Borlaug Global Rust Initiative (BGRI)
Management of Major Genes and Minor Genes: The Way Forward

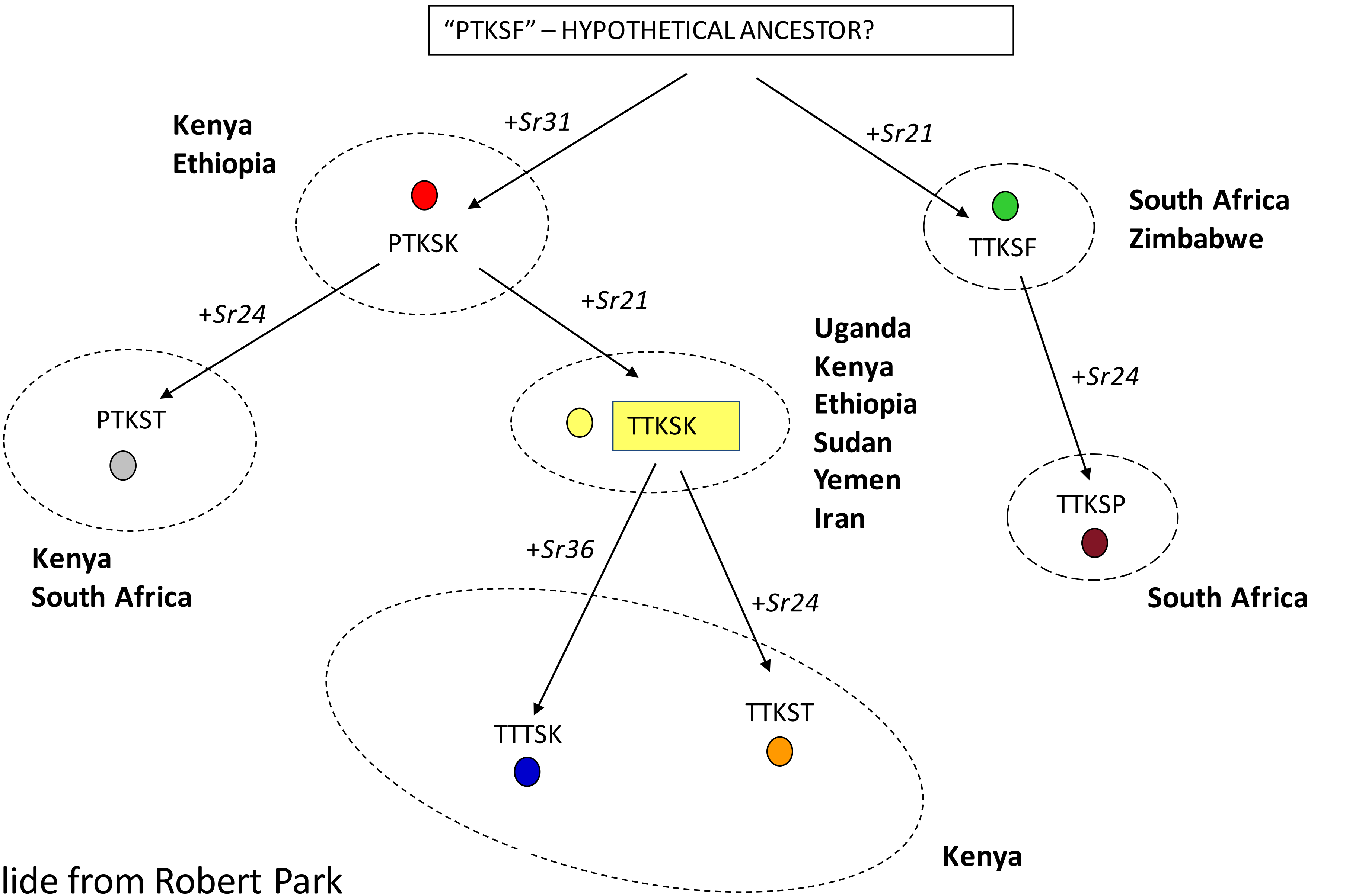
Our goal: long-term protection of global wheat production

Discussion: what approaches to gene management do you think the wheat community/BGRI should be taking for long-lasting protection of wheat against rust diseases?

Panel: Robert Park
Ravi Singh
Richard Michelmore

Moderator: Kathy Kahn

Why should we care about gene management in wheat?

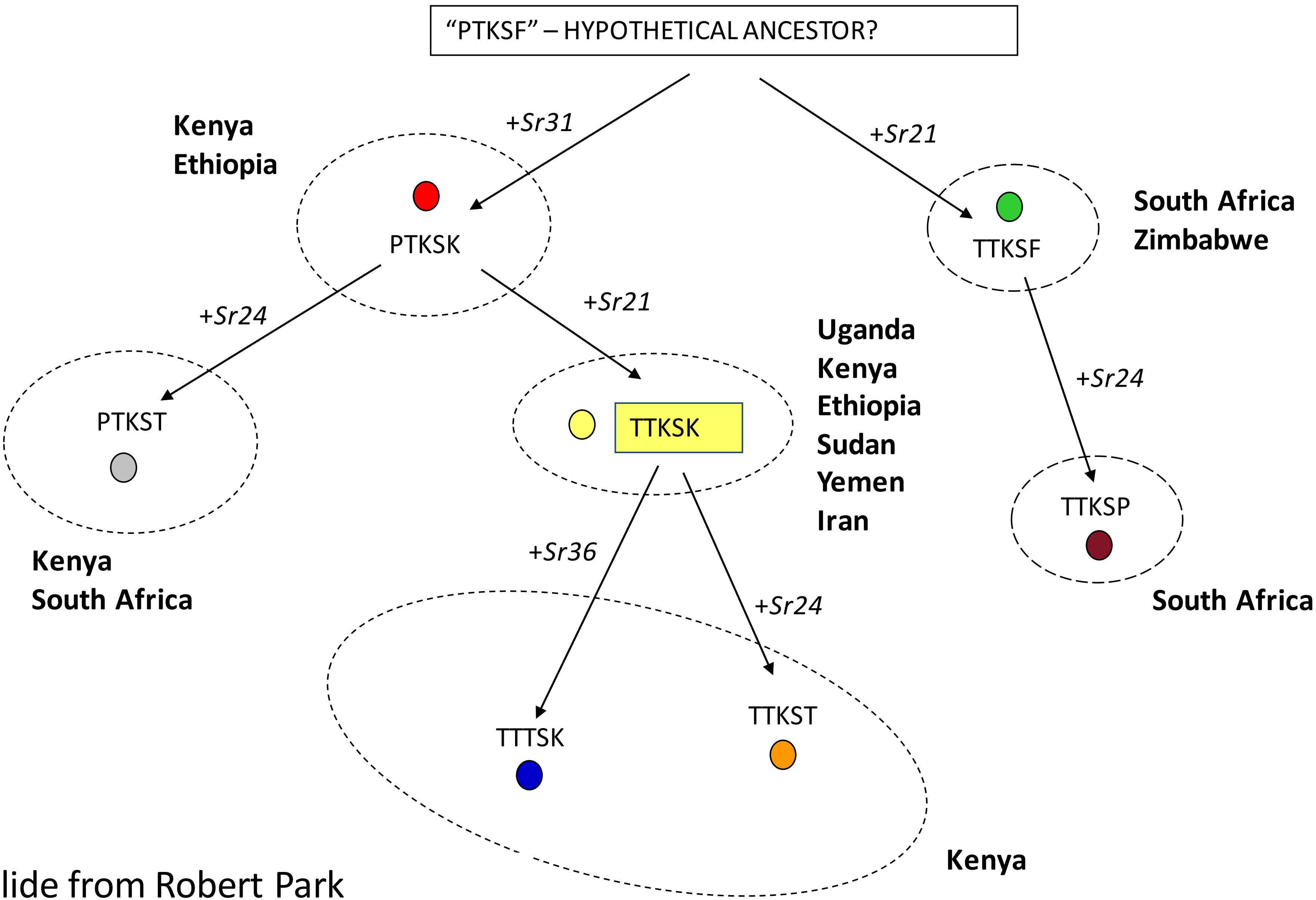


Slide from Robert Park

Why should we care about gene management in wheat?

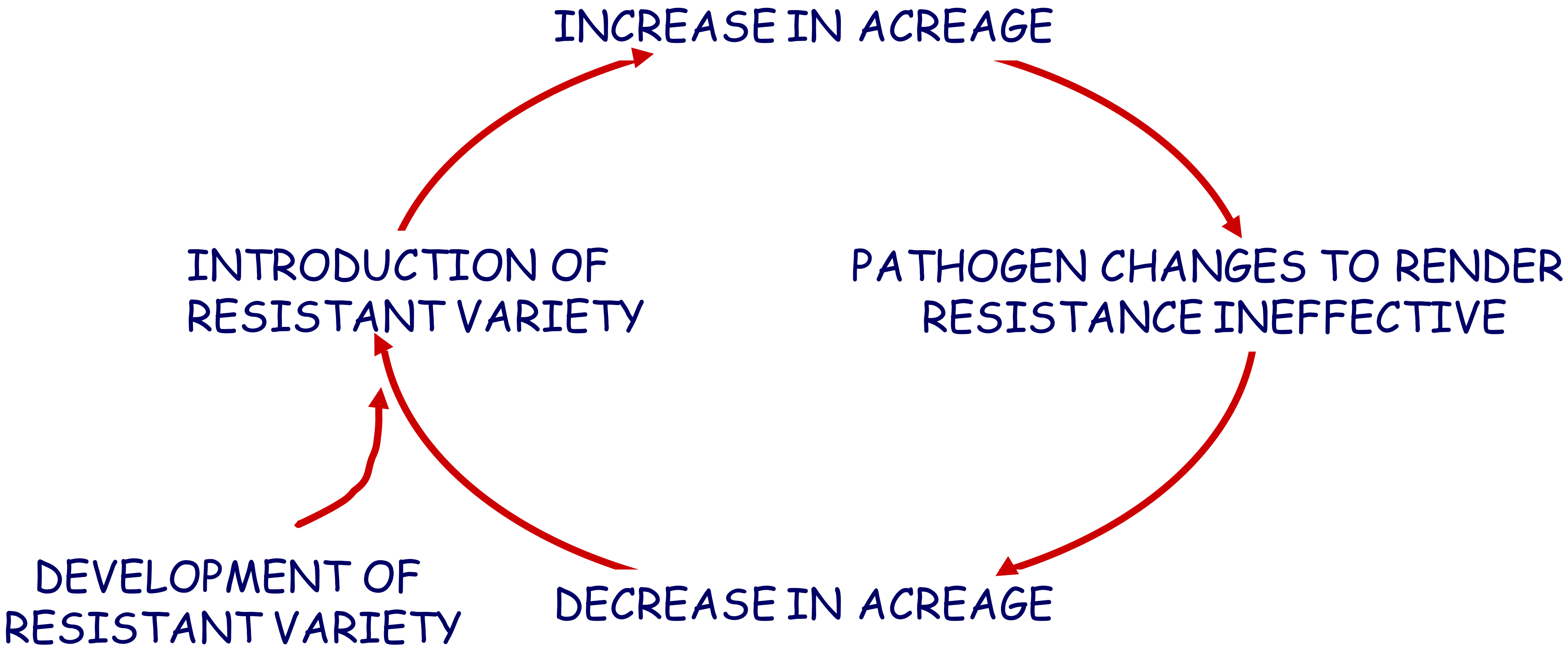
- Emerging pathogen races are overcoming resistance genes present in cultivated wheat → disease
- We don't have enough resistance genes available for wheat breeders NOW

Why should we care about gene management in wheat?



Slide from Robert Park

THE 'BOOM-AND-BUST' CYCLE OF DISEASE CONTROL
The Agricultural Consequences of Pathogen Evolution



(Suneson, 1960)

Slide from Richard Michelmore

What strategies do we have for gene management now?

- Individual genes

  Effectiveness varies

- Cultivars

  Empirical breeding
  Marker assisted approaches
  Transgenic technologies

- Agricultural systems

  Varied control strategies informed by
  surveillance, epidemiology, modeling

WORDS, WORDS, WORDS (Part 1)

Durable resistance to a disease is resistance that remains effective during its prolonged and widespread use in an environment favorable to the disease.

[Roy Johnson, 1984, *Ann. Rev. Phytopathol., 22:309-30*]

"Durability" is a retrospective criterion: what would be helpful to know NOW to bring the future forward?

WORDS, WORDS, WORDS (Part 2)

Major genes: genes of large phenotypic effect

Minor genes: genes of small phenotypic effect

Race-specific = resistance that interacts differentially with pathogen races

Race non-specific = resistance that has not been shown to act differentially with pathogen races after prolonged testing (cannot be proven definitively)

Adult Plant Resistance (APR) = one type of resistance that results in slow development of rust disease on a plant

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The pathogen

Understanding rust pathogens (surveillance) has led to new control strategies eg:

- gene pyramiding – proposed following the recognition of mutation as a major source of variability in wheat rust pathogens

THE FUTURE FOR RUST RESISTANT WHEAT IN AUSTRALIA

By I. A. WATSON and D. SINGH

Introduction

Workers in this country have been prominent among those who have striven to control the ravages of cereal rusts by breeding. Several stem rust resistant varieties of wheat have been evolved at various times, but the most valuable of these have had only a short life as field much in favour of their having arisen by mutation. Several cases of mutation in cereal rusts are well known in the literature. Some will argue that the role of the barberry has not been eliminated, but this alternate host is so sparsely distributed in the areas where wheat is grown that infection from viable teleuto-

"Will lasting resistance ever be developed?....... combined resistances where possible should be used."

(Watson & Singh, 1952)

Gene deployment

1. resistance gene combinations for durability
2. resistance gene diversity for insurance

Resistance gene combinations and diversity

1. major genes
2. minor genes
3. major genes and minor genes

"It seems reasonable to argue that genetic complexity, presented by combining many genes each of small effect is more likely to achieve durable resistance, but this should not lead to the neglect of the opportunities presented by the increasing number of major genes implicated as playing an important role in durable resistance".

Johnson R (1993)
In 'Durability of Disease Resistance'
Eds Th Jacobs, JE Parlevliet

Gene stacks, pyramids, major genes, minor genes….

Cultivar	Released	Stem rust resistance genes	*Lr34/Yr18*?
Sunstate	1992	*Sr2, Sr5, Sr8a, Sr12, Sr38*	[-]
Pelsart	1993	*Sr2, Sr12, Sr36*	[+Lr34/Yr18]
Sunlin	1997	*Sr26, Sr38*	[-]
Wylah	1999	*Sr12, Sr26*	[+Lr34/Yr18]
Lang	2000	*Sr12, Sr24, Sr36*	[+Lr34/Yr18]
Braewood	2001	*Sr2, Sr12, Sr36, Sr38*	[+Lr34/Yr18]
Lorikeet	2001	*Sr30, Sr33*	[+Lr34/Yr18]
EGA Wentworth	2004	*Sr2, Sr5, Sr9g, Sr12, Sr24*	[+Lr34/Yr18]

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Pathogen fitness ("aggressiveness")
-experiences from Australia

- Four clear cases of exotic incursions of wheat rusts with increased fitness:

  - 1925, wheat stem rust standard race 126
  - 1954, wheat stem rust standard race 21
  - 1984, wheat leaf rust standard race 104
  - 2002, wheat stripe rust pathotype 134 E16 A+

- In all cases, the "new" pathotype quickly "replaced" endemic pathotypes, despite no virulence advantage (esp. race 21)

- Breeders were successful in developing resistant cultivars following the first three, and have had considerable success already in tackling the 4th

Rust pathogens worldwide

- **Stem (black) rust:** Ug99 and its derivative races
  >80% of worlds' wheat crop vulnerable
- **Stripe (yellow) rust:** Fast global colonization and evolution of aggressive, high temperature adapted races
  - $50 million worth of fungicide now used in Australia
  - Epidemics in several countries of Middle East and Central Asia on some varieties previously protected by *Yr27*
  - Breakdown of resistance genes (*Yr1,Yr17, Yr31)* in North America
- **Leaf (brown) rust:** Durum attacking races in Americas, North Africa and Southern Europe, and reliance on fungicides in South America

Rational utilization of resistance genes to achieve a long-term solution: currently available options

- Need a better strategy to ensure the utilization of race-specific resistance genes in combinations
- Wider application of minor genes based resistance breeding

Why CIMMYT has chosen the minor genes based breeding approach-

- About half of the spring wheat varieties in Asia, Middle East, Africa and Latin America are IARCs-derived
- Mega-varieties continue to dominate despite releases of many varieties
- Numerous races of rust pathogens and their mutating and migrating nature
- Inadequate annual virulence analysis and monitoring
- Slow variety turnover in most countries
- Opportunity to break-out of "Boom-and-Bust" cycles and focus breeding for other challenges to ensure increased productivity

HOW CAN WE ACHIEVE DURABLE RESISTANCE?

Strategies to enhance durability of resistance

Use knowledge of pathogen variability to inform strategies for resistance gene deployment. New opportunities from new technologies for rapid and comprehensive genotyping

Diversify selection pressure on pathogen

Pyramid/stack multiple genes – increase evolutionary hurdle

Utilize 'durable' resistance – empirical rather than mechanistic

Match life expectancy of resistance and cultivar

PATHOGEN POPULATION GENETICS SHOULD DRIVE DEPLOYMENT OF RESISTANCE GENES

Influenza paradigm

Continual sampling of pathogen
Virulence phenotyping, *in-situ* trap plots & *ex-situ* differentials
Gene-space sequencing (10s)
SNP genotyping (1000s)

Resistance gene discovery pipeline
Germplasm screens
Mapping, molecular markers
Molecular characterization

+

Deployment of effective resistance genes
Pyramiding, MAS or effector-driven selection
Allo- and sympatric diversity
Temporal adjustment of resistance genes deployed
Transgenic approaches for novel resistance strategies

Potential Challenges to Implementation of the Influenza Paradigm for Resistance Gene Deployment

Collection of pathogen samples from diverse, low-tech locations.

Global coordination of pathogen sampling.

Data processing and interpretation.

Data-driven consensus building and decision making.

Sufficient numbers of genes for pipeline (conventional &/or transgenic).

Persuading breeders (public and private) to participate and coordinate.

Providing agronomically acceptable options to famers and consumers.

Revision/adaption of regulatory/registration requirements to accommodate agronomically equivalent cultivars with different resistance genes.

Success is possible!

EIAR/Cornell photo: USAID-supported seed multiplication in Ethiopia of CIMMYT-derived wheat varieties with multi-genic resistance to Ug99 stem rust