WHAT THE WORLD EATS:

WHEAT

CIMMYT

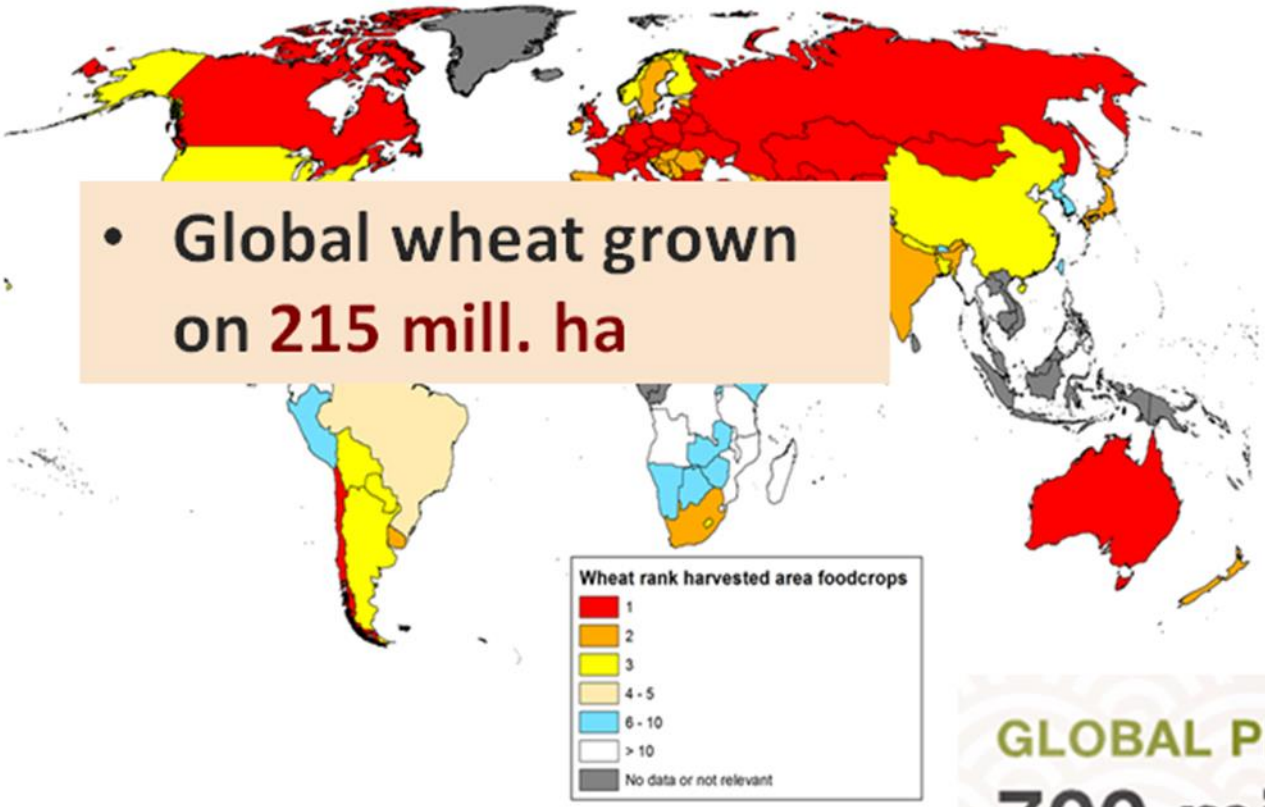
INTERNATIONAL MAIZE AND WHEAT IMPROVEMENT CENTER

Food Security • Hunger & Malnutrition • Economic Development • Climate Change

Importance of wheat

- Globally the most important food crop
- Second most important food crop in the developing world after rice
- Most important protein source in North and South
- Food to 2.5 billion poor people (< 2 USD) crucial crop for “food security”
- Main staple for an estimated 1.2 billion poor (< 2$ per day, “wheat-dependent”)
- Provides calories (20%) and protein (20%) in Low income developing Countries
- Provides income to farmers in 80 developing countries, and over 128 countries in total, including about 170 million poor family members
- Most traded commodity (total export value estimated at 48.6 billion USD)

Wheat importance as area harvested crops



- Global wheat grown on 215 mill. ha

Source: FAO-Stats, 2015

- Globally the most important food crop
- 2nd important food source for 2.5 billion poor (< US$2) in 89 countries
- Crucial role Global Food Security
- Largest traded primary commodity (total export value= 48.6 Billion US$)

Wheat Production by Country

2016-2017 (Metric Tons)

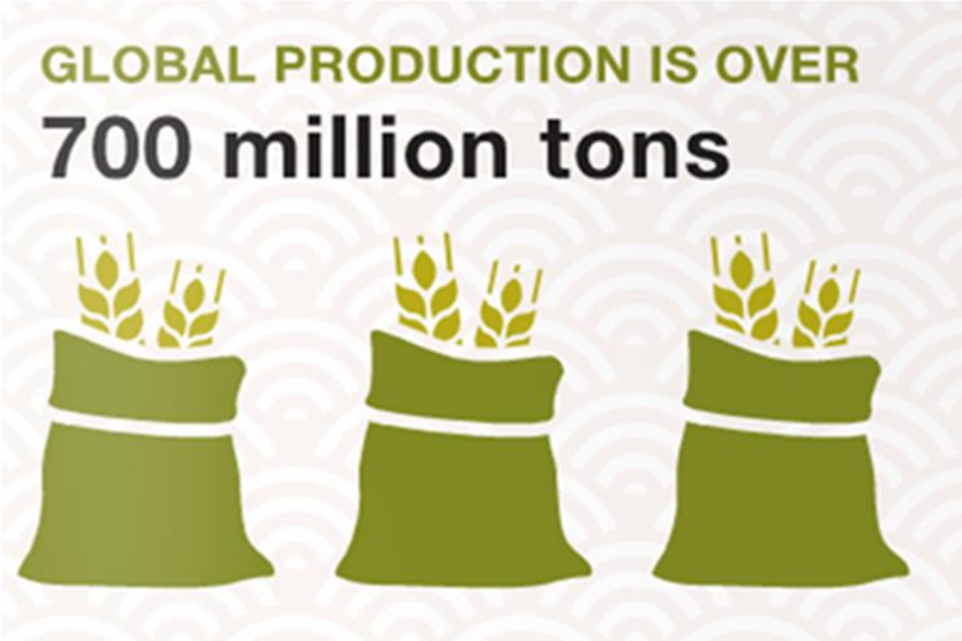
EU-27: 147,500,000

China: 130,000,000

India: 88,000,000

Russia: 72,000,000

United States: 63,156,000



GLOBAL WHEAT PRODUCTION

2017/2018

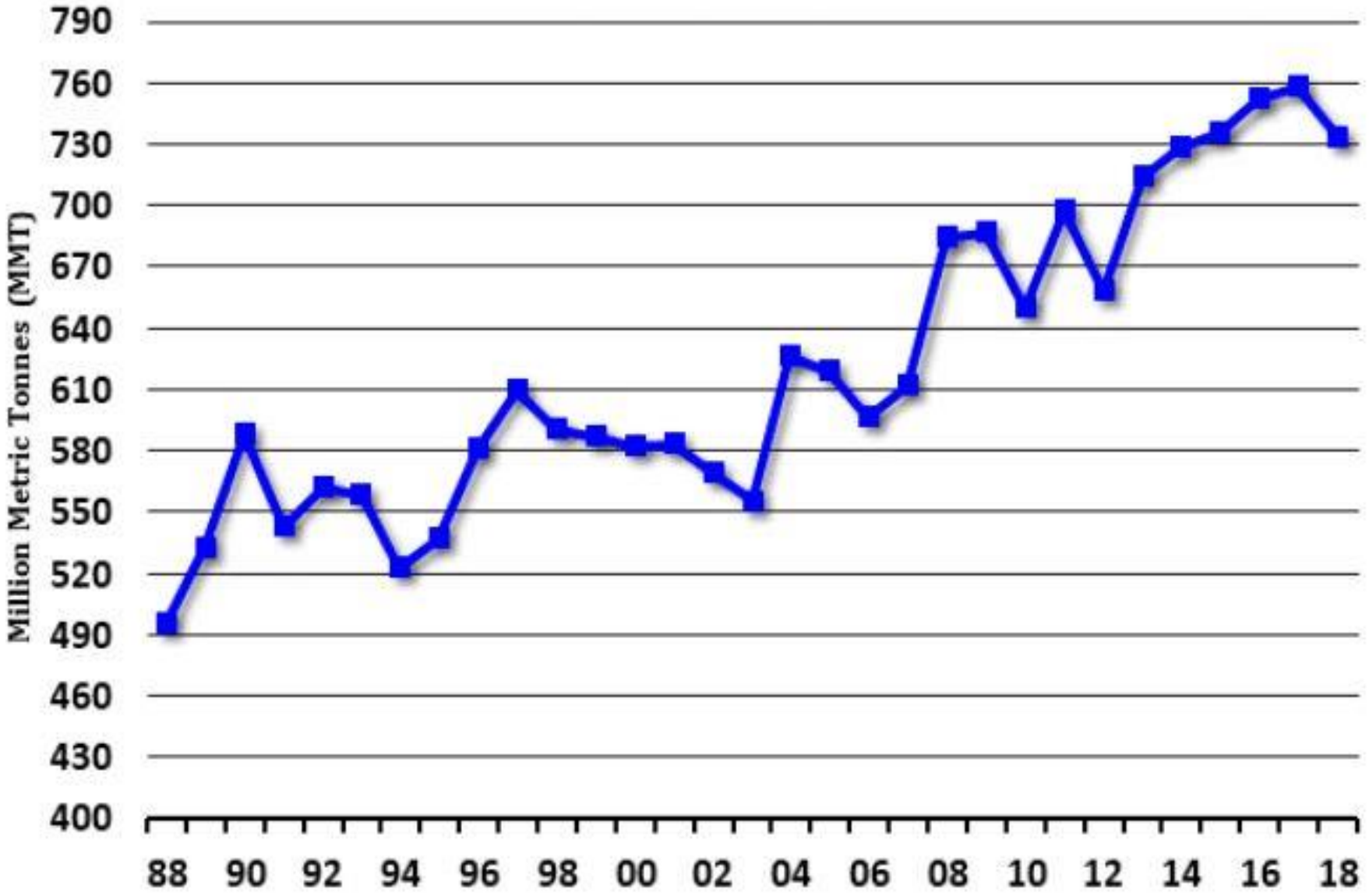
[1]MIDEAST: LEBANON, IRAQ, IRAN, ISRAEL, JORDAN, KUWAIT, SAUDI ARABIA, YEMEN, UNITED ARAB EMIRATES, AND OMAN

[2]N.AFRICA: ALGERIA, EGYPT, LIBYA, MOROCCO, AND TUNISIA

MATTHEWPOT

SOURCE: USDA WASDE, AUGUST 2017

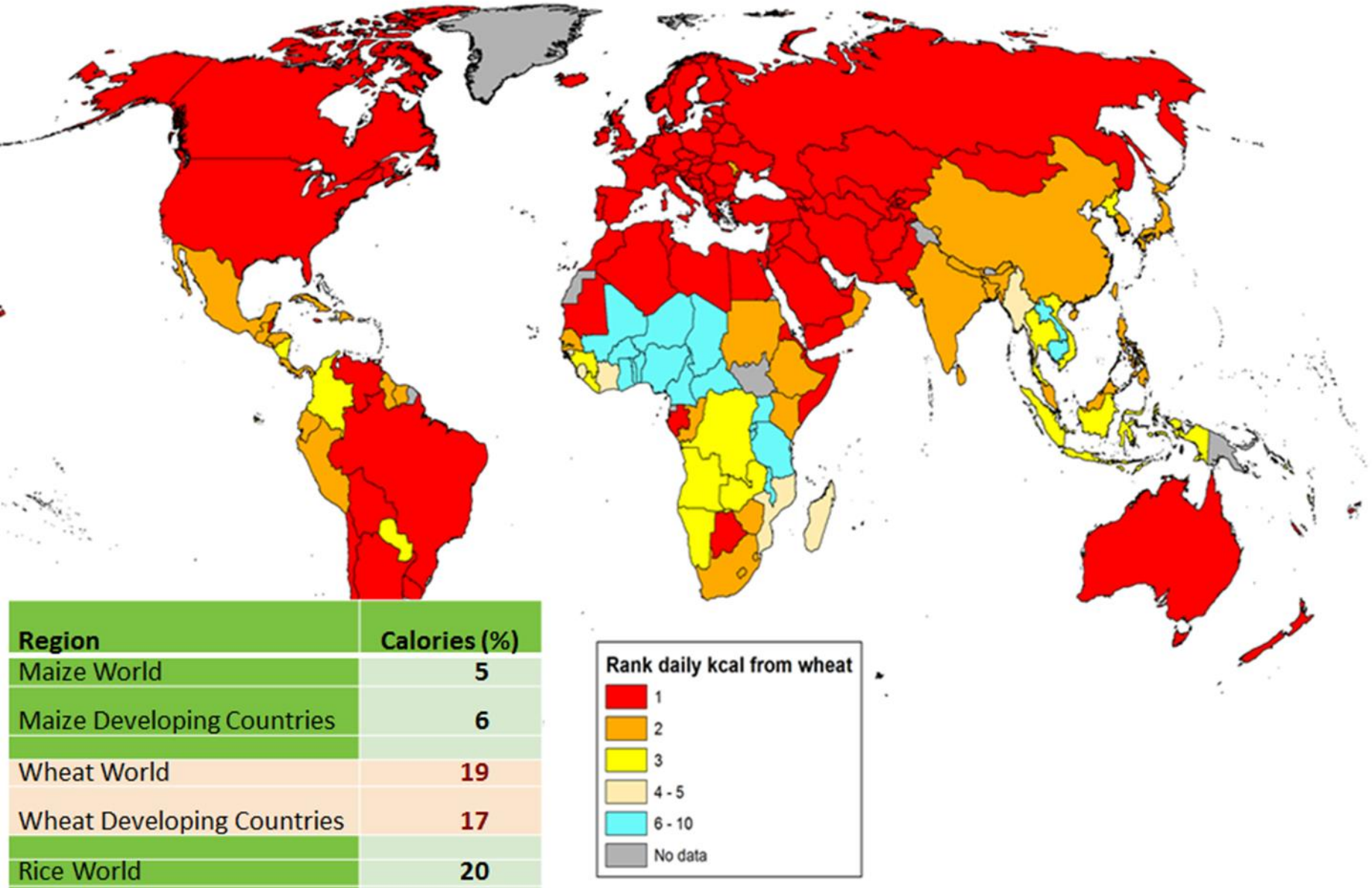
World Wheat - Production



Most Recent: 732.998 As Of 09/12/2018

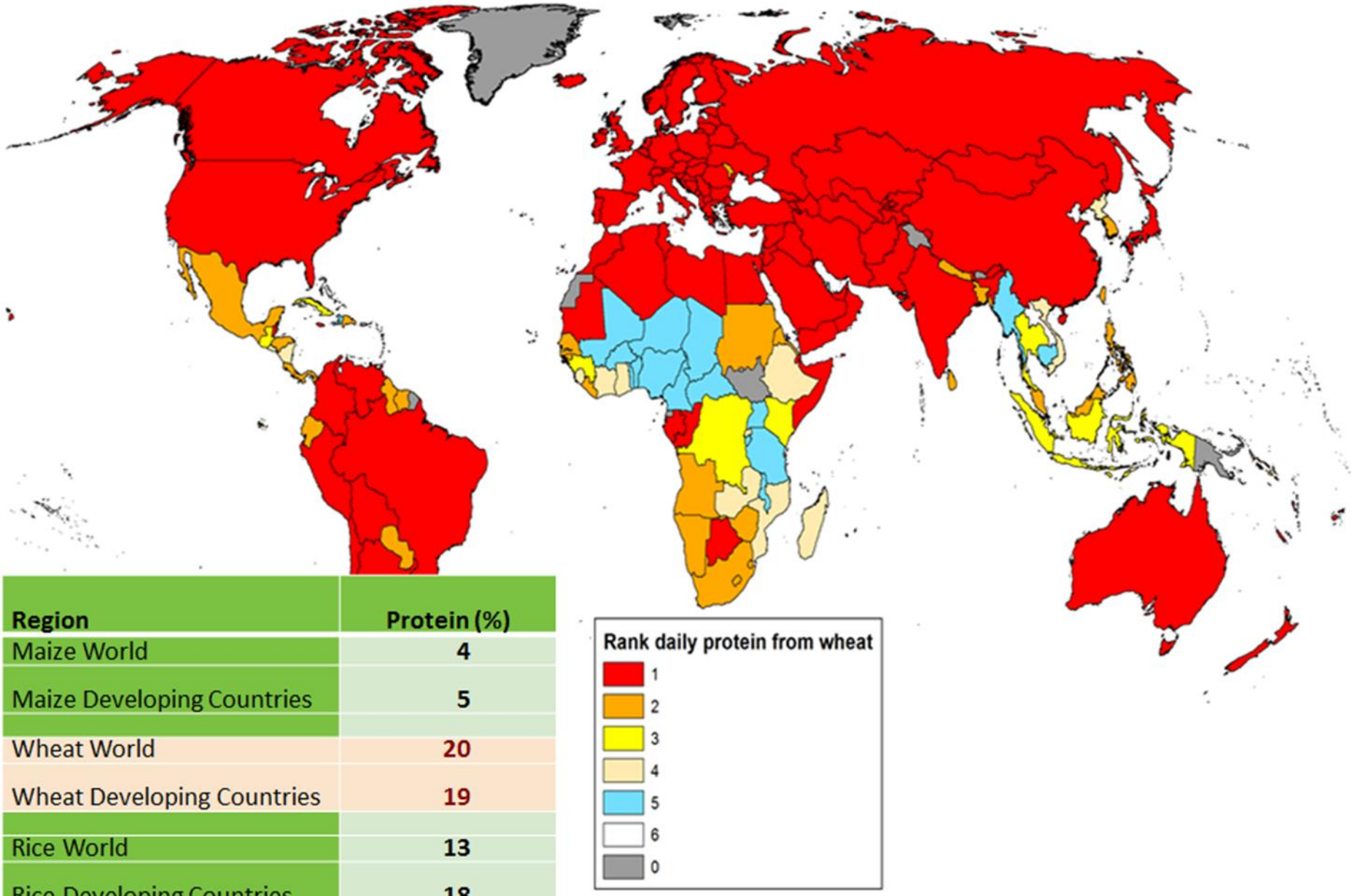
The Hightower Report

Importance of Wheat as calorie source



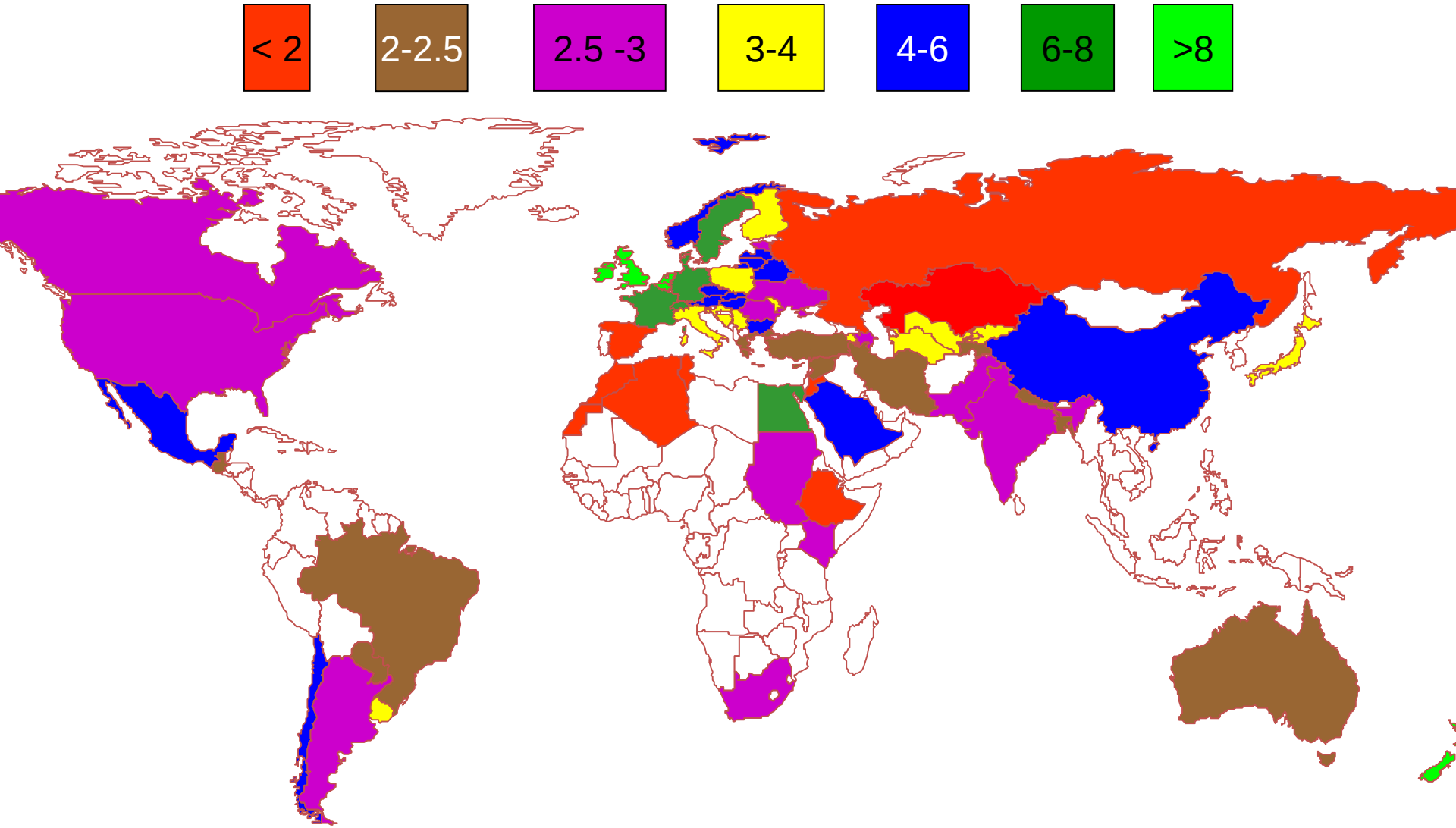
Region	Calories (%)
Maize World	5
Maize Developing Countries	6
Wheat World	19
Wheat Developing Countries	17
Rice World	20
Rice Developing Countries	25

Protein from Wheat
Importance for each country as plant protein source (2010-12)



Region	Protein (%)
Maize World	4
Maize Developing Countries	5
Wheat World	20
Wheat Developing Countries	19
Rice World	13
Rice Developing Countries	18

Average Wheat Yield of countries



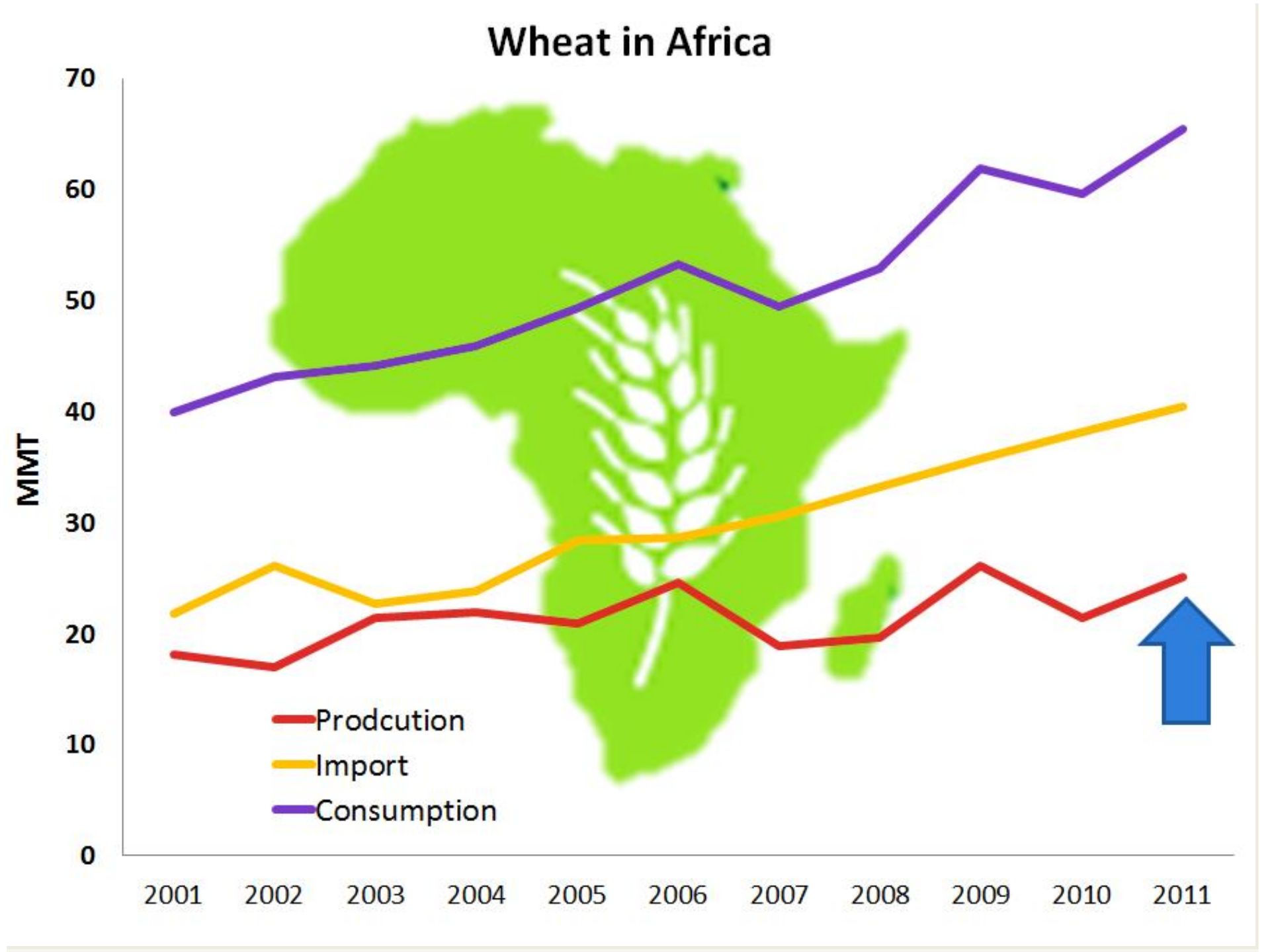
Wheat production – two different worlds

	Developed countries	Less developed countries
Wheat Area	105 mlln ha	115 mlln ha
Average yield	2.9 t/ha	3 t/ha
Average farm size	40 ha - > 5000 ha	1 – 3 ha
Rainfed	100 mlln ha	60 mlln ha
Irrigated	5 mlln ha	55 mlln ha
Max Yield	8 t/ha (UK, WW)	6.5 t/ha (Egypt, SW)

Source: H-J Braun

Wheat production in SAARC Countries

Area	Element	Year	Unit	Value
Afghanistan	Area harvested	2016	ha	2.300210
Afghanistan	Yield	2016	hg/ha	19803
Afghanistan	Production	2016	tonnes	4.555110
Bangladesh	Area harvested	2016	ha	445003
Bangladesh	Yield	2016	hg/ha	30296
Bangladesh	Production	2016	tonnes	1.348186
Bhutan	Area harvested	2016	ha	1465
Bhutan	Yield	2016	hg/ha	18307
Bhutan	Production	2016	tonnes	2683
India	Area harvested	2016	ha	30.230000
India	Yield	2016	hg/ha	30930
India	Production	2016	tonnes	93.500000
Nepal	Area harvested	2016	ha	745823
Nepal	Yield	2016	hg/ha	23288
Nepal	Production	2016	tonnes	1.736849
Pakistan	Area harvested	2016	ha	9.143097
Pakistan	Yield	2016	hg/ha	28442
Pakistan	Production	2016	tonnes	26.005213


Wheat in Africa
70
60
50
40
30
20
10
0
MMT
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Prodcution
Import
Consumption

Wheat Area harvested (Mha), yield (t/ha) and production (MMT) in Sub Saharan Africa countries for the periods from 1970-1990, 1991-2010, and 2011-2014.

Country	Area harvested (Mha)			Yield (t/ha)			Production (MMT)		
	1970-1990	1991-2010	2011-2014	1970-1990	1991-2010	2011-2014	1970-1990	1991-2010	2011-2014
Ethiopia	**0.709**	**1.075**	**1.584**	**1.008**	**1.425**	**2.282**	**0.696**	**1.663**	**3.627**
South Africa	1.885	0.920	0.524	1.085	2.278	3.609	2.043	2.003	1.885
Kenya	0.123	0.143	0.148	**1.698**	**2.118**	**2.602**	**0.208**	**0.302**	**0.372**
Sudan	0.170	0.253	0.182	1.245	2.053	1.851	0.204	0.494	0.339
Zambia	0.003	0.015	0.036	**3.278**	**6.001**	**6.705**	**0.014**	**0.091**	**0.241**
Tanzania	0.053	0.057	0.107	1.503	1.526	1.165	0.077	0.076	0.123
Nigeria	0.024	0.043	0.092	**1.817**	**1.613**	**1.100**	0.041	0.063	0.104
Rwanda	0.004	0.018	0.037	0.888	1.007	2.054	**0.004**	**0.020**	**0.076**
Zimbabwe	0.034	0.039	0.019	**4.794**	**4.522**	**2.400**	0.168	0.182	0.044
Eritrea	-	0.025	0.024	0.000	0.657	1.022	-	0.017	0.025
Uganda	0.005	0.008	0.014	**2.061**	**1.750**	**1.549**	0.010	0.013	0.021
Mozambique	0.005	0.004	0.017	1.093	1.164	1.221	0.006	0.005	0.020
Lesotho	0.048	0.022	0.014	0.740	0.811	1.001	0.033	0.017	0.014
DR Congo	0.006	0.007	0.006	0.678	1.262	1.304	0.004	0.009	0.008
Burundi	0.009	0.011	0.010	0.707	0.786	0.614	0.006	0.008	0.007
Angola	0.009	0.003	0.004	0.796	1.237	0.988	0.008	0.004	0.003
SSA	**3.101**	**2.652**	**2.845**	**1.598**	**1.900**	**2.125**	**3.538**	**4.921**	**6.986**
Africa	**8.56**	**9.06**	**10.04**	**1.18**	**2.01**	**2.59**	**10.03**	**18.39**	**25.98**
World	**226.43**	**218.38**	**219.51**	**1.95**	**2.73**	**3.20**	**442.20**	**596.18**	**702.55**

Challenges to global wheat production

- 1.7% increase in global production annually; i.e. average yield to rise from 3 t/ha to 5 t/ha by 2050
- Climate change scenarios: unpredictable warmer temperatures and drought stresses
- Depleting ground water for irrigation
- Energy and fertilizer costs
- Competition with other crops
- Emerging diseases and pests and their new biotypes
- Declining agricultural research capacity

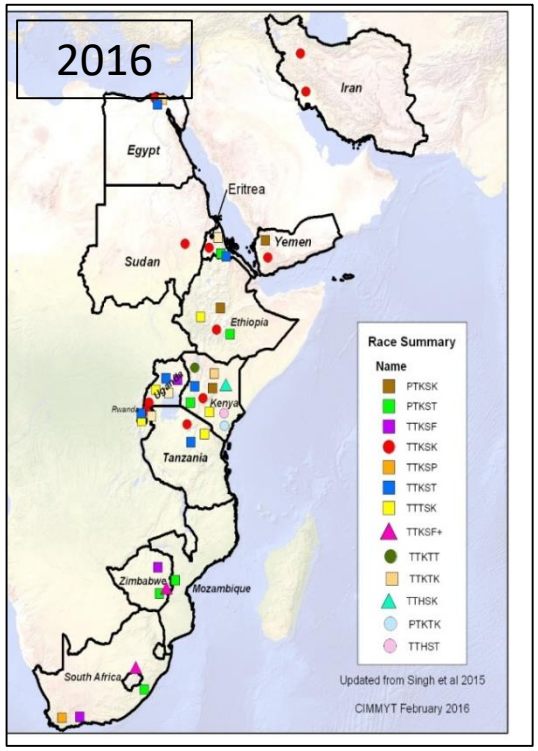
Challenges

Productivity challenges

- 80% small scale farmers, subsistence farming
- Limited resources for inputs
- Slow variety replacement

Technological challenges

- Need for integrated and best fit technologies for rain-fed and irrigated wheat systems
- Low level of mechanization



Biotic and Abiotic stresses

- Biotic stresses (diseases, insect pests and weeds)
- Abiotic stresses (drought, heat, salinity, soil acidity)
- Low soil fertility

Key issues for wheat production

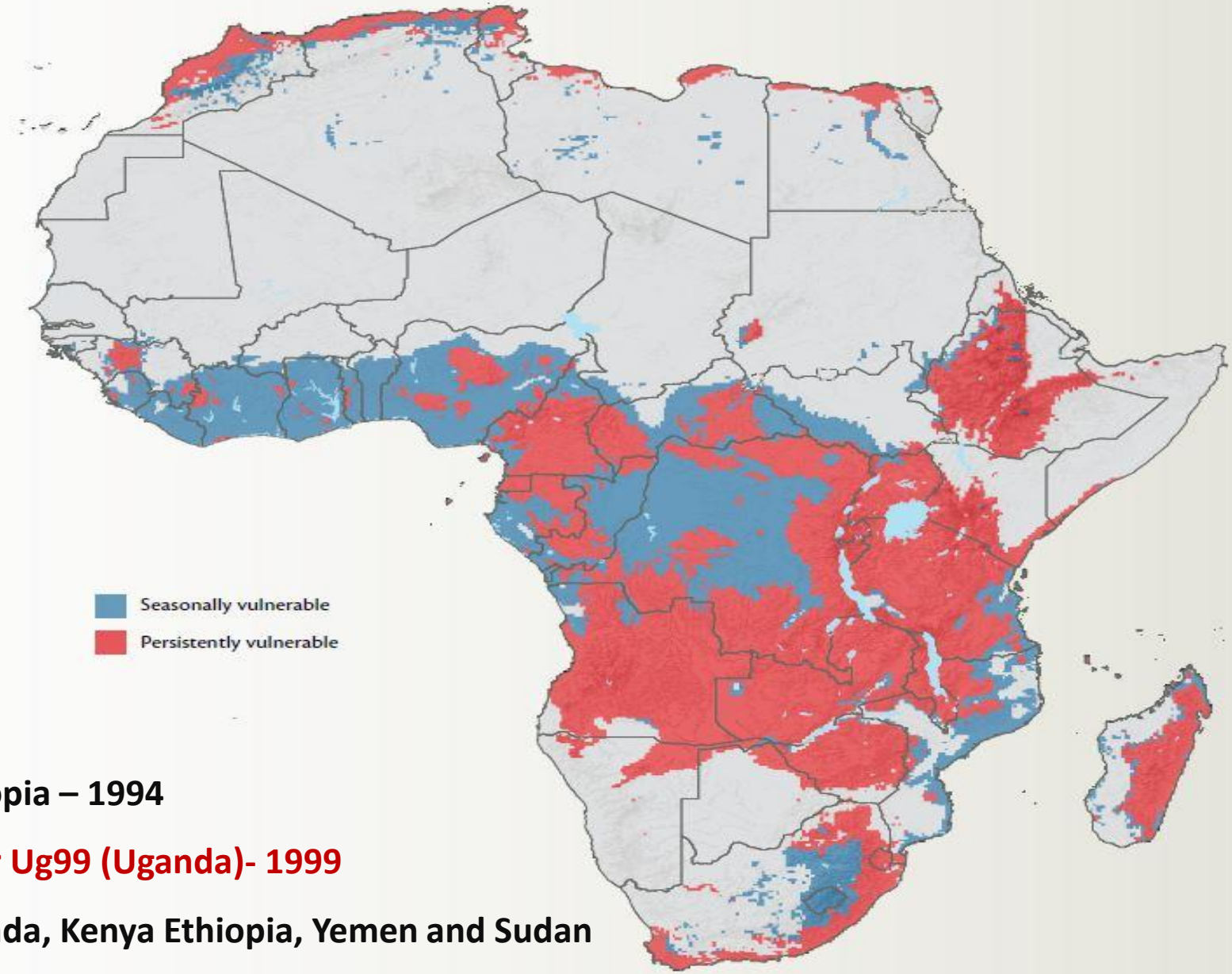
- Developing **suitable technologies and varieties**
- Access to **affordable inputs**
- Effective and sustainable **wheat seed systems**
- Strengthen **wheat extension systems**
- **Increasing productivity** among small holders
- Making wheat more **competitive and profitable** for domestic farmers
- Making **wheat value chains** work more effectively
- Fostering regional **collaboration and cooperation**
- Putting in place **appropriate policies** that foster wheat industry

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	0	++	+++
Septoria	+	0	++	+++	++	++	++	+++
Spot blotch	+	+++	0	0	0	+	++	+
Tan spot	0	+	+	+	+++	0	++	+++
Nematodes	++	++	+++	++	0	+	+	+
Root diseases	++	+	++	++	+	+	+	+
Wheat blast	0	+	0	0	0	0	++	0
Powderymildew	++	+	0	0	0	0	+	++
Smuts/bunts	+	++	++	++	+	+	+	+

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

WHEAT PRODUCTION AREAS AND VULNERABILITY TO STEM RUST



Ethiopia – 1994

After Ug99 (Uganda)- 1999

Uganda, Kenya Ethiopia, Yemen and Sudan

Why Ug99 is a global threat?

- **Highly aggressive - broad virulence spectrum**

Several *Sr* genes rendered ineffective *(including Sr31)*

- **>80% of wheat lines world wide found susceptible when tested in Kenya 2006-2008**
- **Migrated from Uganda to Kenya, Ethiopia,**

Yemen, Sudan and reported in Iran (2007)

13 races in 13 different countries

- **Continuously evolving 13 races identified in the Ug99 lineage 5 races in Kenya (hot spot)**
- **Predicted migration to other regions – S. Asia,**

East and central Asia and the pacific

- **Early epidemics can cause >70% losses**

Effectiveness of Known *Sr* genes to TTKS (Ug99) Lineage

Origin of *Sr* genes	Ineffective	Effective
Triticum aestivum[f]	5, 6, 7a, 7b, 8a, 8b, 9a, 9b, 9f, 9h, 10, 16, 18, 19, 20, 23, 30, 41, 49, 54, McN, Wld-1, Tmp (or *Sha7*)[a,b]	15[a,b,f], 28[a], 29[b,c], 42[a,b], 48, 55[b,d], 56[b,d], 57[b,d], 58[b,d], Huw234[a,b], ND643[c], Yaye[b]
T. turgidum	9d, 9e, 9g, 11, 12, 17	2[b,d], 13[a,b], 14[a,b]
T. monococcum	21	22, 35[a]
T. timopheevi	36	37[c]
Aegilops speltoides		32[c], 39[c] 47[e]
Ae. tauschii		33[b], 45[a,b], 46[a,e], TA10171[e], TA10187[a,e], TA1662[a,e]
Ae. searsii		51
Ae. geniculata		53
Dasypyrum villosum		52
T. comosum	34	
T. ventricosum	38	
T. araraticum		40[c]
Thinopyrum elongatum	24	25[a], 26, 43[a,c]
Th. intermedium		44[a,c]

a Virulence for the gene is known to occur in other races

b Level of resistance conferred in the field usually inadequate under high disease pressure

c Unsuitable for utilization due to linkage with undesirable traits in the translocation

d Confers slow rusting adult plant resistance

e Not tested for resistance to Ug99 in field trials to determine effectiveness

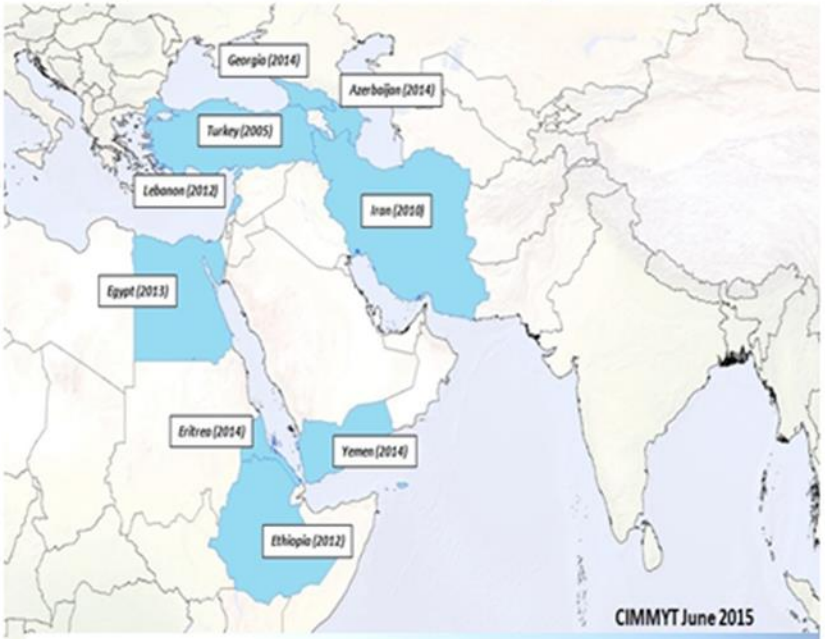
f Data from multiple research groups are not consistent; initial studies determined Sr15 was ineffective however recent data shows avirulence in Ug99 lineage

(Singh et. al 2014)

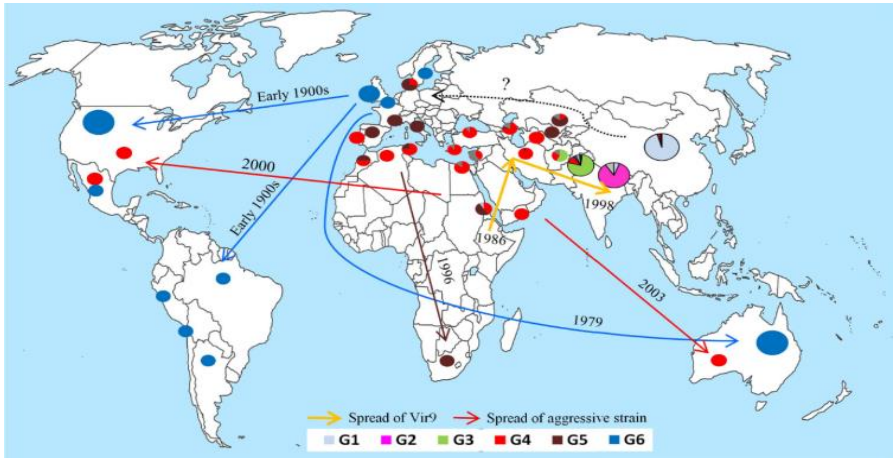
Challenges: Race TKTTF (Digalu race)

- Digalu race (race TKTTF) not in Ug99 race group; genetically unrelated
- In Turkey since at least 2005. Increasingly detected across a wide geographical range.
- Germany and Denmark detected TKTTF-like variants in 2013 (virulence on 4 additional Sr genes: *Sr33, Sr7a, SrTt-3, Sr45* , 2 very distinct genotypes (type A and type B) (Olivera et al., 2015))
- Race TKTTF was first detected in Ethiopia in August 2012 (trace). Epidemics in Ethiopia on cv Digalu 2013, 2014 and 2015, Kenya 2015
- New variants being detected – becoming the predominant race group in East Africa (replacing Ug99)

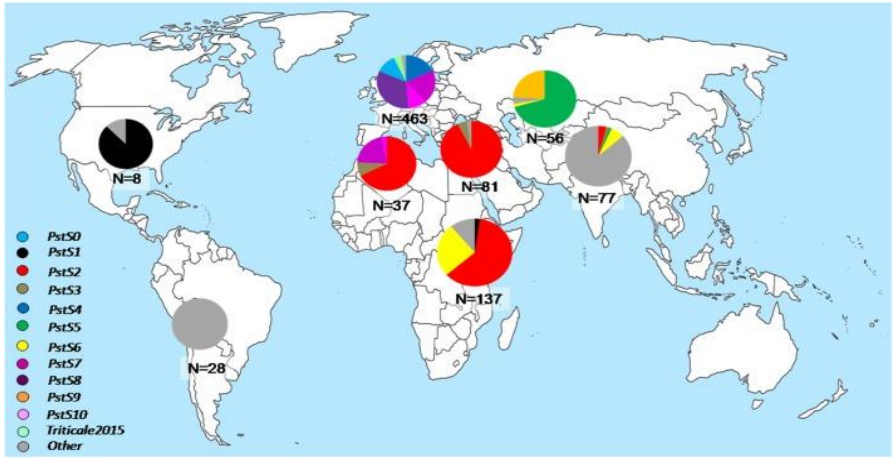
Map 1: Race TKTTF confirmed countries and year of first detection



Continuing challenge: Spread of aggressive *Puccinia striiformis* (yellow rust) races (e.g. PstS1/PstS2, Warrior & other) adapted to warmer temperatures



Countries with red dots with confirmed presence of PstS1/PstS2 race group Source: Ali et al. (2014) PLoS



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.

PstS1	*PstS1,v10,v24,v27*	-,2,-,-,-,6,7,8,9,10,-,-,24,25,27,-,-,AvS,-	East Africa
	PstS1,v17	-,2,-,-,-,6,7,8,9,-,-,17,-,25,-,-,-,AvS,-	North America
	PstS1,v17,v27	-,2,-,-,-,6,7,8,9,-,-,17,-,25,27,-,-,AvS,-	North America
	PstS1,v3,v17,v27	-,2,3,-,-,6,7,8,9,-,-,17,-,25,27,-,-,AvS,-	North America
	PstS1,v3,v17,v27,v32	-,2,3,-,-,6,7,8,9,-,-,17,-,25,27,32,-,AvS,-	North America
	other	other	North America
PstS2	*PstS2*	-,2,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	East Africa, West Asia, South Asia
	PstS2,v1	1,2,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	East Africa, West Asia
	PstS2,v3	-,2,3,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	East Africa
	PstS2,v27	-,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	East Africa, West Asia, North Africa
	Pst2,v1,v27	1,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	East Africa, West Asia
	PstS2,v3,v27	-,2,3,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	East Africa
	PstS2,v10,v24	-,2,-,-,-,6,7,8,9,10,-,-,24,25,-,-,-,AvS,-	East Africa, West Asia
	PstS2,v3,v10,v24,v27	-,2,3,-,-,6,7,8,9,10,-,-,24,25,27,-,-,AvS,-	East Africa
	PstS2,v10,v24,v27	-,2,-,-,-,6,7,8,9,10,-,-,24,25,27,-,-,AvS,-	West Asia

- Early infection
- Faster disease build up
- Disease progression under warmer temp.
- New areas of adaptation
- Faster evolution of new virulences
- Reduced effectiveness of resistance

- Breeding programs challenged with diverse, evolving & migrating *Pst* population
- In Mexico virulence evolved for: *Yr1*, *Yr3*, *Yr10*, *Yr24*(=*Yr26*), *Yr17*, *Yr27* & *Yr31* in *Pst1* lineage in 12 years
  (a new virulence every alternate year)

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

Priority diseases for CIMMYT wheat breeding

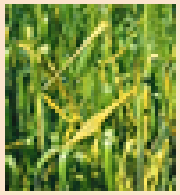
Core traits

All mega-environments

Rust diseases

- **Stem rust (including Ug99)**

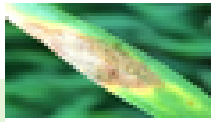
- **Stripe rust**

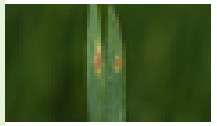


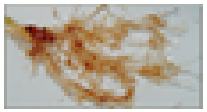
- **Leaf rust**

Key traits for specific mega-environments

- **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 (ME5)**

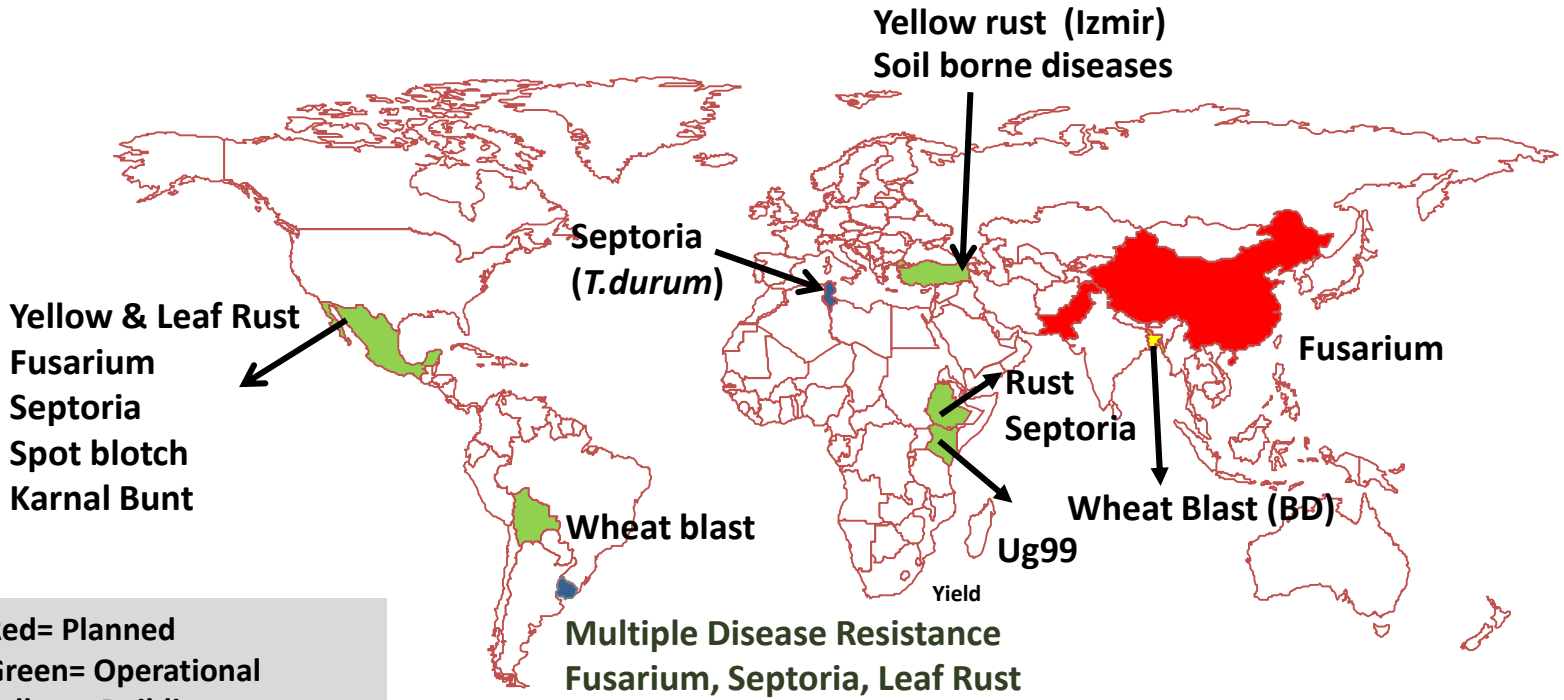






Main objective is to achieve resistance durability, averting major epidemics, and minimizing chemical control

A global disease phenotyping network for wheat improvement



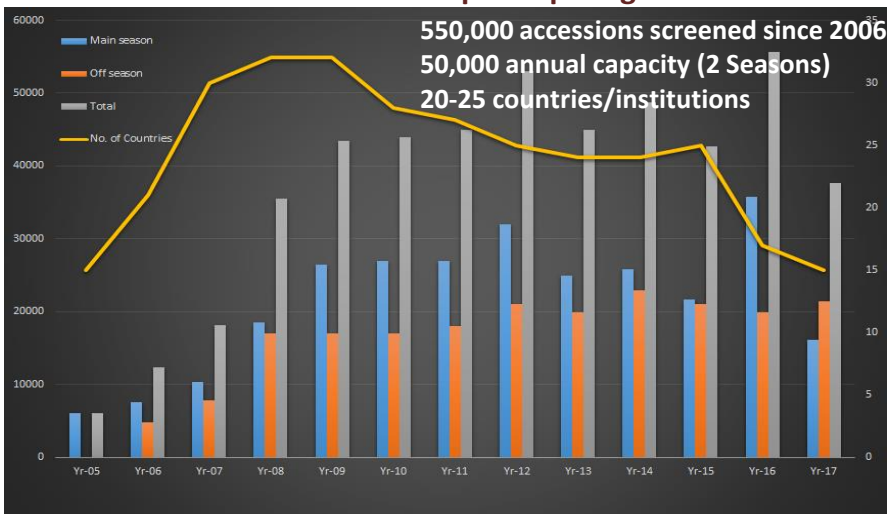
Red= Planned
Green= Operational
Yellow= Building up

Phenotyping Platforms

- Hubs for generating high quality phenotypic data, under defined good practices, and promoting training and sharing of the generated knowledge.
- Sites represent hotspots for specific diseases for evaluation and selection

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

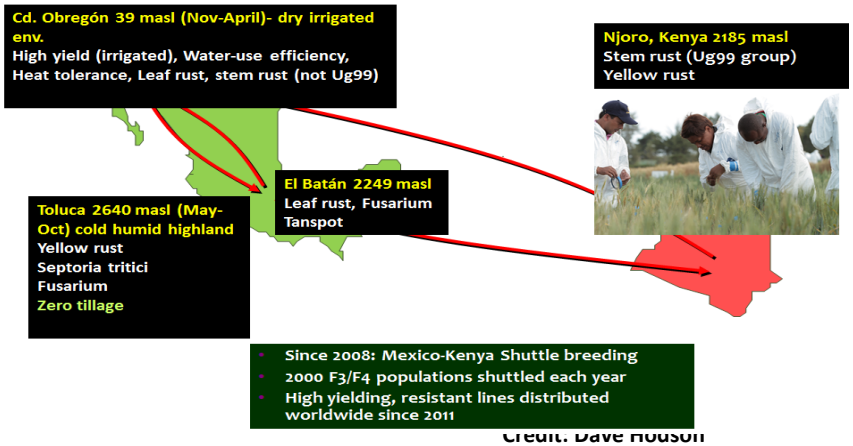
Wheat accessions phenotyped during 2005 to 2017 for Ug99 stem rust resistance and participating countries



Rapid cycling of breeding materials

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

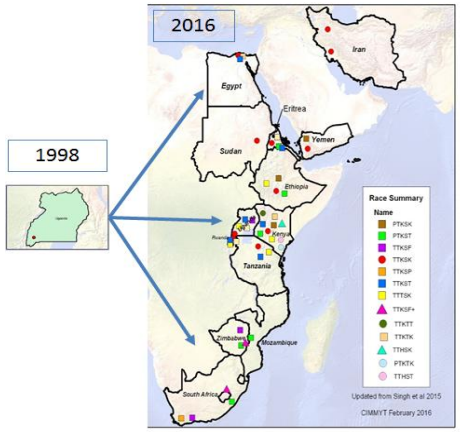
A five-year recurrent breeding cycle



Credit: Dave Hodson

Improved Survey and surveillance

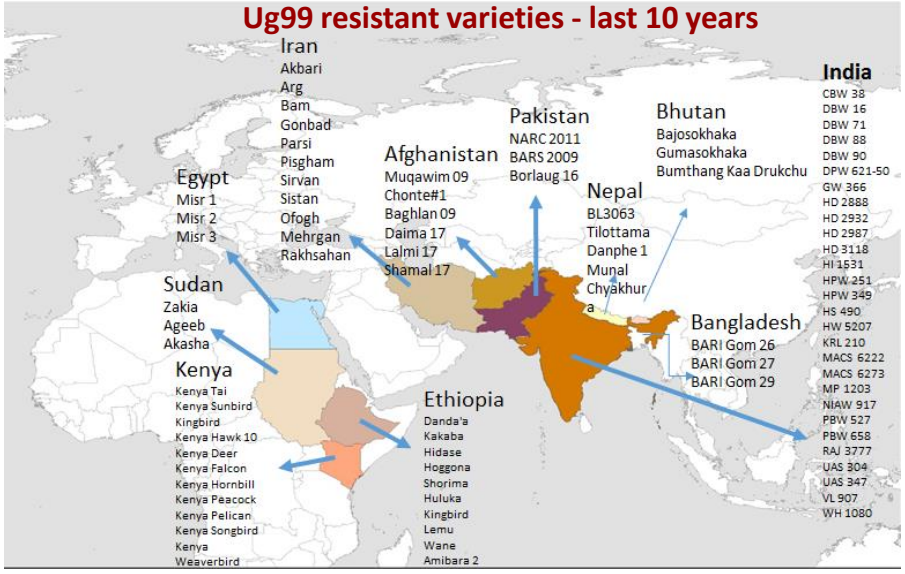
Spread of Ug99 Race Group 1998-2016



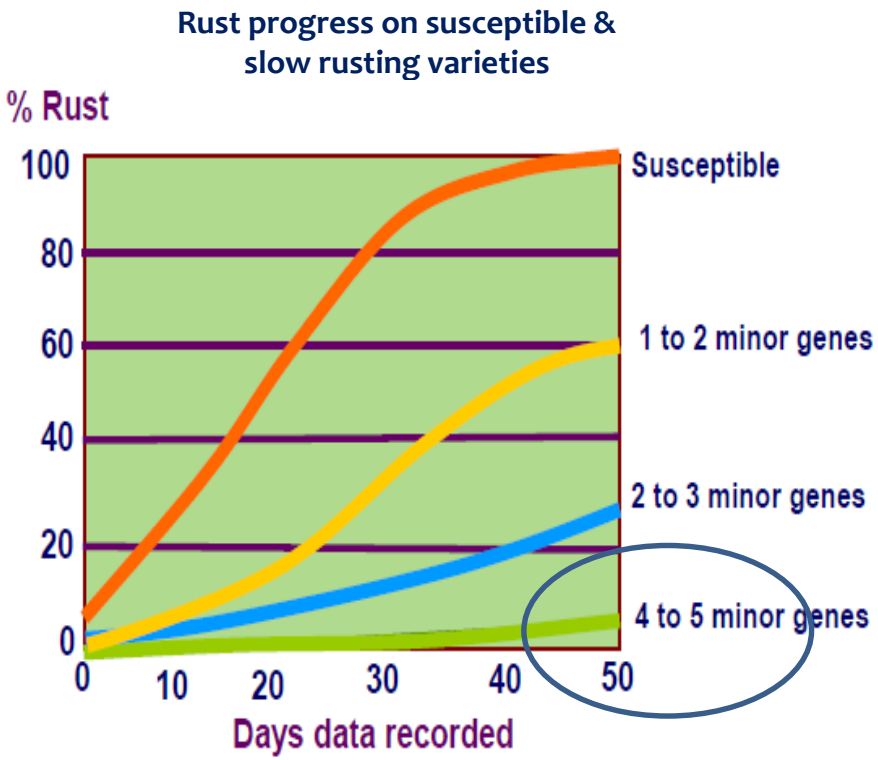
- **1998/9**: 1 Ug99 race (TTKSK) detected in 1 country (Uganda)
- **2016**: 13 Ug99 races detected across 13 countries (Africa and Middle East)
- **2013/14**: 5 new Ug99 races detected in Kenya
- **PTKTK** (low IT on Sr21,Sr36 and Sr24)
- **TTHSK** (low IT on Sr36, Sr30, SrTmp and Sr24)
- **TTHST** (high on Sr9e and Sr17)
- **TTKTK** (virulent to SrTmp)
- **TTKTT**(virulent to Sr24 and SrTmp)

- **Reference centres: CDL, GRRC, AAFC**

Ug99 resistant varieties - last 10 years



Pleiotropic multi-pathogen & other slow rusting genes for achieving resistance durability



Near-immunity (trace to 5% severity) achieved by combining 4-5 genes

(similar approach for other leaf spotting diseases, fusarium head blight and wheat blast)

- ***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**

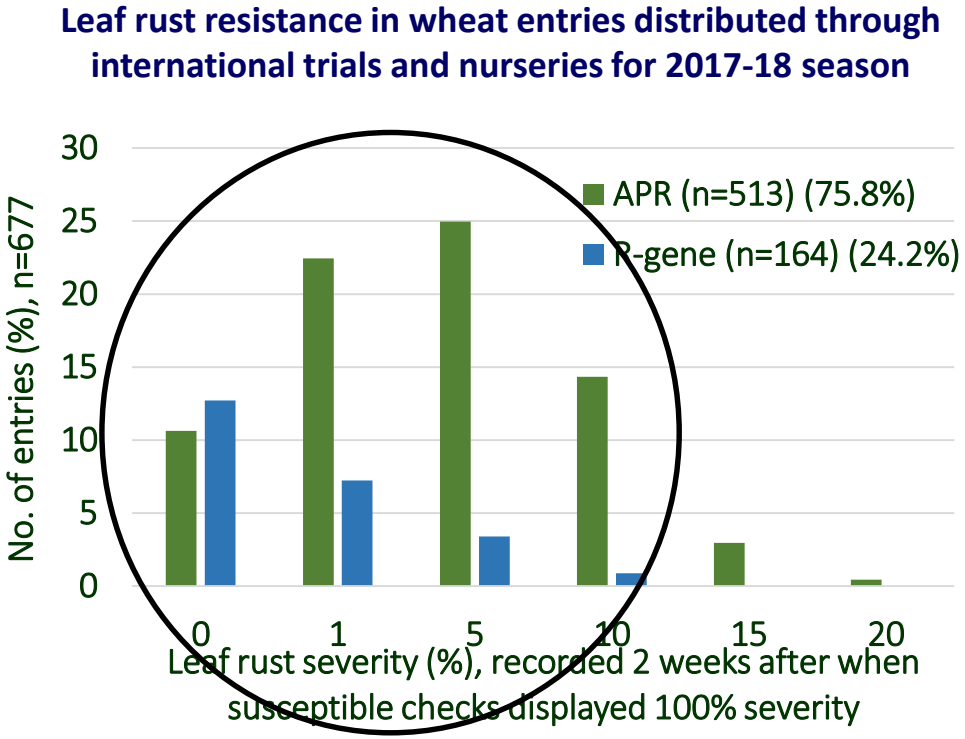
- ***Sr2/Yr30/Lr*** **chromosome 3BS**
- ***Lr68*** **chromosome 7BL**
- **Various consistent QTLs, some with effects on multiple pathogens, e.g. on 1BS, 2AL, 2BS, 2DL, 5AL, 5BL, 6AL and 7BL** (Li et al. 2014. Crop Sci. 54:1907-192)

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 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)

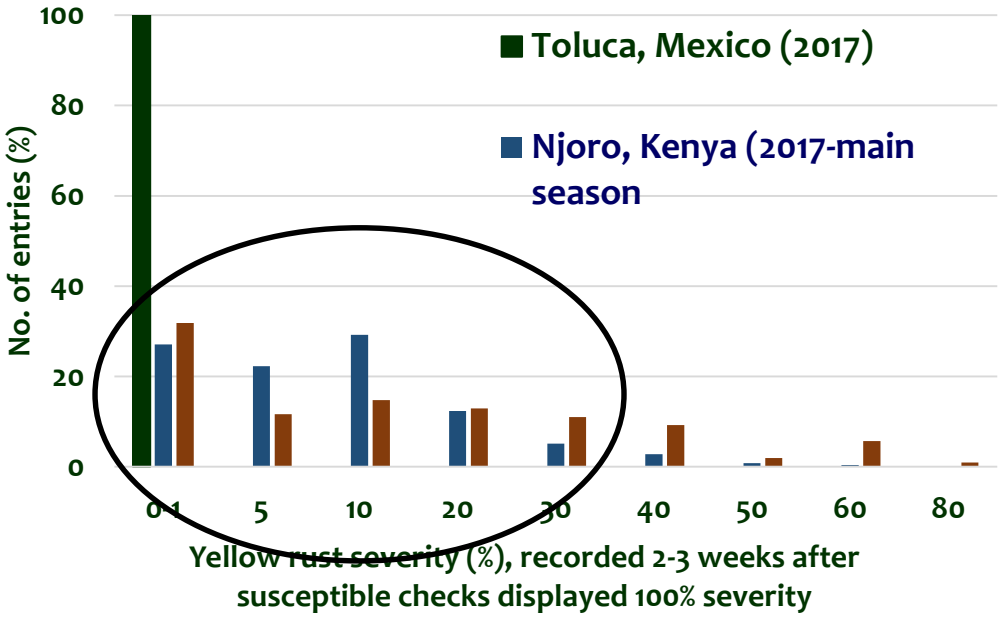
Slow rusting adult-plant resistance to leaf rust: mainstreamed in CIMMYT wheat germplasm



- **CIMMYT-derived varieties and breeding materials possess high levels of resistance**
- **Leaf rust not a concern in countries growing CIMMYT- derived varieties**
- **Excellent example of durability and main-streaming**

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

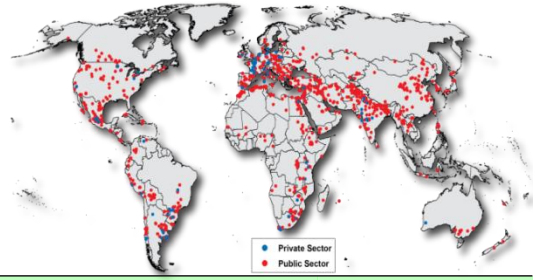
Yellow rust severity of 1092 wheat lines at three sites under high disease pressure



A majority of highly resistant lines in Mexico show high to intermediate resistance levels in Kenya and India

- **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), *YrF* (2BS), etc.**

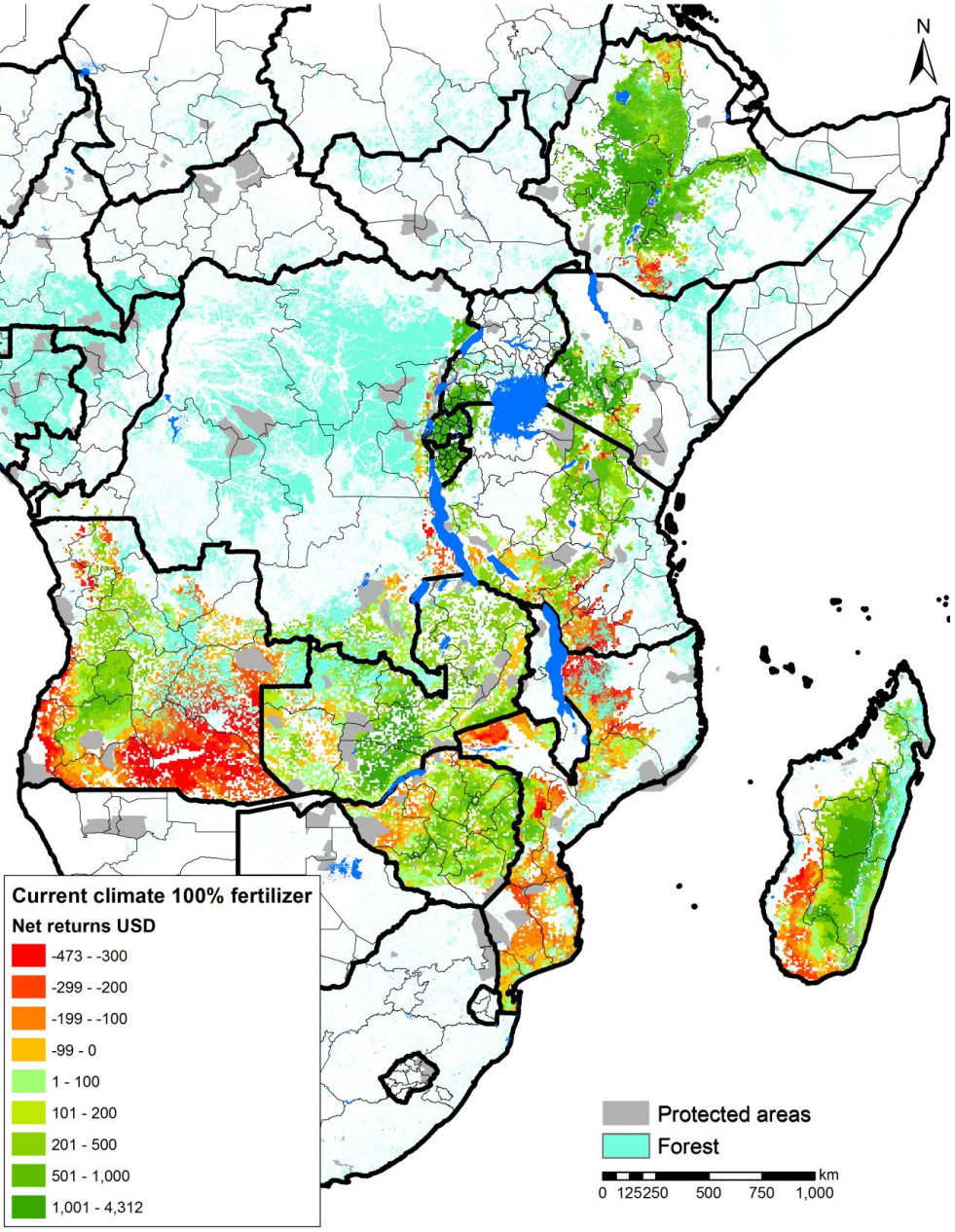
Worldwide distribution of new High Yielding Wheat Germplasm through Trials and Nurseries



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
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
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

- 120-150 sets of each trials/nurseries distributed annually worldwide
- 40-50% increase in demand during the last decade

Opportunities for Africa



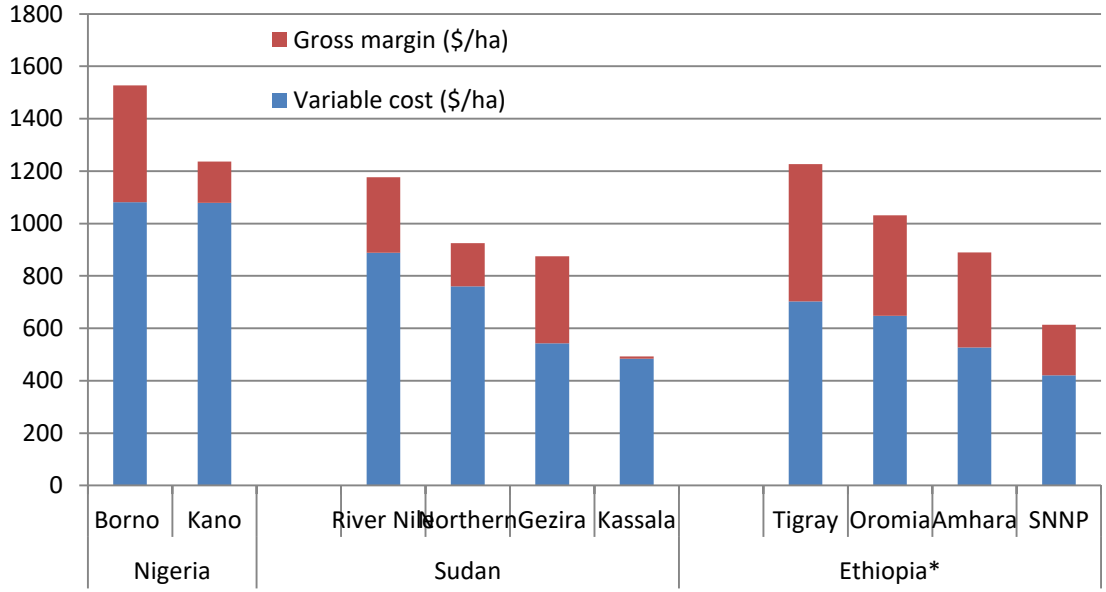
NER under High intensification (for pixels NER>0)

Country	Average NER (US$/ha)	Land with positive NERs (%)
Angola	275	32
Burundi	1061	100
Ethiopia	771	90
Kenya	931	92
Madagascar	731	76
Mozambique	145	21
Rwanda	1461	96
Tanzania	384	71
DRC	302	76
Uganda	994	100
Zambia	444	86
Zimbabwe	309	76

Nearly 20-100% of land economically profitable for rainfed wheat production

Shiferaw et. al 2012

Profitability of wheat in Africa

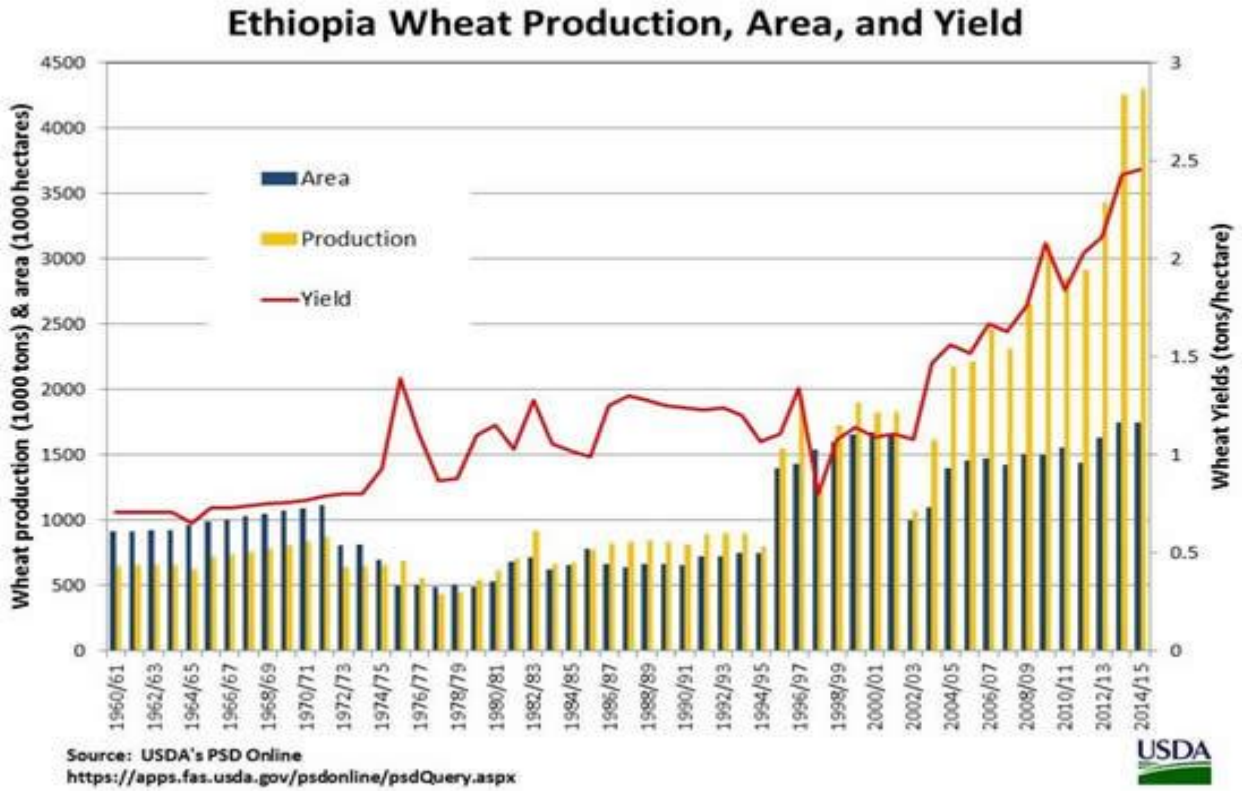


Country	STATE	Benefit/Cost ratio	ROR
Nigeria	Borno	1.41	41%
	Kano	1.15	15%
Sudan			
	River Nile	1.32	32%
	Northern	1.25	25%
	Gezira	1.55	55%
	Kassala	1.00	0%
Ethiopia*			
	Tigray	1.74	74%
	Oromia	1.59	59%
	Amhara	1.69	69%
	SNNP	1.46	46%

The highest rate of returns were in the Rainfed systems in the highlands of Ethiopia (60-74%) and Sudan (55%).

(SARD-SC)

Progress : Transformation of Ethiopia wheat production (1960 – 2015)



Major drivers of the transformation:

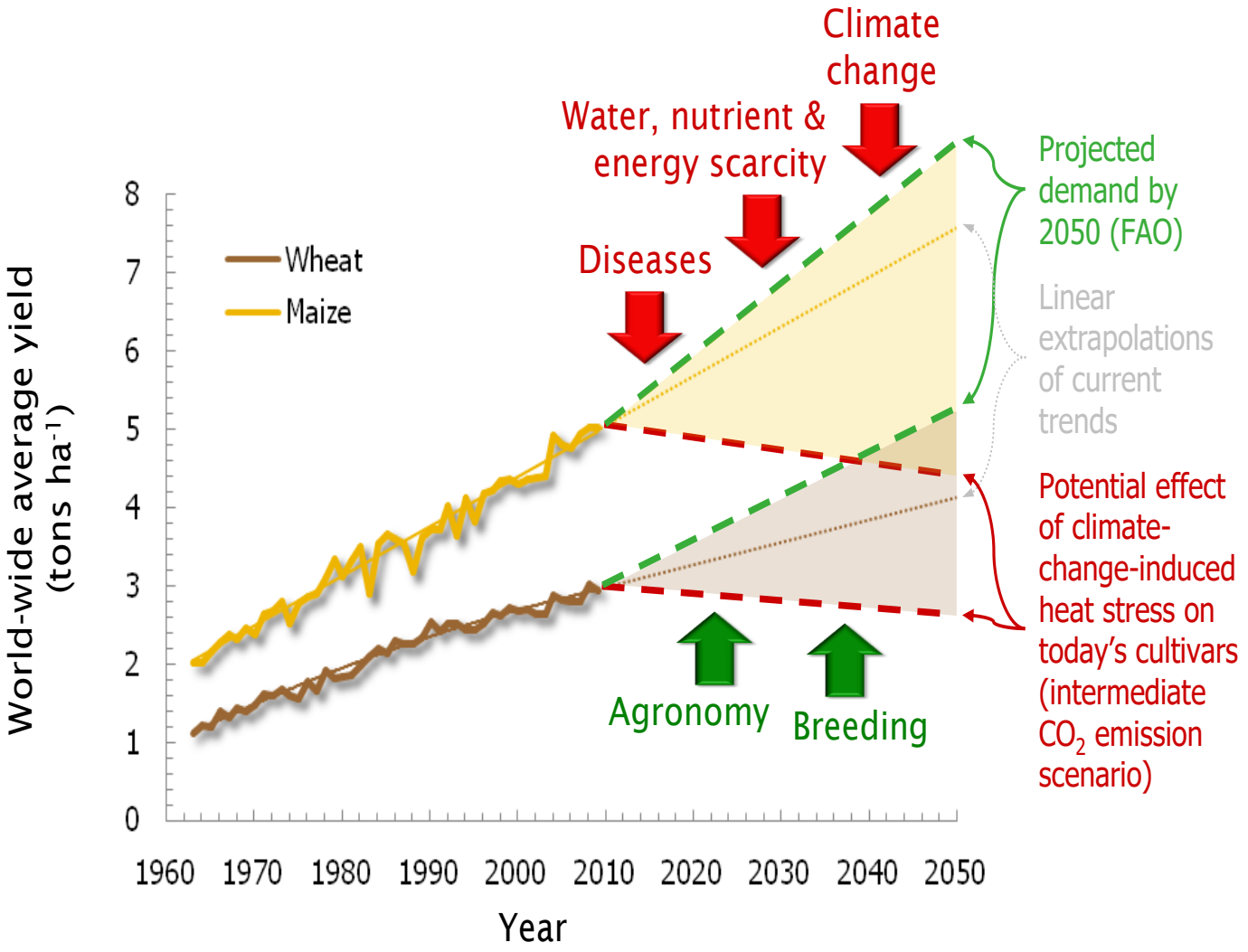
- Record wheat harvest > 4MMT in 2014 (400% increase since 2000)
- Varieties – high yielding, rust resistant, quality from CIMMYT/ICARDA
- Favorable policies, strong government commitment
- Seed delivery systems – accelerated pre-release seed multiplication
- Agronomic packages and Effective extension system

Genetic Gains are also made in conjunction with improvements in management.

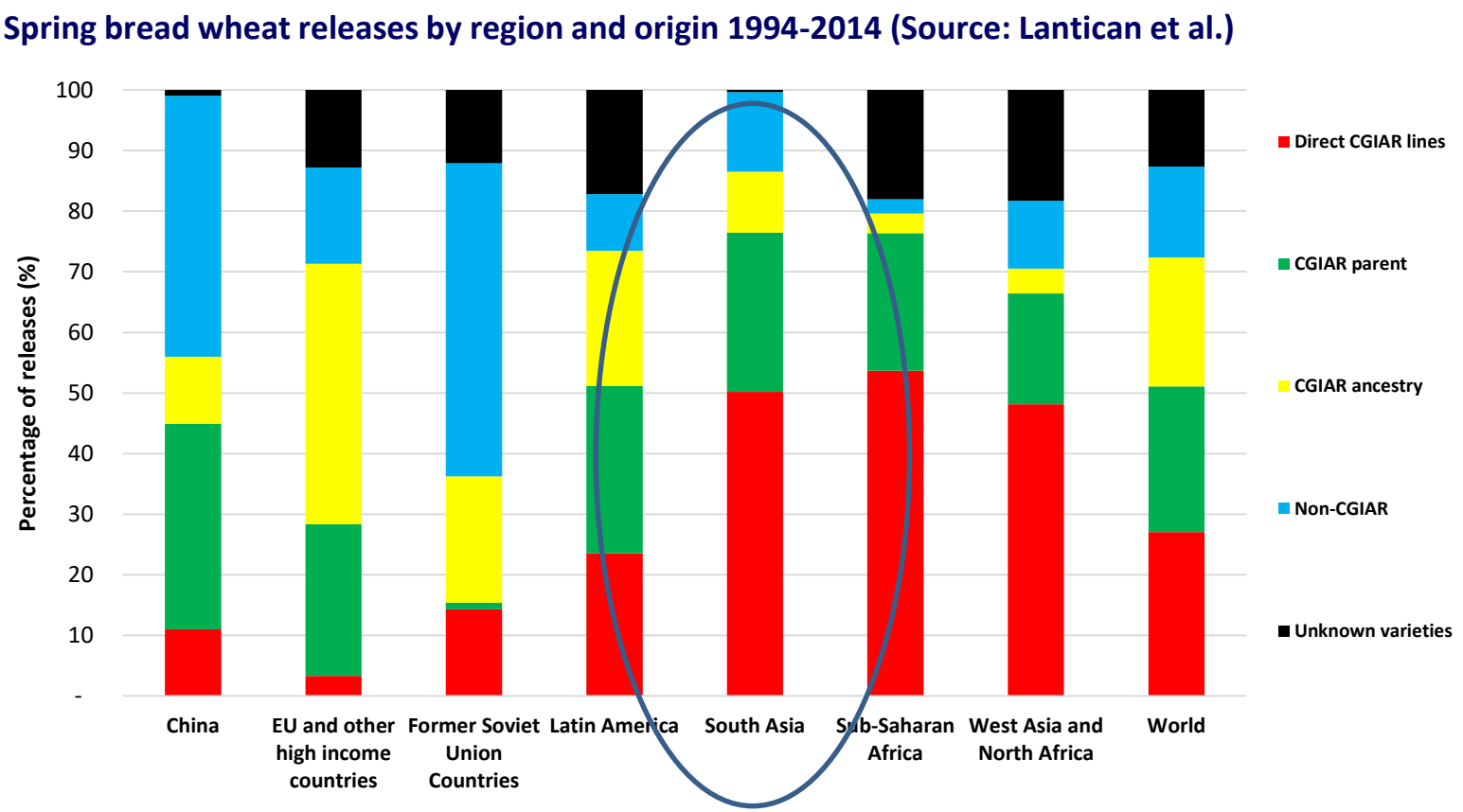
1/3 breeding

1/3 agronomy

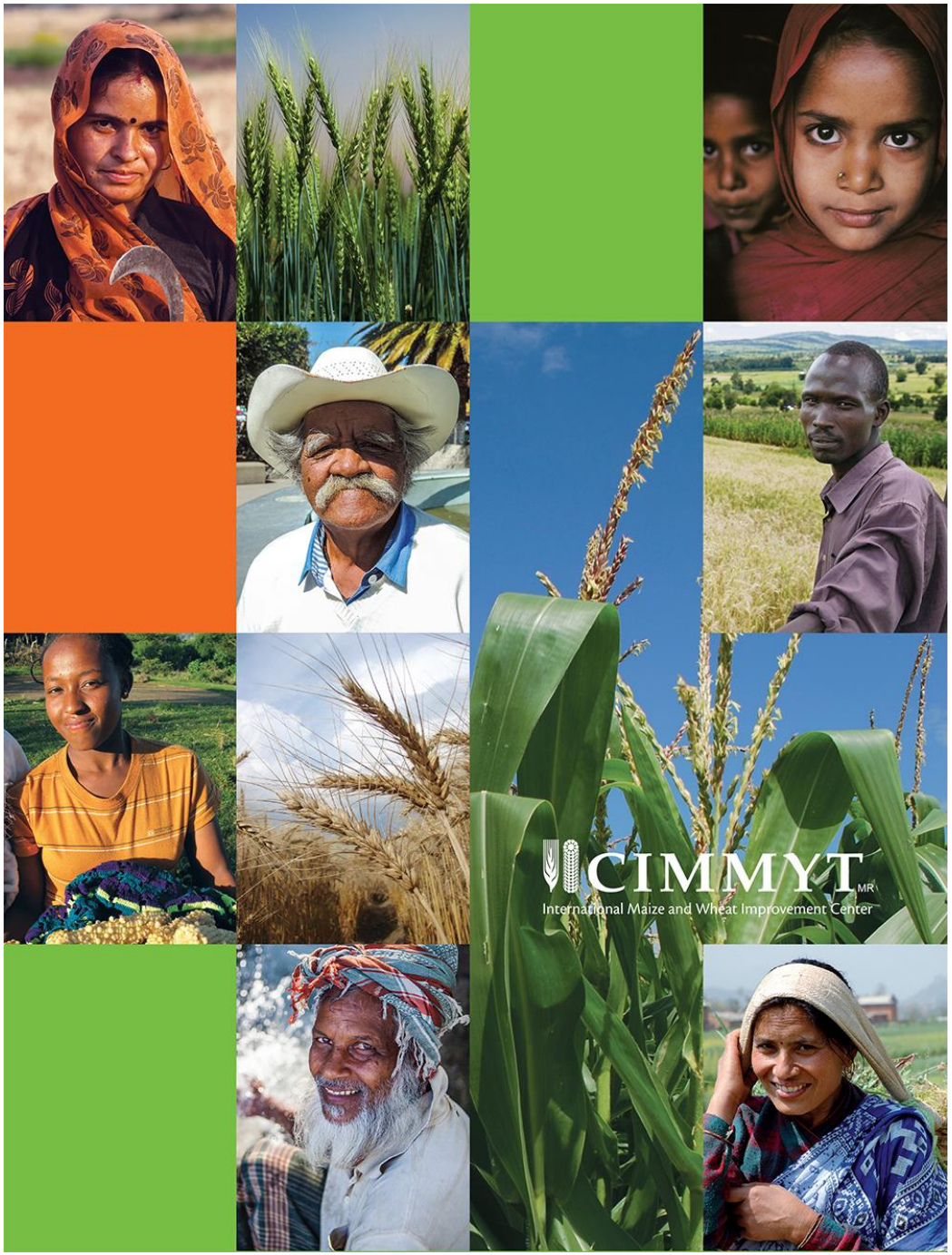
1/3 policies



Global partnerships :Impacts of CGIAR-Wheat



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.



Thank you for your interest!

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