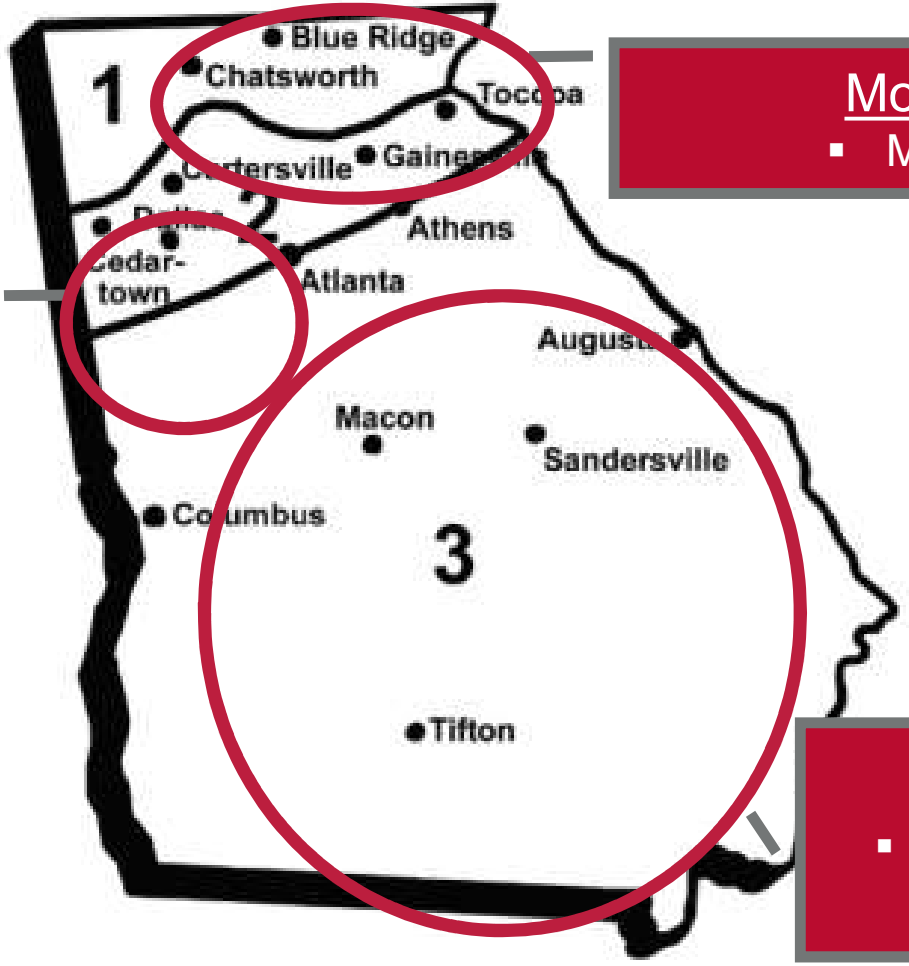
Fungicide resistance management for powdery and downy mildews

College of Agricultural & Environmental Sciences
Department of Plant Pathology
UNIVERSITY OF GEORGIA

Dr. Phillip Brannen

~ 1,580 acres



Mountain Region

- Mostly *Vitis vinifera*

West Georgia

- Mostly hybrids

South Georgia

- Mostly muscadines and hybrids

(Hickey 2017)

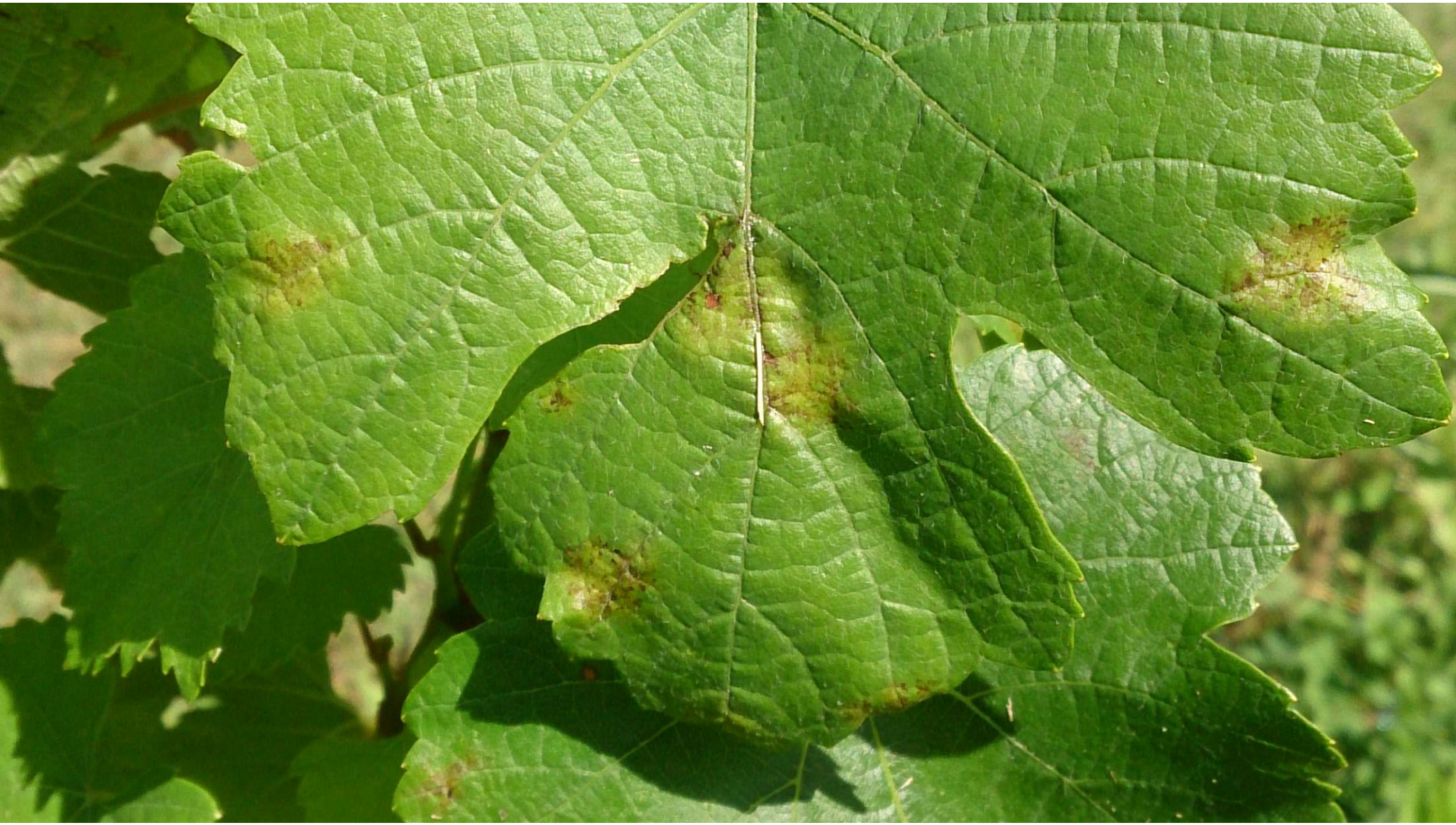
Grapevine downy mildew
Plasmopara viticola

- Oomycete, obligate parasite, diploid
- Native to North America
- Attacks all green parts of the vine, but leaves are particularly susceptible
- Up to 100% crop loss if unmanaged
- Managed by fungicide applications between pre-bloom and senescence

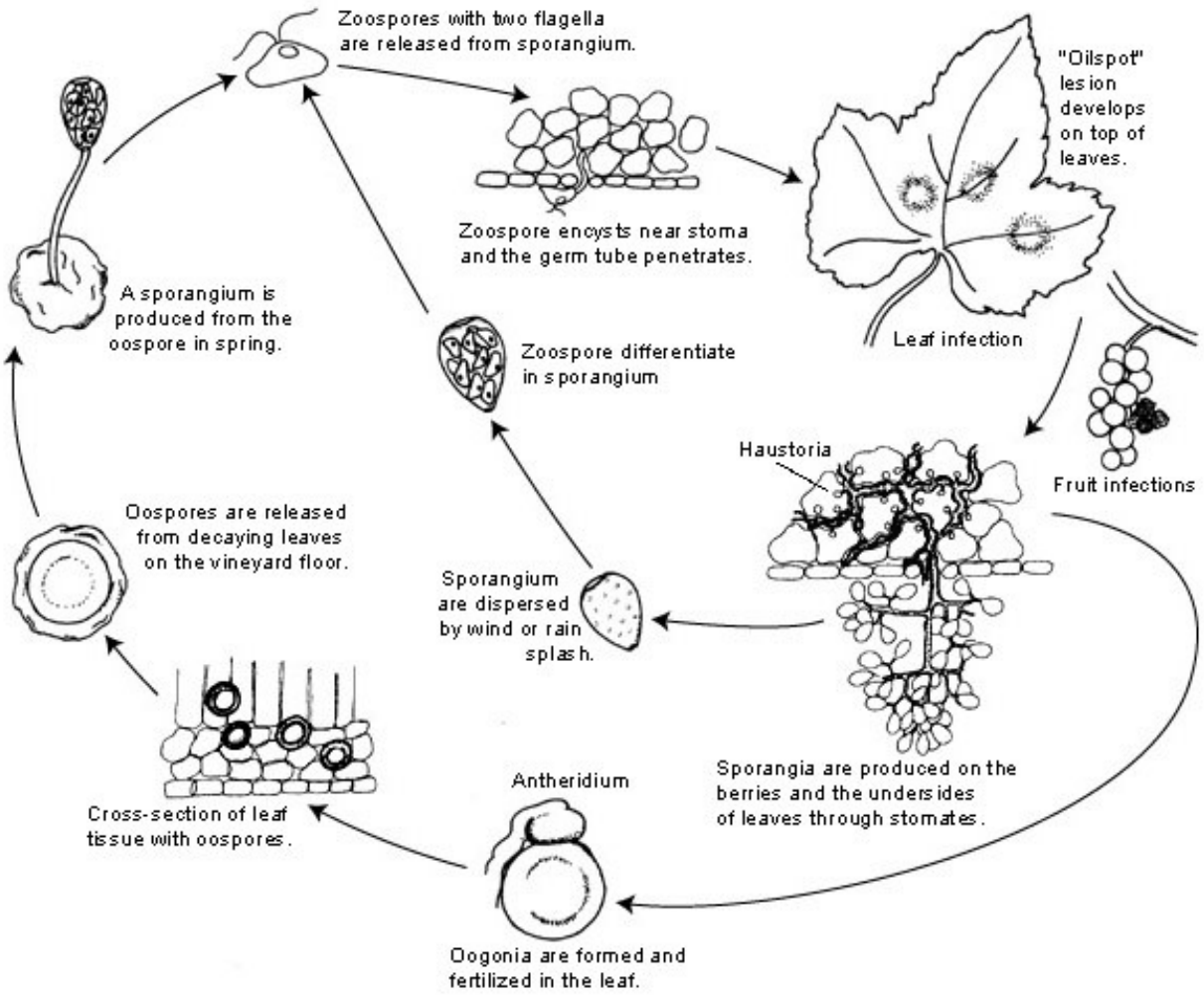
(Gessler et al. 2011)

Grapevine Downy Mildew (*Plasmopara viticola*)

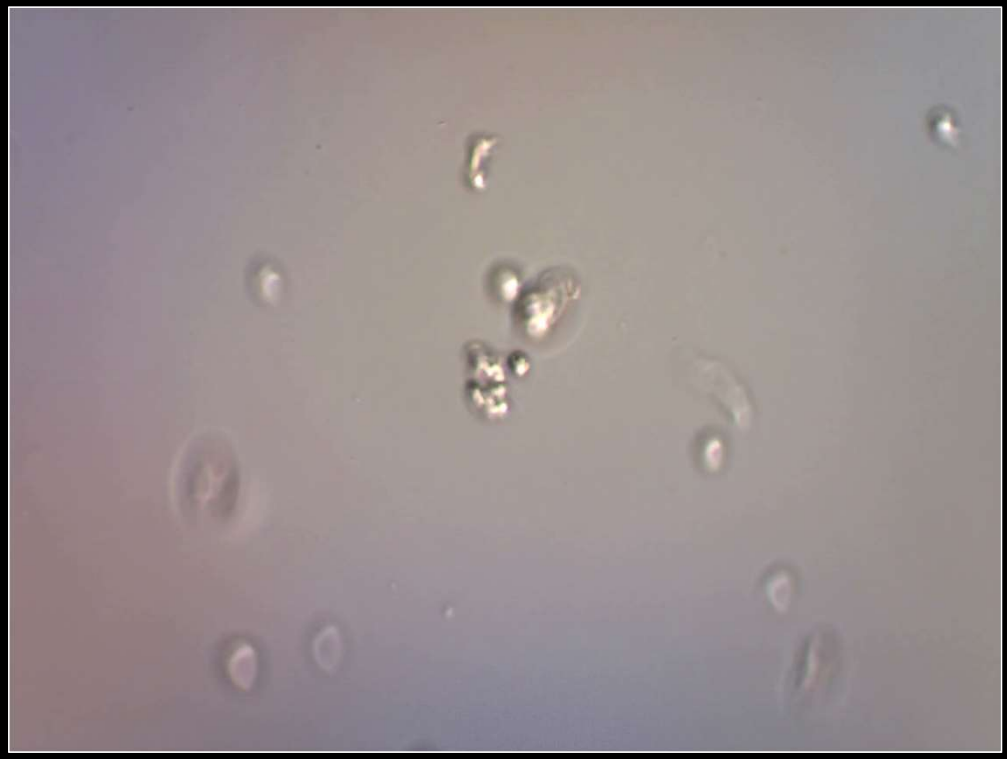
- Signs
  - White “downy” growth on the underside of leaves or on berries
- Symptoms
  - “Oil spots” on the top of leaves
  - Dessication and defoliation
- Management
  - Fungicide applications



Life Cycle



APS



Fungicides	FRAC Code	Efficacy
Ametocradin + dimethomorph (Zampro)	40 + 45	+++++ Systemic
Azoxystrobin (Abound)	11	??? Systemic (Resistance prevalent; always mix with mancozeb or Captan)
Boscalid + Pyraclostrobin (Pristine)	7 + 11	??? Systemic (Resistance prevalent; always mix with mancozeb or Captan)
Captan	M4	++++ Contact protectant; combine with Phosphonates
Cyazofamid (Ranman)	21	++++ Locally systemic; combine with Phosphonates
Famoxadone + Cymoxanil (Tanos)	11 + 27	++++ Use with Captan or mancozeb (required)
Mancozeb	M3	++++ Contact protectant
Mandipropamid (Revus)	40	+++++ Translaminar protectant
Mandipropamid + Difenoconazole (Revus Top)	3 + 40	+++++ Translaminar protectant
Mefanoxam + Mancozeb (Ridomil Gold MZ)	4 + M3	+++++ Systemic + contact protectant
Phosphonates (Prophyt, etc.)	33	++++ Systemic (combine with Captan)
Ziram	M3	++++ Contact protectant
Zoxamide + Mancozeb (Gavel)	22 + M3	++++ Contact protectant fungicides

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Combined risk: 0.5 – 1.5 = low, 2-6 = medium, 9 = high

Fungicide Risk \ Pathogen Risk	1 Low *Rhizoctonia* Rusts Soil borne pathogens Smuts & Bunts	2 Medium Eyespot *Mycosphaerella graminicola* *Rhynchosporium*	3 High *Botrytis* *Blumeria* *Magnaporthe* *Venturia* *Plasmopara* *Penicillium* *M.fijiensis* *Phytophthora infestans***
High Benzimidazoles QoIs Phenylamides Dicarboximides	3	6	9
Medium Carboxanilides DMIs Phenylpyrrols Phosphorothiolates Anilinopyrimidines MBI-Ds	2	4	6
Low Coppers, sulphur Chlorothalonil Dithiocarbamates Phthalimides MBI-Rs Probenazole	0.5*	1	1.5

* This low score reflects the long standing record of 'no resistance' in this low risk group.
** *P infestans* is considered by some to be a medium risk as the high risk classification is based largely on the reaction to phenylamides

Brent and Holloman 2007

Fungicide Resistance in *P. viticola* (other growing areas)

1983 FRAC 4: Phenylamides (PA)
- Metalaxyl, mefenoxam

1997 FRAC 27: Cyanoacetamide oximes
- Cymoxanil

2000 FRAC 11:Quinone outside Inhibitors (QoI)
- Azoxystrobin, pyraclostrobin

2003 FRAC P07: Phosphonates
- Fosetyl-Al, phosphorous acid and salts

2007 FRAC 40: Carboxylic acid amides (CAA)
- Mandipropamid

(FRAC 2018)

Fungicide classes with *P. viticola* resistance

- Quinone outside Inhibitors (QoI)
- Carboxylic acid amides (CAA)
- Phenylamides (PA)
- Phosphonates
- Cyanoacetamide oximes

FRAC 2018

Fungicide classes with *P. viticola* resistance

- Quinone outside Inhibitors (QoI)
- Carboxylic acid amides (CAA)
- Phenylamides (PA)
- Phosphonates
- Cyanoacetamide oximes

FRAC 2018

Objectives

- Survey fungicide sensitivities in current Georgia downy mildew populations
- Evaluate field efficacy of fungicides against downy mildew

Resistance Testing

Bioassays

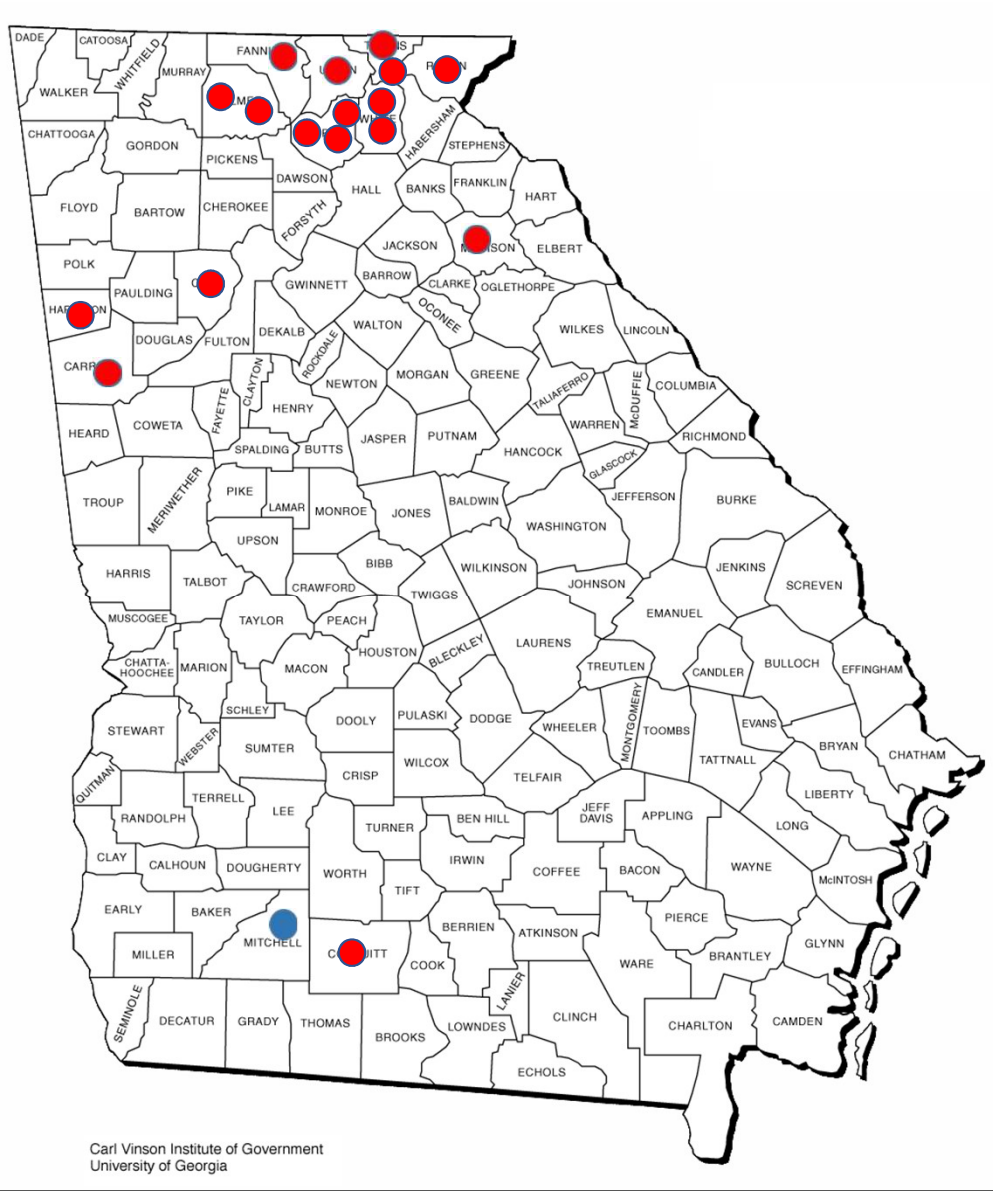
- Revus
  (mandipropamid; CAA Group 40)
- Abound
  (azoxystrobin; QoI Group 11)
- Ridomil
  (mefenoxam; PA Group 4)

Bioassay results

			QoI		CAA		PA	
County	Vineyard	Year Collected	Bioassay Resistant Isolates/Total	Percentage Resistance	Bioassay Resistant Isolates/Total	Percentage Resistance	Bioassay Resistant Isolates/Total	Percentage Resistance
Carroll	A	2018	1/1	100	0/1	0	0/1	0
Cobb	B	2017	5/5	100	0/5	0	0/5	0
Colquitt	C	2017	0/11	0	0/11	0	0/11	0
Fannin	D	2017	4/4	100	0/4	0	0/4	0
Gilmer	E	2017	2/2	100	0/2	0	0/2	0
	F	2017	5/5	100	0/5	0	0/5	0
Haralson	G	2018	4/4	100	0/4	0	0/4	0
Lumpkin	H	2018	2/2	100	0/2	0	0/2	0
	I	2018	1/1	100	0/1	0	0/1	0
	J	2018	4/4	100	0/4	0	0/4	0
Mitchell	L	2017	NS		NS		NS	
Rabun	M	2017	7/7	100	0/7	0	0/7	0
White	Q	2017	3/3	100	0/3	0	0/3	0
	R	2017	3/3	100	0/3	0	0/3	0

County	Vineyard	Year collected	QoI Resistant isolates/total[a]	QoI Percent resistance	CAA Resistant isolates/total[b]	CAA Percent resistance
Carroll	A	2018	16/16	100	0/5	0
Cobb	B	2017	8/8	100	0/1	0
Colquitt	C	2015	0/6	0	--	--
	C	2016	0/15	0	--	--
	C	2017	0/19	0	0/28	0
	C	2018	3/3	100	0/1	0
Fannin	D	2017	16/16	100	0/5	0
Gilmer	E	2017	6/6	100	0/2	0
	F	2015	10/10	100	--	--
	F	2017	12/12	100	0/2	0
Haralson	G	2018	15/15	100	0/3	0
Lumpkin	H	2018	5/5	100	0/3	0
	I	2015	4/4	100	0/1	0
	I	2018	9/9	100	0/3	0
	J	2018	14/14	100	0/4	0
Madison	K	2018	18/18	100	0/4	0
Mitchell	L	2016	0/1	0	--	--
	L	2017	0/4	0	--	--
Rabun	M	2015	8/8	100	--	--
	M	2017	6/6	100	0/4	0
Towns	N	2018	7/7	100	0/4	0
	O	2018	15/15	100	0/4	0
Union	P	2015	6/6	100	--	--
	P	2016	9/9	100	0/6	0
	P	2017	15/15	100	0/10	0
White	Q	2017	3/3	100	0/2	0
	R	2015	5/5	100	0/5	0
	R	2017	8/8	100	0/5	0

- Resistant
- Sensitive



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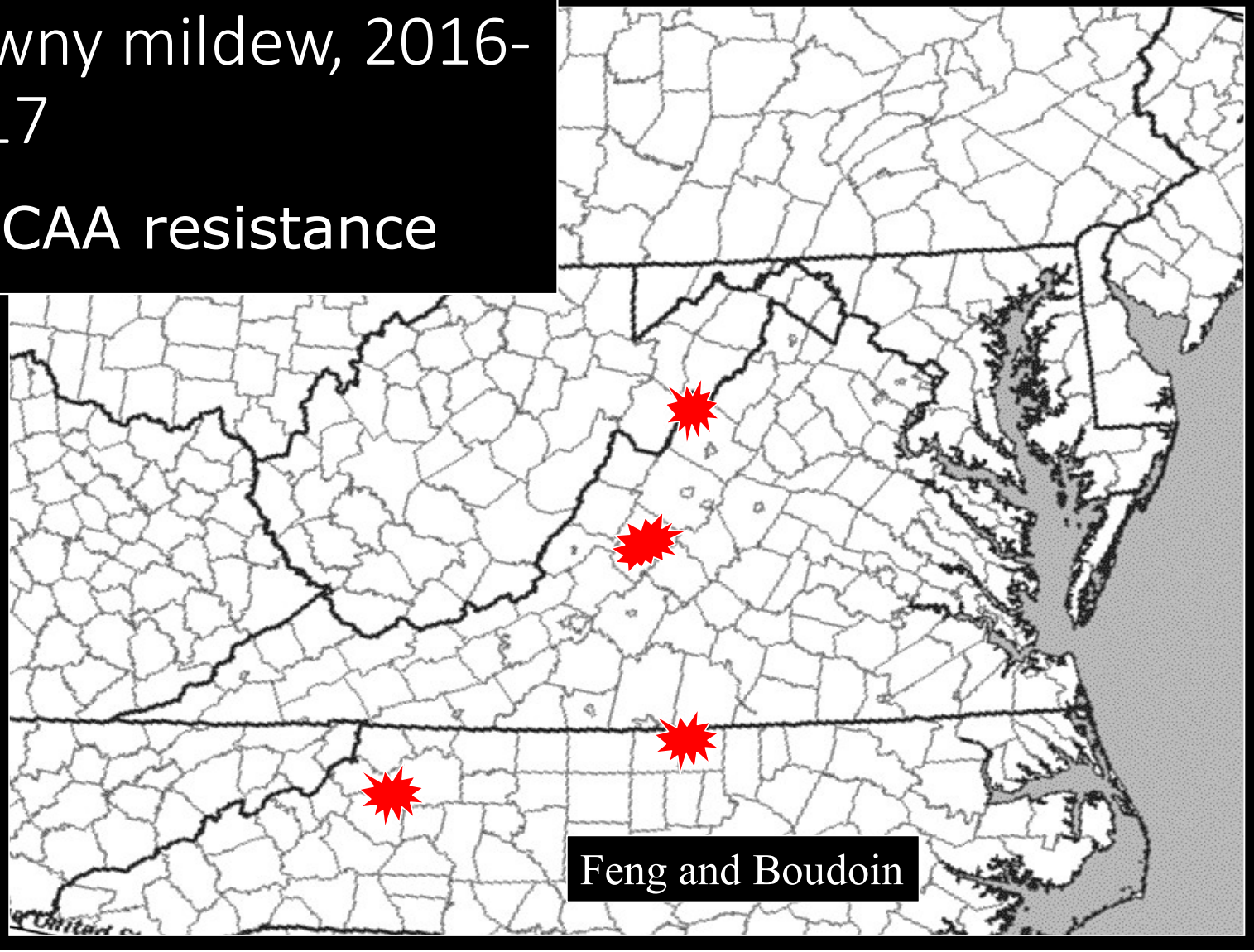
QoI

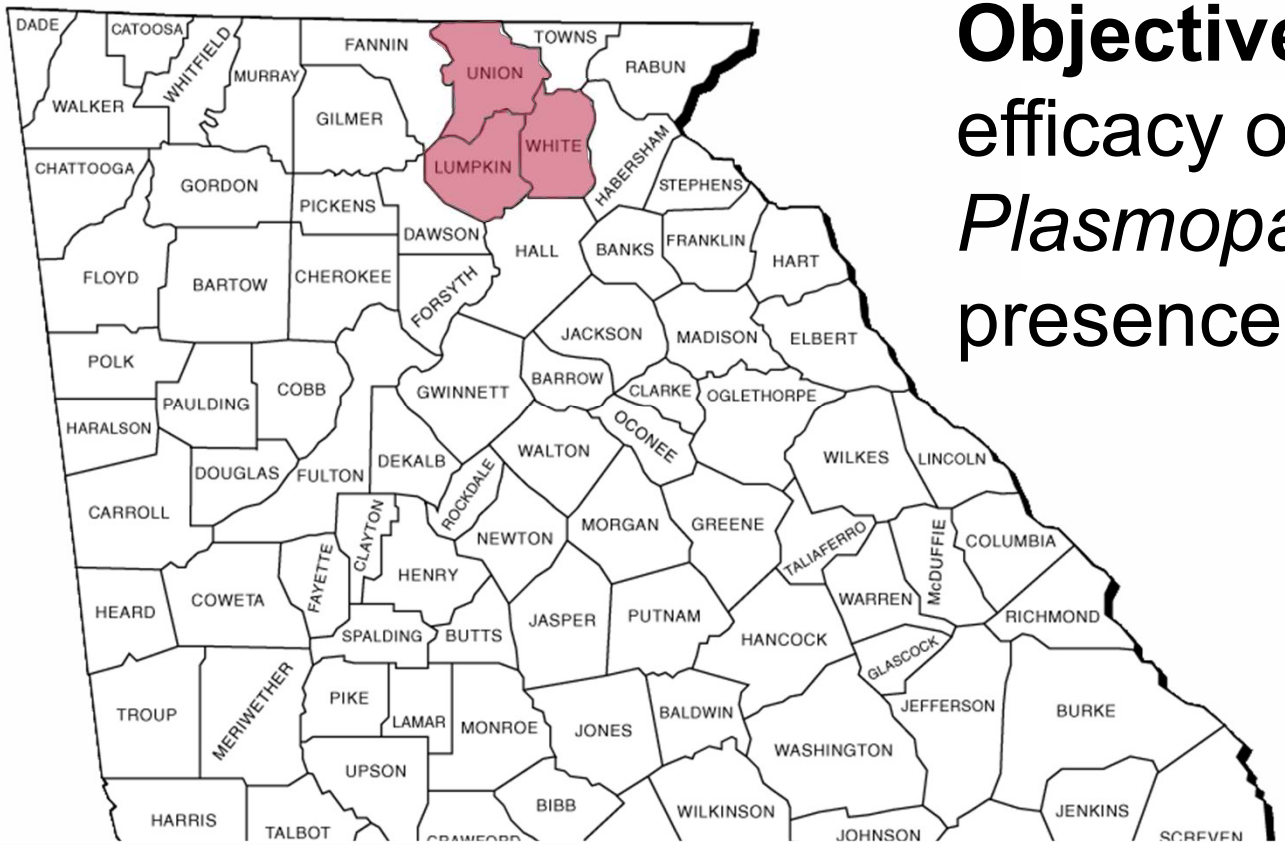
Group 11
Ex. Abound, Pristine

Downy mildew, 2016-2017

CAA resistance



2018 Field Trials



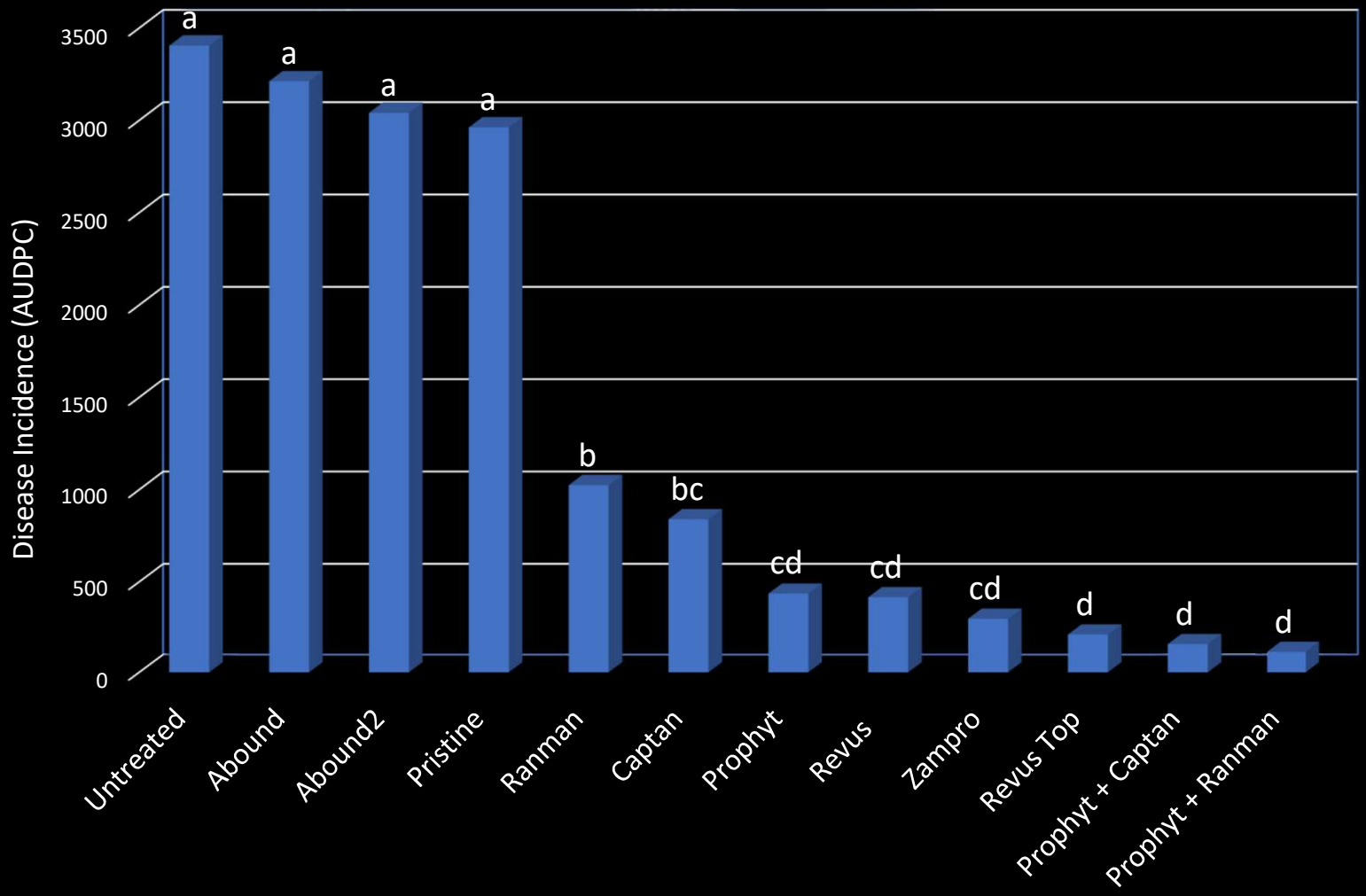
Objective 2: Evaluate field efficacy of fungicides against *Plasmopara viticola* in the presence of resistant isolates

Field Efficacy Trials

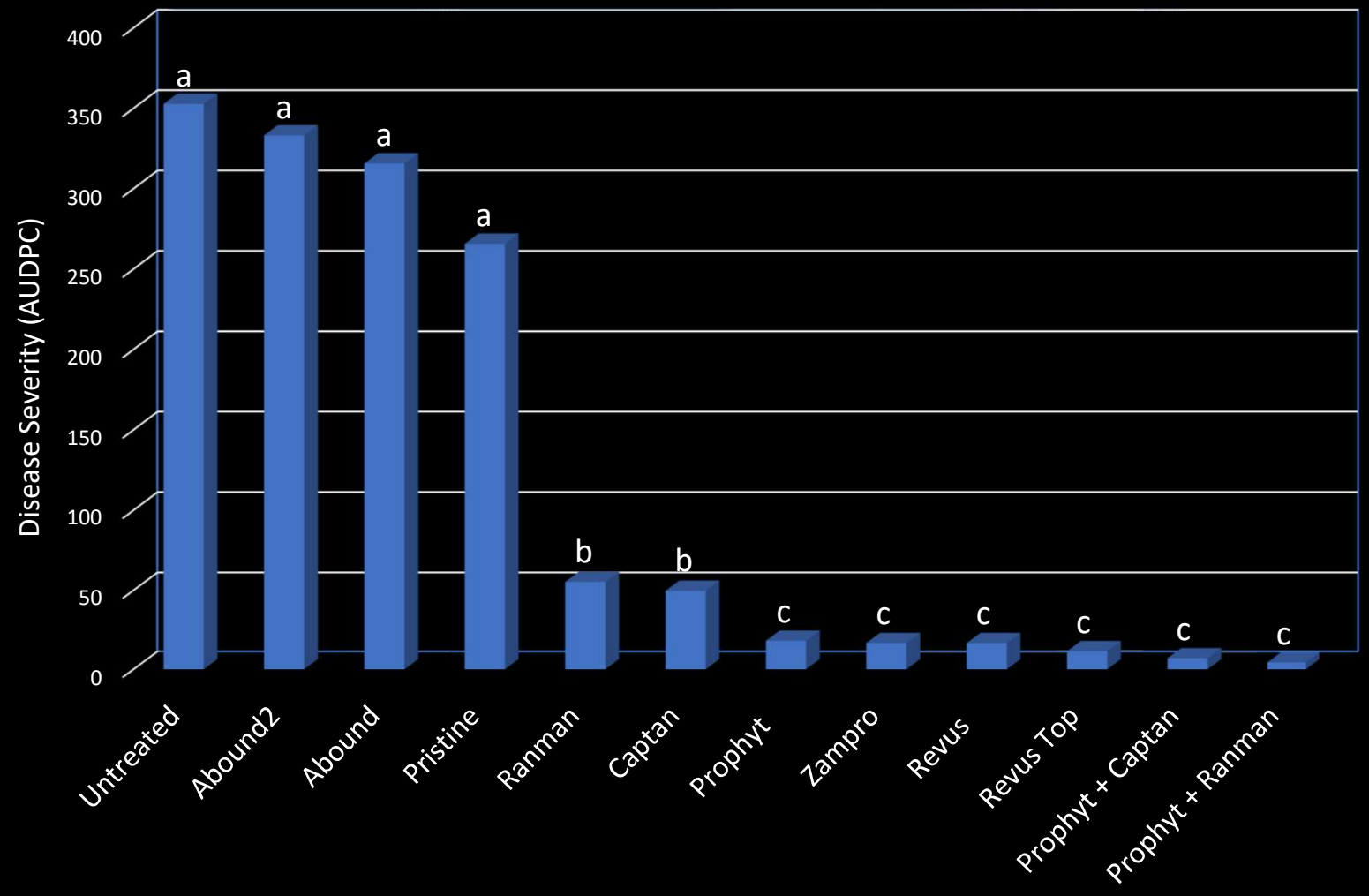
- Randomized complete block
- 11 Treatments

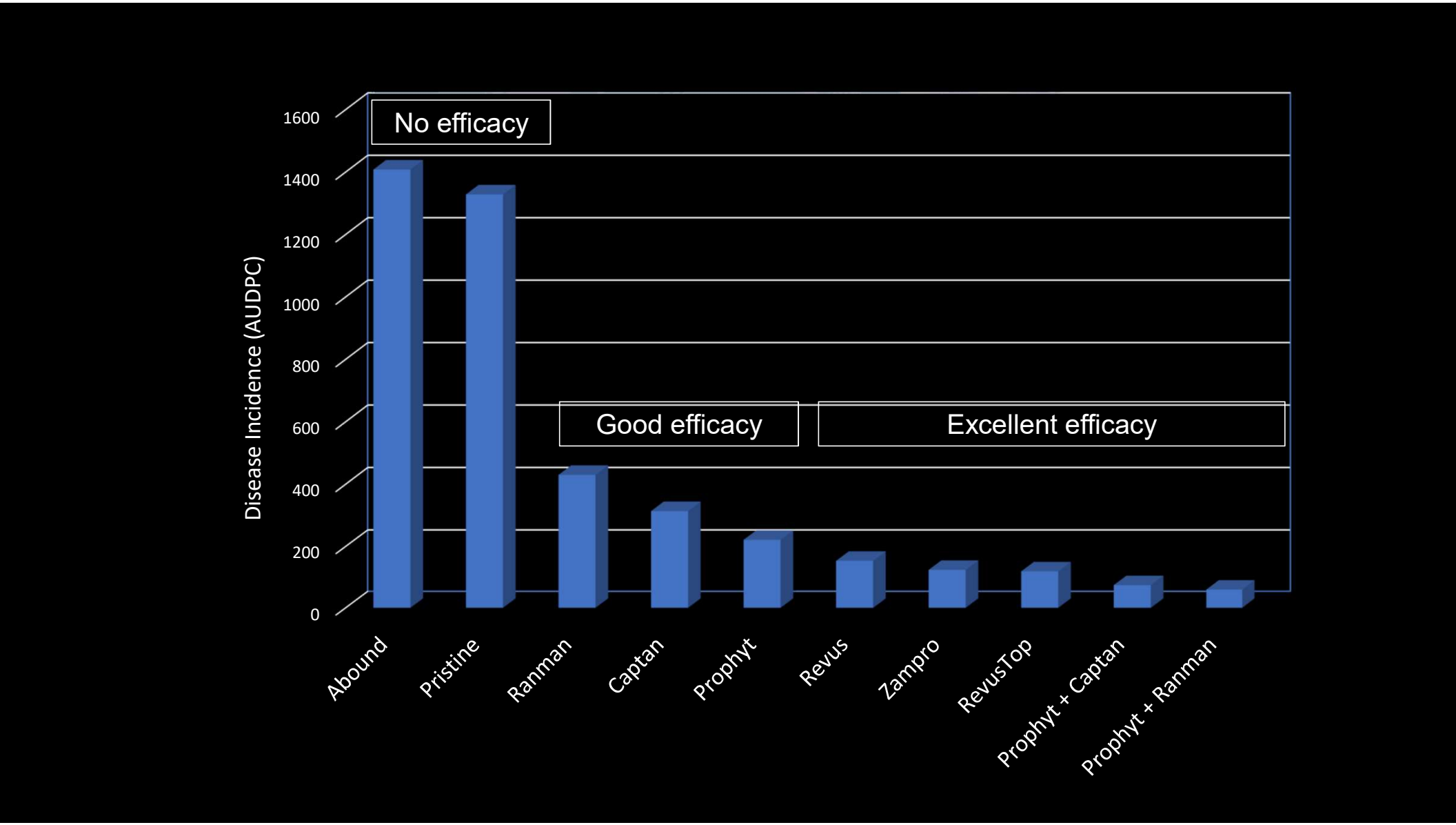
Abound (x2)	QoI
Pristine	QoI + SDHI
Ranman	QiL
Revus	CAA
Revus Top	CAA + DMI
Captan	Phthalimide
Zampro	QoSI + CAA
Prophyt	Phosphonate
Prophyt + Ranman	Phosphonate + QiL
Prophyt + Captan	Phosphonate + phthalimides

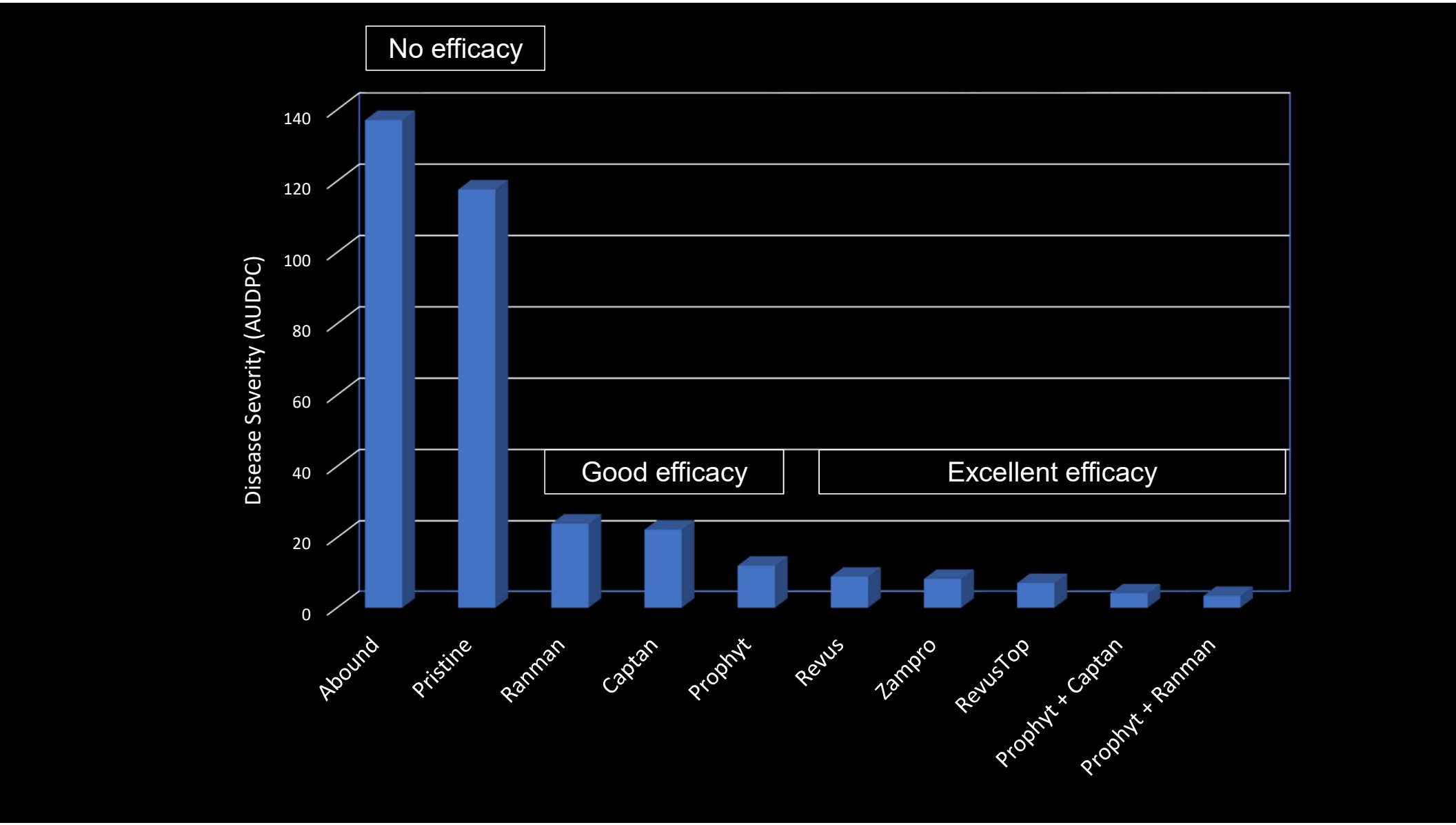
Blairsville, GA Incidence



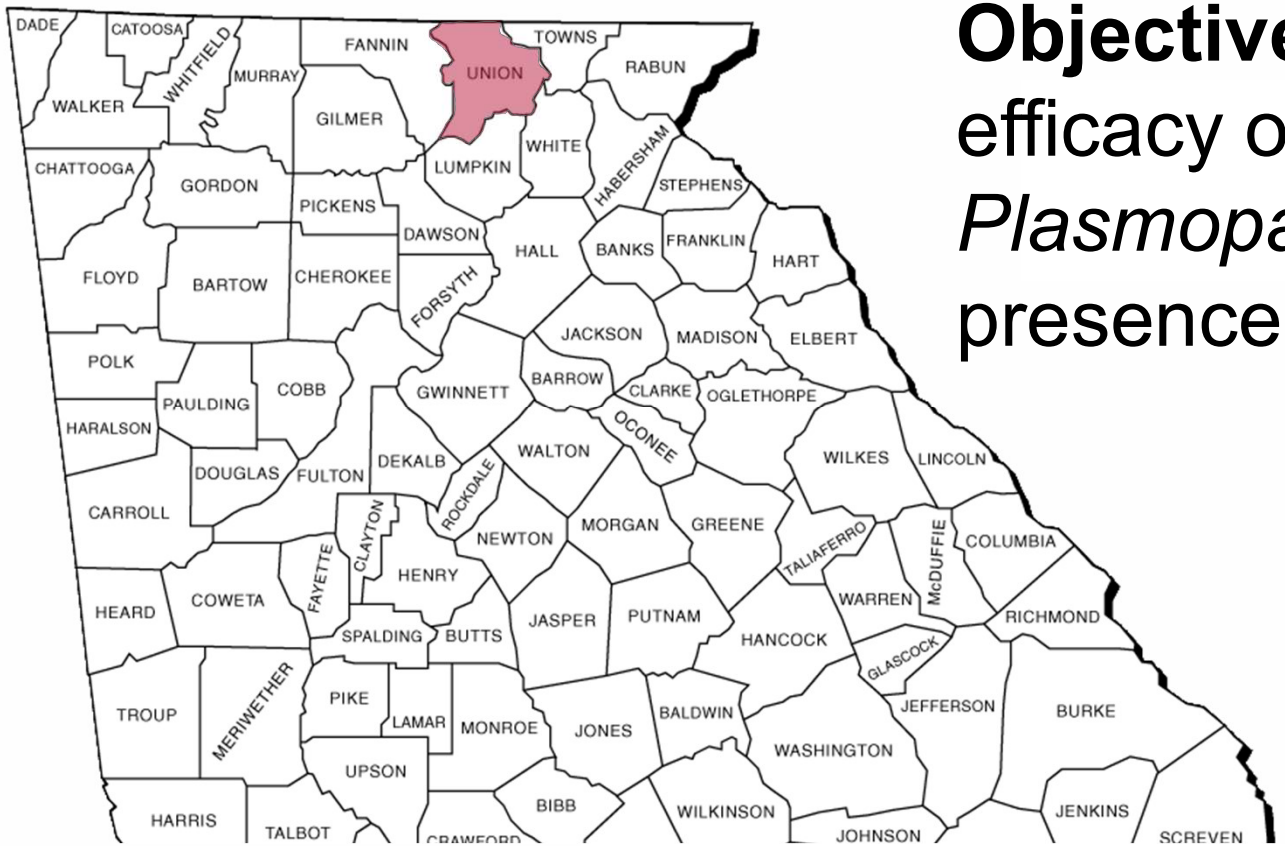
Blairsville, GA Severity




No efficacy
Good efficacy
Excellent efficacy
Disease Incidence (AUDPC)
1600
1400
1200
1000
800
600
400
200
0
Abound
Pristine
Ranman
Captan
Prophyt
Revus
Zampro
RevusTop
Prophyt + Captan
Prophyt + Ranman


No efficacy
Good efficacy
Excellent efficacy
Disease Severity (AUDPC)
140
120
100
80
60
40
20
0
Abound
Pristine
Ranman
Captan
Prophyt
Revus
Zampro
RevusTop
Prophyt + Captan
Prophyt + Ranman

2019 Field Trials



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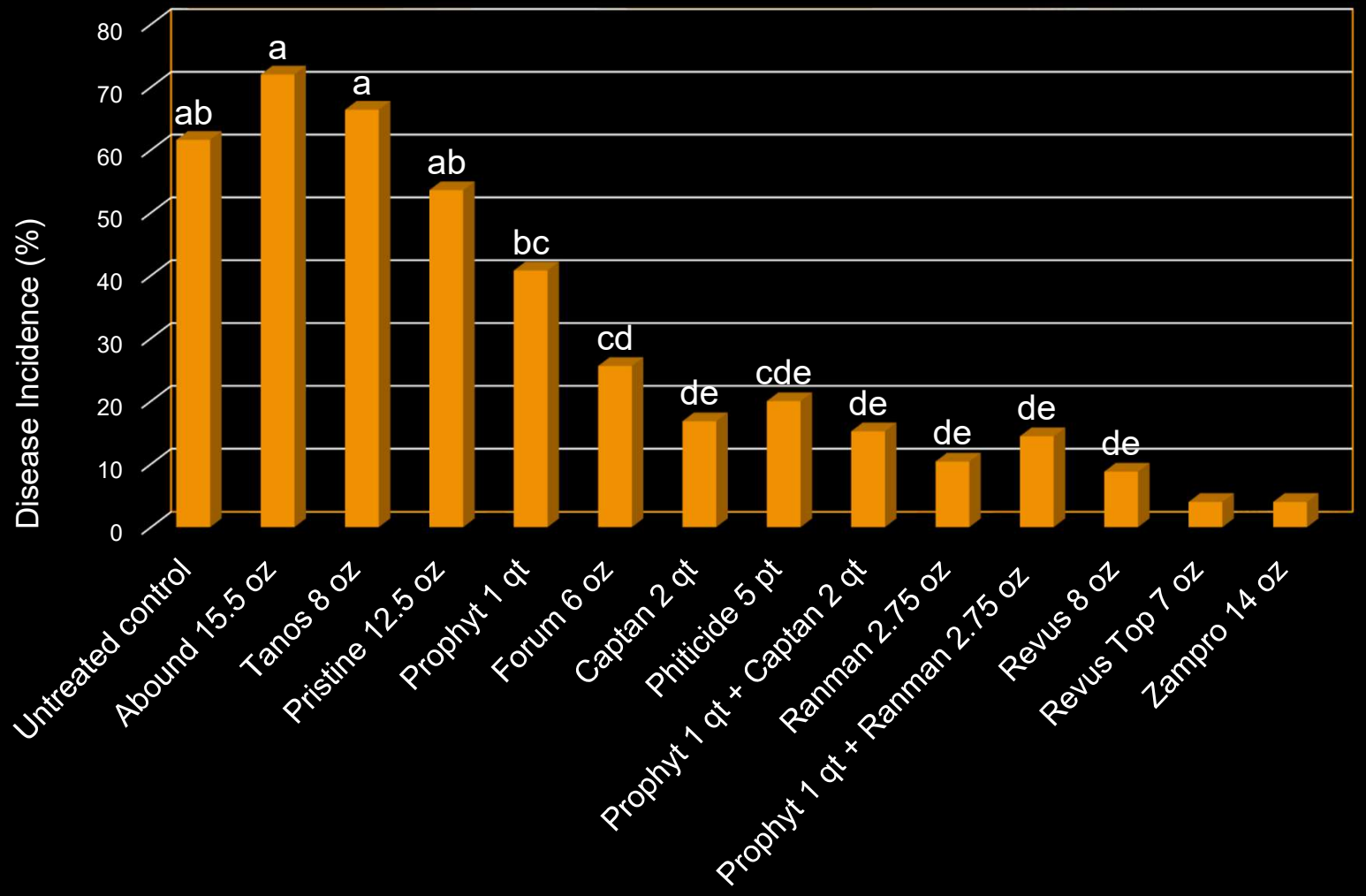
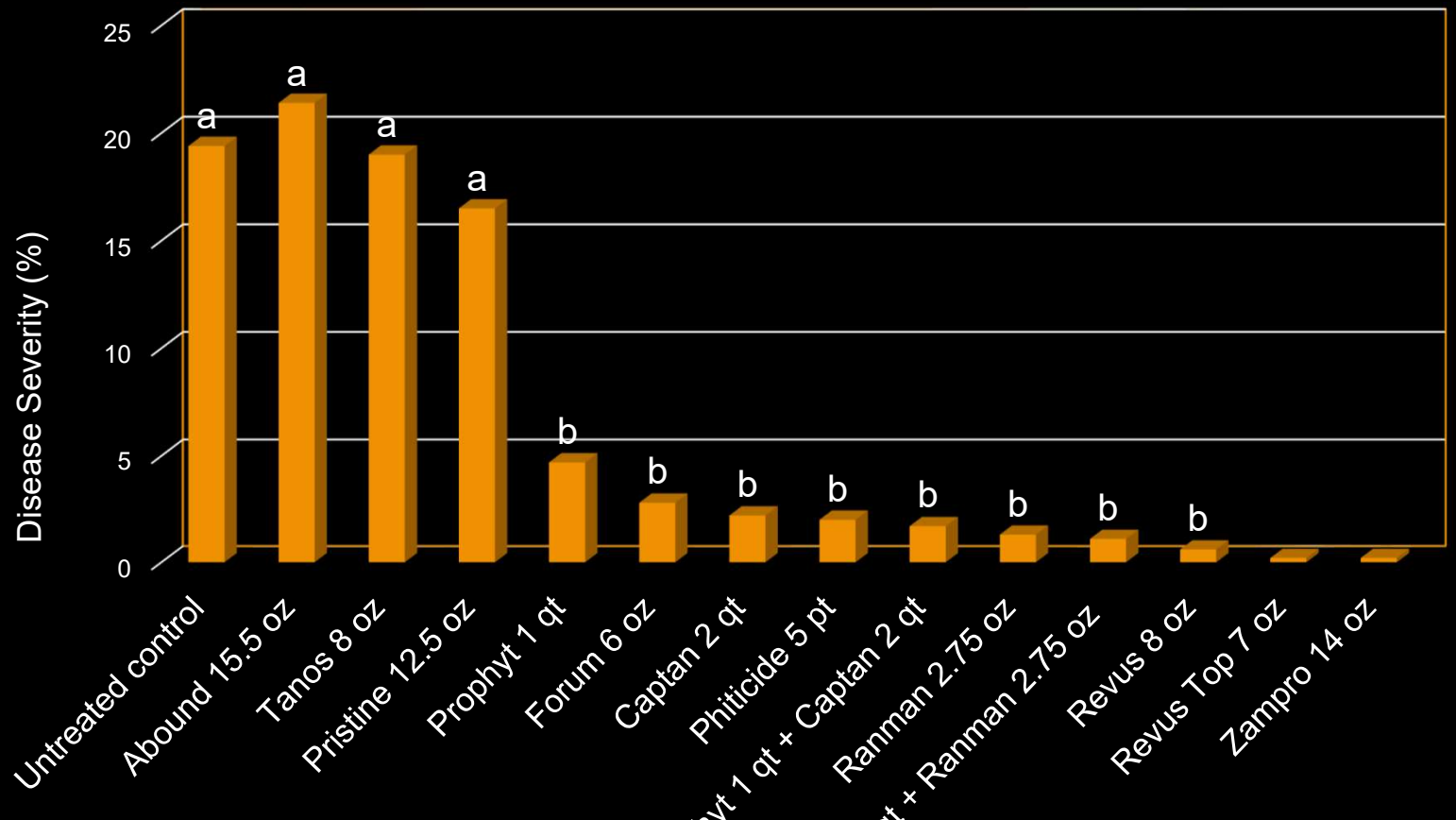


Blairsville, GA Severity



Conclusions

Based on bioassays, PCR of known resistance-causing mutations, and field evaluation of fungicides:

- Downy mildew QoI resistance (G143A) is widespread in Georgia vineyards
- No CAA or PA resistance found in downy mildew populations in Georgia
- Presence of resistance leads to documented control failures with QoIs in the field, and cross resistance is complete

Grape Powdery Mildew (GPM)

- Caused by an obligate biotrophic fungus and found in every grape producing region of the world
- Reproduces both asexually and sexually throughout the season
- Signs and symptoms: white powdery growth on the surface of fruit and/or leaves

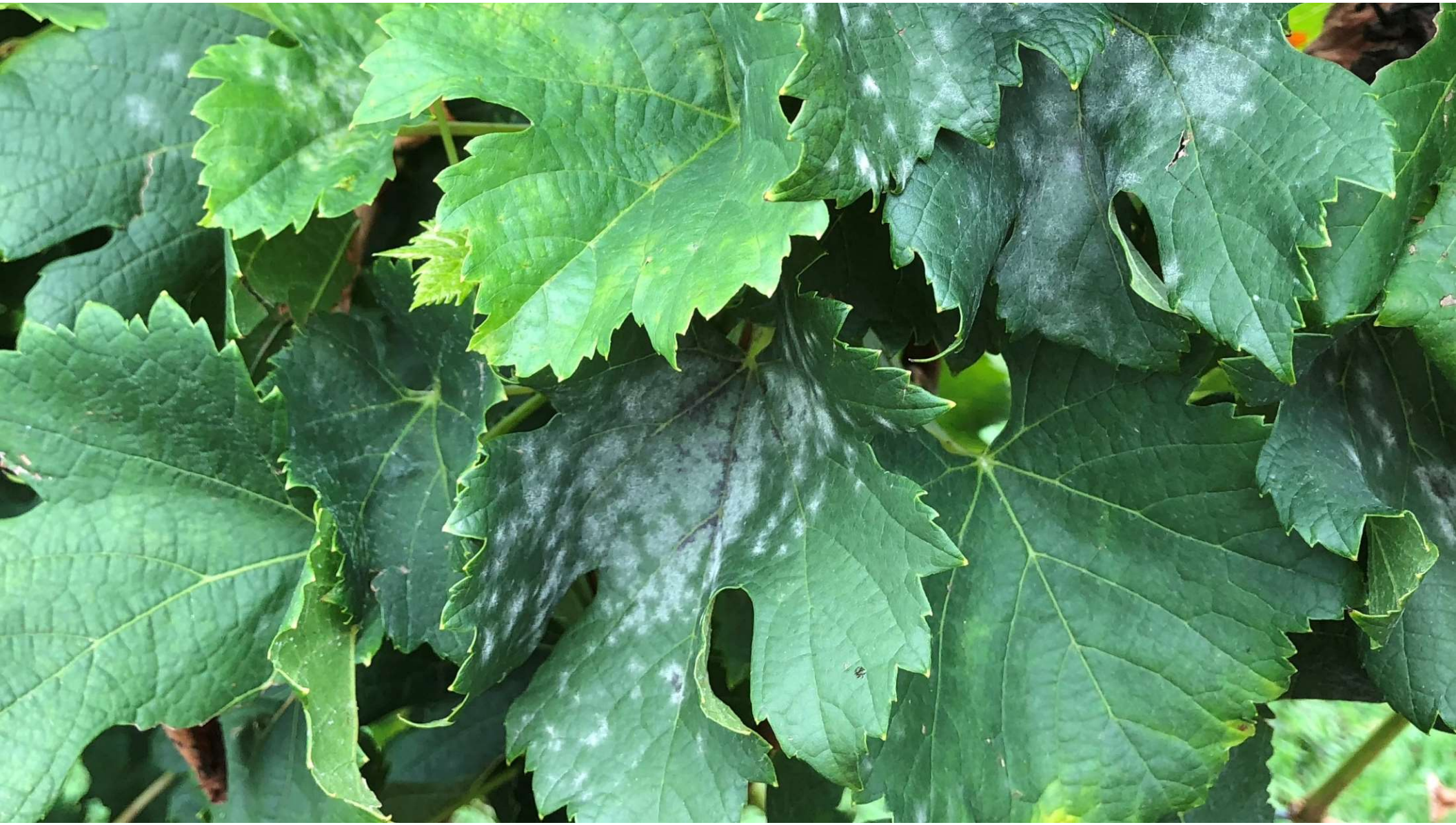
Grape Powdery Mildew (GPM)

- Can infect all green tissue of the grapevine
- Zero tolerance for disease – any amount will cause off-flavors in wine
- Interferes with photosynthesis causing poor fruit production
- Will cause berries to split (increased rots) and defoliation in severe cases

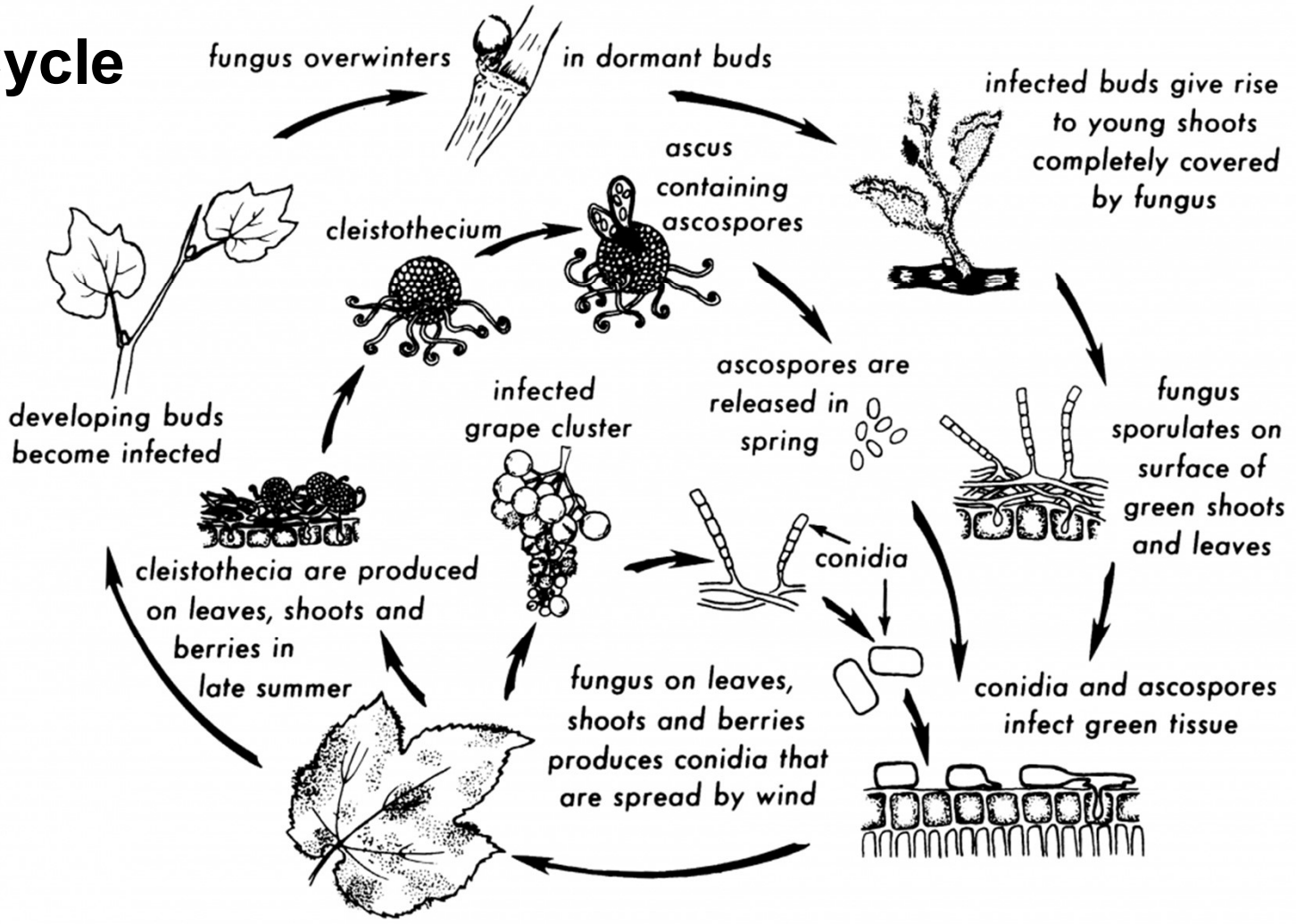
Fungicide Resistance in GPM

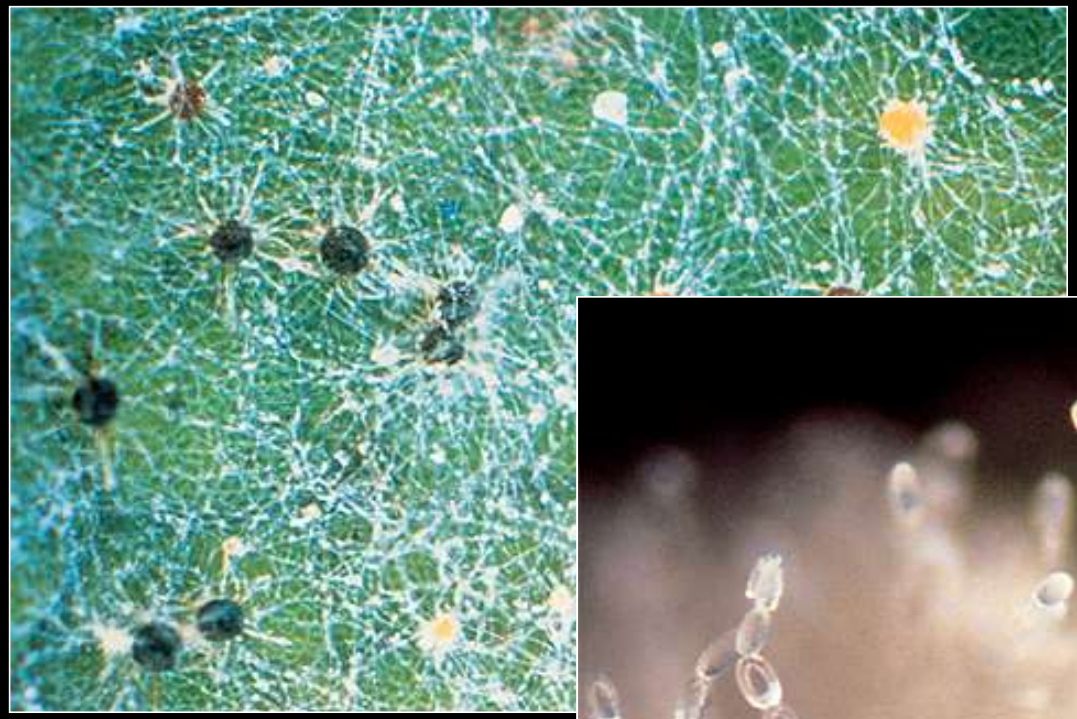
- Resistance development has been reported in **QoIs** (Wong & Wilcox 2002), **DMIs** (Délye et al. 1997), and **SDHIs** (Cherrad et al. 2018) in various parts of the world

- Resistance development and fungicide efficacy for controlling GPM in Georgia has not been confirmed or studied



Life Cycle


fungus overwinters
in dormant buds
infected buds give rise to young shoots completely covered by fungus
ascus containing ascospores
cleistothecium
developing buds become infected
ascospores are released in spring
infected grape cluster
fungus sporulates on surface of green shoots and leaves
conidia
cleistothecia are produced on leaves, shoots and berries in late summer
fungus on leaves, shoots and berries produces conidia that are spread by wind
conidia and ascospores infect green tissue



Fungicides	FRAC Code	Contact or Systemic
Abound (azoxystrobin)	11	Systemic
Aprovia (benzovindiflupyr)	7	Systemic
Inspire Super (difenoconazole + cyprodinil)	3 + 9	Systemic
Luna Experience (fluopyram + tebuconazole)	3 + 7	Systemic
Microthiol Disperss (sulfur)	M2	Contact protectant
Pristine (pyraclostrobin + boscalid)	7 + 11	Systemic
Quintec (quinoxyfen)	13	Contact protectant
Rally (myclobutanil)	3	Systemic
Stylet-oil (paraffinic oil)	NC	Contact protectant
Torino (cyflufenamid)	U6	Contact protectant
Vivando (metrafenom)	U8	Contact protectant

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Surveying for resistance

- Swabbing PM from as many GA vineyards as possible
- Sending to Corvallis, Oregon USDA to test for QoI and DMI resistance

DMI

GA Swab Y136F Summary

Status	Total	%
Mutant Type	17	**23**
Wild Type	0	0
Mixed	58	**77**
Total	75	100

QoI

GA Swab G143A Summary

Status	Total	%
QoI resistant	75	**100**
QoI sensitive	0	0
Mix Sensitive/Resistant	0	0
Total	75	100

Blairsville Research Station 2019

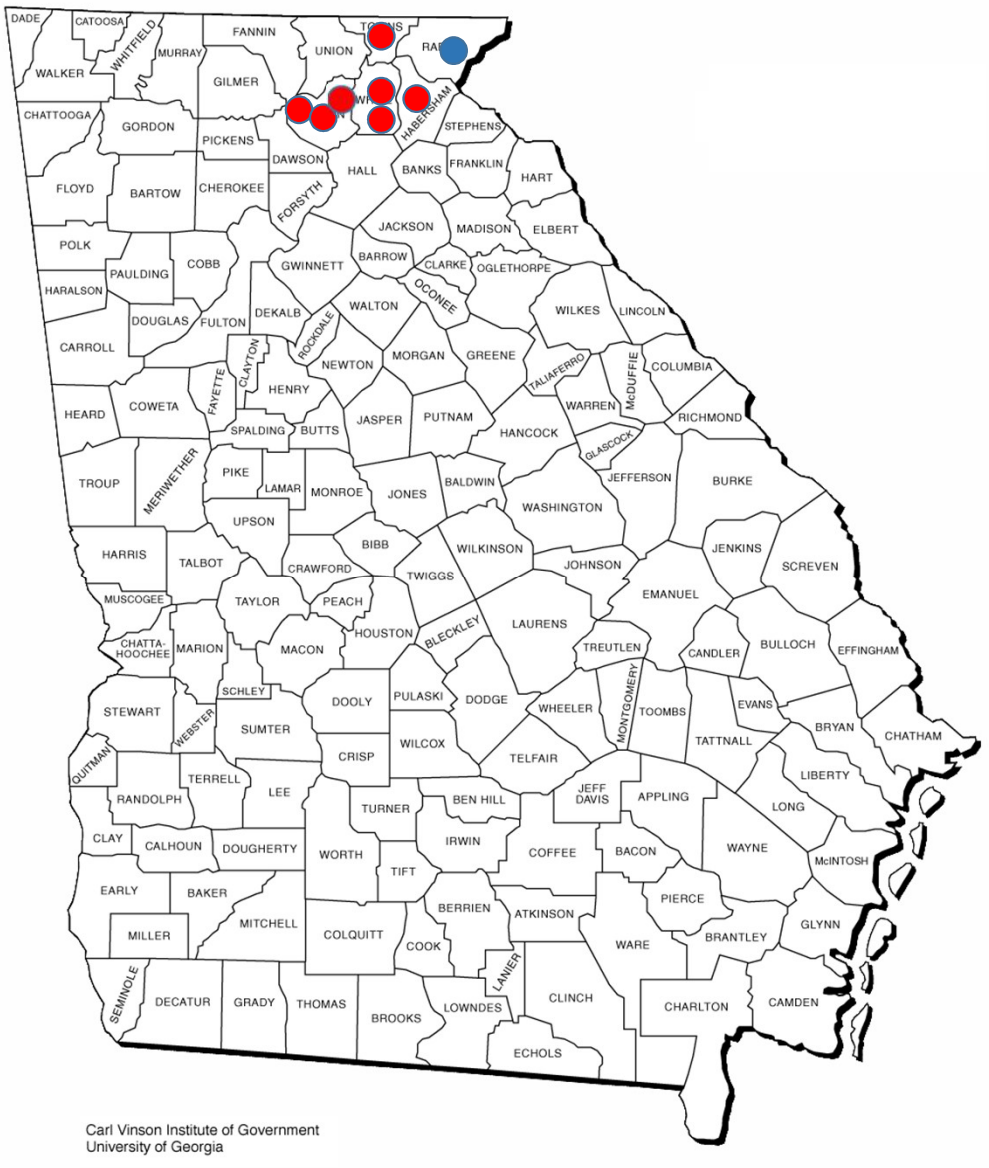
Purpose of Study

- Survey the wine grape (*Vitis vinifera*) growing region of Georgia for resistance development in GPM

- To assess the efficacy of several classes of fungicides registered to control GPM under Georgia conditions

2018

- Resistant
- Sensitive

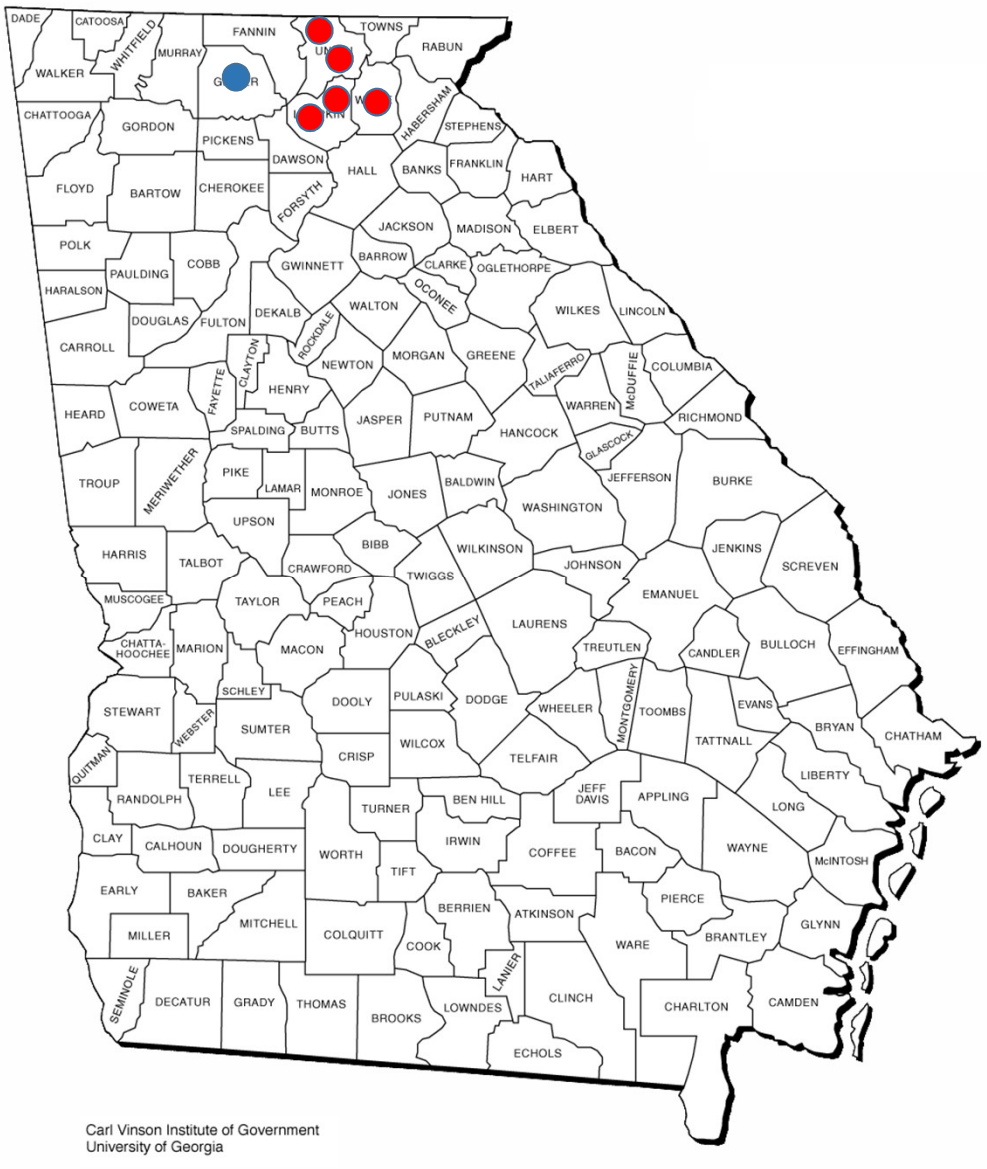


QoI

Group 11
Ex. Abound, Pristine

2019

- Resistant
- Sensitive

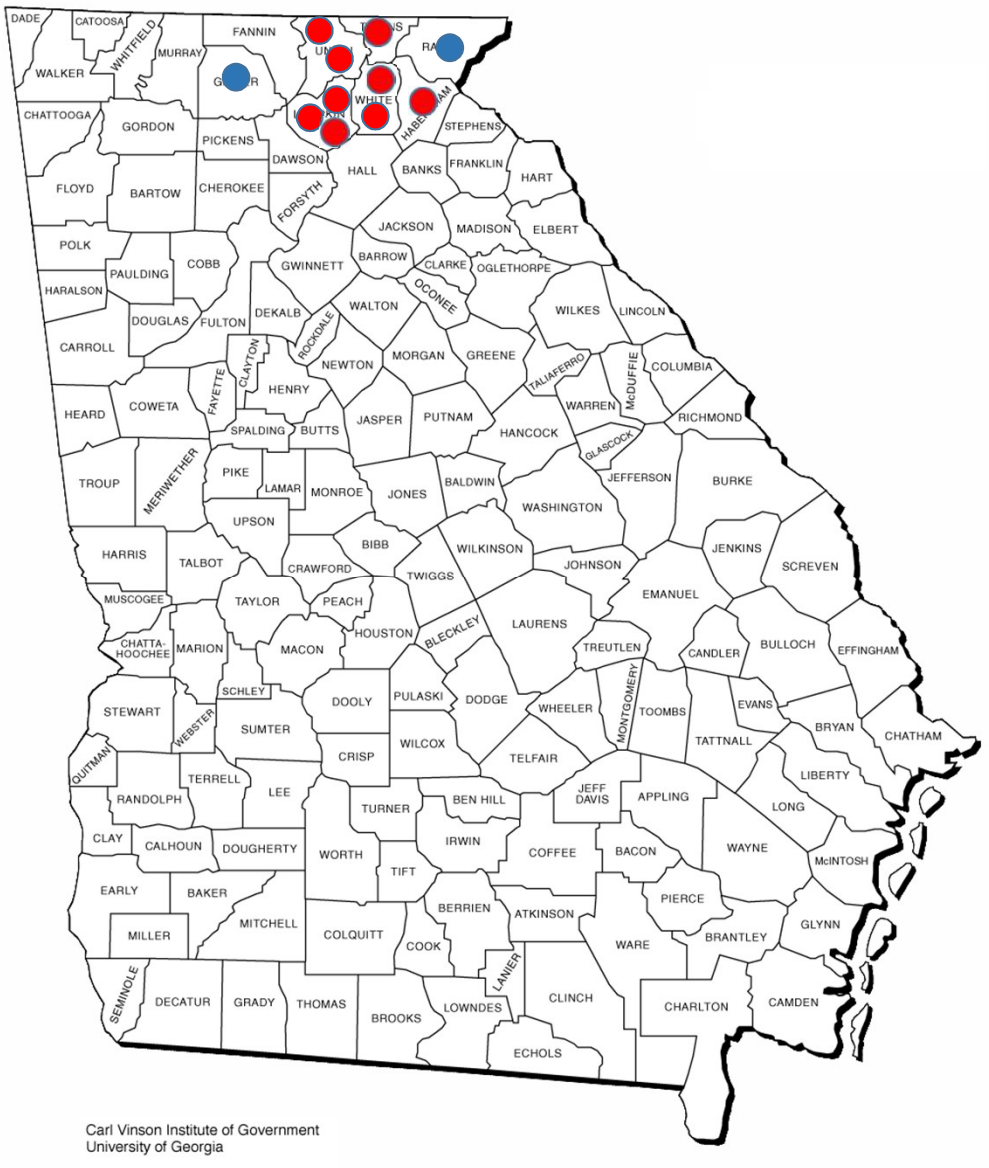


QoI

Group 11
Ex. Abound, Pristine

Current

- Resistant
- Sensitive



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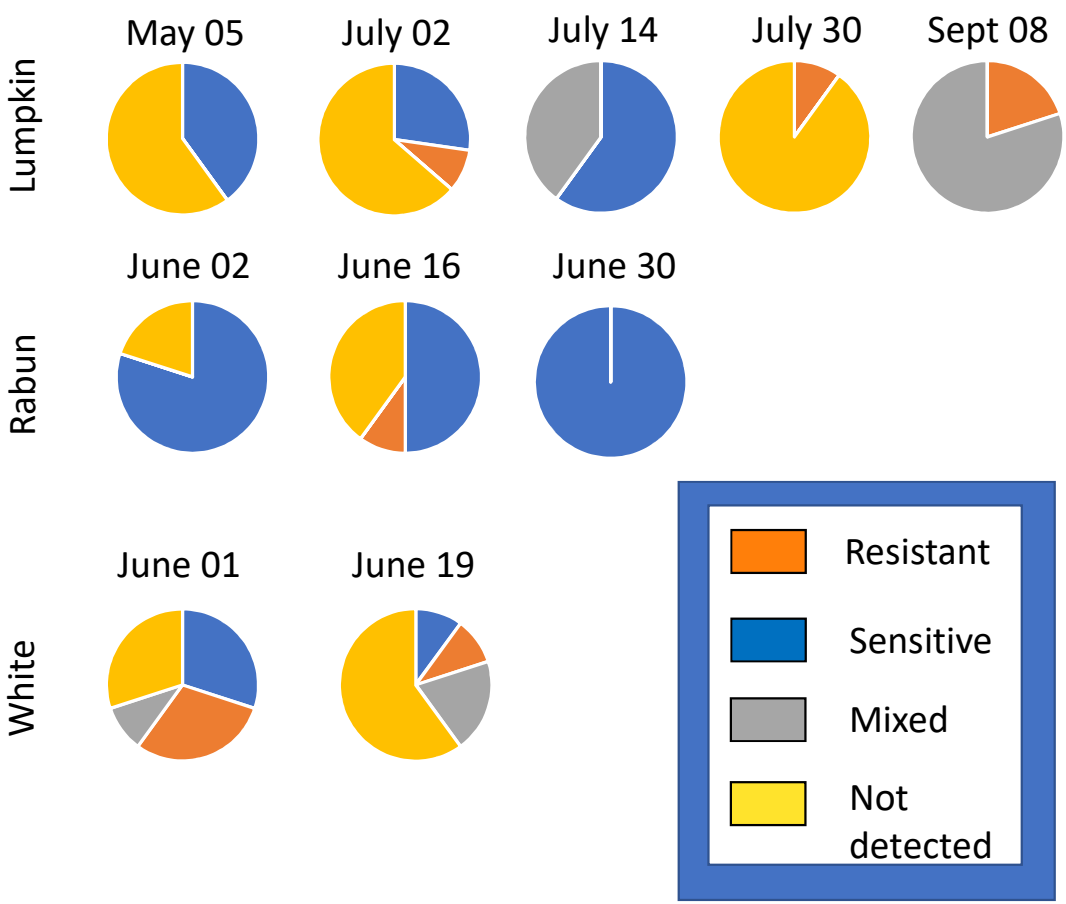
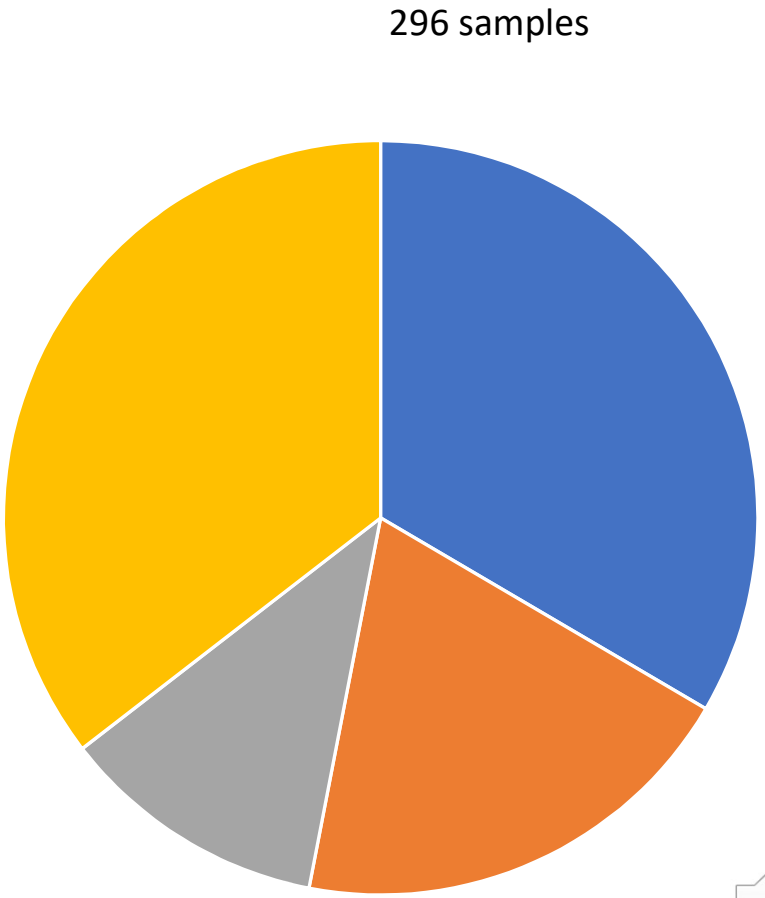
QoI

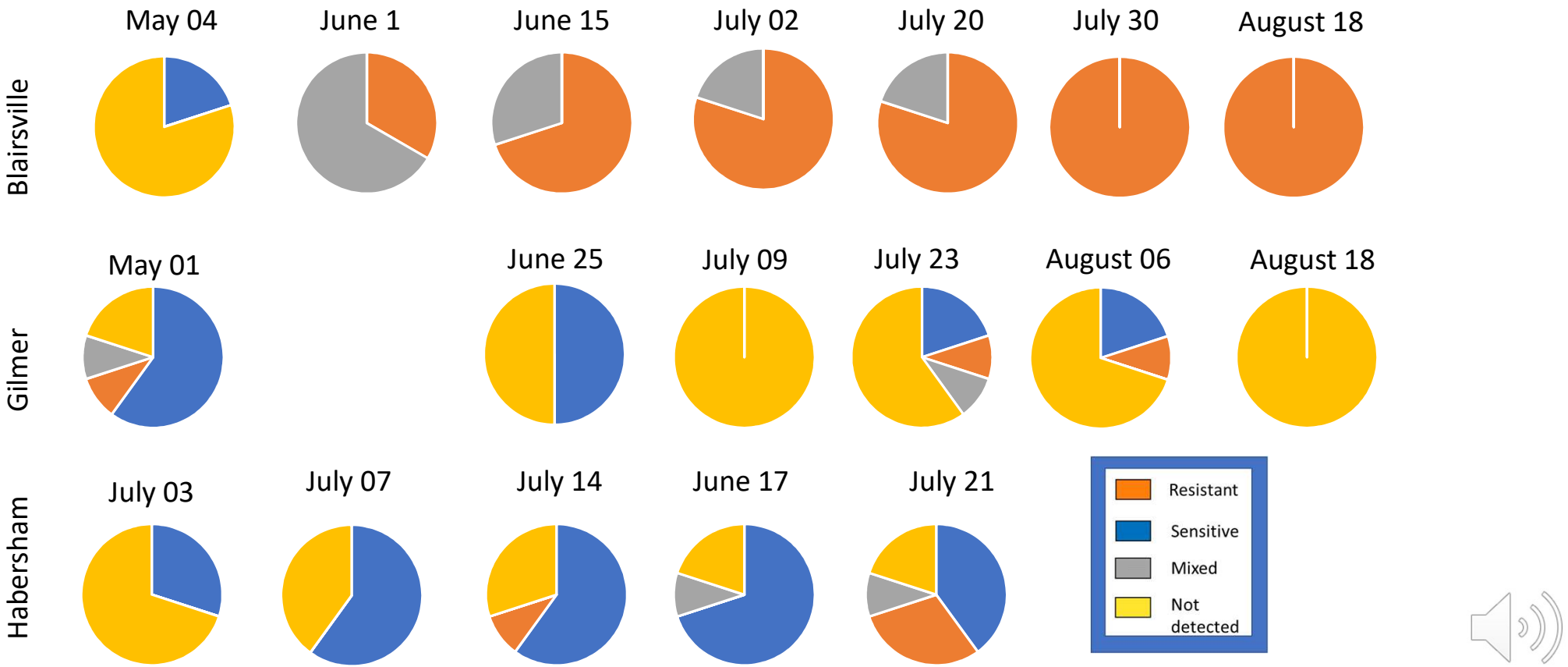
Group 11
Ex. Abound, Pristine

Georgia samples



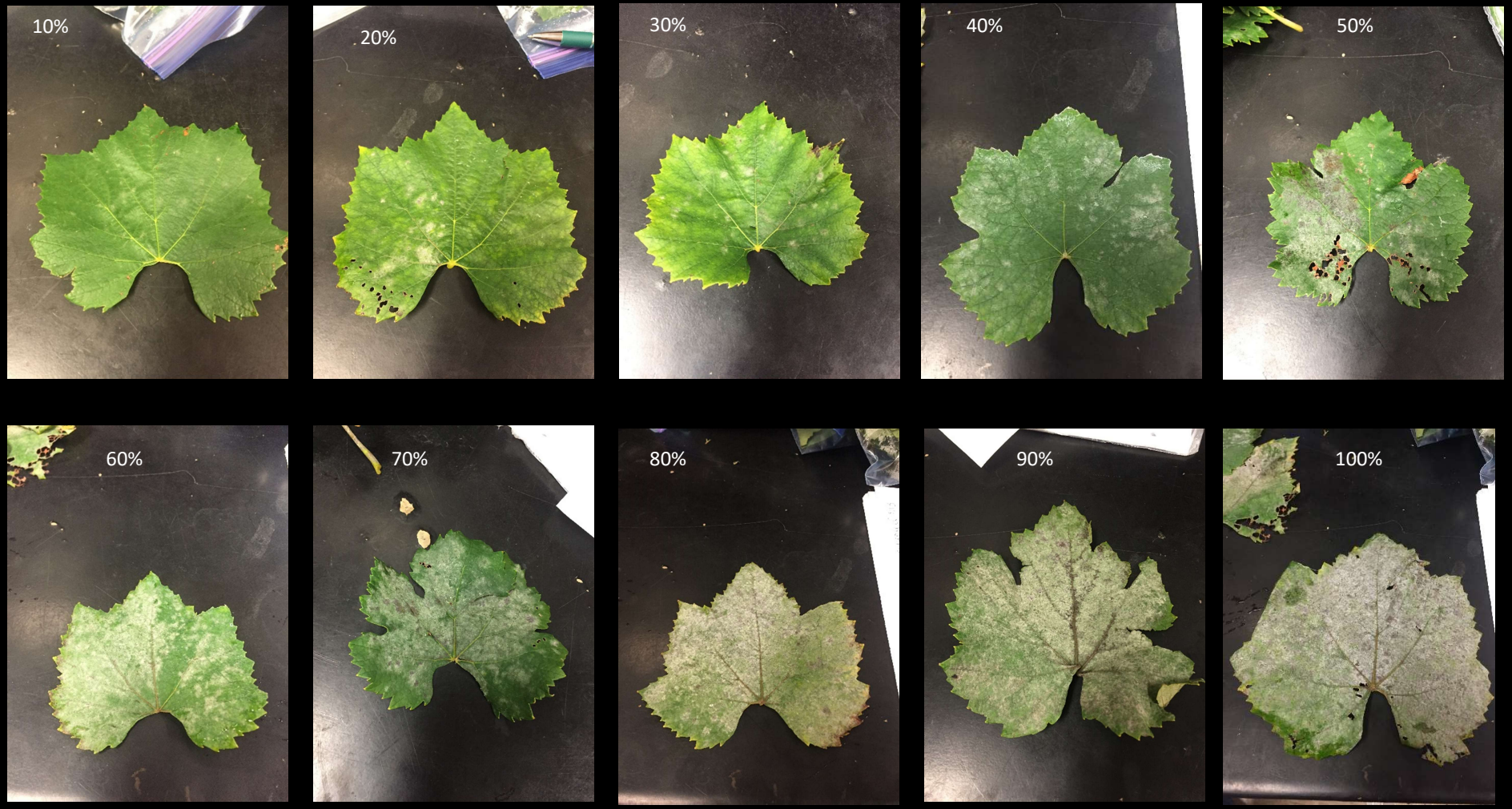


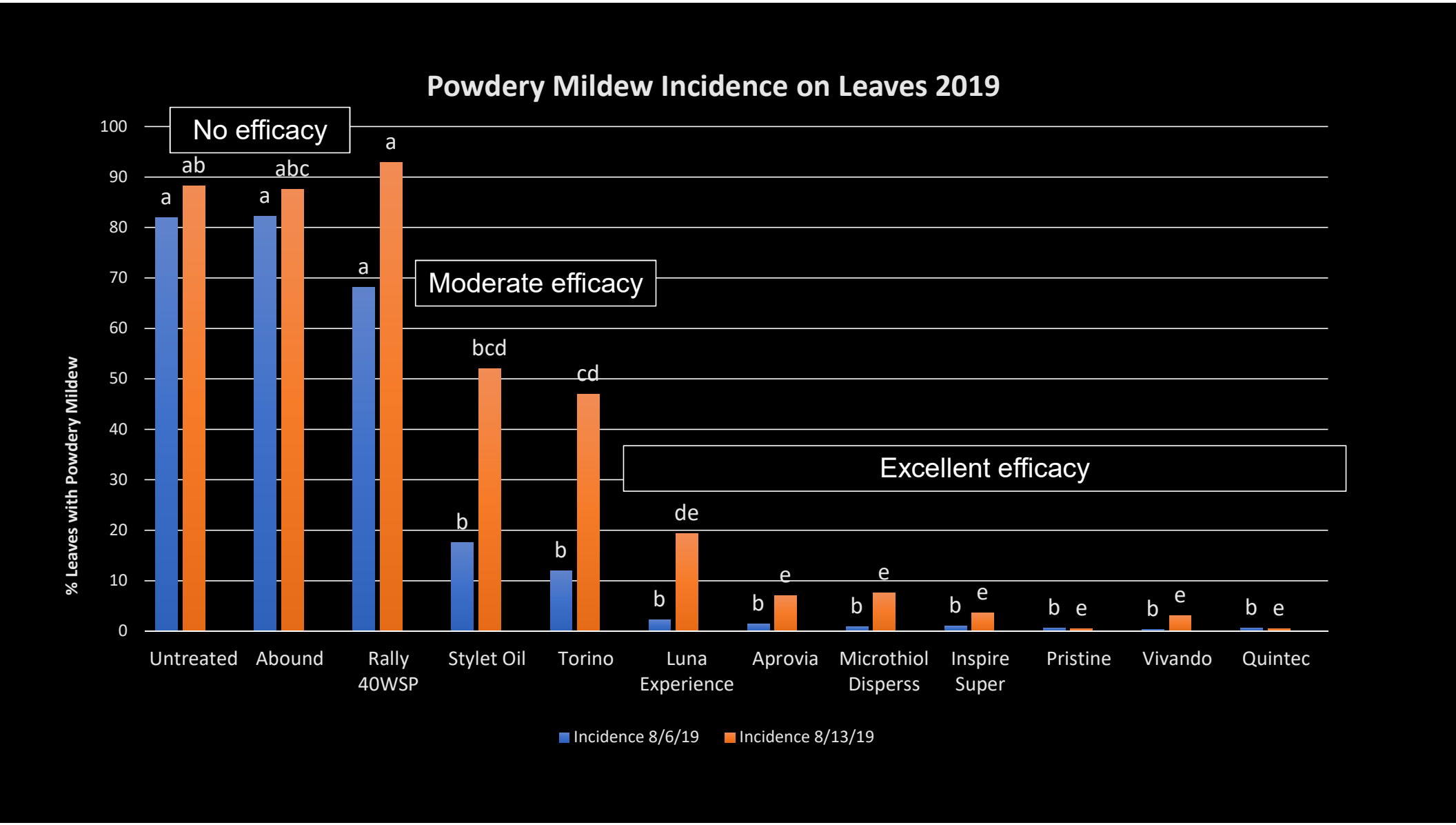
Georgia samples

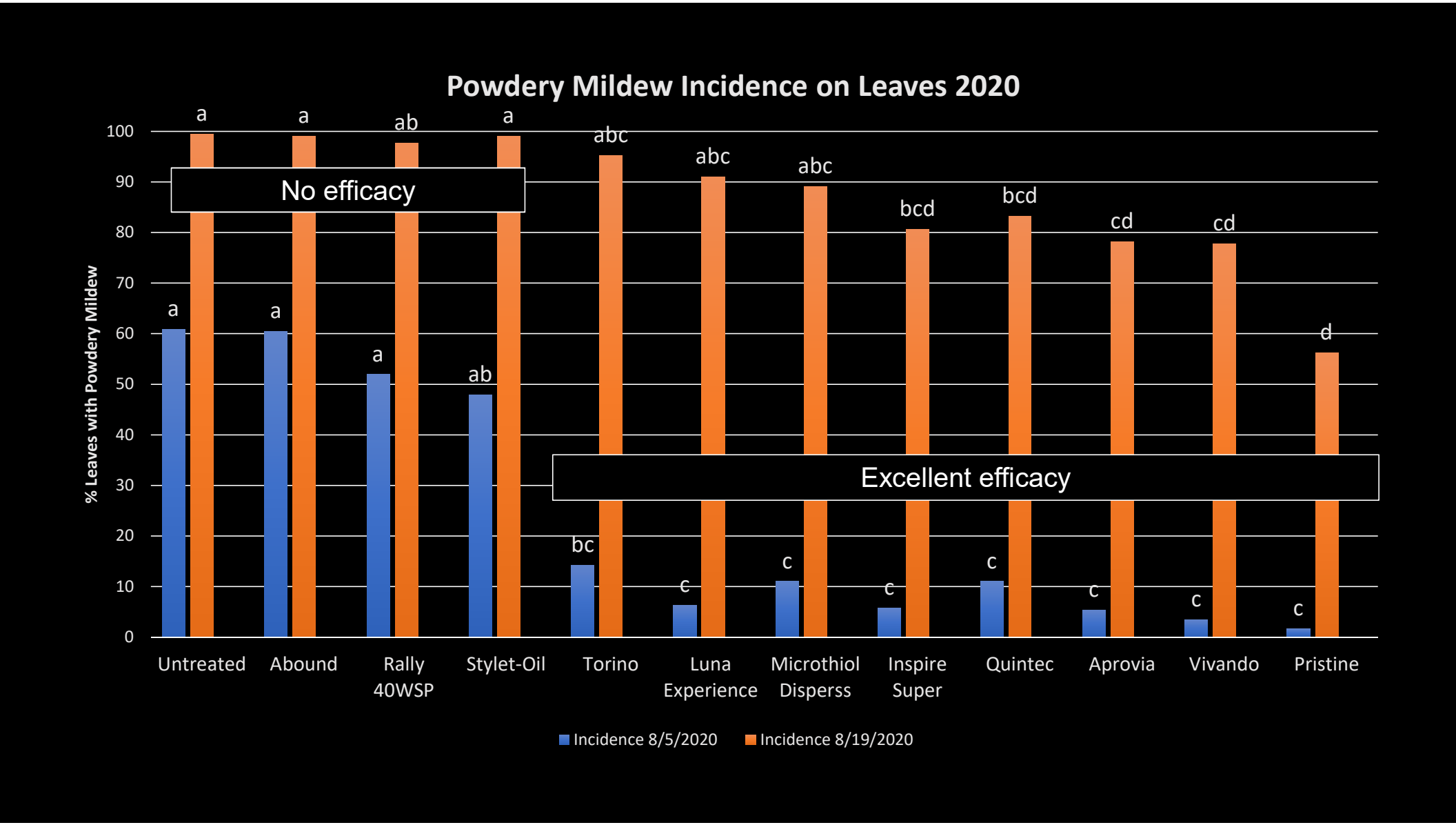


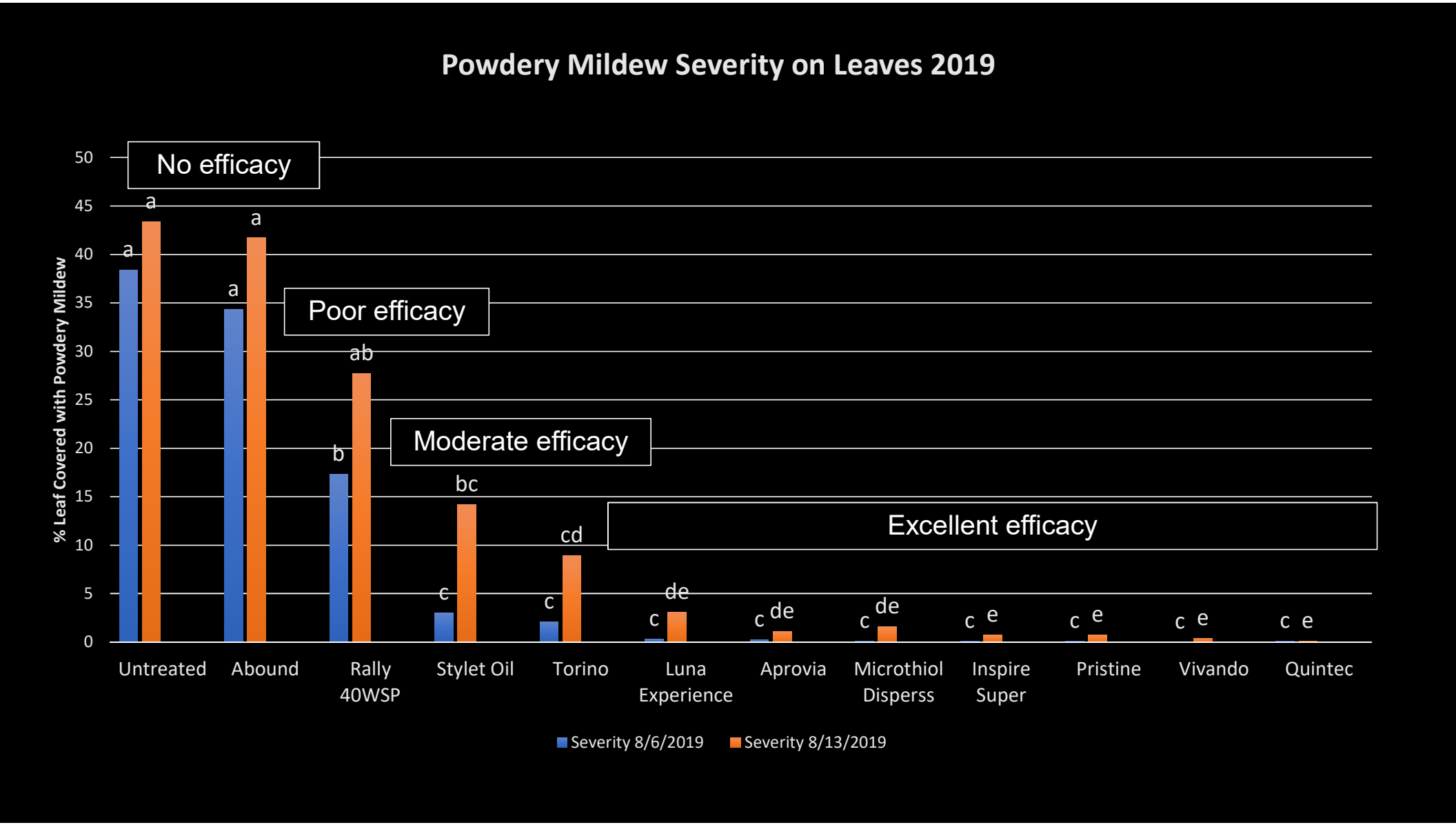
Experimental Design

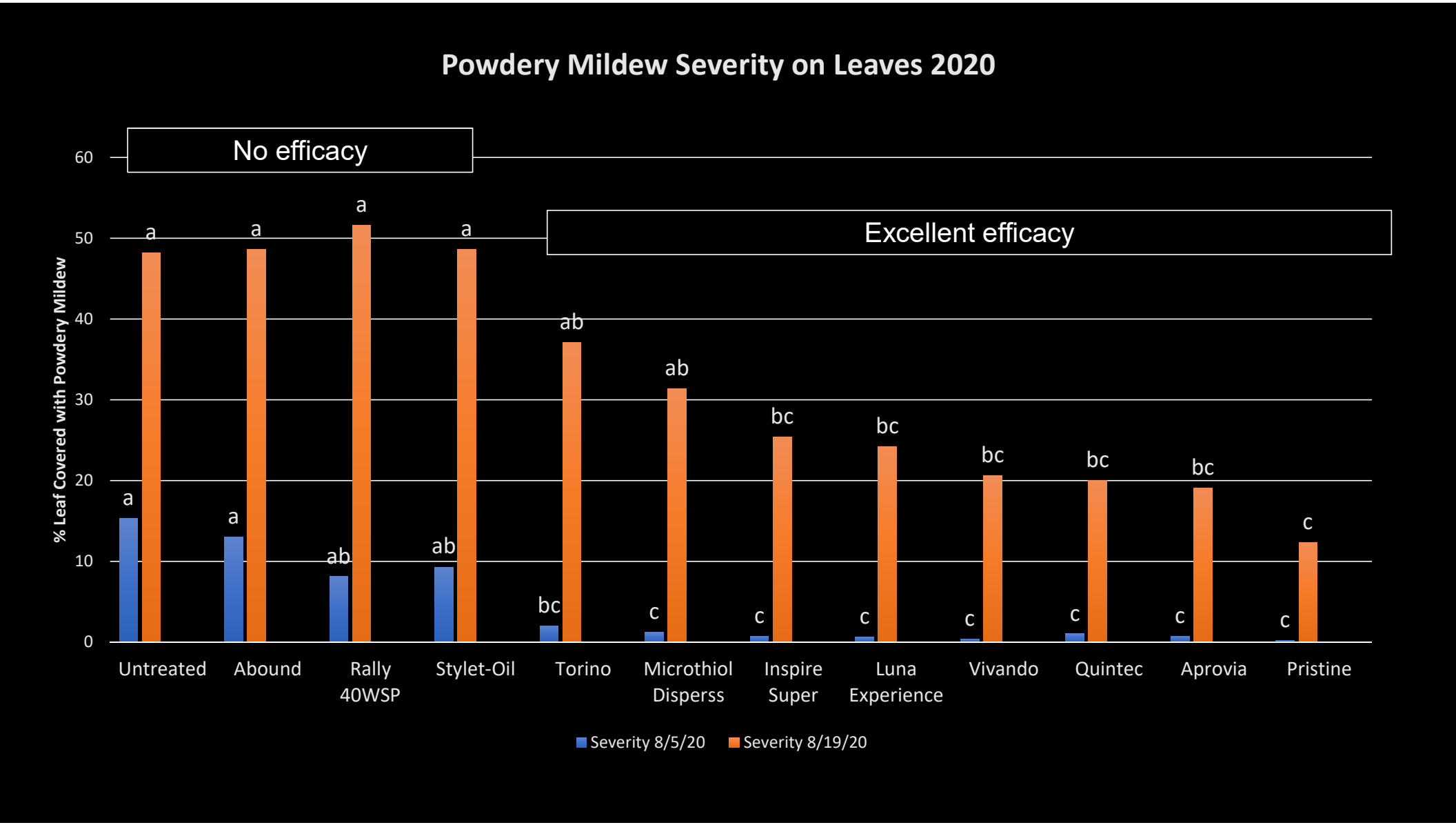
- Eleven different fungicides tested with various modes of action
- 5 replications per treatment applied with 2L CO2 sprayers at 50 gallon/acre spray volume; 6 applications from bloom to bunch closure
- Randomized complete block design
- UGA Mountain Research and Education Center in Blairsville, GA


10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


Powdery Mildew Incidence on Leaves 2019
No efficacy
Moderate efficacy
Excellent efficacy
% Leaves with Powdery Mildew
100
90
80
70
60
50
40
30
20
10
0
a
ab
a
abc
a
a
b
bcd
b
cd
b
de
b
e
b
e
b
e
b
e
b
e
b
e
Untreated
Abound
Rally 40WSP
Stylet Oil
Torino
Luna Experience
Aprovia
Microthiol Disperss
Inspire Super
Pristine
Vivando
Quintec
Incidence 8/6/19
Incidence 8/13/19


Powdery Mildew Incidence on Leaves 2020
% Leaves with Powdery Mildew
100
90
80
70
60
50
40
30
20
10
0
No efficacy
Excellent efficacy
a
a
ab
a
abc
abc
abc
bcd
bcd
cd
cd
d
a
a
a
ab
bc
c
c
c
c
c
c
c
Untreated
Abound
Rally 40WSP
Stylet-Oil
Torino
Luna Experience
Microthiol Disperss
Inspire Super
Quintec
Aprovia
Vivando
Pristine
Incidence 8/5/2020
Incidence 8/19/2020


Powdery Mildew Severity on Leaves 2019
% Leaf Covered with Powdery Mildew
50
45
40
35
30
25
20
15
10
5
0
No efficacy
Poor efficacy
Moderate efficacy
Excellent efficacy
a
a
a
a
b
ab
c
bc
c
cd
c
de
c
de
c
de
c
e
c
e
c
e
c
e
Untreated
Abound
Rally 40WSP
Stylet Oil
Torino
Luna Experience
Aprovia
Microthiol Disperss
Inspire Super
Pristine
Vivando
Quintec
Severity 8/6/2019
Severity 8/13/2019


Powdery Mildew Severity on Leaves 2020
No efficacy
Excellent efficacy
% Leaf Covered with Powdery Mildew
60
50
40
30
20
10
0
a
a
ab
ab
bc
c
c
c
c
c
c
c
a
a
a
a
ab
ab
bc
bc
bc
bc
bc
c
Untreated
Abound
Rally 40WSP
Stylet-Oil
Torino
Microthiol Disperss
Inspire Super
Luna Experience
Vivando
Quintec
Aprovia
Pristine
Severity 8/5/20
Severity 8/19/20

Field Trial Conclusions

- In our research vineyard, we found resistance to both QoIs and DMIs in *Erysiphe necator*
- QoIs = qualitative resistance; DMIs = quantitative resistance
- There are still many chemical classes that perform well in Georgia in the presence of resistance

Overall Resistance Conclusions

- Powdery mildew, downy mildew, and Botrytis are all likely resistant to strobilurins (ex. Abound, Pristine)
- DMI resistance is occurring in Georgia, but we are unsure of how widespread it is
- Be cautious of using DMIs to control powdery mildew (ex. Rally, Procure, Tebuconazole)
- Mix with sulfur to avoid potential management failure


Questions?