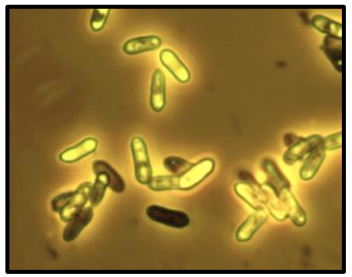
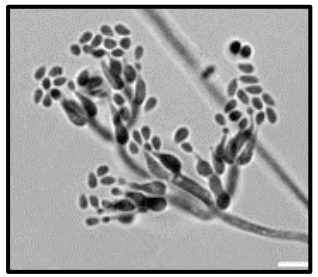




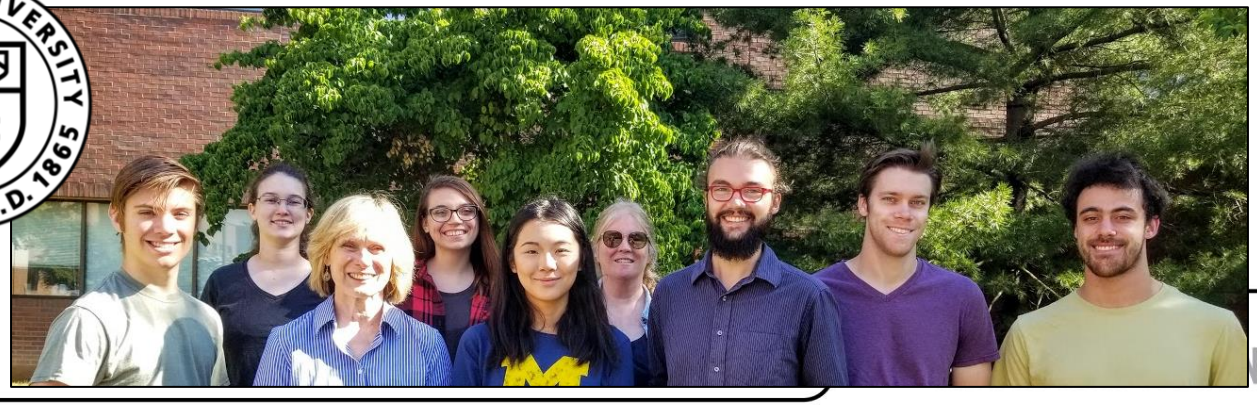

COMPATIBILITY OF BIOINSECTICIDES AND NATURAL ENEMIES IN THE GREENHOUSE

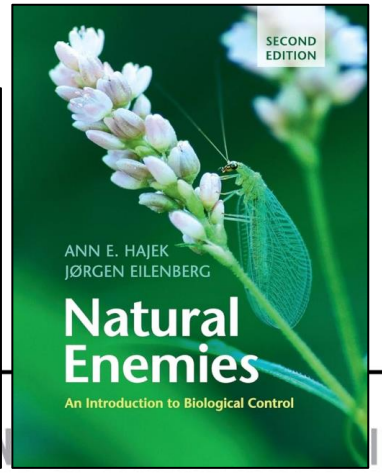
Eric Clifton, PhD
Research & Development Lead

BioWorks®
A MEMBER OF BIOBEST GROUP

WHO IS THIS GUY?

- Graduate school in Entomology at Iowa State University
  (entomopathogenic fungi, corn rootworms, aphids, nematodes)
- Postdoc at Cornell University with Dr. Ann Hajek
  (biocontrol of Asian longhorned beetle and spotted lanternfly)
- Joined BioWorks R&D in 2022
  (insects, mites, diseases in greenhouse and specialty agriculture)





WHO IS THIS GUY?

Field experience studying the efficacy of mycoinsecticides and the impacts on non-target insects

BioWorks Product Compatibility

BioWorks Product	Second Product Brand name	Compatibility (* See Comments)
EpiShield™		
EpiShield™	Molt-X®	Yes*
EpiShield™	MilStop®	Yes
EpiShield™	SuffOil-X®	Yes*
EpiShield™	BotryStop® WP	Yes*
EpiShield™	ON-Gard®	Yes*
EpiShield™	CEASE®	Yes
EpiShield™	Agri-Mek® SC	Yes
EpiShield™	Nealta® Miticide	Yes
EpiShield™	Shuttle® O	Yes
EpiShield™	Kontos®	Yes
EpiShield™	Pylon®	Yes
EpiShield™	Akari® 5SC	Yes

We found **9 non-target insects** killed by BoteGHA (*B. bassiana* strain GHA verified by genomic data)

Hemiptera
1 *Acanalonia conica* (Acanaloniidae)
3 *Flatormenis proxima* (Flatidae)

Lepidoptera
2 larvae (species unknown)
1 *Atteva aurea* (Attevidae)

Coleoptera
1 *Lagriinae* sp.

Hymenoptera
1 Vespid sp.

Groundcloths for catching dead SLF and non-targets (sampled every 3-4 d)

Environmental Entomology, 49(4), 2020, 854–864
doi: 10.1093/ee/nvaa064
Advance Access Publication Date: 3 June 2020
Research

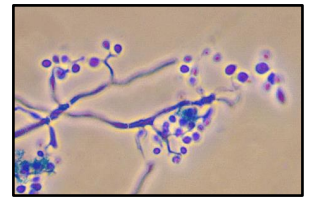
Pest Management

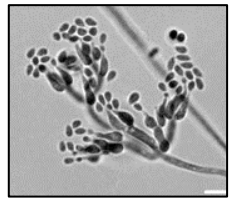
Applications of *Beauveria bassiana* (Hypocreales: Cordycipitaceae) to Control Populations of Spotted Lanternfly (Hemiptera: Fulgoridae), in Semi-Natural Landscapes and on Grapevines

Eric H. Clifton,[1,6] Ann E. Hajek,[1] Nina E. Jenkins,[2] Richard T. Roush,[3] John P. Rost,[4] and David J. Biddinger[2,5]

TALK OUTLINE

- Recap on biocontrol, mycoinsecticides and biocontrol agents
- What is compatibility and how do we test this?
- Biopesticides and biocontrol agents that get along
- Examples where they don't get along so well…
- Summary and additional resources





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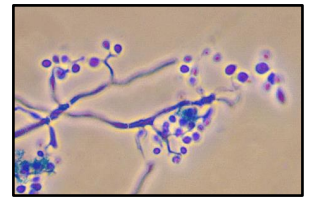
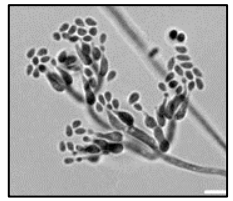
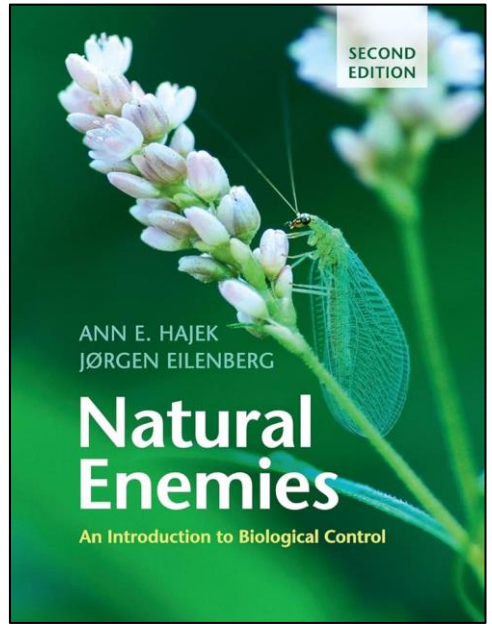




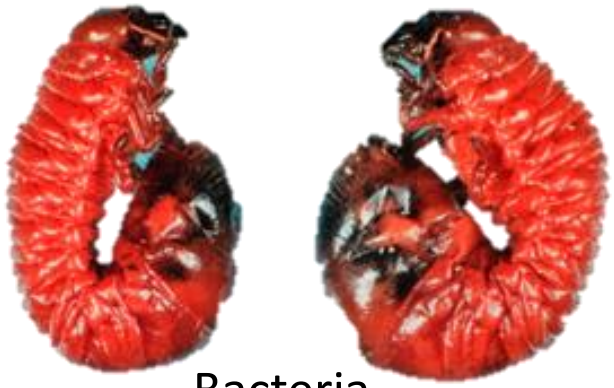
WHAT IS BIOLOGICAL CONTROL

The use of natural enemies (predators, parasitoids and pathogens) to control pest populations

"Good bugs and microbes attacking bad bugs"



THE FASCINATING DIVERSITY OF INSECT PATHOGENS



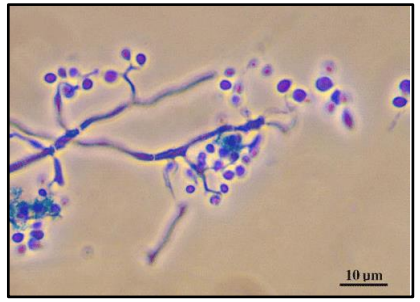
Bacteria

Works®
A MEMBER OF BIOBEST GROUP

REFRESHER ON TERMS

- **Biopesticides** – regulated by EPA
  - Biochemical products – derived from natural materials, e.g. potassium bicarbonate
  - Microbial products – use microorganisms as active ingredients with direct or indirect activity
    - **Mycoinsecticides** – use fungi to target pests or diseases
- **Biocontrol agents** (BCA's)
  - Predatory insects or mites, e.g. ladybugs and swirskii mites
  - Entomopathogenic nematodes, e.g. *Steinernema* spp.
  - Parasitic wasps, e.g. *Aphidius* and *Encarsia* spp.



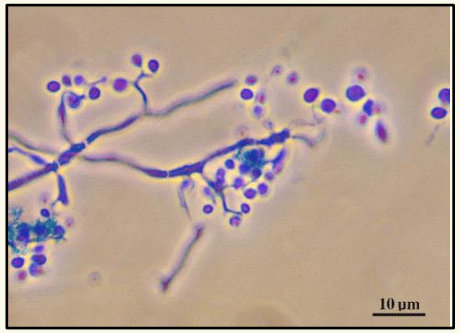



BIOPESTICIDES WITH FUNGI (MYCOINSECTICIDES)

Beauveria products

Botanigard
(Certis USA)
Beauveria bassiana
Strain GHA

BioCeres
(Anatis Protection)
Beauveria bassiana
Strain ANT-03



Velifer (BASF)
Beauveria bassiana
Strain PPRI 5339

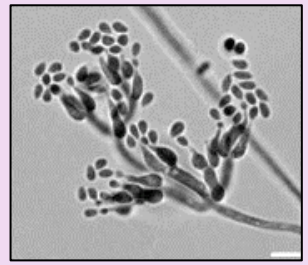
Metarhizium products

LALGUARD M52
(Lallemand Plant Care)
Metarhizium brunneum
Strain F52

Isaria/Cordyceps products

NOFLY (Blacksmith Bioscience)
Isaria fumosorosea
Strain FE 9901

PFR-97
(Certis USA)
Isaria fumosorosea
Apopka Strain 97



BIOCONTROL AGENTS AND SUPPLIERS

Left Figure: John Sanderson, Suzanne Wainwright-Evans & Ronald Valentin

ARBICO organics

Beneficial Insectary
A member of Biobest Group

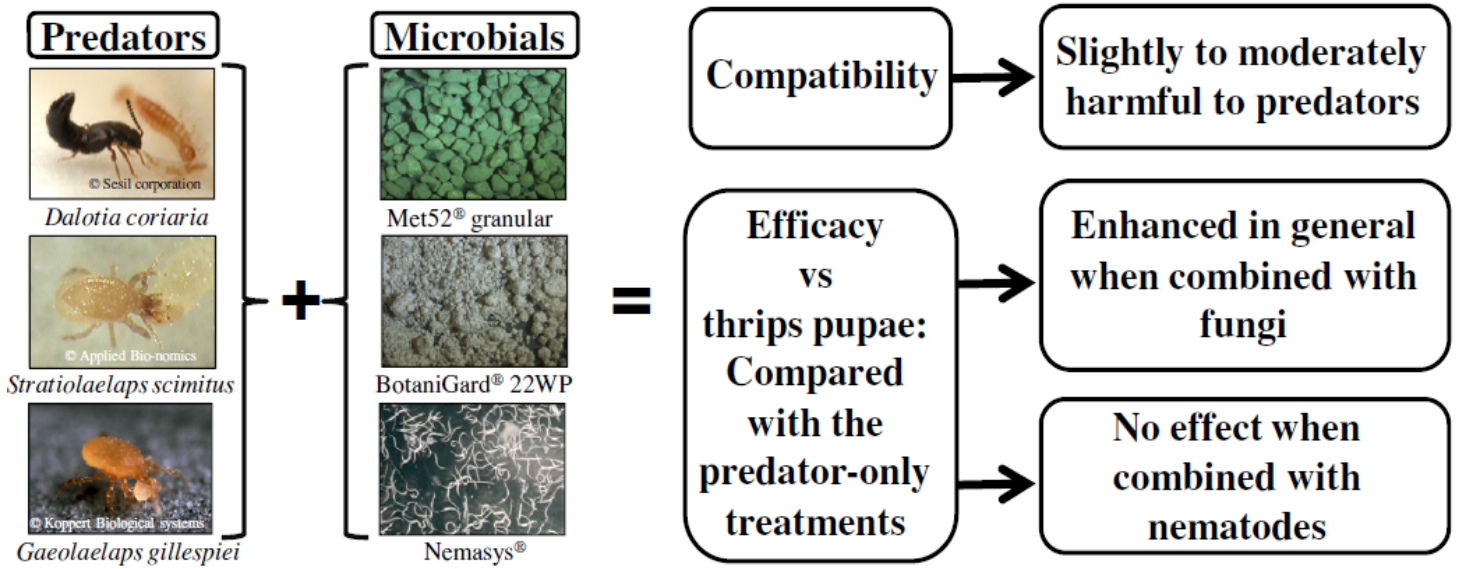
BIOBEE
Inspired by Nature

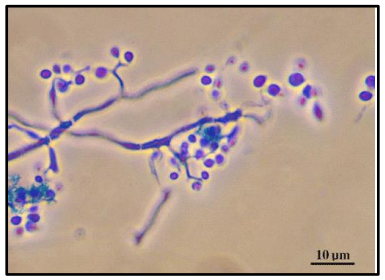
Bioline
AgroSciences
Cultivating Bioalliances

Koppert

IT'S A TEAM EFFORT

- Plant health, scouting and cultural control methods increase the likelihood of success for biocontrol programs (e.g., sticky cards, weed control, inspecting new plant material)
- **Successful biocontrol programs typically use multiple BCAs and biopesticides** (e.g., >2 parasitoids and biopesticides for aphids; kitchen sink for thrips)



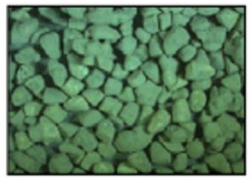


Reference: Saito, T., & **Brownbridge, M.** (2016). Compatibility of soil-dwelling predators and microbial agents and their efficacy in controlling soil-dwelling stages of western flower thrips Frankliniella occidentalis. *Biological Control*, *92*, 92-100.

IT'S A TEAM EFFORT

Combination of *Dalotia coriaria* and mycoinsecticides worked better on western flower thrips pupae than each biocontrol used alone

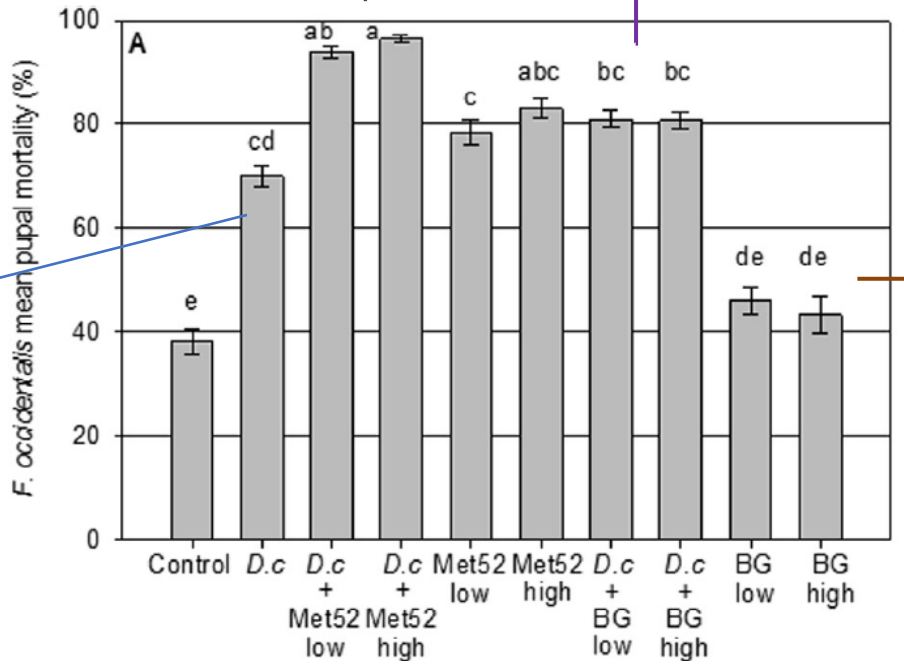
+



Met52® granular

***Dalotia* + Met52**
90-95% control

Dalotia alone
70% control



+

***Dalotia* + BotaniGard WP**
80% control

BotaniGard WP alone
45-50% control

Reference: Saito, T., & **Brownbridge, M.** (2016). Compatibility of soil-dwelling predators and microbial agents and their efficacy in controlling soil-dwelling stages of western flower thrips Frankliniella occidentalis. *Biological Control*, *92*, 92-100.

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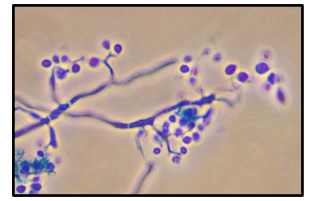
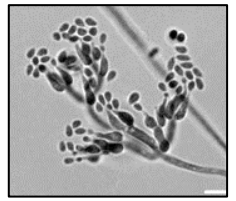


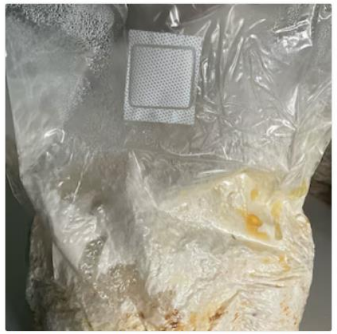


CAN BCA'S AND BIOPESTICIDES PLAY NICE?

- General assumption is that biopesticides and OMRI-approved products are safer than conventional pesticides – tread carefully! **Some biochemical products have broad spectrum activity**, e.g., products with modes of action like suffocation and desiccation.
- **Not all microbial products are EPA registered**, and thus they cannot make label claims about efficacy.
  Dr. Brownbridge will talk more about this in the afternoon session.


Beauveria bassiana 10ml liquid culture syringe


Beauveria bassiana mushroom fungus agar cu...


5lbs Fully Colonized Mycelium Grain Spawn Bl...

Examples of items sold on Etsy when you search for "Beauveria"

WHEN PESTICIDES ARE NOT COMPATIBLE

1. Pesticides that do not mix well or have reduced physical and chemical stability when mixed.

2. Pesticides that reduce the survival, foraging efficiency, and reproduction of biological control agents.

WHEN PESTICIDES ARE NOT COMPATIBLE

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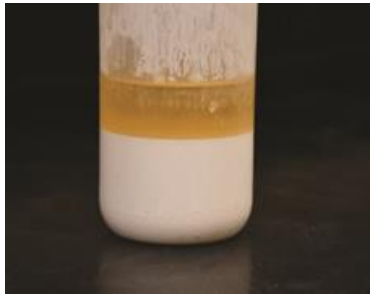
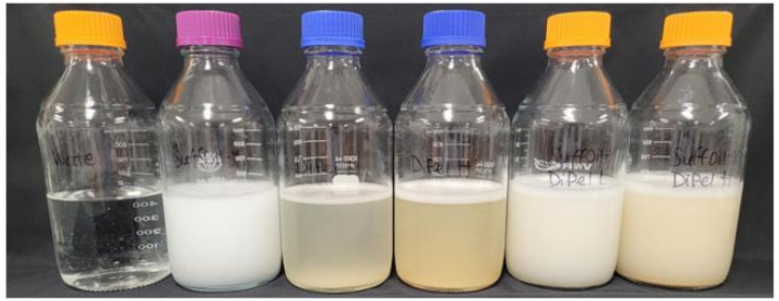
"Jar Test" Check for active ingredients that separate into distinct layers in the spray tank or produce excess foaming, curdling, heat, and changes to pH





JC Chong, April 2023
eorganic.org

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JC Chong, April 2023
eorganic.org

WHEN PESTICIDES ARE NOT COMPATIBLE

Insects and mites may be exposed to pesticides via:

- **Direct exposure**
  - Sprayed directly with pesticides
  - Contact with fresh residues (solution has just dried)

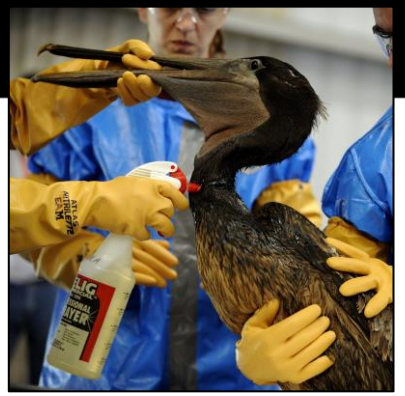
- **Residual exposure**
  - Contact days after pesticide application
  - Walk on or in contact with pesticide residues
  - Ingest plant tissues with aged residue

JC Chong, April 2023
eorganic.org

NATURAL ENEMY COMPATIBILITY (SUB-LETHAL EFFECTS)

Many studies have documented sublethal effects; however, only mortality tests are considered

- **Physiological effects**
  - Development
  - Adult longevity
  - Immunology
  - Fecundity
  - Sex ratio
- **Behavioral effects**
  - Mobility
  - Navigation/orientation
  - Feeding behavior
  - Oviposition behavior
  - Learning performance



Oil residue on foliage

Always read the labels and be mindful of pesticide overuse. "Too much of a good thing" can be bad for BCAs.

Reference: The sublethal Effects of Pesticides on Beneficial Arthropods, Annu. Rev. Entomol. 2007. 52:81–106

NATURAL ENEMY COMPATIBILITY

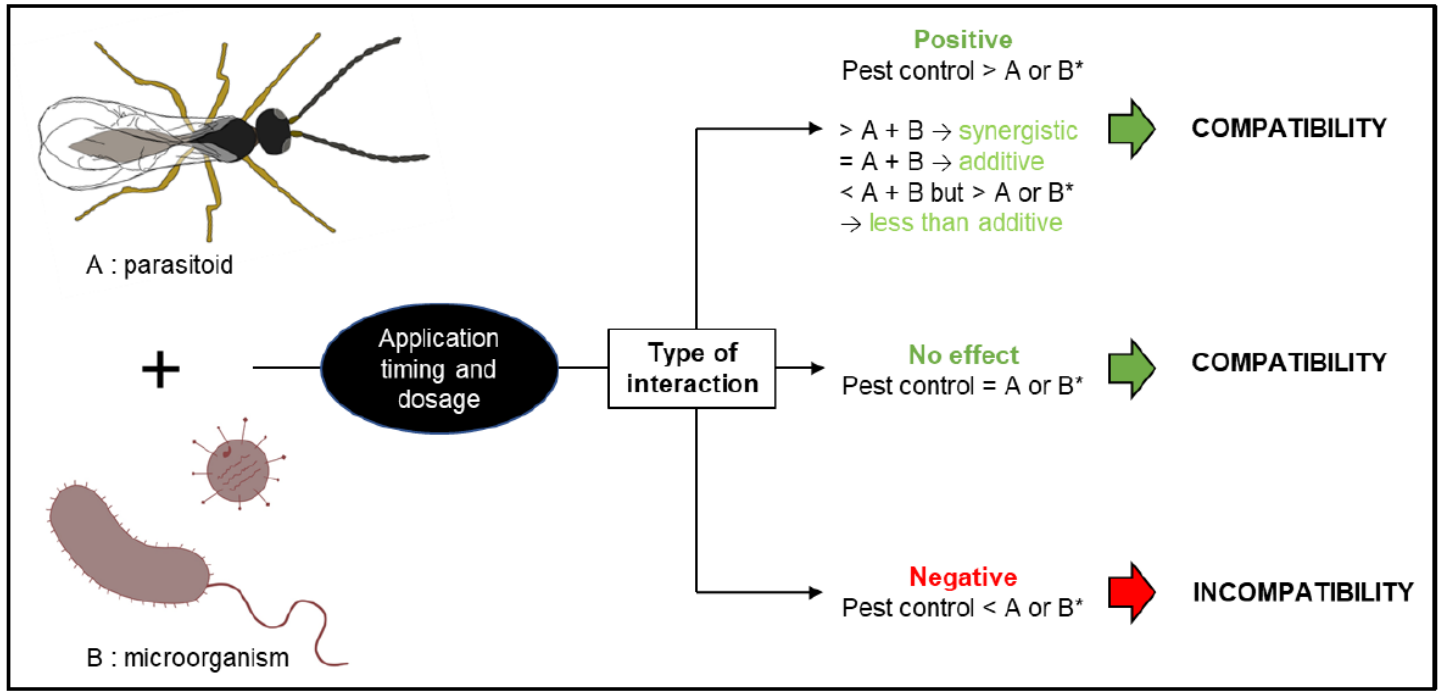
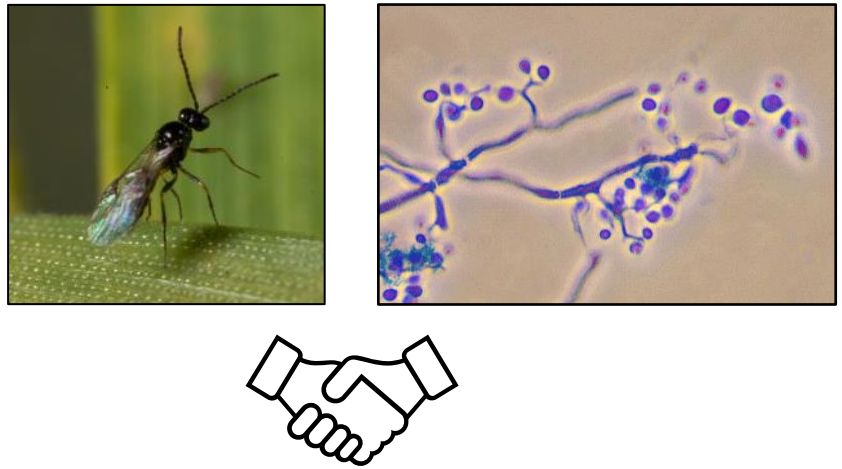


Figure 1. Types of interactions and factors influencing the compatibility of entomopathogenic microorganisms and parasitoids. * Comparison made with the more effective of agents **A** or **B**.

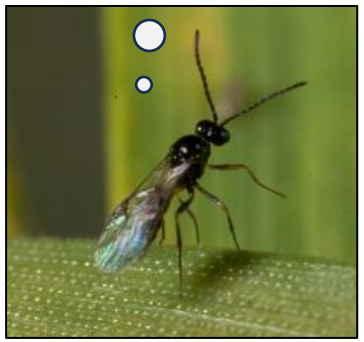


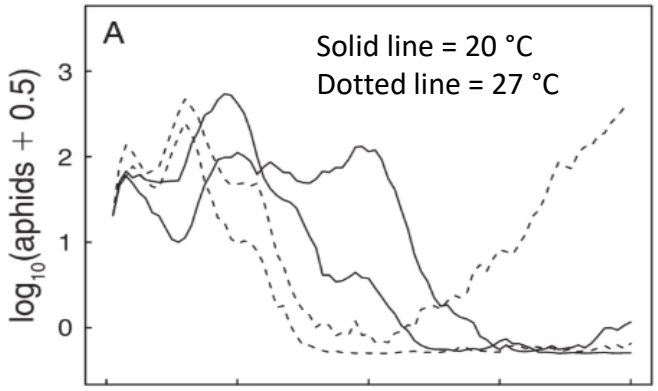
Koller et al. (2023). Entomopathogens and Parasitoids Allied in Biocontrol: A Systematic Review. Pathogens, 12(957). https://doi.org/10.3390/pathogens12070957

NATURAL ENEMY COMPATIBILITY

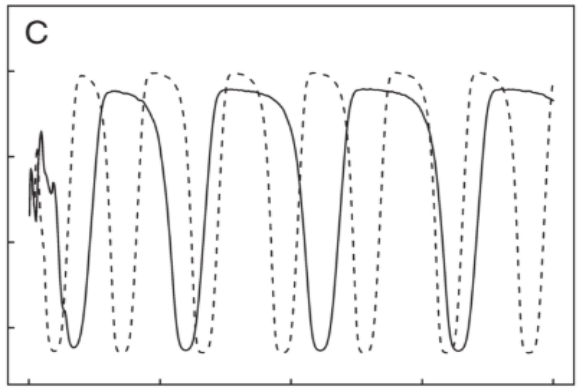
BCA's and mycoinsecticides could be compatible, but you may not always want to use them at the same time!

Who will be my victim?

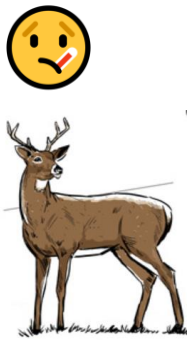




Aphids over time



Parasitoids over time



BCA's may not attack weaker prey, including those infected by microbes

Reference: Meisner et al. (2014). Temperature effects on long-term population dynamics in a parasitoid-host system. Ecological Monographs, 84(3).

BIOPESTICIDE AND BCA COMPATIBILITY

Can I use this biopesticide with my program and BCAs?

BIOPESTICIDE AND BCA COMPATIBILITY

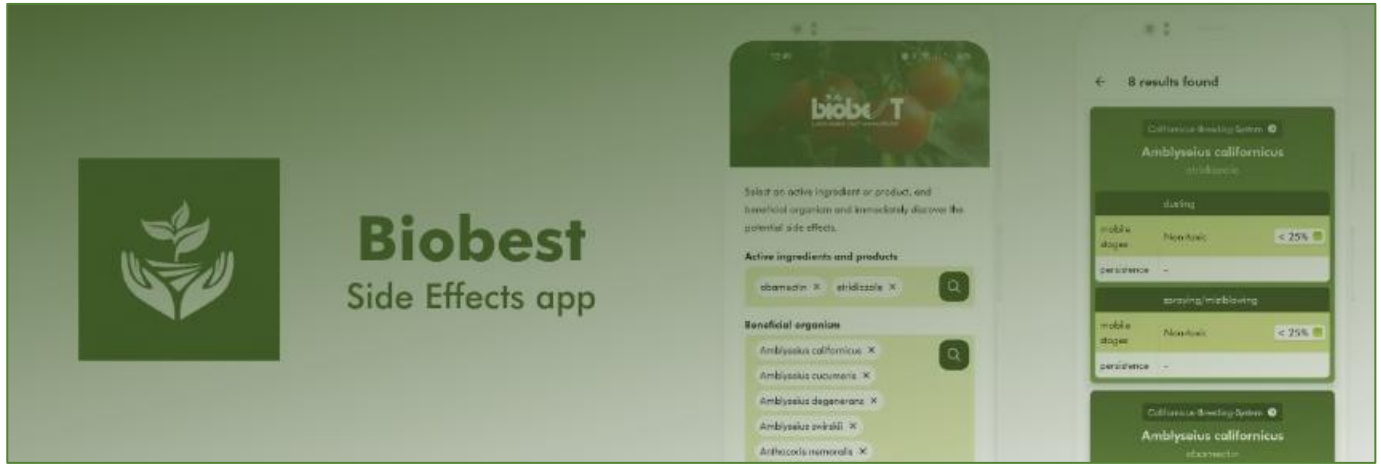
Can I use this biopesticide with my program and BCAs?

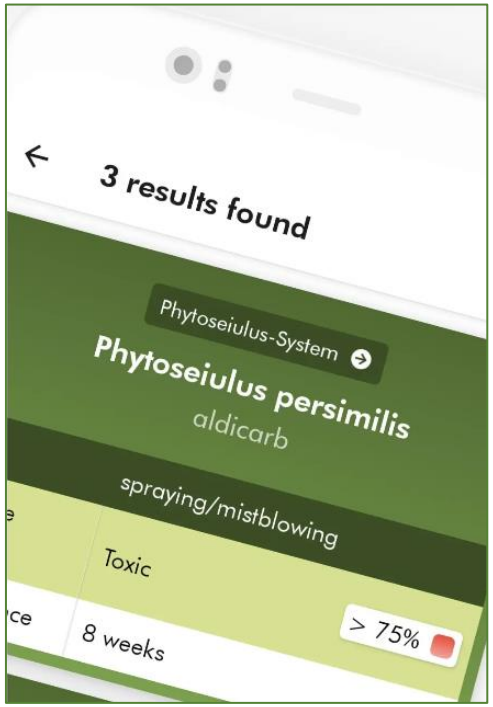
"It depends..." 

HELPFUL DATABASES

1. Not harmful to slightly harmful < 25% reduction
2. Moderately harmful 25 - 50% reduction
3. Harmful 50 - 75% reduction
4. Very harmful > 75% reduction

- sideeffects.koppert.com
- biobestgroup.com/side-effects-app
- betterplants.basf.us





HELPFUL DATABASES

Koppert sideeffects.koppert.com

Home Company Distribution News & Press Working at Koppert Contact Newsletter

1 Not harmful to slightly harmful < 25% reduction
2 Moderately harmful 25 - 50% reduction
3 Harmful 50 - 75% reduction
4 Very harmful > 75% reduction

Select

Beneficial organism | Agent

Koppert product | Latin name

Type here

Encarsia formosa

Amblyseius swirskii
SWIRSKI-MITE

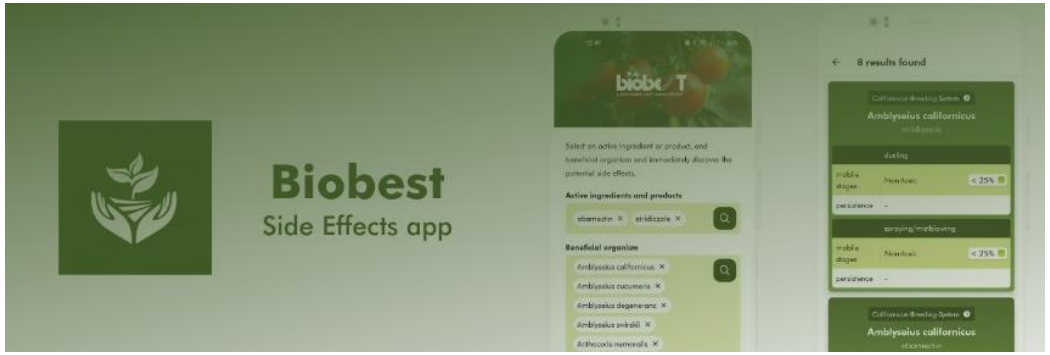
Results

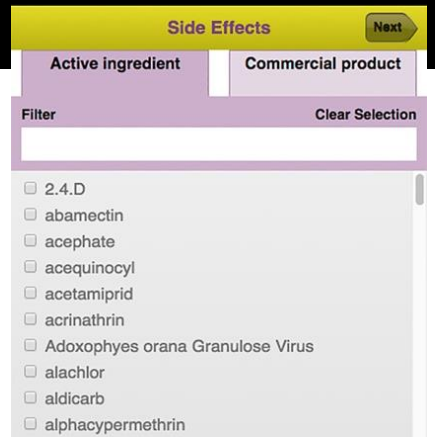
Side effects		MYCOTAL Lecanicillium muscarium strain Ve6	azadirachtin
		SP = Spray	SP
Amblyseius swirskii SWIRSKI-MITE	population		2
	egg	1	
	adult	1	1
	persistence	0 w	
Encarsia formosa	adult	1	2
	pupa	1	1
	persistence		

Mycotal

Azadirachtin (example)

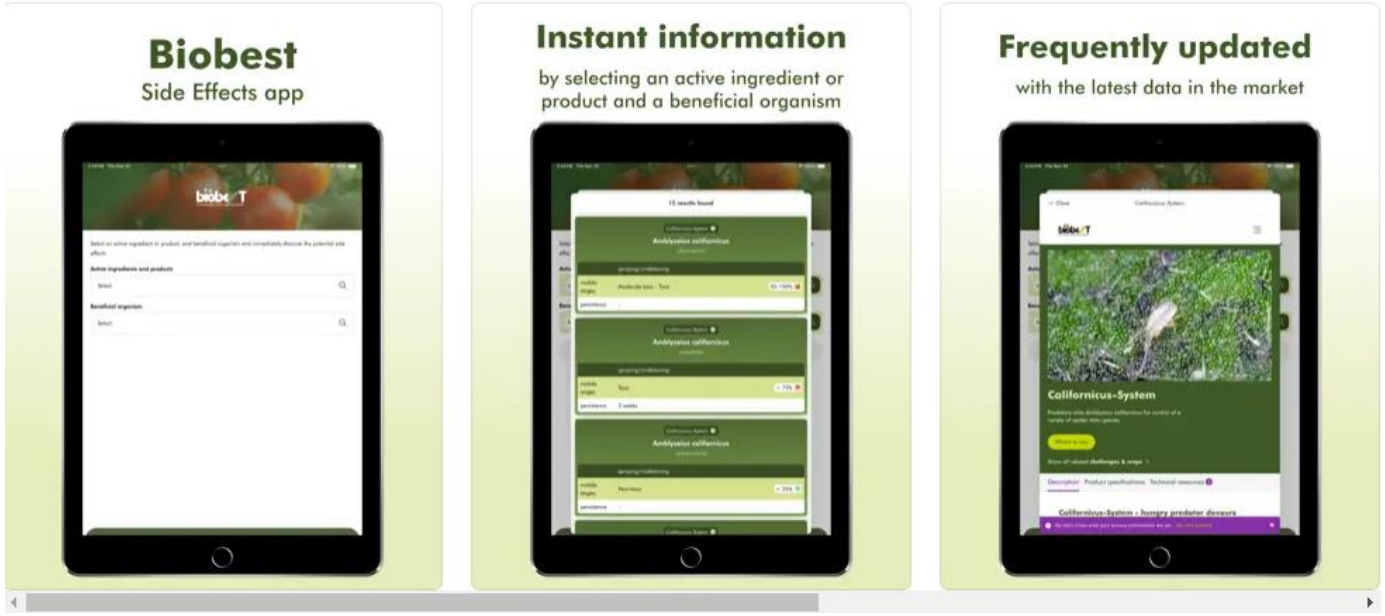
HELPFUL DATABASES

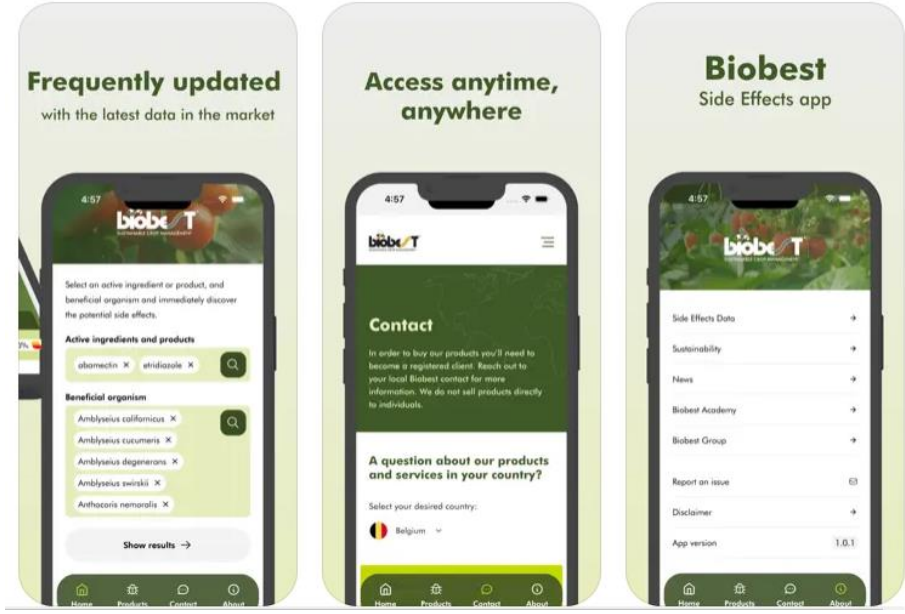




biobestgroup.com/side-effects-app

Mobile app for phones and tablets



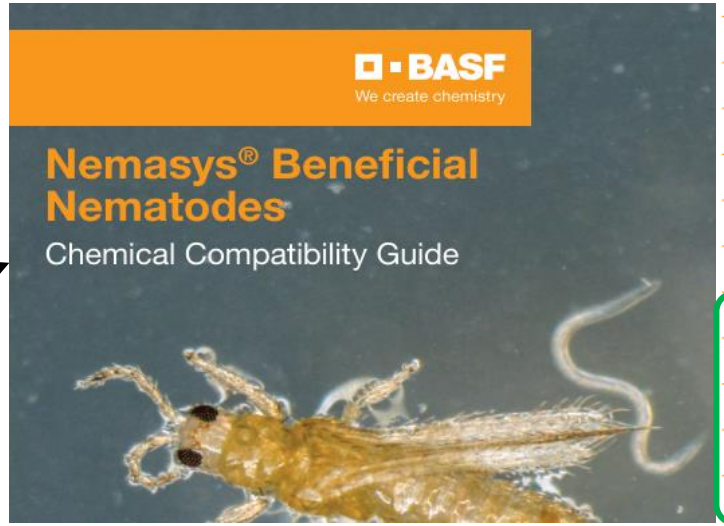


HELPFUL DATABASES

Downloads and Resources

- Nemasys® Usage & Handling
- Beneficial Nematode Treatment Guide
- Nemasys Chemical Compatibility Guide
- Nemasys Fungus Gnat Interiorscapes Technical Information Bulletin
- Nemasys Fungus Gnat Technical Information Bulletin
- Nemasys Injector Chart
- Nemasys Technical Information Bulletin
- Nemasys Western Flower Thrips Technical Information Bulletin
- Beneficial Nematodes Best Practices

betterplants.basf.us



Insecticide-Miticide		
Abamectin	Avid + Various	Apply separately, 7-day interval
Acephate	Orthene TT&O	Suitable for tank mixing
Acetamiprid	TriStar 8.5 SL	Apply separately, 14-day interval
Afidopyropen	**Ventigra® insecticide**	Suitable for tank mixing
Aldicarb	Temik 10G	Apply separately, 14-day interval
Alpha-cypermethrin	**Fendona® CS controlled release insecticide**	Suitable for tank mixing
Aluminum tris	Aliette WDG	Apply separately, 7-day interval
Azadarachtin	Molt-x	Suitable for tank mixing
Azinphosmethyl	Guthion	Apply separately, 14-day interval
Bacillus thuringiensis	Dipel DF	Suitable for tank mixing
Beauveria + Pyrethrins	Botanigard Maxx	Suitable for tank mixing
Beauveria bassiana	Botanigard ES	Suitable for tank mixing
Beauveria bassiana	**Velifer® fungal contact insecticide/miticide**	Suitable for tank mixing
Beauveria bassiana	Naturalis	Suitable for tank mixing

Western Flower Thrips

Control of western flower thrips (WFT) is best accomplished with a program approach. The initial drench application of Nemasys® should be applied to the soil or growing media for control of soil-dwelling WFT early in the growth cycle, whereas subsequent applications of Nemasys should be made as foliar sprays to target foliar-dwelling WFT.

	Area	Application Volume
Initial Soil Drench	1000 ft²	50 gal.

	Area	Application Volume
Foliar	1000 ft²	2.5 gal.

Application

Treated Area	Number of Trays	Water Volume
1,100 ft²	1 x 50 million	0.50 gal.
2,200 ft²	2 x 50 millions	1.00 gal.
3,300 ft²	3 x 50 millions	1.50 gal.
4,400 ft²	4 x 50 millions	2.00 gal.
5,500 ft²	1 x 250 million	2.50 gal.
11,000 ft²	2 x 250 millions	5.50 gal.
16,500 ft²	3 x 250 millions	8.30 gal.
22,000 ft²	4 x 250 millions	11.00 gal.

Light Infestation

Treated Area	Number of Trays	Water Volume
4,400 ft²	1 x 50 million	0.10 gal.
8,800 ft²	2 x 50 millions	0.20 gal.
13,200 ft²	3 x 50 millions	0.30 gal.
17,600 ft²	4 x 50 millions	0.40 gal.
22,000 ft²	1 x 250 million	0.50 gal.
44,000 ft²	2 x 250 millions	1.00 gal.
66,000 ft²	3 x 250 millions	1.70 gal.
88,000 ft²	4 x 250 millions	2.20 gal.

Nemasys® Beneficial Nematodes: Best Management Practices

Pesticide Use with Natural Enemies

Should never be used (4):

- Toxic
- Persist 2-3 months

Clean up & spot sprays (3):

- Moderately toxic
- Persist 2-3 weeks

Functional IPM tools (2):

- Slightly toxic but has a place
- Short to no residual

Somewhat compatible (1):

- Non-toxic, minimal sub-lethal effects
- Short to no residual

Toxicity Rating Chart*

IPM Impact Rating[1]	Mortality /Reduction	Toxicity
1	<25%	Non-Toxic
2	25-50%	Slightly Toxic
3	50-75%	Moderately Toxic
4	>75%	Toxic

1. Side-effects Database, IPM Impact, 2019

http://www.omafra.gov.on.ca/english/crops/hort/news/grower/2005/02gn05a1.htm

Should Never be Used (4)

- Toxic
- Persist 2-3 months
  - Marathon, Orthene, Dursban, Permethrin (IRAC 4A, 1B, 3A)

		acephate	chlorpyrifos	imidacloprid		permethrin
		s	s	s	i	s
Amblyseius swirskii	Nymph/adult	? i	? i	3	1	? i
	Persistance	? i	? i	? i	-	? i
Aphidius spp.	Larva	4	4	4	1	4
	Adult	4	4	4	1	4
	Persistance	? i	? i	? i	-	>8 w
Aphidoletes aphidimyza	Larva	2	4	4	1	4
	Adult	4	4	4	1	4
	Persistance	>8 w	? i	? i	-	>8 w
Encarsia formosa	Larva	4	4	3	1	4
	Adult	4	4	4	1	4
	Persistance	>8 w	? i	? i	-	>8 w

Side effects		ORTHENE acephate	DURSBAN chlorpyrifos		WOPRO IMIDACLOPRID 70WG MARATHON imidacloprid	
		SP	SP	SPK	SP	DR
Amblyseius swirskii	population	4	4		3	1
	adult					1
	persistence	6 - 8 w			3 w	0 w
Aphidius colemani	adult	4	4		4	1
	larva					
	mummy		4		4	1
	persistence					0 w
Aphidoletes aphidimyza	adult	4	4		4	1
	larva	2			4	1
	persistence	8 - 12 w				0 w
Encarsia formosa	population				4	4
	adult	4	4	3		
	larva					
	pupa	4	3			
	persistence	8 - 12 w	8 - 12 w		> 12 w	> 12 w

Clean Up & Spot Sprays (3)

- Moderately toxic
- Persist 2-3 weeks
  - Avid, Pylon (IRAC 6, 13)

Abamectin	Vertimec 18EC	18th	I.	*Phytoseiulus persimilis*	Predatory mite	Extended lab	13.5g	4th
Abamectin	Vertimec	18g	I.	*Orius insidiosus*	Plant dwelling predator	Initial toxicity	18g	4th
Abamectin	Vertimec	18th	I.	*Araneae*	Plant dwelling predator	Field	9g	1
Abamectin	Abamectin DVA 18EC	18th	I.	*Amblyseius largoensis*	Predatory mite	Initial toxicity	1.08g	3rd
Chlorfenapyr	Pirate	240	I.	*Orius insidiosus*	Plant dwelling predator	Initial toxicity	200 g	2
Chlorfenapyr	Chlfenamyr F	100	I.	*Aphidius gifuensis*	Parasitic hymenoptera	Initial toxicity	20g	4th
Chlorfenapyr	Intrepid		I.	*Amblyseius californicus*	Predatory mite	Field aged	96g	1

KOPPERT BIOLOGICAL SYSTEMS		AVID abamectin	PYLON chlorfenapyr
		SP	SP
Amblyseius swirskii	population		3
	adult	4	
	persistence	< 2 w	
Aphidius colemani	adult	4	4
	larva		1
	mummy		1
	persistence	1 w	> 4 w
Aphidoletes aphidimyza	adult	4	3
	larva	4	4
	persistence	1 w	4 w
Encarsia formosa	adult	4	4
	larva		1
	pupa	1	
	persistence	3 w	3 w
Eretmocerus eremicus	adult	3	3
	larva	1	3
	persistence	1 w	
Orius insidiosus	adult	3	2
	nymph	3	1
	persistence	1 w	

Functional IPM Tools (2):

- Slightly toxic but has a place
- Short to no residual
  - Oil, soap, botanicals, Ventigra, MainSpring, Kontos, Endeavor (IRAC UN, UNE, 9B, 9D, 28, 23)

Compatibility with Beneficial Arthropods

Ventigra Insecticide

Insect	Lifestage	Mortality	Exposure Type
Amblyseius swirskii	Adult motiles	23% (%reduction compared to UTC)	Direct Spray- insect and plant
Euseius tularensis	Mixed population	0% (%reduction compared to UTC)	Field Spray
Neoseiulus californicus	Adult motiles	5%	Indirect- dry residue
Orius insidiosus	Adults	15%	Indirect- dry residue
Coccinella septempunctata	larvae	10%	Indirect- dry residue
Chrysoperla carnea	larvae	3%	Indirect- dry residue
Phytoseiulus persimilis	Adult motiles	10%	Indirect- dry residue

Ventigra's AI = Afidopyropen

JMS Stylet Oil is compatible with *Orius* and some parasitoids, but predatory mites are more sensitive and would have more exposure to the oils & residues.

KOPPERT BIOLOGICAL SYSTEMS

		ENDEAVOR pymetrozine		JMS STYLET OIL SPRAYING OIL mineral oil	M-PEDE potassium salts of fatty acids
		SP	DR	SP	SP
Amblyseius swirskii	population		1	4	
	adult	1		3	3
	egg	1			
	persistence	0 w	0 w		0 w
Aphidius colemani	adult	2	2	1	4
	mummy	1	1	1	
	persistence	1 w		0 w	
Aphidoletes aphidimyza	adult	2	1	1	4
	larva	3	2	1	
	persistence			0 w	0 w
Encarsia formosa	adult	1	1	1	4
	larva		1		
	pupa	1		1	2
	persistence			0 w	0 w
Orius insidiosus	adult	1		1	
	nymph	1			
	persistence	0 w		0 w	
Phytoseiulus persimilis	adult	1	1	3	4
	nymph	1		3	4
	egg	1			2
	persistence				0 w

Somewhat compatible (1):

- Non-toxic, minimal sub-lethal effects
- Short to no residual
  - Microbials, botanicals (IRAC UN, UNB, UNE, UNF, UNM)

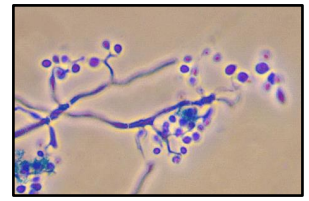
Still use caution! Pyrethrins can be lethal to some BCA's with direct exposure

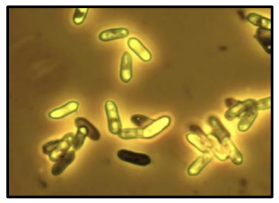
Beauveria bassiana GHA	Botanigard 22WP		I.	*Orius laevigatus*	Plant dwelling predator	Extended lab	7x500g (7D)	2
Beauveria bassiana GHA	Botanigard ES9601		I.	*Orius laevigatus*	Plant dwelling predator	Extended lab	7x1000ml (7D)	1
Beauveria bassiana GHA	Botanigard ES		I.	*Nesidiocoris tenuis*	Plant dwelling predator	Semi-field	250 g	1
Beauveria bassiana GHA	Botanigard ES		I.	*Orius insidiosus*	Plant dwelling predator	Semi-field	250 g	1

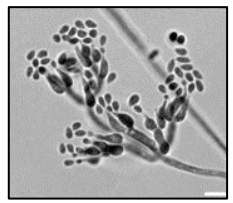
KOPPERT BIOLOGICAL SYSTEMS		adoxophyes orana granulovirus	azadirachtin	pyrethrins
		SP	SP	SP
Amblyseius swirskii	population	1	2	
	adult		1	
	persistence			
Aphidius colemani	population			
	adult	1	1	4
	larva	1	1	
	mummy			1
	persistence		0 w	1 w
Aphidoletes aphidimyza	adult	1	1	4
	larva	1	1	4
	persistence			> 1 w
Encarsia formosa	adult	1	2	4
	larva	1		
	pupa		1	
	persistence			0 w
Eretmocerus eremicus	population			
	adult	1	1	
	larva	1	1	2
	pupa			
	persistence			1 w
Orius insidiosus	adult	1	1	
	nymph	1	2	
	persistence		0 w	

TALK OUTLINE

- Recap on biocontrol, mycoinsecticides and biocontrol agents
- What is compatibility and how do we test this?
- **Biopesticides and biocontrol agents that get along**
- Examples where they don't get along so well…
- Summary and additional resources

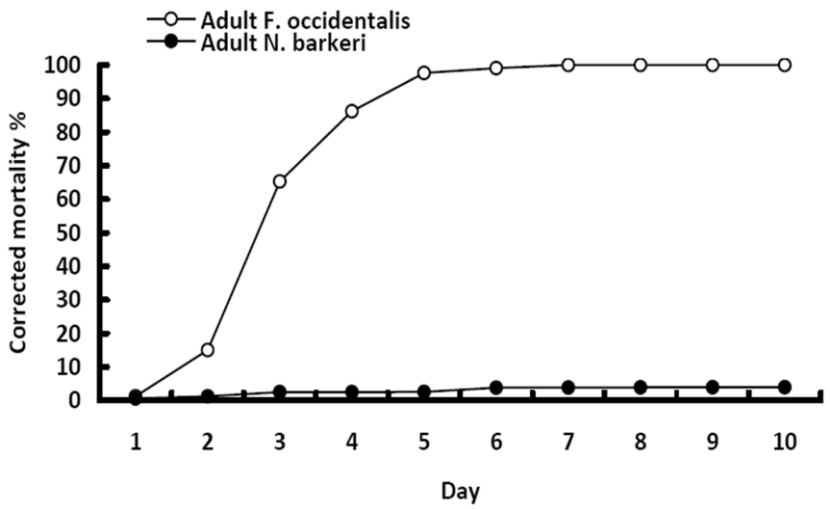


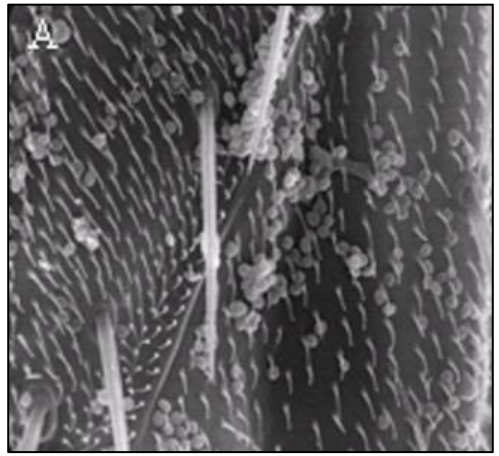


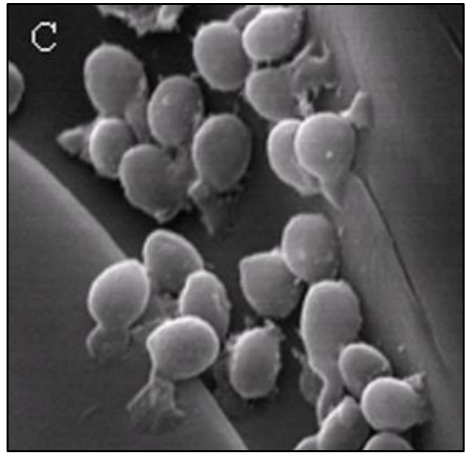


BEAUVERIA ON THRIPS AND PREDATORY MITES

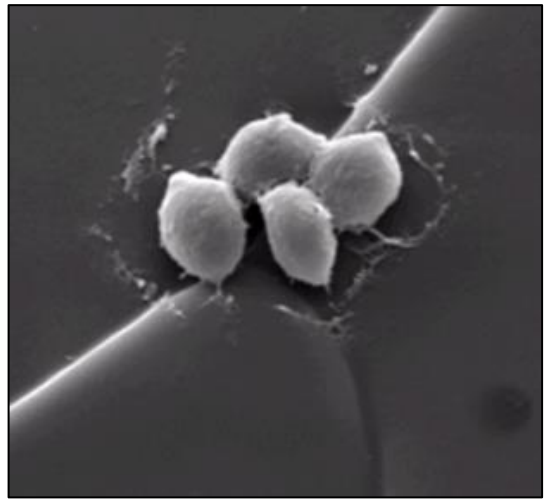
"…we never observed penetration of the predator's cuticle and conidia were shed gradually from the body, further demonstrating that B. bassiana strain SZ-26 show high toxicity against F. occidentalis but no pathogenicity to the predatory mite *Neoseiulus barkeri*."







Thrips cuticle



Predatory mite's cuticle

Wu S, Gao Y, Zhang Y, Wang E, Xu X, et al. (2014) An Entomopathogenic Strain of *Beauveria bassiana* against *Frankliniella occidentalis* with no Detrimental Effect on the Predatory Mite *Neoseiulus barkeri*: Evidence from Laboratory Bioassay and Scanning Electron Microscopic Observation. PLOS ONE 9(1): e84732. https://doi.org/10.1371/journal.pone.0084732

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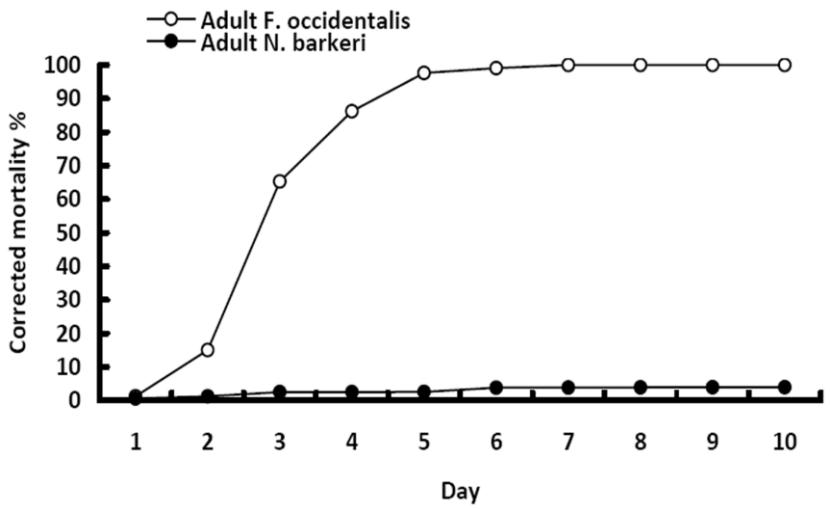
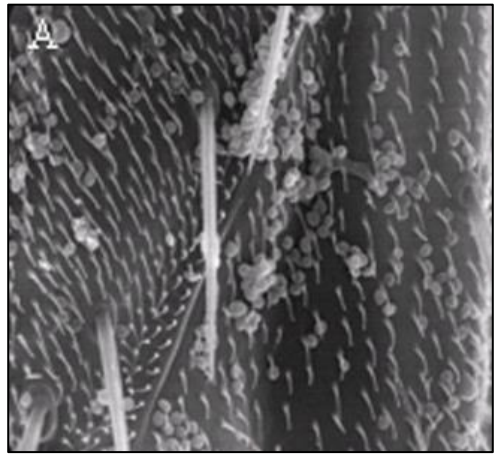
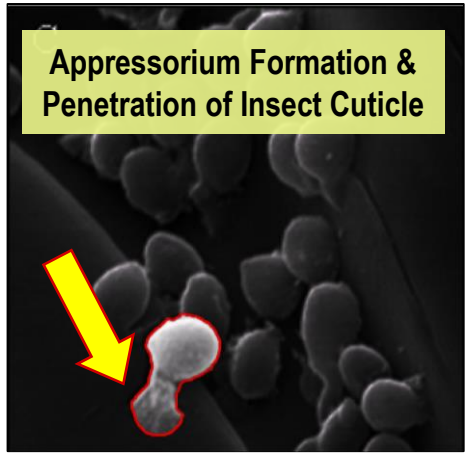
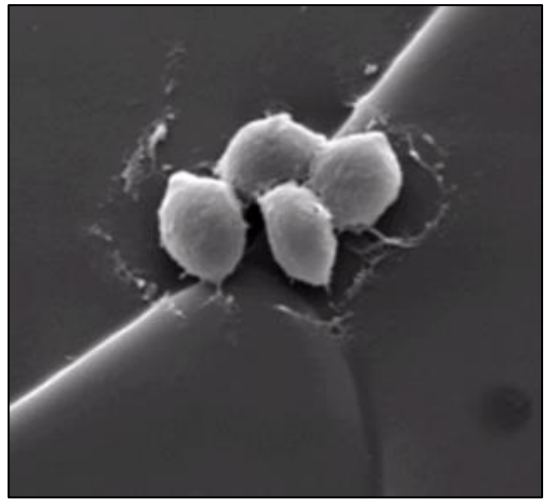






Thrips cuticle



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BEAUVERIA ON THRIPS AND PREDATORY MITES

***Phytoseiulus persimilis* mites exposed to *Beauveria bassiana* spent more time grooming (cleaning themselves), but there was no negative impacts on predation rate.**

The combination of *B. bassiana* and *P. persimilis* mites showed synergistic effects in controlling twospotted spider mites.

Wu, S., Xing, Z., Sun, W., Xu, X., Meng, R., & Lei, Z. (2018). Effects of Beauveria bassiana on predation and behavior of the predatory mite Phytoseiulus persimilis. Journal of Invertebrate Pathology, 153, 51-56.

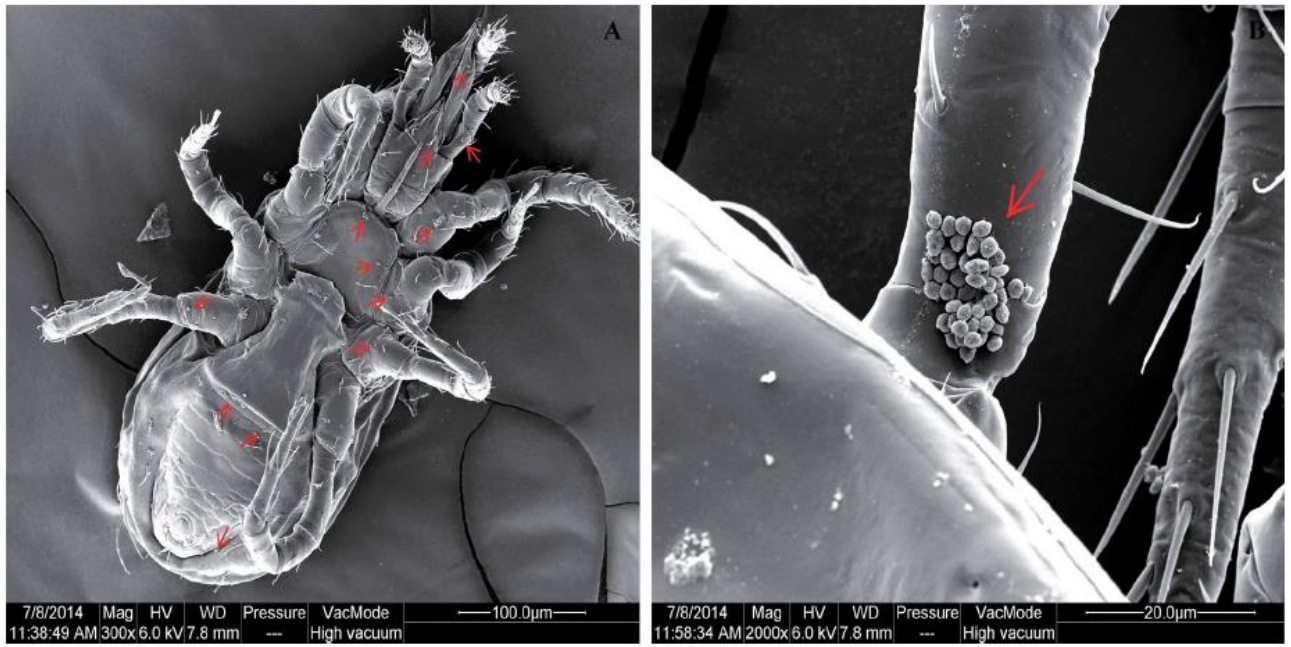


Fig. 5. Attachment of fungal conidia on the body of *P. persimilis* after mounting the leaf disk following treatment with *B. bassiana*. Red arrows signify the position of conidia adhesion. (A) Conidia attached to the mite's legs, gnathosoma, plastron and ventral surfaces; (B) Conidia aggregation on the mite's leg. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

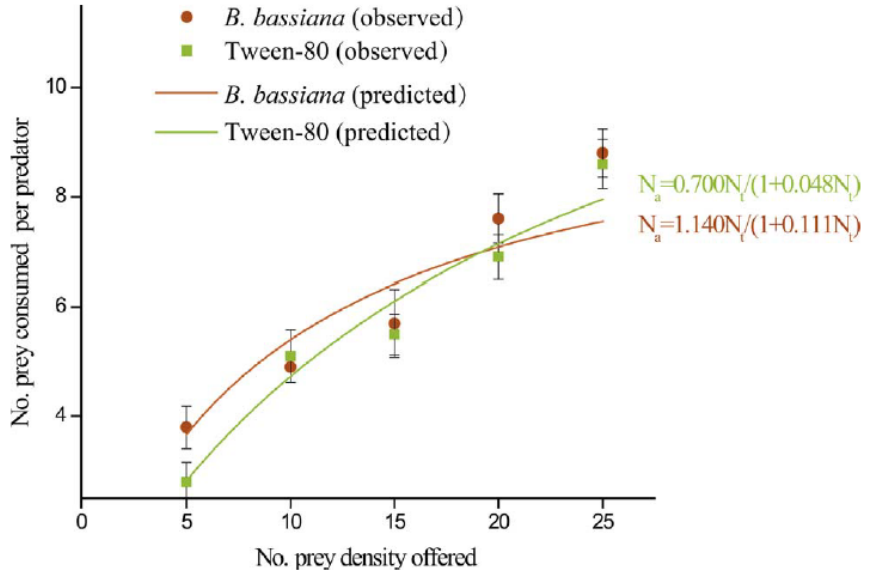
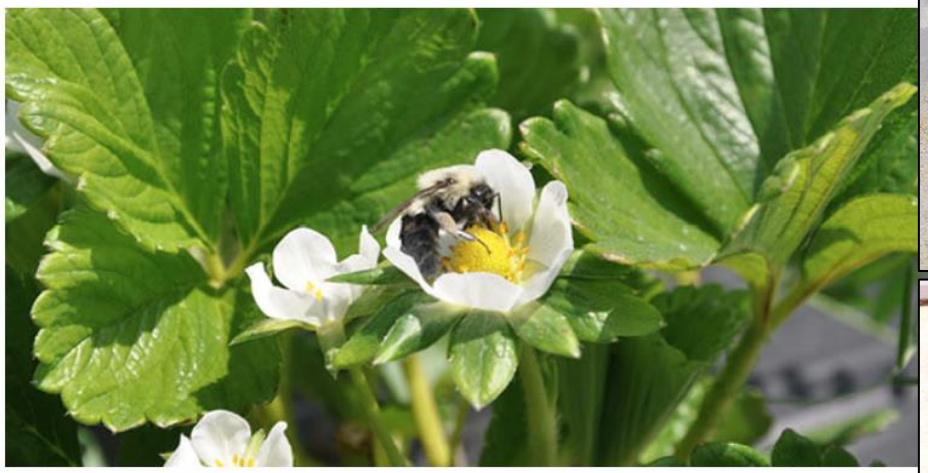


Fig. 2. Functional response of adult female *P. persimilis* to *T. urticae* adults previously sprayed with *B. bassiana* and Tween-80. Each point and bar represent mean and SE.

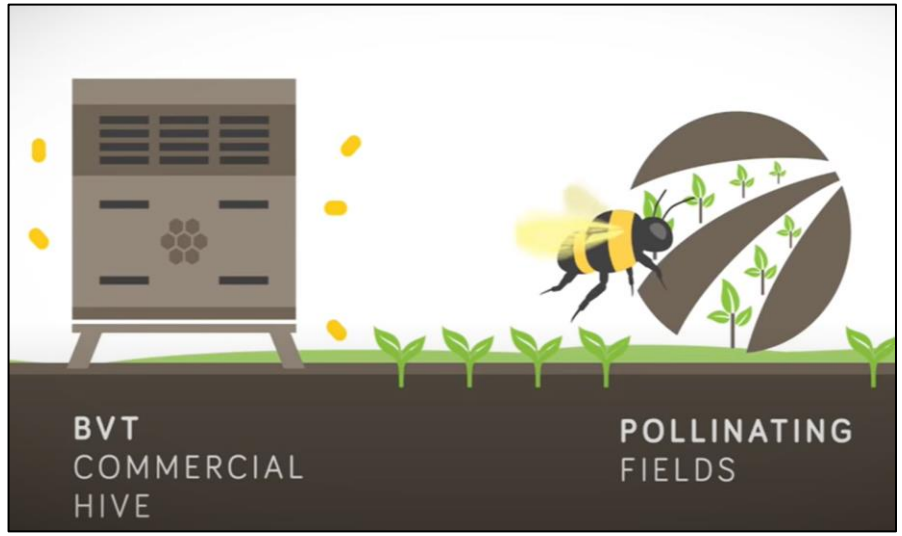
SLIGHTLY RELATED – BEE VECTORING

- Commercial bumble bees can be used to both pollinate and vector biopesticides.
  The company Bee Vectoring Technology (BVT) was initiated from research dating back to 2006.
- Studies including BotaniGard WP have shown compatibility in this system

beevt.com



Innovative Bee Delivery Tech Helps Strawberries Fight Botrytis



Scenario #1: Managing western flower thrips with BCAs, nematodes, and curative sprays of SuffOil-X on greenhouse tomatoes.

Egg
(In leaf tissue)

Larva
1 & 2
(on plant → exposed)

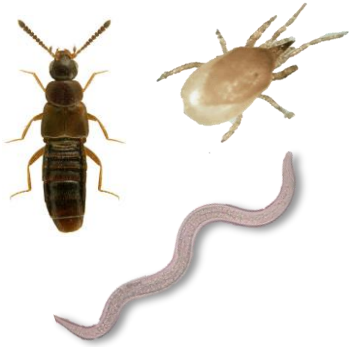
Pupa
(in soil)

Adult
(on plant → exposed)

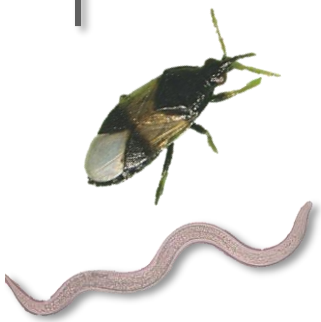
86°F — 3 days — 1.5 + 1.5 days — 3 days — 20 – 40 days

Orius
A. swirskii
A. Cucumeris

SuffOil-X spray?



Dalotia,
S. scimitus
S. feltiae



Orius
S. feltiae

SuffOil-X rescue spray?

Scenario #2: Managing western flower thrips with BCAs, nematodes, and **BotaniGard WP** on greenhouse ornamentals. The grower has blooms that are very sensitive to oils.

Egg
(In leaf tissue)

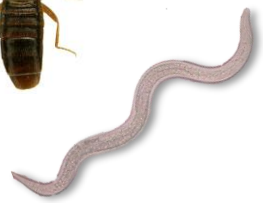
Larva
1 & 2
(on plant → exposed)

Pupa
(in soil)

Adult
(on plant → exposed)

86°F — 3 days — 1.5 + 1.5 days — 3 days — 20 – 40 days

Orius
A. swirskii
A. Cucumeris
Botanigard
dips and sprays



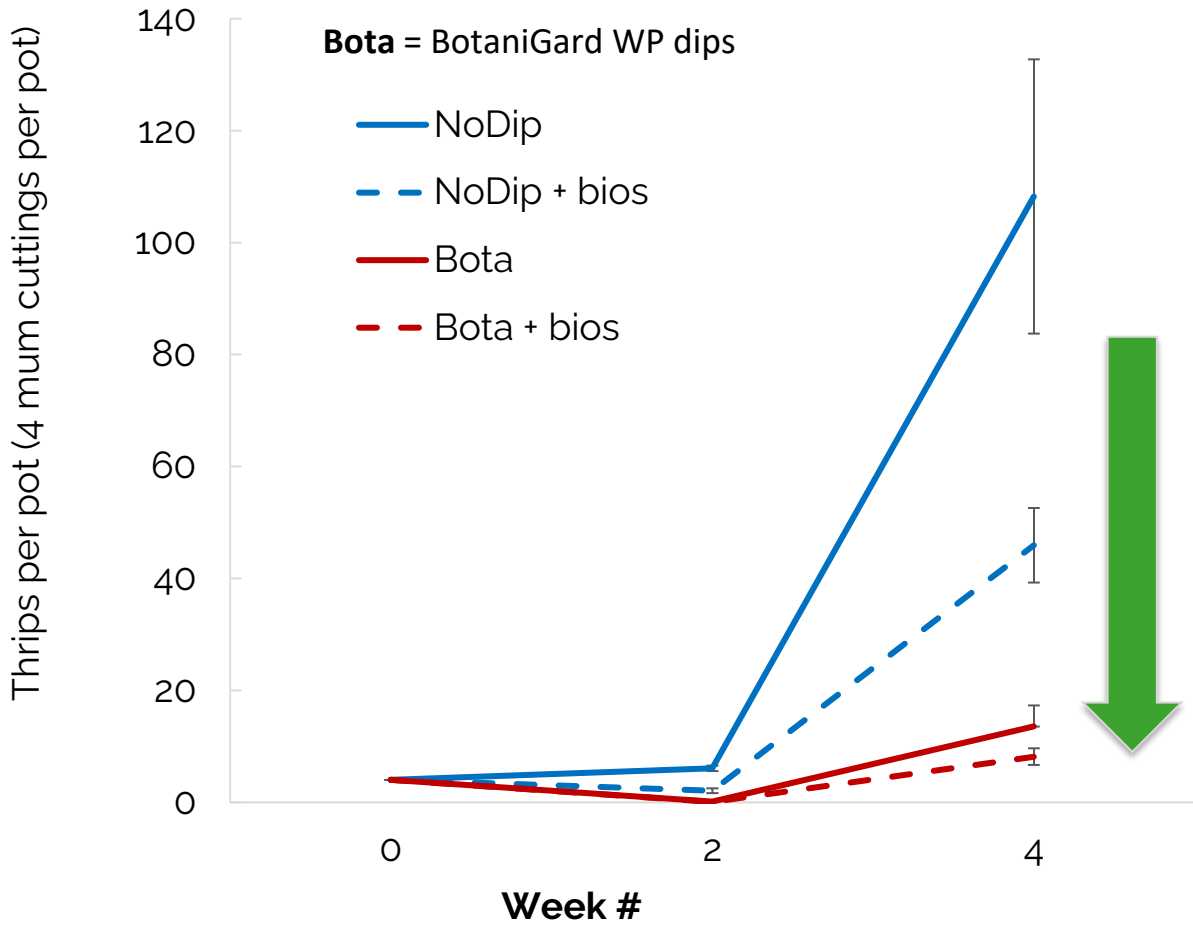
Dalotia,
S. scimitus
S. Feltiae
Botanigard drench

Orius
S. feltiae
Botanigard spray

Successful Biocontrol Programs

- Preventative vs reactive
- Propagation:
  - Cuttings
    - Insects/mites/disease
    - Pest resistance
    - Pesticide residues
  - Dipping

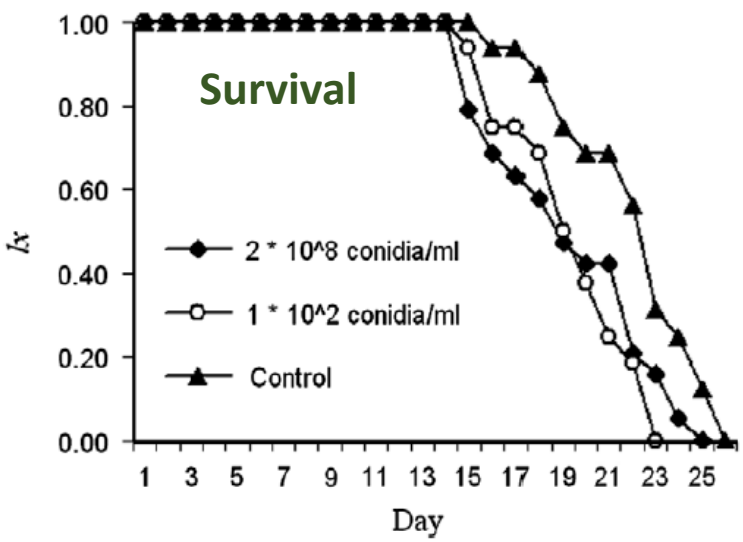
Vineland Research & Innovation Center

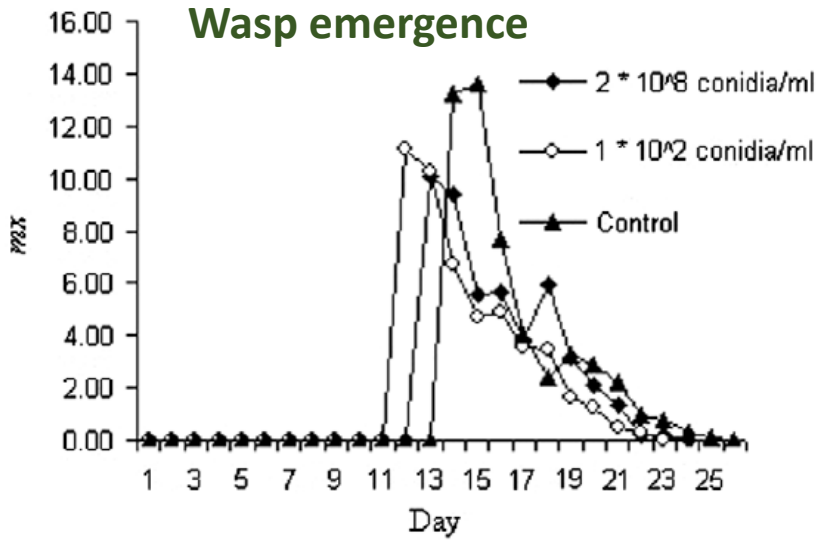


BEAUVERIA WITH APHID PARASITOIDS

In general, aphid parasitoids are compatible with *Beauveria* treatments, but aphid control was better when parasitoids were released at least 48 hr before spraying aphids with the fungus

"The presence of the fungus caused a longer duration between parasitoid mummy formation and female emergence, with the longest duration when the aphids were exposed to the parasitoids 24 h after fungal infection"





Aphidius matricariae

Rashk et al. (2009). Interactions among the entomopathogenic fungus, Beauveria bassiana (Ascomycota: Hypocreales), the parasitoid, Aphidius matricariae (Hymenoptera: Braconidae), and its host, Myzus persicae (Homoptera: Aphididae)." Biological Control 50(3)

TALK OUTLINE

- Recap on biocontrol, mycoinsecticides and biocontrol agents
- What is compatibility and how do we test this?
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- **Examples where they don't get along so well…**
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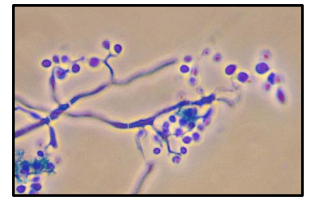
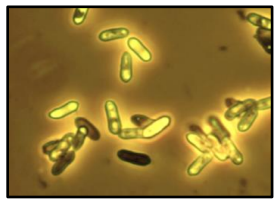
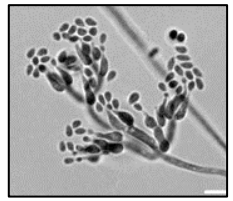






AZADIRACHTIN PRODUCTS

EcoGarden®

Botanical Insecticide, Miticide, and Nematicide

ACTIVE INGREDIENT	% by Wt.
Azadirachtin	1.2%
OTHER INGREDIENTS	98.8%
TOTAL	100.0%

Contains 0.35 grams Azadirachtin per fluid ounce.

REPELLANT, ANTIFEEDANT, AND INSECT GROWTH REGULATOR (IGR)

- Active ingredient: 1.2% azadirachtin
- IRAC code: UN (unknown MOA)
- Target pests: Broad spectrum
- Known compatibility of azadirachtin (in general; spray):
  - Predatory insects: harmless
  - Predatory mites: harmless to moderately harmful
  - Parasitoids: harmless

Minute pirate bug (*Orius*)

Experiments done by JC Chong →

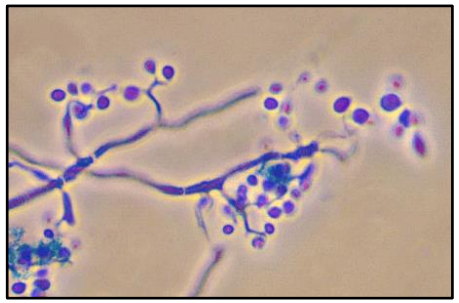
- EcoGarden used at 58 fl oz per acre (High rate for outdoor vegetables)
- Placed in cups with treated tomato leaves and flour moth eggs (food)
- **80% mortality for *Orius* adults, low egg production, and low hatch (Note – data is from laboratory studies)**

This does not mean that all azadiracthin-based products would be harmful to *Orius*…it can vary with different formulations and rates

BEAUVERIA AND PIRATE BUGS

Jaronski et al. (1998) studied *Beauveria bassiana* GHA outdoors in cotton and melon fields that also released BCA's

- 10% infection rate in *Orius* sp. sampled from cotton fields
- Minimal impacts on *Eretmocerus* wasps



Laboratory studies on mycoinsecticides and compatibility with natural enemies usually exaggerate the negative impacts that might occur in the field or greenhouse

Minute pirate bug *(Orius*)

***Eretmocerus* wasp**

Jaronski et al. (1998). Effect of a Beauveria bassiana-based mycoinsecticide on beneficial insects under field conditions. Brighton Crop Protection Conference.

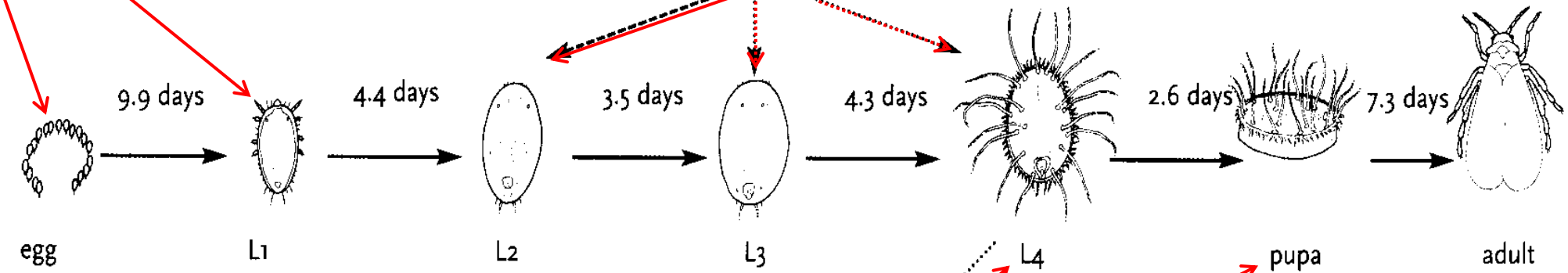
A. swirskii

Encarsia formosa

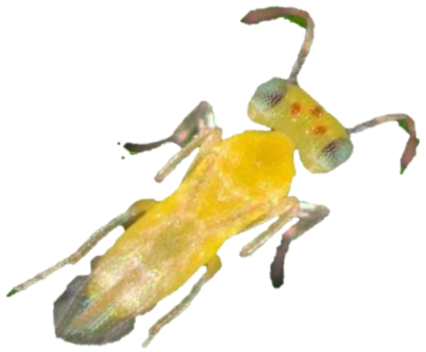
Compatible applications:
Oil, soap, Mycoinsecticides,
Botanicals, Ventigra,
MainSpring, Kontos, Endeavor

Host: *Trialeurodes vaporariorum*
(Greenhouse whitefly)

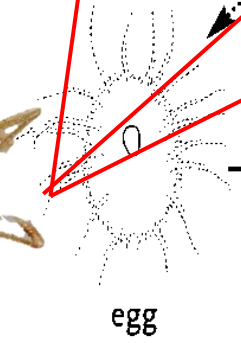
from egg to adult: 32 days



E. eremicus

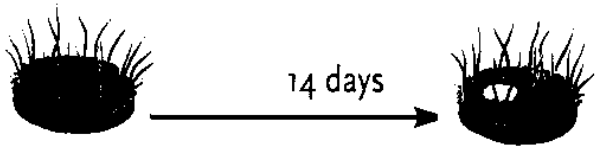


D. hesperus



host feeding
parasitism

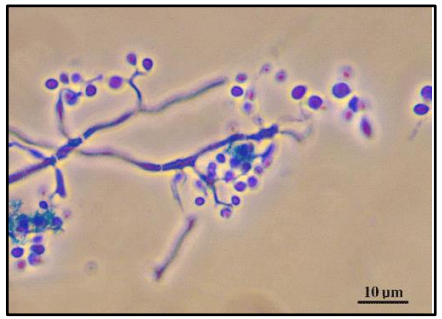
from egg to adult : 27 days

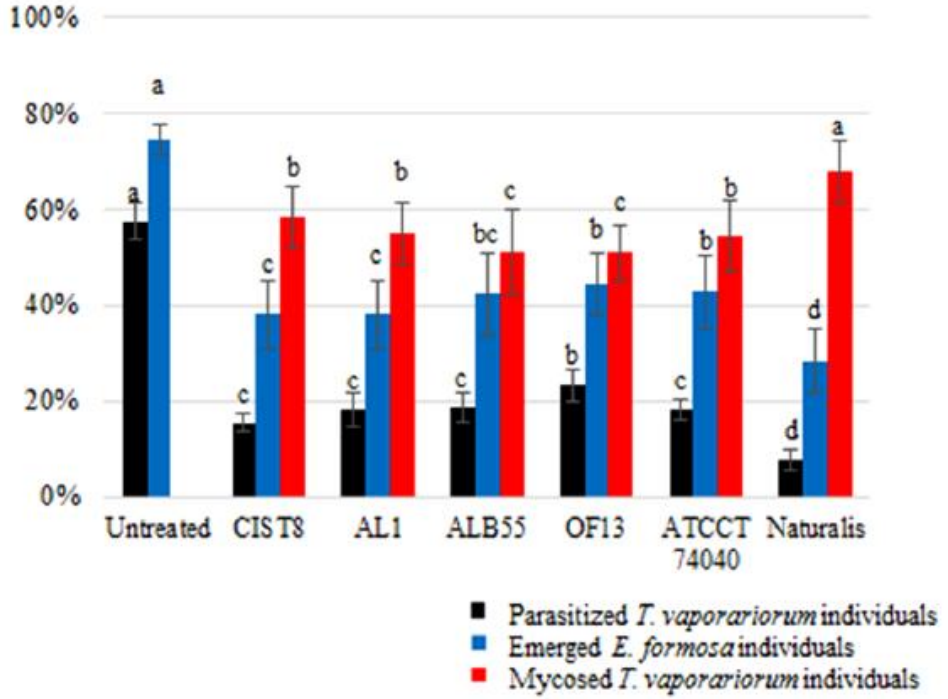


BEAUVERIA SPRAYS HURTING NATURAL ENEMIES

- The entomopathogenic fungal strains negatively affected *E. formosa* development and its parasitization activity of whitefly nymphs.
- This effect was more pronounced when the fungal strains were applied before parasitization.

Photo: Koppert





Oreste et al. (2016). Effect of Beauveria bassiana and Metarhizium anisopliae on the Trialeurodes vaporariorum-Encarsia formosa system." *Journal of Pest Science*, 89.

MYCOINSECTICIDES TYPICALLY SAFE FOR PARASITOIDS

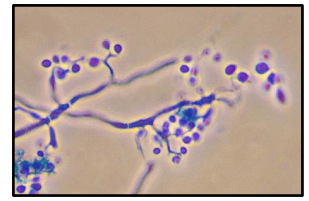
	Combinations of Parasitoids and Entomopathogenic Microorganisms	Aphelinidae				Braconidae									
		A. abdominalis	*E. formosa* 	*E. furuhashii*	*E. mundus*	*A. colemani*	*C. insularis*	*C. flavipes*	*D. longicaudata*	*D. rapae*	*D. gelechiidivoris*	*H. hebetor*	*M. bicoloratus*	*M. pallidipes*	*S. agrili*
Bacteria	*Bacillus thuringiensis* var. *aizawai*														
	Bacillus thuringiensis var. *israelensis*														
	Bacillus thuringiensis var. *kurstaki*											1 d			
	Brevibacillus laterosporus														
Fungi	*Acremonium sclerotigenum*									1					
	Beauveria bassiana	1 td	5 t		1	2		3		2 t					1
	Lecanicillium longisporum		3 td												
	Lecanicillium muscarium		1 t	1 td		1 t 2				1					
	Metarhizium anisopliae		1 t			1		4	1		1 t	2 t			
	Metarhizium brunneum					1									
	Metarhizium robertsii								1						
	Paecilomyces variotii									1					
	Simplicillium sp.									1					
Viruses	*Helicoverpa armigera* NPV											1 td			
	Spodoptera exigua MNPV												1 td	1 td	
	Spodoptera frugiperda MNPV						2 t								
	Total	1	10	1	1	7	2	7	2	6	1	4	1	1	1

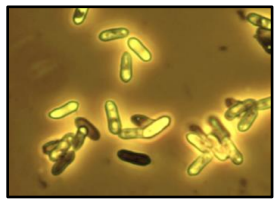
Green = combination reported as compatible; **red** = combination reported as incompatible; no fill = no report of compatibility

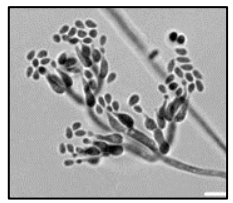
Koller et al. (2023). Entomopathogens and Parasitoids Allied in Biocontrol: A Systematic Review. Pathogens, 12(957). https://doi.org/10.3390/pathogens12070957

TALK OUTLINE

- Recap on biocontrol, mycoinsecticides and biocontrol agents
- What is compatibility and how do we test this?
- Biopesticides and biocontrol agents that get along
- Examples where they don't get along so well…
- **Summary and additional resources**

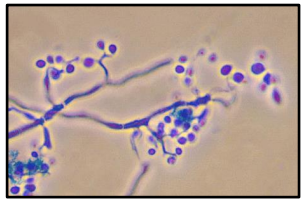


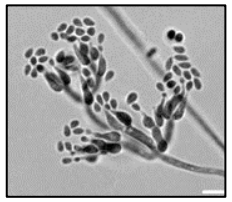




TAKE HOME MESSAGES

- **The safety of mycoinsecticides is specific, depending on isolate (the TGAI strain), host (pest), application methods, rates, and the biocontrol agent under evaluation**
- Do your homework before tank mixing products
- Talk to your BCA and biopesticide suppliers about your biocontrol programs (they might have the perfect suggestions for growers with similar needs)
- Use the compatibility websites and apps; get the most for your money



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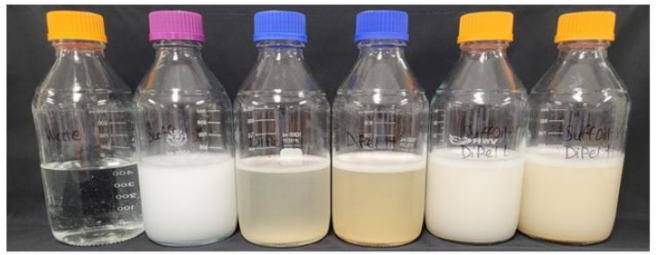
COMPATIBILITY (TANK MIXES)

BioWorks Product Compatibility

BioWorks Product	Second Product Brand name	Compatibility (* See Comments)
EpiShield™		
EpiShield™	Molt-X®	Yes*
EpiShield™	MilStop®	Yes
EpiShield™	SuffOil-X®	Yes*
EpiShield™	BotryStop® WP	Yes*
EpiShield™	ON-Gard®	Yes*
EpiShield™	CEASE®	Yes
EpiShield™	Agri-Mek® SC	Yes
EpiShield™	Nealta® Miticide	Yes
EpiShield™	Shuttle® O	Yes
EpiShield™	Kontos®	Yes
EpiShield™	Pylon®	Yes
EpiShield™	Akari® 5SC	Yes



BOTANIGARD® PRODUCT COMPATIBILITY

All products tested for compatibility and reported in this document have been evaluated for impact on *Beauveria bassiana* strain GHA spores and physical compatibility only. Tests were not carried out to evaluate impact on the partner product integrity or for plant phytotoxicity. Compatibility has been tested at normal tank mix dilutions, not in concentrated stock tank dilutions (such as for injecting at 1:100). Physical compatibility can be impacted by your water quality, tank residues, or the addition of other materials in the spray tank. All chemistries available have not been tested. As a rule of thumb, for unlisted products, wait 4-5 days before or after a fungicide application to apply BotaniGard. Most insecticides will not harm BotaniGard. Ask your distributor for information regarding specific products.

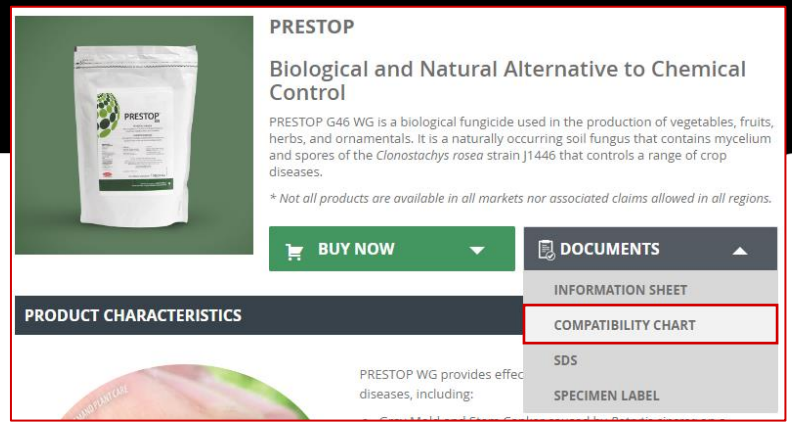
*Compatibility with spores applies to BotaniGard® ES, BotaniGard® 22WP, Mycotrol® ESO and Mycotrol® WPO.

- *Read and follow label directions for all tank mix materials.*
- *Always maintain constant agitation in your spray tank.*
- *Make applications of tank mix solutions as soon as possible after mixing.*

ADJUVANTS

ACTIVE INGREDIENT(S)	BRAND NAME	MAXIMUM TESTED RATE	COMPATIBILITY
Alcohol Ethoxylate and Alkyl Phenol Ethoxylate	Activate PlusTM	4 pts/100 gal	Yes
Aklylphenol ethoxylate, alcohol ethoxylate, tall oil fatty Acids	Activator® 90	4 pts/100 gal	Yes
Paraffinic oil, Polyol fatty acid esters, and Polyethoxylated derivatives	Agridex®	2 gal/100 gal(2.0% v/v)	Yes, poor emulsion with ES

CERTIS Biologicals



PRESTOP® LALLEMAND

COMPATIBILITY CHART

TANK MIX COMPATIBILITY

Compatible

Active Ingredient (a.i.)	Duration (hours)	Brand Names
Azoxystrobin + Difenoconazole	6	Ortiva Top
Ametoctradine + Metiram	6	Enervin
Bacillus pumilus QST 2808	6	Sonata
Bacillus subtilis QST 713	6	Rhapsody
Bacillus subtilis strain IAB/BS03	6	Aviv
Bacillus thuringiensis subsp. *aizawai*, strain ABTS-1857	6	Xentari Bio Insecticide
Bacillus thuringiensis subsp. *kurstaki*, strain ABTS-351	6	Dipel DF
Beeswax, plant-based oils	6	DeccoNatur550
Boscalid + Kresoxim-methyl	6	Collis
Boscalid + Pyraclostrobin	6	Pageant Intrinsic | Pristine
Burkholderia spp. A396 (heat killed)	6	Venerate XC
Canola Oil 96%	6	Vegol Crop Oil
Chestnut wood extract (80% tannins)	6	Dexa FL
Chromobacterium substugae PRAA4-I	6	Grendevo
Coniothyrium minitans CON/M/91-08	6	LALSTOP CONTANS WG
Copper Hydroxide	6	Kocide 3000
Copper Oxychloride + Copper Hydroxide	6	Badge SC | Badge X2
Cuprous Oxide	6	Nordox
Cyflufenamid	6	Cyflodium
Cyprodinil + Fludioxonil	6	Switch
Fenhexamid	6	Decree 50 WDG | Elevate
Fludioxonil	6	Geoxe WG
Fluopicolide + Fosetyl-Al	6	Profiler
Fluopyram + Trifloxystrobine	6	Broadform | Luna Sensation
Fosetyl Al	6	Aliette 80
Magnesium Oxide + Sulphur Trioxide	6	EpsoTop
Mandipropamid + Zoxamide	6	Revoluxio
Mefentrifluconazole	6	Avelyo | Maxtima
Metiram	6	Polyram DF
Micronized Sulfur	6	Microthiol Disperss

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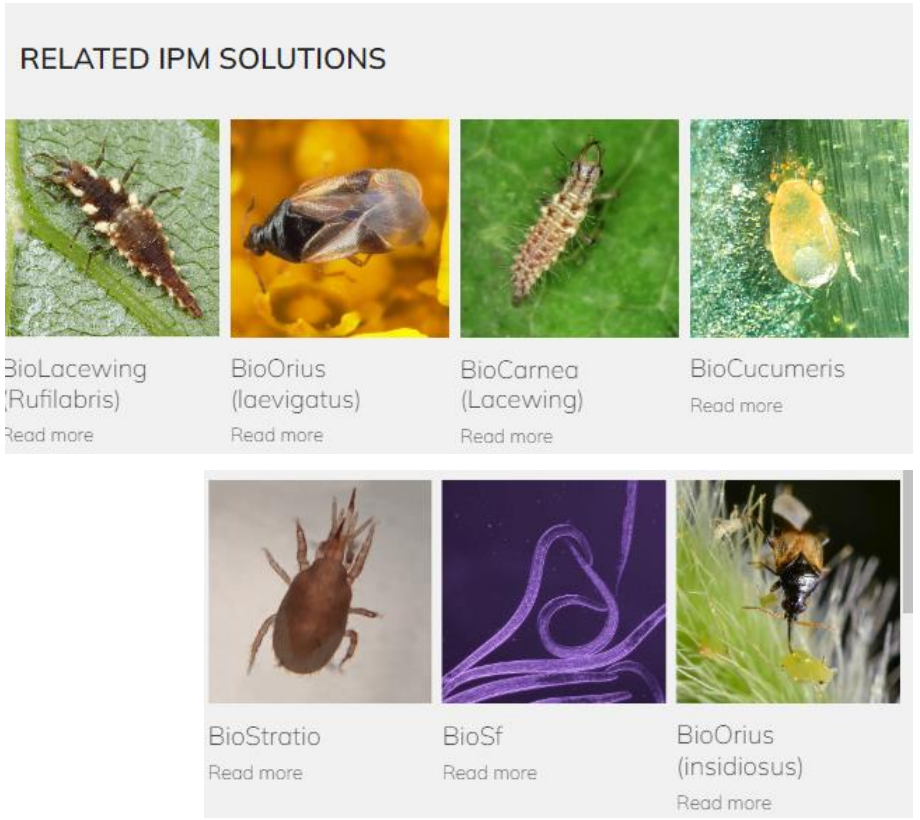
Common Pests and their Natural Enemies

- **Thrips**
  - *Orius insidiosus*
  - *Amblyseius cucumeris*
  - *Amblyseius swirskii*
  - *Stratiolaelaps scimitus*
  - *Dalotia coriaria*
  - *Steinernema feltiae*

- **Aphids**
  - *Aphidius colemani*
  - *Aphidius ervi*
  - *Aphidius matricariae*
  - *Aphelinus abdominalis*
  - *Aphidoletes aphidimyza*
  - *Chrysoperla rufilabris*

- **Whitefly**
  - *Encarsia formosa*
  - *Eretmocerus eremicus*
  - *Amblyseius swirskii*
  - *Dicyphus Hesperus*

- **Mites** (spider, broad)
  - *Amblyseius cucumeris*
  - *Amblyseius californicus*
  - *Amblyseius andersoni*
  - *Amblyseius swirskii*
  - *Phytoseiulus persimilis*



- **Fungus gnats**
  - *Steinernema feltiae*
  - *Dalotia coriaria*
  - *Stratiolaelaps scimitus*

Successful Biocontrol Programs

Develop & follow a strategy:

- Forecast inputs start to finish
- Cultural, mechanical, sanitation
- Monitoring, scouting, recordkeeping
  - Pest ID essential
- Use & timing of compatible inputs
- Consider all possible pest problems

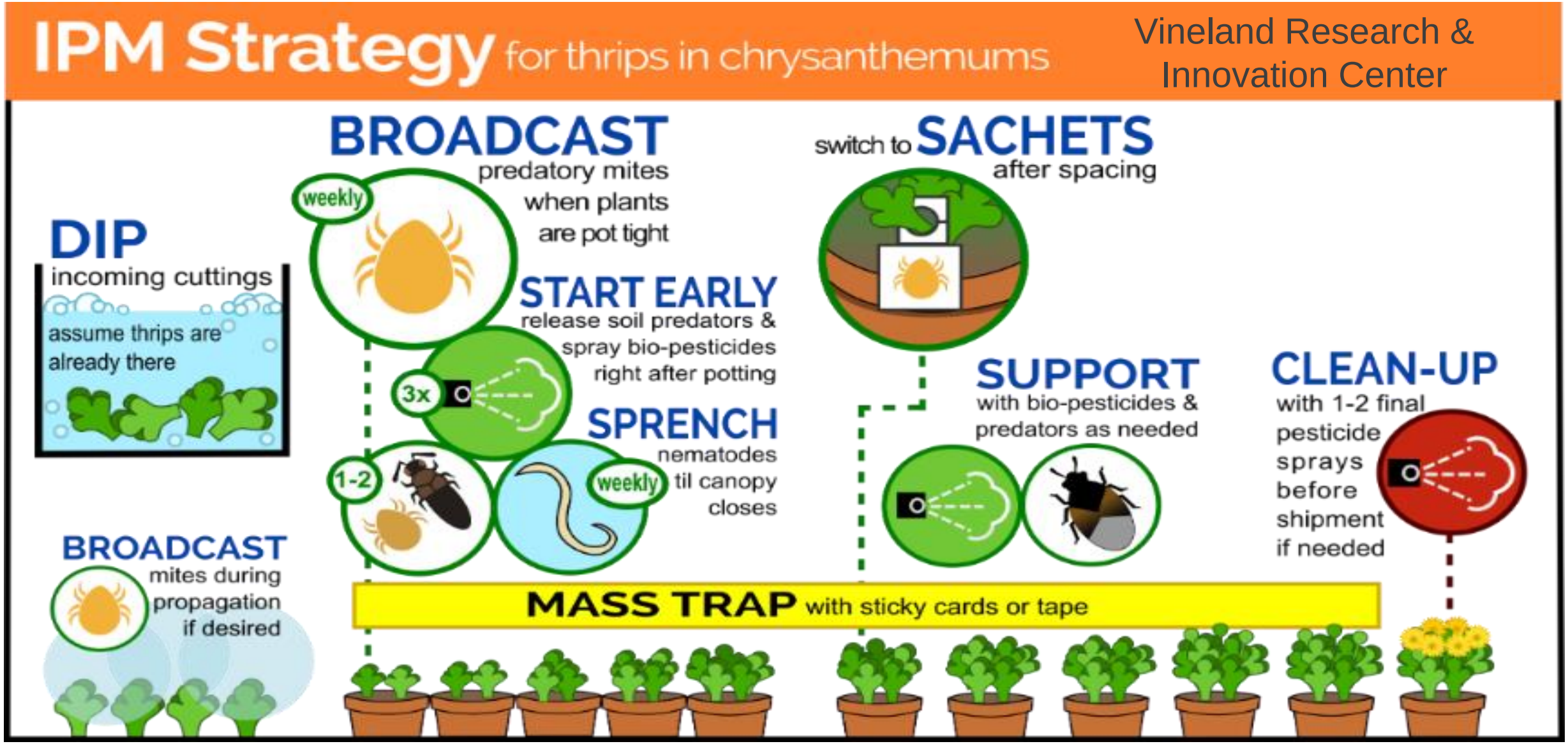
Be proactive, not reactive!

	2014			Crop 1	Crop 2		Crop 3	Crop 4	Crop 5	Aphids - a	Crop 6	Crop 7	Crop 8	Crop 9	Crop 10	Thrips
	Jan-Mar			Apr-Jun					Jul-Sep				Oct-Dec			
18-Dec	Hypoaspis	35.2		01-Apr	A. cuc sachets		72.1		08-Jul	Hypoaspis	35.2		07-Oct	Hypoaspis	70.4	
	A. cuc	13.7			A. s sachets		492.2		15-Jul	Hypoaspis	35.2			A. swirskii	154.2	
20-Dec	Nemasys	179			Hypoaspis		35.2		17-Jul	A. swirskii	102.8			A. californi	17.9	
30-Dec	Hypoaspis	35.2			A.cuc		27.4		22-Jul	Nemasys	369			Nutrimite	280	
	A. cuc	13.7		08-Apr	A. cuc		27.4			Hypoaspis	35.2		15-Oct	Hypoaspis	52.8	
06-Jan	A. cuc	13.7			Hypoaspis		35.2			A. swirskii	102.8			A. swirskii	102.8	
	Hypoaspis	35.2			Nemasys		369			Orius	35.9			Enc/Eret Bl	122.2	
13-Jan	Hypoaspis	35.2		14-Apr	A. swirskii		129.1		29-Jul	Hypoaspis	35.2		21-Oct	Nutrimite	280	
	A. cuc	13.7		15-Apr	Hypoaspis		35.2			A. swirskii	102.8			Hypoaspis	52.8	
21-Jan	A. cuc	13.7		22-Apr	Persimilis		24.2			Orius	35.9			A. swirskii	102.8	
	Hypoaspis	35.2			Orius		35.9			BotaniGard	988.8			Eret. Mix	167.4	
28-Jan	A. cuc	13.7			A. ervi		59.2		06-Aug	Hypoaspis	35.2		28-Oct	A. swirskii	154.2	
	Hypoaspis	35.2			Encarsia		27.2			A. swirskii	205			Hypoaspis	52.8	
	Nemasys	179			Hypoaspis		35.2			Orius	35.9			Eret. Mix	167.4	
	A. colemani	63			A. cuc		27.4			A. cuc Sache	225.3			Nemasys	369	
04-Feb	A. colemani	63			A.swirskii		102.8			A. cuc Sache	39.5		04-Nov	A. swirskii	154.2	
	A. cuc	13.7		29-Apr	Hypoaspis		35.2		12-Aug	A. swirskii	205.6			Hypoaspis	52.8	
	Hypoaspis	35.2			A. cuc		27.4			Hypoaspis	35.2			Met52	195.75	
11-Feb	A. colemani	63			A. swirskii		102.8			Aphidius	21			Nutrimite	280	
	A. cuc	13.7		05-May	Hypoaspis		35.2			Nutrimite	280		11-Nov	A. swirskii	154.2	

http://greenhouseipm.org/

Start Clean, Stay Clean

Don’t always need to start from scratch. Effective IPM programs are out there!



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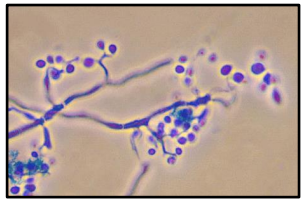
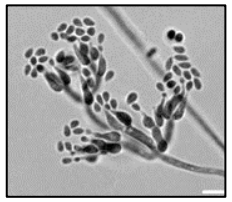
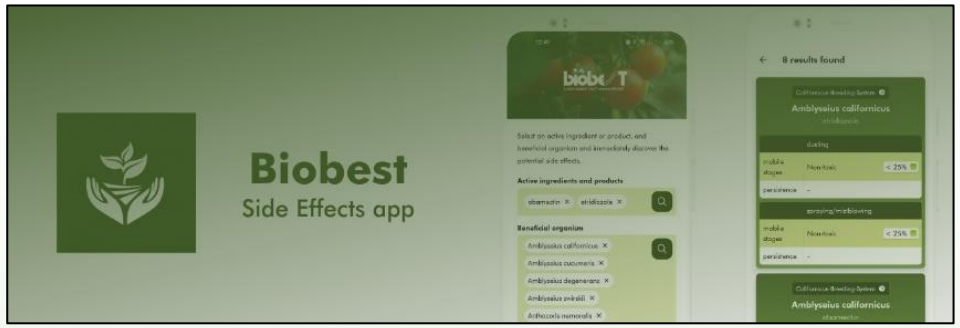
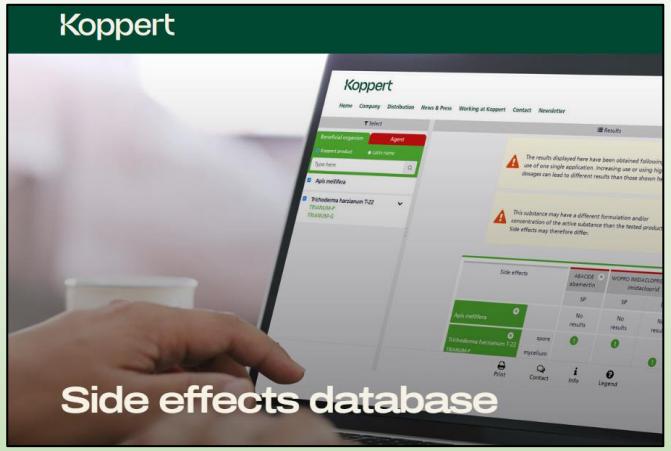
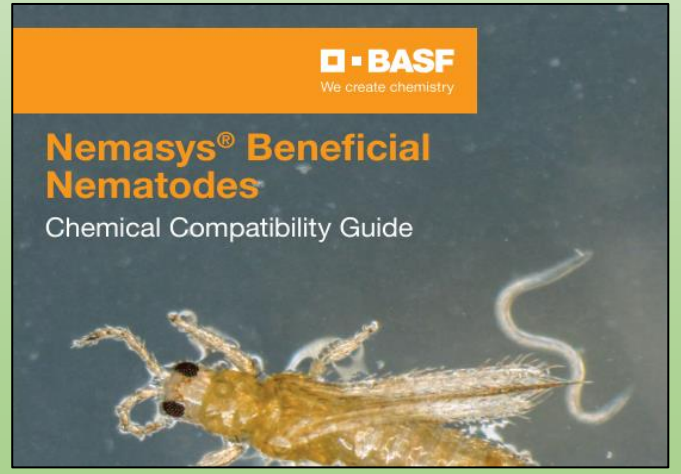




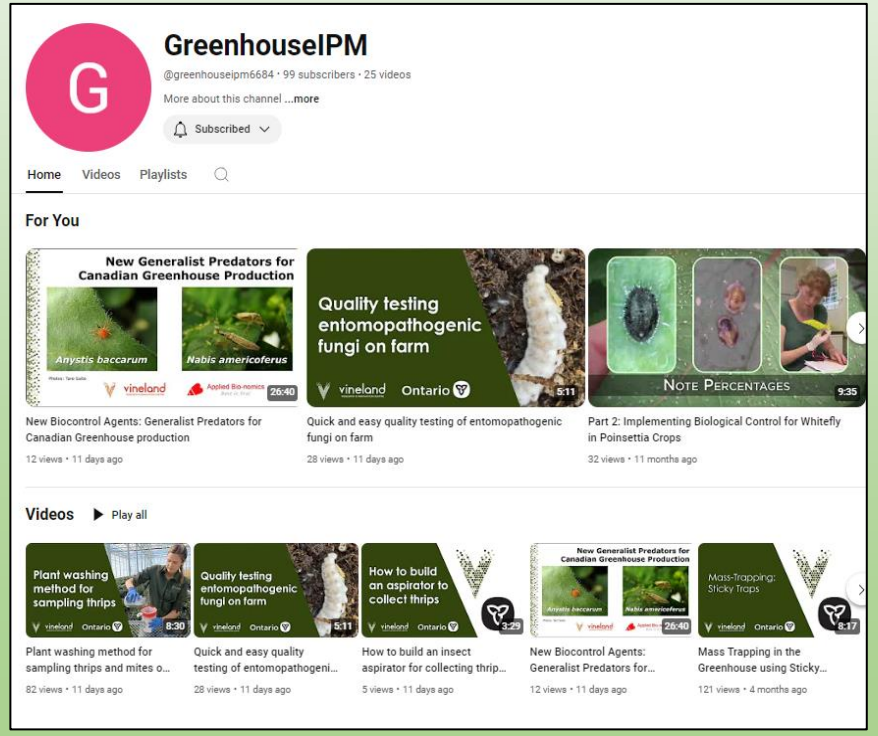




vinelandresearch.com/research-program/biological-crop-protection/

Program Resources

- GreenhouseIPM YouTube Playlist
- Biological Crop Protection Research Services
- Thrips identification key
- Grower Guide: Quality Assurance of Biocontrol Products



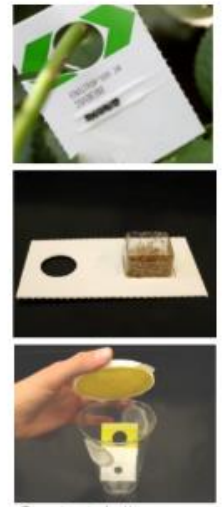
Encarsia formosa

Packaging
Pupae on cards or in blister packs

Quality assessment at arrival
Count the number of empty pupae on at least 3 cards at receipt, mark the cards and place them in the crop. Count again after 2 weeks. To calculate the quantity, take the difference between the two counts. Or, place card or blister pack in a screened container at room temperature in a shaded place for 2 weeks and count the number of emerged adults. Add a piece of yellow sticky card in the container for easy counting. An even distribution of adults on the card suggests flight capability. Repeat either method for at least 3 cards or blister packs

Difference between males and females
Almost all adults are female. Females have a yellow abdomen, males are completely black

Signs of activity in the crop
Black (greenhouse whitefly) or golden (Bemisia) parasitised scales after 5 weeks



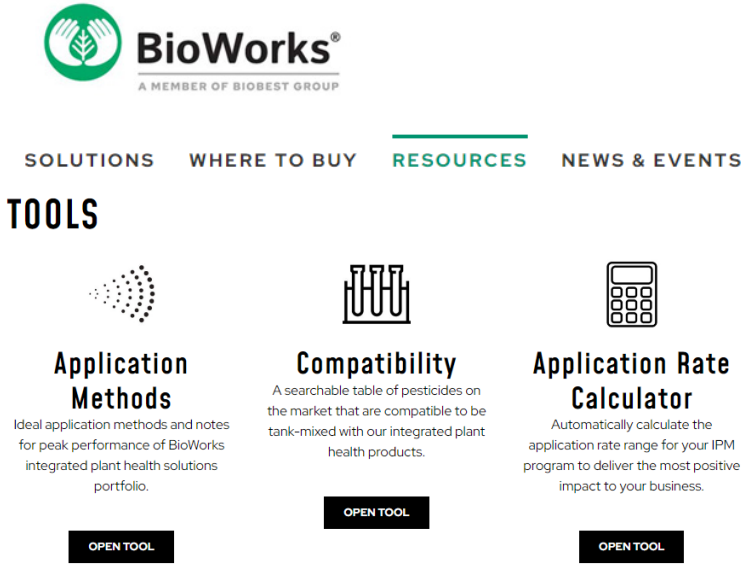
From top to bottom: Encarsia pupae on card (Koppert), Encarsia pupae in blister pack, container set-up (Vineland Research and Innovation Centre)

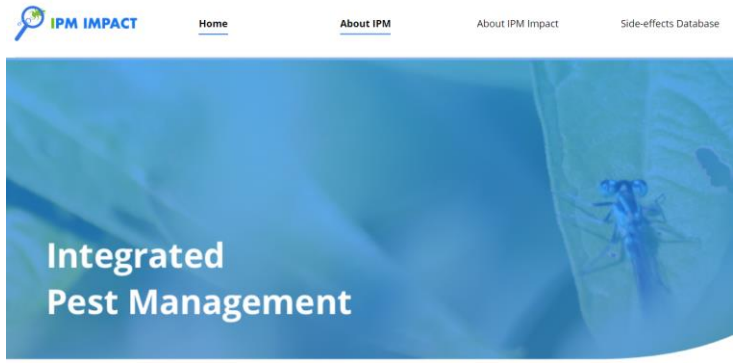
From left to right: Parasitized (black) and unparasitized (white) greenhouse whitefly pupae (Biobest), parasitized Bemisia pupa (IODHO-Maud Dubois)

vineland
RESEARCH & INNOVATION CENTRE

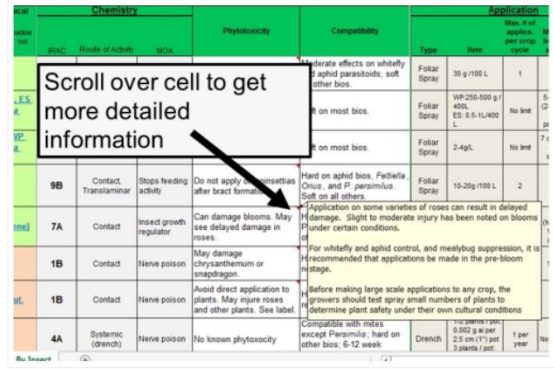
Compatibility Resources

- IOBC https://www.iobc-wprs.org/
- Greenhouse IPM http://greenhouseipm.org/
- Koppert https://sideeffects.koppert.com/
- BioBest https://www.biobestgroup.com/side-effects-app
- IPM Impact https://www.ipmimpact.com/
- BioWorks https://bioworksinc.com/ask-us/product-compatibility/
- BASF https://betterplants.basf.us/products/nemasys--beneficial-nematodes.html
- Canada Onfloricuture/OMAFRA GH Floriculture Registered Pesticides 2019: https://onfloriculture.com/
- Biopesticide companies
- Natural enemy companies





- OMAFRA Greenhouse Floriculture Registered Pesticide Spreadsheet 2019. Updated Information on Pesticide Products for use on Greenhouse Ornamental crops can be found in this downloadable and editable spreadsheet. This file contains all information growers need to make an informed decision. This includes phytotoxicity, compatibility with natural enemies, and direct links to the most recent label. Detailed notes can be found in cells with a red tab in the corner.



Additional IPM Resources

- Consultants such as https://bugladyconsulting.com
- Universities and extension services (contact your local extension office)
- Vineland Research & Innovation Center https://www.vinelandresearch.com/
- Crops that attract insects https://www.canr.msu.edu/news/crops_that_are_insect_magnets_in_the_greenhouse
- IRAC https://irac-online.org/ & FRAC https://www.frac.info/
- MSU/IRAC pesticide resistance database https://www.pesticideresistance.org/
- BPIA: https://www.bpia.org/
- Canada Onfloricuture Blog https://onfloriculture.com/
- Bee Precaution pesticide rating https://www2.ipm.ucanr.edu/beeprecaution/
- ESA https://www.entsoc.org/
- GrowerTalks Magazine https://www.growertalks.com/ 5 part series on best practices for biocontrol and many more great articles!

Acknowledgments & References

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- Vineland Research Center