Resistance Gene Management: Concepts and Practice

Fourth International Workshop on the Genetics of Host-Parasite Interactions in Forestry

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Strategies for Major Genes

- One gene at a time
- Gene rotation
- Gene “pyramids”
- Mixtures
- Regional deployment

Working With Minor Genes

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Working With Minor Genes

“Alien” resistance for wheat stem rust

Bacterial blight of rice

Septoria tritici blotch of wheat

Lessons

Don’t believe that your favorite pathogen or favorite resistance gene is an exception

“Silver Bullets” usually aren’t

Are There Places for a Single-Gene Approach?

- Marginal environments
- As a stop-gap measure

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Mechanisms

- Probability of multiple mutations
- Residual gene effects
- Favorable combinations

Year Cultivar	licensed	Rust reaction When licen.	1978	Known resistance genes
Kota	Pre-1923	S	S	*Sr28*
Marquis	Pre-1923	S	S	Sr7b, 18, 19, 20
Red Bobs	1926	S	S	Sr7b, 10
Reliance	1932	S	S	Sr5, 16, 18, 20
Thatcher	1935	R	S	Sr5, 9g, 12, 16
Renown	1937	R	S	*Sr2,* 7b, 9d, 17
Redman	1946	R	S	*Sr2,* 7b, 9d, 17
Lee	1950	R	S	*Sr9g,* 11
Selkirk	1953	R	R	Sr2, 6, 7b, 9d, 17, 23
Canthatch	1959	MR	S	Sr5, 7a, 9g, 12, 16
Pembina	1959	R	R	Sr2, 5, 6, plus
Manitou	1965	R	R	*Sr5,* 6, 7a, plus
Neepawa	1969	R	R	*Sr5,* plus
Pitic 62	1969	R	S	Sr8, 9b
Napayo	1972	R	R	*Sr5,* 6, 7a, plus

ID of Gene Combinations in Progeny

- Shotgun method
- Phenotypic expression of reaction type
- Molecular markers

Pyramid Components

Sr2, Sr6, Sr17, Sr24, Sr31, Sr36, Sr38

Arrival of "Ug99" has caused havoc in the wheat breeding world

Lesson: Pyramids have been highly useful, but may not be permanent

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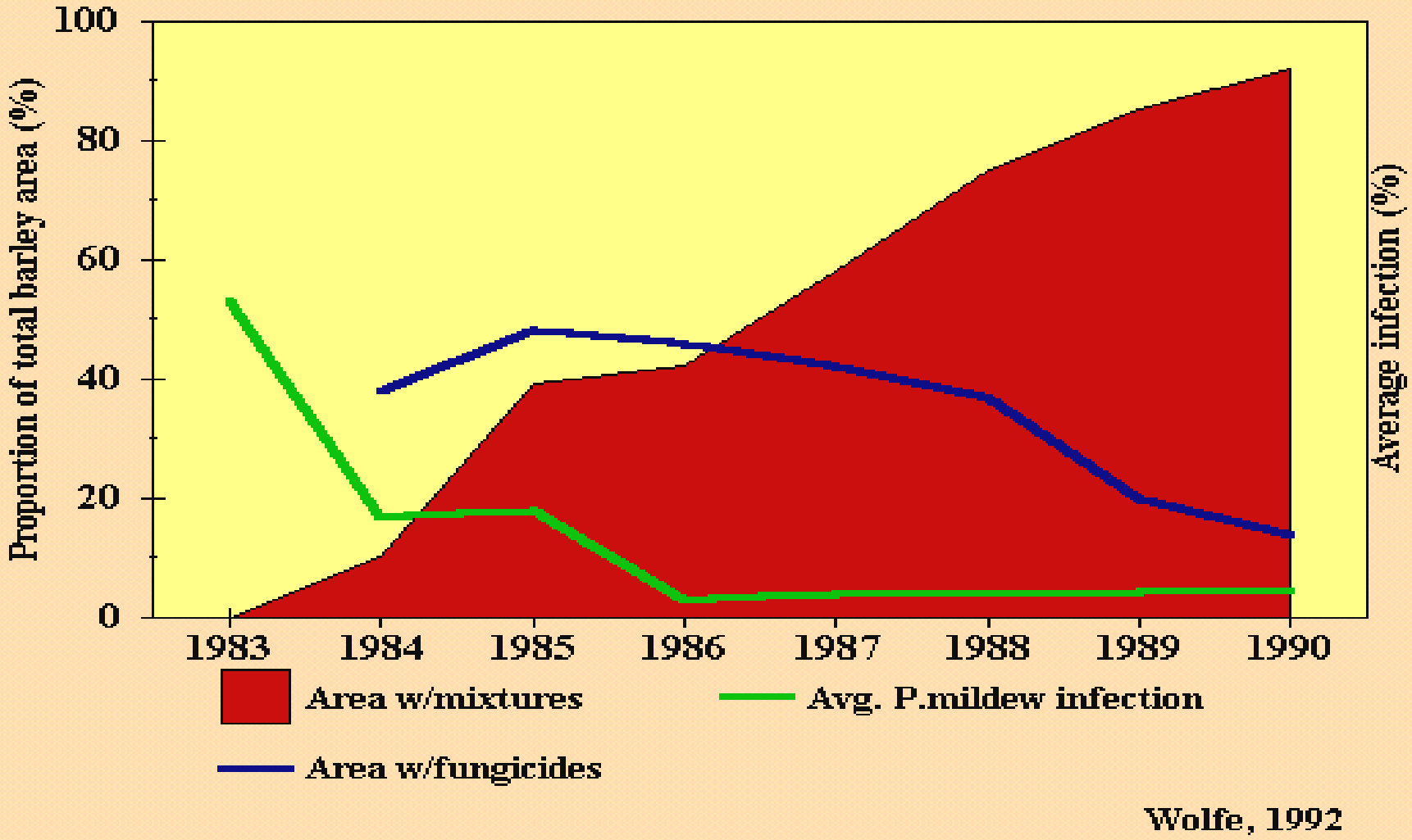
Working With Minor Genes

A A A A B C A B

A A A A A B C A

A A A A C A B C

A A A A B C A B



Wolfe, 1992

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With Mixtures, Anything Can Happen

Empirical testing critical

Effectiveness of Mixtures

- Can be highly dependent on degree of inoculum pressure
- Plant size issue?

The “Superrace” Fear

- Should certainly take steps to discourage
- Has been overemphasized
  - little support from field
  - models are greatly over-simplified

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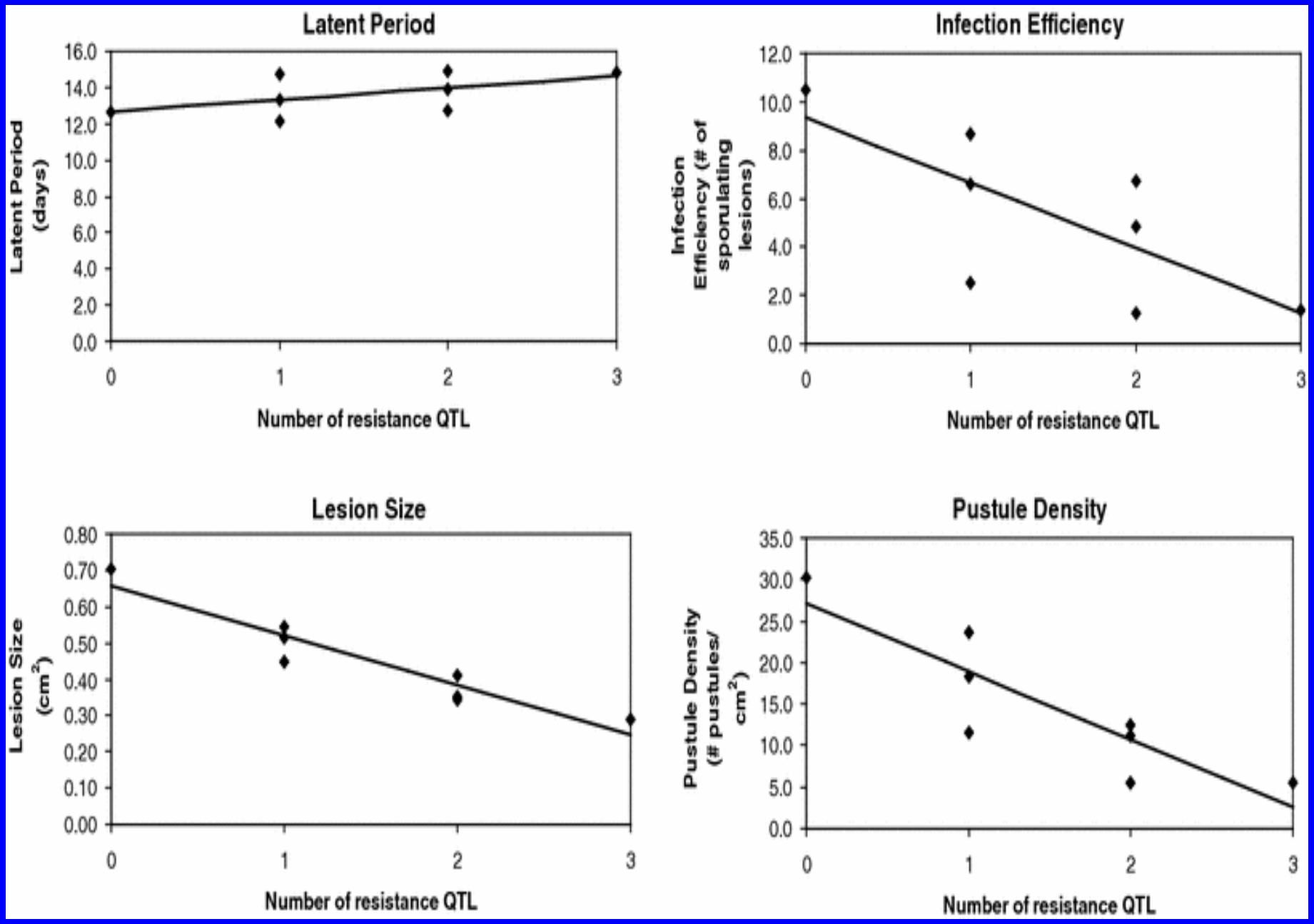
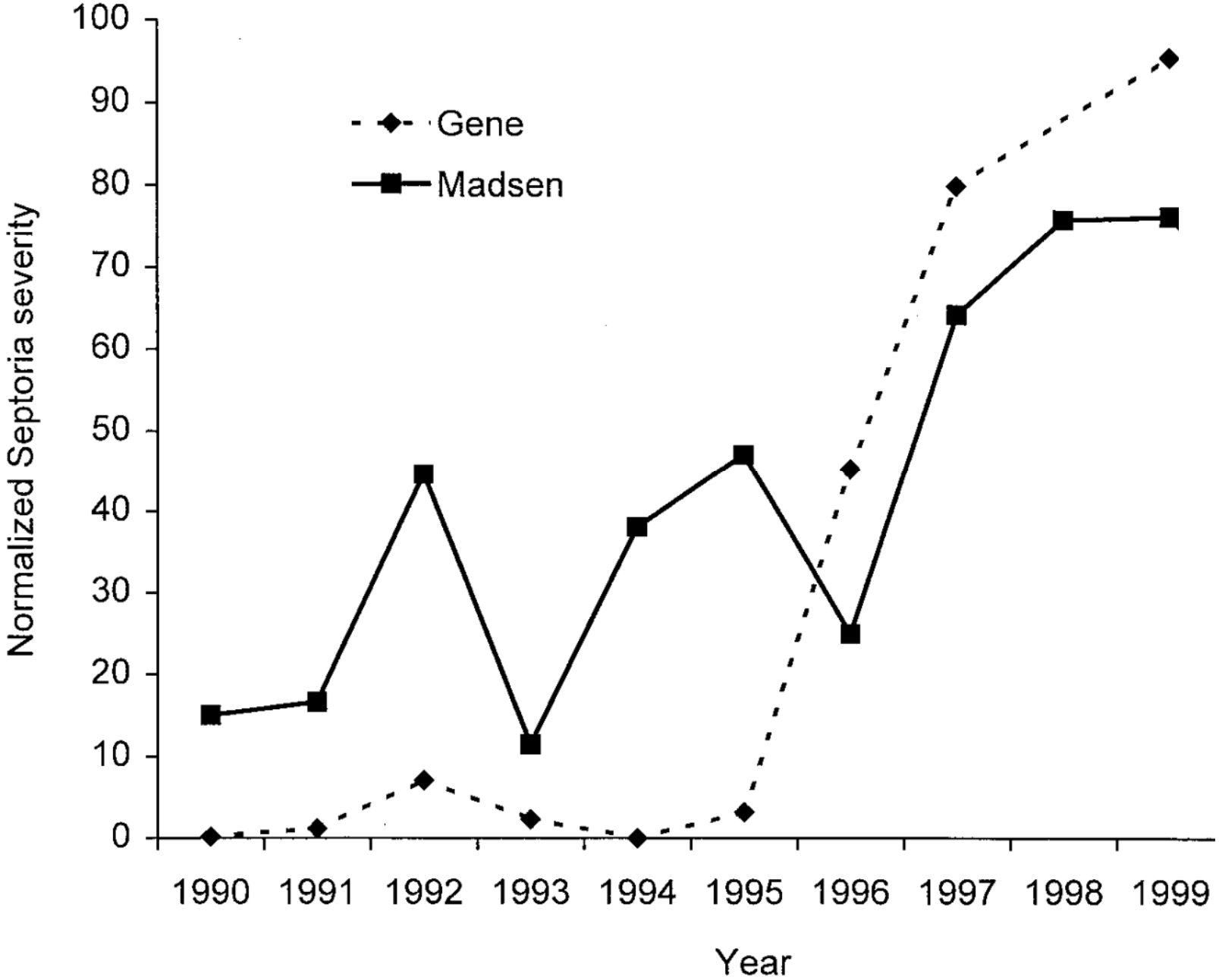
Working With Minor Genes

Minor Gene Resistance

- Often more available than we think
- Simply purging the more susceptible material can be very useful
- Inheritance is much less complex than once thought


Latent Period
Latent Period (days)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
1
2
3
Number of resistance QTL
Infection Efficiency
Infection Efficiency (# of sporulating lesions)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
1
2
3
Number of resistance QTL
Lesion Size
Lesion Size (cm2)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1
2
3
Number of resistance QTL
Pustule Density
Pustule Density (# pustules/ cm2)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
1
2
3
Number of resistance QTL

Are Minor Genes Truly Non-Specific?


Gene
Madsen
Normalized Septoria severity
100
90
80
70
60
50
40
30
20
10
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Year

QTL Analysis and MAS

QTL Analysis and MAS

Molecular Breeding

- Biology and engineering are very different
- High-quality phenotyping is still the most important ingredient of a resistance breeding program, and this likely will always be so

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Working With Minor Genes

Don’t Forget About IPM

Potato late blight severity:

Susceptible, no fungicide =	100%
Weekly fungicide =	56%
Minor gene resistance =	46%
Resistance + fungicide =	9%

Stuff Happens

Stuff That Happens

- **“Little” Stuff**

  race changes

  relatively frequent

- **Big Stuff**

  population displacements, “selective sweeps”

  on the order of ~50 or 100 years or more

Stripe Rust

Puccinia striiformis

VIDAL L. INRA

Stuff Is Going to Happen

Major Gene	Minor Gene
Qualitative	Quantitative
Complete	Partial
Race-specific	Non-specific
Specific	General
Vertical	Horizontal
Intolerance	Tolerance

Do Not Be Surprised When Stuff Happens

Summary

How I Look at the Soybean Rust Situation From An Outside Perspective

Single Gene at a Time "Use It Till You Lose it"

- May be needed as a stop-gap measure
- In general, don't go there
  - Puts growers at risk
  - Disruptive to breeding programs

Rotating Genes

- Likely a disaster
- Virulence unlikely to decline to previous levels

Pyramids or Combinations of Major Genes

- Useful in increasing durability of major genes
- More complex than using single genes
- Takes time to determine which combinations work best

Mixtures or Blends of Major Genes

- Not much information available for soybean rust
- Perhaps worth investigating

Regional Deployment

- Likely very useful if done
- Is it feasible?

Minor Gene Resistance

- It's hard to go wrong with this approach
- May take a bit more effort up front
- Likely to eliminate a lot of headaches in the longer term

Molecular Biology Will Never Replace Field Experience

Do Not Be Surprised When Stuff Happens

Free Advice is Often Worth
What You Pay For It

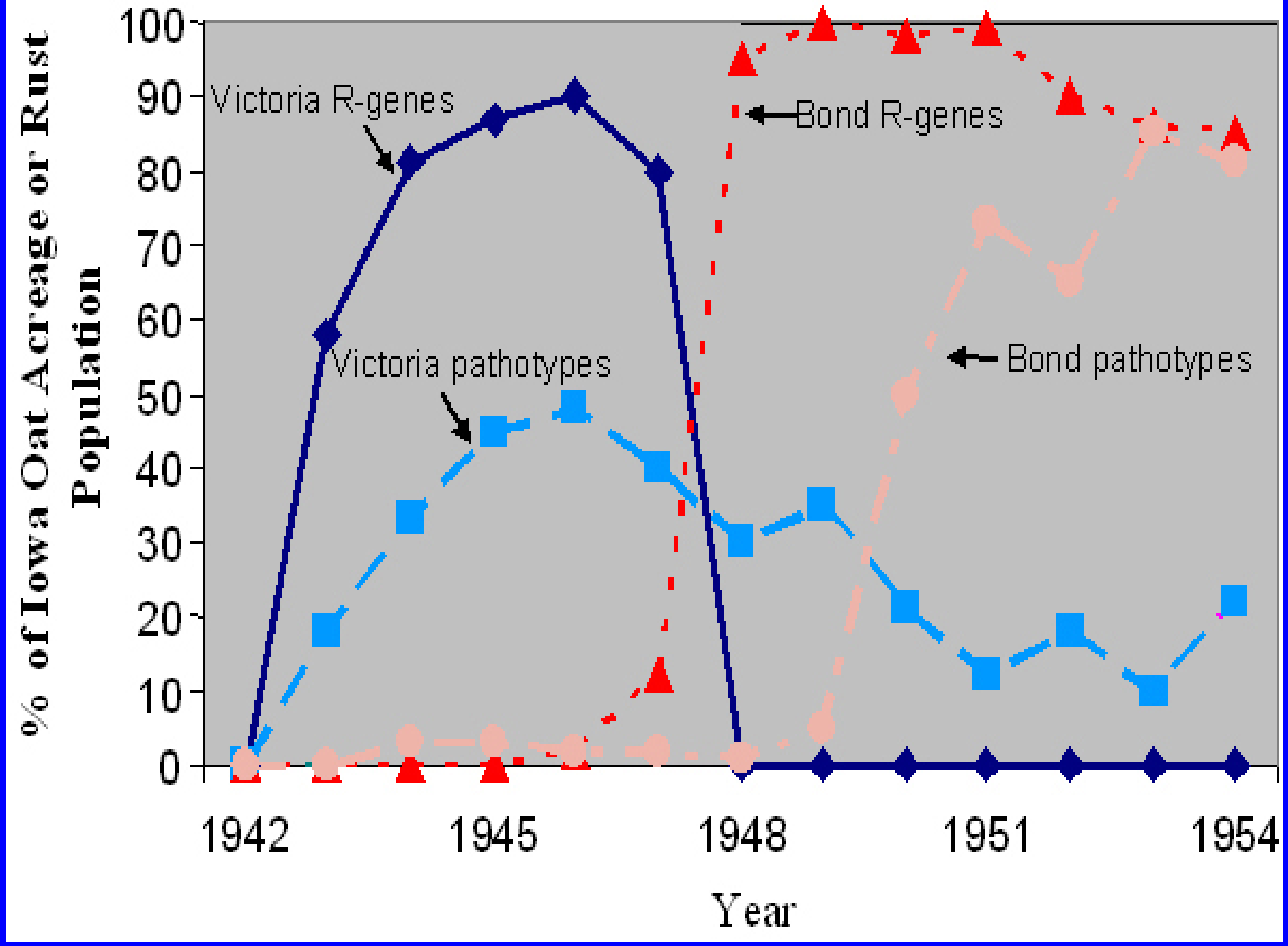
Major Gene Resistance

- Single gene
- Usually dominant
- Often gives complete resistance
- Relatively straightforward to work with in a breeding program
- Highly specific to pathogen race
- Very often unstable over time

Major Genes

Interact With the Pathogen in a "Gene-for-Gene" System

How Does This Work??


% of Iowa Oat Acreage or Rust Population
100
90
80
70
60
50
40
30
20
10
0
Victoria R-genes
Victoria pathotypes
Bond R-genes
Bond pathotypes
1942
1945
1948
1951
1954
Year

Major Genes

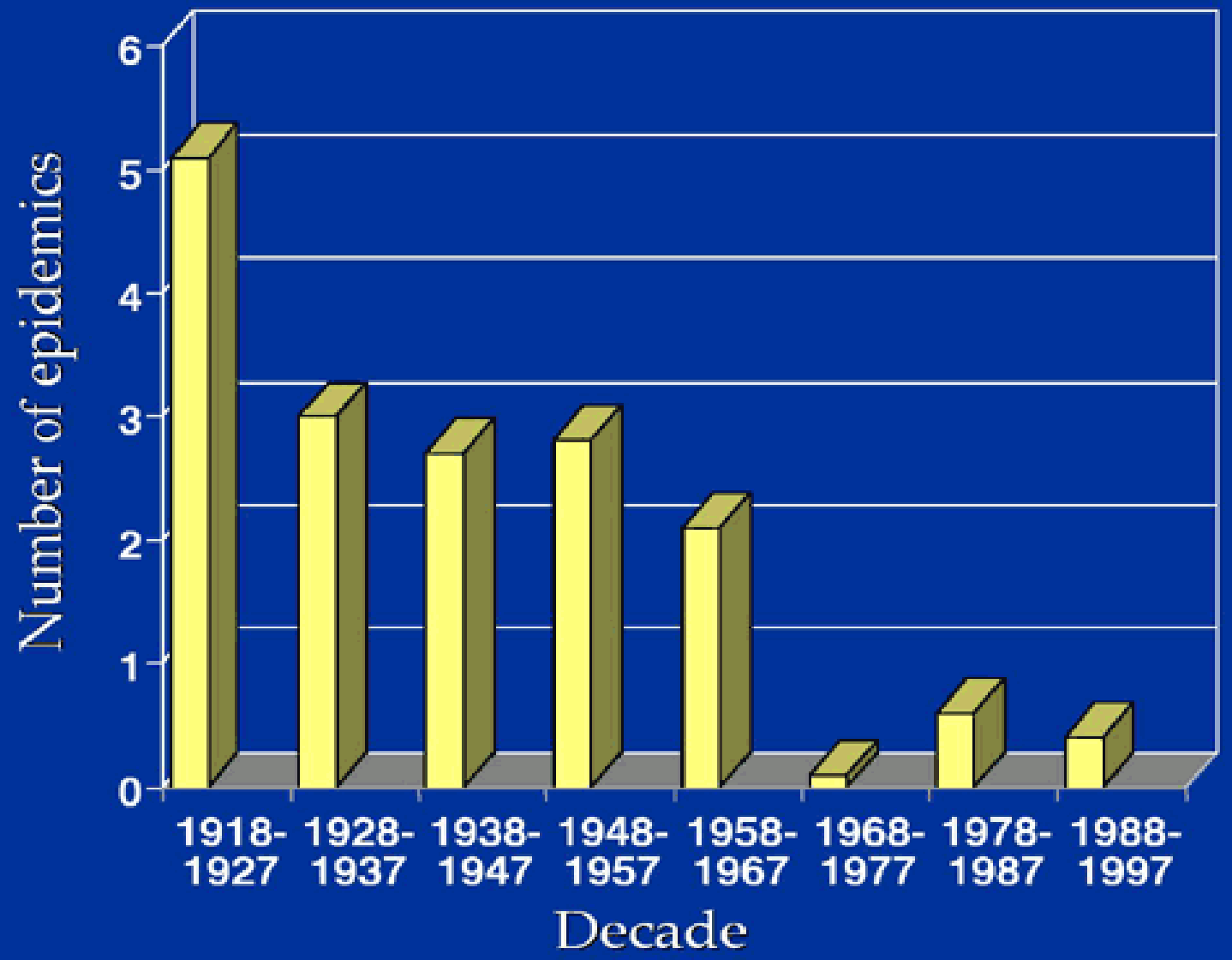
Very Easy for the Pathogen to Overcome

Results in “Boom-and-Bust” Cycles

Minor Gene Resistance

- Multiple gene inheritance
- Often recessive
- Usually gives incomplete resistance
- Can be more complicated to work with
- Not highly specific
- Tends to be very stable over time

Average Number of Wheat Stem Rust Epidemics in Barberry Eradication Area



Vertifolia Effect

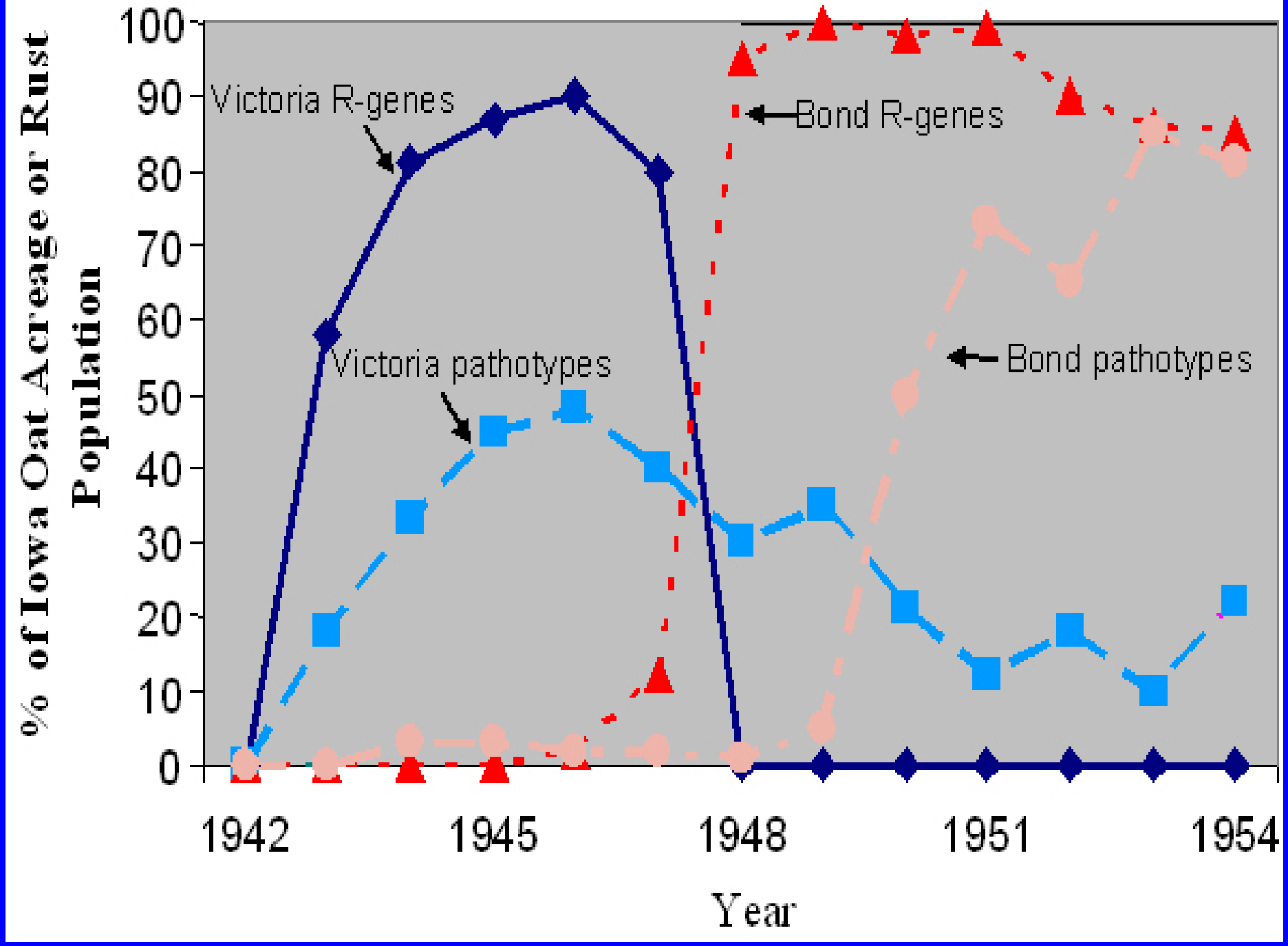
Percent of Willamette Valley Winter Wheat Acreage Planted to 'Foote'

Year	Percent
2001	22
2002	50
2003	50
2004	51
2005	32
2006	4

Lessons:

The Vertifolia Effect can be real

“Perfect Storms” do happen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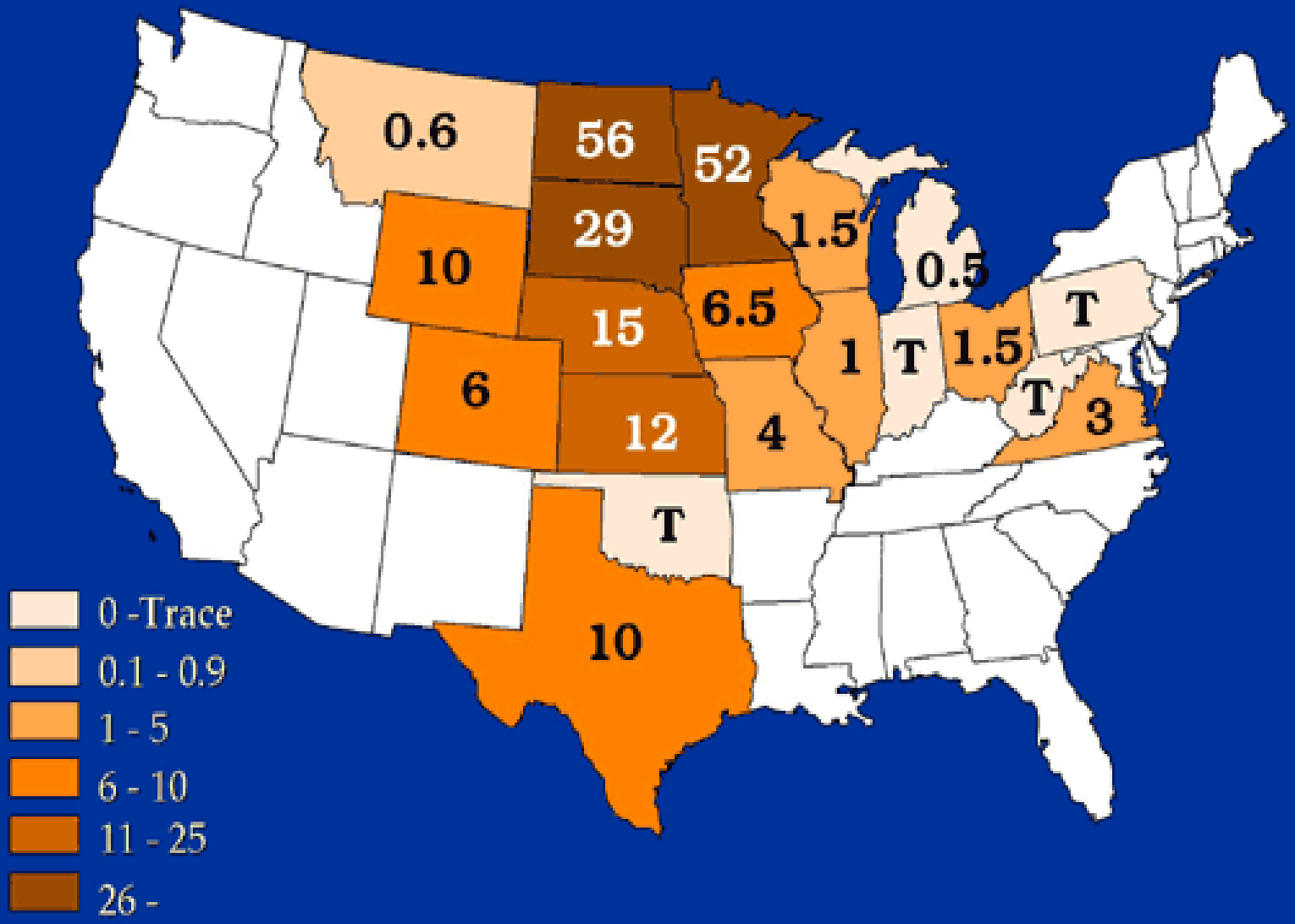
1935 % Loss to Wheat Stem Rust
After Barberry Eradication



Percent of winter wheat sown to cultivar mixtures in 2008 (source: NASS)

- Oregon 12%
- Washington 25%
- Kansas 10%

1999 – Race TTKSK

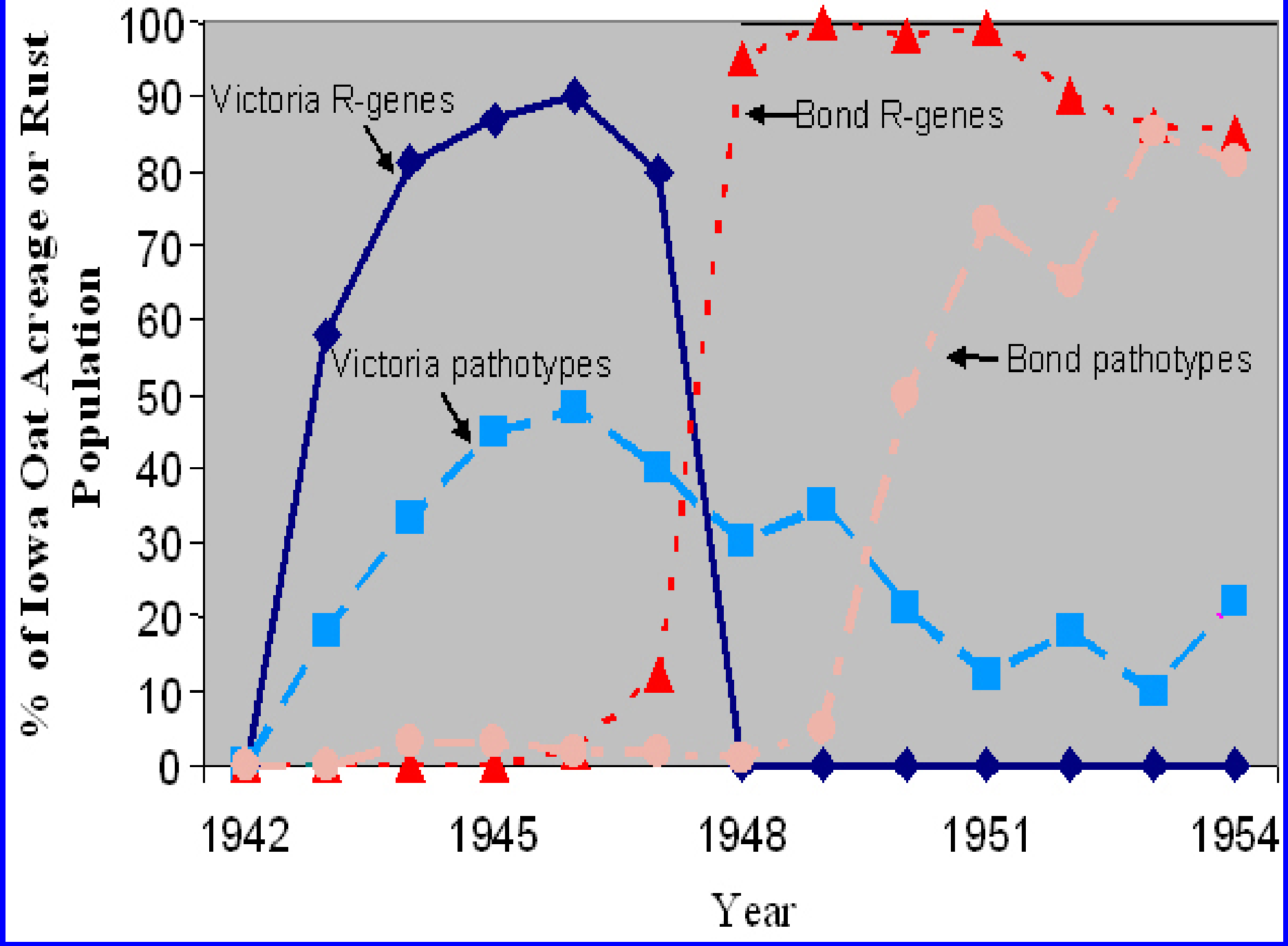
(Sr31 + Sr38)

2006 – Race TTKST

(Sr31 + Sr38 + Sr24)

Race TTTSK

(Sr31 + Sr38 + Sr36)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Lessons:

Single major genes are usually unstable and make crops vulnerable to sudden yield losses

- QTL Analyses

Use of Top Crosses to Maintain Minor Genes for Stripe Rust Resistance While Improving Other Traits

Can be relatively easy to maintain minor gene resistance once you have it

Minor Gene Resistance

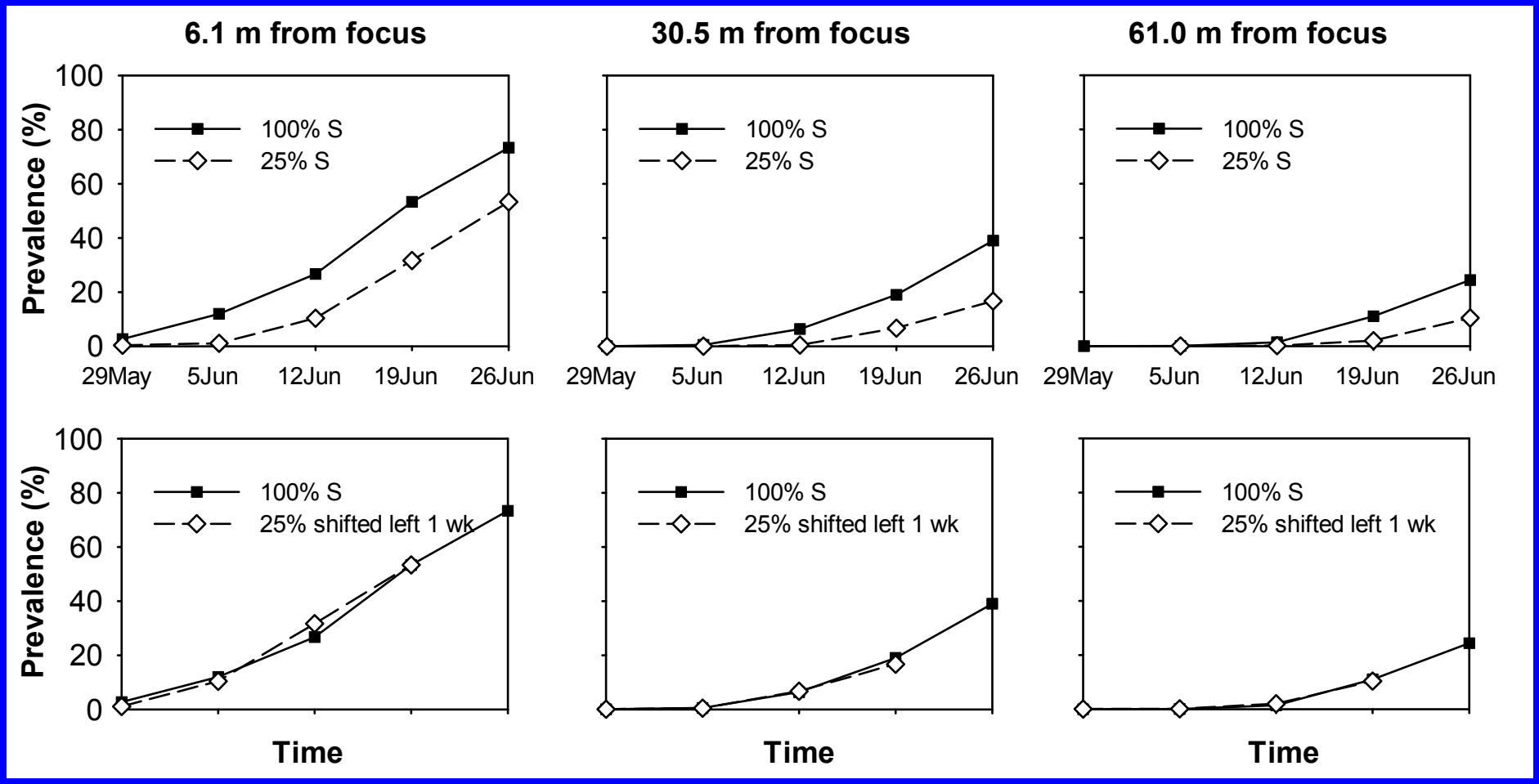
Commonly only 2-4 genes identified

1 or 2 that contribute majority of effect

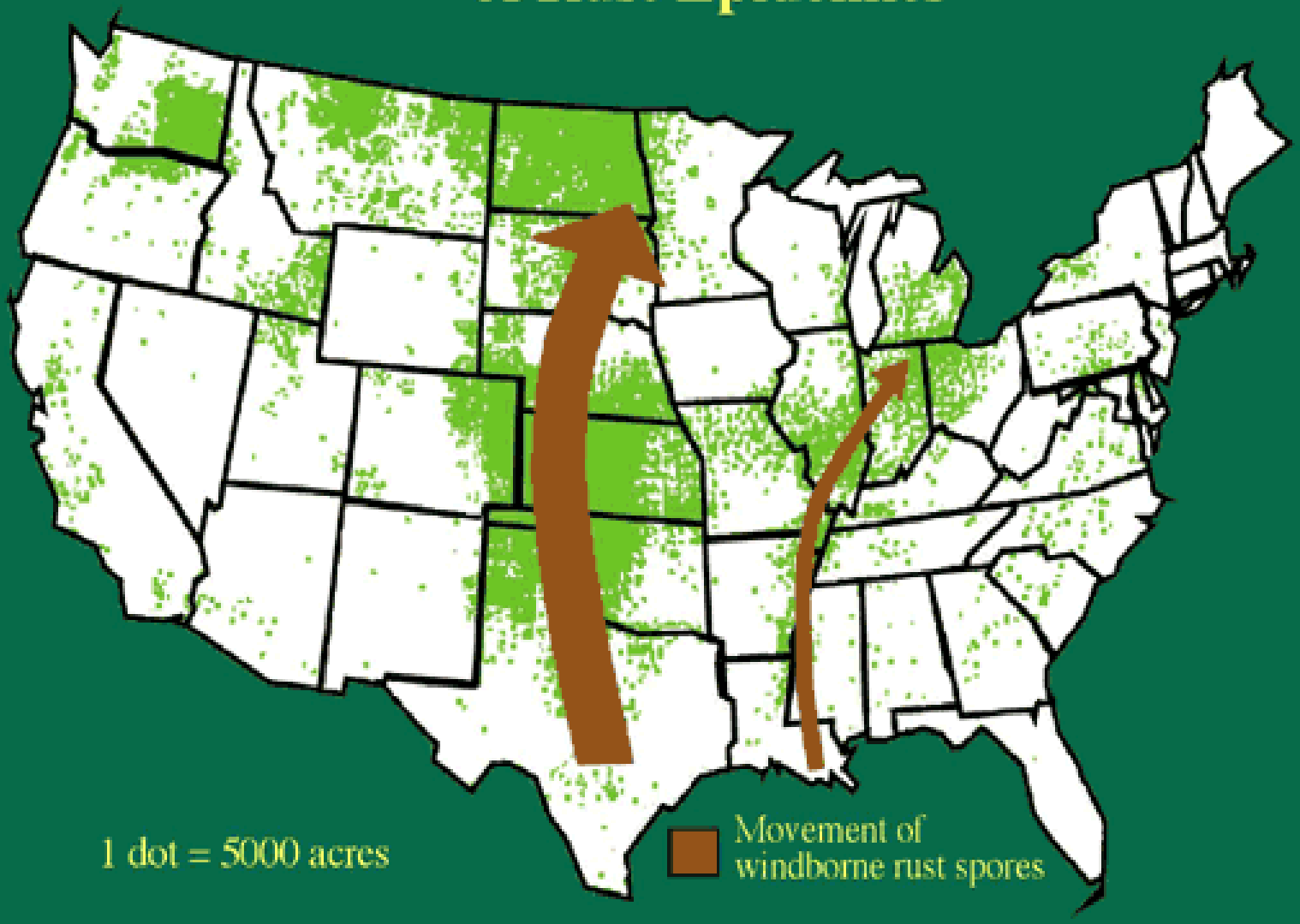
Heritability usually moderate to high

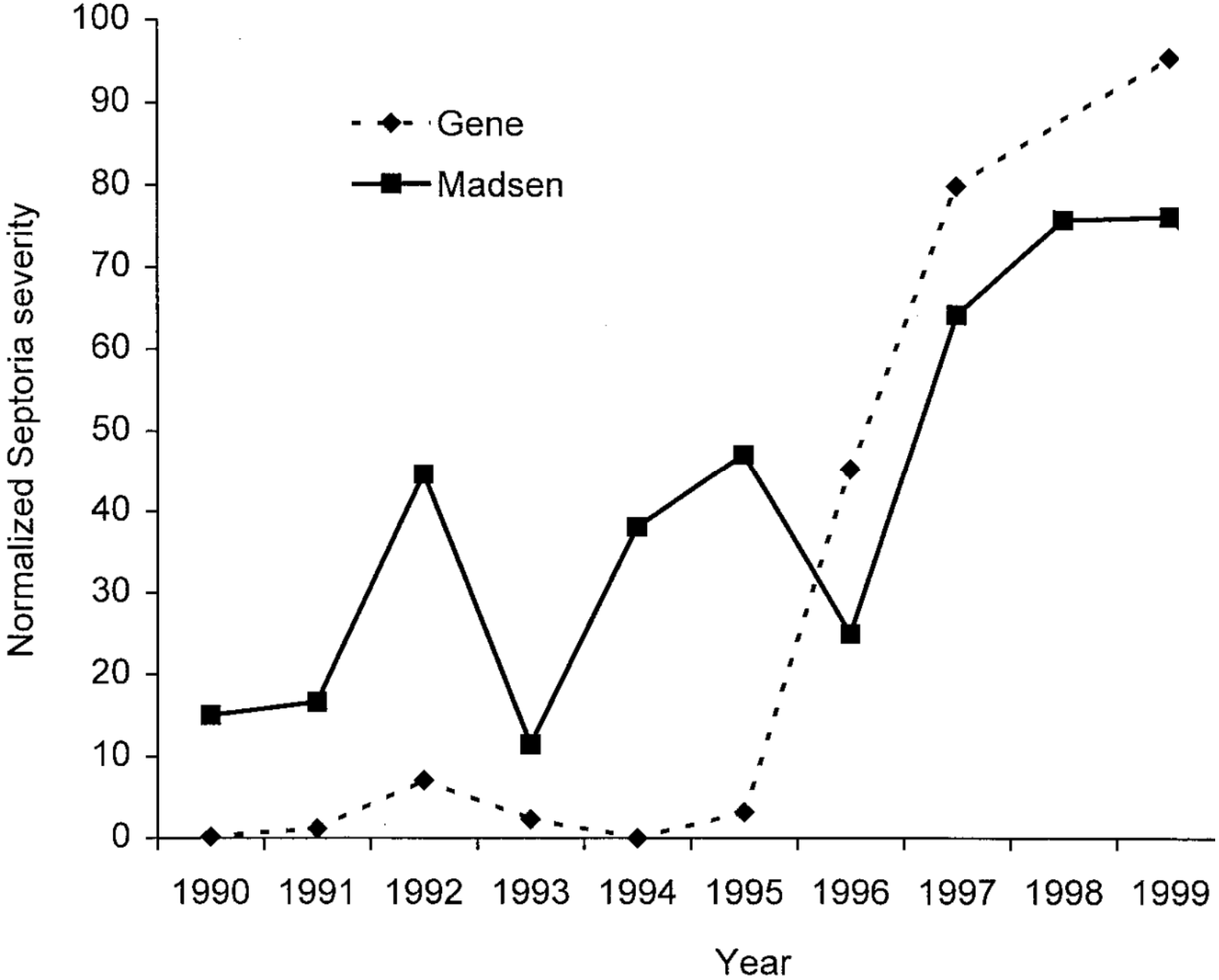
“Components” of resistance usually controlled by the same genes

QTL Analysis and MAS


6.1 m from focus
30.5 m from focus
61.0 m from focus
Prevalence (%)
100
80
60
40
20
0
100% S
25% S
25% shifted left 1 wk
29May
5Jun
12Jun
19Jun
26Jun
Time

Wheat Production and the Annual Spread of Rust Epidemics

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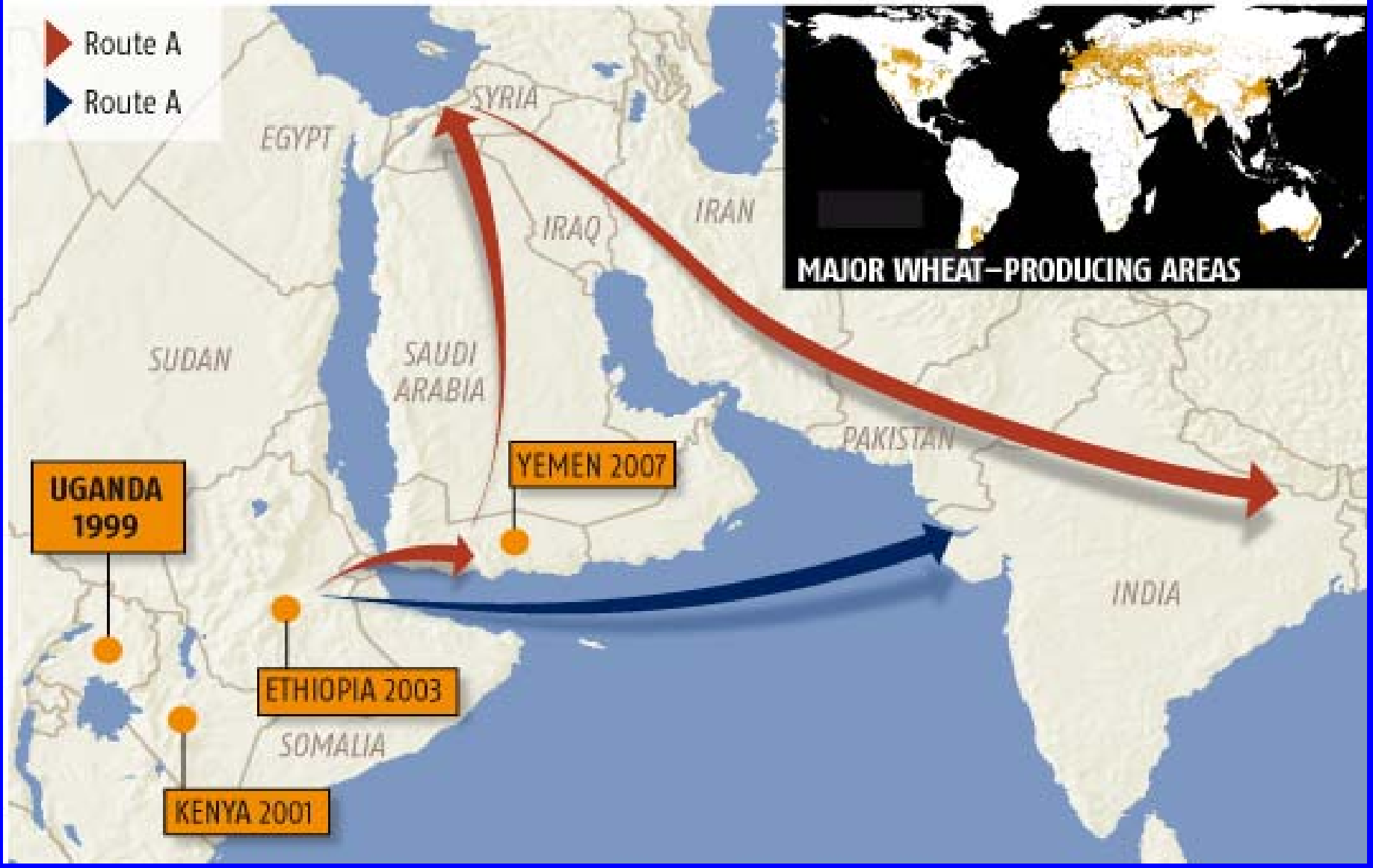
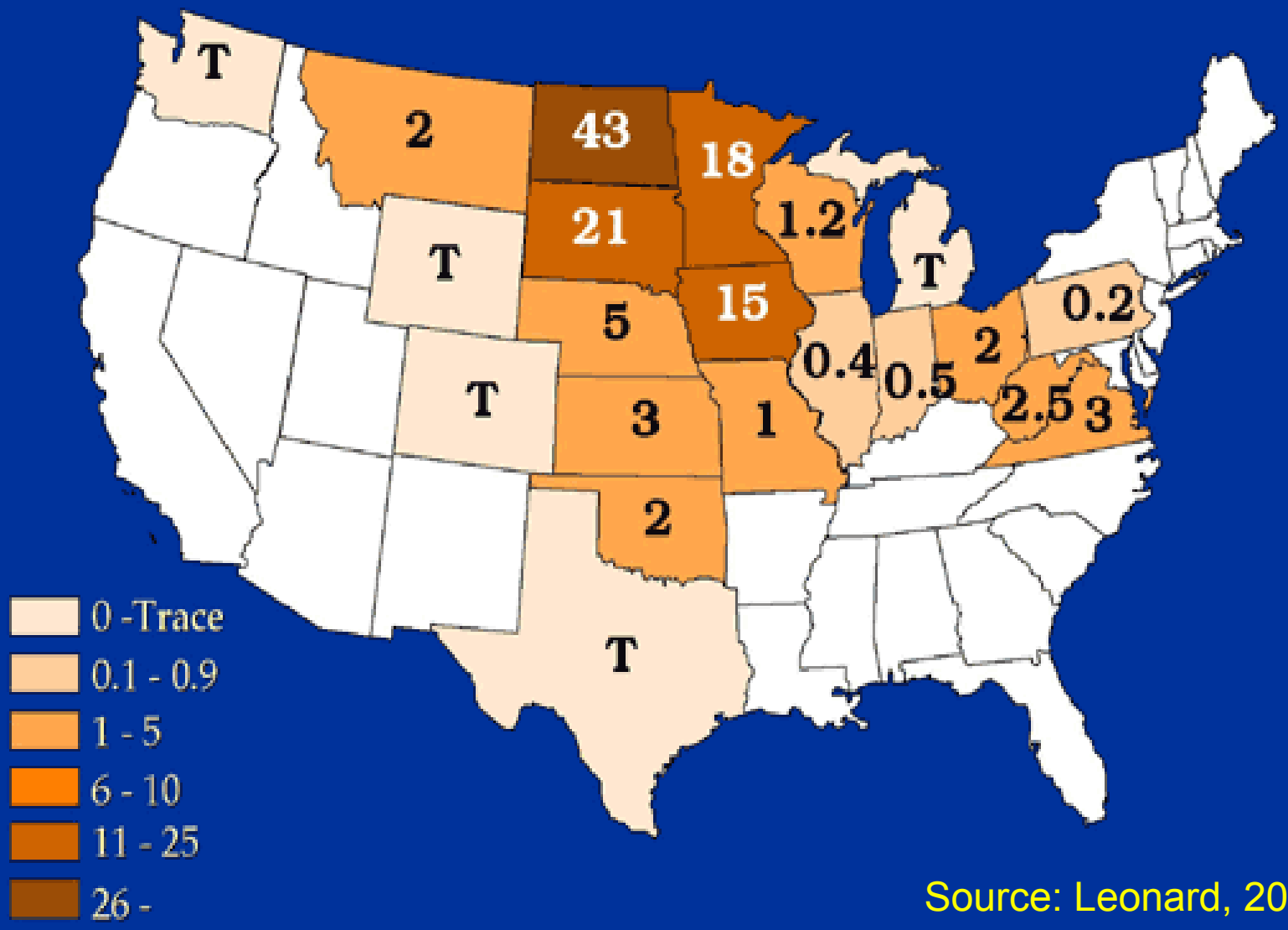
POSSIBLE MIGRATION ROUTES OF WHEAT RUST Ug99

Based on prevailing winds and areas of wheat production, route A via the Arabian peninsula is considered the more likely route for the continuing advance of the disease



1954 % Loss to Wheat Stem Rust



Source: Leonard, 2001