SDHI Fungicide Resistance:

Influence of application rate & mixes on selection for resistance

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Fungicide Resistance

- Fungicide resistance is problematic
  - Insensitivity to fungicide > management failures
  - Loss of a fungicide class
- History of fungicide resistance development
- Goal: Delay resistance development

Succinate Dehydrogenase Inhibitors (SDHI)

-Important class of fungicides
-Target a single process within fungi
-Risk of resistance development

Single-site fungicide: Complex II succinate dehydrogenase inhibitors (SDHI)

- FRAC Code: 7 / MOA: interfere with cellular respiration: Inhibits spore germination, mycelial growth, & sporulation
- Effective against many fungal diseases – resistance not reported in all systems

Apple Scab

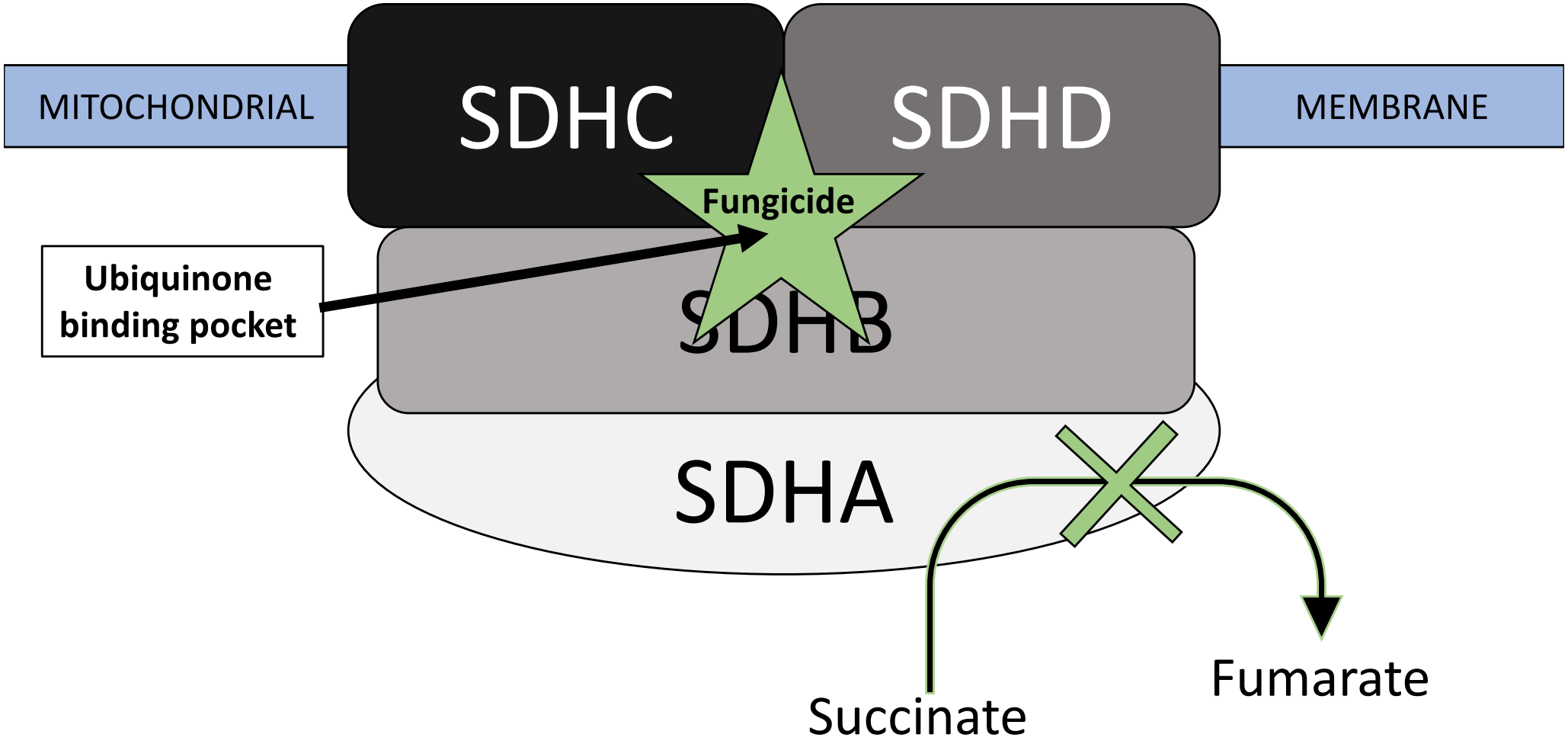
Cherry leaf spot

Brown rot

Succinate Dehydrogenase Inhibitors

FRAC 7

Complex II: Cellular respiration interference



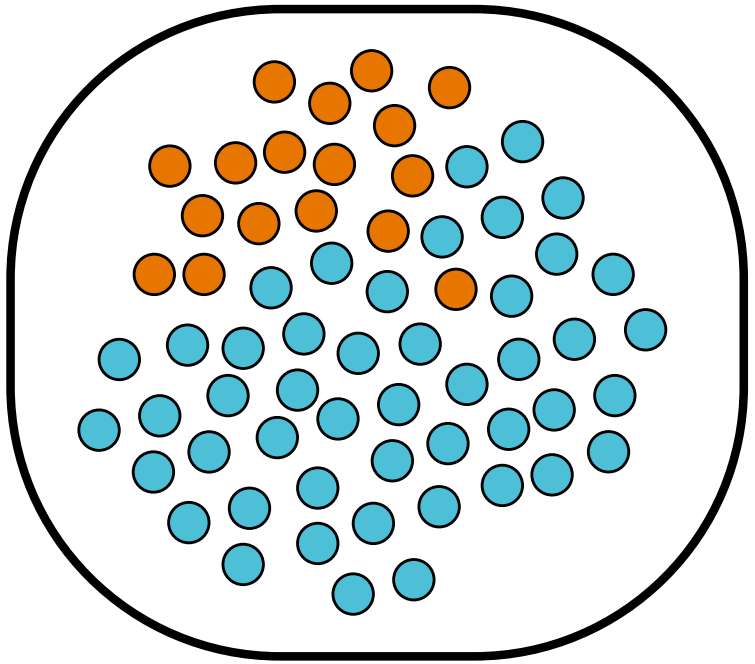
Phases of Resistance Development

1. Emergence*

2. Establishment

*Fungicides are not inherently mutagenic, mutations are **pre-existing**
*Advantageous mutations occur **infrequently**

Application of a fungicide does not cause emergence, rather may select for establishment



Pathogen Population

- Sensitive Isolate
- Resistant Isolate

(adapted from van den Bosch et al 2011)

Project Overview

Question: How can we delay the development of fungicide resistance through altering application practices?

Hypothesis: Fungicide application rate has an effect on resistance development.

Effect of dose rate and mixtures of fungicides on selection for QoI resistance in populations of *Plasmopara viticola*

Jean-Luc Genet,* Grazyna Jaworska and Francine Deparis
DuPont Crop Protection, European Research and Development Centre, F-68740 Nambsheim, Fran

Dose and number of applications that maximize fung effective life exemplified by *Zymoseptoria tritici* on v model analysis

F. van den Berg[a]*, N. D. Paveley[b] and F. van den Bosch[a]

The dose rate debate: does the risk of fungicide resistance increase or decrease with dose?

F. van den Bosch[a]*, N. Paveley[b], M. Shaw[c], P. Hobbelen[a] and R. Oliver[d]

[a]*Rothamsted Research, Harpenden AL5 2JQ;* [b]*ADAS High Mowthorpe, Dugglesby YO17 8BP;* [c]*School of Biological Sciences, University of Reading, Reading RG6 6AS, UK; and* [d]*Environment & Agriculture, ACNFP, Curtin University, Bentley, WA 6102, Australia*

RESEARCH ARTICLE

Does High-Dose Antimicrobial Chemotherapy Prevent the Evolution of Resistance?

Troy Day[1,2,3]*, Andrew F. Read[3,4]

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Accepted for publication 16 December 2016.

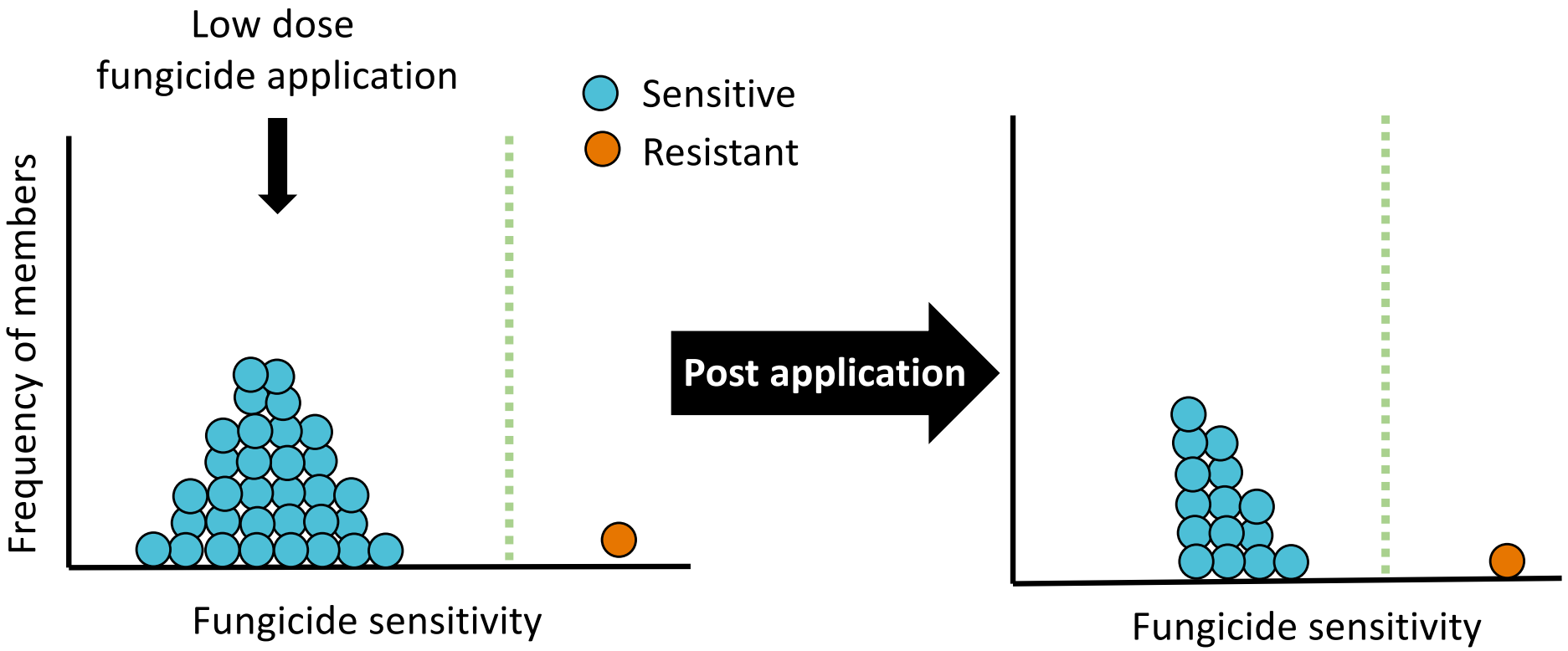
les: The Role of Fungicide Dose

Bonhoeffer, and Frank van den Bosch

urich, LFW, Zurich, CH-8092, Switzerland; second author: ADAS
ogy, Institute of Integrative Biology, ETH Zurich, CHN, Zurich
Q, United Kingdom.

“The dose rate debate”

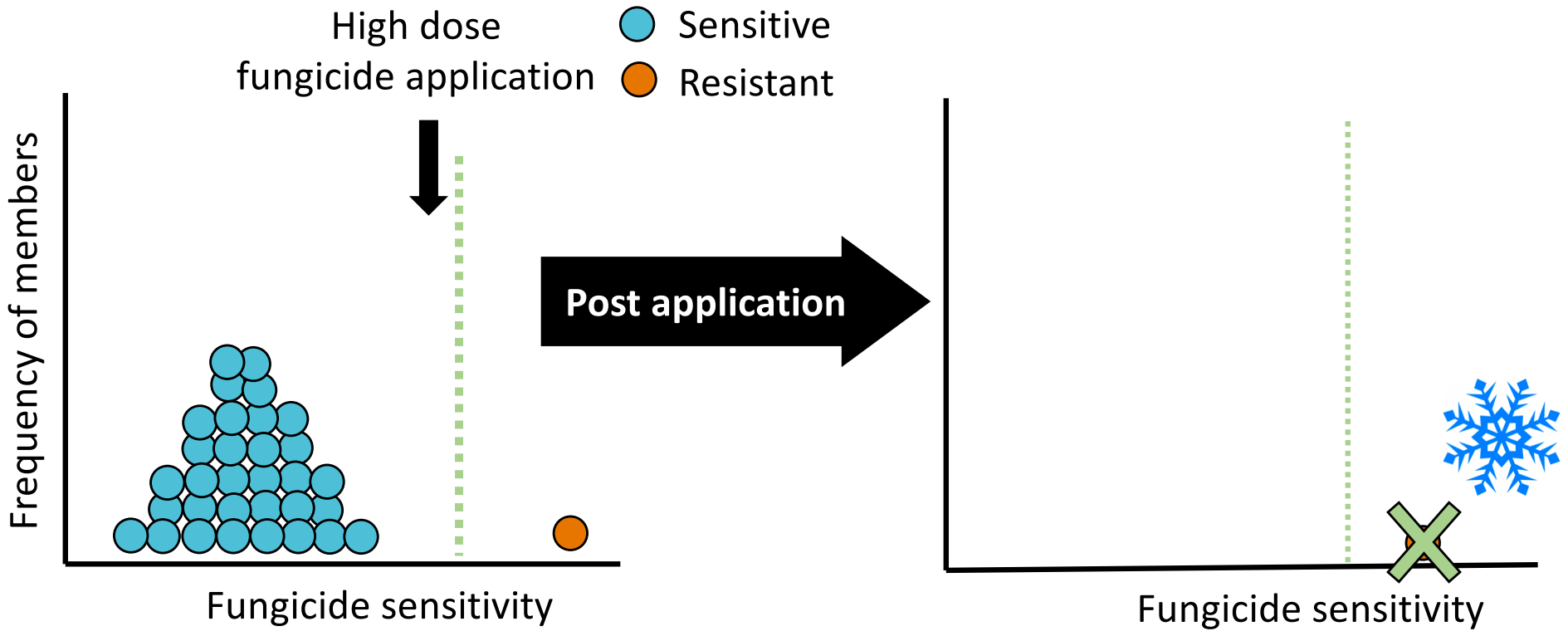
Hyp A: Low dose → resistance develops slowly



Competition between S and R slows selection down for R

“The dose rate debate”

Hyp B: High dose → resistance development less likely



Overall S population reduced → R unable to cause disease and/or overwinter

How does fungicide rate affect SDHI resistance development?

General Experimental Methods

Repeated fungicide applications
-High rate
-Low rate
-Untreated

Isolate collection

In vitro fungicide assay

How does fungicide rate affect SDHI resistance development?

Apple Scab

Stemphylium Leaf Blight

Apple Scab: *Venturia inaequalis*

- Apple scab is a perennial problem
- High input system (10+ fungicide applications/year)
- Fungicide resistance is reported for nearly all single-site fungicides chemistries
- Presently, no SDHI fungicide resistance?

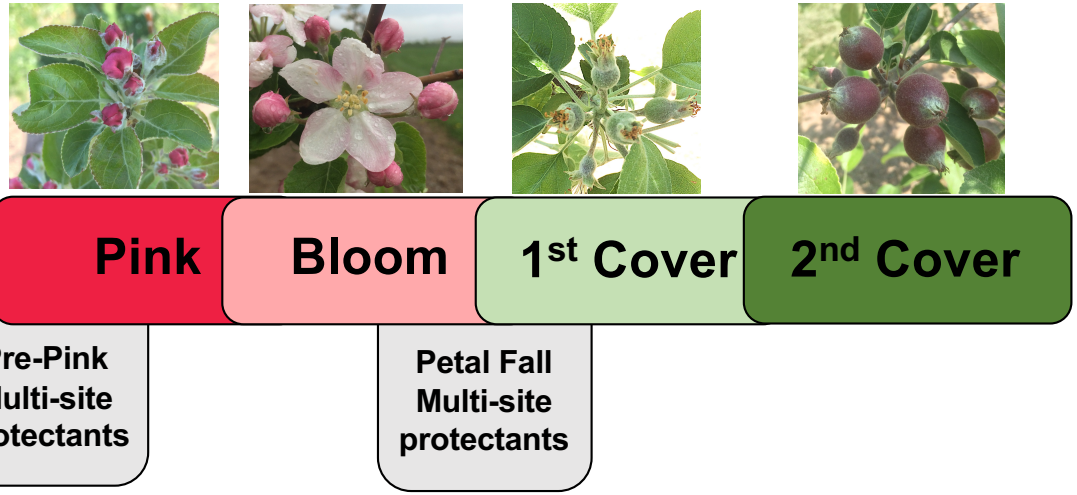
Resistant Management Experiment

Commercial product(s)	Active ingredient(s)	Rate(s)	Hypothesis tested
Control	-	-	No selection pressure
Sercadis	Fluxapyroxad (26.55%)	7 fl. oz/A	high rate
Sercadis	Fluxapyroxad (26.55%)	3.5 fl. oz/ A	low rate
Merivon	Fluxapyroxad (21.26%) & Pyraclastrobin (21.26%)	4 fl. oz/A	Single-site & second single-site
Sercadis & Koverall	Fluxapyroxad (26.55%) & Mancozeb (80%)	3.5 fl. oz/A & 3lbs/A	Single-site & multi-site

Resistant Management Experiment

Treatment Applications:
7-14 day intervals

Orchard 1: Empire, Jonagold
Orchard 2: Jersey Mac

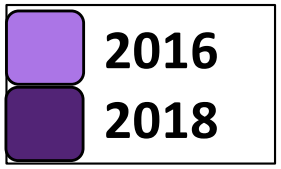


2016 & 2017 & 2018

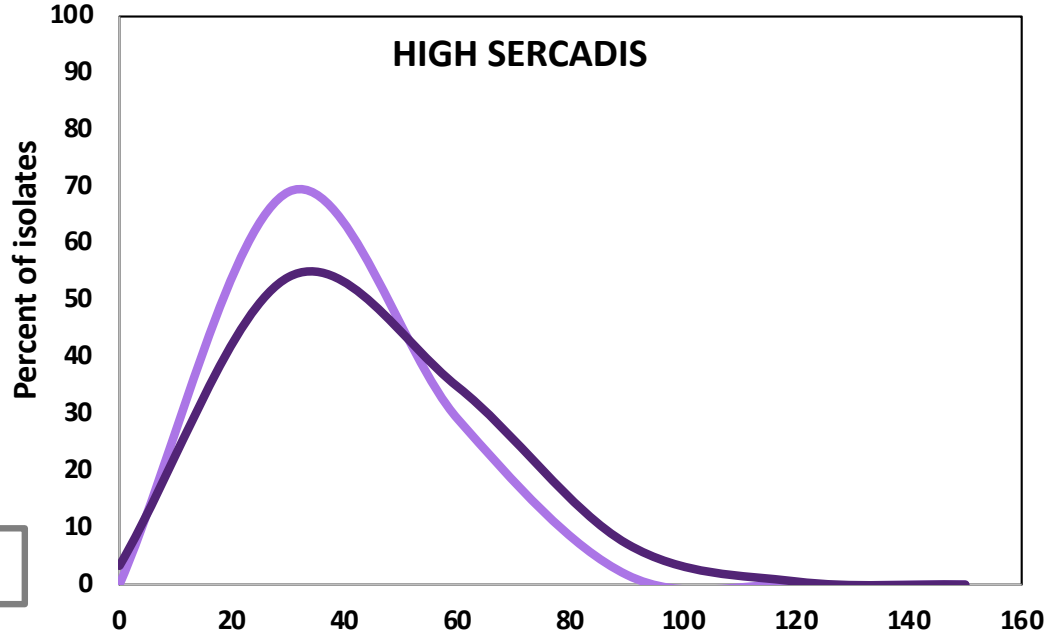
Lesion Collection:
20 isolates each
4 replicate treatment blocks

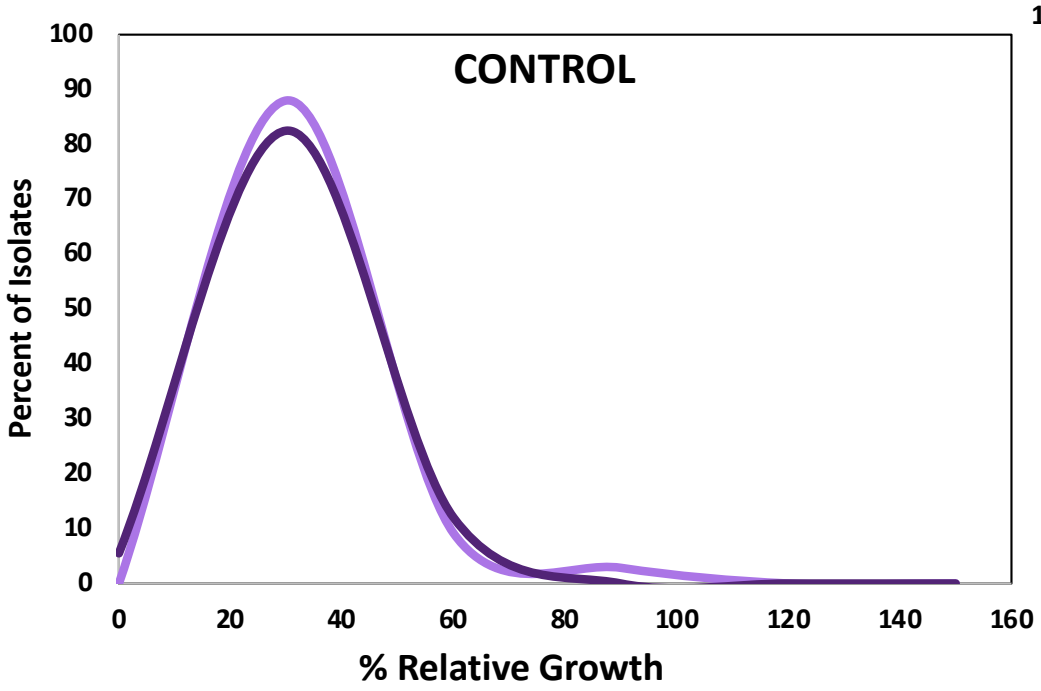
Fungicide sensitivity:
Relative growth assays

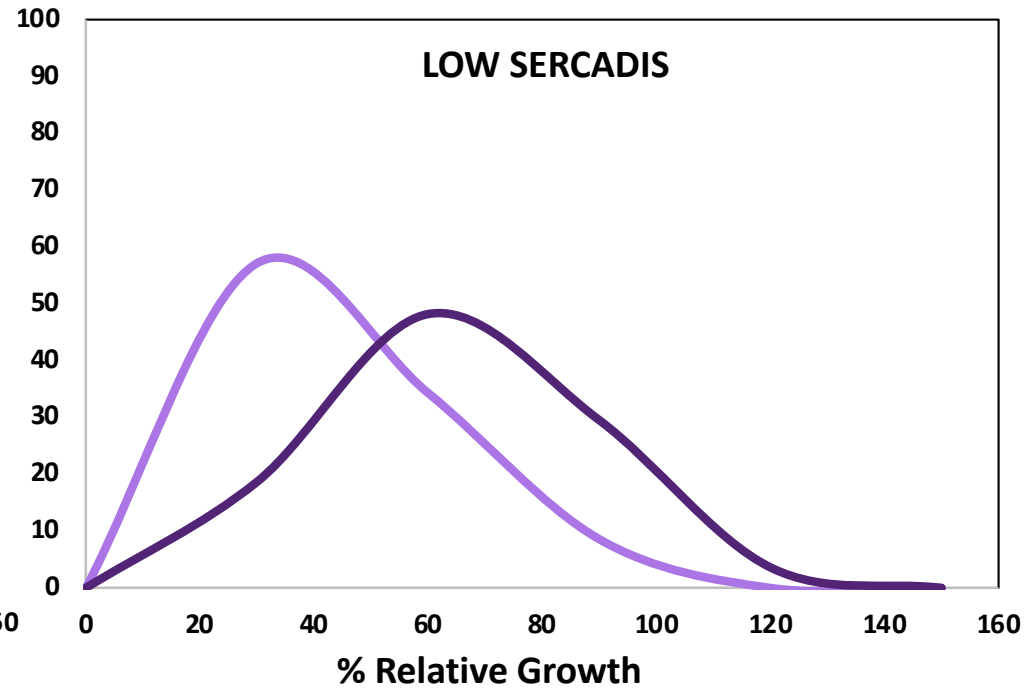
Shifts in Sensitivity Orchard 1 (2016-2018)



% Relative Growth Fungicide Sensitivity



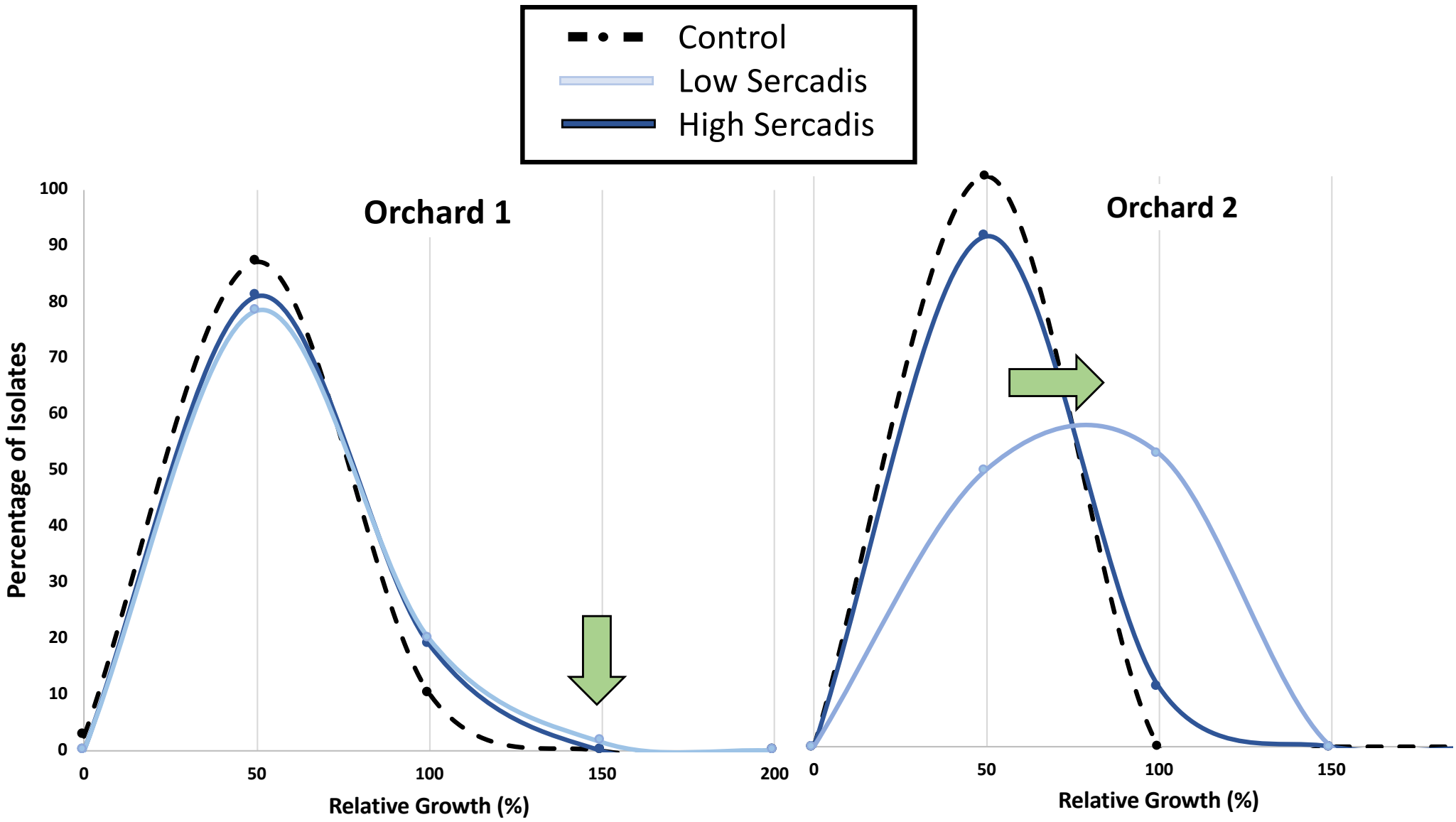




Effect of low rate vs. high rate (2018)

after three years

% Relative Growth Fungicide Sensitivity

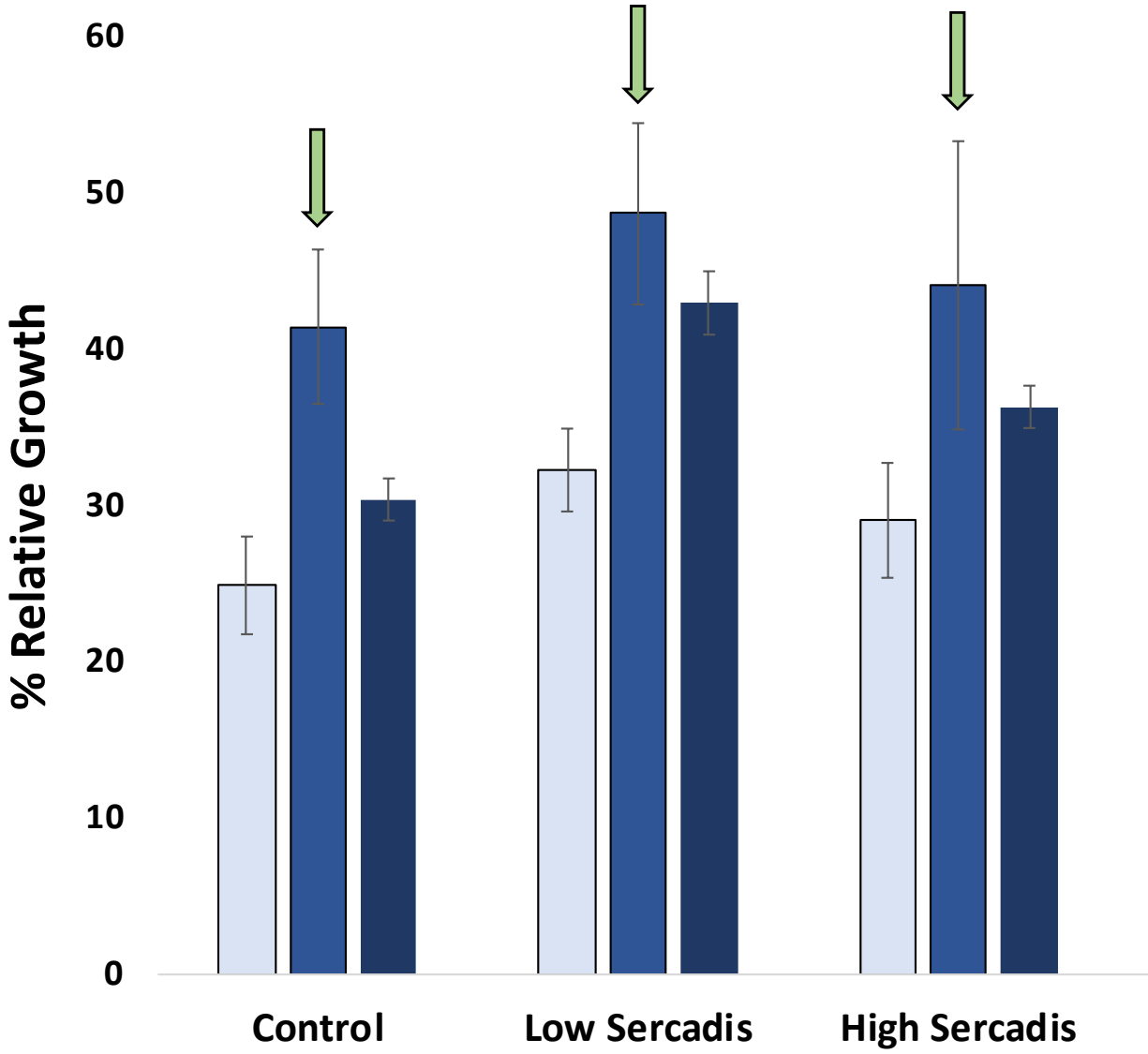


What happened in 2017?

2016: Dry Season
2017: Wet Season
2018: Dry Season

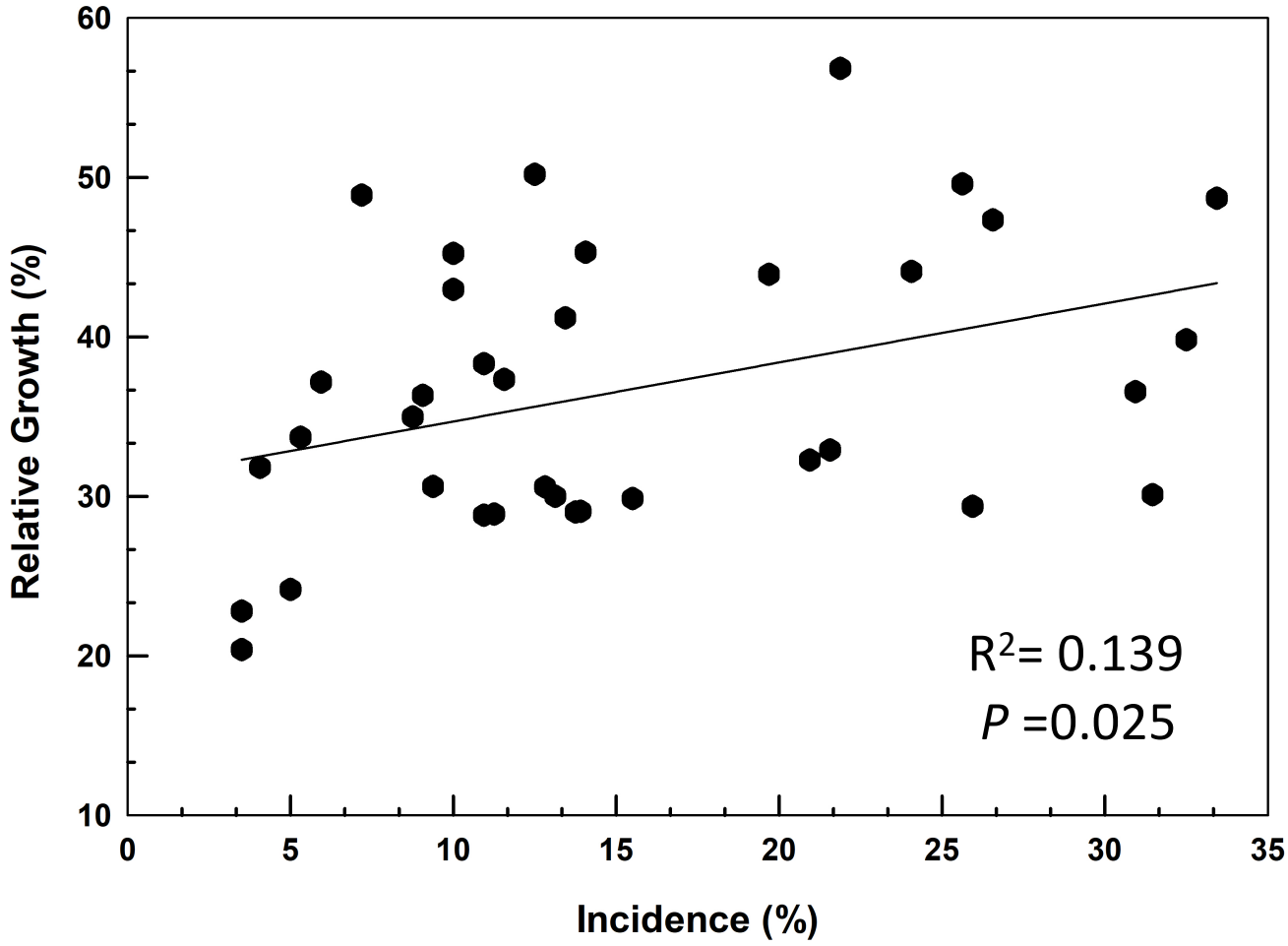
Correlation with increased disease incidence in field

Larger population → greater chance of isolates with reduced sensitivity



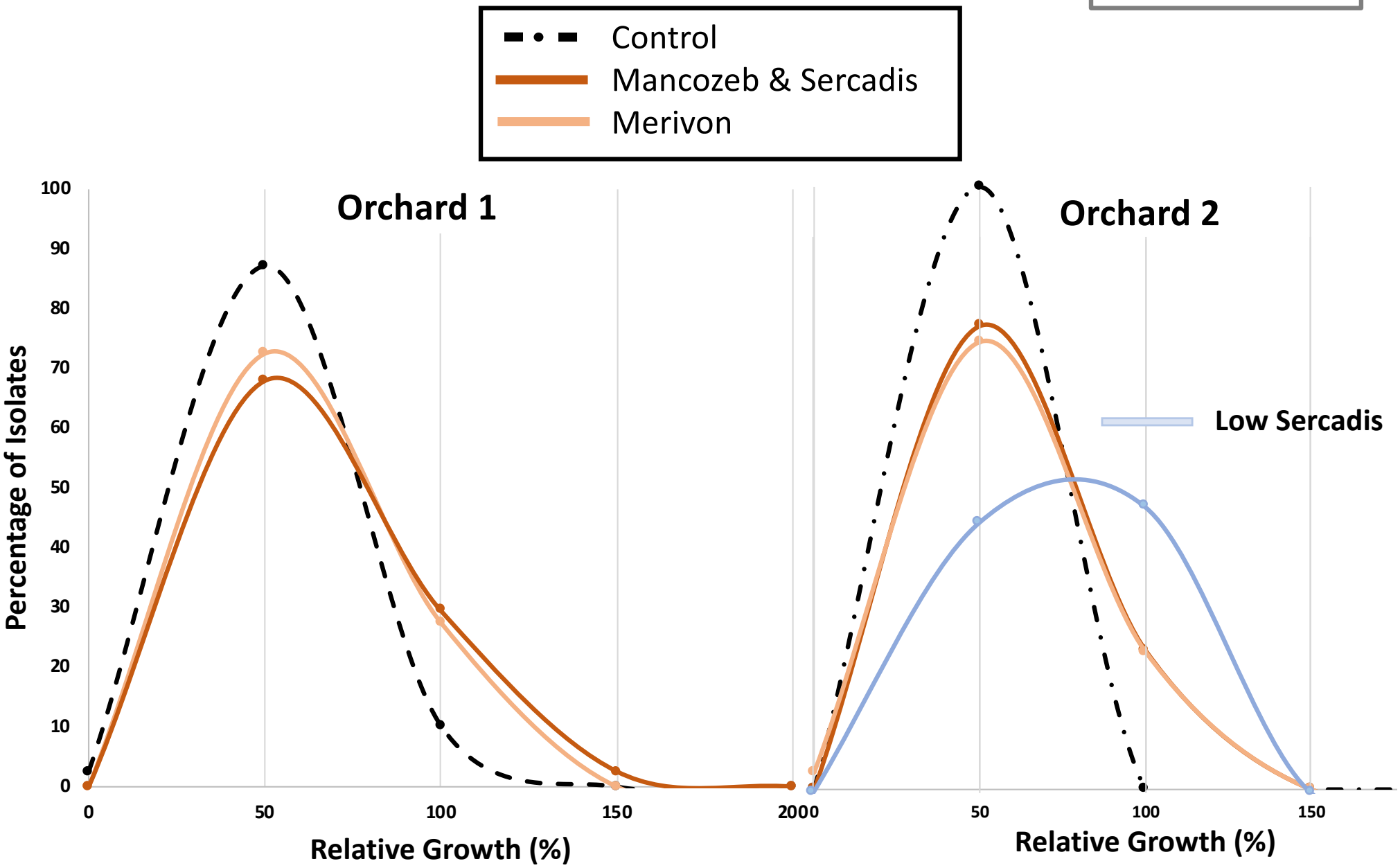
Correlation between incidence and relative growth

- **Exceptionally weak, but significant correlation**
- **Potential explanation**: The larger the pathogen population, the greater the chance of resistance emergence



Effect of Mix w/ Single vs. Multi-site (2018)

after three years



Resistant Management Experiment

2018

Commercial product(s)	Active ingredient(s)	Rate(s)	Hypothesis testing
Control	-	-	No selection pressure
Sercadis	Fluxapyroxad (26.55%)	7 fl. oz/ A	high rate
Sercadis	Fluxapyroxad (26.55%)	3.5 fl. oz/ A	low rate

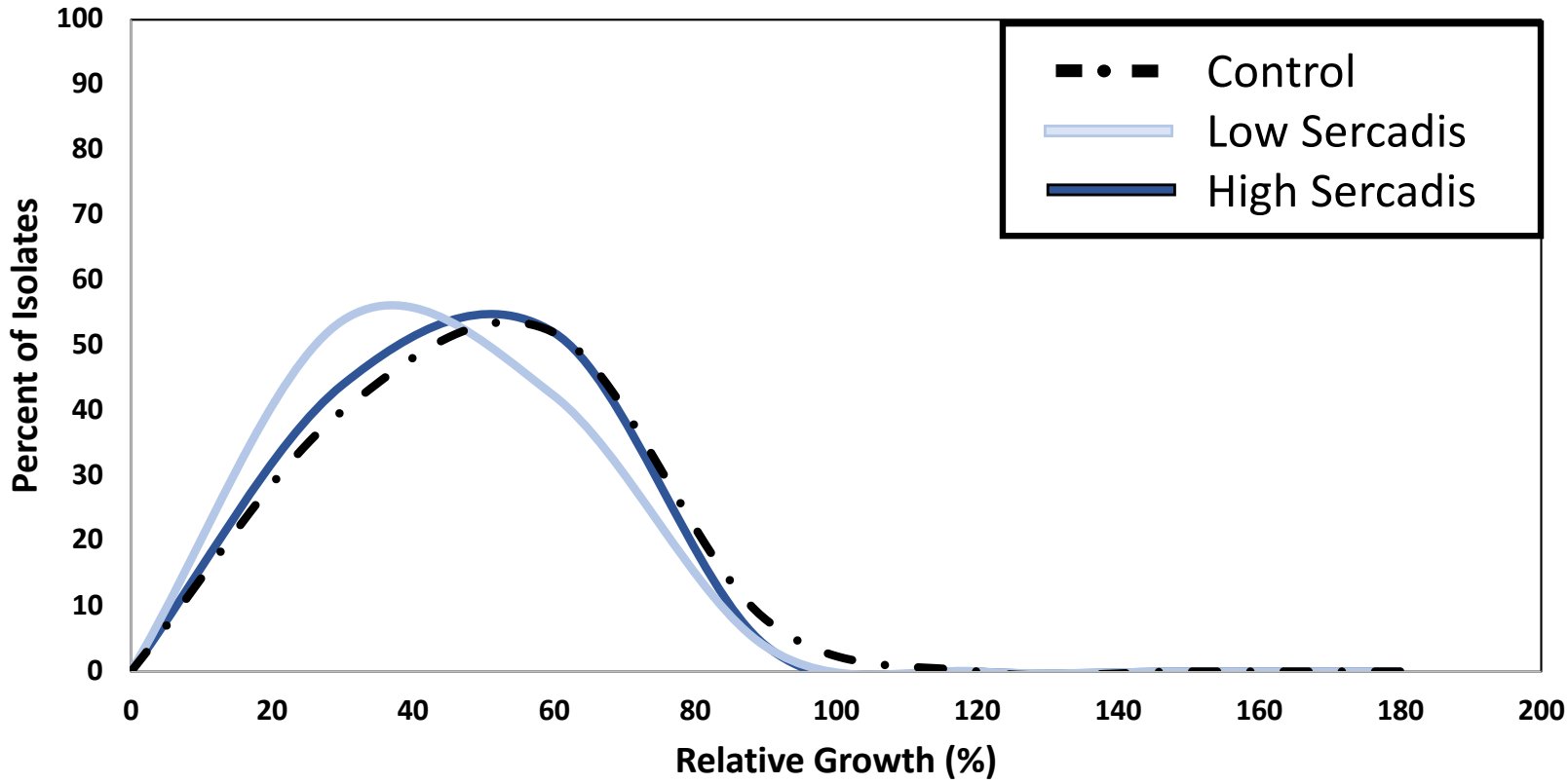



Increased selection pressure within a year

Lesion Collection

Fungicide Sensitivity

2018: Increased Selection

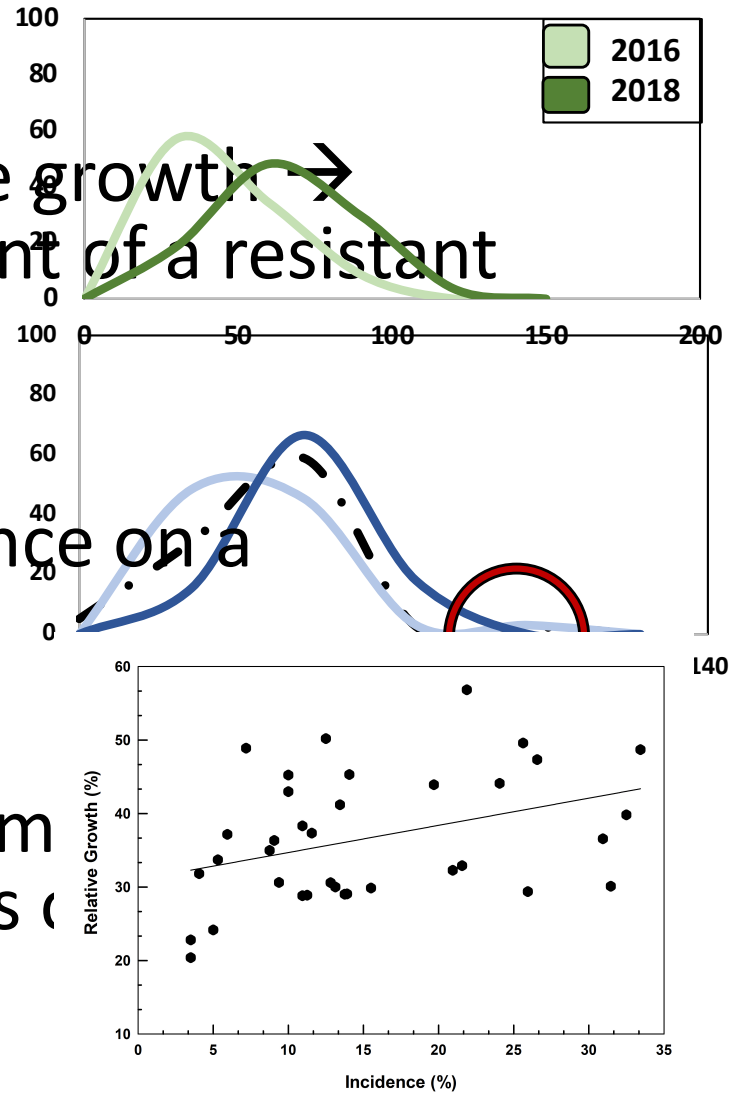


Dry primary season & low scab pressure → smaller chance of developing isolates with reduced sensitivity

Lessons learned from apple scab

To be repeated a 4th year

- Regardless of treatment, selection towards a reduction in sensitivity.
- Subset of isolates with high relative growth → future concern for the establishment of a resistant population? (Low rate)
- Disease pressure has a large influence on a population's fungicide sensitivity.
- Management decisions should be m in high disease years with emphasis class rotation and minimizing use.



How does fungicide rate affect SDHI resistance development?

Apple Scab

Stemphylium Leaf Blight

Stemphylium Leaf Blight: *Stemphylium vesicarium*

- Similar pathosystems to apple scab: Ascomycete fungus with similar lifecycle. Onion is also highly sprayed crop
- Similar historical loss of single-site chemistries
- Onion growers are asking these same questions: ability to use lower rates to decrease costs?

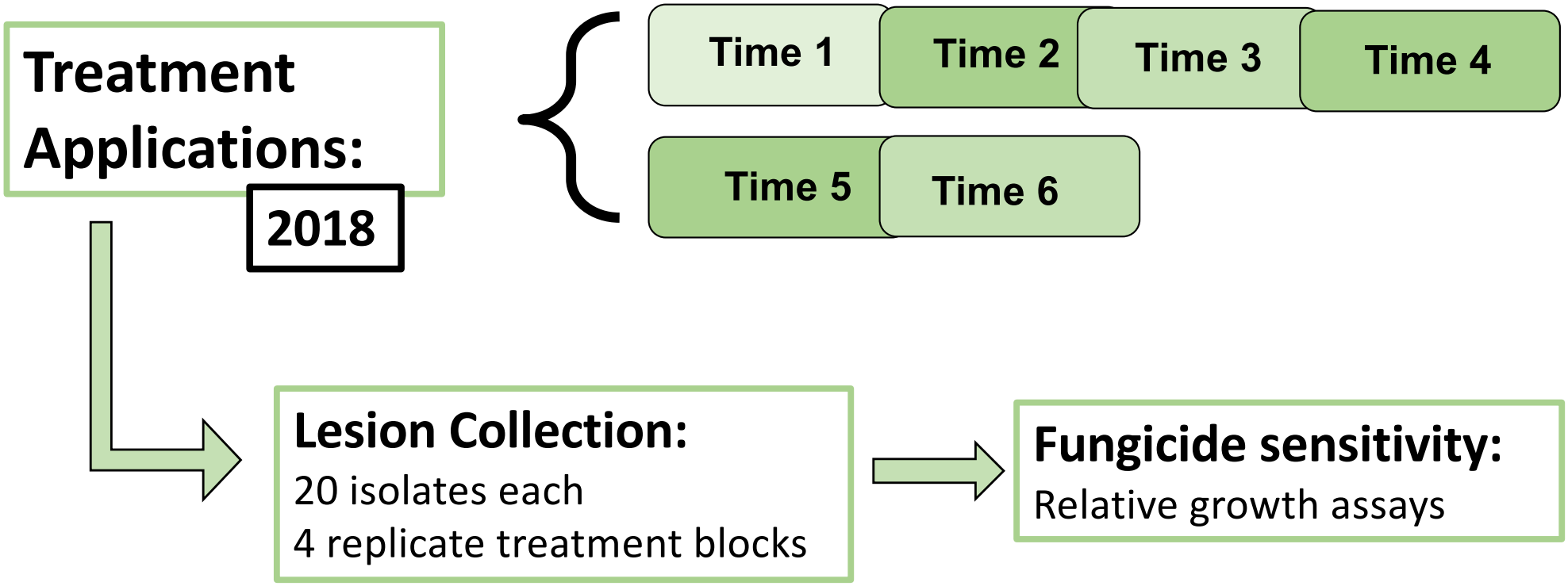
Symptoms of stemphylium leaf blight on onion

Resistant Management Experiment

Commercial product(s)	Active ingredient(s)	Rate(s)	Hypothesis testing
Control	-	-	No selection pressure
Merivon	Fluxapyroxad (21.26%) & Pyraclastrobin (21.26%)	9 fl. oz/A	High rate
Merivon	Fluxapyroxad (21.26%) & Pyraclastrobin (21.26%)	5.5 fl. oz/ A	Low rate
Luna Tranquility	Fluopyram (11.3%) & Pyrimethanil (33.8%)	16 fl. oz/A	High rate
Luna Tranquility	Fluopyram (11.3%) & Pyrimethanil (33.8%)	12 fl. oz/A	Low rate
Sercadis & Tilt	Fluxapyroxad (26.55%) & Propiconazole (41.8)	8 fl. oz/A	1 Week Rotation
Sercadis & Tilt	Fluxapyroxad (26.55%) & Propiconazole (41.8)	8 fl. oz/A	2 Week Rotation

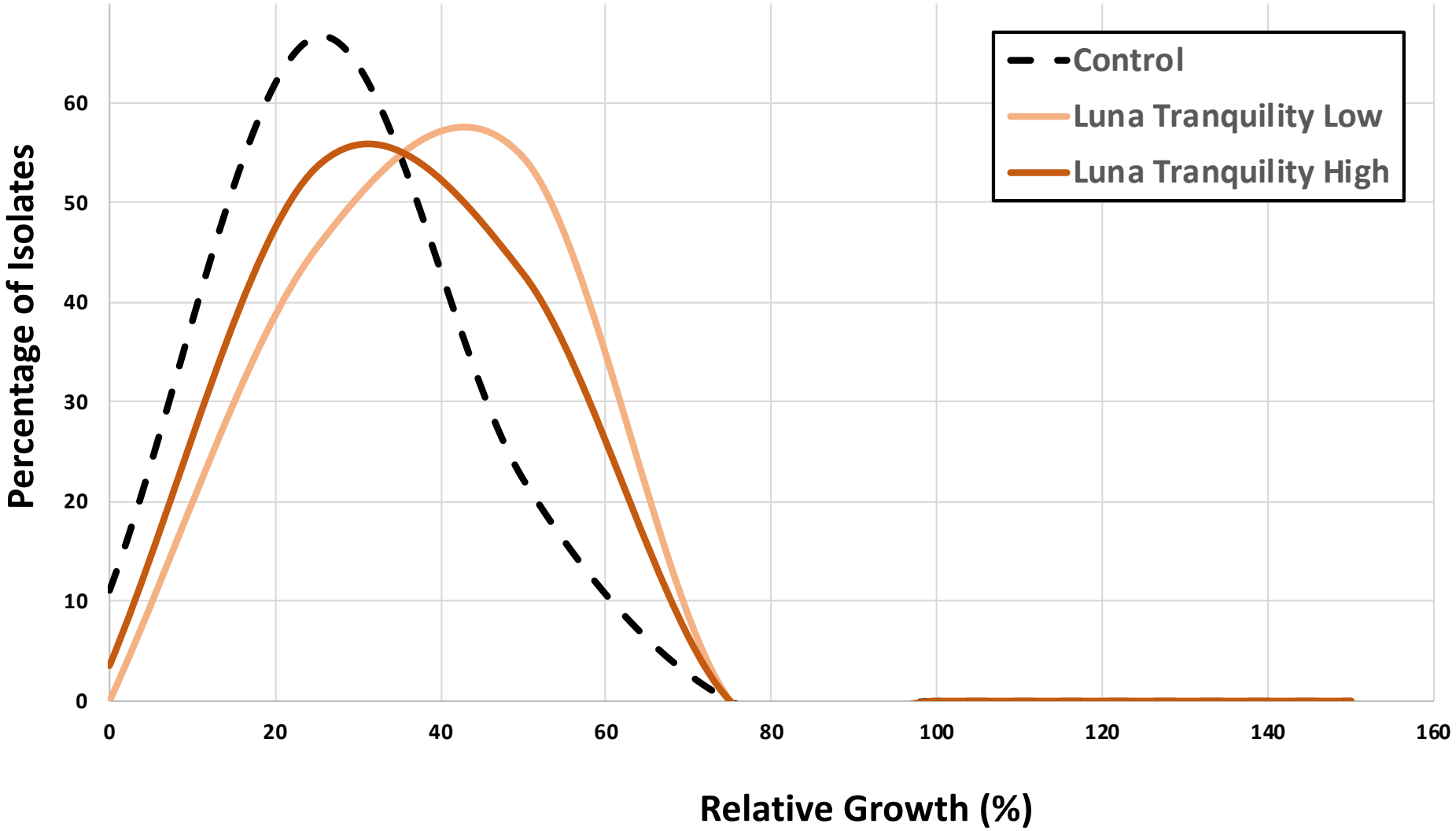
Christy Hoepting
Cornell Cooperative Extension

Resistant Management Experiment



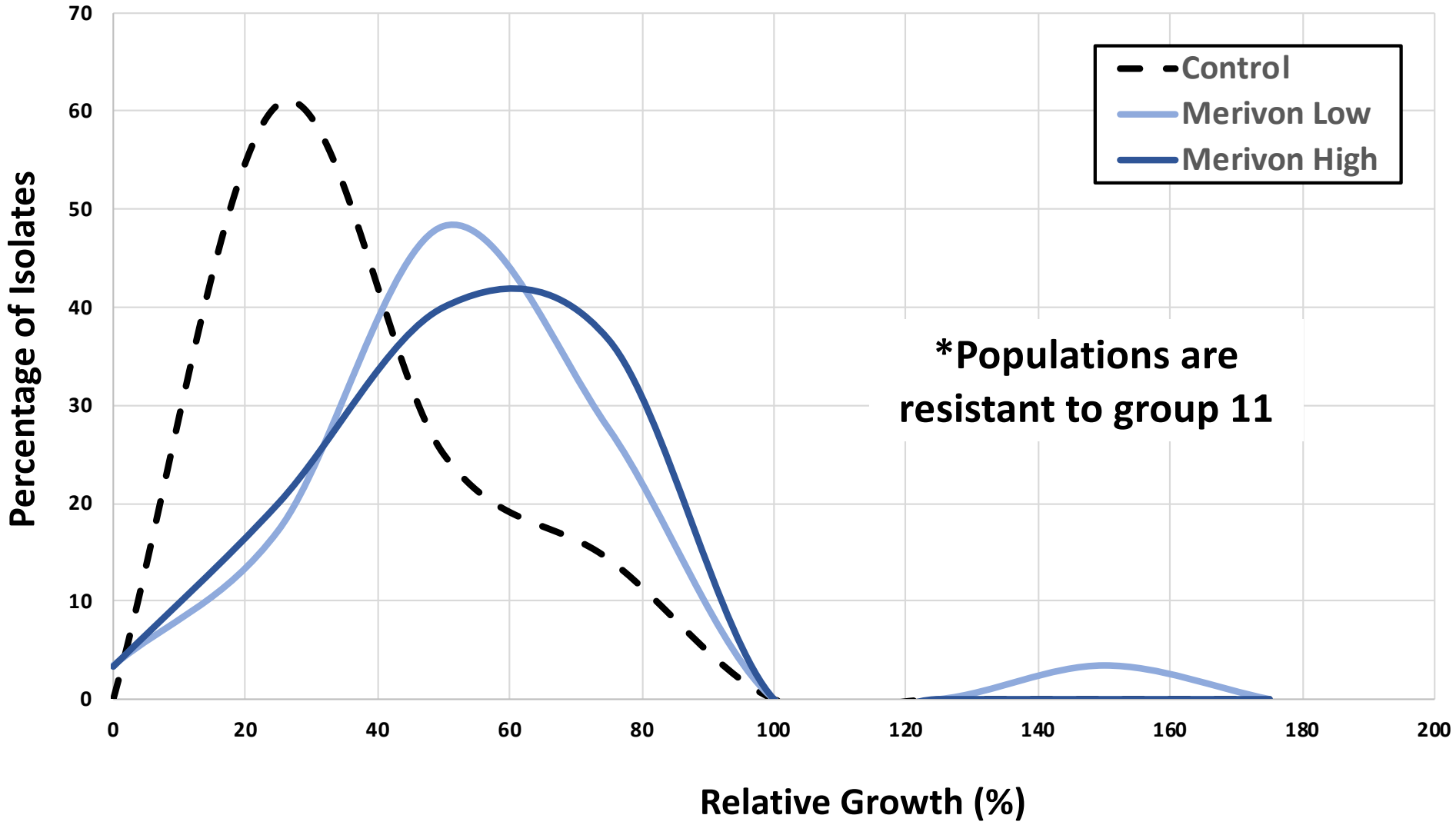
Sensitivity of Stemphylium to SDHIs

after one year



Sensitivity of Stemphylium to SDHIs

after one year

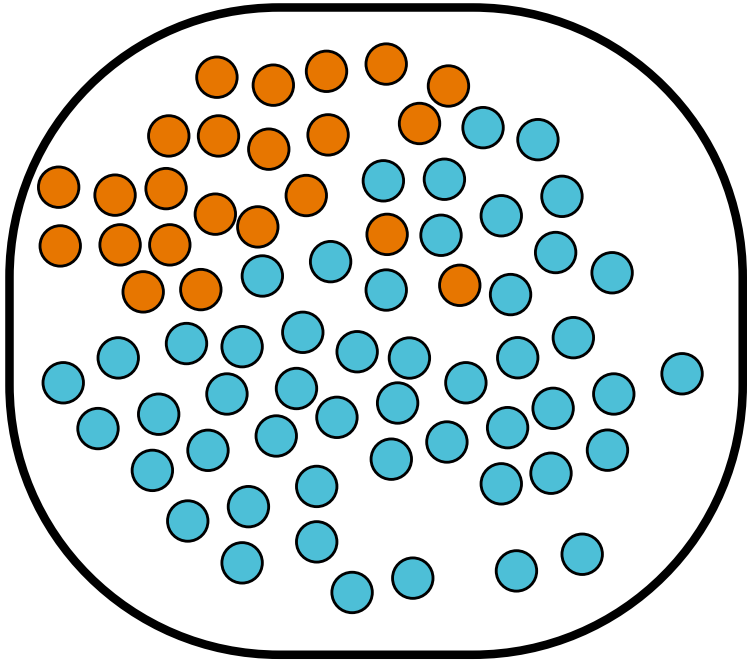


Lessons learned from Stemphylium

- Shifts in sensitivity occurring within one year of use, regardless of rate applied
- Differences between high and low rate?
  - Small subset of isolates with high relative growth (low rate)
- Two effective ingredients versus one, shift not as strong & no subset of isolates with high RG
- Similar patterns as seen with apple scab

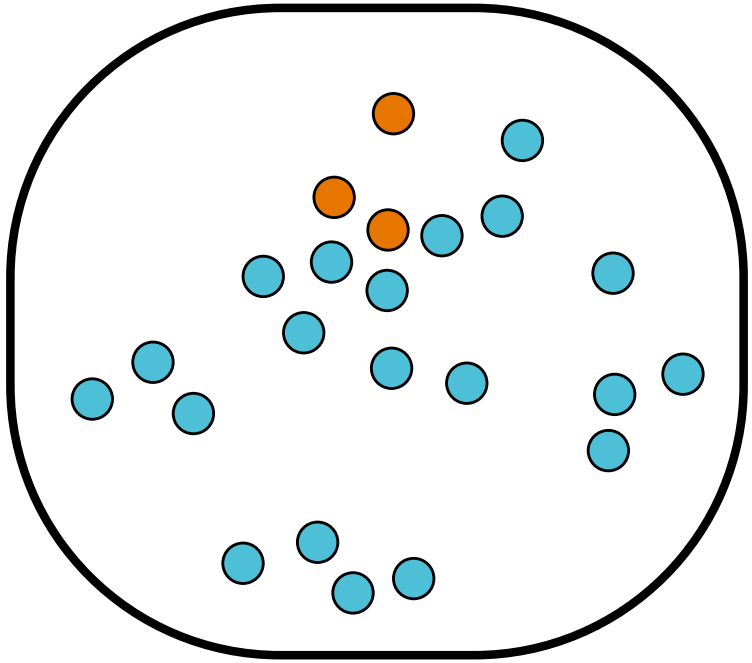
Population Size More Indicative?

Large Population Size



Higher probability of advantageous mutation occurring

Small Population Size



Lower probability of advantageous mutation occurring (if it occurs at all)

Pathogen Population

- Sensitive Isolate
- Resistant Isolate

Research Implications

- Immediate implications for growers
  - Aid in slowing down selection
  - Ensure longevity of SDHI fungicides
  - Application to a variety of broad systems
- Contribute to understanding about resistance development

- Highly effective control is the best method for delaying resistance – Manage population size

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Cornell AgriTech

New York State Agricultural Experiment Station

Apple scab & powdery mildew concerns for 2017

- Secondary apple scab pressure heavy June to August rains: 13 infections & 11” inches
- SDHI fungicides – remain effective
- Heavy rains and cooler weather kept mildew pressure low

Apple scab & powdery mildew trials

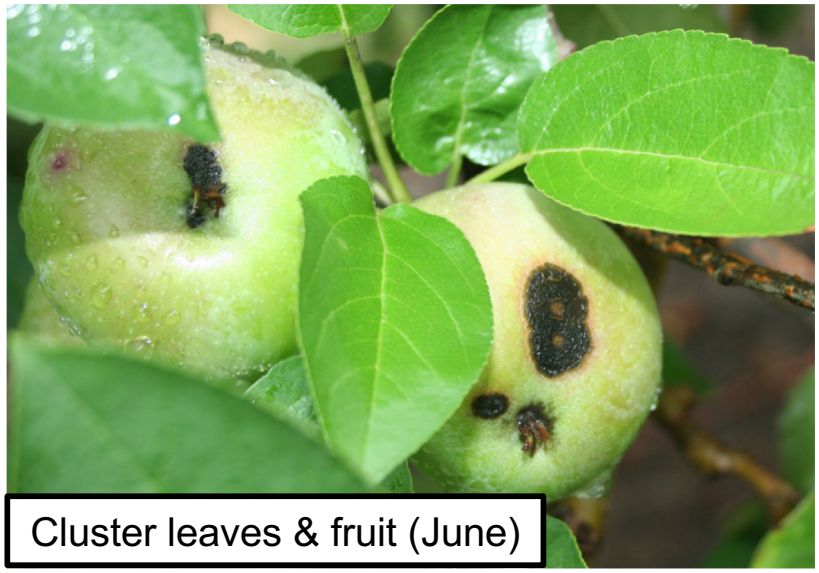
- 3.1-acre planting site Empire' and 'Jonagold'-M.9/M.111 interstem (18-20 years old)
- Widely-spaced two tree plots

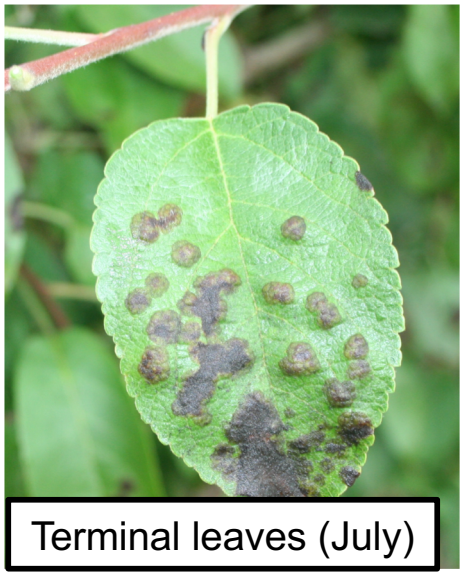
Apple scab & powdery mildew trials

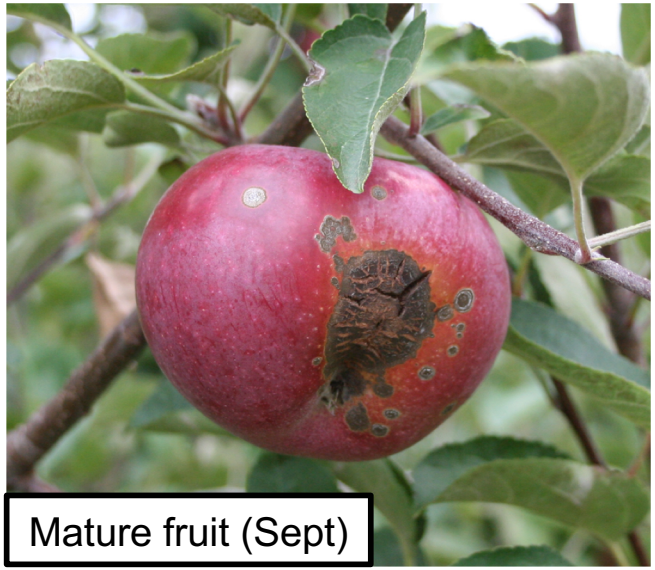
- Fungicide treatments
  - Dilute handgun application timed at **7-10 day intervals from TC- 2nd cover** or 14-21 days from 3rd-7th cover
  - Alternated with effective protectant standards ➔ not to exceed max applications (4 applications)

Apple scab trials

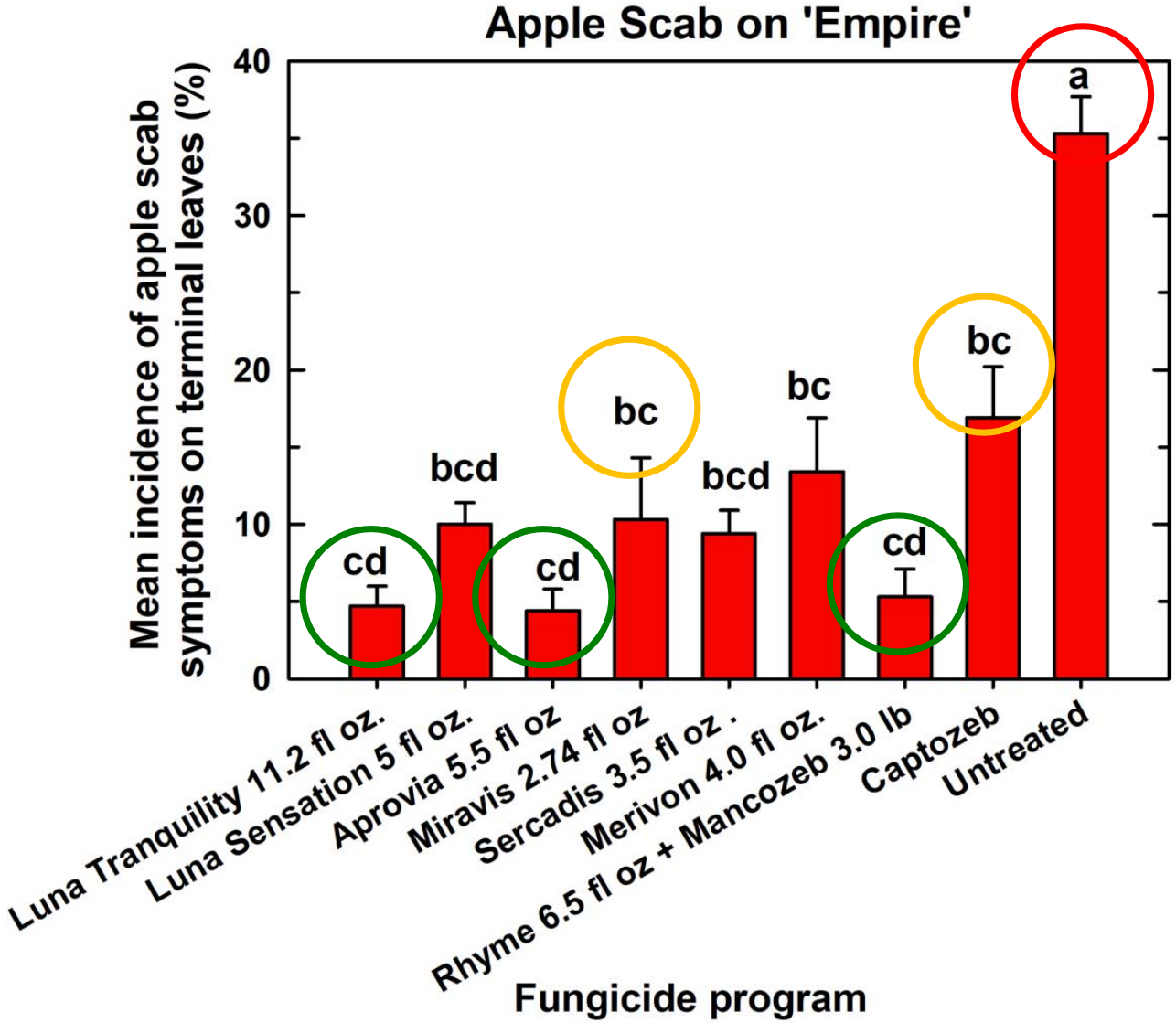
- Apple scab evaluation
  - Incidence any lesion on cluster leaves and fruit (June), terminal leaf scab (July), & **fruit (Sept)**


Cluster leaves & fruit (June)


Terminal leaves (July)

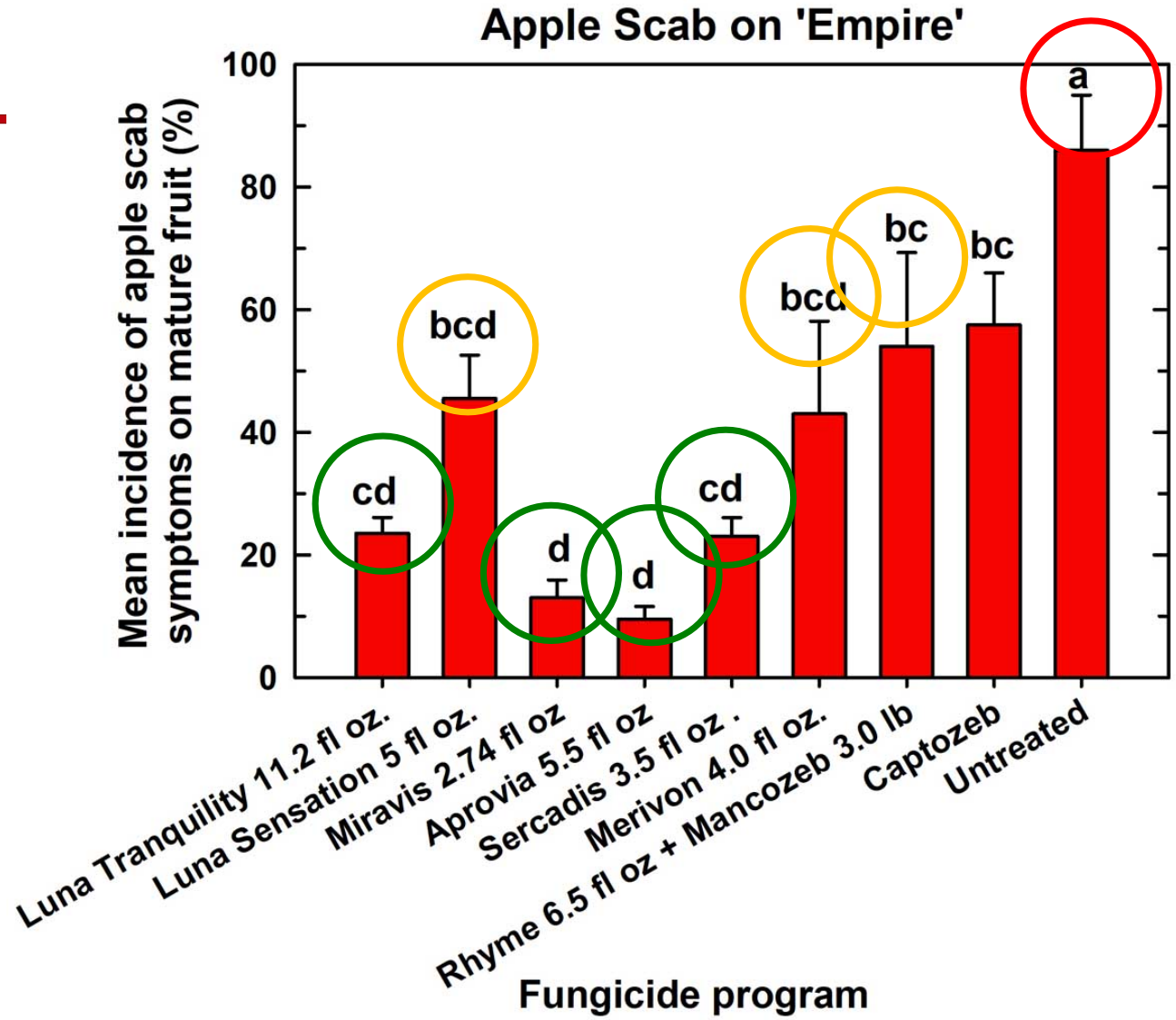

Mature fruit (Sept)

Apple scab trials (2016)



- **Dry year – little fruit infection:** SDHI(premixes) better than protectants, Miravis, Luna tranquility, Aprovia ≥ DMIs

Apple scab trials (2017)



- **Wet year – high levels of fruit infection:** Aprovia, Miravis, Luna tranquility, Sercadis, SDHI(premixes), > protectant & DMIs

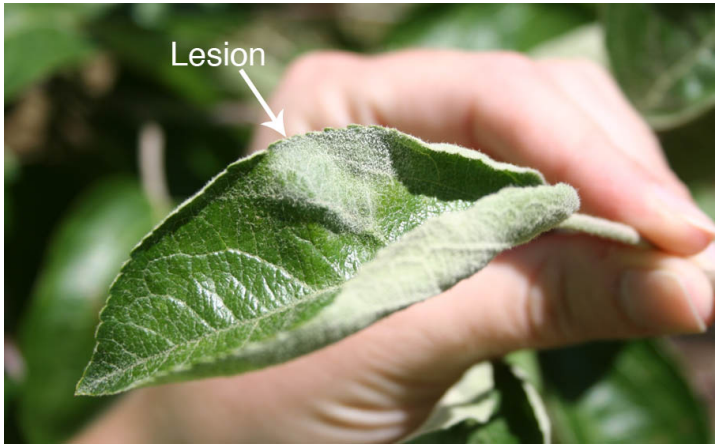
Apple scab trials: Trends and considerations

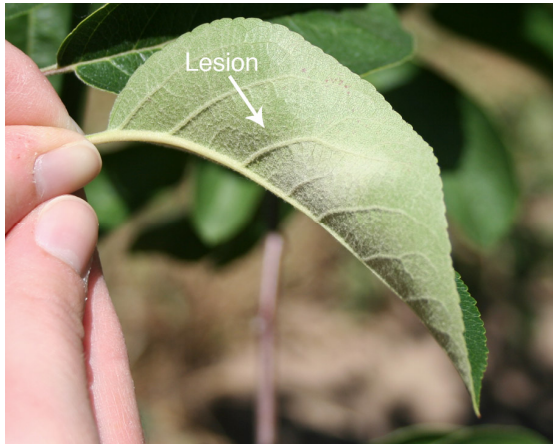
- Apple Scab
  - DMIs still work on DMI resistant populations in dry years
  - QoI/SDHI premixes **may be affected** by practical resistant to QoI fungicides in wet years
  - Stand alone SDHI fungicides strong against apple scab: Aprovia & Miravis highly potent

Powdery mildew trials

Disease assessment

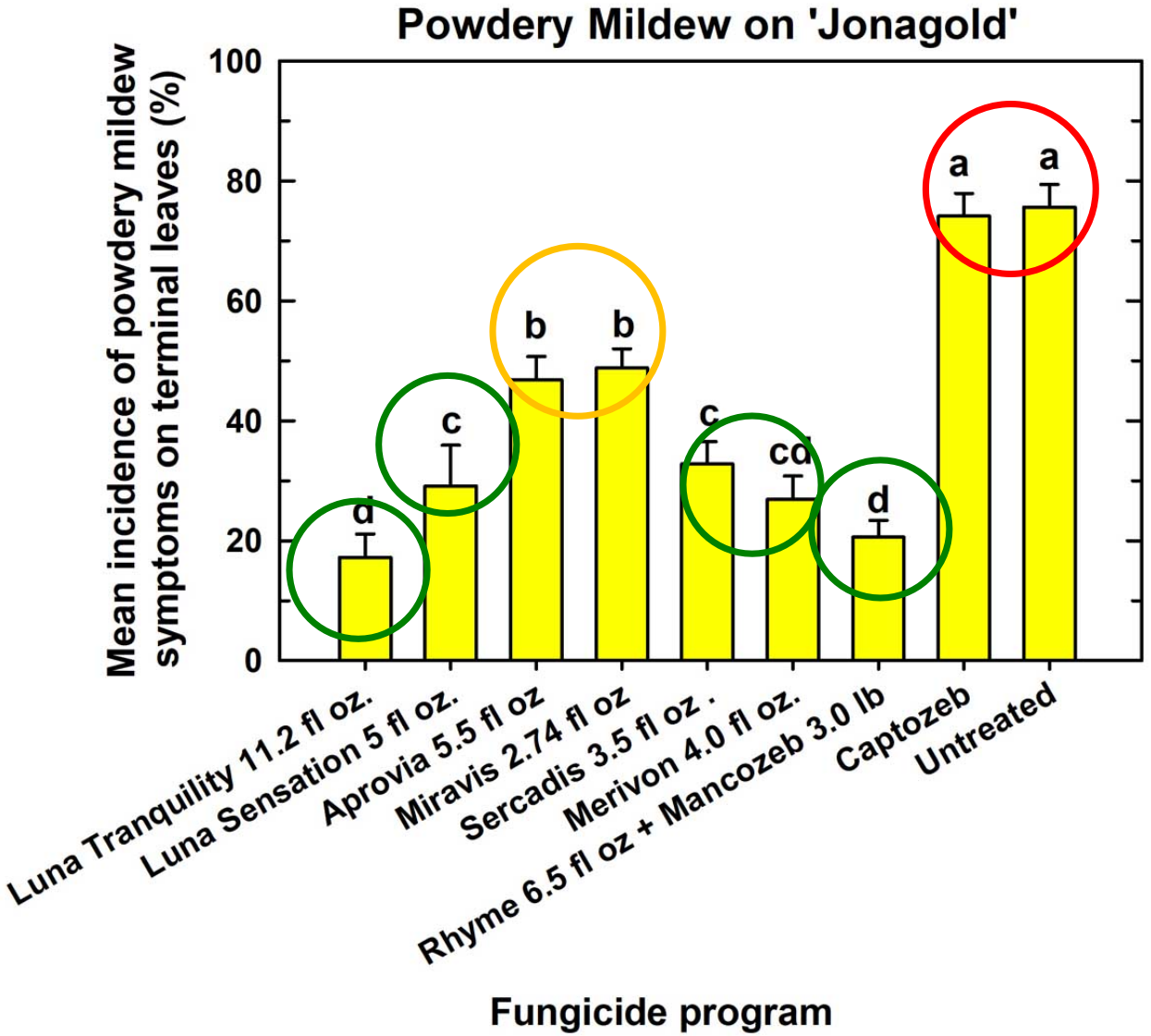
- Powdery mildew:
  - Primary mildew (June) & Secondary mildew (July)





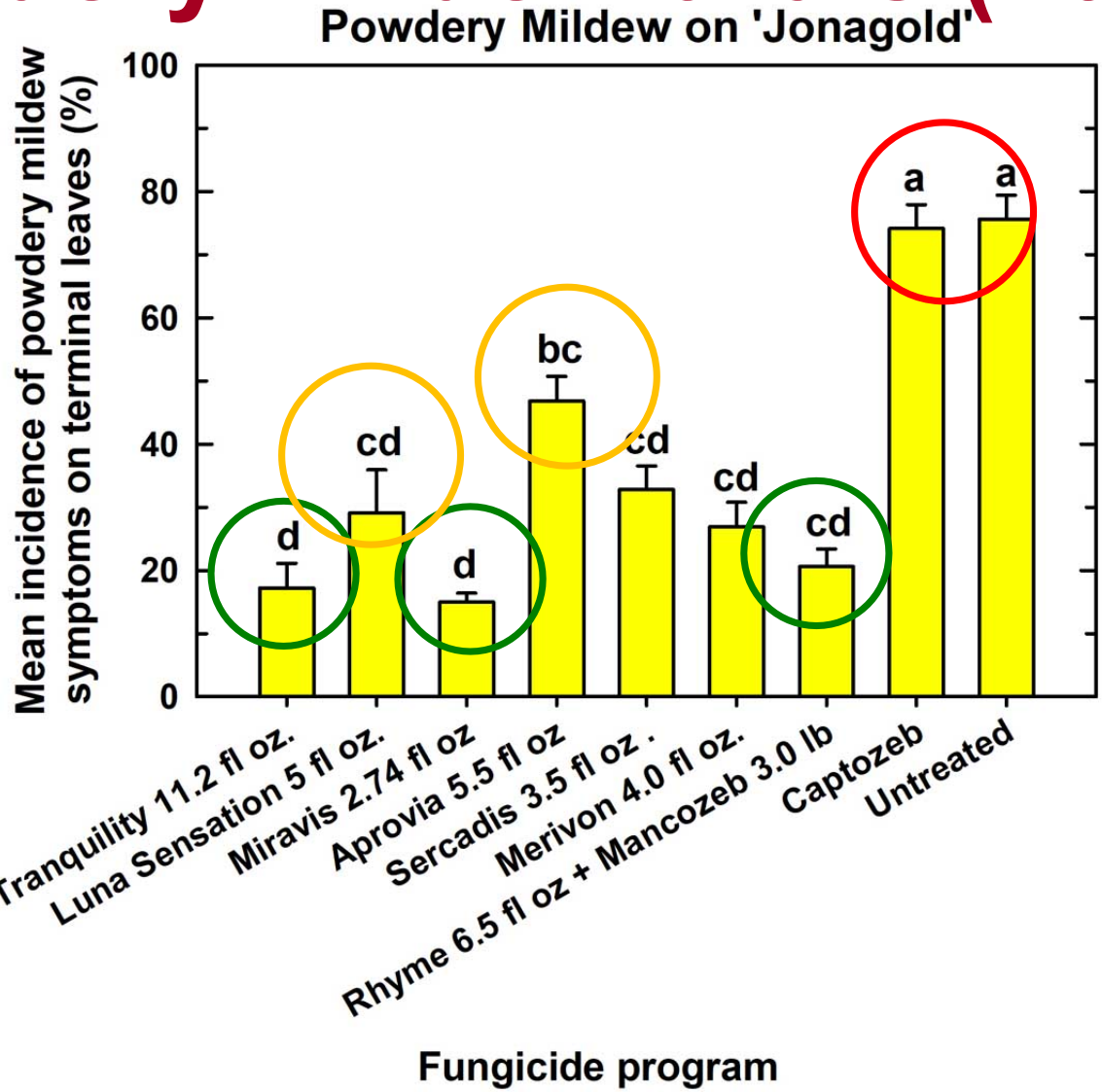
  - **Incidence (any lesion) & Severity (% leaf area)**

Powdery mildew trials (2016)



- **Dry year high mildew pressure**: SDHI premixes, HS DMIs (Rhyme & Rally) > standalone SDHIs

Powdery mildew trials (2017)



- **Wet year low mildew pressure** : SDHI premixes, HS DMIs (Rhyme & Rally), Miravis

Powdery mildew trials: Trends and considerations

- Powdery mildew
  - DMIs Topguard (Rhyme) or Rally still strongest mildew fungicides – high rates w/ mancozeb to manage DMI resistant scab
  - QoIs & SDHI-QoI premixes next best line of defense – even with QoI resistance
  - Stand alone SDHI fungicides slight effect against mildew under high pressure, **Miravis?**
  - Sulfur 3.33 lbs/100 7-10 day intervals from bloom to end of terminal growth **= QoIs**: **phyto & smell**