# Varietal resistance breakdown – drawing parallels with fungicide resistance

Mike Grimmer

BCPC Diseases Review, 19th October 2022

# Erosion of varietal resistance in UK wheat

Key wheat varieties see slump in yellow rust rating


Farmers Weekly, 2019

## Resistance breakdown: Septoria's resurgence in 2021

11th November 2021

**Dr Cathy Hooper, RAGT Seeds technical sales manager, reviews the late Septoria tritici epidemic that hit many wheat crops this season.**

Farmers Guide, 2021

# Integration for effective control

## How to combine:

- Mixtures: Fungicide + Fungicide
- Pyramiding: Host resistance + Host resistance
- Integration: Host resistance + Fungicide

+

# Integration for effective control

## Fungicide mode of action mixtures
## Multiplicative Survival Model (MSM):

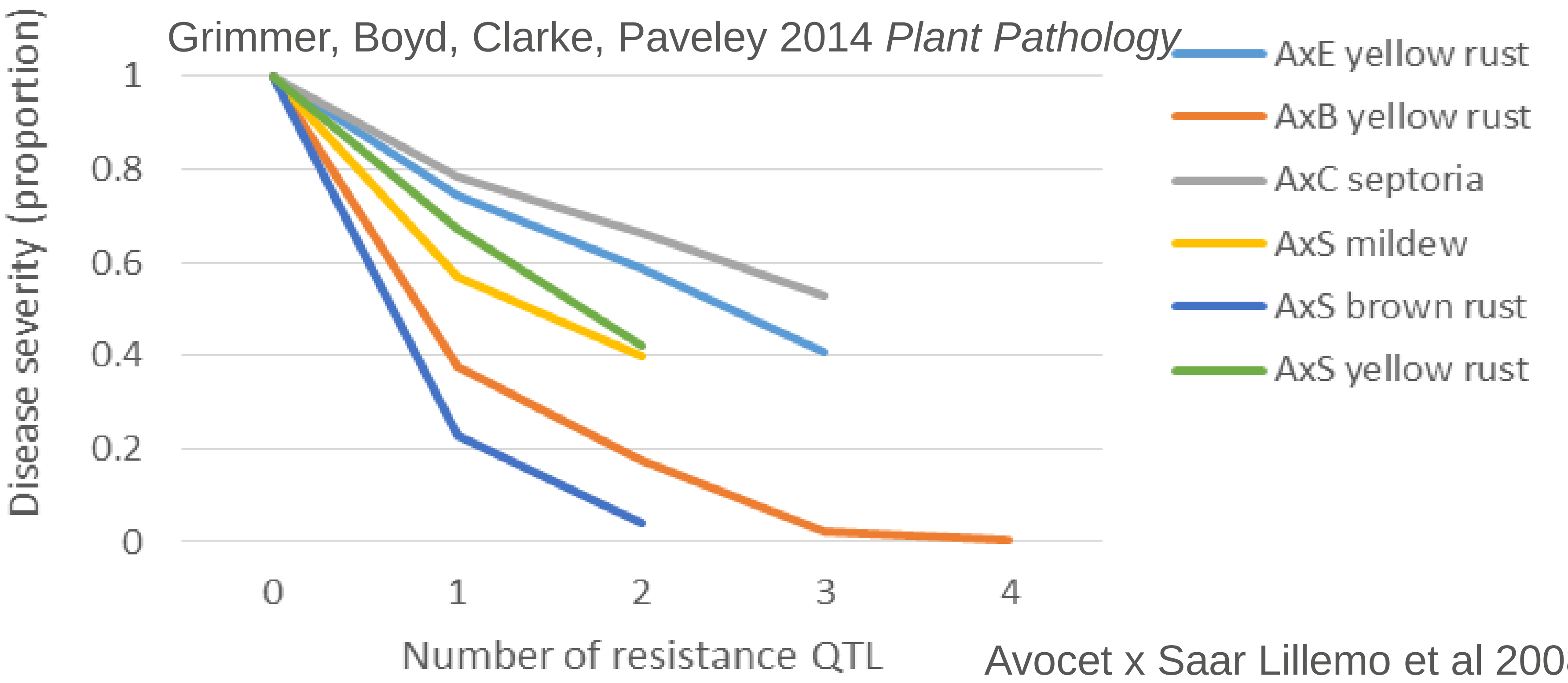
| | Fungicide A 90% control | + | Fungicide B 90% control | |
|---|---|---|---|---|
| Survival fraction = | 0.1 | X | 0.1 | = 0.01 (1%) |

## Assumes independence of action

Bliss, 1939. The toxicity of poisons applied jointly. *Annals of Applied Biology*

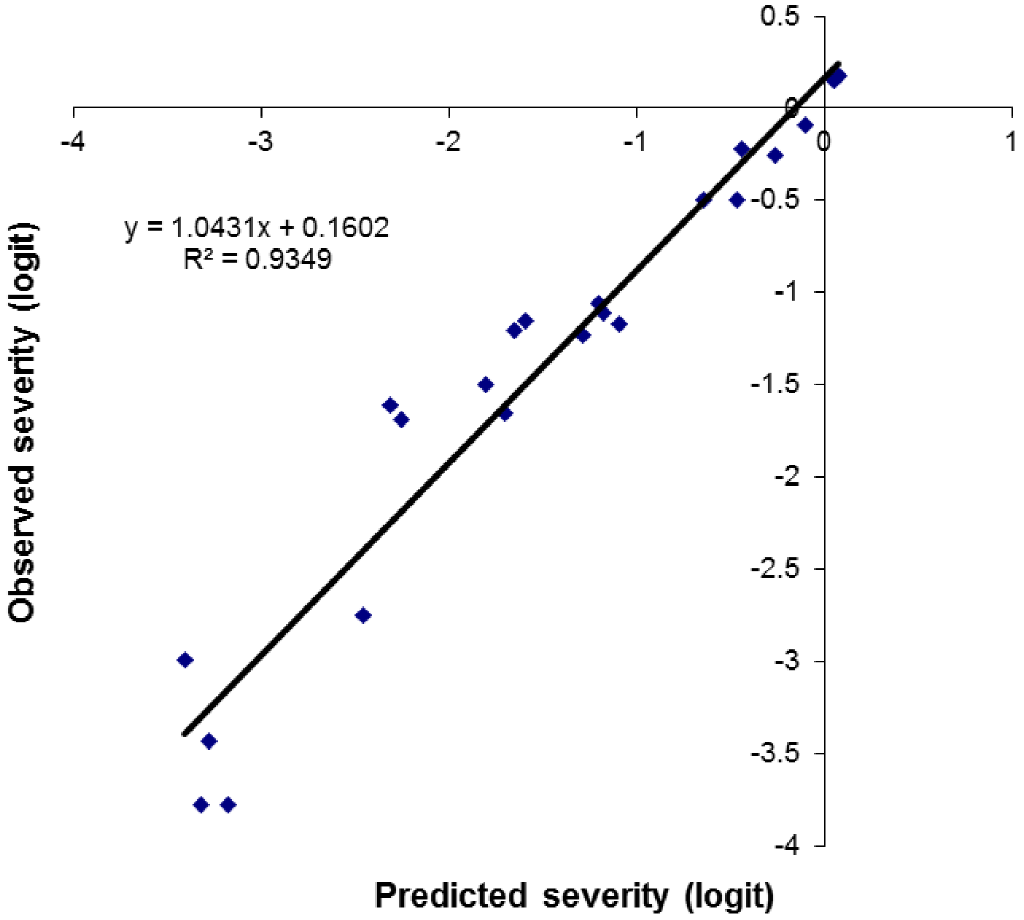
# Integration for effective control

## Pyramiding partial resistance loci




Avocet x Saar Lillemo et al 2008
Avocet x Express Lin & Chen 2009
Alcedo x Brigadier Jagger et al 2011
Avalon x Cadenza data unpub.

# Integration for effective control




Grimmer, Boyd, Clarke, Paveley 2014 *Plant Pathology*

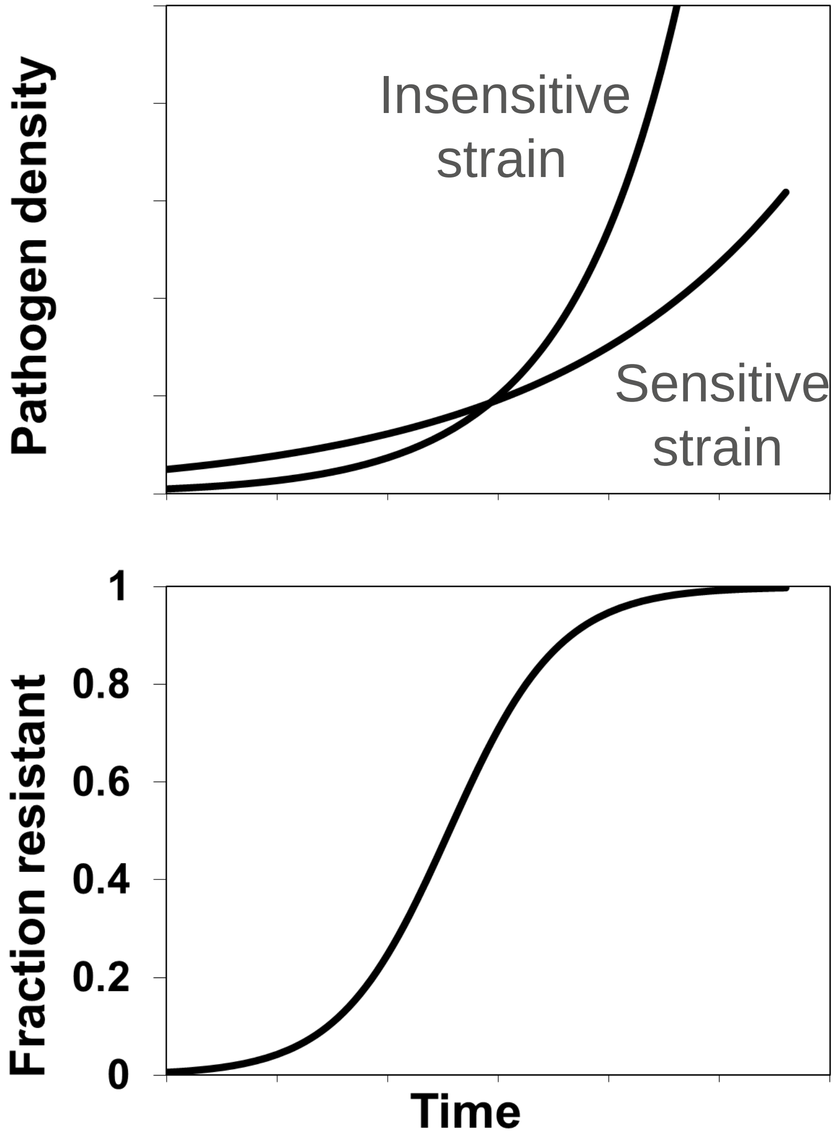
# Integration for long effective life

## How to combine:

- Mixtures: Fungicide + Fungicide
- Pyramiding: Host resistance + Host resistance
- Integration: Host resistance + Fungicide

+

# Integration for <u>long effective life</u> of fungicides






Van den Bosch *et al*. 2011 *Plant Pathology* 60, 597-606

# Governing principle for pathogen evolution

$$sT = (r_R - r_S)\,T$$

Selection

Rate of increase of resistant strain.

Rate of increase of sensitive strain.

Exposure time.

Milgroom & Fry, 1988 *Phytopathology*
van den Bosch et al. 2014 *Annual Review Phytopathology*

# Governing principle for pathogen evolution

$$sT = (r_R - r_S)\,T$$

Selection

Rate of increase of resistant strain.

Rate of increase of sensitive strain.

Exposure time.

***Strategy 1:*** **Reduce both $r_R$ and $r_S$**

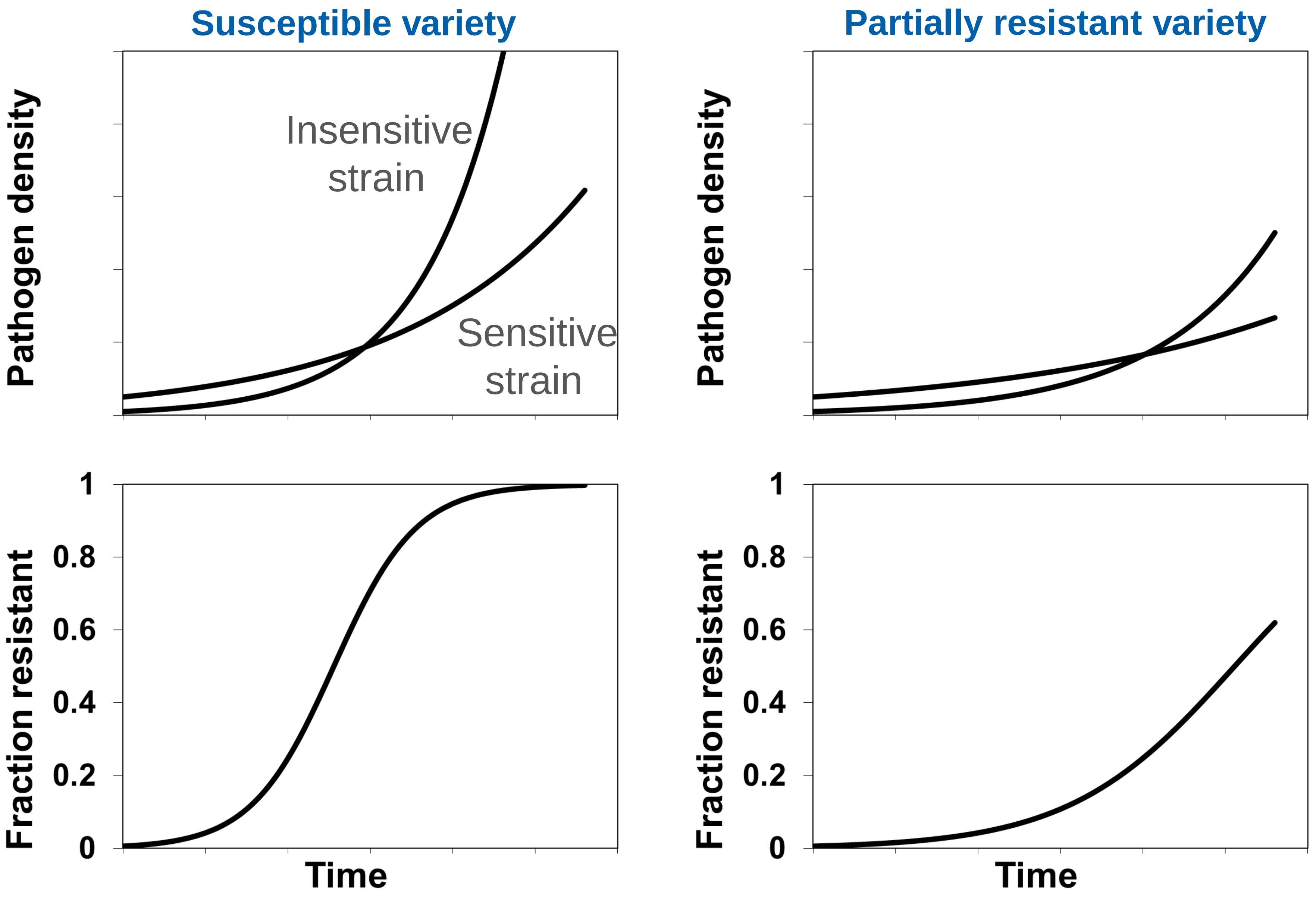
***Strategy 2:*** **Reduce $r_R$ relative to $r_S$**

***Strategy 3:*** **Reduce exposure time**

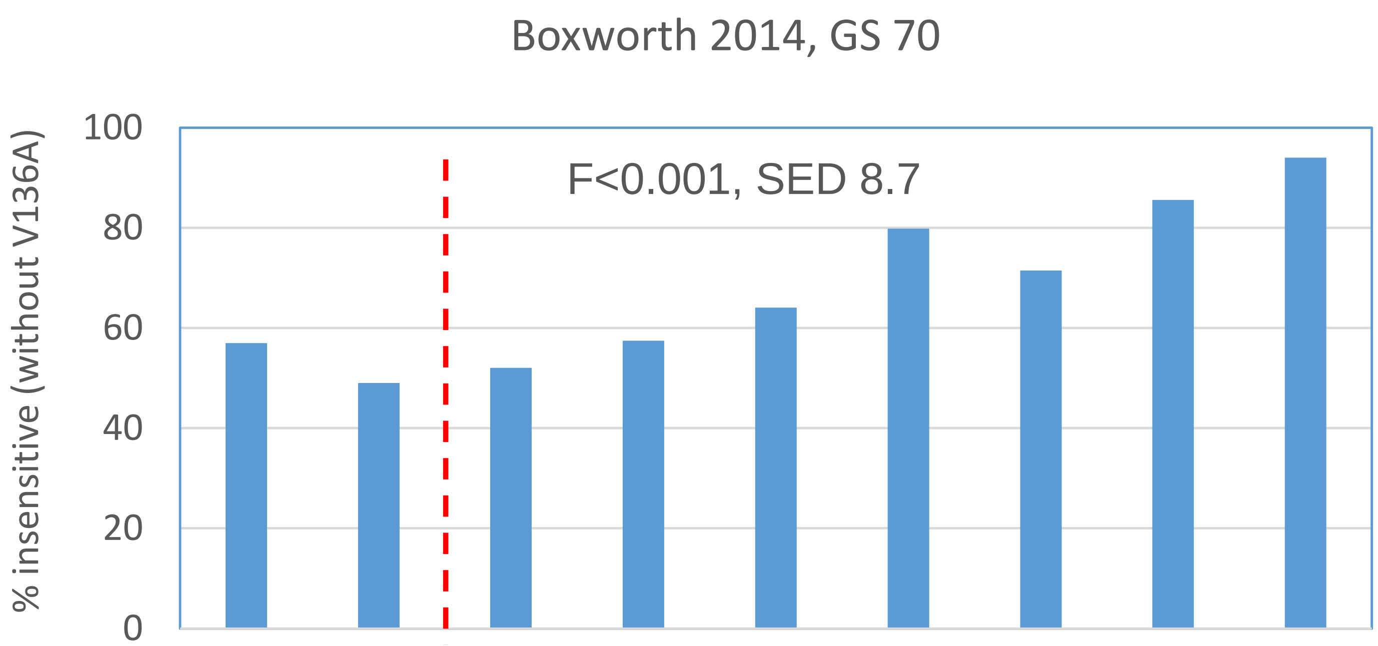
# Predictive value of Governing principle

| | Increase selection | No effect | Decrease selection |
|---|---|---|---|
| Increase dose | **16** | 1 | 2 |
| Increase number of sprays | **6** | 0 | 0 |
| Split the dose | **10** | 0 | 1 |
| Add a mixture partner | 1 | 6 | **46** |

van den Bosch, Oliver, van den Berg, Paveley 2014 *Annual Review Phytopathology*


Susceptible variety
Partially resistant variety
Pathogen density
Insensitive strain
Sensitive strain
Pathogen density
1
0.8
0.6
0.4
0.2
0
Fraction resistant
Time
1
0.8
0.6
0.4
0.2
0
Fraction resistant
Time

# Selection for tebuconazole insensitive *Z. tritici*

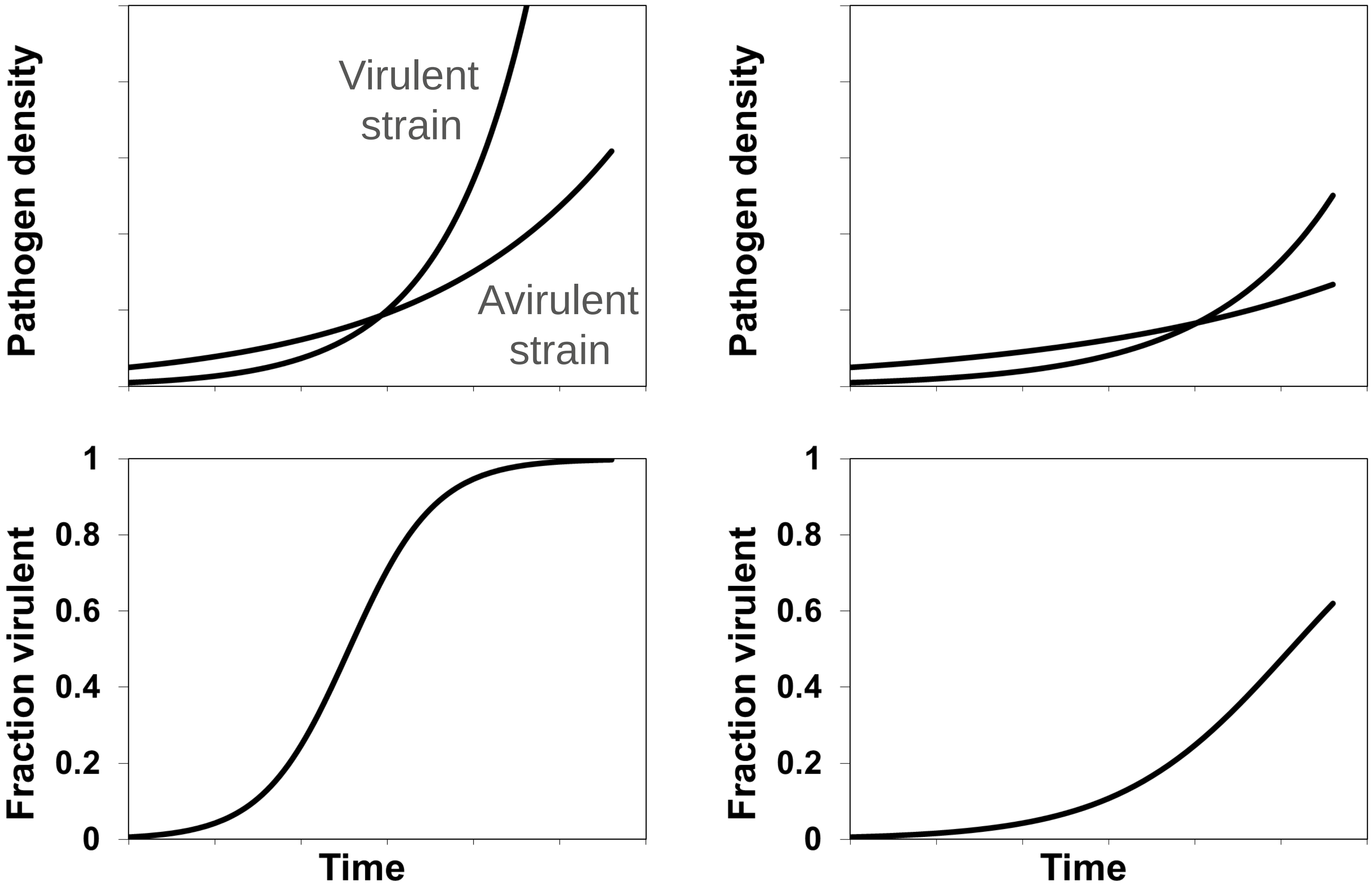



| Variety | Susc | Res | Res | Res | Res | Int | Susc | Susc | Susc |
|---|---|---|---|---|---|---|---|---|---|
| No. applications | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 3 |
| Total dose (units of tebuconazole) | 0 | 0 | 0.25 | 0.5 | 0.75 | 0.75 | 0.75 | 1.0 | 1.5 |

Genotyping data courtesy of Bart Fraaije

Bayer CropScience
Agricultural Products
BASF The Chemical Company
defra Department for Environment Food and Rural Affairs
DuPont The miracles of science
HSE
HGCA
syngenta
Limagrain United Kingdom
ROTHAMSTED RESEARCH
ADAS

Untreated | Fungicide treated



## Governing principles predict:

- Partial (rate-limiting) host resistance reduces selection for fungicide insensitivity by:
  - Strategy 1 (reducing epidemic rates)
  - Strategy 2 (reducing dose)
  - Strategy 3 (reducing number of treatments/exposure)
- Qualitative host resistance reduces selection for insensitivity by:
  - Strategy 3 (reducing number of treatments/exposure)
- Fungicides reduce selection for virulence against partial and qualitative host resistance

# The integration challenge:

Integration creates concurrent selection for virulence and insensitivity

## How to:

- Use disease resistant varieties to minimise fungicide insensitivity evolution, whilst minimising virulence evolution

- Use fungicides to minimise virulence evolution, whilst minimising insensitivity evolution

PROCEEDINGS B

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# Extending the durability of cultivar resistance by limiting epidemic growth rates

Kevin Carolan[1], Joe Helps[1], Femke van den Berg[1,2], Ruairidh Bain[3], Neil Paveley[4] and Frank van den Bosch[1]

[1]Rothamsted Research, Harpenden AL5 5LS, UK
[2]FERA, York YO41 1LZ, UK
[3]SRUC, Edinburgh EH9 3JG, UK
[4]ADAS, High Mowthorpe, Malton, North Yorkshire YO17 8BP, UK

KC, 0000-0003-0853-8457

Research

Check for updates

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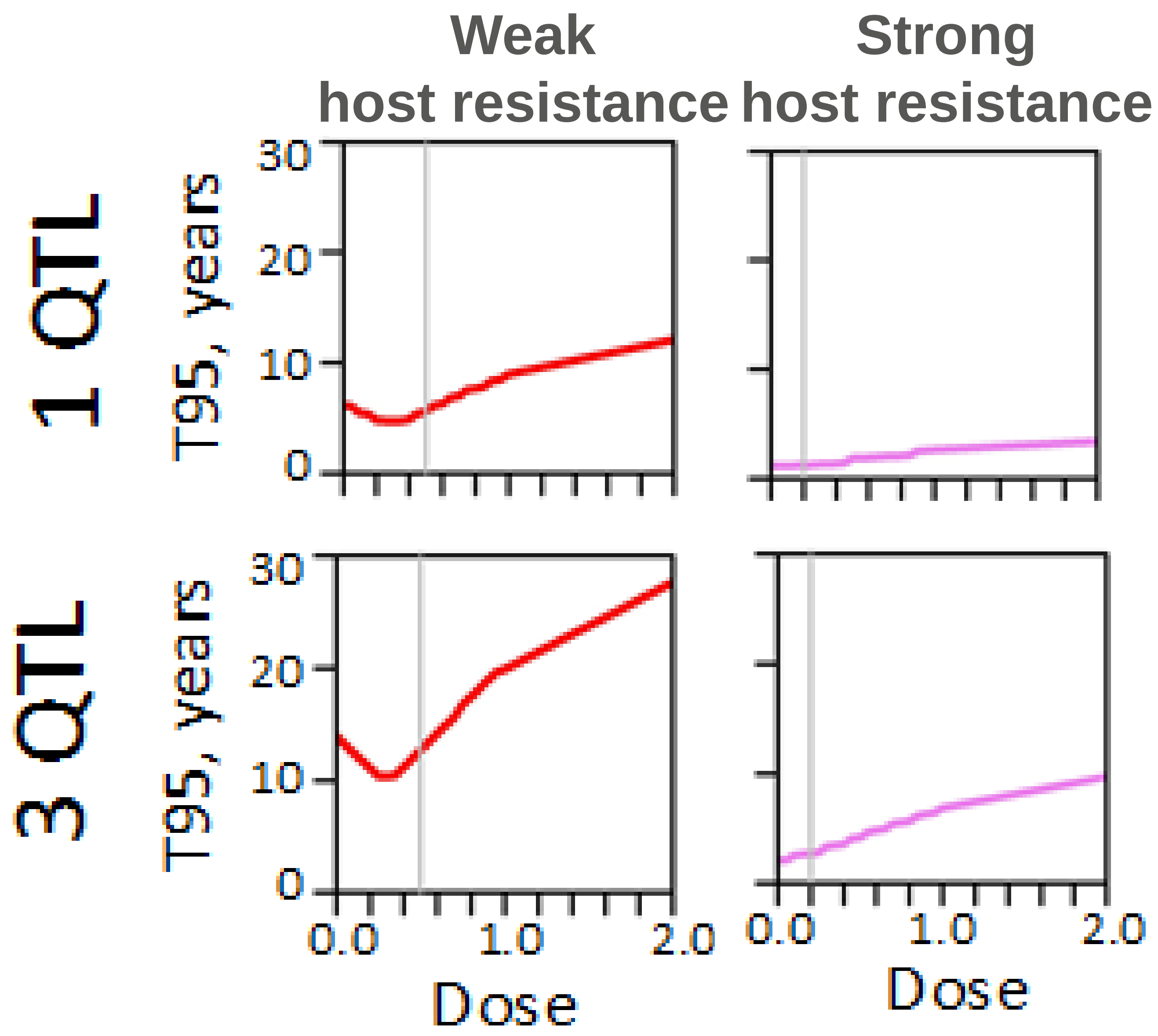
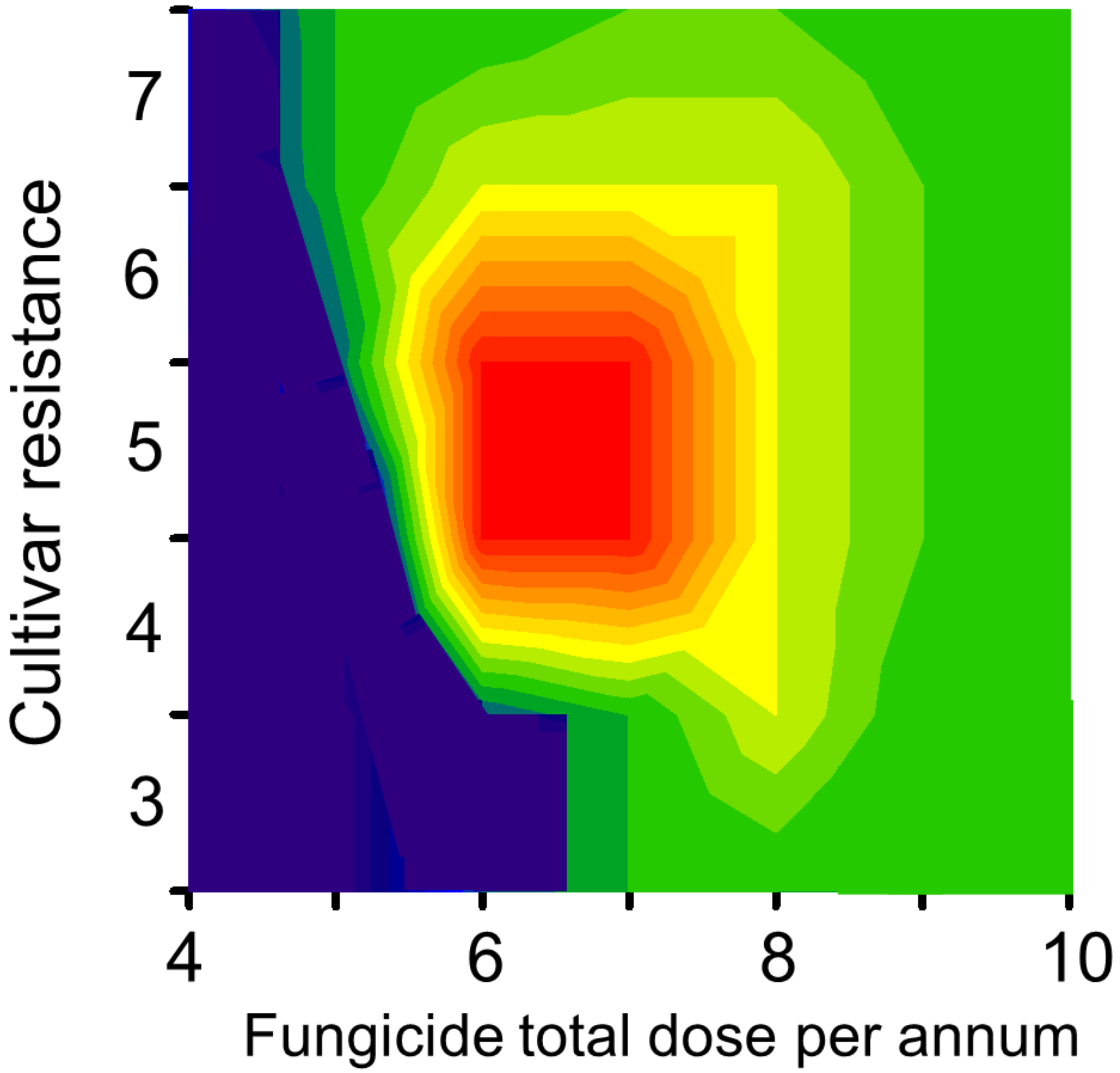
**Subject Category:**
Evolution

Cultivar resistance is an essential part of disease control programmes in many agricultural systems. The use of resistant cultivars applies a selection pressure on pathogen populations for the evolution of virulence, resulting in loss of disease control. Various techniques for the deployment of host resistance genes have been proposed to reduce the selection for virulence, but these are often difficult to apply in practice. We present a general technique to maintain the effectiveness of cultivar resistance. Derived from classical population genetics theory; any factor that reduces the population growth rates of both the virulent and avirulent strains will reduce selection. We model the specific example of fungicide application to reduce the growth rates of virulent and avirulent strains of a pathogen, demonstrating that appropriate use of fungicides reduces selection for virulence, prolonging cultivar resistance. This specific example of chemical control illustrates a general principle for the development



Weak
host resistance
Strong
host resistance
1 QTL
3 QTL
T95, years
T95, years
30
20
10
0
30
20
10
0
0.0
1.0
2.0
0.0
1.0
2.0
Dose
Dose

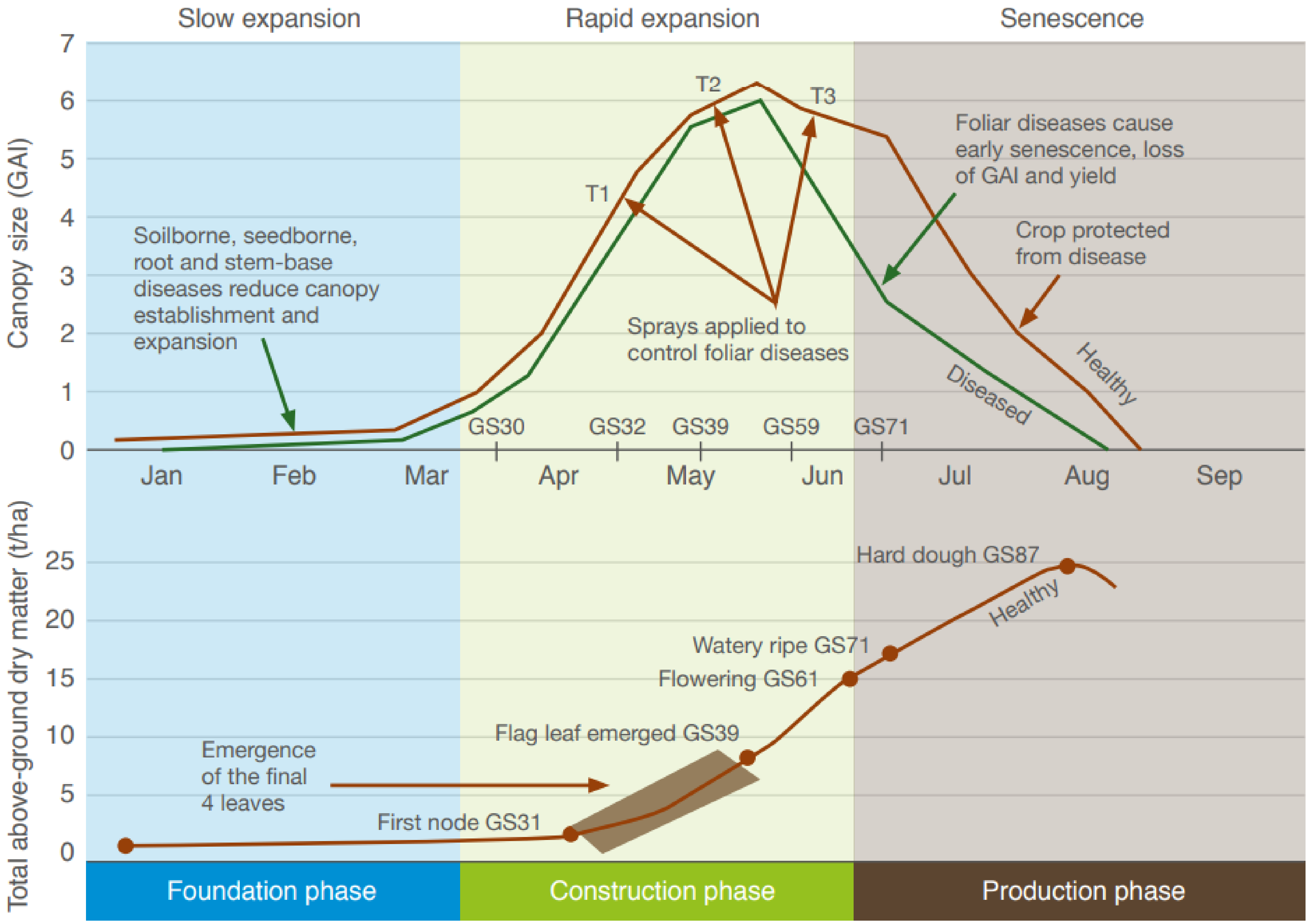



Years of effective control:

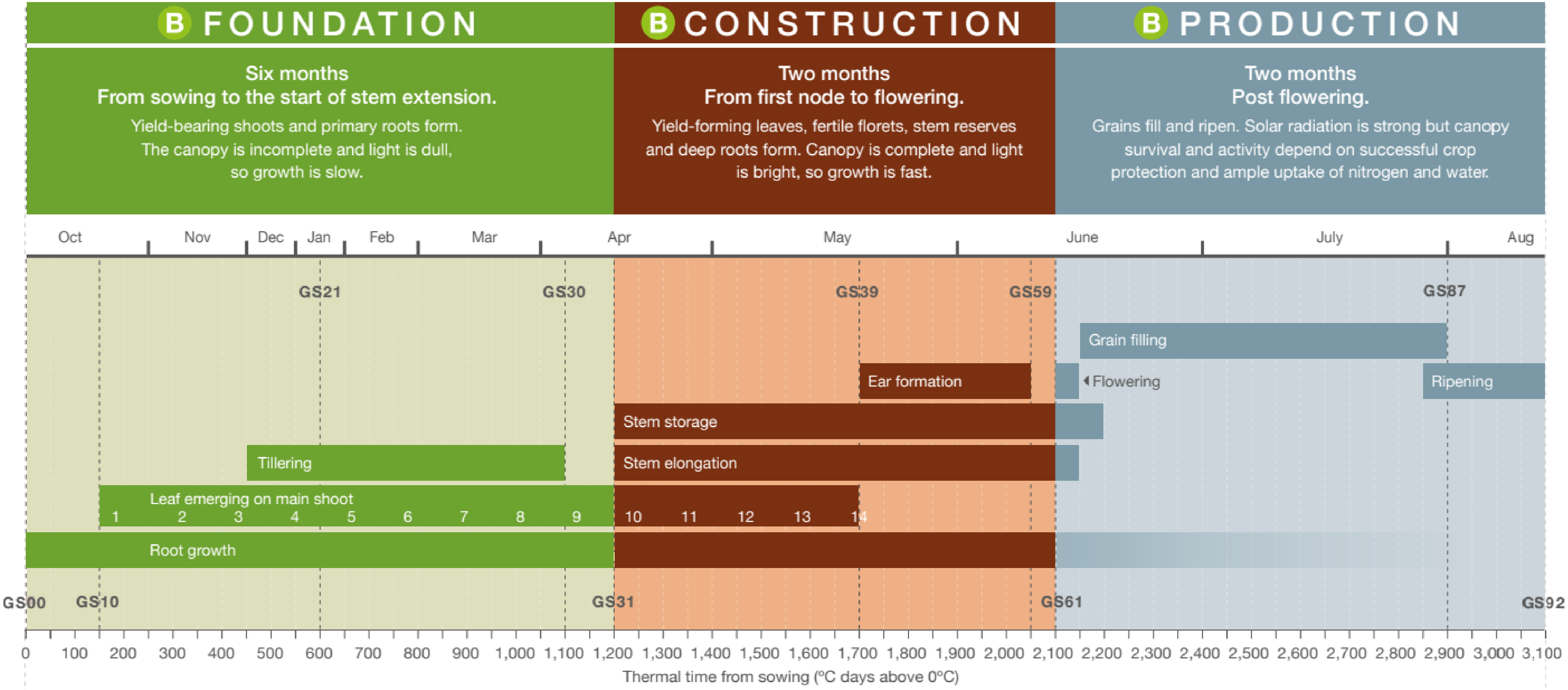
Zero

Low

High




AHDB Wheat and Barley Disease Management Guide




AHDB Wheat Growth Guide

## Generic:

Any independent disease control method that reduces the epidemic growth rate will reduce selection

## Specific:

- Resistant cultivars reduce selection for fungicide insensitive pathogen strains.
- Fungicides reduce selection for virulent pathogen strains.
- More sustainable to integrate and balance chemical and genetic crop protection, than to be heavily dependent on either genetics or chemistry

# Summary

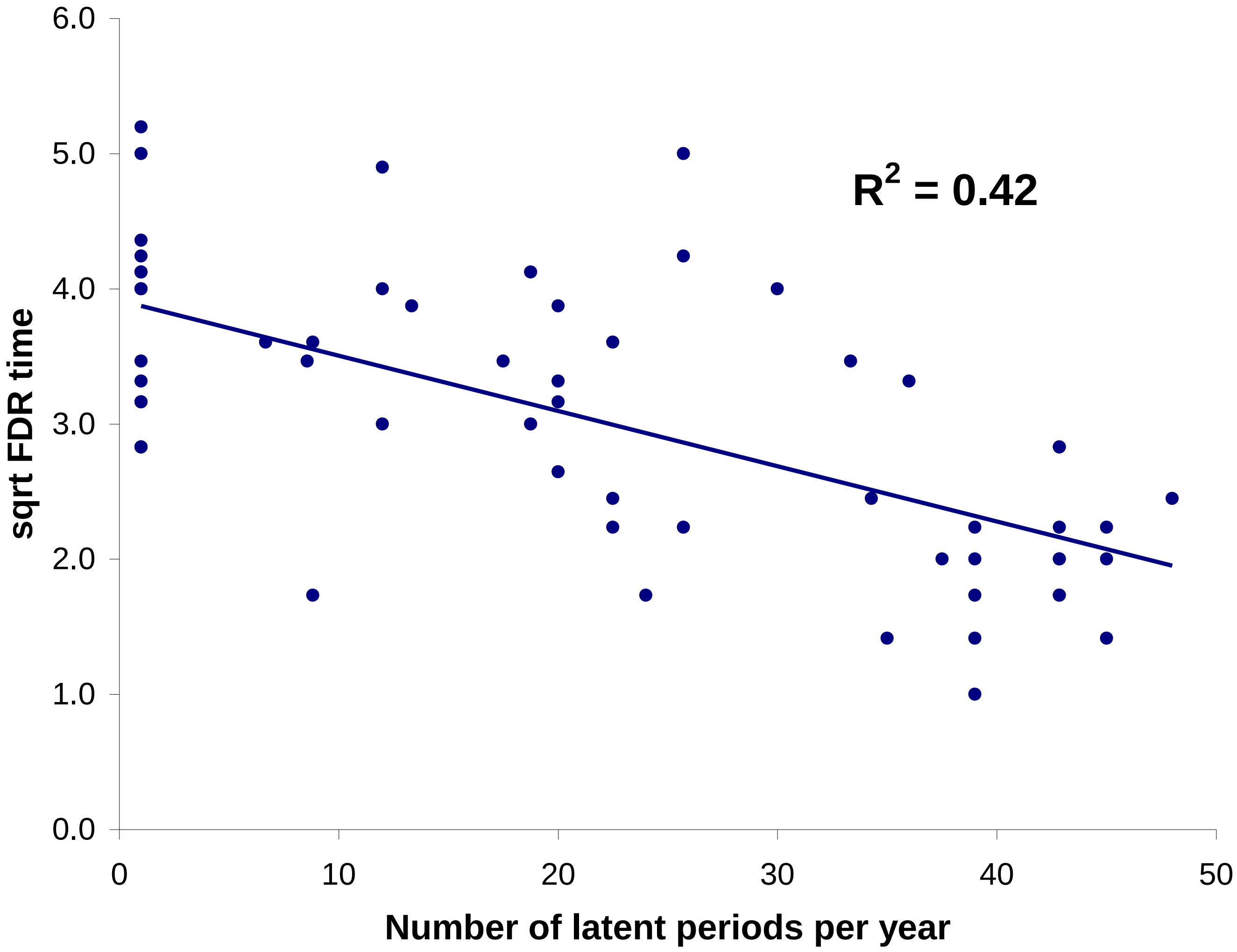
- Cereal farmers need effective and durable control of multiple diseases
- Effectiveness of integrating control predictable
- But control drives pathogen evolution
- Evolution according to simple governing principle
- Good experimental evidence on insensitivity evolution
- Good tools for virulence evolution experiments

# Future perspectives

- Experimental evidence needed for virulence evolution with fungicide use
- Evolutionary potential of different types of resistance gene
- Role of sexual / asexual reproduction on pathogen evolution
- Role of fitness penalties in slowing fungicide resistance
- Impact of Integrated Pest Management (IPM) approaches
- Breeding for alternative traits not affected by evolution
  - Disease escape – traits that reduce contact between inoculum and susceptible tissues
  - Disease tolerance – traits that reduce the impact of disease on yield

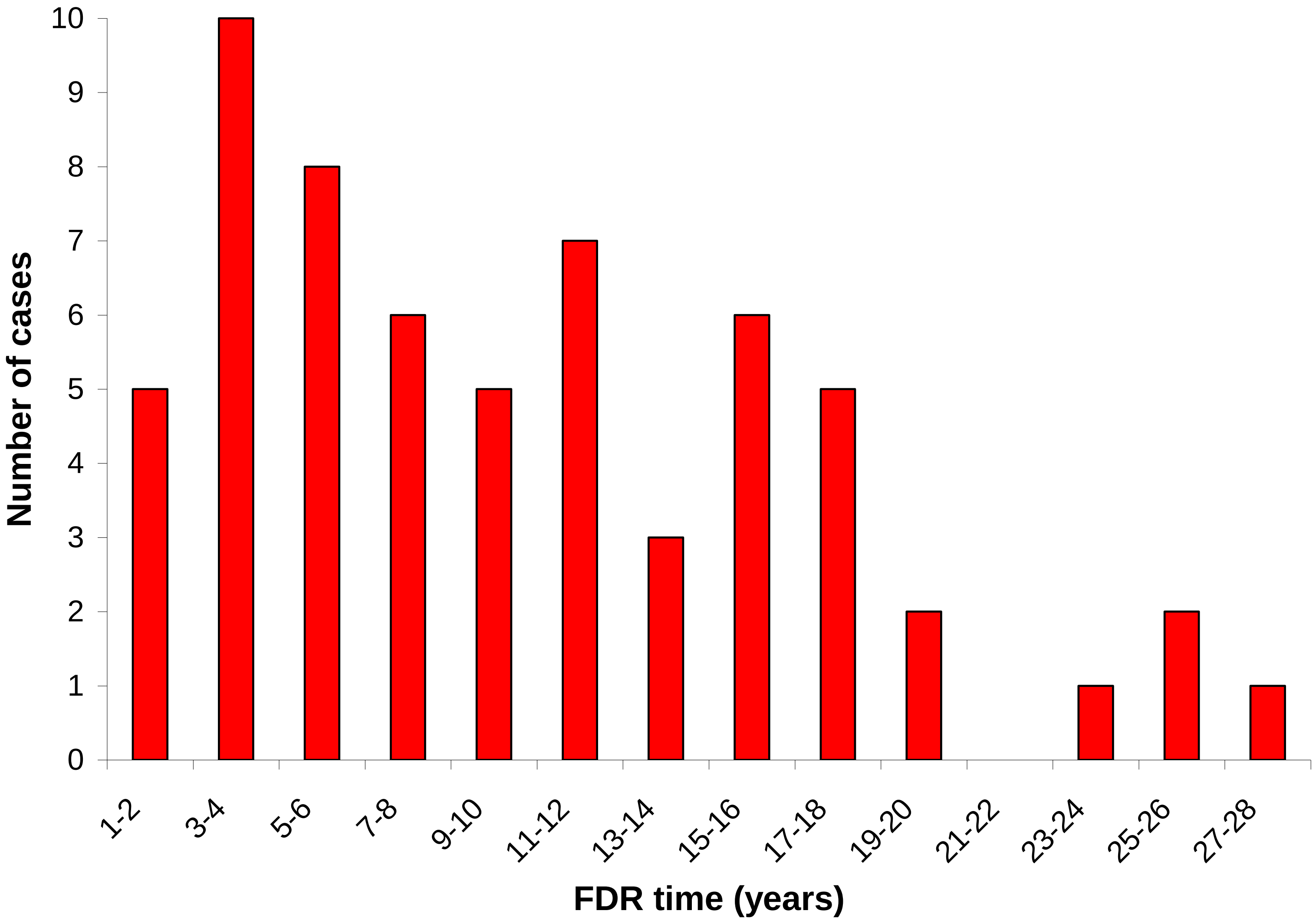
# Thank you!

# Predictive power of LPs / year on sqrt FDR time (n = 59, P = <0.001).




Grimmer *et al*. (2014)
Pest Manag Sci

# Frequency distribution: First Detection of Resistance time (n = 61)



| Pathogen | Fungicide | Agronomic system |
|---|---|---|
| Kingdom | FRAC MOA | Crop species |
| Phylum | FRAC group | Country |
| Class | Chemical group | Area treated – foliar |
| Suborder | Fungicide active substance | Area treated – seed |
| Family | Target protein length | Area treated – total |
| Genus | Target gene copy number | Use intensity (trt. ha/crop ha) |
| Species | Molecular weight | Cropped area |
| Trophic type | Solubility ratio | Country area |
| Mono/poly cyclic | H-bond donor/acceptor potential | Agronomic intensity |
| Resting stage | Topological polar surface area | Outdoor/protected |
| Resting structure | Complexity | Annual/perennial |
| Asexual/sexual | Action | |
| Asexual spore type | Systemicity | |
| Asexual spore volume | Application method | |
| Sexual spore type | Used in mixtures | |
| Sexual spore volume | Efficacy at introduction | |
| Vegetative ploidy level | | |
| No. host species/genera | | |
| Apparent epidemic growth rate | | |
| Basic reproductive number (R0) | | |
| Latent period | | |
| Latent periods per year | | |

# Trait-based risk assessment model

Sqrt (FDR) = Constant +

Latent periods per year (number)

Fungicide complexity (PubChem rating)

Number of crop host species (1-9 or 10+)

Agronomic system (protected or outdoor)

No significant interactions

F probability <0.001

Sqrt (FDR) = Constant – 0.027*LP/year – 0.0024*Fung complexity

# Phases of fungicide resistance evolution

Hobbelen *et al*. (2014) *PLoS One*;
Mikaberidge *et al*. (2017) *Phytopath*.