Integrated strategies for management of multiple diseases and fungicide resistance in strawberry

Natalia Peres
Professor, Plant Pathology
University of Florida
Gulf Coast Research and Education Center

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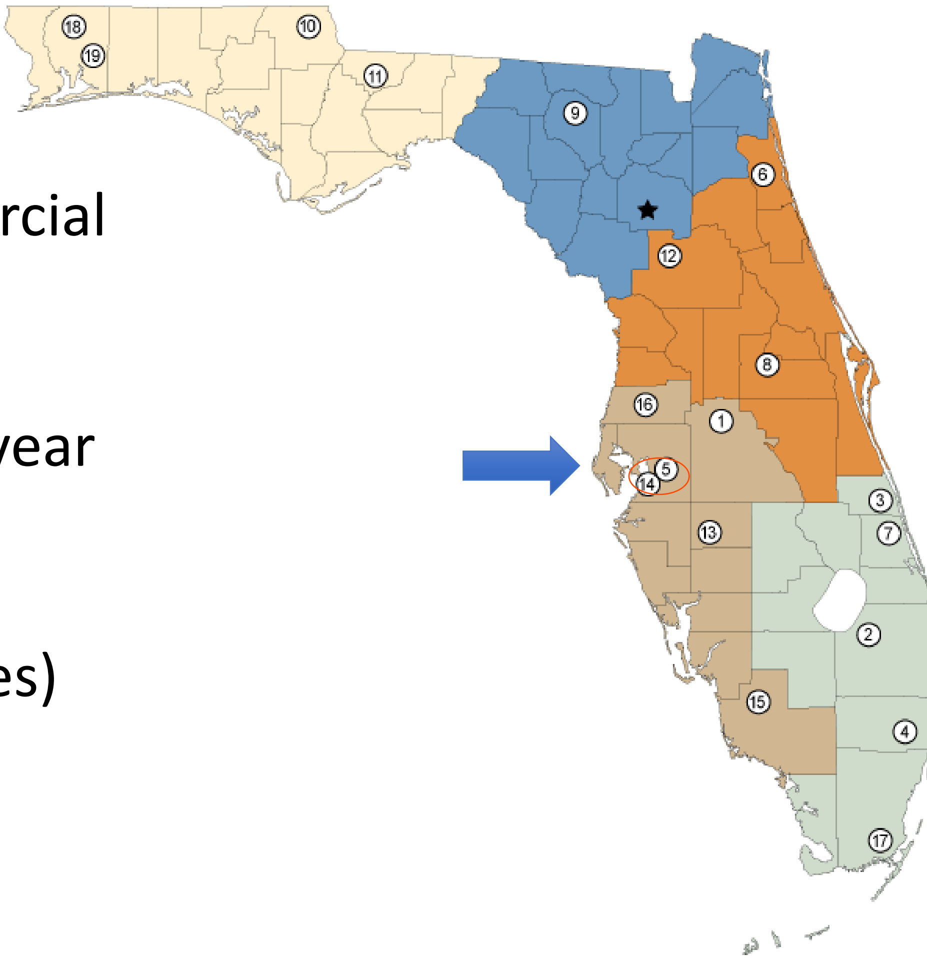
Strawberry is a high value, high risk crop

✓FL ~10,000 acres: 95% commercial production in Hillsborough Co.

✓High value: > US$300 million/year

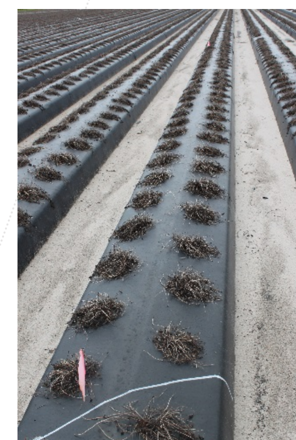
✓High investment: $30,000/ac!!
(average size farm ~20-30 acres)



Annual crop (investment) in FL

Overhead during plant establishment
and freeze protection
Drip irrigation otherwise

RESET



Peak harvest periods

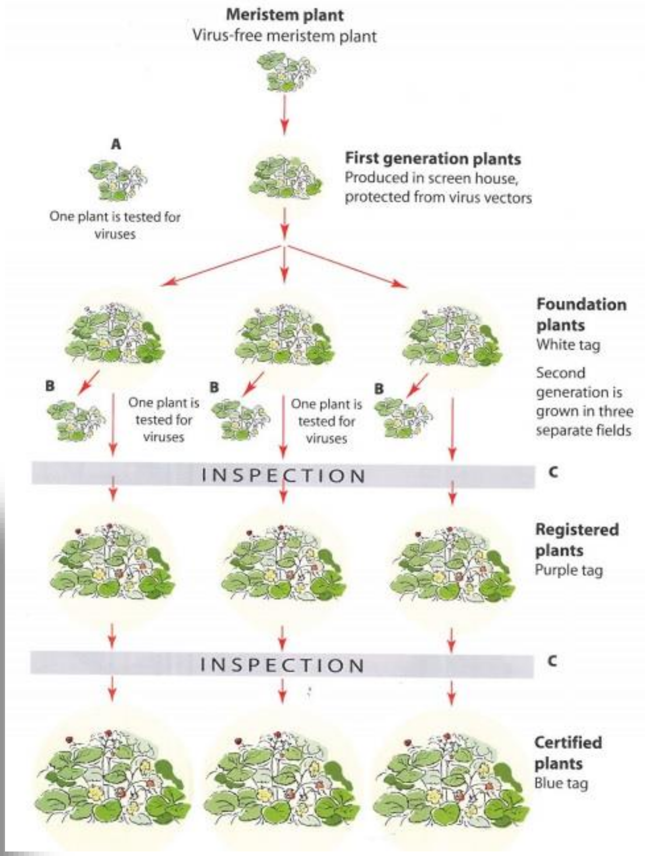
Land prep / planting

Peak bloom periods

Sept Oct Nov Dec Jan Feb Mar Apr

Transplants are produced far from fruit production fields (little control)

CA, NC, Canada



Many diseases introduced with transplants (High risk)

Fungal

Phytophthora crown rot

Phytophthora cactorum

Colletotrichum crown rot

Colletotrichum gloeosporioides

Charcoal rot

Macrophomina phaseolina

Botrytis fruit rot

Botrytis cinerea

Anthracnose fruit rot

Colletotrichum acutatum

Powdery mildew

Podosphaera aphanis

Pestalotia leaf and fruit rot

Neopestalotiopsis spp.

Bacterial

Angular Leaf Spot

Xanthomonas fragariae

Same single-site fungicides available for production fields and nurseries

	Fungicide
Active ingredient	**group**
thiophanate-methyl	1
iprodione	2
Propiconazole, tetraconazole, myclobutanil…	3
mefenoxam	4
penthiopyrad	7
isofetamid	7
pyrimethanil	9
azoxystrobin, pyraclostrobin, trifloxystrobin…	11
quinoxyfen	13
fenhexamid	17
fenhexamid + captan	17 + M4
fosetyl-Al, phosphites	33
azoxystrobin + propiconazole	3 + 11
fluoypram + pyrimethanil	7 + 9
fluxapyroxad + pyraclostrobin	7 + 11
cyprodinil + fludioxonil	9 + 12
cyflufenamid	U6
copper	M1
sulfur	M2
thiram	M3
captan	M4

Emergence of fungicide resistance to multiple fungicides and pathogens – *C. acutatum*

Resistance in Strawberry Isolates of *Colletotrichum acutatum* from Florida to Quinone-Outside Inhibitor Fungicides

Bruna B. Forcelini and **Teresa E. Seijo,** Gulf Coast Research and Education Center, University of Florida, Wimauma 33598; **Achour Amiri,** Tree Fruit Research and Extension Center, Washington State University, Wenatchee 98801; and **Natalia A. Peres,** Gulf Coast Research and Education Center, University of Florida

✓ **First detected during the 2013-14 season**

Fig. 2. Amino acid sequence alignment of the partial *cytochrome b* gene for *Colletotrichum acutatum* isolates from strawberry. A mutation at codon 129 from phenylalanine to leucine was observed for moderately resistant isolates 13-494 and 14-141. A mutation at codon 143 from glycine to alanine was observed for completely resistant isolates 13-466, 13-468, 13-471, 13-472, 13-473, 13-475, 13-479, 14-61, and 14-87. Isolates 98-1, 02-153, 02-159, 02-160, 02-179, 13-73, and 14-57 were sensitive and had no point mutation.

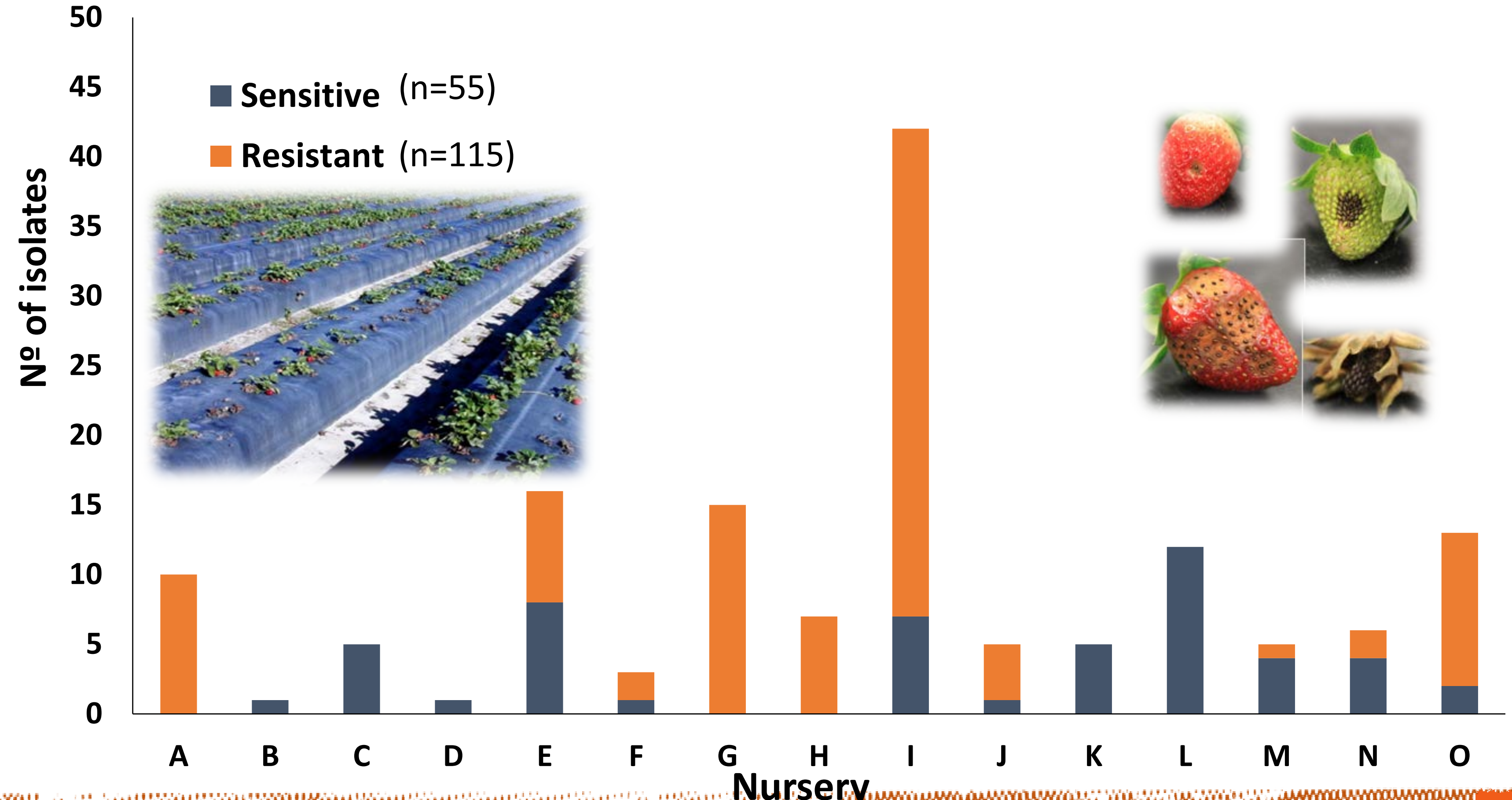
Resistant isolate

Sensitive isolate

Cross resistance among different strobirulin fungicides

Widespread Resistance to QoI Fungicides of *Colletotrichum acutatum* from Strawberry Nurseries and Production Fields

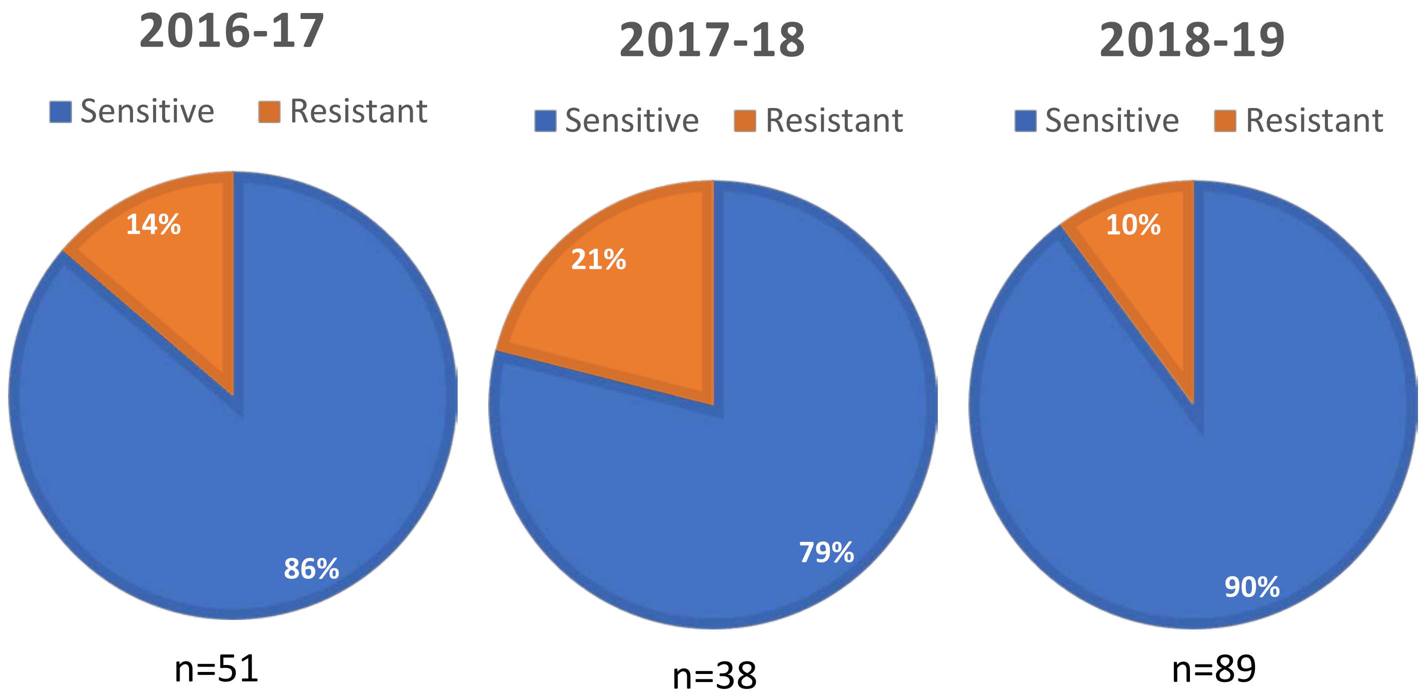
Bruna B. Forcelini and **Natalia A. Peres,**[†] University of Florida, Gulf Coast Research and Education Center, Wimauma, 33598



Resistant strains found in 10 of 15 nurseries sampled!

Emergence of fungicide resistance to multiple fungicides and pathogens – *P. cactorum*

Phytophthora cactorum resistance to FRAC 44 (mefenoxam)



Limited to 2 nursery sources

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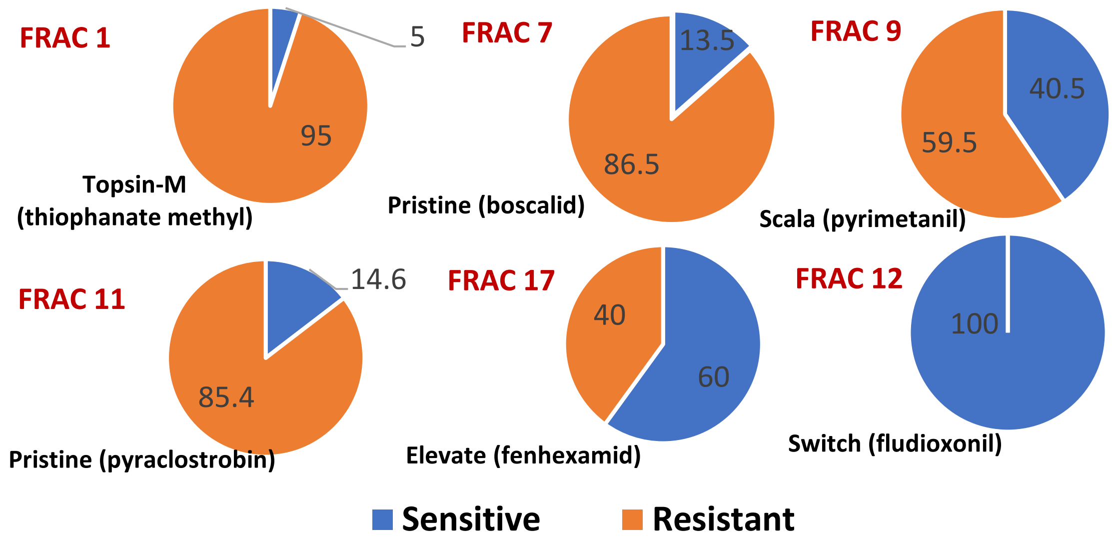
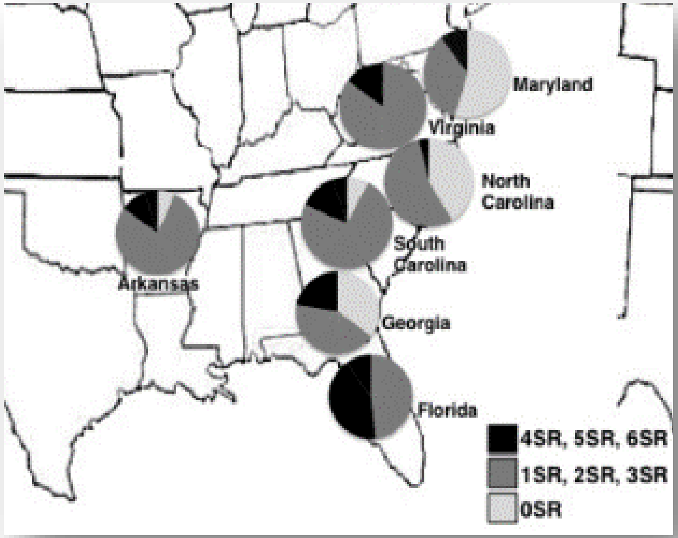
Fungicide Resistance in *Botrytis cinerea:* the *MRSA* of Plant Pathogens





Phenotypic Characterization of Multifungicide Resistance in *Botrytis cinerea* Isolates from Strawberry Fields in Florida

A. Amiri, S. M. Heath, and N. A. Peres, University of Florida, Gulf Coast Research and Education Center, Wimauma, FL 33598

Independent Emergence of Resistance to Seven Chemical Classes of Fungicides in *Botrytis cinerea*

Dolores Fernández-Ortuño, Anja Grabke, Xingpeng Li, and Guido Schnabel

Fenhexamid Resistance in *Botrytis cinerea* from Strawberry Fields in the Carolinas Is Associated with Four Target Gene Mutations

Anja Grabke, Dolores Fernández-Ortuño, and Guido Schnabel, School of Agricultural, Forest and Environme…
…son University, Clemson SC 29634

Resistance to Pyraclostrobin and Boscalid in *Botrytis cinerea* Isolates from Strawberry Fields in the Carolinas

Dolores Fernández-Ortuño, Fengping Chen, and Guido Schnabel, School of Agricultural, Forestry, and Life Sciences, Clem… University, Clemson SC 29634

Resistance to Cyprodinil and Lack of Fludioxonil Resistance in *Botrytis cinerea* Isolates from Strawberry in North and South Carolina

Dolores Fernández-Ortuño, Fengping Chen, and Guido Schnabel, School of Agricultural, Forestry & Life Sciences, Clemson University, Clemson, SC 29634

Location-Specific Fungicide Resistance Profiles and Evidence for Stepwise Accumulation of Resistance in *Botrytis cinerea*

Monitoring Resistance to SDHI Fungicides in *Botrytis cinerea* From Strawberry Fields

Meng-Jun Hu, Department of Agricultural and Environmental Sciences, Clemson University, Clemson, SC 29634; Dolore… Instituto de Hortofruticultura Subtropical y Mediterránea "La Mayora"-Universidad de Málaga-Consejo Superior de Inve… (IHSM-UMA-CSIC), Departamento de Microbiología, Campus de Teatinos, 29071 Málaga, Spain; and Guido Sch… Agricultural and Environmental Sciences, Clemson University

e-Xtra*

Diversity in the *erg27* Gene of *Botrytis cinerea* Field Isolates from Strawberry Defines Different Levels of Resistance to the Hydroxyanilide Fenhexamid

Achour Amiri and Natalia A. Peres, University of Florida, Gulf Coast Research and Education Center, Wimauma 33598

Characterization of Iprodione Resistance in *Botryt…* from Strawberry and Blackberry

Anja Grabke, Dolores Fernández-Ortuño, Achour Amiri, Xingpeng L… Natália A. Peres, Powell Smith, and Guido Schnabel

Fungicide Resistance Profiles in *Botrytis cinerea* from Strawberry Fields of Seven Southern U.S. States

Resistance to Fluopyram, Fluxapyroxad, and Penthiopyrad in *Botrytis cinerea* from Strawberry

Achour Amiri, Stacy M. Heath, and Natalia A. Peres, University of Florida, Gulf Coast Research and Education Center, Wimauma…

Resistance to Fludioxonil in *Botrytis cinerea* from Blackberry and Strawberry

Xingpeng Li, Dolores Fernández-Ortuño, Anja Grabke, and Guido S…

Sources of Primary Inoculum of *Botrytis cinerea* and Their Impact on Fungicide Resistance Development in Commercial Strawberry Fields

Michelle Souza Oliveira, Gulf Coast Research and Education Center, University of Florida, Wimauma 33598; **Achour Amiri,** Tree Fruit Research and Extension Center, Washington State University, Wenatchee 98801; and **Adrian I. Zuniga** and **Natalia A. Peres,**† Gulf Coast Research and Education Center, University of Florida, Wimauma 3598

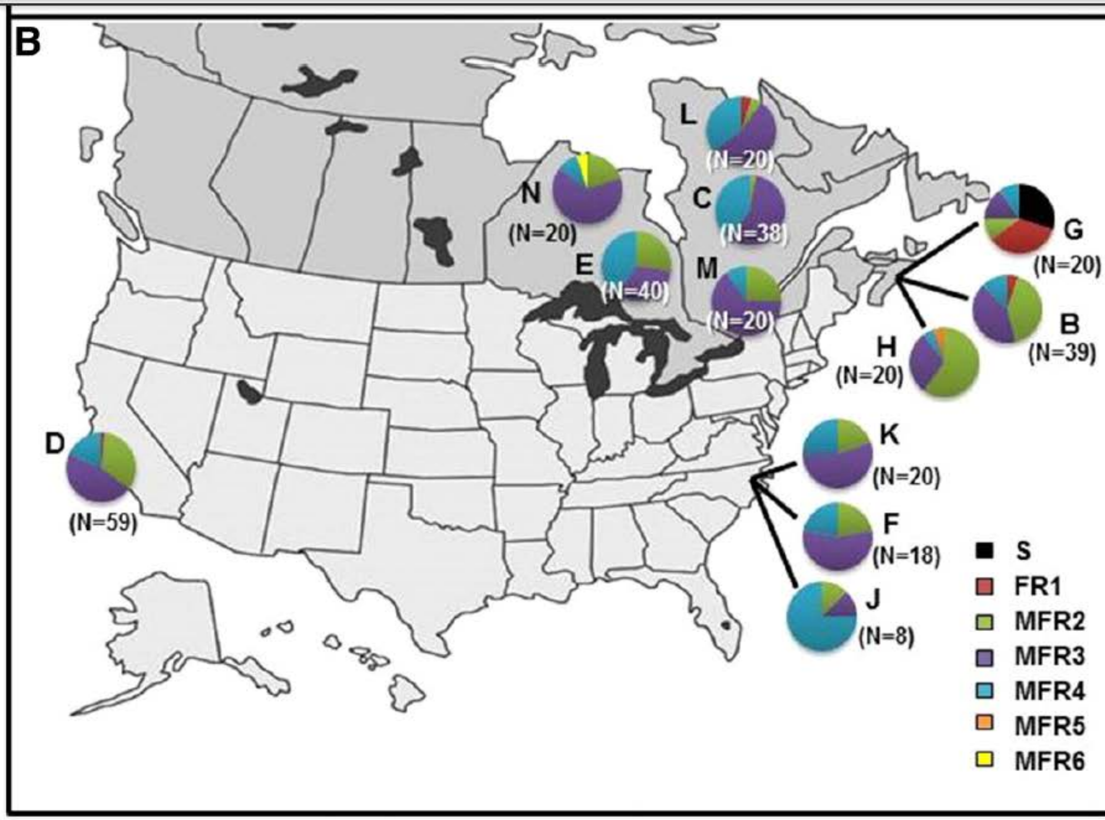


Fig. 2. Frequency of multifungicide resistance (MFR) phenotypes of *Botrytis cinerea* from strawberry transplants collected from different nurseries from California, North Carolina, Nova Scotia, Quebec, and Ontario in **A**, 2011-2012, and **B**, 2013. The fungicides tested were fenhexamid, pyrimethanil, pyraclostrobin, boscalid, fluopyram, penthiopyrad, iprodione, and fludioxonil (S = sensitive, FR1 = resistant to one fungicide, MFR2 = resistant to two fungicides, MFR3 = resistant to three fungicides, MFR4 = resistant to four fungicides, MFR5 = resistant to five fungicides, MFR6 = resistant to six fungicides). N is the number of isolates evaluated in each location. The letter next to each pie refers to the nursery code.

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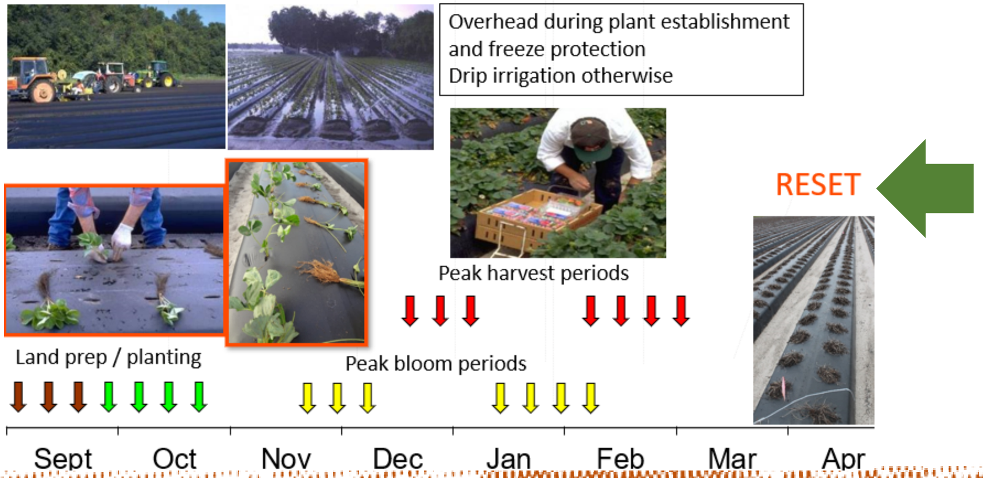
Many projects funded over the years with the overall goal:
Integrating Disease Management Across the Nursery and Fruit Production System

Angular leaf spot
(*Xanthomonas fragariae*)

Anthracnose
(*Colletotrichum acutatum*)

Gray mold
(*Botrytis cinerea*)

Powdery Mildew
(*Podosphaera aphanis*)



United States Department of Agriculture
National Institute of Food and Agriculture

FSREF

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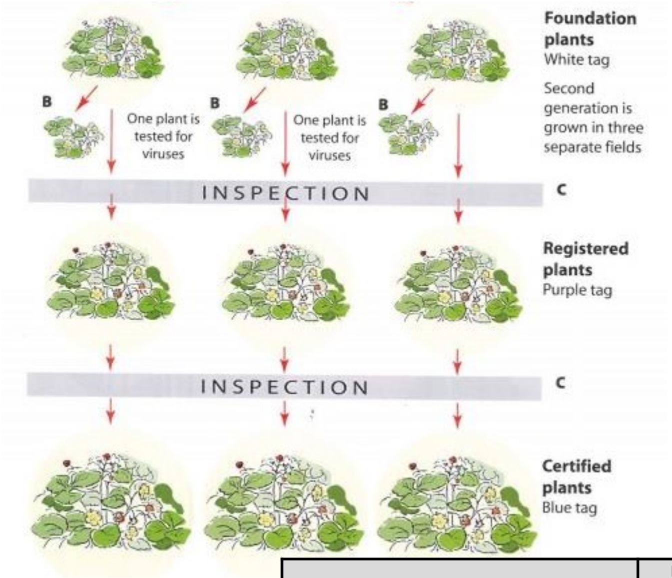
Break epidemic cycles while reducing number applications of single-site fungicides

- ✓Identify new chemical and/or biological products for nursery usage
- ✓Use single-sites only when needed – expand Strawberry Advisory System
- ✓Development of non-chemical management alternatives



Active ingredient	Fungicide group
thiophanate-methyl	1
iprodione	2
propiconazole, tetraconazole, myclobutanil…	3
mefenoxam	4
penthiopyrad	7
isofetamid	7
pyrimethanil	9
azoxystrobin, pyraclostrobin, trifloxystrobin…	11
quinoxyfen	13
fenhexamid	17
fenhexamid + captan	17 + M4
fosetyl-Al, phosphites	33
azoxystrobin + propiconazole	3 + 11
fluoypram + pyrimethanil	7 + 9
fluxapyroxad + pyraclostrobin	7 + 11
cyprodinil + fludioxonil	9 + 12
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copper	M1
sulfur	M2
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Break epidemic cycles while reducing number applications of single-site fungicides

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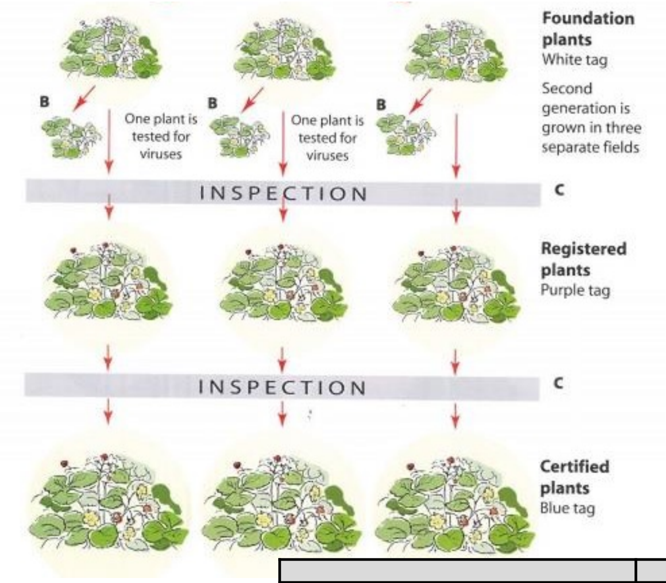

Active ingredient	Fungicide group
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iprodione	2
propiconazole, tetraconazole, myclobutanil…	3
mefenoxam	4
penthiopyrad	7
isofetamid	7
pyrimethanil	9
azoxystrobin, pyraclostrobin, trifloxystrobin…	11
quinoxyfen	13
fenhexamid	17
fenhexamid + captan	17 + M4
fosetyl-Al, phosphites	33
azoxystrobin + propiconazole	3 + 11
fluoypram + pyrimethanil	7 + 9
fluxapyroxad + pyraclostrobin	7 + 11
cyprodinil + fludioxonil	9 + 12
cyflufenamid	U6
copper	M1
sulfur	M2
thiram	M3
captan	M4

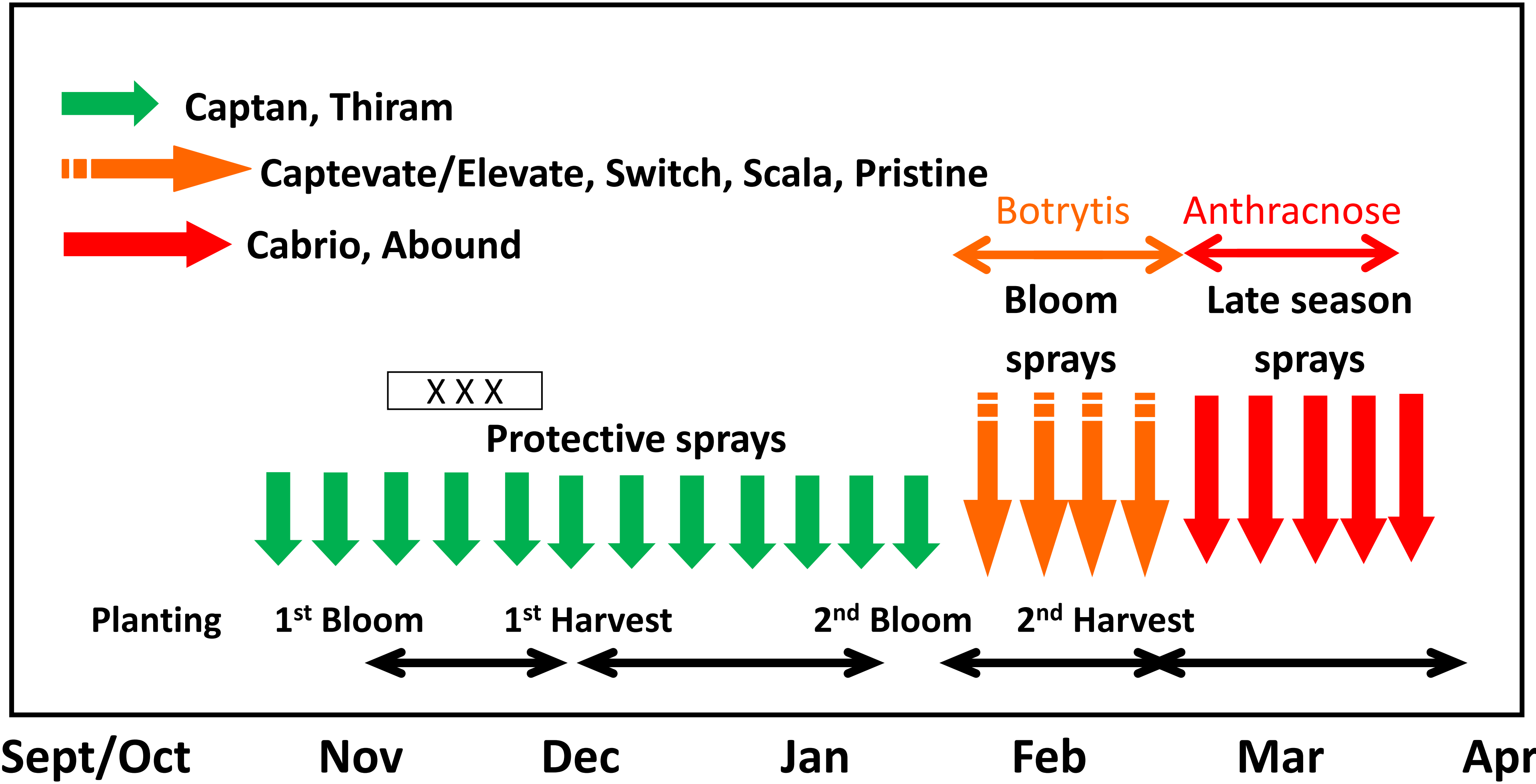
The Strawberry Advisory System

http://sas.agroclimate.org/fl/

A

B

Former recommendation for management of AFR and BFR in Florida ("Low risk")



Development of a Reduced Use Fungicide Program for Control of Botrytis Fruit Rot on Annual Winter Strawberry

D. E. Legard, S. J. MacKenzie, J. C. Mertely, C. K. Chandler, and **N. A. Peres,** University of Florida, Gulf Coast Research and Education Center, Dover, FL

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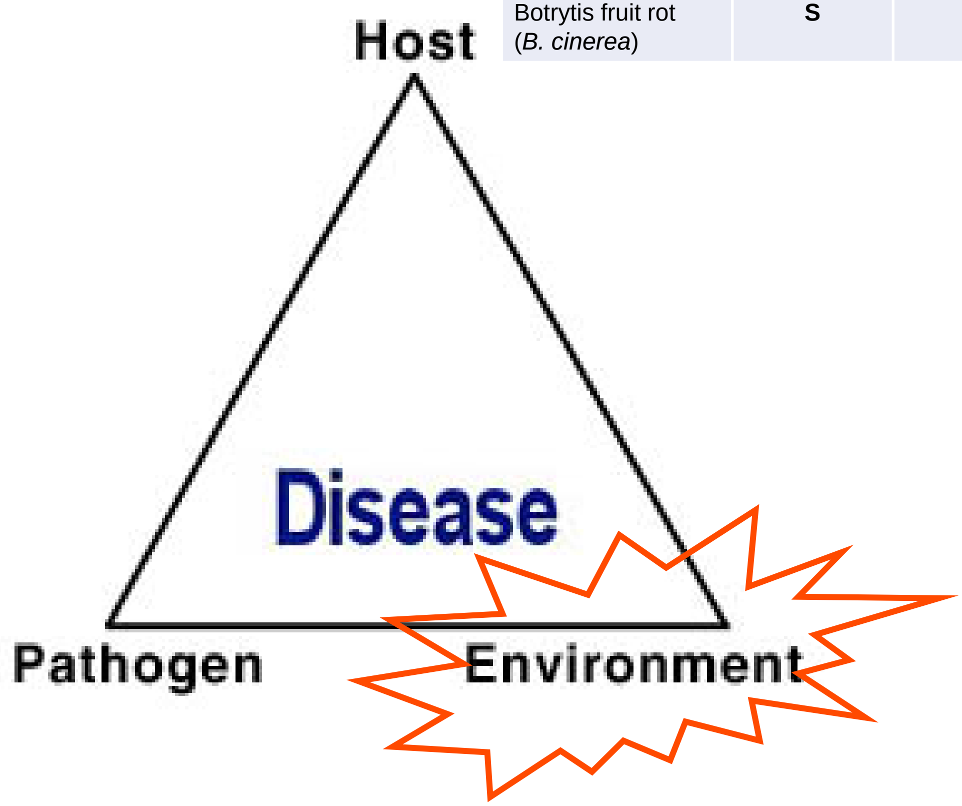
Disease triangle

Disease	Radiance	FL-127	FL Beauty	Brilliance
Anthracnose (*C. acutatum*)	**MR**	**R**	**MS**	**MR**
Botrytis fruit rot (*B. cinerea*)	**S**	**S**	**S**	**S**



Action thresholds were determined based on *disease infection* models

- ✓ Anthracnose: Wilson-Madden *INF* > 0.15; *INF* > 0.5

Use of Leaf Wetness and Temperature to Time Fungicide Applications to Control Anthracnose Fruit Rot of Strawberry in Florida

S. J. MacKenzie and N. A. Peres, University of Florida, Gulf Coast Research and Education Center, Wimauma 33598

- ✓ Botrytis: Bulger-Madden *DI* > 0.5; *DI* >0.7

Use of Leaf Wetness and Temperature to Time Fungicide Applications to Control Botrytis Fruit Rot of Strawberry in Florida

S. J. MacKenzie and N. A. Peres, University of Florida, Gulf Coast Research and Education Center, Wimauma 33598

- ✓Length of most recent wetness period
- ✓Average temperature during wetness event
- ✓Assumption inoculum is always present – low risk

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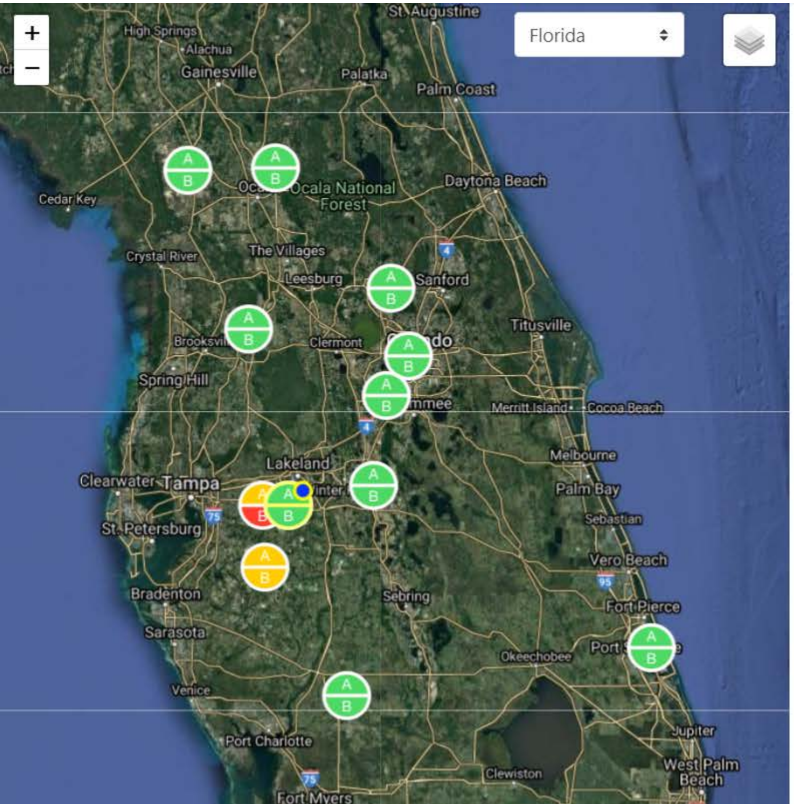
Key parameters monitored:
‘Leaf Wetness Duration’ and Temperature



DISEASE RISK | WEATHER | RECOMMENDATIONS

Date Interval 12/18/2021 - 01/17/2022

Export Table to CSV

Weather Table

Time	Temp (°F)	RH (%)	Rain (in)	Wet	LWD	Avg. Temp. LW	AII	BII
2022-01-17 20:45	49	93	0.00	Yes	2.25	52	**0.03** (Low)	**0.02** (Low)
2022-01-17 20:30	49	92	0.00	Yes	2.00	52	**0.03** (Low)	**0.02** (Low)
2022-01-17 20:15	50	91	0.00	Yes	1.75	53	**0.03** (Low)	**0.02** (Low)
2022-01-17 20:00	51	89	0.00	Yes	1.50	53	**0.03** (Low)	**0.02** (Low)
2022-01-17 19:45	52	87	0.00	Yes	1.25	54	**0.03** (Low)	**0.02** (Low)
2022-01-17 19:30	53	85	0.00	Yes	1.00	54	**0.03** (Low)	**0.02** (Low)
2022-01-17 19:15	54	83	0.00	Yes	0.75	54	**0.03** (Low)	**0.02** (Low)
2022-01-17 19:00	54	81	0.00	Yes	0.50	55	**0.03** (Low)	**0.02** (Low)
2022-01-17 18:45	55	79	0.00	Yes	0.25	55	**0.02** (Low)	**0.01** (Low)
2022-01-17 18:30	56	76	0.00	No	0.00	-	**0.00** (Low)	**0.00** (Low)

BFR High:

- ✓ 18 h LWD
- ✓ 17-25°C

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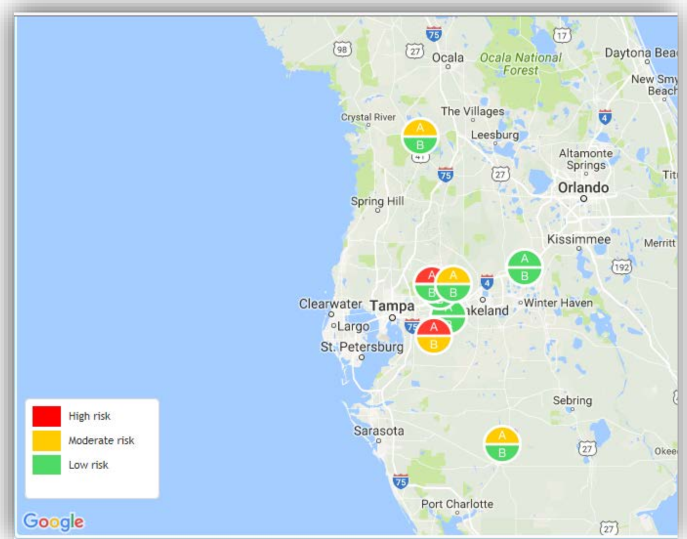
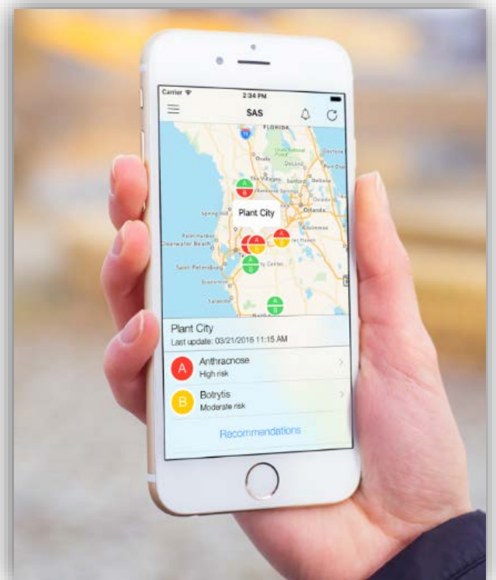
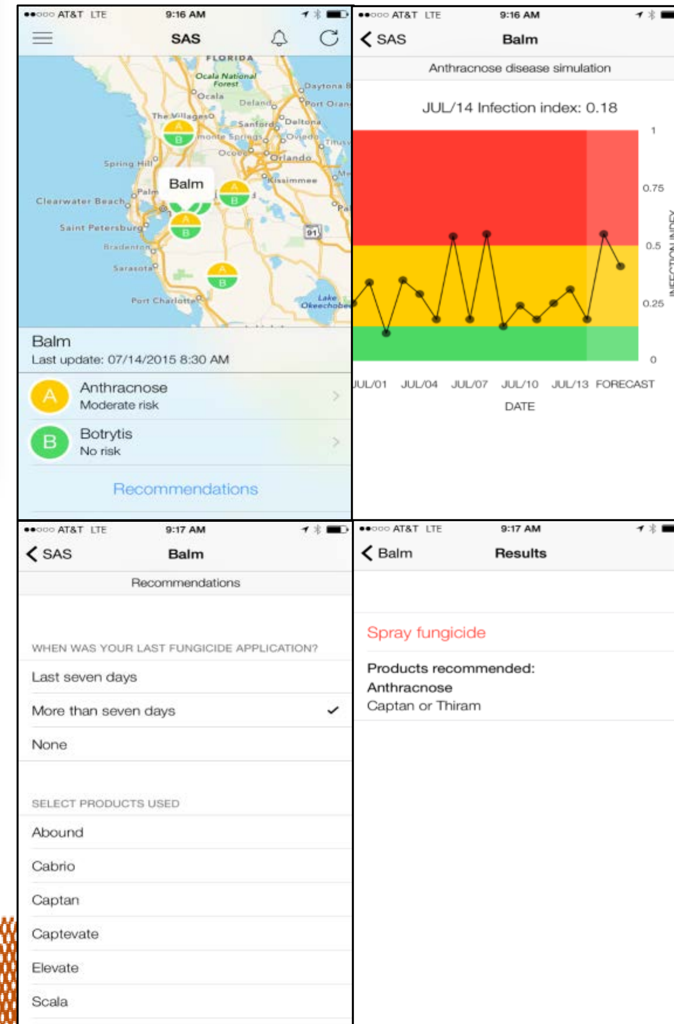
Timely alerts: Web, Email and SMS, App





SAS app



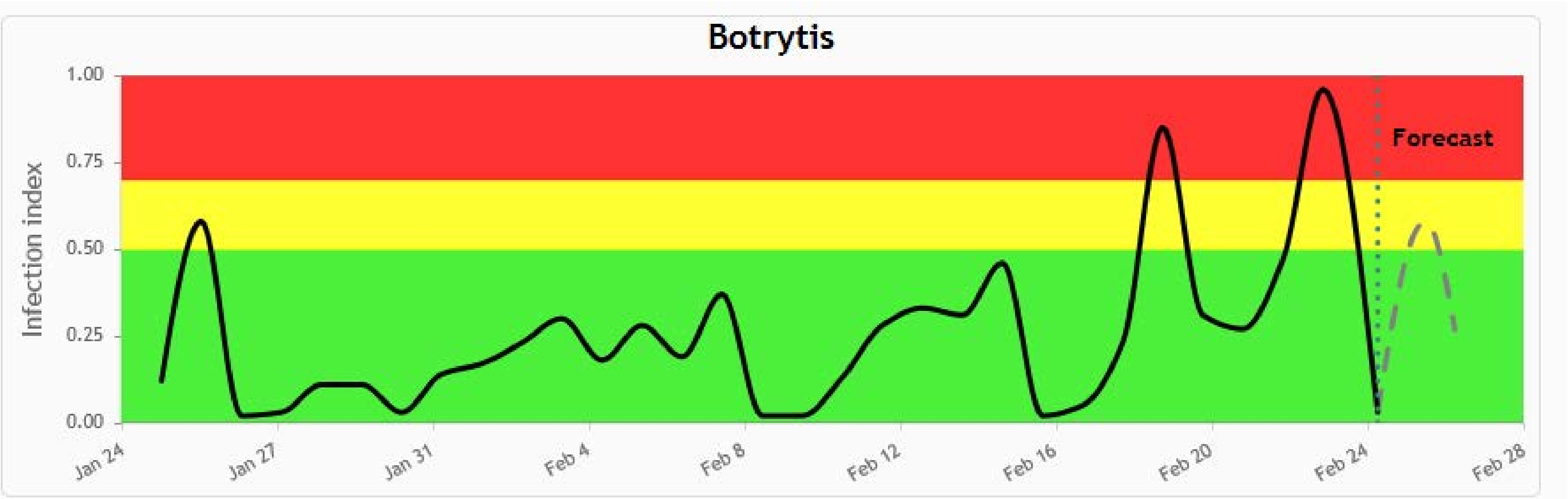
From: alerts@agroclimate.org
To: Peres,Natalia A R
Cc:
Subject: Strawberry Disease Alert

Strawberry Disease Alert

Station: Plant City
Botrytis: Moderate Risk
Anthracnose: Moderate Risk

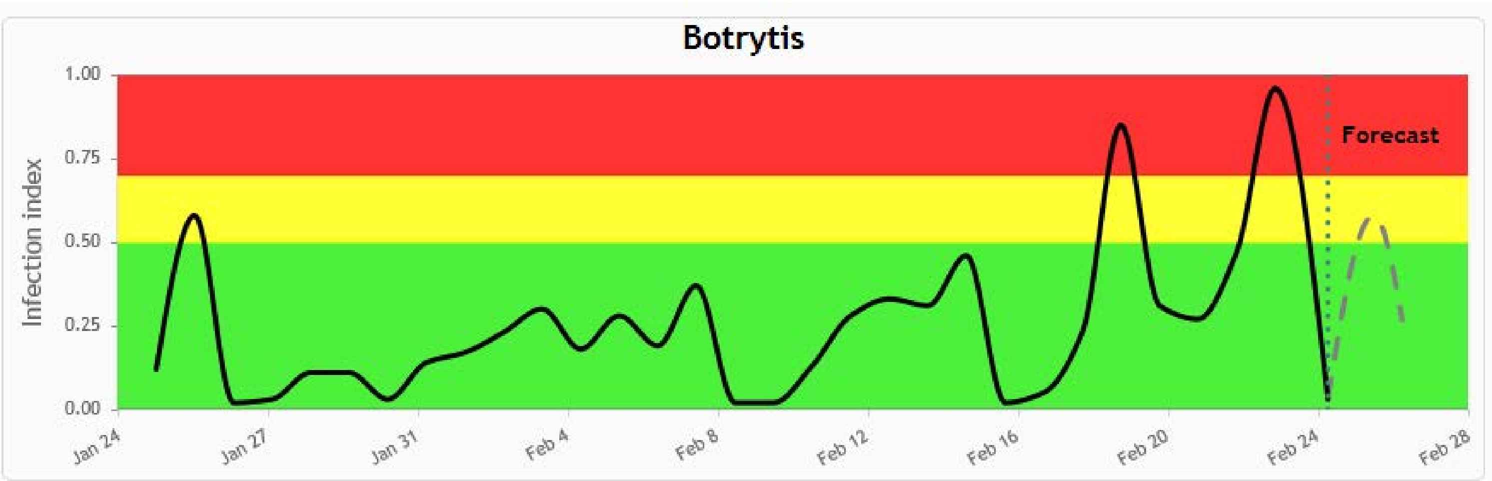
For more information check the Strawberry Disease Tool: http://agroclimate.org/tools/strawberry/

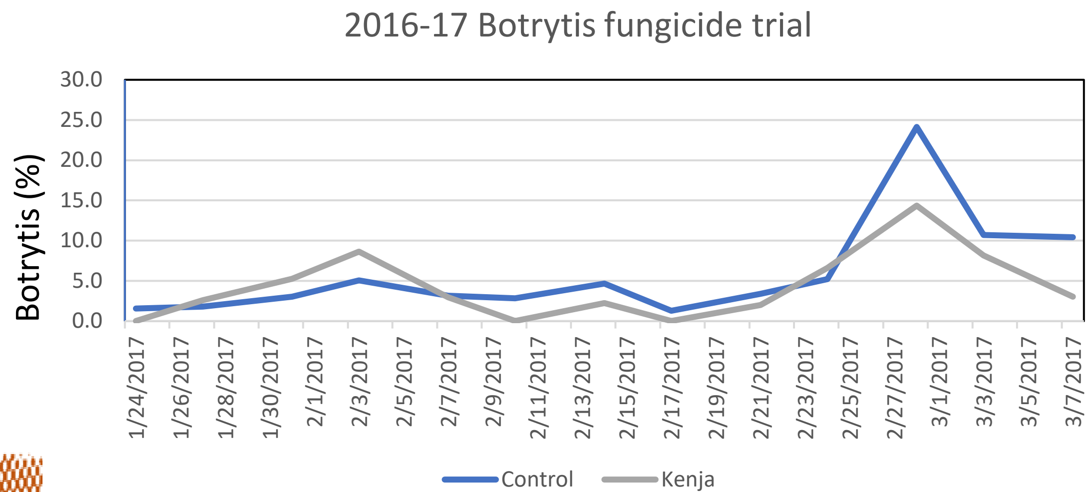
Goal to reduce number of single-site fungicide applications in periods of good weather



Particularly important these days since only a few fungicide products still effective

Even best fungicide not as good as good weather!!





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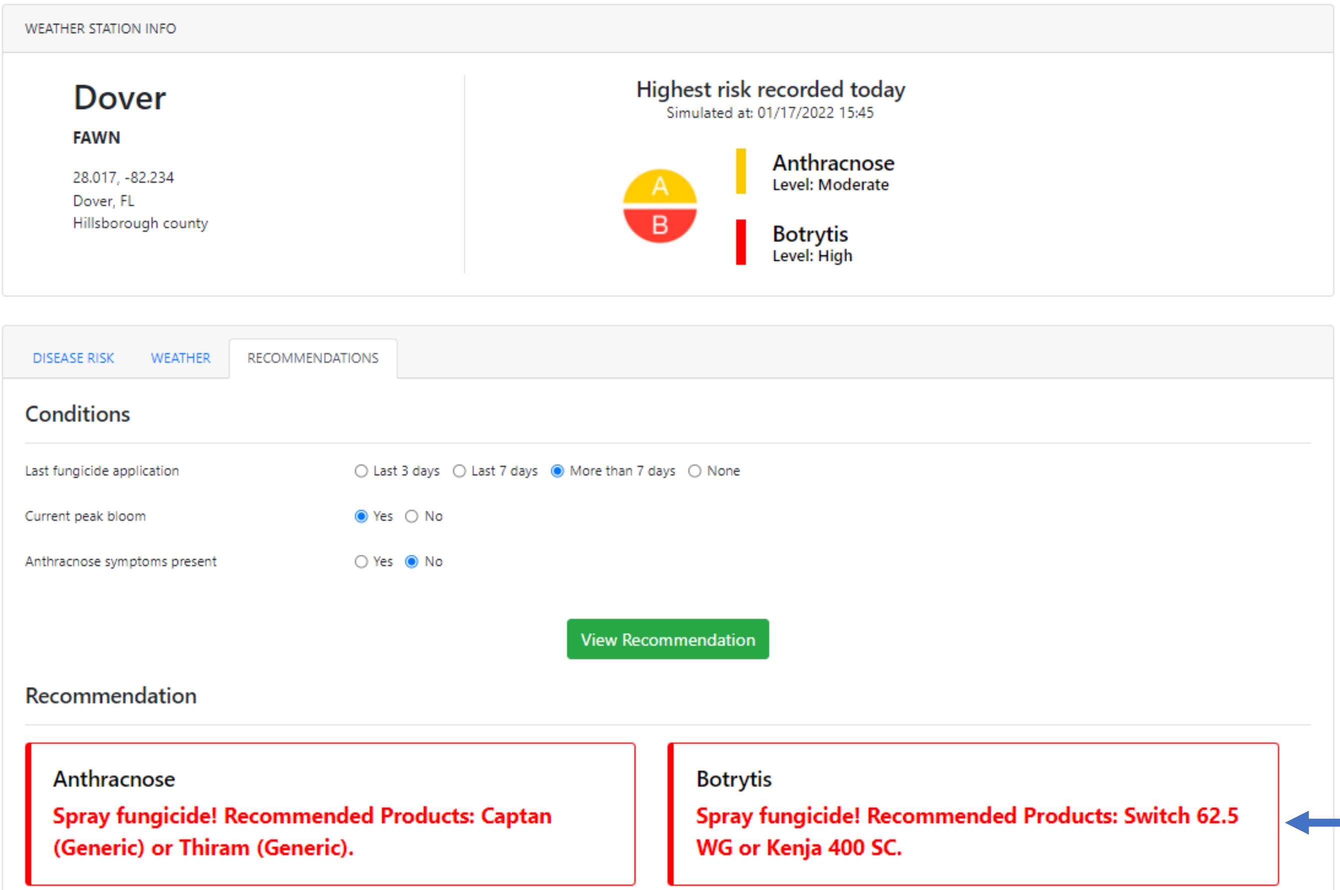
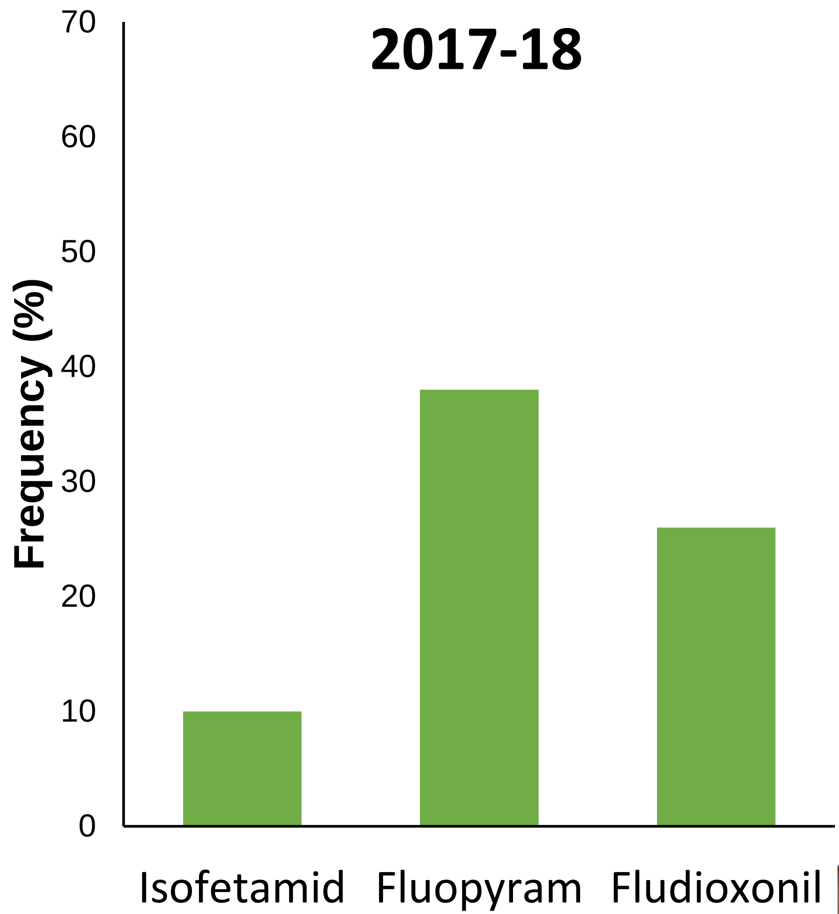
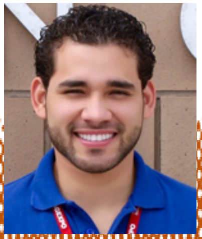
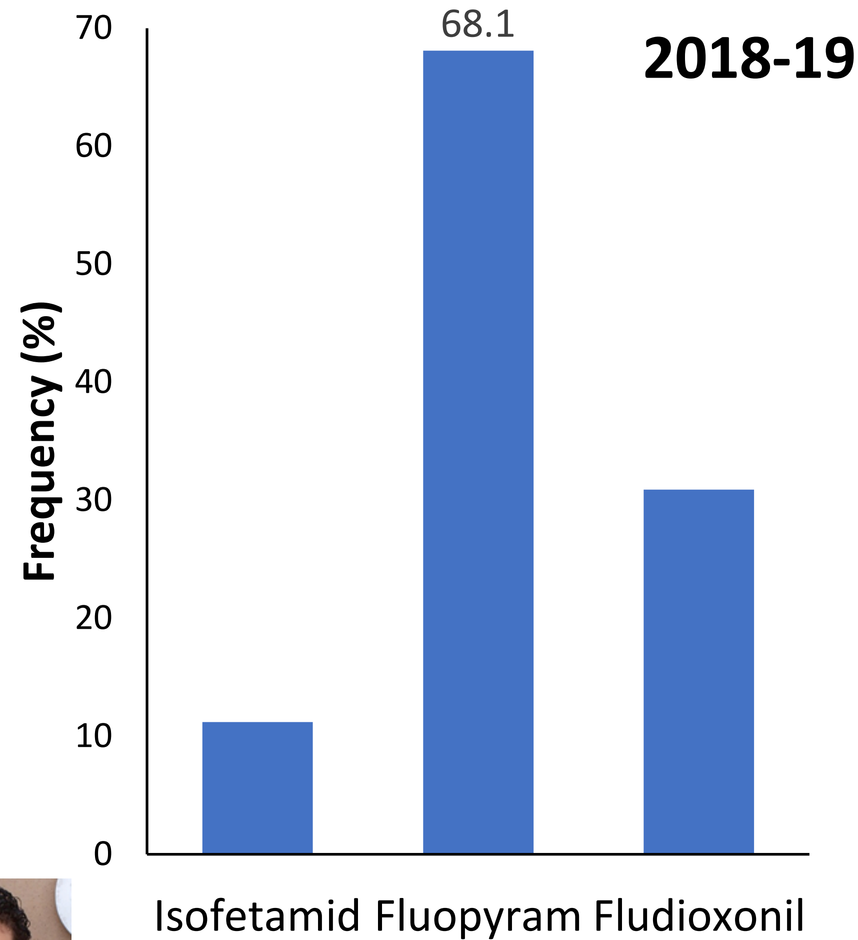
Fungicide Resistance / Wrong Fungicide Selection lead to incorporation of specific fungicide spray recommendation in the SAS



Continued monitoring for *Botrytis* fungicide resistance to adjust recommendations





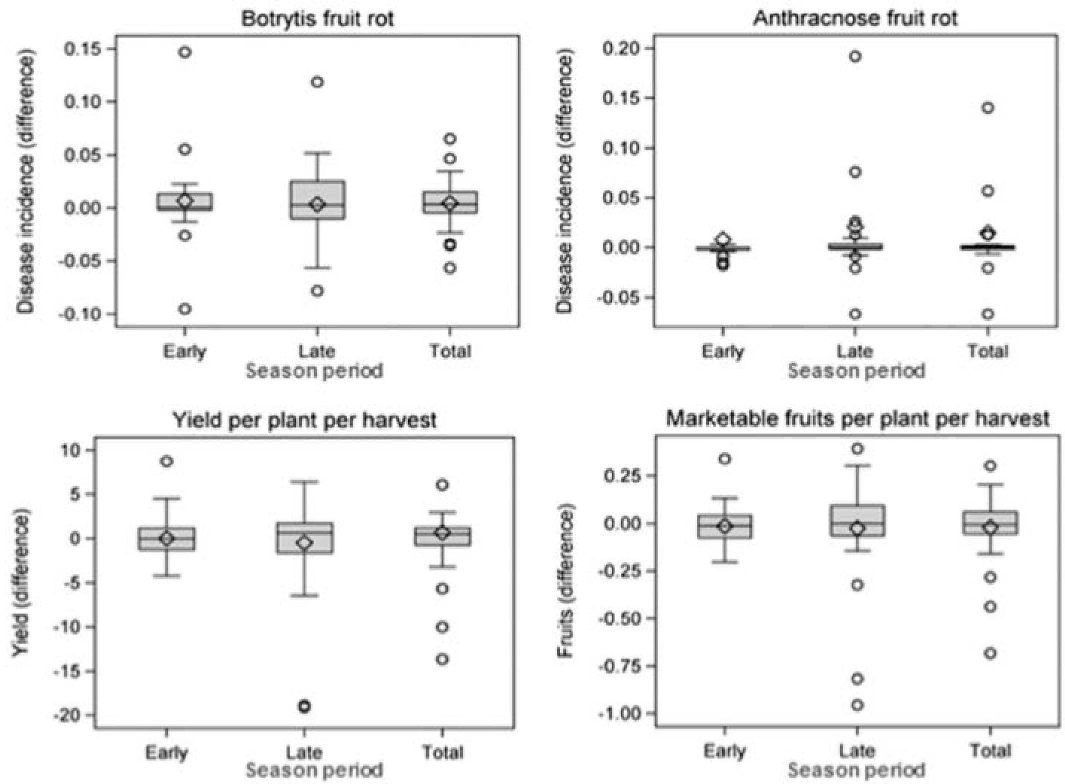


From trials in Commercial Farms to System Adoption

Meta-Analysis of a Web-Based Disease Forecast System for Control of Anthracnose and Botrytis Fruit Rots of Strawberry in Southeastern United States

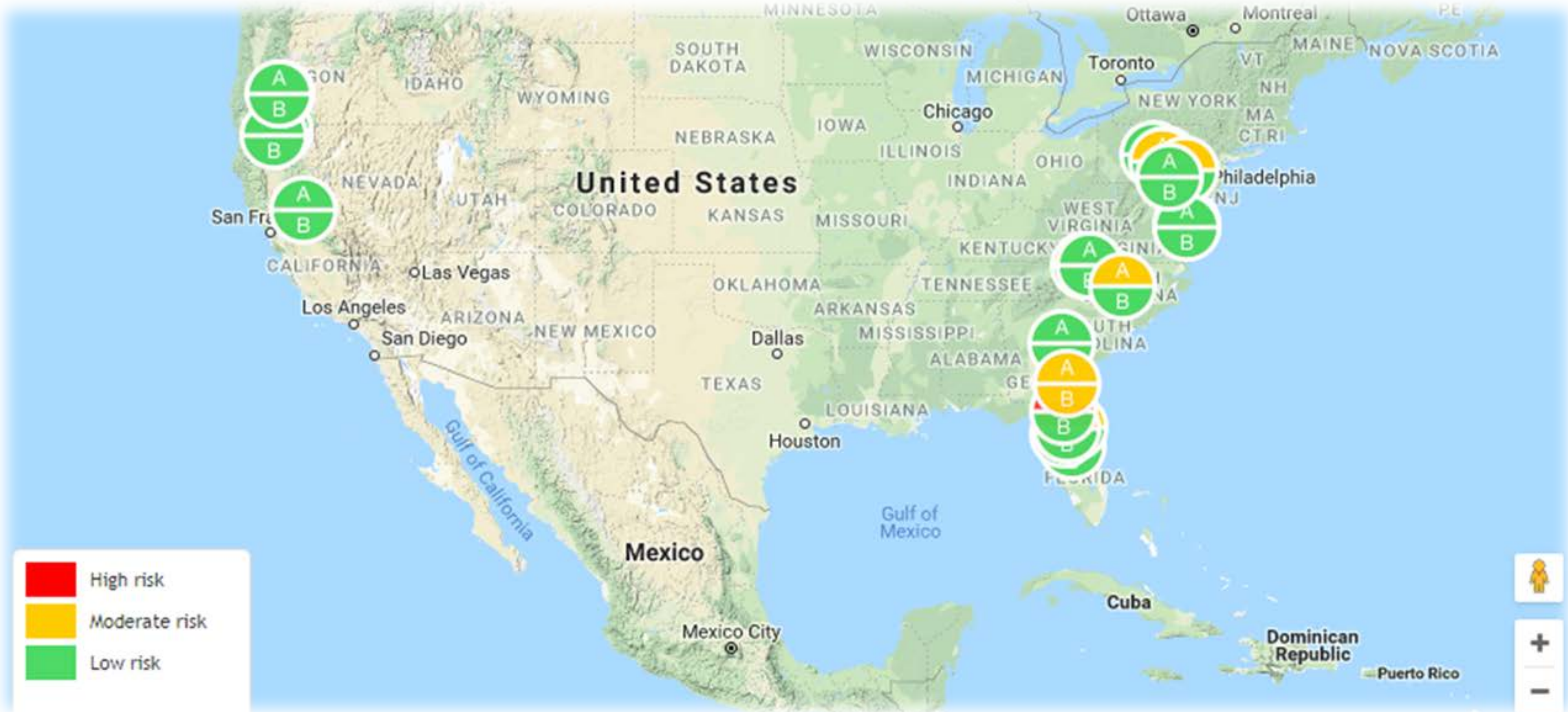
Leandro G. Cordova, Gulf Coast Research and Education Center (GCREC-UF), University of Florida, Wimauma 33598; **Laurence V. Madden,** Department of Plant Pathology, The Ohio State University, Wooster 44691; **Achour Amiri,** Tree Fruit Research and Extension Center, Washington State University, Wenatchee 98801; **Guido Schnabel,** School of Agricultural, Forestry & Life Sciences, Clemson University, Clemson, SC 29634; and **Natalia A. Peres,**† GCREC-UF, University of Florida, Wimauma 33598

- ✓39 trials commercial farms
- ✓Calendar vs. SAS
- ✓AFR and BFR incidence, yield: no difference
- ✓Number fungicide applications: 50% reduction



Strawberry Advisory System has expanded to other production areas, including nurseries

http://agroclimate.org/tools/strawberry/



FL, SC, NC, GA, VA, MD, PA, CA, OR, NY

http://agroclimate.org/tools/sas/fl

http://agroclimate.org/tools/sas/va

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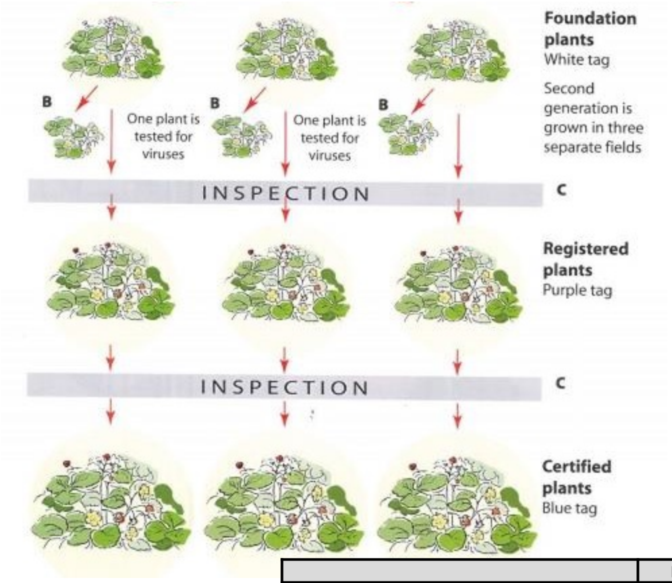
Break epidemic cycles while reducing number applications of single-site fungicides

✓Identify new chemical and/or biological products for nursery usage

✓Use single-sites only when needed – expand Strawberry Advisory System

✓Development of non-chemical management alternatives



Active ingredient	Fungicide group
thiophanate-methyl	1
iprodione	2
propiconazole, tetraconazole, myclobutanil…	3
mefenoxam	4
penthiopyrad	7
isofetamid	7
pyrimethanil	9
azoxystrobin, pyraclostrobin, trifloxystrobin…	11
quinoxyfen	13
fenhexamid	17
fenhexamid + captan	17 + M4
fosetyl-Al, phosphites	33
azoxystrobin + propiconazole	3 + 11
fluoypram + pyrimethanil	7 + 9
fluxapyroxad + pyraclostrobin	7 + 11
cyprodinil + fludioxonil	9 + 12
cyflufenamid	U6
copper	M1
sulfur	M2
thiram	M3
captan	M4

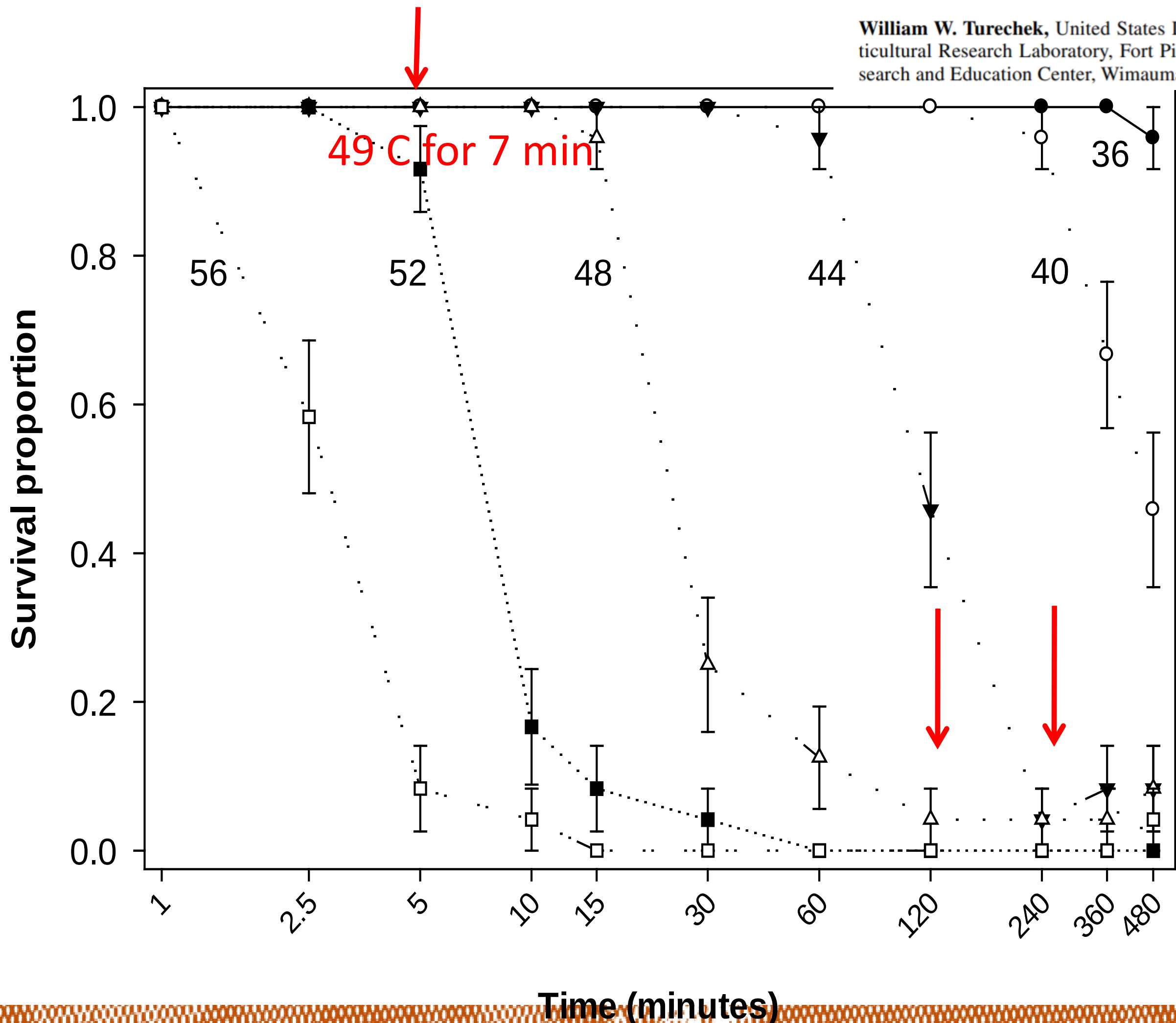
Heat Treatment as a Non-Chemical Alternative for Management of Strawberry Diseases

- ✓Heat treatment had been used in nurseries in the past for management of strawberry pests
- ✓Buchner (1991): 49 C for 7 min for reduction of cyclamen mites
- ✓ However, delayed growth, reduced flowering, and the potential spread of *Xanthomonas* with hot water treatment was observed by nurseries

Lab studies showed that much longer exposure times are needed to reduce *Xanthomonas fragariae*

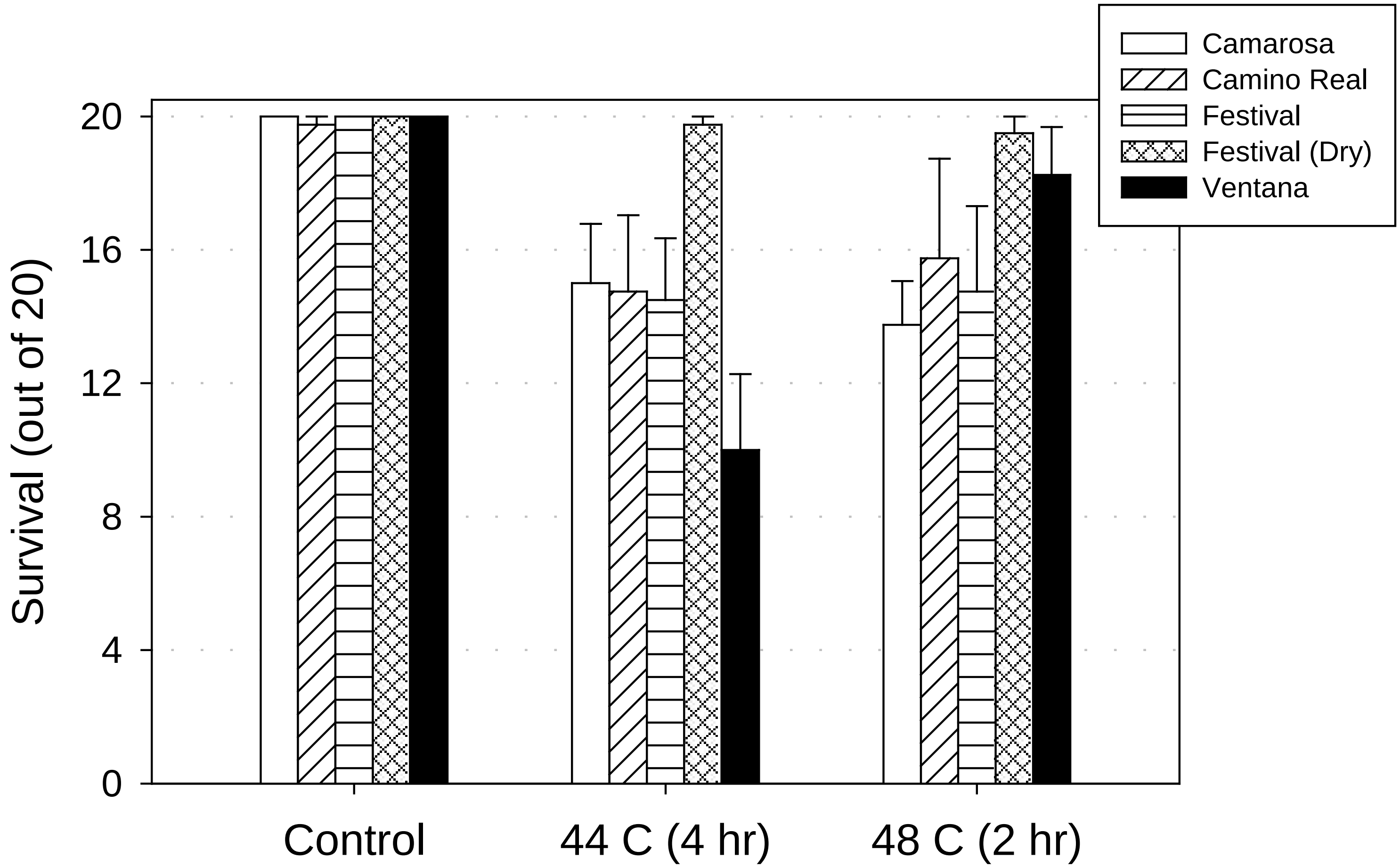
Heat Treatment Effects on Strawberry Plant Survival and Angular Leaf Spot, Caused by *Xanthomonas fragariae*, in Nursery Production

William W. Turechek, United States Department of Agriculture–Agricultural Research Service, United States Horticultural Research Laboratory, Fort Pierce, FL 34945; and **Natalia A. Peres,** University of Florida, Gulf Coast Research and Education Center, Wimauma 33598



Higher temperatures or longer exposure times are needed to reduce *Xanthomonas*

Hot water treatment for prolonged time can cause some plant damage



Heat Treatment Effects on Strawberry Plant Survival and Angular Leaf Spot, Caused by *Xanthomonas fragariae*, in Nursery Production

William W. Turechek, United States Department of Agriculture–Agricultural Research Service, United States Horticultural Research Laboratory, Fort Pierce, FL 34945; and **Natalia A. Peres,** University of Florida, Gulf Coast Research and Education Center, Wimauma 33598

Heat treatment units with aerated steam were built in Florida and California

Lassen Canyon nursery, CA

UF-GCREC, FL

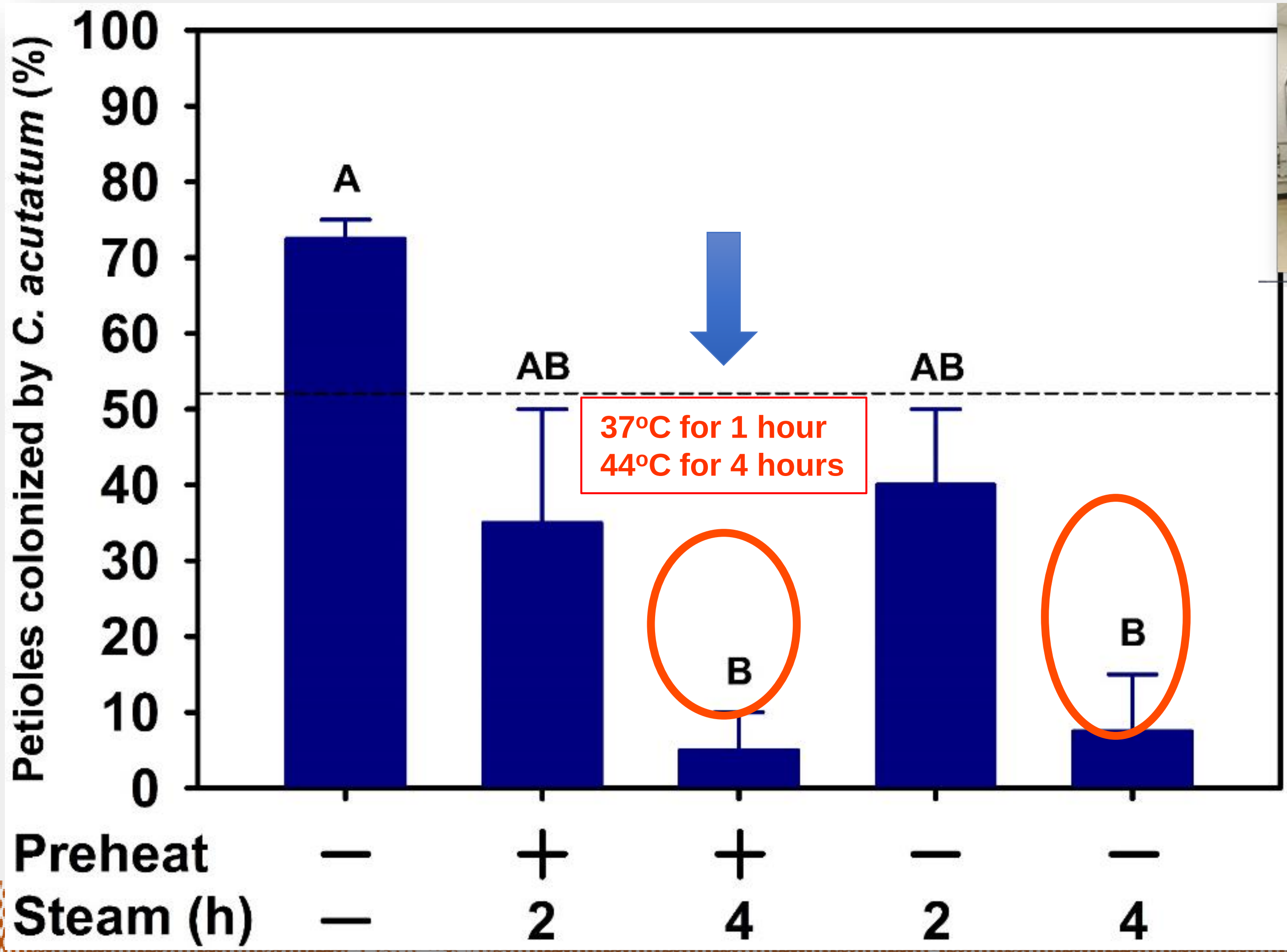
‘Aerated steam’ (plant sauna) field trials

Treatment
1. Non-treated control
2. Preheat (37°C, 1 h) + Steam (44°C, 2 h)
3. Preheat (37°C, 1 h) + Steam (44°C, 4 h)
4. Steam (44°C, 2 h)
5. Steam (44°C, 4 h)

The Effects of Heat Treatment on the Gene Expression of Several Heat Shock Protein Genes in Two Cultivars of Strawberry

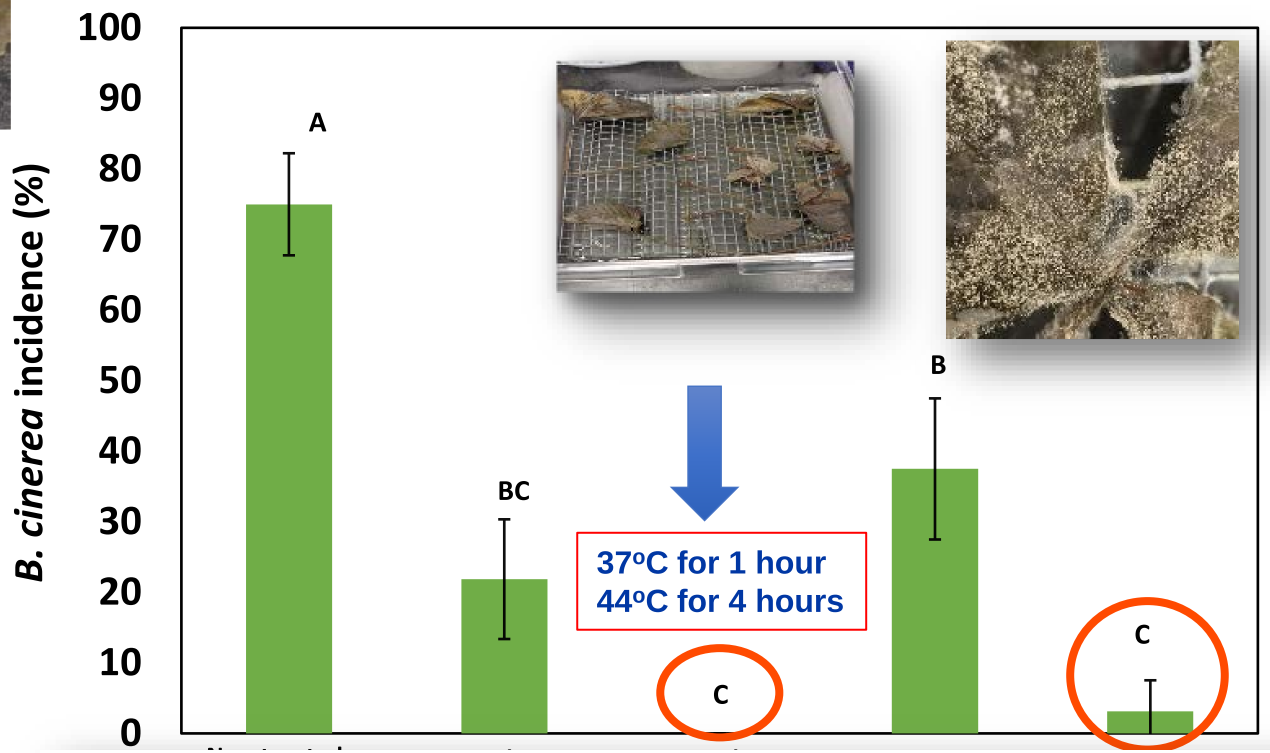
Reginald Brown, Hehe Wang, Melanie Dennis, Janet Slovin & William W. Turechek

In addition to *Xanthomonas*, two-stage steam treatment (37 C for 1 hour f.b. 44 for 4 hours) reduced colonization of transplants by *C. acutatum*



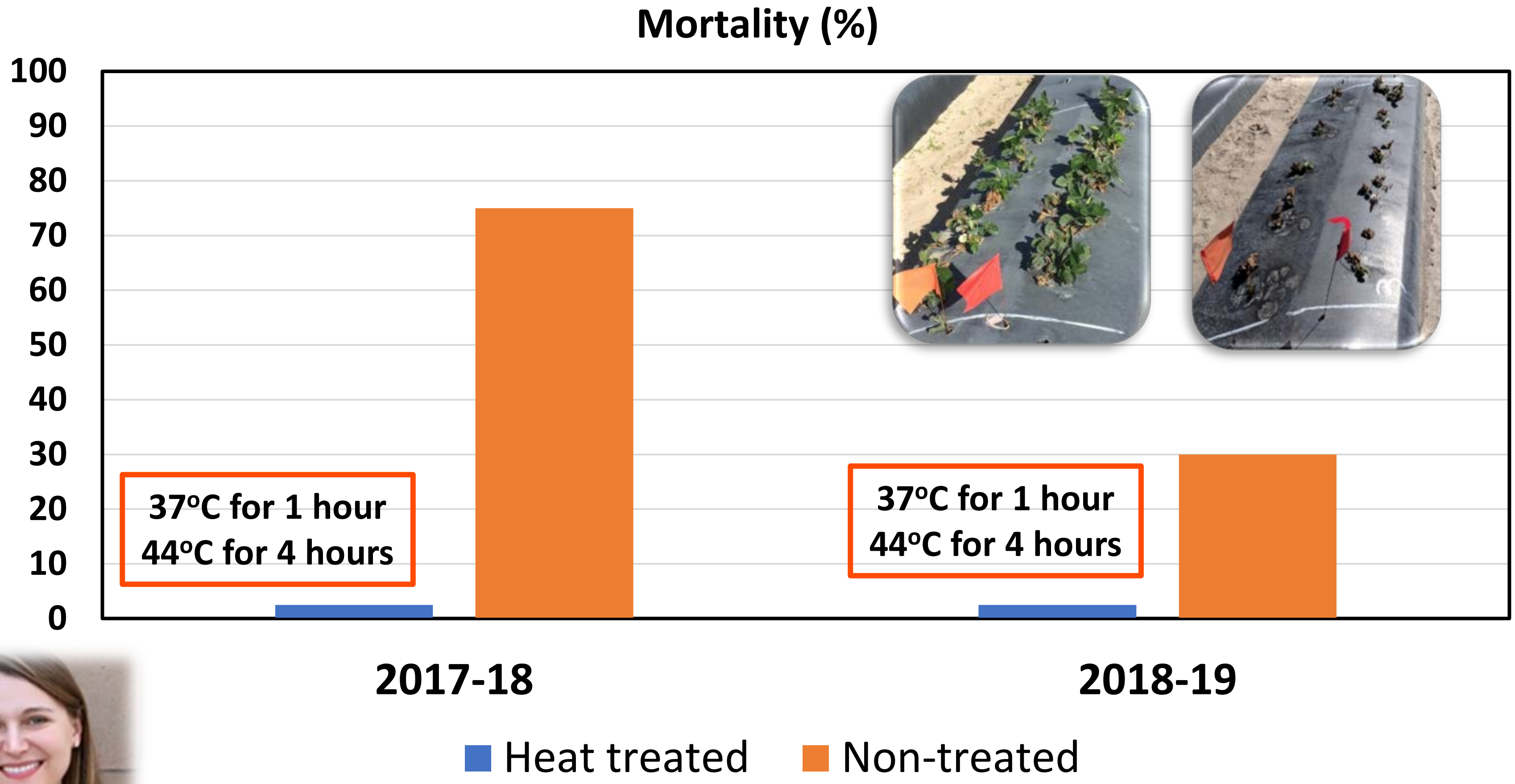
Steam treatment also reduced colonization of transplants by fungicide-resistant strains of *B. cinerea*

Plants inoculated with a mix with 2 sensitive and 2 resistant isolates



Preheat	—	+	+	—	—
Steam (h)	—	2	4	2	4

Heat treatment also reduce mortality of transplants inoculated with Phytophthora



Aerated steam is a better alternative than hot water

- **Pros**
  - Has less adverse effects on plants than Hot Water Treatment
  - Effective at reducing a number of pathogens, including *Xanthomonas*, *Colletotrichum*, *Botrytis*, *Phytophthora, Podosphaera,* and *Neopestalotiopsis* sp.
- **Cons**
  - Treatment application requires specialized units
  - Treatment times take ~6 hours

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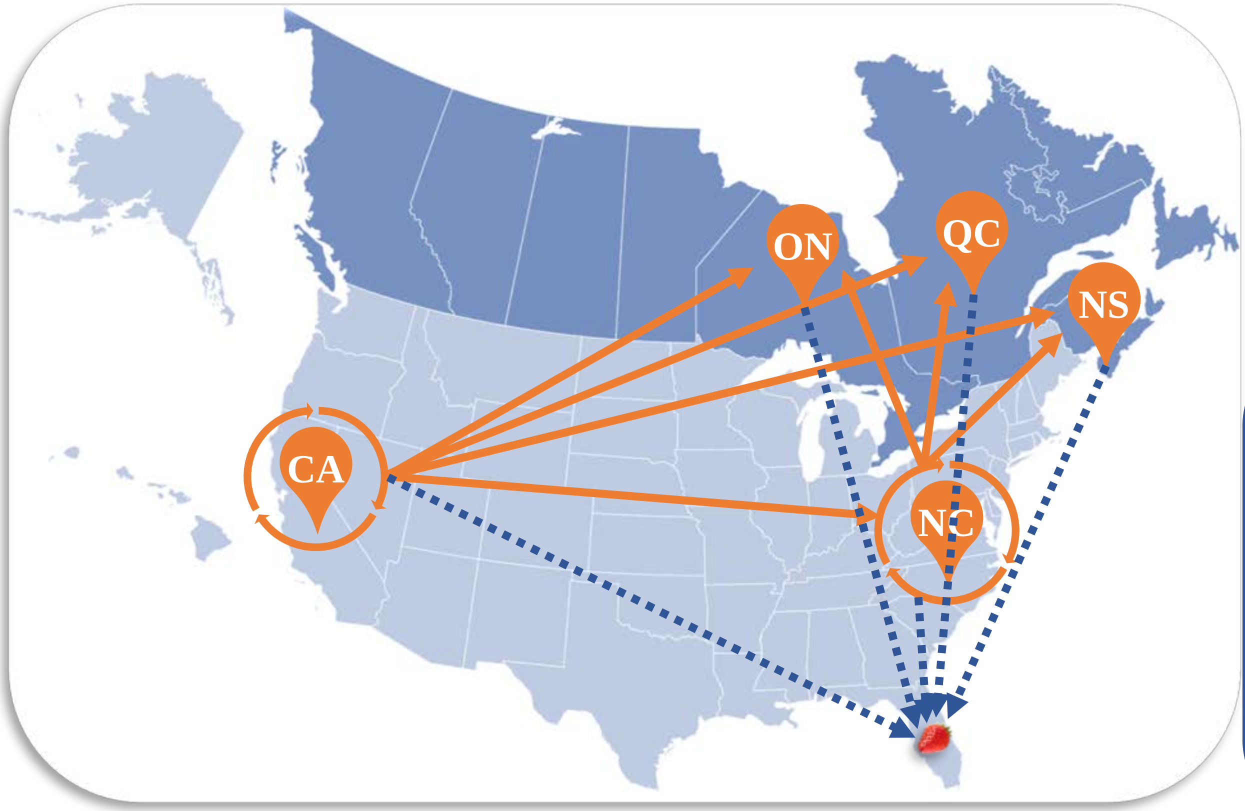
Research

The Use of Aerated Steam as a Heat Treatment for Managing Angular Leaf Spot in Strawberry Nursery Production and Its Effect on Plant Yield

William W. Turechek[1,†] | Ole Myhrene[2] | Janet Slovin[3] | Natalia A. Peres[4] |

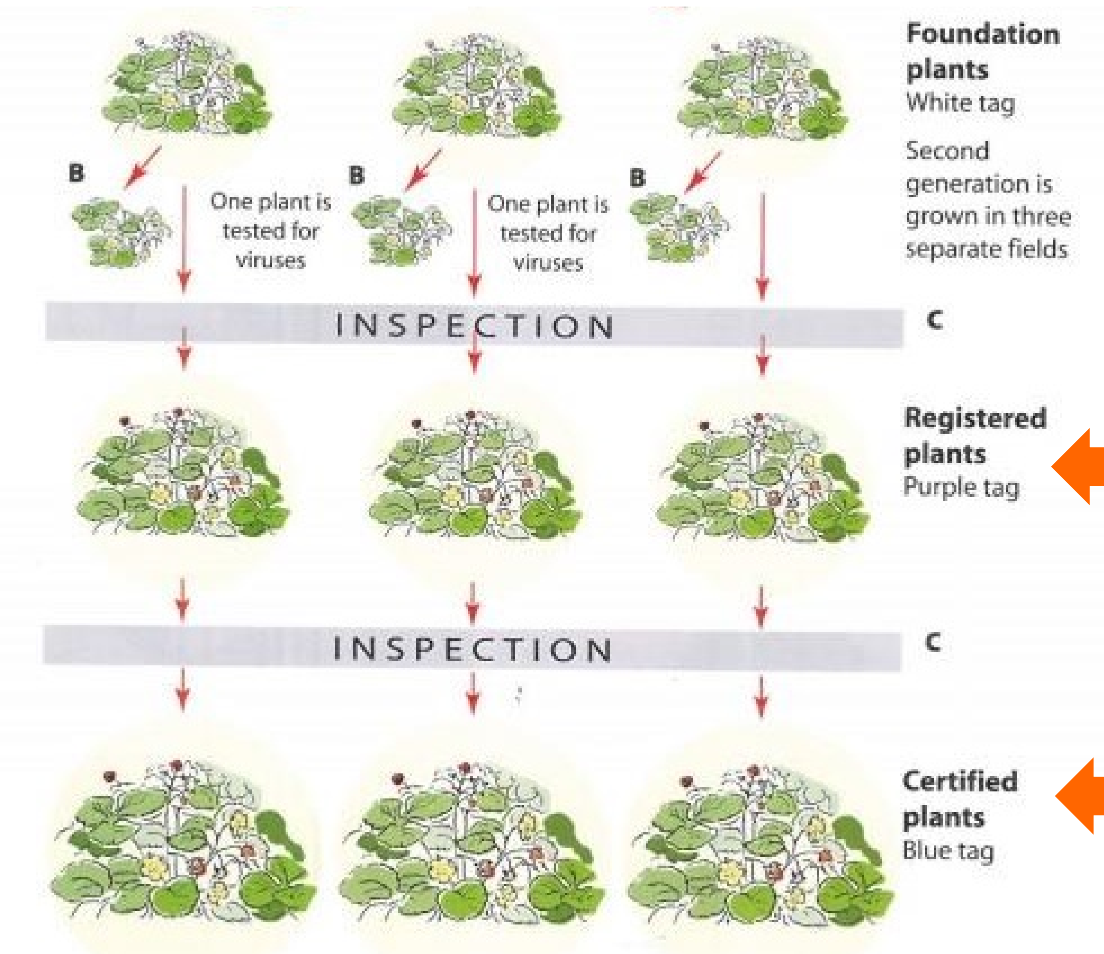
Heat treatment can reduce risk of spreading diseases among nurseries



Quiescently-infected pathogens

X. fragariae
C. acutatum
B. cinerea
P. aphanis
Phytophthora spp
Neopestalotiopsis

Heat treatment of transplants can reduce risks of epidemics



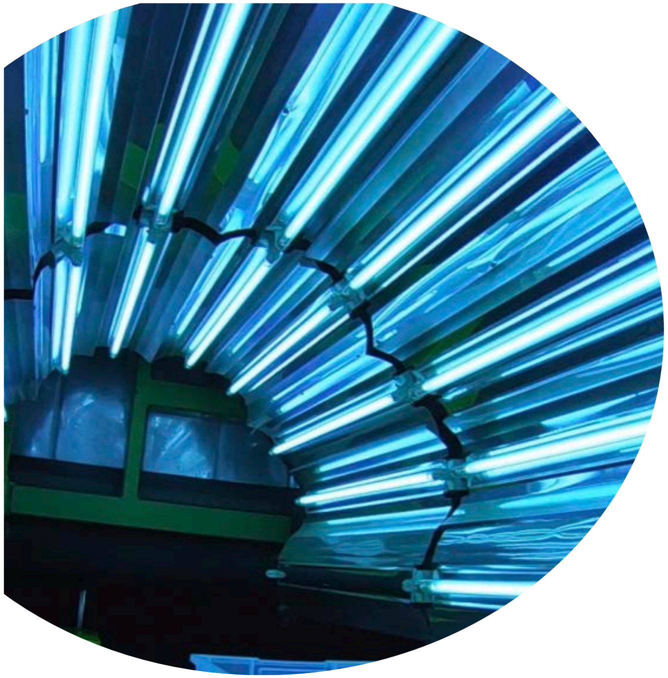
Heat treat

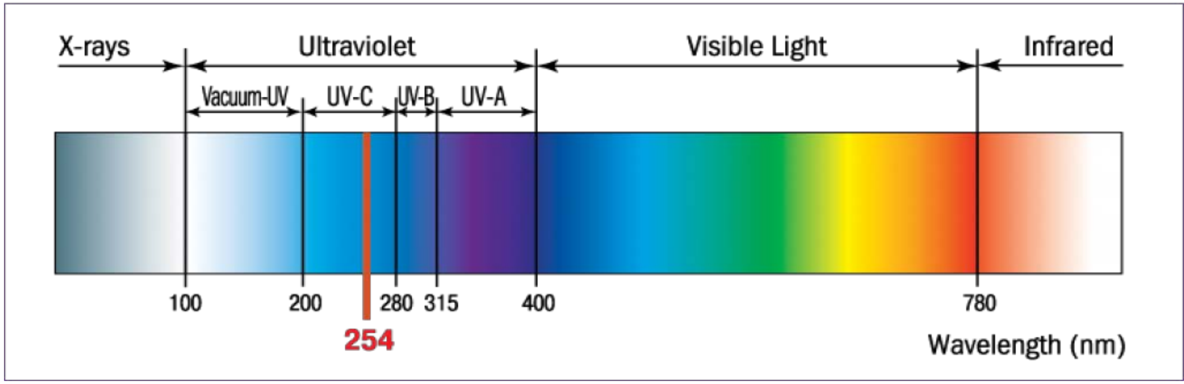
Heat treat

UV Light as a Non-Chemical Alternative for Management of Strawberry Diseases

✓Lamps producing ultraviolet light have been commonly available for over 75 years

Schuch *et al*., 2013





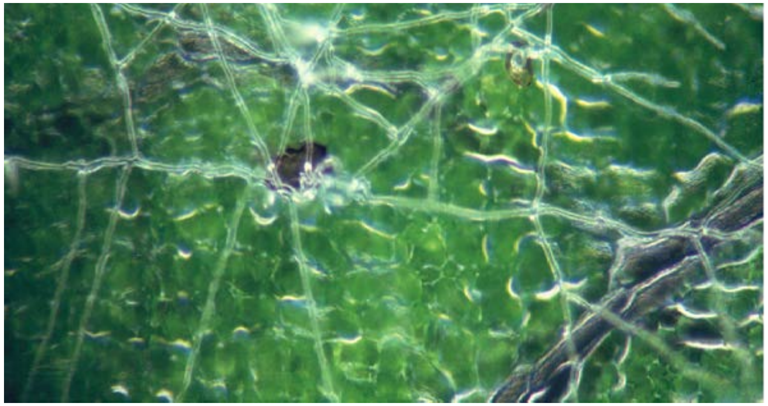
✓UV wavelength from 250 to 280 nm is most effective

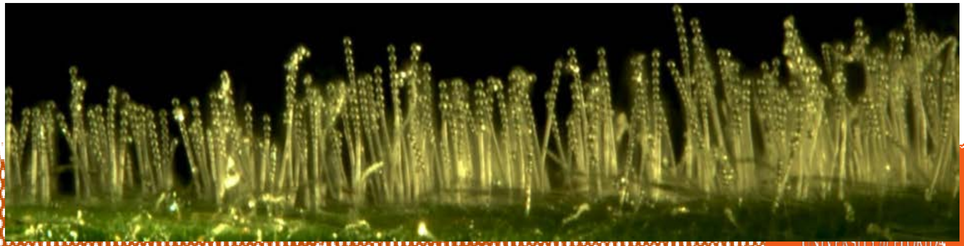
UV Light as a Non-Chemical Alternative for Management of Plant Diseases

- ✓Mode of action of UV: damage to pathogen DNA
- ✓Many pathogens have evolved systems that repair DNA damage by UV (UVA) in daylight
- ✓Breakthrough in Norway by Suthaparan et al. (2016) using nighttime application of UV
- ✓Repair systems are [recharged by blue and UVA] reduced during darkness

What pathogens can be controlled with UV?

- ✓ Powdery mildews among the most exposed plants pathogens to UV light
- ✓ Wholly external to the host
- ✓ More severe in greenhouses/protected structures

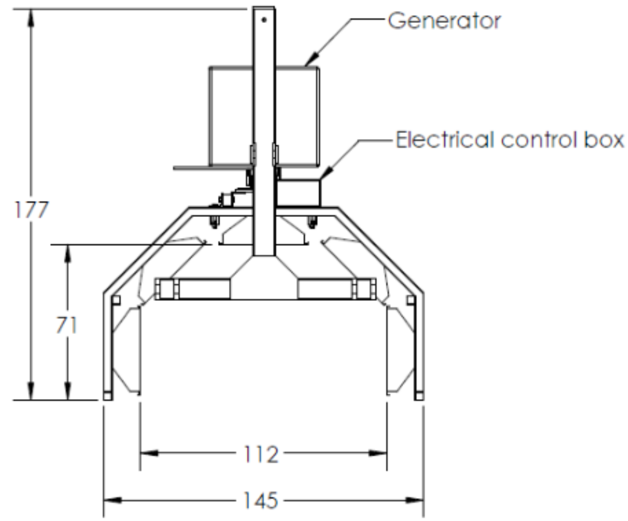




UV Light has been used for management of Powdery Mildew in greenhouses

Research and some commercial usage of UV in greenhouses in Europe

UV Light Use: From Greenhouse to Field Application



- Tractor-drawn units designed;
- Internal hemicylindrical array;
- 20 UVC germicidal lamps (254nm);
- Powered by a generator

Cornell University

Dr David Gadoury

Lighting Research Center
Rensselaer

Dr Mark Rea
Dr Andrew Bierman

Wish Farms GENERATIONS OF SWEETNESS

Fancy Farms INC.

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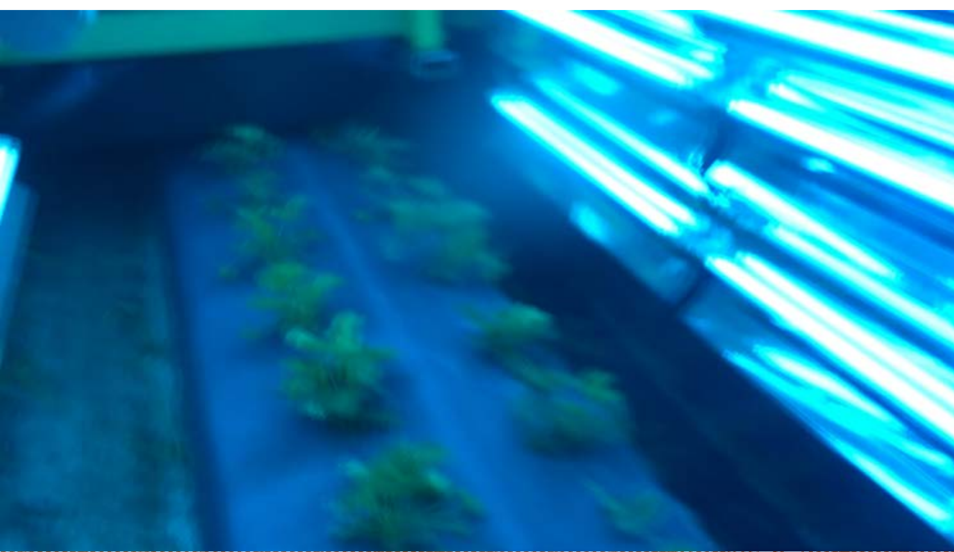
UV Light Use: From Greenhouse to Field Application

Field trials in Florida

- Applied 1x or 2x per week (after sunset)
- Speed = 1.4 mph (2.3 kph) to 3.4 mph (5.6 kph)
- Doses evaluated = 68, 85, 170 J/m^2



Cornell University

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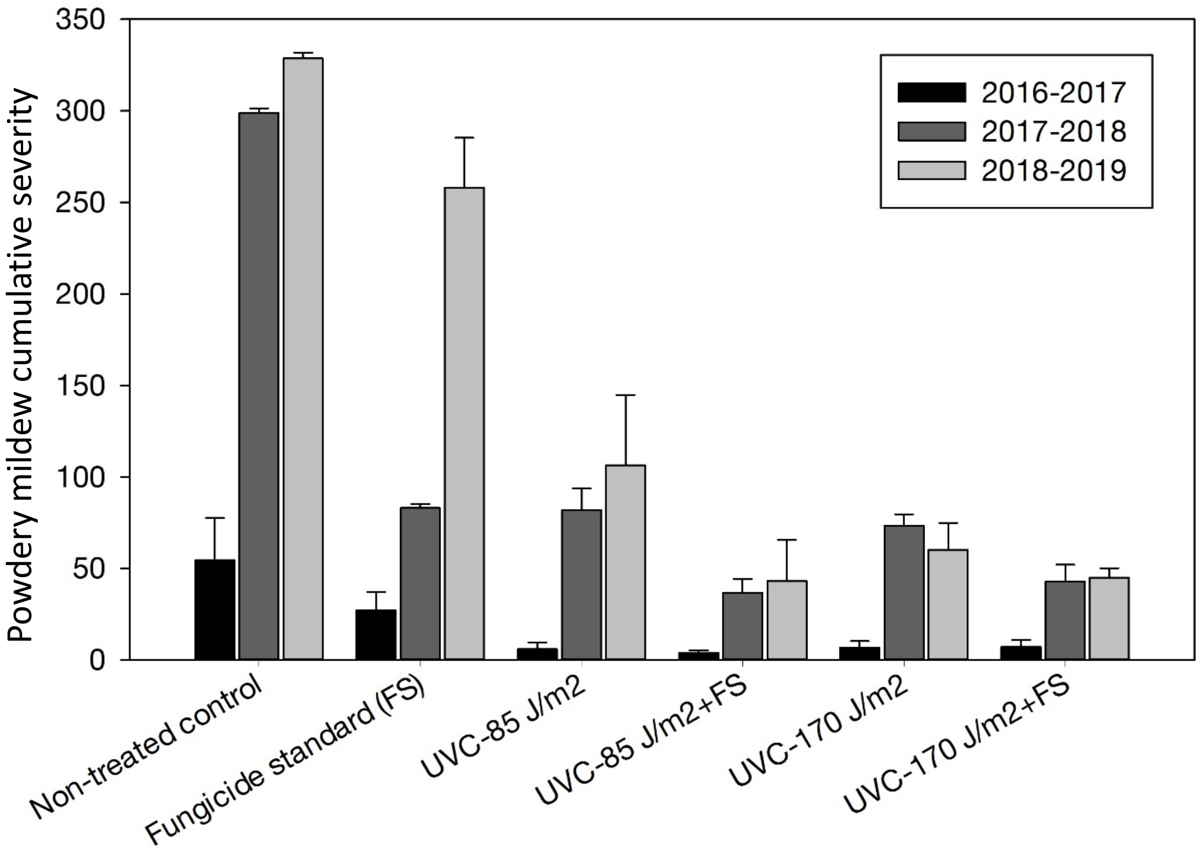
UV treatments were similar or more effective than standard fungicide sprays for PM



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Many other units built and currently being tested on strawberry and other crops

Autonomous UV Robot "Thorvald"

SAGA
ROBOTICS

Summary integrated strategies to manage multiple diseases and fungicide resistance in strawberry

- ✓Create a better linkage between fruit and plant producers [improved extension efforts to nurseries]
- ✓Recommendation for nurseries to rely more on multi-site fungicides (captan, thiram, sulfur, chlorotalonil) as the basis of disease management program [alternative groups]
- ✓Save single-site materials – *more expensive and prune to resistance selection* – for *fruit* and *critical periods*! [SAS]
- ✓Integrate other disease management practices instead of relying only on fungicides [resistant cultivars, non-chemical alternatives such as heat and UV]

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Thank you!!
FSREF
USDA
United States Department of Agriculture
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