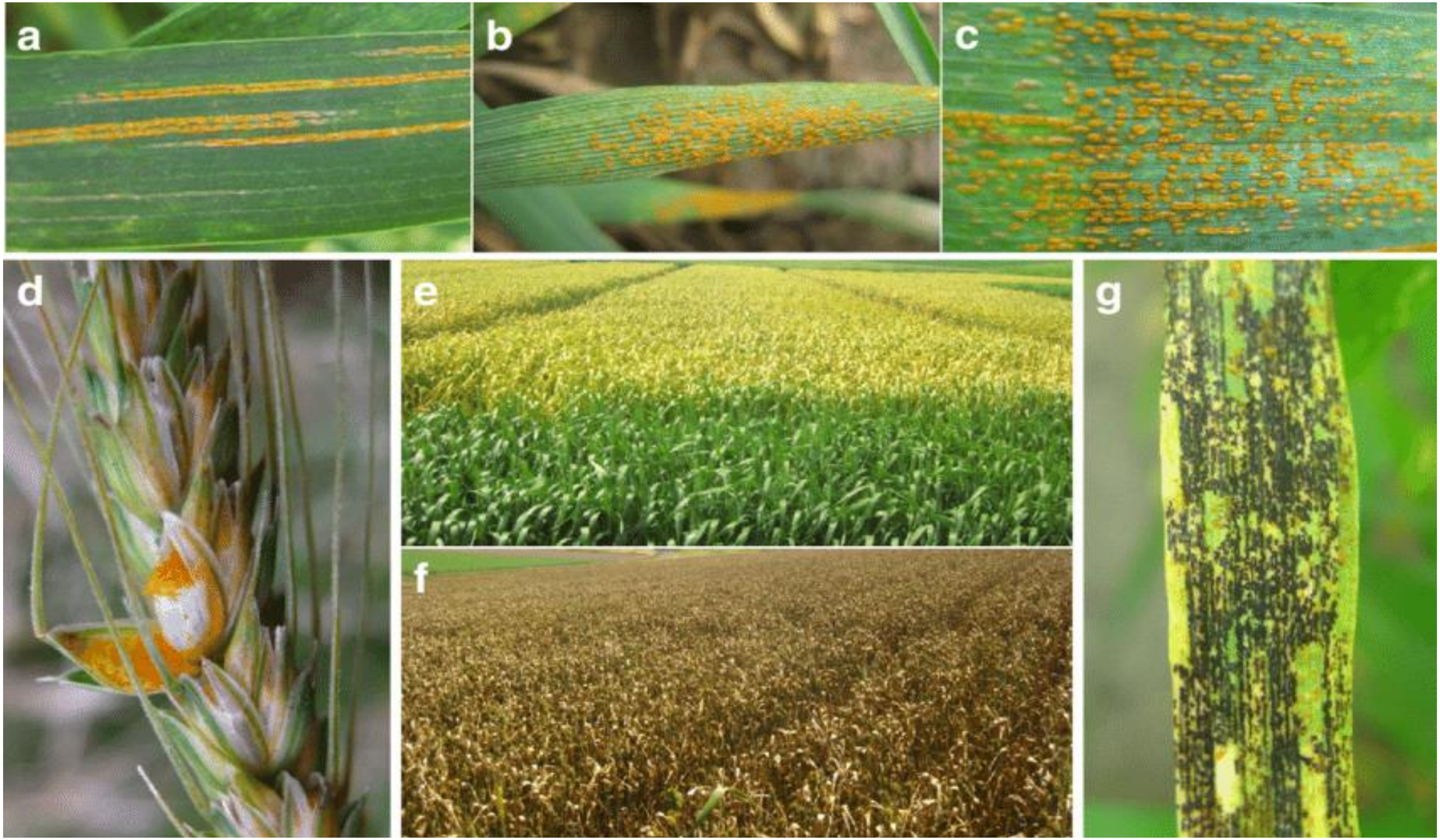

Symptoms and signs of wheat stripe rust.
a Uredinia in stripes on a flag leaf.
b Uredinia in a cluster on a seedling leaf, not forming stripes.
c Uredinia on a flag leaf without forming obvious stripes.
d Stripe rust on a wheat head showing masses of urediniospores on an immature kernel.
e Severe stripe rust covering plots of a susceptible variety.
f Stripe rust destroyed the crop of a susceptible variety in an experimental plot.
g Black telia on a wheat leaf

Stripe Rust (Yellow Rust)

Puccinia striiformis

Symptoms: The pustules of stripe rust, which, contain yellow to orange-yellow urediospores, usually form narrow stripes on the leaves. Pustules also can be found on leaf sheaths, necks, and glumes.

Development: Primary infections are caused by wind-borne urediospores that may have travelled long distances. The disease may develop rapidly when free moisture (rain or dew) occurs and temperatures range between 10-20C. At temperatures above 25C, the production of urediospores is reduced or ceases and black teliospores are often produced.

Host/Distribution: Stripe rust can attack wheat, barley, triticale, and many other related grasses. The disease is found in all highland and/or temperate areas where cereals are grown. No alternate host is known in natural conditions- Barberry in green house conditions

Importance: Severe infections can cause yield losses, mainly by reducing the number of kernels per spike, test weights, and kernel quality.

Control:

1. The use of resistant cultivars.
2. Control of volunteer wheat and seeding dates.
3. The use of fungicide sprays

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Leaf rust

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Leaf Rust (Brown Rust)

Puccinia triticina /Puccinia recondita

Symptoms: The postules are **circular or slightly elliptical, smaller than those of stem rust**, usually **do not coalesce**, and contain masses of **orange to orange-brown urediospores** Infection sites primarily are found on the upper surfaces of leaves and leaf sheaths, and occasionally on the neck and awns.

Development: Primary infections usually are light and develop from wind-borne urediospores that may have travelled long distances. The disease can develop rapidly when free moisture is available and temperatures are near 20C. Successive generations of urediospores can be produced every 10-14 days if conditions are favorable. As plants mature or when environmental conditions are not favorable, masses of black teliospores may become evident.

Hosts/Distribution: Leaf rust can affect wheat, triticale and many other related grasses. The disease is found wherever temperate cereals are grown. The alternate hosts are *Thalictrum*, *Isopryum*, *Anemonella*, and *Anchusa* spp.

Importance: Severe early infections can cause significant yield losses, mainly by reducing the number of kernels per spike, test weights, and kernel quality.

Control:
1. The use of resistant cultivars.
2. Control of volunteer wheat and seeding dates.
3. The use of fungicide sprays.

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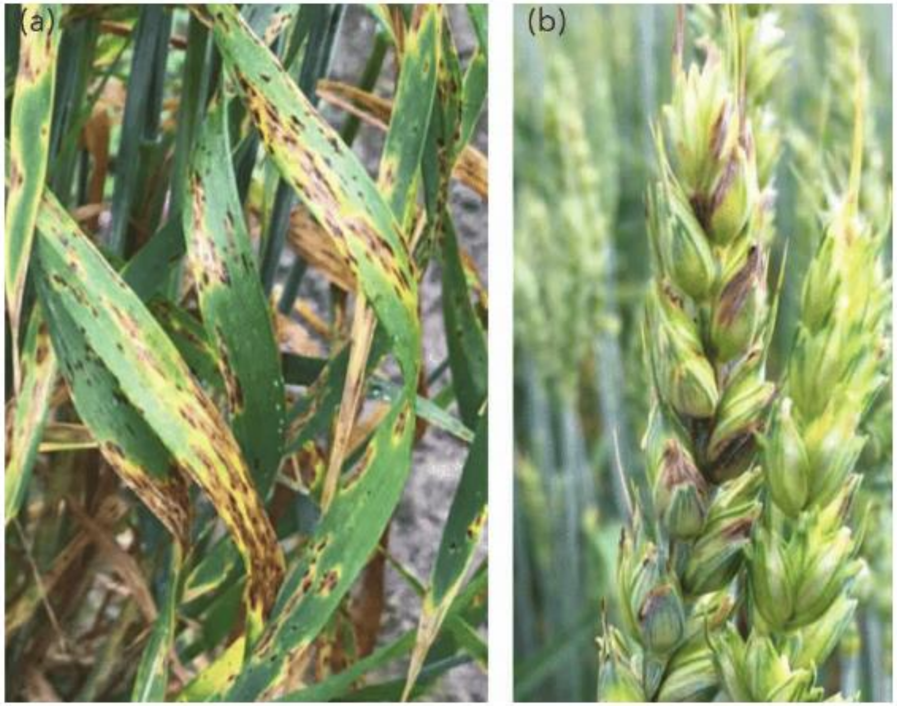
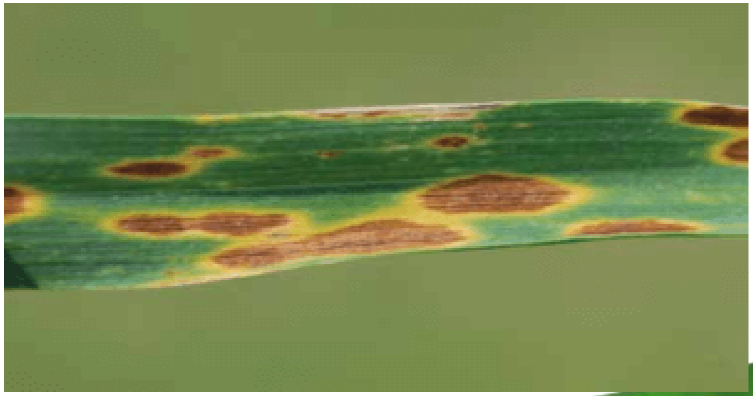
Septoria Nodorum Blotch-Leptosphaeria nodorum (S. nodorum)



Symptoms of Septoria nodorum blotch in wheat. (a) Symptoms on leaves, photographed by Morten Lillemo. (b) Symptoms on head, photographed by Andrea Ficke.



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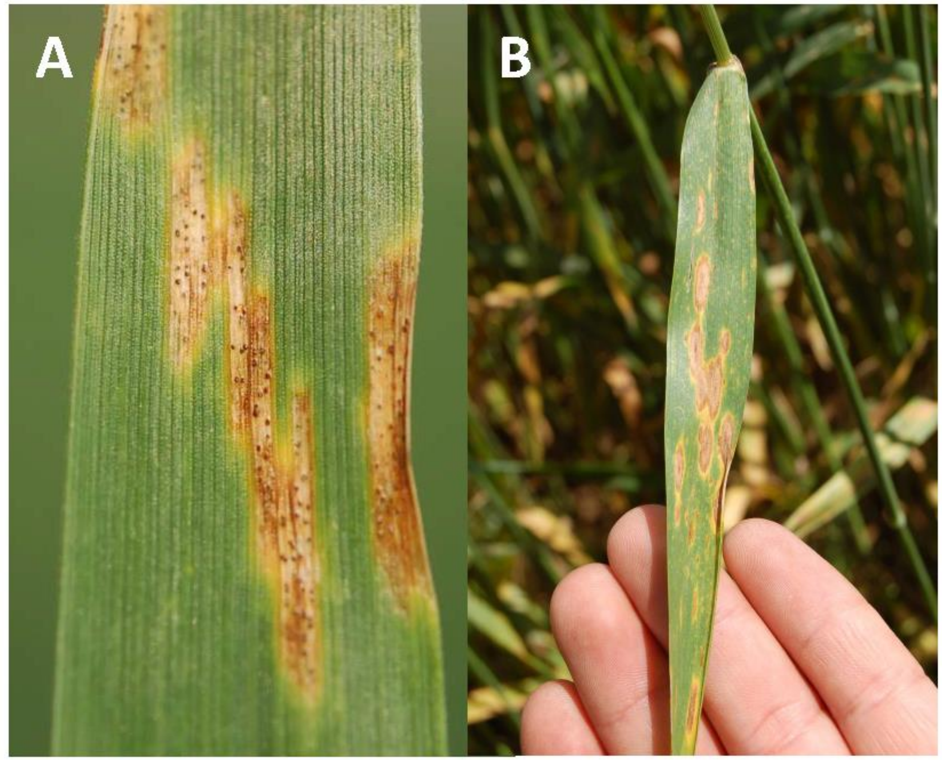

Typical symptoms of Septoria tritici blotch with distinct black pycnidia

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Septoria Diseases

Septoria Tritici Blotch- Mycosphaerella graminicola (Septoria tritici)
Septoria Nodorum Blotch-Leptosphaeria nodorum (S. nodorum)

Symptoms: Initial infection sites tend to be **irregular in shape, oval to elongated chlorotic spots** or **lesions**. As these sites expand, the centers of the lesions become **pale, straw colored, and slightly necrotic**, **often with numerous small black dots (pycnidia).** The lesions of septoria tritici blotch tend to be **linear and restricted laterally**, while those of septoria nodorum blotch are more **lens shaped**. All above ground plant parts can be affected. Light infection produces only scattered lesions, but heavy infection can kill leaves, spikes, or even the entire plant. Identification of species in the field can be difficult, and microscopic examination is often necessary.

Development: Initial infections tend to be on the lower leaves, progressing to the upper leaves and spikes if environmental conditions remain favorable. Cool temperatures (10-15C) and prolonged wet, cloudy weather favors the development of these diseases.

Hosts/Distribution: These are primarily diseases of wheat, but other cereals are somewhat susceptible. The diseases are limited to temperate wheat-growing areas where cool and moist conditions prevail.

Importance: Major losses can occur, through seed shriveling and lower test weights, if these diseases reach severe levels prior to harvest.

Fusarium Head Blight

Scab (Head Blight)

Fusarium spp. (Fusarium graminearum)

Symptoms: Infected florets (especially the outer glumes) become slightly darkened and oily in appearance. Conidiospores are produced in sporodochia, which gives the spike a bright pinkish color. Infected kernels may be permeated with mycelia and the surface of the florets totally covered by white, matted mycelia.

Development: Several species of Fusarium can attack the spikes of small grain cereals; the ovaries are infected at anthesis, and infection is favored by warm and humid weather during and after heading. Temperatures between 10 and 28C are required for infection. Once primary infection has occurred, the disease can spread from floret to floret by mycelial growth through the spike structure.

Hosts/Distribution: All small grain cereals may be affected by this disease. Fusarium spp. are present in nearly all soils and crop residues.

Kernels of infected grain (also referred as tombstone kernels) are lightweight and shrunken. These kernels can be loss during combining or seed cleaning and result in a lower overall yield. **There is a very low tolerance for infect grain in food and animal feed. This is to protect against harmful toxins produced by the fungus call mycotoxins. DON (deoxynivalenol) is the most common toxin found.** It can cause reduced feed intake in livestock, reduce the baking quality of wheat, and malting and brewing qualities of barley. The disease can also affect the germination rate and seedling vigor if the grain is planted again.

Control:

1. The use of resistant cultivars.
2. Cultutal – quality seed, **residue management, crop rotation, Drying and storage**
3. The use of fungicide sprays

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Barley yellow dwarf

Barley yellow dwarf virus, Cereal yellow dwarf virus

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Barley yellow dwarf

Barley yellow dwarf virus, Cereal yellow dwarf virus

Symptoms vary between cultivars and leaf yellowing may be slight to severe with interveinal chlorosis.

Early severe infections can result in:

•increased number of poorly developed tillers

•reddening of flag leaves

•delayed maturity

•shrivelled grain

•reduced yields.

Late infections may only cause slight yield loss and slightly shrivelled grain.

Vectors

Many species of aphids infest grasses, including cereal crops. Twenty-five have been reported as vectors of BYDVs (for review, see Halbert and Voegtlin, 1995). The most important vectors include *Rhopalosiphum padi*, *R. maidis*, *R. rufiabdominalis*, *Sitobion avenae*, *Metopolophium dirhodum* and *Schizaphis graminum*.

Control

Cultural practices that could help reduce BYDVs incidence include changing sowing dates in order to avoid primary infection through viruliferous aphids, removal of cereal regrowths and stubble that can act as reservoirs of virus and vectors

As there is no chemical treatment effective against the virus, chemical control of BYDVs can only be achieved through control of its vectors

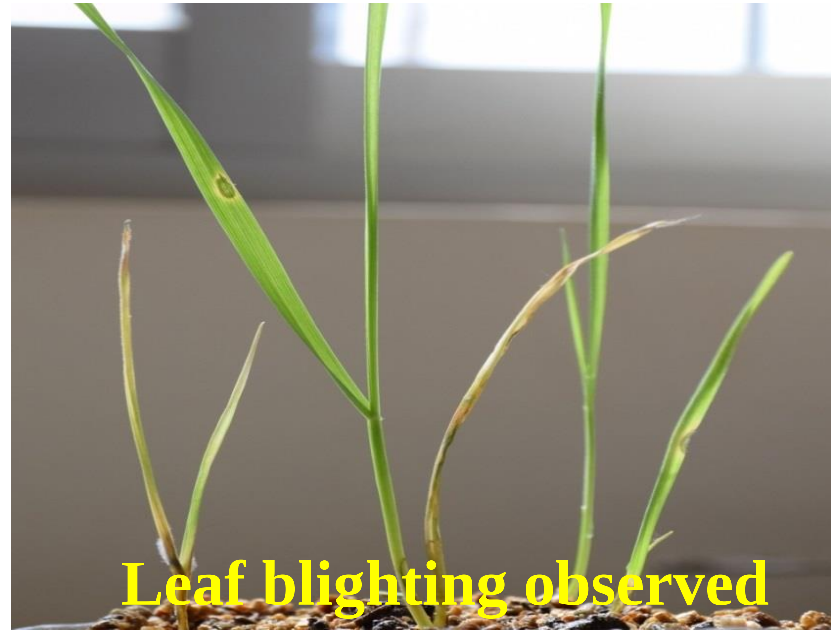
Genetic resistance

Wheat Blast

- Discovered in Parana State of Brazil in 1985 and since then spreading to an area of about 3.0 mha causing losses of 10-100% depending on years, genotypes, planting date and environment.
- Reported in C & S Brazil, low lying areas of Santa Cruz region of Bolivia, S and SE Paraguay, and NE Argentina.
- Observed in Bangladesh in 2016

Wheat Blast-Symptoms

Symptoms looks like FHB



Leaf blighting observed

Grains shriveled, poorly developed

Spores of *Magnaporthe oryza*

Wheat Blast is SCARY!!!- ZAMBIA

Damage can increase in intensity and spread due to:

- Wheat blast is seed borne and airborne disease
- No durable resistant cultivars and most are susceptible.
- Pathogen population is very diverse, exhibits many pathotypes that could cross-infect different hosts and overcome resistance.
- Fungicide schemes are partially effective under medium to low disease pressure. Pathogen shows ability to develop fungicide resistance.
- Wheat producing regions including Bangladesh, *India*, USA and Ethiopia might be at additional risk as their climatic conditions are similar to blast endemic regions.

Fungicide(s)					
Class	Active Ingredient	Product	Rate/a (fl. oz)	Stem Rust[1]	Harvest Restriction
Strobilurin	Azoxystrobin 22.9%	Quadris 2.08 SC	6.2 - 10.8	VG	45 days
	Pyraclostrobin 23.6%	Headline 2.09 EC	6.0 - 9.0	G	Feekes 10.5
Triazole	Metconazole 8.6%	Caramba 0.75 SL	10.0 - 17.0	E	30 days
	Propiconazole 41.8%	Tilt 3.6 EC PropiMax 3.6 EC Bumper 41.8 EC	4.0	VG	Feekes 10.5
	Prothioconazole 41%	Proline 480 SC	5.0 - 5.7	VG	30 days
	Tebuconazole 38.7%	Folicur 3.6 F[2]	4.0	E	30 days
	Prothioconazole 19% Tebuconazole 19%	Prosaro 421 SC	6.5 - 8.2	E	30 days
Mixed mode of action	Metconazole 7.4% Pyraclostrobin 12%	TwinLine 1.75 EC	7.0 - 9.0	VG	Feekes 10.5
	Propiconazole 11.7% Azoxystrobin 7.0%	Quilt 200 SC	14.0	VG	Feekes 10.5
	Propiconazole 11.7% Azoxystrobin 13.5%	Quilt Xcel 2.2 SE	14.0	--[3]	Feekes 10.5
	Propiconazole 11.4% Trifloxystrobin 11.4%	Stratego 250 EC	10.0	VG	35 days

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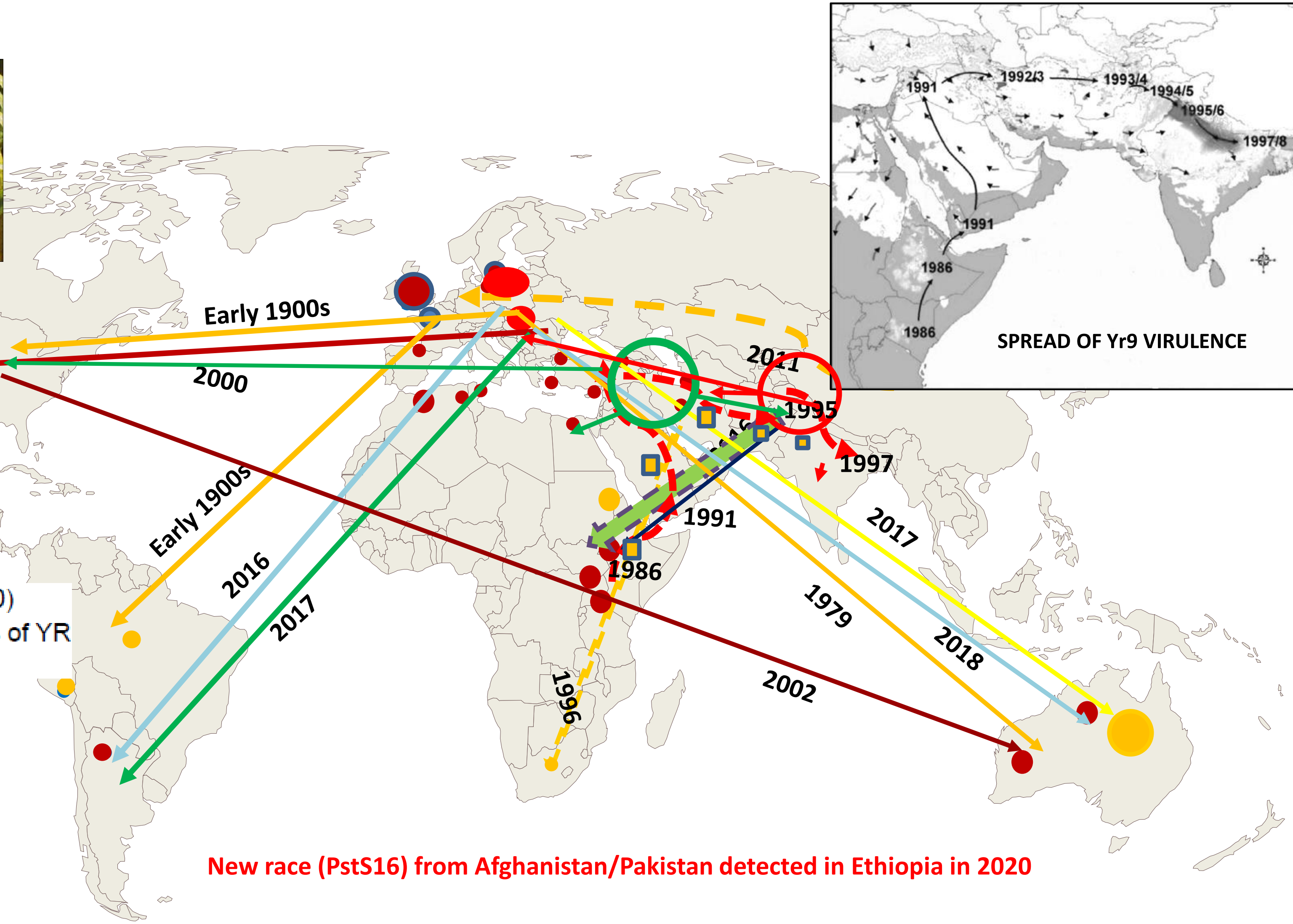
Spread of aggressive *Puccinia striiformis* (yellow rust) races

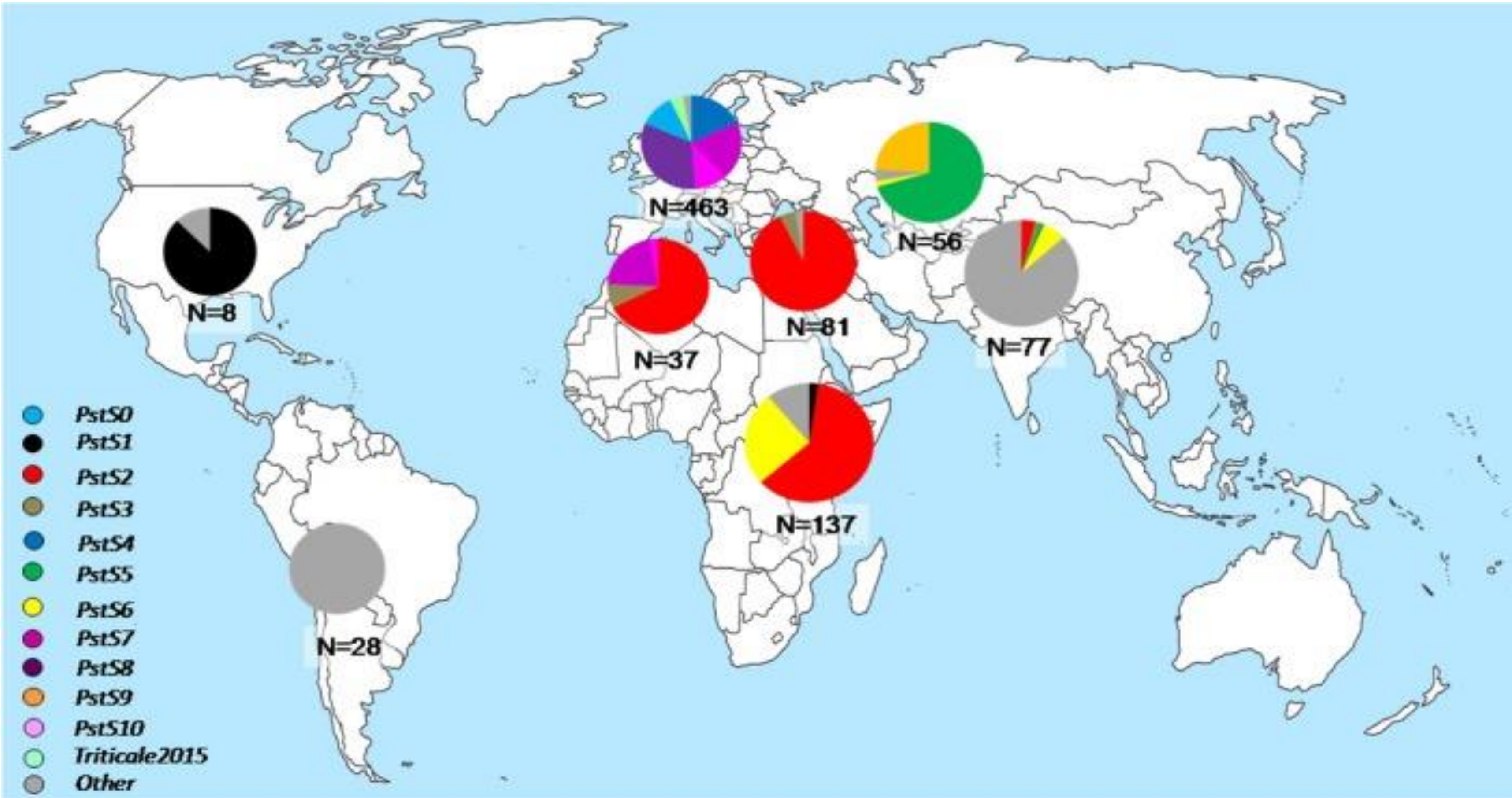


- PstS10
- PstS11
- PstS13
- PstS14
- PstS1/S2
- PstS16

Yr27 breakdown (2002-2004)

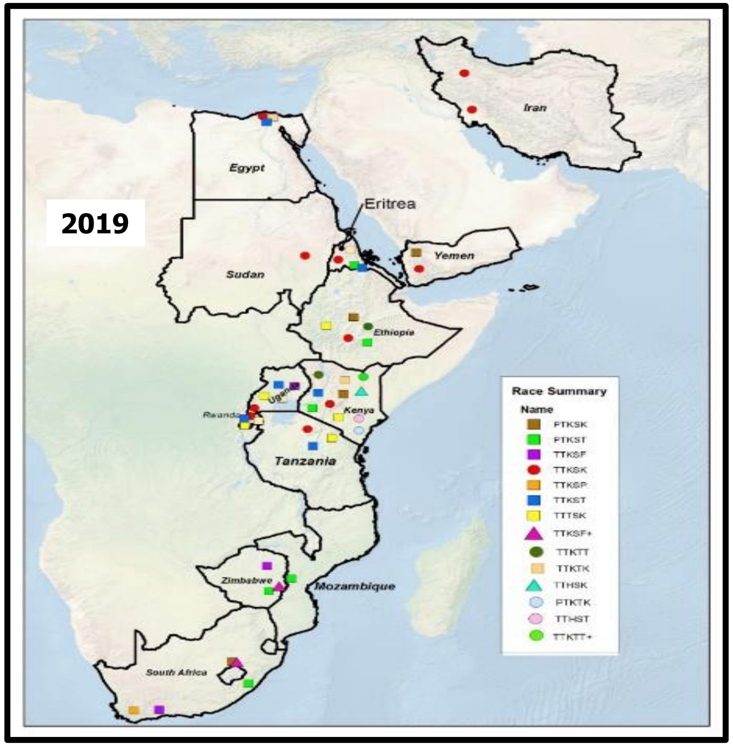
- New emerging genetic groups of yellow rust
- Faster transcontinental spread
- Localized severe epidemics

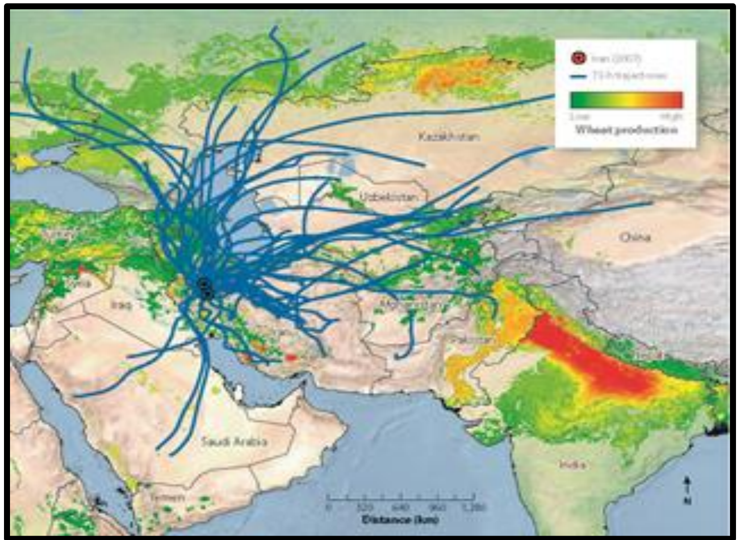
Source: Updated from Ali et al. (2014) PLoSPathog10(1): e1003903. doi:10.1371/journal.ppat.1003903



Different colors show different lineages identified from global samples during 2009-2015 at GRRC, Denmark **Source: Ali et al. (2017) Front Plant Sci 8: 1057.**

Stem rust Ug99: a global threat?



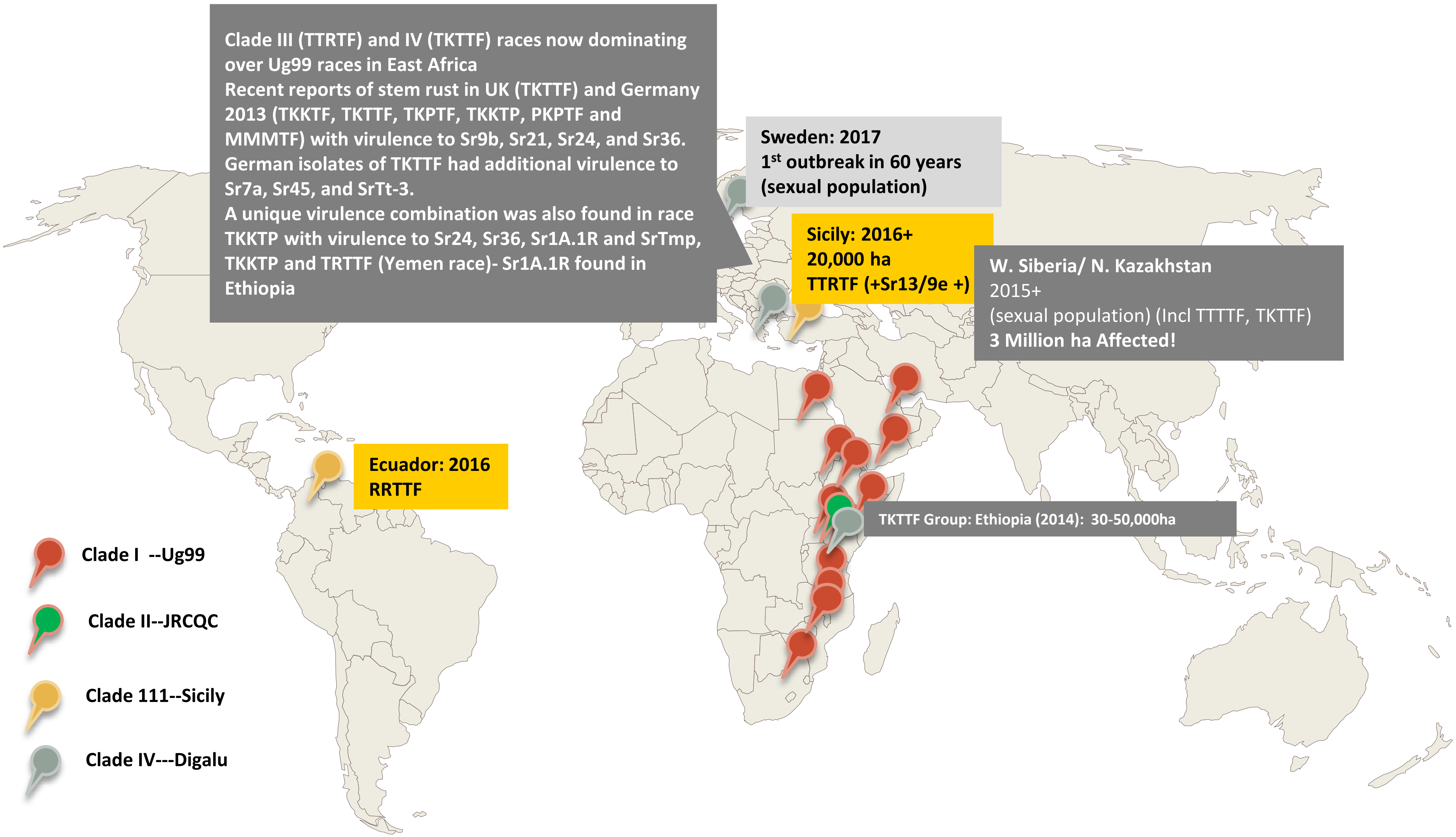


- **>80%** of wheat varieties grown world wide found susceptible when tested in Kenya
- **Migrated** from Uganda to 13 different countries (S. Africa - Middle East- Iran)
- **Highly aggressive** - broad virulence spectrum

> 50% SR genes rendered ineffective including Sr31

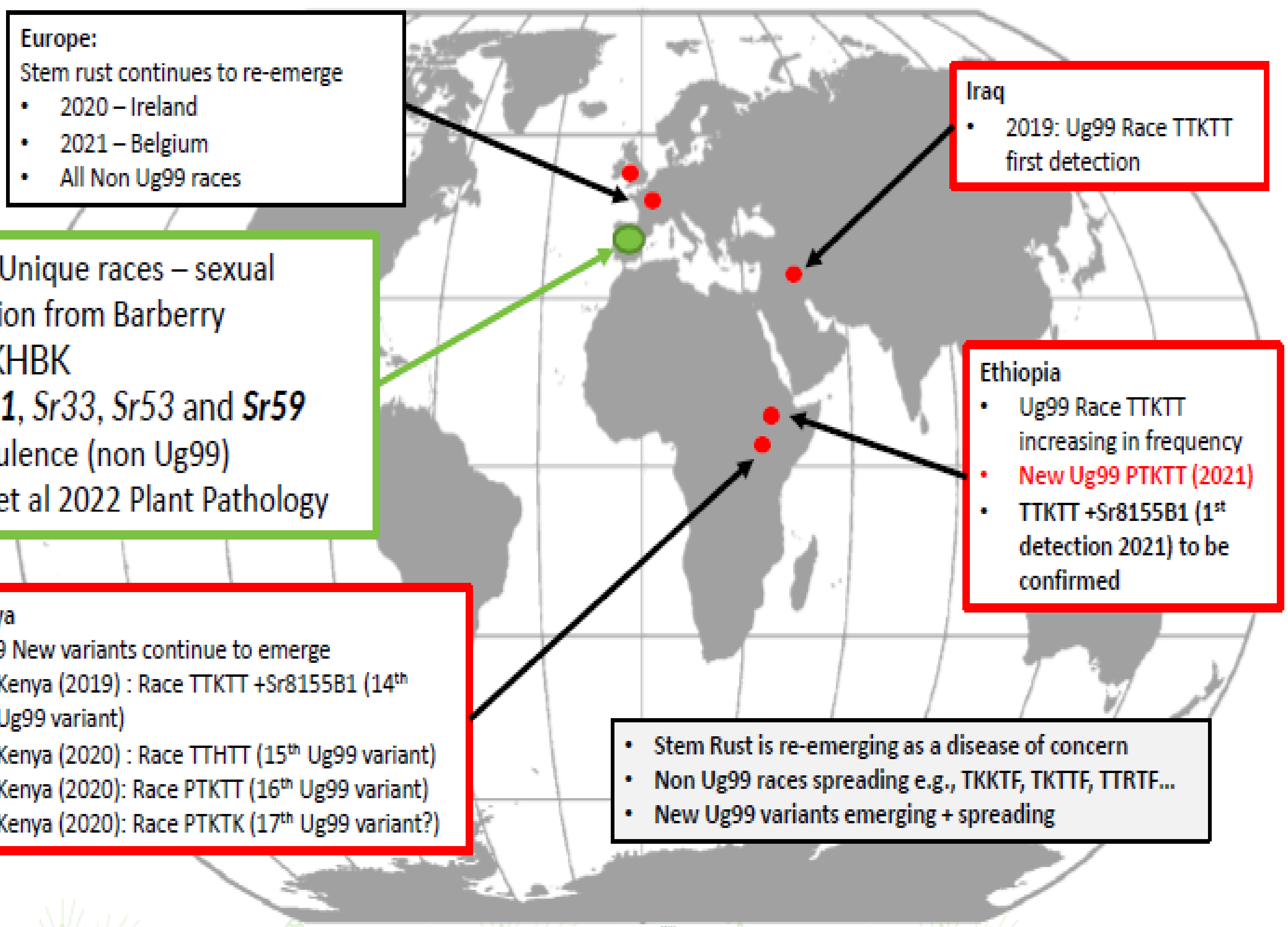
- Continuously evolving **17 races** in identified in the Ug99 lineage
- 9 races evolved in Kenya **(hot spot)**
- Predicted migration to other regions **– S. Asia, East and central Asia and the pacific**
- Early epidemics with susceptible varieties can cause **>70% losses**

Stem rust races: evolution & spread



Sicily race (TTRTF) had confimed virulence for 23 *Sr* genes (IT 3 or higher)
Sr5, *Sr6*, *Sr7a*, *Sr7b*, *Sr8a*, *Sr9a*, *Sr9b*, *Sr9d*, *Sr9e*, *Sr9g*, *Sr10*, *Sr11*, *Sr13 b*, *Sr17*, *Sr21*, *Sr35*, *Sr36*, *Sr37*, *Sr38*, *Sr44*, *Sr45*, *SrTmp*, and *SrMcN*.

Stem rust races : recent update



Europe:
Stem rust continues to re-emerge
- 2020 – Ireland
- 2021 – Belgium
- All Non Ug99 races

Spain – Unique races – sexual population from Barberry
Race TKHBK
Vir: ***Sr31***, *Sr33*, *Sr53* and ***Sr59***
Sr31 virulence (non Ug99)
Olivera et al 2022 Plant Pathology

Iraq
- 2019: Ug99 Race TTKTT first detection

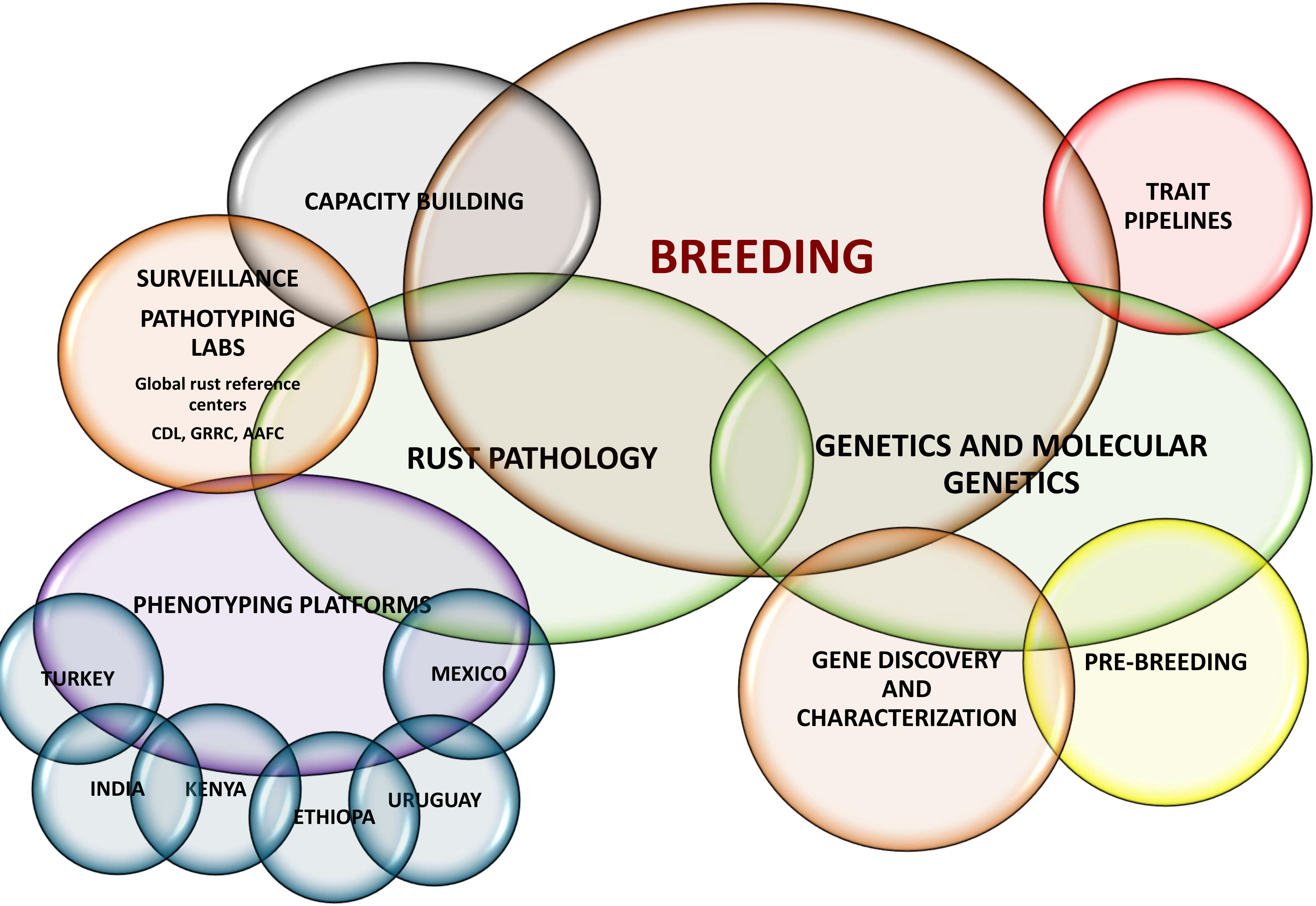
Ethiopia
- Ug99 Race TTKTT increasing in frequency
- New Ug99 PTKTT (2021)
- TTKTT +Sr8155B1 (1st detection 2021) to be confirmed

Kenya
Ug99 New variants continue to emerge
- Kenya (2019) : Race TTKTT +Sr8155B1 (14th Ug99 variant)
- Kenya (2020) : Race TTHTT (15th Ug99 variant)
- Kenya (2020): Race PTKTT (16th Ug99 variant)
- Kenya (2020): Race PTKTK (17th Ug99 variant?)

- Stem Rust is re-emerging as a disease of concern
- Non Ug99 races spreading e.g., TKKTF, TKTTF, TTRTF...
- New Ug99 variants emerging + spreading

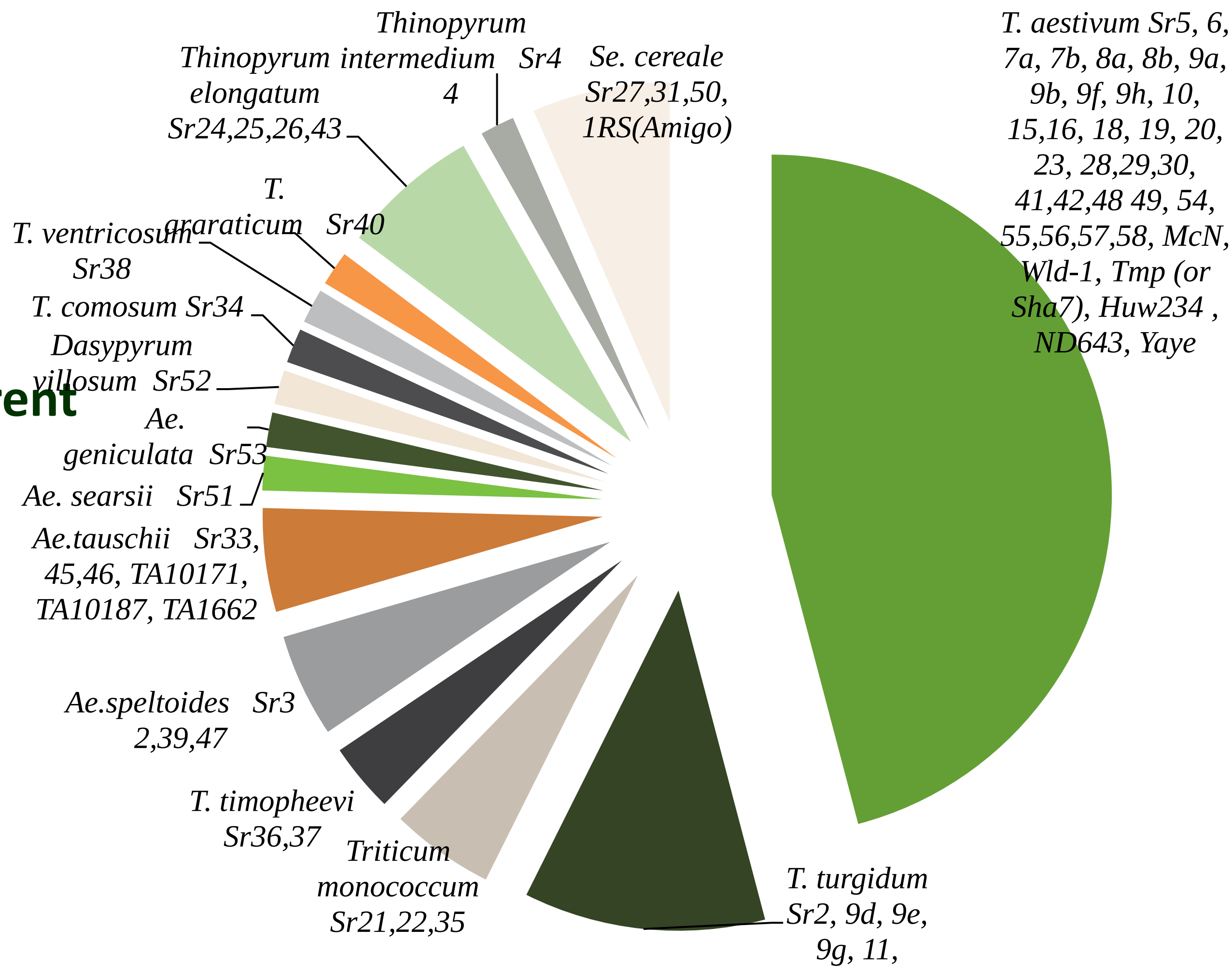
USDA University of Minnesota GRRC GLOBAL RUST REFERENCE CENTER ICARDA EIAR CIMMYT

RUST RESEARCH –BW, DW, Physiology



Stem (black) rust- known resistance genes (63)

- 35 genes from ***Triticum aestivum***
- 38 genes from 14 different species and genera
- Majority race-specific
- Some alien genes successfully used



APR genes for stem rust

Sr2, Sr55, Sr56, Sr57, Sr58

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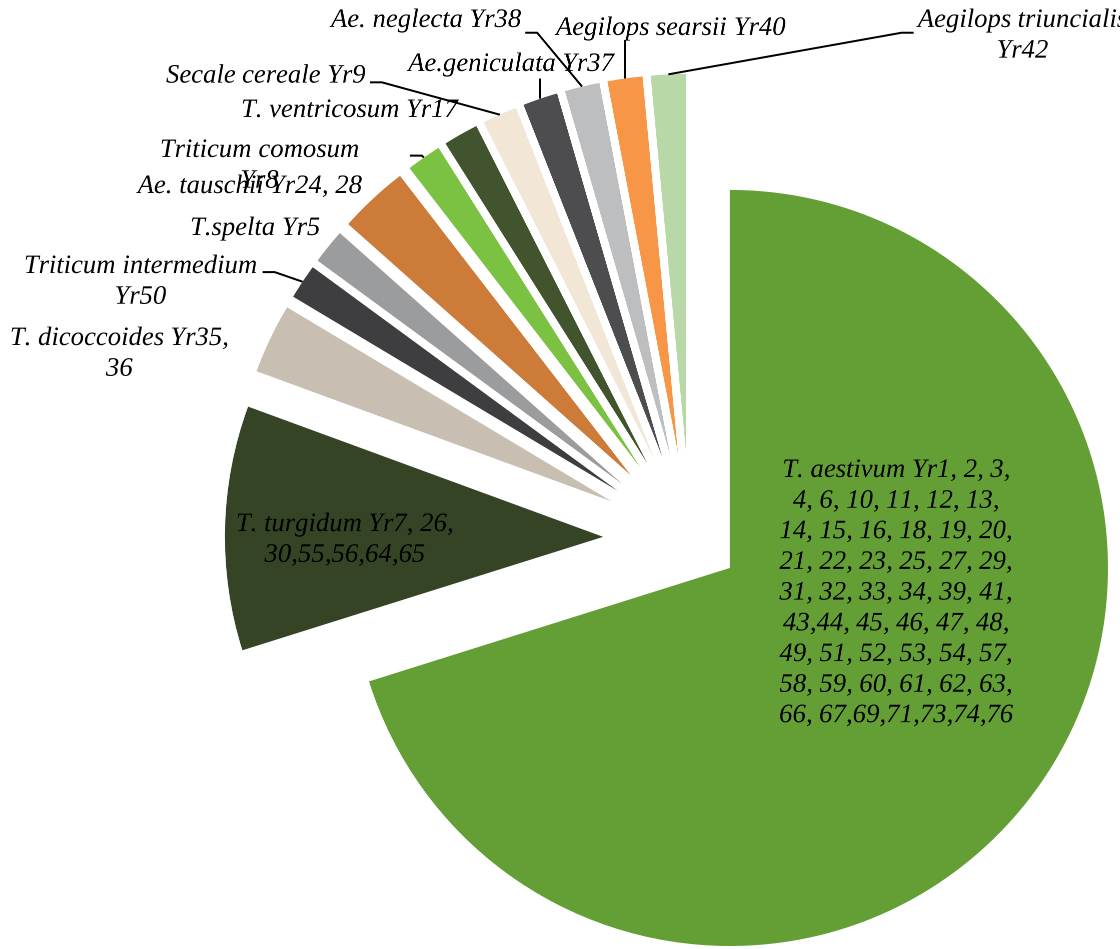
Stripe (yellow) rust (83)



- 52 genes from *Triticum aestivum*
- 20 genes from 11 different species and genera

APR genes for YR

Yr11, Yr12, Yr13, Yr14, Yr16 (2DL), Yr18 (7DS), Yr29 (1BL), Yr30 (3BS), Yr34 (5AL), Yr36 (6BS), Yr39 (7BL), Yr46 (4DL), Yr48 (5AL), Yr49 (3DS), Yr52 (7BL), Yr54 (2DL), Yr56 (2AS), Yr58 (3BS), Yr59 (7BL), Yr60 (4AL), Yr62 (4BL), Yr68 (4BL), Yr71 (3DL), Yr75 (7AL), Yr77 (6DS), Yr78 (6BS), Yr79 (7BL), Yr80 (3BL), Yr82 (3BL)

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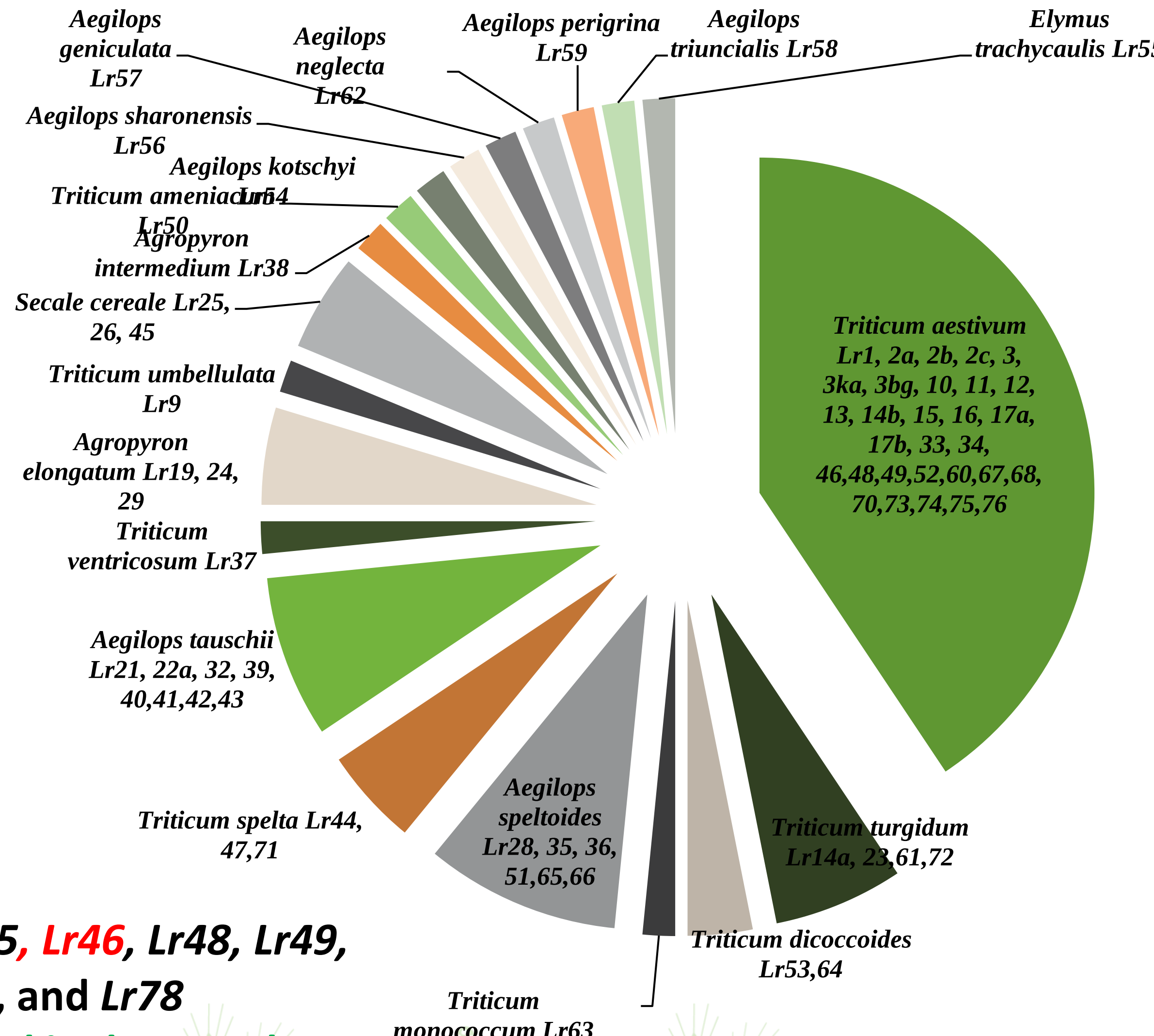
Leaf (brown) rust (80)

– 30 genes from *T. aestivum*
– 39 genes from 19 different species and genera



APR genes for leaf rust

Lr12, Lr13, Lr22a, Lr34, Lr35, Lr46, Lr48, Lr49, Lr67, Lr68, Lr74, Lr75, Lr77*, and *Lr78

Only *Lr46* has been reported in durum wheat

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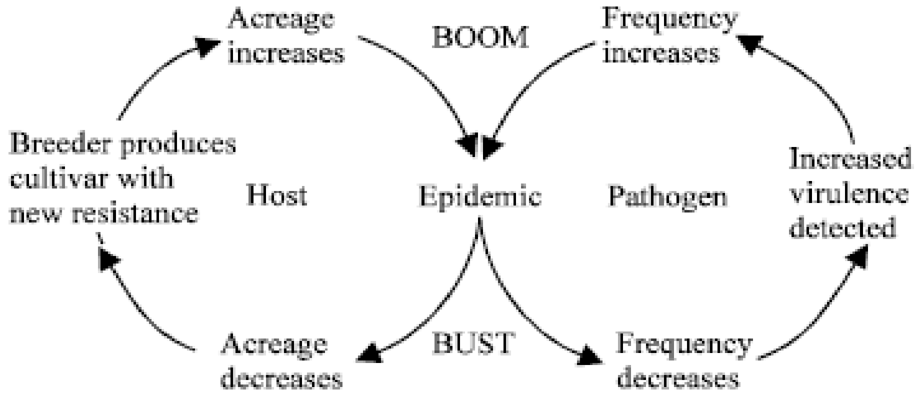
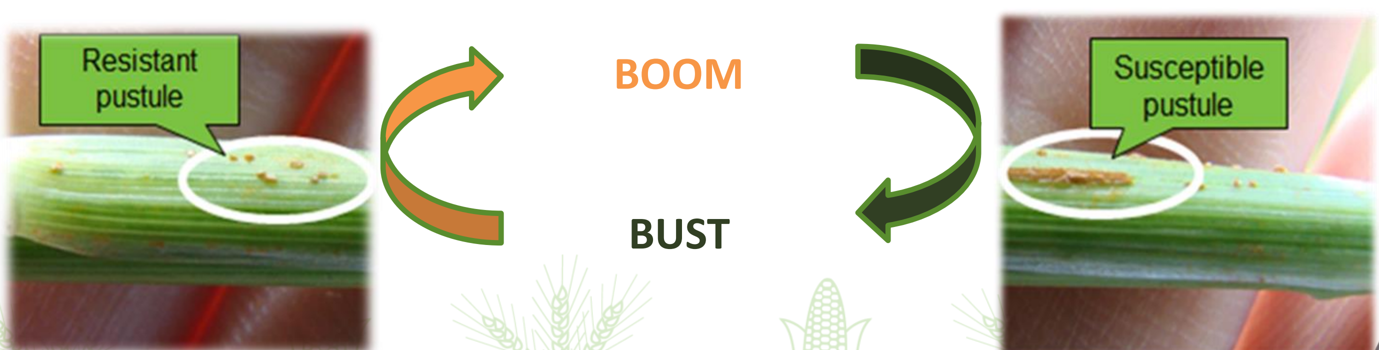


"Ug99" races evolved in Kenya

- **TTKSK (Ug99) 2001**
- **TTKST (Ug99+Sr24) 2006**
- **TTTSK (Ug99+Sr36) 2007**
- **TTKTK (Ug99+Srtmp) 2014**
- **TTKTT (Ug99+ Sr24+Srtmp) 2014**
- **TTKTK (Ug99+Srtmp+ Sr8155-B1 allele) 2018**



Variety Robin
2009
Resistant to "Ug99"

Variety Robin
2014
Susceptible to "Ug99+Srtmp"&
"Digelu" race

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Why APR strategy to enhance durable resistance at CIMMYT?

- Huge diversity of rust races with **unknown virulence(s)**
- **Mutating** and **migrating** nature of rust pathogens
- **Annual virulence analysis and monitoring** required
- Most known race-specific genes **effective in one or more wheat growing regions**
- **Slow variety turnover** in many countries
- **Pleotropic effect** on other diseases
- Opportunity to break-out of **"Boom-and-Bust"** cycles and focus breeding for other important traits

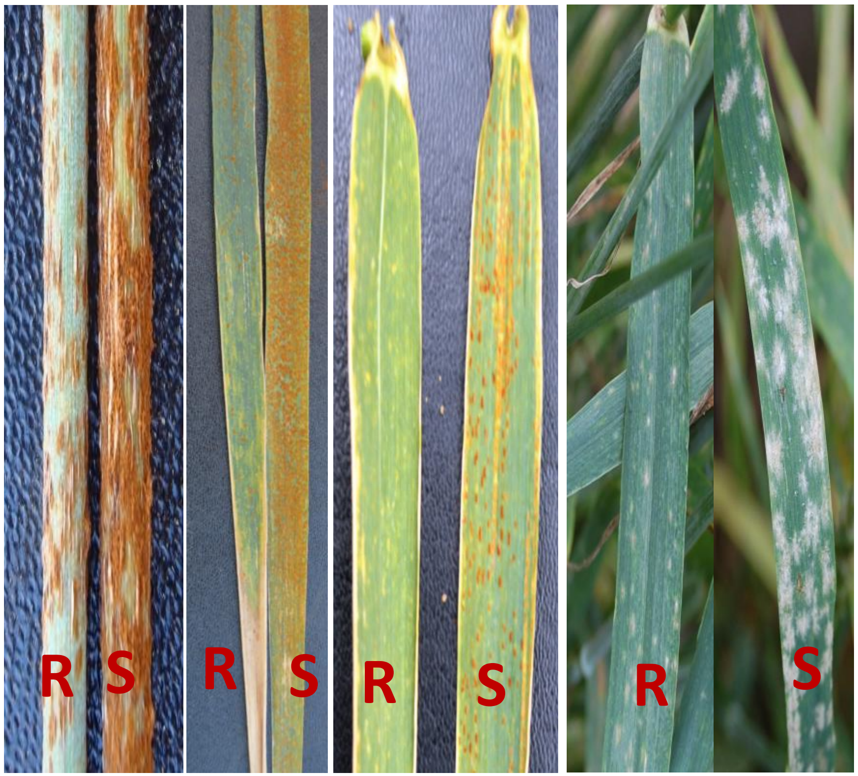
Without durable resistance, stem rust—a formidable and evolving threat to global food security—could cause losses of **$1.12 BILLION**

CIMMYT

Slow rusting, adult plant resistance genes

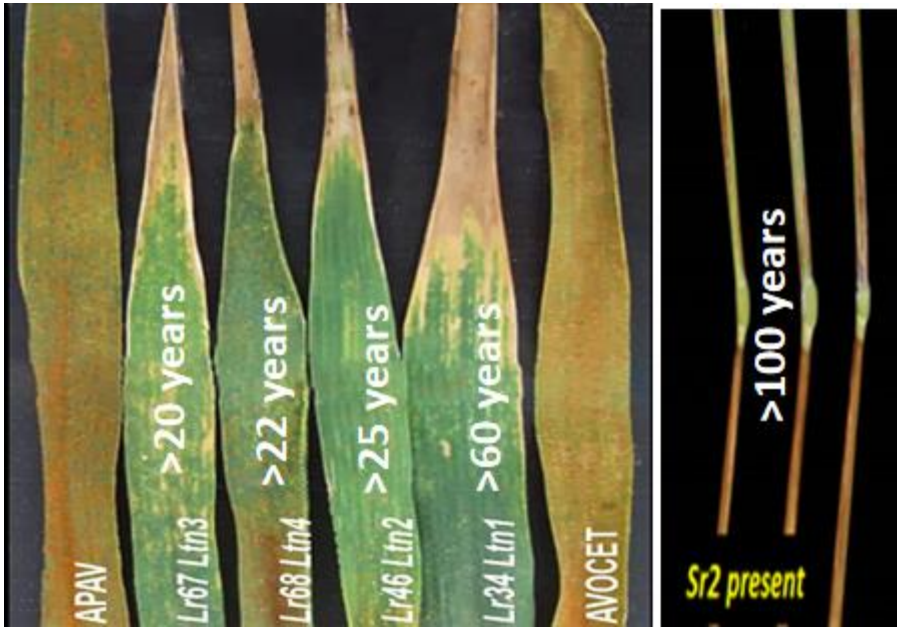
Four catalogued genes confer pleotropic resistance to multiple pathogens (PAPR)

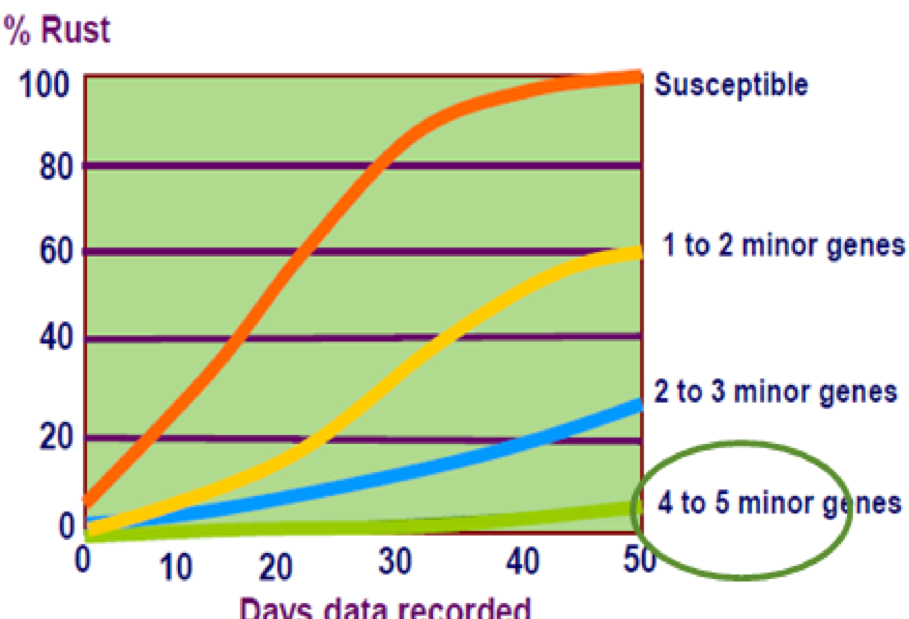
Lr67/Yr46/Sr55/Pm46



- *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, fusarium head blight, leaf tip necrosis)
- *Lr46* [Syn.=*Yr29=Sr58=Pm39=Ts?=Ltn2*] chromosome 1BL
- *Lr67* [Syn.= *Yr46=Sr55=Pm46=Ltn3*] chromosome 4DL (“PI250413”)
- *Sr2/Yr30/Lr* chromosome 3BS
- *Lr68* chromosome 7BL
- **Various consistent QTLs, some with effects on multiple pathogens, e.g. on 1BS, 2AL, 2BS, 2DL, 5AL, 5BL, 6AL and 7BL** (Li et al. 2014. Crop Sci. 54:1907-192)
- **New genomic regions on chromosomes 1BL, 2AS and 6BL in CIMMYT germplasm**

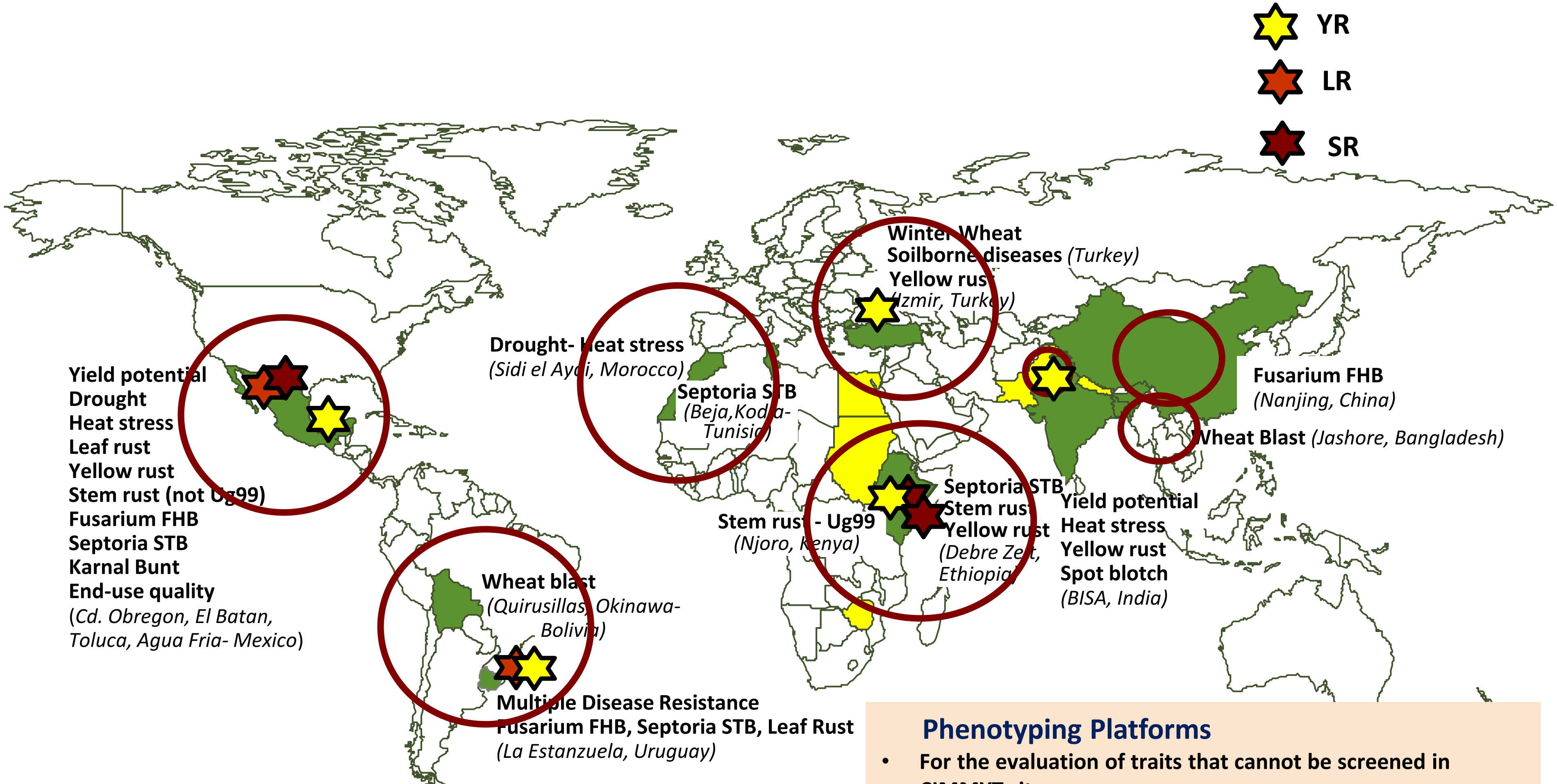




- **Near-immunity (trace to 5% severity) achieved by combining (4-5 genes)**
- **A similar genetics for other leaf spotting diseases, fusarium head blight)**

Reliable phenotyping is Key!!!!!

International wheat disease phenotyping network)



Phenotyping Platforms

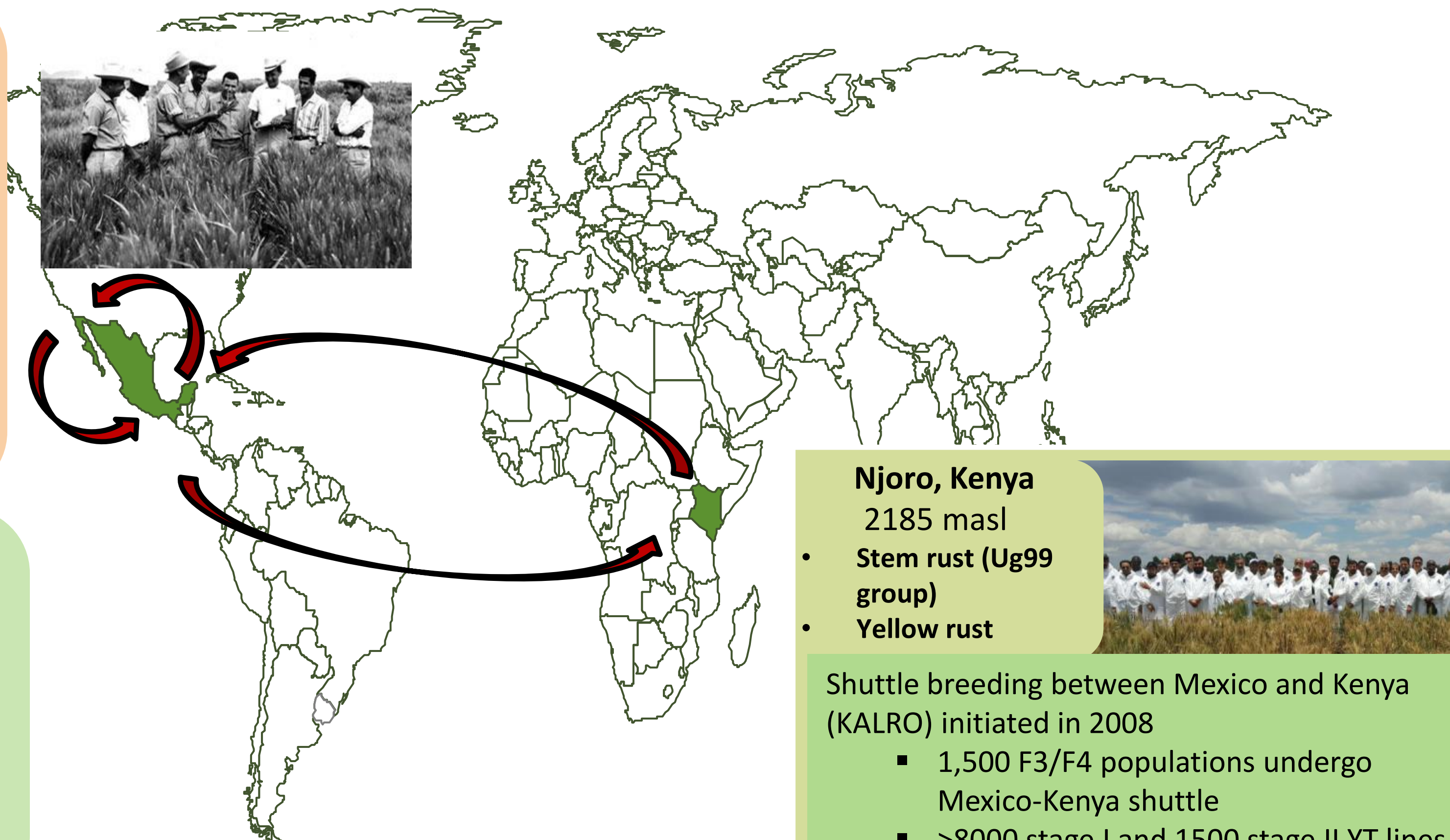
- For the evaluation of traits that cannot be screened in CIMMYT sites
- Platforms hosted by NARs where environments are optimal for specific trait phenotyping
- Hubs for generating high quality phenotypic data, under defined good management practices
- Sites represent hotspots for pathogenic diversity facilitating both evaluation and selection

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

WINTER CYCLE
Cd. Obregon
39 masl
- High yield potential
- (irrigated)
- Water-use efficiency
- Heat tolerance
- Leaf rust
- Stem rust (not Ug99)

SUMMER CYCLE
Toluca
- 2640 masl
- Yellow rust
- Septoria STB

El Batán
2249 masl
- Leaf rust
- Fusarium FHB



Njoro, Kenya
2185 masl
- **Stem rust (Ug99 group)**
- **Yellow rust**

Shuttle breeding between Mexico and Kenya (KALRO) initiated in 2008
- 1,500 F3/F4 populations undergo Mexico-Kenya shuttle
- >8000 stage I and 1500 stage II YT lines evaluated every year
- High yielding, resistant lines distributed worldwide since 2011

Grain yield performance testing of advanced lines Cd. Obregon, Mexico (2018-22)

- 1st year yield trials Irrigated (4500entries + Checks, 2 reps):
  - Raised bed- Optimum irrigation

- 2nd year yield trials or EYT (1400 entries + Checks, 3 reps):
  - Flat- Optimum Irrigation (drip irrigation)
  - Raised bed- Optimum Irrigation
  - Raised bed- Moderate drought stress (1 supplementary Irrigation)
  - Flat- High drought stress (drip irrigation)
  - Raised bed-Late sown (3 months) heat stress
  - Raised bed-Early sown (1 month) heat stress

Yield potential phenotyping- Flat

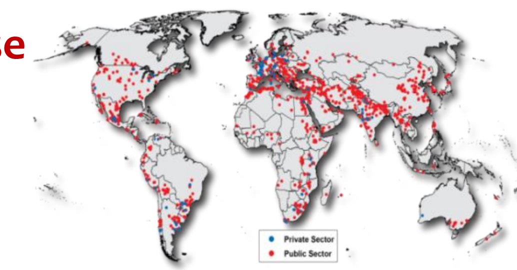
Yield potential phenotyping- Bed

Drought tolerance phenotyping: Drip irrigation

Heat tolerance phenotyping: Late sowing

CIMMYT

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



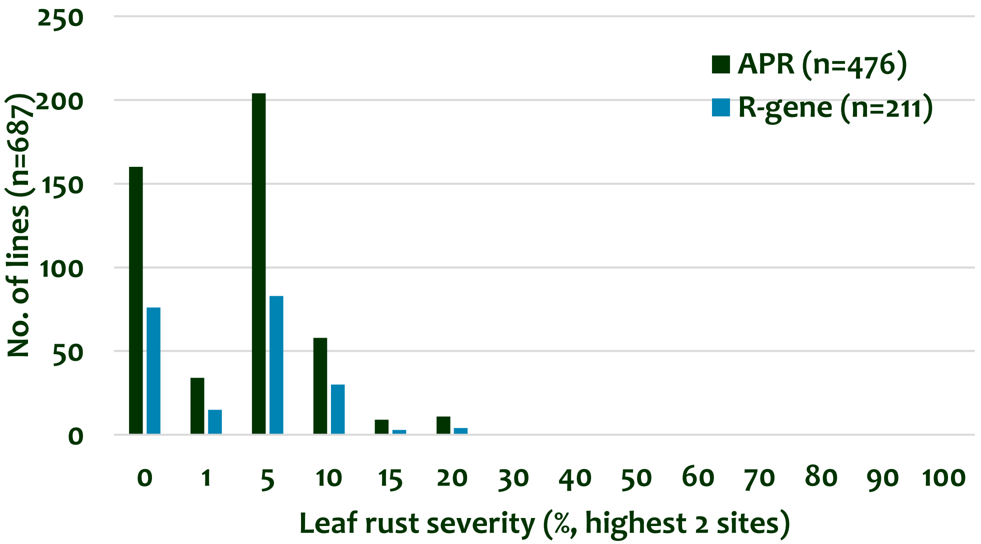
50-150 sets of each trials/nurseries distributed annually worldwide to over 85 countries

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

Slow rusting adult-plant resistance to leaf rust in CIMMYT wheat germplasm

- CIMMYT-derived varieties and breeding materials possess high levels of resistance
- Leaf rust under control for 25 years in countries growing CIMMYT- derived varieties
- *Lr46/Yr29* nearly fixed
- Excellent example of durability

Leaf rust resistance in 687 wheat lines (international distribution in 2020) under high leaf rust pressures

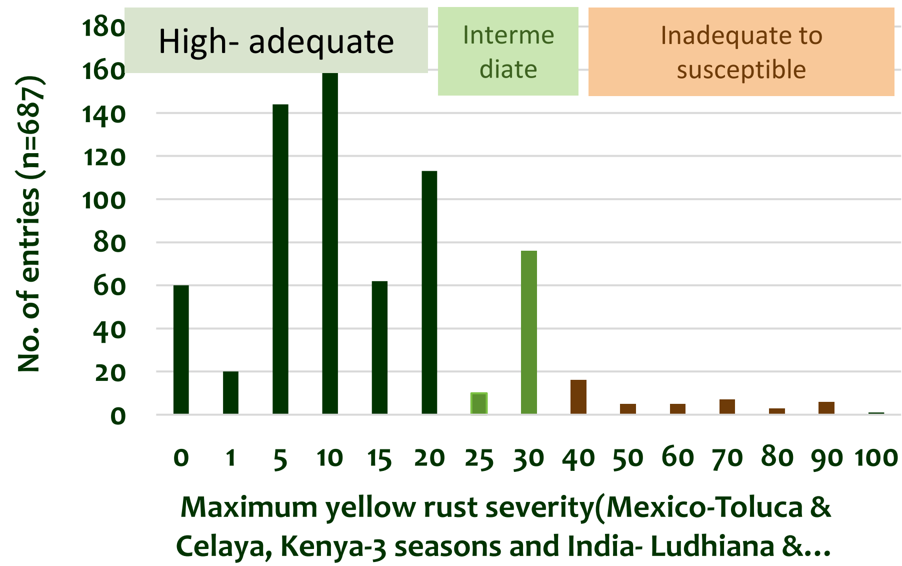


CIMMYT

Achieving all-stage near-immune, multi-genes based resistance to yellow rust

- **4-5 slow rusting genes based APR effective in most areas where infection begins at post stem elongation stages**
- **Early infections in some areas from aggressive races cause juvenile susceptibility**
- **High levels of all-stage resistance from interactions of slow rusting genes with small/ intermediate effect race-specific genes; e. g. *Yr48* (5AL), *Yr54* (2DL), *Yr60* (4BL), *Yr67* (7BL), etc.**
- **Simultaneous field-based selection for resistance with other agronomic traits increases genetic gains**

Highest yellow rust severity of 687 wheat lines at 5 field sites/environments under high disease pressures



- **Highly resistant lines in Mexico show varying resistance levels in Kenya and India due to presence to different races & environment**
- ***Phenotyping efforts increased in India and Kenya for culling***

CIMMYT

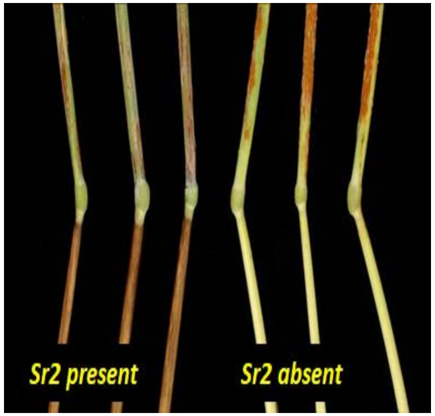
Progress in breeding Ug99 stem rust resistance in CIMMYT wheats: resistance in current international trials and nurseries

- **10-15%** lines with high levels of adult plant resistance
- **40-50%** lines with adequate adult plant resistance
- **20-30%** lines with at least 8 race-specific resistance genes (*Sr13a, Sr22, Sr25, Sr26, Sr50, SrND643, SrHuw234, SrNing*)
- **20-30%** lines with inadequate resistance

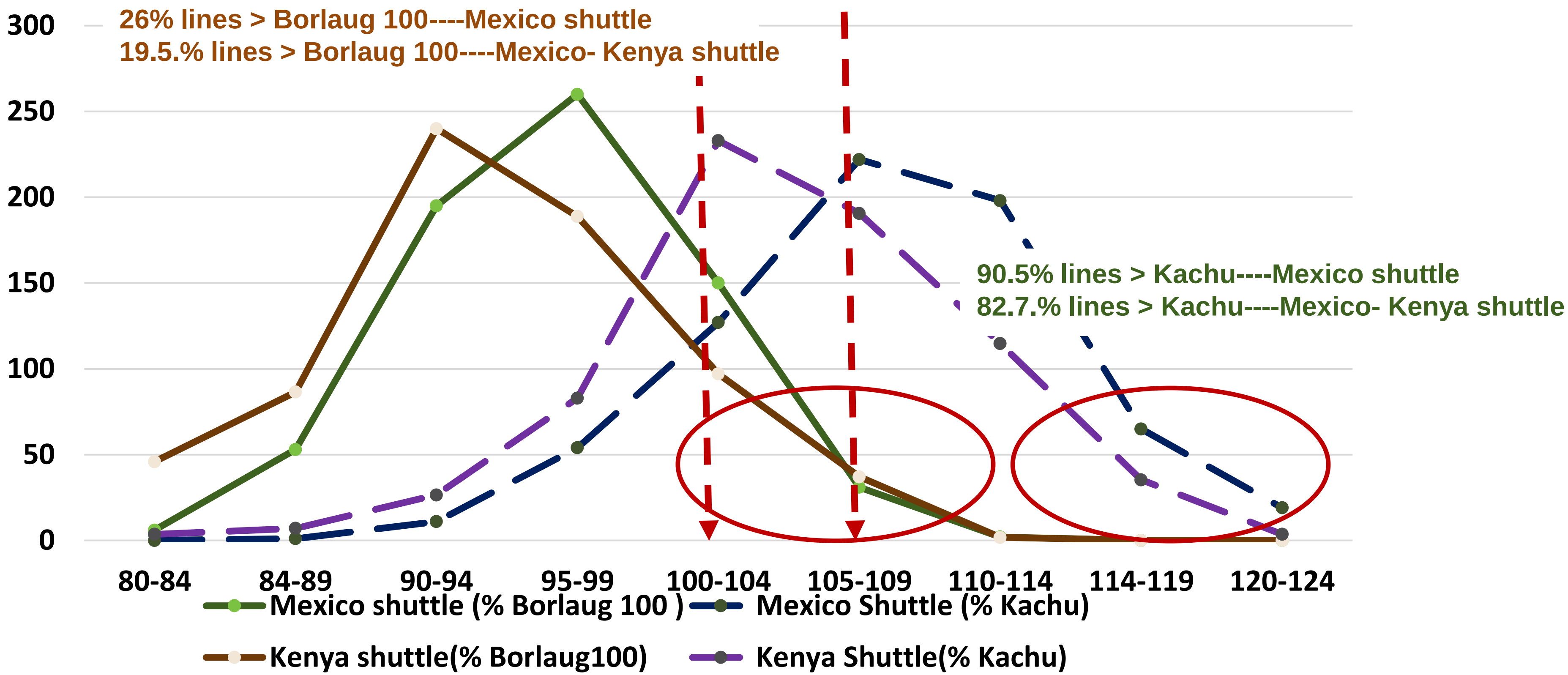
New lines with high yields and high levels of complex adult-plant resistance to stem rust (Njoro, Kenya 2018)

Sr2-Complex
(*Sr2* and other minor genes)

- *Sr2* transferred to wheat from 'Yaroslav' emmer in 1920s by McFadden
- Linked to pseudo-black chaff
- Confers only moderate levels of resistance (about 30% reduction in disease severity)



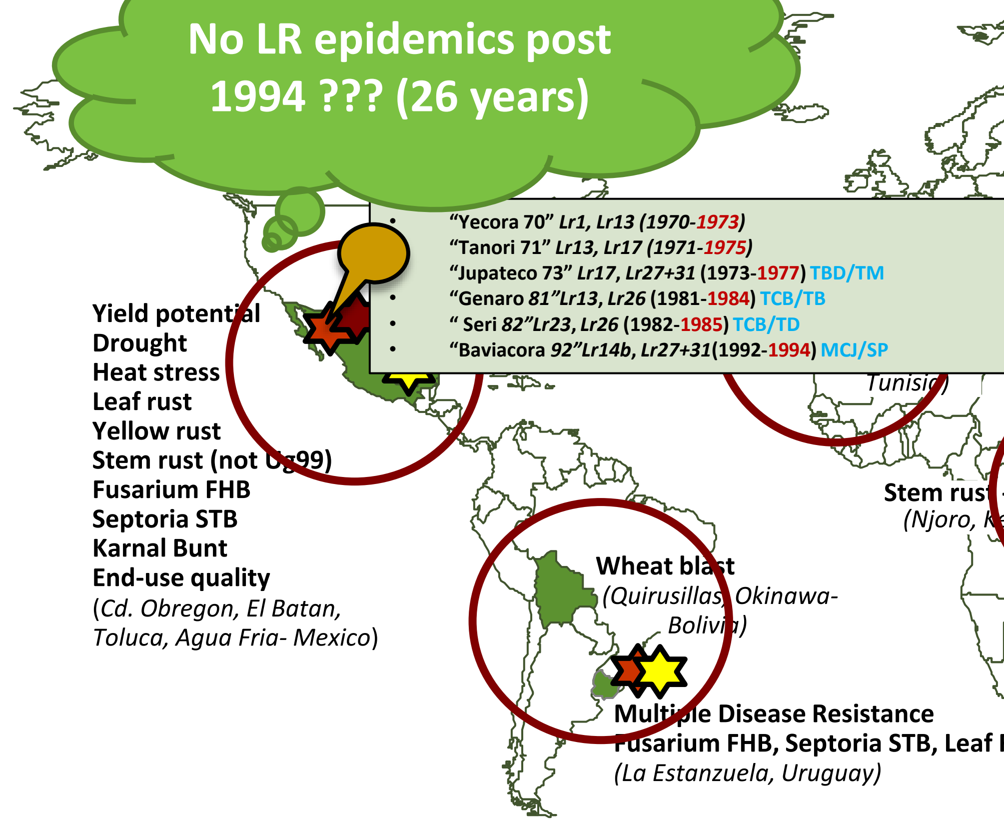
Comparison of grain yield performance of 697 EYT lines (Stage II) 2018-19 derived from Mexico Shuttle and Mexico Kenya Shuttle breeding schemes



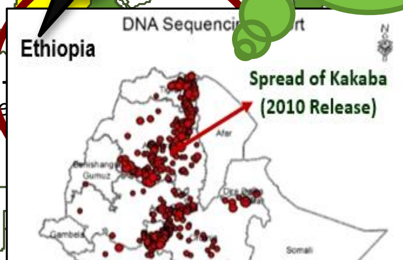
APR based resistance works!!!

Reliable phenotyping is Key

International wheat phenotyping network & Disease phenotyping network



- "Yecora 70" *Lr1, Lr13 (1970-1973)*
- "Tanori 71" *Lr13, Lr17 (1971-1975)*
- "Jupateco 73" *Lr17, Lr27+31* (1973-1977) TBD/TM
- "Genaro 81" *Lr13, Lr26* (1981-1984) TCB/TB
- " Seri 82" *Lr23, Lr26* (1982-1985) TCB/TD
- "Baviacora 92" *Lr14b, Lr27+31* (1992-1994) MCJ/SP



APR varieties in East Africa

- Kakaba (Picaflor) 2010
Pedigree :KIRITATI//SERI-82/RAYON-89
- Currently occupies >**40%** area
- Dandaa (Danphe) 2010
- Kingbird - released in Kenya (and Ethiopia (2015)
u #1) 2018

Leaf rust

Stem rust

Leaf rust resistance breeding since 1967 and projected to 2007, the benefit-cost ratio was found to be **27:1.**

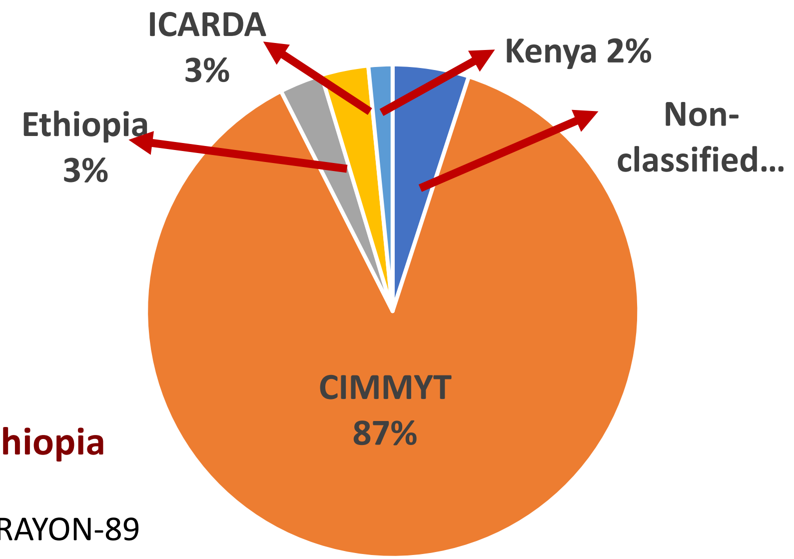
(Marasas et al. 2004)

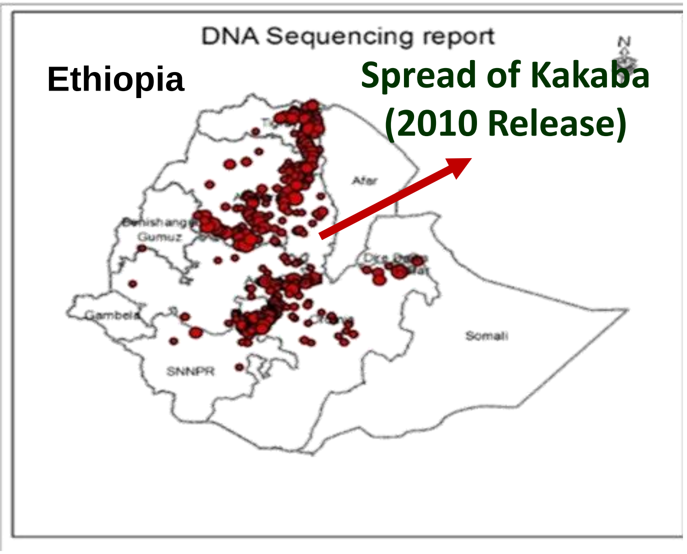
MMYT

Ethiopia: wheat Impact studies using DNA Fingerprinting

Ethiopia

- 89% of samples from all provinces CIMMYT derived varieties
- 55% of sampled households growing rust resistant varieties
- 45% of samples varieties released in last 10 years





APR based varieties in Ethiopia

Kakaba (Picaflor) 2010

Pedigree :KIRITATI//SERI-82/RAYON-89

Currently occupies >40% area

Dandaa (Danphe) 2010

Pedigree : KIRITATI//2*PBW-65/2*SERI-82

Kingbird 2015

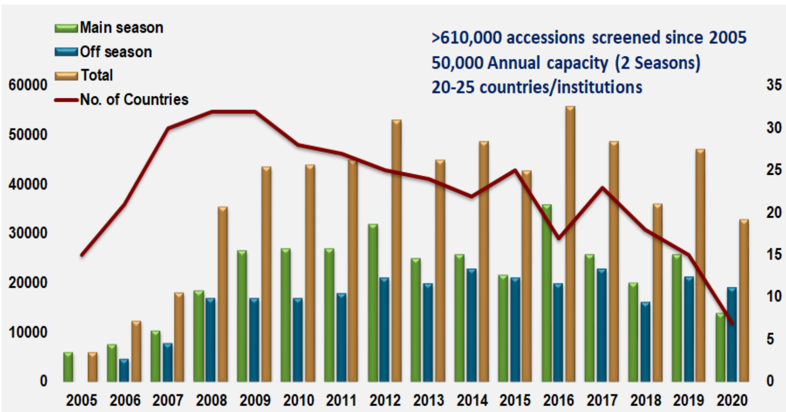
Pedigree : TAM-200/TUI/6/PAVON-76//CAR-422/ANAHUAC-75/5/BOBWHITE /CROW//BUCKBUCK/PAVON-76/3/YECORA-70/4/TRAP-1

Deka (Arableu #1) 2018

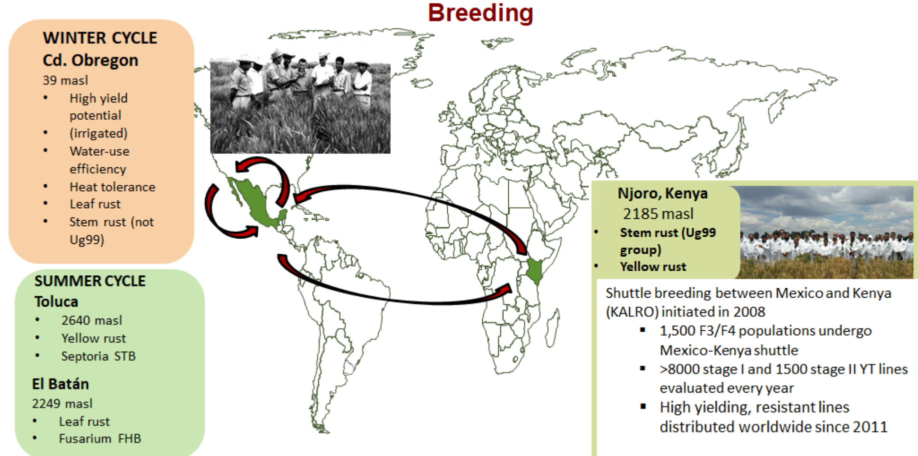
Pedigree Attila/3*Bacanora*2//Baviacora92/3/Kiritati/Weebil#1/4/Danphe

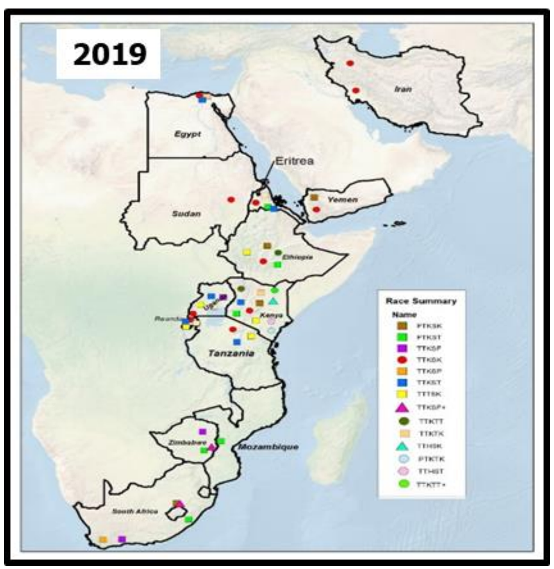
Mitigating the threat of stem rust: PP in Kenya and Ethiopia

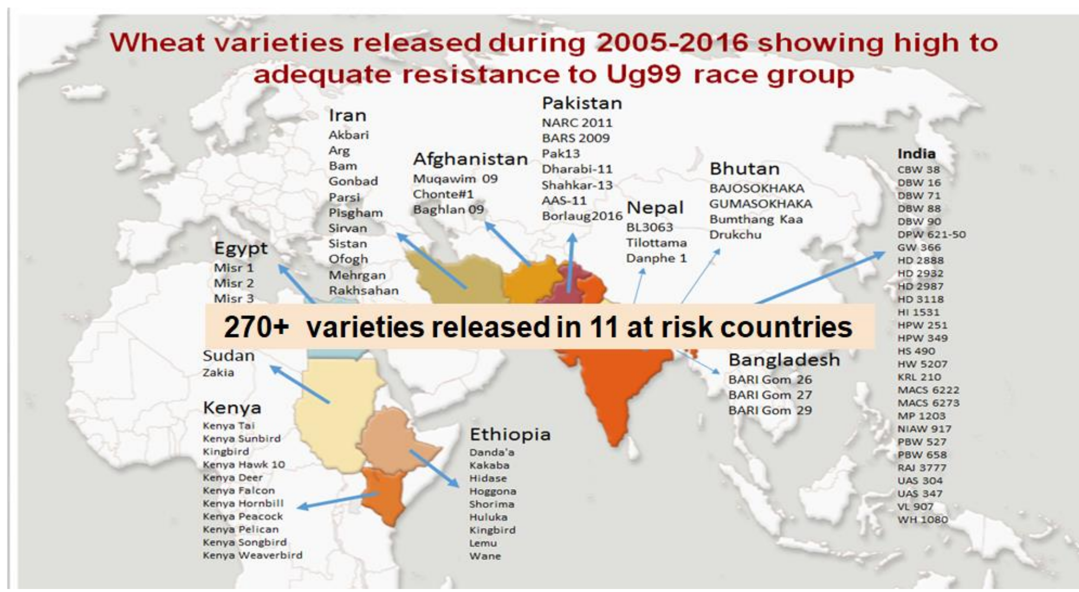
Wheat accessions phenotyped during 2005-2020 for Ug99 resistance at Njoro (Kenya) and participating countries, in partnership with KALRO



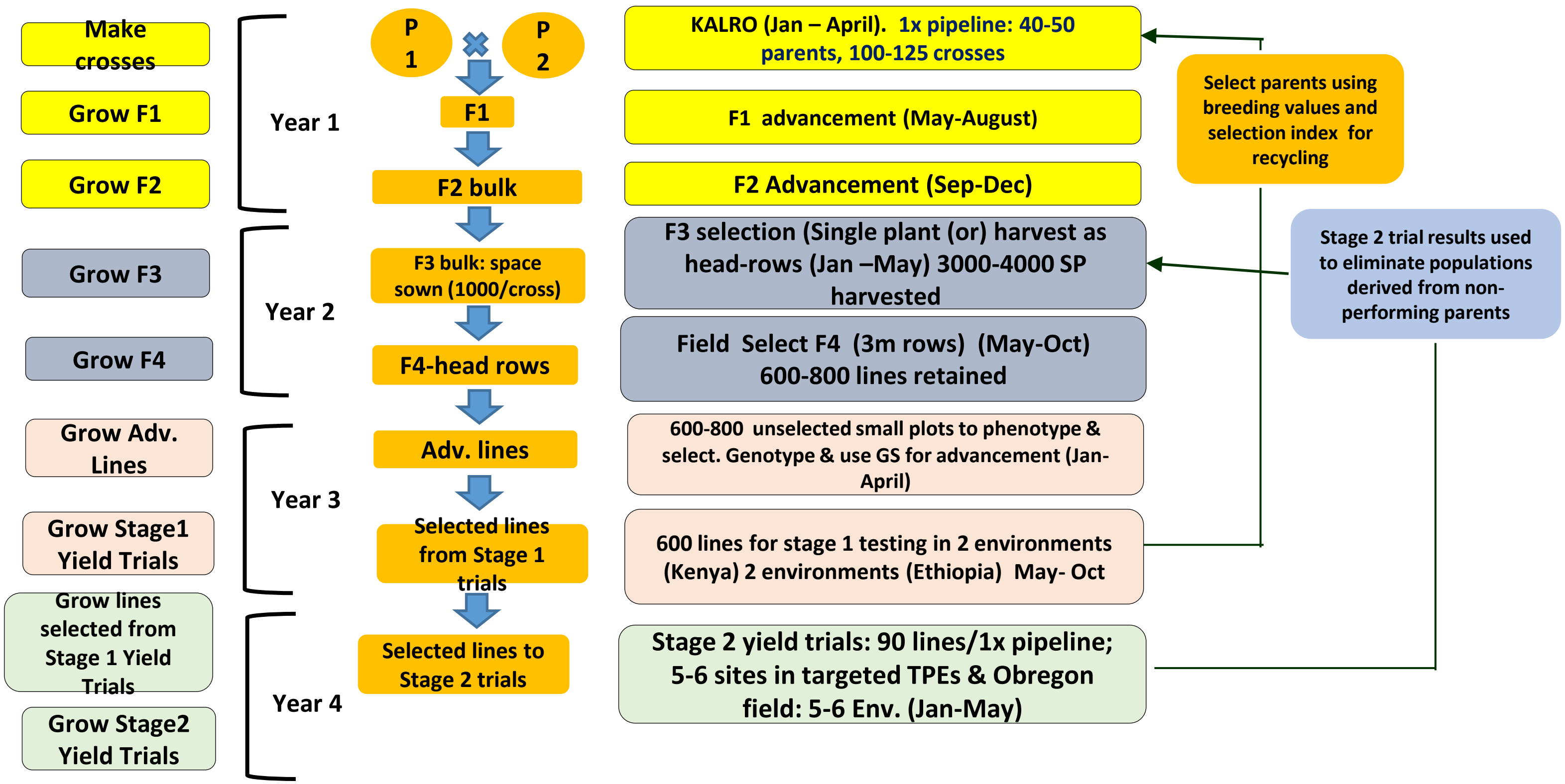
Mexico (Cd. Obregon-Toluca/El Batan)- Kenya International Shuttle Breeding







RBGA Scheme: 3 years breeding cycle- East African breeding pipeline



We can try out possibility of three cycles a year if that can be achieved as a small experiment in 2022 in parallel with a few croses

(East African Wheat Improvement Nursery)

- **Kenya**
- **Ethiopia**
- **Tanzania**
- **Burundi**

Expanding to Rwanda, Nigeria, Zambia and Zimbabwe and private seed companies (Seed co., NASECO, Kenya Seed)

Conclusions

- High genetic diversity is present in wheat germplasm to diseases and pests
- New races of rust fungi, especially yellow rust and stem rust, continue to evolve, mutate and migrate
- Pyramiding 4-5 genes, that individually have small to intermediate effect genes, leads to near-immune, durable resistance to rusts and other fungi
- Breeding should emphasize development of more productive varieties that carry resistance to all important diseases to protect crop without a cost to farmer

Acknowledgements

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DGGW project
HarvestPlus project
Zn Mainstreaming project

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FFAR, USA
ICAR, India
USAID, USA

Farmers' organizations:

Agrovegetal, Spain
GRDC, Australia
Patronato-Sonora, Mexico

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Thank you for your interest!

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