WSU Efficacy of New Products for Control of *Erwinia Amylovora* Blossom Infections – Summary report 2016 to 2020.

S.Tianna DuPont, WSU Extension Specialist, Assistant Professor. Washington State University Extension. Wenatchee, WA

New product trials are conducted to provide research-based information about the efficacy of new and potential new products. Twenty to forty products and combinations are tested annually. Many of the products trialed are numbered compounds not reported here. Please consider results preliminary when less than three years of results are available. When sufficient testing has been performed new products are added to Crop Protection Guide recommendations. *It is not recommended to use products without multi-year positive results.*

Abbreviated methods

Efficacy testing trials conducted in Wenatchee WA are designed in a replicated complete block with single tree replicates. Individual trees with 100+ clusters in each of 4-5 blocks are designated to each treatment. Products are applied according to manufacturer recommendations using a Stihl SR420 blow mister backpack sprayer with a wetting agent. Products are applied to wet, calibrated to equal 100 gal/A. Trees are inoculated with *Erwinia Amylovora* at $1x10^6$ CFU ml^{-1} at 100% bloom of the king blooms. Included in these trials as a comparison and as "treated checks" are FireLine (oxytetracycline 17%) at 1.5 lbs. / 100 gal. / A and FireWall (streptomycin sulfate 17%), at 1.5 lbs. / 100 gal. / A and an organic standard (Blossom Protect+Buffer Protect 2x followed by soluble copper). An untreated and inoculated check treatment and an untreated non-inoculated check treatment are included. Trees are visually evaluated for flower cluster infection for six weeks following treatment. Cluster infection counts are summed across all dates. Fruit are evaluated for fruit skin marking during the third week in July. For full methods including environmental conditions during bloom see yearly reports.

Coppers

Coppers are generally effective disease control products. Free copper ions are taken up by cells and cause toxicity by non-selectively denaturing proteins in cells. Copper products labeled for tree fruit are either "fixed coppers" (e.g. copper oxide (e.g., Nordox), copper hydroxide (e.g., Kocide, Champ) which very slowly release copper ions forming residual protection or "soluble coppers" designed to have a lower phytotoxicity. For example, Cueva is a copper octanoate (copper salt of fatty acid/copper soap). Copper soaps have less ion burn potential on plant surfaces. Previsto, a copper hydroxide is formulated with a 'polymer matrix' designed to release copper ions over time for residual activity. Fixed coppers are generally used at green tip (Shane and Sundin, 2011) to reduce inoculum in the orchard. Soluble coppers are used during bloom in semi-arid Washington but can cause phytotoxicity in wetter areas in Oregon and California (Smith, 2012, 2015; Johnson, 2016). Current recommendations in Washington include Previsto at 3 qt/A and Cueva at 4 qt/A during the bloom period for Organic management.

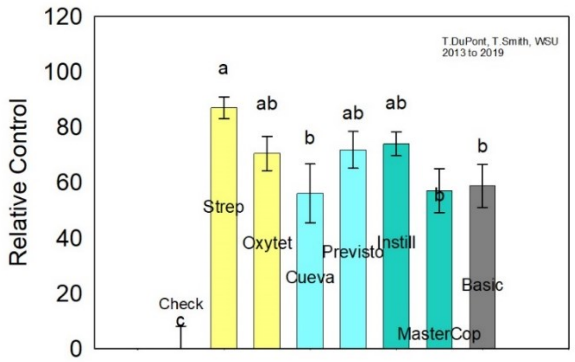


Fig 1. Relative control of copper products. Antibiotics applied at 50% bloom, 100% bloom and petal fall. Coppers applied day before and day after 100% bloom. Inoculation at 100% bloom. Firewall (streptomycin standard) at 0.5-1.8 lb/100 gal; Fireline (oxytet standard) 1-1.5 lb/100 gal; Cueva (copper octanoate) 4 qt/A; Previsto (copper hydroxide) 3 qt/A; Instill (copper sulfate pentahydrate) 30-40oz/A; Mastercop 2.5pt/A; Copper Hydroxide basic Champ, Kocide, Badge 0.5 lb/A/1.25 pints/A.

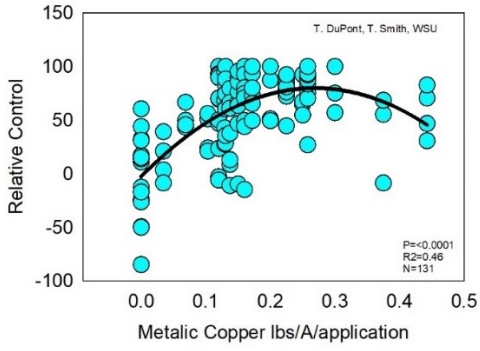


Fig 2. Relative control of fire blight blossom infections at multiple rates of metallic copper. Data include Cueva, Previsto, NuCop, Champ, Badge, Phyton, Mastercop, Instill.

Rate trials. Copper products vary widely in the concentration of metallic copper in the product. Analysis based on metallic copper content of copper products combined over multiple years and products indicates an optimum range of metallic copper application for fire blight control between 0.16 and 0.25 lbs per 100 gal per acre of metallic copper equivalent (Figure 1; $p<0.001$; $R2=0.46$).

While higher copper rates had higher russet than low rates marking was very low for all rates across three years (less than 3 on a 0 to 15 scale). Previsto at 5 qt per 100 gal had significantly higher russet than other treatments in 2017. Recommended rates are 4 qts/ 100 gal Cueva and 3 qts per 100 gal Previsto. See 'Fire blight management: new products and effective rates' WTFRC Final Report for details.

New product trials. In addition to Cueva (4 qt) and Previsto (3 qt) which have had consistent efficacy over many years, Instill (*copper sulfate pentahydrate; 30-40oz/A)* has performed well in four years of trials (Fig 1). Mastercop performed similarly to Cueva and Previsto when applied at 2.5 pt/A (2017,2019). Use precaution with new products as less data on fruit marking is available.

Table 1. Effect of new products on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2019.[‡¥]

Treatment	Rate per 100 gallons water	Application timings[x]	Infections per 100 clusters				Fruit Marking[ɣ]
Streptomycin (Firewall 17)[yz]	28 oz	50% bloom, FB, PF	4.6	±	2.7	a	0
Oxytetracycline (Fireline 17)[yz]	24 oz	50% bloom, FB, PF	5.8	±	3.2	a	0
Organic Standard (Lime sulfur, Blossom Protect+ Buffer Pro., Previsto)	6 gal, 1.24 lb + 8.75 lb, 4 qrt	LS: 70%; BP: 20%, 80%; PR: FB, PF	7.8	±	3.1	ab	0.04
copper hydroxide (Previsto) (3.3% metallic Cu)	3 qt	day before and day after FB, PF	7.8	±	3.7	ab	0.04
copper sulfate pentahydrate (Mastercop) (5.4% metallic Cu)	2.5 pt	day before and day after FB, PF	9.9	±	2.6	abc	0.01
copper sulfate pentahydrate (Instill) (5.4% metallic Cu)	30 oz	day before and day after FB, PF	10.5	±	4.6	abcd	0.01
Basic Copper (50% metallic)	1 lb	day before and day after FB, PF	11.4	±	4.0	abcd	
copper octanoate (Cueva) (1.8% metallic Cu)	4 qt	day before and day after FB, PF	11.5	±	4.1	abcd	0.11
Water, Inoculated Check	NA	FB, PF	19.0	±	9.9	cde	0

[‡]Application dates were: April 21 (pink), April 23 (20% bloom), April 24 and 25 (50% bloom), April 26 (full bloom minus 1 day), April 27 (full bloom), April 28 (full bloom plus 1 day), May 1, 2019 (petal fall), May 2, May 4 and May 6, and May 10, 2019. Inoculation was conducted on the evening of April 27, 2019 at full bloom (of king blooms) using a suspension of freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1.3 x10^6 CFU per ml and on May 1, 2019 using live culture prepared at 1x10^6 CFU ml^{-1}.

[¥] Inoculated with *Erwinia amylovora* 153 (streptomycin sensitive fireblight strain) at 100% bloom (FB) 1x10^6 CFU ml^{-1} solution.

[y] Amended with Regulaid: 30 fl. oz. per 100 gallons. [Z]Buffered to 5.6 pH.

[x]FB = full bloom (100% bloom of king bloom); PF = petal fall.

[ɣ]Average of 25 fruit per tree on a 1 to 15 scale.

Table 2. Effect of new copper products on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2017.[‡ ¥]

Treatment	Rate per 100 gallons water	Application timings[x]	Infections per 100 clusters			
Streptomycin (Firewall 17)[yz]	28.8 oz	50% bloom, FB, PF	0.3	±	0	j
Oxytetracycline (Fireline 17)[yz]	24 oz	50% bloom, FB, PF	3.8	±	2	fghij
Blossom Protect + Buffer Protect	1.25 lb + 8.75 lb	20% bloom, 80% bloom	10	±	4	cdefghij
copper sulfate pentahydrate (Mastercop) (5.4% metallic Cu)	2.5 pt	day before and day after FB	3.8	±	2	fghij
copper sulfate pentahydrate (Instill) (5.4% metallic Cu)	30 oz	day before and day after FB	6.3	±	3	defghij
Spectrum	30 oz	day before and day after FB	9.3	±	3	cdefghij
Untreated, Inoculated Check	water	FB	23	±	5	ab

[‡]Application dates were; April 28 (20% bloom); April 29 (50% bloom); April 30 (80%); May 2 (full bloom); May 9 (Petal fall), 2017. Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml.

[¥] Inoculated with *Erwinia amylovora* 153 (streptomycin sensitive fireblight strain) at 100% bloom (FB) 1x10^6 CFU ml^{-1} solution.

[x]FB = full bloom (100% bloom of king bloom); PF= petal fall.

[y]Amended with Regulaid: 30 fl. oz. per 100 gallons. [Z]Buffered to 5.6 pH.

Table 3. Effect of copper products on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2016.[‡]

Treatment	Rate per 100 gallons water	Application timings	Infections per 100 clusters			
Streptomycin standard (Firewall 17)[yz]	1.5 lb	50% bloom, 100% bloom, PF	1.2	±	0.8	ef

Oxytetracycline standard (Fireline 17) [yz]	1.5 lb	50% bloom, 100% bloom, PF	4.5	±	1.9	def
Blossom Protect + Buffer Protect	20 oz +140 oz	20%, 50% and 100% bloom, PF	5.7	±	2.4	def
copper hydroxide (Previsto) (3.3% metallic Cu)	3 qt	day before and day after 100% bloom	9.0	±	1.9	cdef
copper sulfate pentahydrate (Mastercop) (5.4% metallic Cu)	16 oz	20% bloom and 100% bloom	21.9	±	2.4	abcdef
copper sulfate pentahydrate (Mastercop) (5.4% metallic Cu)	24 oz.	20% bloom and 100% bloom	27.9	±	4.1	abcdef
copper octanoate (Cueva) (1.8% metallic Cu)	3 qt.	100% bloom	27.0	±	9.1	abcdef
Untreated, Inoculated Check	water	100% bloom	45.0	±	10.9	a

[‡]Application dates April 8 (20% bloom); April 9 (50% bloom); April 11 (full bloom); April 15 (Petal fall). Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml.
[y] Amended with Regulaid: 30 fl. oz. per 100 gallons. [Z]Buffered to 5.6 pH.

Alum

Alum (Potassium aluminum sulfate) has been tested for four years in Washington. This compound is experimental (non-labeled). It has had consistent positive results with an average of 75% control relative to the untreated check in 2016, 2017 and 2019 when the product was applied at an 8 to 10 lb per 100 gal rate (Figure 3). This control was lower than but not significantly different than the oxytetracycline check (82% control) and the streptomycin check (91% relative control). Marking from chemical russet was negligible in all (< 1 on a 0 to 15 scale).

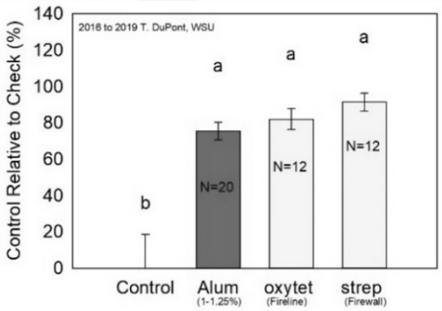


Figure 3. Relative control of *Erwinia Amylovora* by Alum in Washington 2016 to 2019[1]. Alum applied at full bloom (approx.12 hr before inoculation) and petal fall at a rate of 8-10 lb/100 gal. Antibiotics applied at 50%, 100% bloom and petal fall.

Table 4. Effect of Mineral Product Treatments on *Erwinia Amylovora* infection of apple blossoms in Wenatchee, WA 2019.[‡ ɣ]

Treatment	Rate per 100 gal	Application timings	infections per 100 clusters			
Streptomycin standard (Firewall 17)[yz]	28.8 oz	50% bloom, 100% bloom, petal fall	4.8	±	2.8	a
Oxytetracycline standard (Fireline 17) [yz]	24 oz	50% bloom, 100% bloom, petal fall	5.7	±	3.1	a
Organic standard (lime sulfur, Blossom Protect+ Buffer Protect, Previsto)	6 gal 1.24+8.75 lb 3 qt	LS: 70% bloom BP: 20% bloom, 80% bloom PR: 100% bloom, petal fall	6.1	±	1.1	a
Alum (0.5%)	4 lb	100% bloom, petal fall	8.3	±	4.7	a
Alum (0.75%)	6 lb	100 % bloom, petal fall	9.0	±	3.5	a
Alum (1%)	8 lb	100% bloom, petal fall	4.3		2.7	a
Alum (1.25%)	10 lb	100% bloom, petal fall	4.5		2.3	a
Untreated, Inoculated check	NA	100% bloom	21.0	±	11.1	b

[‡]Application dates were: April 21 (pink), April 23 (20% bloom), April 24 and 25 (50% bloom), April 26 (full bloom minus 1 day), April 27 (full bloom), April 28 (full bloom plus 1 day), May 1, 2019 (petal fall), May 2, May 4 and May 6, and May 10, 2019. Inoculation was conducted on the evening of April 27, 2019 at full bloom (of king blooms) using a suspension of freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1.3 x10^6 CFU per ml and on May 1, 2019 using live culture prepared at 1x10^6 CFU ml^{-1}.
[y] Amended with Regulaid: 30 fl. oz. per 100 gallons. [Z]Buffered to 5.6 pH.
[ɣ]No significant fruit marking found for any treatments.

Table 5. Effect of Mineral Product Treatments on *Erwinia Amylovora* infection of apple blossoms in Wenatchee WA 2020.[‡ ɣ]

Treatment	Rate per 100 gal	Application timings	infections per 100 clusters			
Streptomycin standard (Firewall 17)[yz]	28.8 oz	50% bloom, 100% bloom, petal fall	2.8	±	1.2	a
Oxytetracycline standard (Fireline 17) [yz]	28.8 oz	50% bloom, 100% bloom, petal fall	8.2	±	2	b

Organic Standard + Blossom Protect + Buffer Protect + Soluble Copper (Previsto)	1.24 lb + 8.75 lb 3 qt	50% bloom, 80% bloom, 100% bloom, petal fall	9.5	±	1.3	bc
Alum[y]	8 lb	100% bloom, petal fall	22	±	4.2	d
TDA-NC-1[x]	17.1 g	Tight cluster, 50% bloom, 100% bloom + 1 day, petal fall	13	±	2.3	bc
Water-treated check	NA	100% bloom, +1 day, petal fall	31	±	7.1	d

[‡]Application dates were: April 14 (20% bloom), April 16 (50% bloom), April 17 (80% bloom) and April 18 (full bloom), April 19 (full bloom plus 1 day), April 22 (petal fall). Inoculation was conducted on the evening of April 18, 2020 at full bloom (of king blooms) using a suspension of 50% freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain) and 50% live cells, which was prepared at 24 x 10^6 CFU per ml.
[y] Amended with Regulaid: 30 fl. oz. per 100 gallons.
[z]Buffered to 5.6 pH.
[x] Amended with Silwet oil at 0.0125%. Copper sulfate product.
[¤]No significant fruit marking found for any treatments.

Table 6. Effect of Aluminum Potassium Sulfate on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2017. [‡¤]

Treatment	rate per 100 gal	Application timings	infections per 100 clusters			
Streptomycin (Firewall 17) [yz]	28.8 oz	50% bloom, 100% bloom, PF	0.3	±	0.6	a
Oxytetracycline (Fireline 17) [yz]	24 oz	50% bloom, 100% bloom, PF	3.8	±	3.4	a
Alum	4 lb	100% bloom, PF	5.8	±	6.9	a
Alum	6 lb	100% bloom, PF	6.6	±	2.6	a
Alum	8 lb	100% bloom, PF	7.6	±	6.2	a
Alum	10 lb	100% bloom, PF	4.3	±	1.6	a
VP20	9 lb	100% bloom, PF	9.25	±	3.75	ab
Untreated, Inoculated Check	water	100% bloom	22.6	±	10	b

[‡]Application dates were; April 28 (20% bloom); April 29 (50% bloom); April 30 (80%); May 2 (full bloom); May 9 (Petal fall), 2017. Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml.
[y] Amended with Regulaid: 30 fl. oz. per 100 gallons.
[z]Buffered to 5.6 pH.
[¤]No significant fruit marking found for any treatments.

Table 7. Effect of Aluminum Potassium Sulfate on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2016. [‡¤]

Treatment	Rate per 100 gallons water	Application timings	infections per 100 clusters			
Streptomycin (Firewall 17)[z,y]	1.5 lb	50% bloom, 100% bloom, PF	1.2	±	0.8	ef
Oxytetracycline (Fireline 17) [z,y]	1.5 lb	50% bloom, 100% bloom, PF	4.5	±	1.9	def
Blossom Protect + Buffer Protect	20 oz 140 oz	20%, 50% and 100% bloom, PF	5.7	±	2.4	def
Previsto	3 qt	day before and day after 100% bloom	9.0	±	1.9	cdef
Alum	133.5 oz	100% bloom, PF	13.2	±	6.3	bcdef
Untreated, Inoculated Check	water	100% bloom	45.0	±	10.9	a

[y] Amended with Regulaid: 30 fl. oz. per 100 gallons.
[z] Buffered to 5.6 pH.
[‡]Application dates April 8 (20% bloom); April 9 (50% bloom); April 11 (full bloom); April 15 (Petal fall). Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml.
[¤]No significant fruit marking found for any treatments.

Oxidizers

Several new peroxide products with higher levels of peracetic acid have recently been released (e.g. Jet Ag, Oxidate 5.0). Peracetic acid denatures proteins, disrupts cell wall permeability, and oxidizes sulfhydryl and sulfur bonds in proteins, enzymes, and other metabolites. Peracetic acid and peroxide oxidizers generally have little residual activity.

New peroxide + peracetic acid products have only two years of data. A third year of data is needed to determine appropriate rates and timings.

Table 8. Effect of hydrogen peroxide, peracetic acid treatments applied to Red delicious apple trees on infection from *Erwinia Amylovora* in apple blossoms in Orondo, Washington in 2020.[‡]

	Rate per 100 gal	Application timings	strikes per 100 clusters[u]			
Streptomycin standard (Firewall 17)[z,y]	28.8 oz	50% bloom, 100% bloom, petal fall	2.8	±	1.2	a
Oxytetracycline standard (Fireline 17)[z,y]	28.8 oz	50% bloom, 100% bloom, petal fall	8.2	±	2	b
Organic standard (Blossom Protect/ Buffer Protect + Previsto)	1.24 lb 8.75 lb 3 qt	50% bloom, 80% bloom, 100% bloom, petal fall	9.5	±	1.3	b
hydrogen peroxide (26.5%), peracetic acid (4.9%) (J)	128 fl oz	Day after inoc and 3 days after inoc[v]	28	±	3.9	c
hydrogen peroxide (27%), peracetic acid (5%) (O)	128 fl oz	Day after inoc and 3 days after inoc	24	±	3.8	c
hydrogen peroxide (27%), peracetic acid (5%) (O)	50 fl oz	Day after inoc and 3 days after inoc	28	±	4.1	c
Untreated water check	----	100% bloom, +1 day, petal fall	31	±	7.1	c

[‡]Application dates were: April 15, pink, April 19 (20% bloom), April 21 (50% bloom), April 23 (full bloom), April 24 (full bloom plus 1 day), April 28 (petal fall). Inoculation was conducted on the evening of April 23, 2020 at full bloom (of king blooms) using a suspension of freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1.3 x10^6 CFU per ml.
[y] Amended with Regulaid: 30 fl. oz. per 100 gallons.
[z] Buffered to 5.6 pH.
[u] Transformed log(x + 1) prior to analysis of variance; non-transformed means are shown.
[v] Note inoculation was done at dusk. Day after spray is done early morning next day. 3 days after inoculation coincided with petal fall sprays.

Table 9. Effect of hydrogen peroxide, peracetic acid treatments applied to Red delicious apple trees on infection *Erwinia Amylovora* in apple blossoms in Orondo Washington, 2019.[‡]

	Rate per 100 gal	Application timings	strikes per 100 clusters				fruit marking[¥]
Streptomycin standard (Firewall 17)[z,y]	28.8 oz	50% bloom, 100% bloom, petal fall	4.6	±	2.7	a	0
Oxytetracycline standard (Fireline 17)[z,y]	24 oz	50% bloom, 100% bloom, petal fall	5.8	±	3.2	a	0
Organic standard (lime sulfur, Blossom Protect+ Buffer Protect, Previsto)	6 gal 1.24 +8.75lb 3 qt	LS: 70% bloom BP: 20% bloom, 80% bloom PR: 100% bloom, petal fall	7.8	±	3.1	a	0.04
oxytet (Fireline 17)[zy] + hydrogen peroxide (26.5%), peracetic acid (4.9%) (J)	24 oz + 128 oz	Fireline at: 50% bloom, 100% bloom, PF; Jet Ag at 5, 7, 10, 14 days after full bloom	4.0		2.5	a	
oxytet (Fireline 17)[zy] + hydrogen peroxide (27%), peracetic acid (5%) (O)	24 oz + 128 fl oz	Fireline at: 50% bloom, 100% bloom, PF; Oxidate T&V at 5, 7, 10, 14 days after full bloom	4.7	±	1.6	a	8.2±0.7
Untreated, Inoculated check	----	100% bloom	20.9	±	11.1	b	0

[‡]Application dates were: April 21 (pink), April 23 (20% bloom), April 24 and 25 (50% bloom), April 26 (full bloom minus 1 day), April 27 (full bloom), April 28 (full bloom plus 1 day), May 1, 2019 (petal fall), May 2, May 4 and May 6, and May 10, 2019. Inoculation was conducted on the evening of April 27, 2019 at full bloom (of king blooms) using a suspension of freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1.3 x10^6 CFU per ml and on May 1, 2019 using live culture prepared at 1x10^6 CFU ml^{-1}.
[y] Amended with Regulaid: 32 fl. oz. per 100 gallons. [z] Buffered to 5.6 pH.
[¥]Average of 25 fruit per tree on a 1 to 15 scale.

Figure 4. Russet fruit marking of hydrogen peroxide, peracetic acid treatment 2 in 2019.

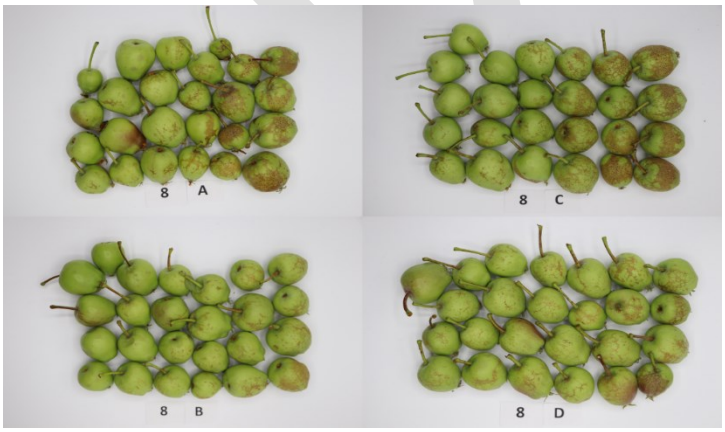


Figure 5. Effect of treatments applied to Red delicious apple trees to suppress fire blight on the population size of *E. amylovora* strain 153N on flowers at Full Bloom (FB), Petal Fall (PF) and Petal Fall + 1 week (PF+1) in Washington 2020.

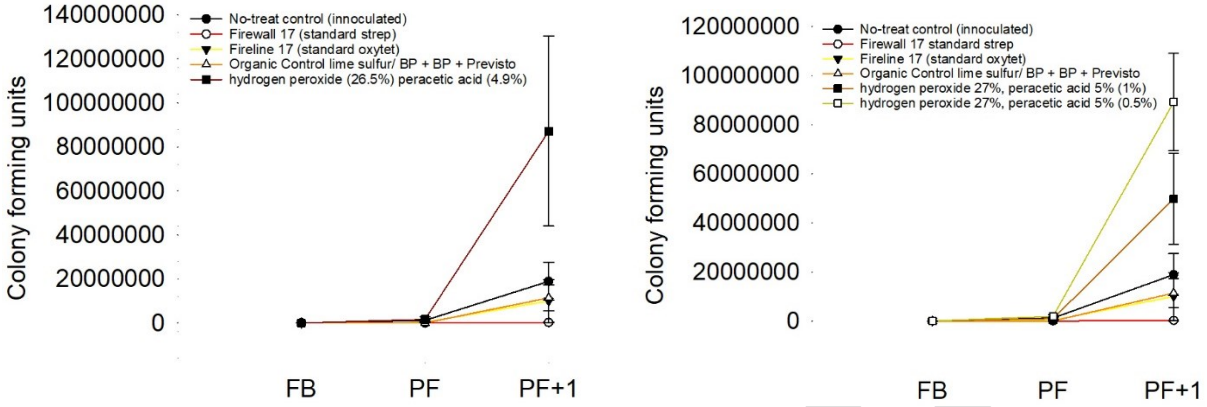


Table 10. Effect of hydrogen peroxide, peracetic acid products on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2016.[‡]

Treatment	Rate per 100 gal	Application timings	infections per 100 clusters			
Streptomycin standard (Firewall 17) [zy]	1.5 lb	50%, 100% bloom, PF	1.2	±	0.8	ef
Oxytetracycline standard (Fireline 17) [zy]	1.5 lb	50%, 100% bloom, PF	4.5	±	1.9	def
Blossom Protect + Buffer Protect, then hydrogen peroxide (27.1%), peracetic acid (2.0%) (O)	20 oz + 140 oz 128 oz	50%, 100% bloom, PF	4.9	±	2.5	def
Blossom Protect + Buffer Protect	20 oz + 140 oz	20%, 50%, 100% bloom, PF	5.7	±	2.4	def
hydrogen peroxide (27.1%), peracetic acid (2.0%) (O)	128 oz	20%, 50%, 100% bloom, PF	35.8	±	6.3	abc
Untreated, Inoculated Check	water	100%	45.0	±	10.9	a

[y] Amended with Regulaid: 30 fl. oz. per 100 gallons. [Z]Buffered to 5.6 pH.
[2]FB = full bloom (100% bloom of king bloom); PF= petal fall.
[‡]Application dates April 8 (20% bloom); April 9 (50% bloom); April 11 (full bloom); April 15 (Petal fall). Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml.

Essential Oils

Essential oils (e.g. from thyme, mint, cinnamon, oregano) have known antimicrobial activity. In one laboratory study active compounds from *Origanum compactum* (oregano family) and *Thymus vulgaris (Thyme)* were most effective (Kokoskova *et al.*, 2011). In another study, Apium graveolens (celery seed) and Curcuma longa (turmeric) essential oils showed a reduction in *Erwinia amylovora* virulence (Akhlaghi *et al.*). These oils are rich in antioxidative phenolic compounds which are believed to be responsible for their antimicrobial activity (Chizzola *et al.*, 2008). Several essential oil products are available commercially which may be of interest including Thymegard, Thymox, and Cinnerate.

New essential oil products have only two years of data. A third year of data is needed to determine appropriate rates and timings.

Table 11. Effect of Essential Oil/ Plant Extract Treatments on infection of *Erwinia Amylovora* in apple blossoms 2020 Orondo, WA. [‡]

Treatment	Rate per 100 gal	Application timings	infections per 100 clusters			fruit marking
Streptomycin standard (Firewall 17)[yz]	28.8 oz	50% bloom, 100% bloom, petal fall	2.8	±	1.2	a
Oxytetracycline standard [y] (Fireline 17)[yz]	28.8 oz	50% bloom, 100% bloom, petal fall	8.2	±	2	b
Organic Standard (Blossom Protect/Buffer) + Soluble Copper (Previsto)	1.24 lb 8.75 lb 3 qt	50% bloom, 80% bloom, 100% bloom, petal fall	9.5	±	1.3	bc
Thyme oil (23%)	2 qrt	80% bloom, 100% bloom +1 day, petal fall	17	±	2.3	cd
Thymol (23%)	2 qrt	80% bloom, 100% bloom, petal fall	22		3.5	d
Cinnamon oil (60%)	1 qt	50% bloom, morning after inoc, petal fall	19	±	3.5	d
TS28	21.9 ml	100% bloom, +1 day, petal fall	23	±	5.5	cd
TS108	25 ml	100% bloom, +1 day, petal fall	31	±	5.8	d

ET91	38.4 oz	100% bloom, +1 day, petal fall	10	±	6.6	b
Lupine[u]	40 oz	50% bloom, morning after inoc, petal fall	22.6	±	4.1	cd
Water-treated check	NA	100% bloom, +1 day, petal fall	31	±	7.1	d

[y] Amended with Regulaid: 30 fl. oz. per 100 gallons.
[z]Buffered to 5.6 pH.
[‡]Application dates were: April 14 (20% bloom), April 16 (50% bloom), April 17 (80% bloom) and April 18 (full bloom), April 19 (full bloom plus 1 day), April 22 (petal fall). Inoculation was conducted on the evening of April 18, 2020 at full bloom (of king blooms) using a suspension of 50% freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain) and 50% live cells, which was prepared at 24 x 10^6 CFU per ml.
[u]Banda de Lupinus albus doce (20%).

Table 12. Effect of Essential Oil/Plant Extract Treatments on infection of *Erwinia Amylovora* in apple blossoms in 2019 Wenatchee, WA.[‡]

Treatment	Rate per 100 gal	Application timings	strikes per 100 clusters**				fruit marking
Streptomycin standard (Firewall 17)[yz]	28.8 oz	50% bloom, 100% bloom, petal fall	4.6	±	2.7	a	0
Oxytetracycline standard (Fireline 17) [yz]	24 oz	50% bloom, 100% bloom, petal fall	5.8	±	3.2	a	0
Organic standard (lime sulfur,	6 gal	LS: 70% bloom					0
Blossom Protect+ Buffer Protect,	1.24+8.75 lb	BP: 20% bloom, 80% bloom					
Previsto)	3 qt	PR: 100% bloom, petal fall	6.1	±	1.2	a	
Cueva/ Previsto	4qt/3qt	day before and day after 100% bloom, petal pall	9.7	±	2.7	a	0
Thyme oil (23%)	2 qrt	50%, 100% bloom, petal fall, + 4 post petal fall apps	9.2	±	5.3	a	4.1 ± 0.9
Untreated, Inoculated check	NA	100% bloom	20.9	±	11.1	b	0

[z]Buffered to 5.6 pH. [y] Amended with Regulaid: 32 fl. oz. per 100 gallons.
[‡]Application dates were: April 21 (pink), April 23 (20% bloom), April 24 and 25 (50% bloom), April 26 (full bloom minus 1 day), April 27 (full bloom), April 28 (full bloom plus 1 day), May 1, 2019 (petal fall), May 2, May 4 and May 6, and May 10, 2019. Inoculation was conducted on the evening of April 27, 2019 at full bloom (of king blooms) using a suspension of freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1.3 x10^6 CFU per ml and on May 1, 2019 using live culture prepared at 1x10^6 CFU ml^{-1}.

Figure 6. Russet fruit marking of Thyme oil treatment with eight applications, Washington 2019.

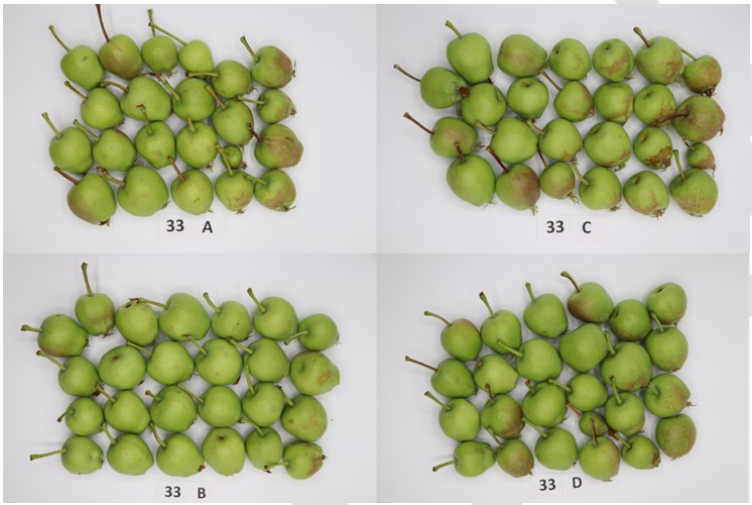
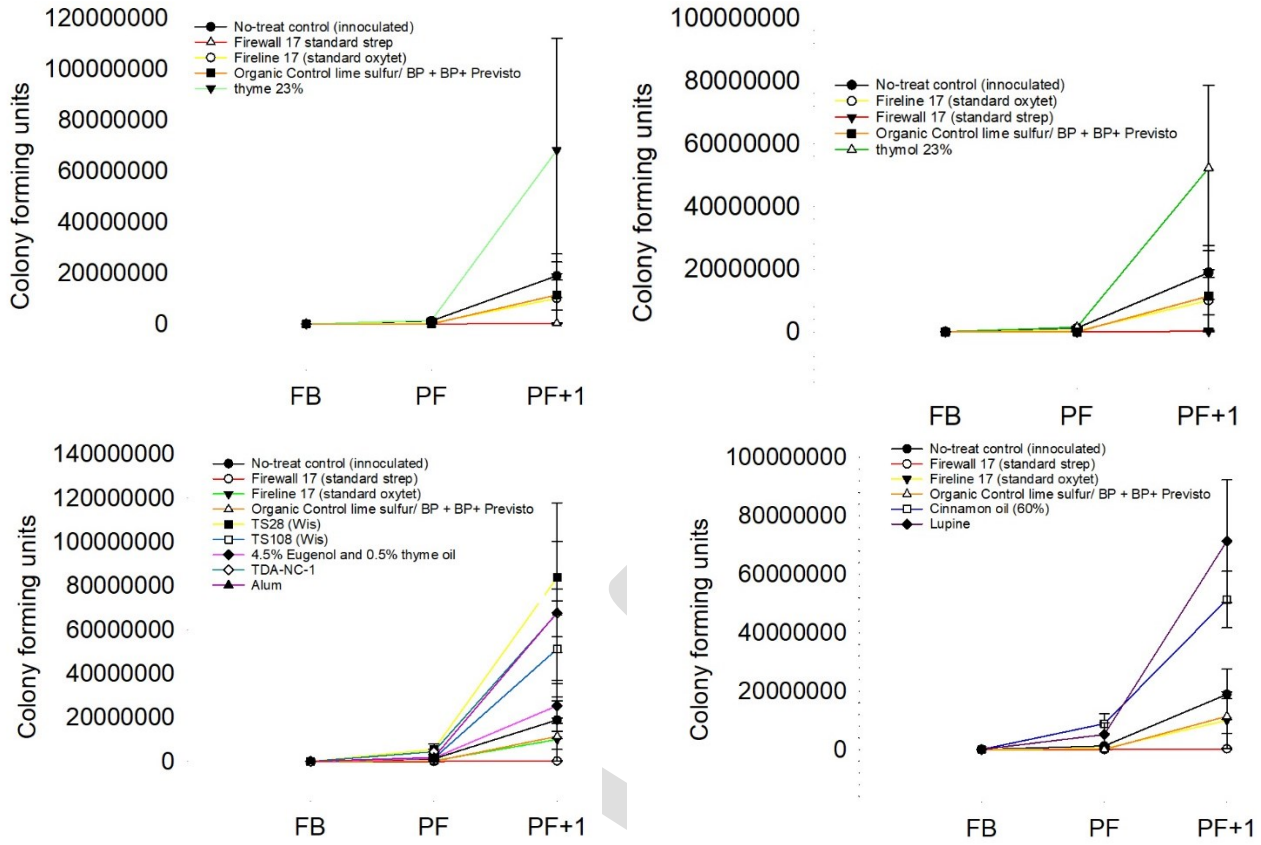


Figure 7. Effect of essential oil/ plant extract treatments applied to Red delicious apple trees to suppress fire blight on the population size of *E. amylovora* strain 153N on flowers at full bloom (FB), petal fall (PF) and petal fall + 1 week (PF+1) in 2020 Orondo, WA.



Biological Control Products

Blossom Protect is a combination of two strains of *Aureobasidium pullulans*, a yeast that occurs naturally in Pacific Northwest pome fruit flowers. This organism grows on the nectary and stigmas of treated flowers and competes directing with the fire blight pathogen for the nutritional resource available on these surfaces. Blossom Protect is applied with a companion buffer, Buffer Protect, which reduces the pH of the sprayed suspension and helps the yeast grow faster than the pathogen. In Pacific Northwest trials, Blossom Protect has been the most effective bio-control organism to date (Johnson et al. 2014). If this product is used, it is important to spray every row at least once.

Bacteriophage. A *bacteriophage* is a type of virus that infects bacteria. "*Bacteriophage*" literally means "bacteria eater," because *bacteriophage* destroy their host cells. *Bacteriophage* infect bacteria and multiply inside the host (lytic cycle), killing the host and releasing the progeny. *Bacteriophages* are composed of a nucleic acid molecule that is surrounded by a protein structure. *Bacteriophage* are very specific to a type of bacteria which make them an attractive option for IPM management. However, bacteriophage have some challenging features. Phage can only replicate in bacterial cells and are sensitive to environmental conditions. pH, UV, and precipitation can all reduce their ability to live on the leaf surface (Gill and Abedon, 2003). Interestingly, there is some evidence that bacteriophage can be effective when they penetrate and translocate through the plant (Nagy *et al.*, 2015). For example, bacteriophage have been effective for bacterial wilt of tomato in greenhouse trials (Iriarte *et al.*, 2012; Fujiwara *et al.*, Vol. 77, No. 12).

Bacillus. Serenade Optimum is an apparently 'fruit safe' material, made by fermenting a strain of *Bacillus subtilis*. The antimicrobial activity of Serenade comes primarily from biochemical compounds produced by the bacterium during fermentation, and not because of the bacterium's colonization of flowers in the orchard.

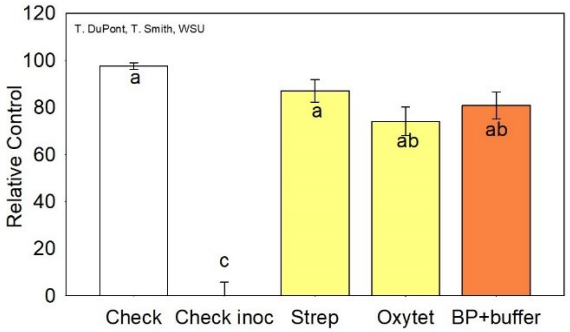


Figure 8. Blossom Protect in WSU Trials 2013, 2014, 2016, 2017. Two applications of Blossom Protect + Buffer Protect at 1.24 lb+8.75 lb applied twice during 50-100% bloom.

Table 13. Effect of Biological Control Product Treatments on *Erwinia Amylovora* infection of apple blossoms in Wenatchee WA in 2020.[‡]

Treatment	Rate per 100 gallons water	Application timings	Strikes per 100 clusters**			
Untreated, Inoculated Check	water	100% bloom, +1 day, petal fall	31	±	7.1	c
Streptomycin standard (Firewall 17)[zy]	28.8 oz	50% bloom, 100% bloom, petal fall	2.8	±	1.2	a
Oxytetracycline standard (Fireline 17) [zy]	28.8 oz	50% bloom, 100% bloom, petal fall	8.2	±	2.0	b
Organic standard (Blossom Protect/Buffer Protect +Previsto)	1.24 lb 8.75 lb 3 qt	50% bloom, 80% bloom, 100% bloom, petal fall	9.5	±	1.3	b
Phage7	2 qt	100% bloom 12hr before ap, +1 day, +3 days	24	±	4.8	c
Phage7	2 qt + 0.1 lb	100% bloom 12hr before ap, +1 day, +3 days	31	±	3.7	c

** Transformed log(x + 1) prior to analysis of variance; non-transformed means are shown.
[y] Amended with Regulaid: 30 fl. oz. per 100 gallons.
[z] Buffered to 5.6 pH.
[‡]Application dates were: April 14 (20% bloom), April 16 (50% bloom), April 17 (80% bloom) and April 18 (full bloom), April 19 (full bloom plus 1 day), April 22 (petal fall). Inoculation was conducted on the evening of April 18, 2020 at full bloom (of king blooms) using a suspension of 50% freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain) and 50% live cells, which was prepared at 24 x 10^6 CFU per ml.

Table 14. Effect of Biological Control Product Treatments on *Erwinia Amylovora* infection of apple blossoms in Wenatchee, WA 2019.[‡]

Treatment	Rate per 100 gallons water	Application timings	Infections per 100 clusters			
Streptomycin standard (Firewall 17)[zy]	28.8 oz	50% bloom, 100% bloom, petal fall	4.6	±	2.7	a
Oxytetracycline standard (Fireline 17) [zy]	24 oz	50% bloom, 100% bloom, petal fall	5.8	±	3.2	ab
Organic standard (lime sulfur, Blossom Protect+ Buffer Protect/ Previsto)	6 gal 1.24 lb/8.75 lb 3 qt	LS: 70% bloom BP: 20% bloom, 80% bloom PR: 100% bloom, petal fall	6.1	±	1.1	ab
Cueva/ Previsto	4qt/3qt	day before and day after 100% bloom, petal pall	9.7	±	2.7	abc
Phage7[y]	1 qt	50% bloom, 100% bloom, petal fall	17.3	±	3.6	bc
Phage7 (Agriphage) +oxytet (Fireline) [y]	1 qt + 0.1 lb	50% bloom, 100% bloom, petal fall	12.4	±	3.4	abc
Bacillus Subtilis (A)	30 oz	50% bloom, 100% bloom, petal fall	22.5	±	7.1	c
Bacillus Subtilis QST 713 strain (SO)	20 oz	day before and day after 100% bloom, petal fall	16.0	±	3.2	abc
Untreated, Inoculated Check	water	100% bloom	20.9	±	11.1	c

[y]Amended with Regulaid: 32 fl. oz. per 100 gallons.
[z]Buffered to 5.6 pH.
[‡]Application dates were: April 21 (pink), April 23 (20% bloom), April 24 and 25 (50% bloom), April 26 (full bloom minus 1 day), April 27 (full bloom), April 28 (full bloom plus 1 day), May 1, 2019 (petal fall), May 2, May 4 and May 6, and May 10, 2019. Inoculation was conducted on the evening of April 27, 2019 at full bloom (of king blooms) using a suspension of freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1.3 x10^6 CFU per ml and on May 1, 2019 using live culture prepared at 1x10^6 CFU ml^{-1}.

Figure 10. Effect of Biological Control treatments applied to Red delicious apple trees to suppress fire blight on the population size of *E. amylovora* strain 153N on flowers in Wenatchee, WA 2020.

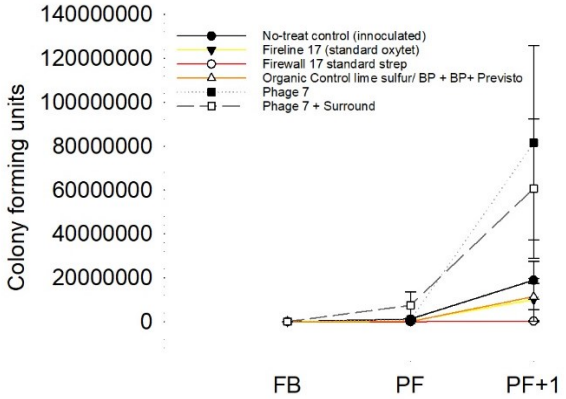


Table 15. Effect of biological control products on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2017.

Treatment	Rate per 100 gallons water	Application timings[x]	Infections per 100 clusters			
Streptomycin standard (Firewall 17)[zy]	28.8 oz	50% bloom, FB, PF	0.3	±	0	a
Oxytetracycline standard (Fireline 17)[zy]	24 oz	50% bloom, FB, PF	3.8	±	2	ab
Blossom Protect + Buffer Pro.	1.25 lb + 8.75 lb	20% bloom, 80% bloom	10	±	4	abc
BW165N	3 lbs	100%, +7 day	13	±	4	abc
CX-10250[v]	4.5 oz	TC & 50% bloom	16	±	8	bc
CX-10250[v] & Double nickel	4.5 oz, 2 qrt	50% bloom; Double nickel day before and day after FB	9.8	±	5	abc
Double nickel	2 qrt	day before and day after FB	15	±	6	bc
Untreated, Inoculated Check	water	FB	23	±	5	c

[‡]Application dates were; April 28 (20% bloom); April 29 (50% bloom); April 30 (80%); May 2 (full bloom); May 9 (Petal fall), 2017. Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml. Inoculated with *Erwinia amylovora* 153 (streptomycin sensitive fireblight strain) at 100% bloom (FB) at 1x10^6 CFU ml^{-1} solution.
[x]FB = full bloom (100% bloom of king bloom); PF= petal fall.
[y]Amended with Regulaid: 32 fl. oz. per 100 gallons. [Z]Buffered to 5.6 pH.
[v] *Bacillus mycoides* isolate J (LG)

Table 16. Effect of biological control products on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2016.[‡]

Treatment	Rate per 100 gal	Timing	Infections per 100 clusters			
Streptomycin standard (Firewall 17) [zy]	1.5 lb	50%, 100% bloom, PF	1.2	±	0.8	ef
Oxytetracycline standard (Fireline 17) [zy]	1.5 lb	50%, 100% bloom, PF	4.5	±	1.9	def
Blossom Protect + Buffer Protect, then Oxidate	20 oz + 140 oz 128 oz	50%, 100% bloom, PF	4.9	±	2.5	def
Blossom Protect + Buffer Protect	20 oz + 140 oz	20%, 50%, 100% bloom, PF	5.7	±	2.4	def
Serenade then Cueva	20 oz., 3 qts	20%, 50%, 100% bloom, PF	22.0	±	5.9	abcdef
Serenade Optimum	20 oz	50%, 100% bloom	24.3	±	6.6	abcdef
CX-10250 [v]	4.5 oz	Tight Cluster, 50% bloom, PF	33.9		3.5	abcd
Cueva	3 qt	100% bloom	27.0	±	9.1	abcdef
Bacteriophage FQ C + Buffer Protect	32 oz. FQ + 140 oz	20%, 50%, 100% bloom, PF	29.0	±	3.9	abcdef
Bacteriophage FQ A + Serenade	32 oz FQ + 20 oz Serenade	20%, 50%, 100% bloom, PF	31.0	±	3.9	abcd
Bacteriophage FQ B	32 oz. FQ	20%, 50%, 100% bloom, PF	33.6	±	5.8	abcd
Oxidate	128 oz	20%, 50%, 100% bloom, PF	35.8	±	6.3	abc
Bacteriophage FQ A	32 oz. FQ	20%, 50%, 100% bloom, PF	37.3	±	11.6	abc
Untreated, Inoculated Check	water	100%	45.0	±	10.9	a

[y] Amended with Regulaid: 30 fl. oz. per 100 gallons. [Z]Buffered to 5.6 pH.

[2]FB = full bloom (100% bloom of king bloom); PF= petal fall.

[‡]Application dates April 8 (20% bloom); April 9 (50% bloom); April 11 (full bloom); April 15 (Petal fall). Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml.

[v] *Bacillus mycoides* isolate J (LG)

Systemic Acquired Resistance Products (SARs)

Systemic acquired resistance is a plant defense response. Naturally induced by wounding or pathogen infection the Jasmonic acid + ethylene or salicylic acid pathways are stimulated activating the plant's defense response. Induced systemic resistance is a similar process where non pathogenic rhizo bacteria stimulate the jasmonic acid+ ethylene pathways. Resulting pathogenesis related proteins (PRs) such as chitinases, glucanases (microbial activity); peroxidase, lysozyme (membrane permeability); and signaling; lignin (strengthen cell walls), plant defensins thionins, and proteinase inhibitors help protect plant cells from infection.

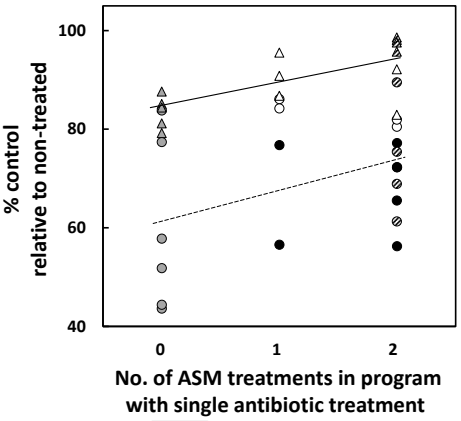


Figure 11.

Acibenzolar-S-methyl (ASM, Actigard 50 WG), is a synthetic inducer of systemic acquired resistance (SAR). Its mode of action is to mimic the plant hormone, salicylic acid, which is responsible for priming the plant's defense system. Actigard has established efficacy in the Pacific Northwest. When used in combination with antibiotics to prevent bloom infections Actigard improves antibiotic control by approximately 10% (Figure 11) (Johnson *et al.*, 2016). Actigard is also used as a therapeutic where 1 oz/ 1 quart with 1% silicone based penetrant is applied to a 2-3 ft section of the tree at the time of of cutting fire blight strikes (Johnson and Temple, 2014).

In response to recent interest in certified organic alternatives to Actigard limited trials have been conducted in Washington. Dr. Ken Johnson in Oregon has tested a wider range of products. Aditional data is needed before product use recommendations are conclusive.

Table 17. Effect of new products on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2017.

Treatment	Rate per 100 gallons water	Application timings [x]	Infections per 100 clusters			
Streptomycin standard (Firewall 17)[zy]	28.8 oz	50% bloom, FB, PF	0.3	±	0	d
Oxytetracycline standard (Fireline 17) [zy]	24 oz	50% bloom, FB, PF	3.8	±	2	cd
Blossom Protect + Buffer Pro.	1.25 lb + 8.75 lb	20% bloom, 80% bloom	10	±	4	bcd
Plant Extract R	2 qt.	20% bloom, 80% bloom, PF	13	±	4	abc
Regalia + Blossom Protect + Buffer	2 qt, 1.25 lb, 8.75 lb	20% bloom, 80% bloom, PF	11	±	3	bcd
Plant Extract R + Cueva	2 qt, 3 qt	Regalia at 20% bloom, Regalia + Cueva at 80% bloom & FB+1	25	±	8	a
Untreated, Inoculated Check	water	FB	23	±	5	ab

[‡]Application dates were; April 28 (20% bloom); April 29 (50% bloom); April 30 (80%); May 2 (full bloom); May 9 (Petal fall), 2017. Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml. Inoculated with *Erwinia amylovora* 153 (streptomycin sensitive fireblight strain) at 100% bloom (FB) 1x10^6 CFU ml^{-1} solution.

[x]FB = full bloom (100% bloom of king bloom); PF= petal fall.

[y]Amended with Regulaid: 32 fl. oz. per 100 gallons. [Z] Buffered to 5.6 pH.

Table 18. Effect of systemic acquired resistance products on incidence of apple clusters diseased with fire blight in pathogen-inoculated trials conducted in Wenatchee, WA in 2016.[‡]

Treatment	Rate per 100 gallons water	Timing*	infections per 100 clusters			
Streptomycin standard (Firewall 17)[zy]	1.5 lb	50% bloom, 100% bloom, PF	1.2	±	0.8	ef
Oxytetracycline standard (Fireline 17) [zy]	1.5 lb	50% bloom, 100% bloom, PF	4.5	±	1.9	def
Blossom Protect + Buffer Protect	20 oz 140 oz	20%, 50% and 100% bloom, PF	5.7	±	2.4	def

Actigard Cueva	2 oz 2 qt	Actig.Tight Cluster, Act.+ Cueva 20% bloom, Cueva day before and day after 100% bloom	14.6	±	4.1	bcdef
Plant Extract R	32 oz	50% and 100% bloom	32.1	±	8.3	abcd
Plant Extract R	64 oz	50% and 100% bloom	41.7	±	6.1	ab
Untreated, Inoculated Check	water	100% bloom	45.0	±	10.9	a

[Y] Amended with Regulaid: 32 fl. oz. per 100 gallons. [Z] Buffered to 5.6 pH.

[‡] Application dates April 8 (20% bloom); April 9 (50% bloom); April 11 (full bloom); April 15 (Petal fall). Inoculation was conducted at full bloom of the king blooms with *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x10^6 CFU per ml.

Test products noted as trial data only.

YOU ARE REQUIRED BY LAW TO FOLLOW THE LABEL. It is a legal document. Always read the label before using any pesticide. You, the grower, are responsible for safe pesticide use. Trade (brand) names are provided for your reference only. No discrimination is intended, and other pesticides with the same active ingredient may be suitable. No endorsement is implied.

Funding and Acknowledgements Project support provided by Washington State Tree Fruit Research Commission, Washington and Oregon Fresh Pear Committee, USDA NIFA IR4 and gift grants from Certis, Symagro, Marrone, BioSafe, Adama, Gowan, and AgroResearch. Thank you to technical support provided by Abigail Kowalski, Jared Dean, Esteban Guitierez.

References

Fujiwara, A., Fujisawa, M., Hamasaki, R., Kawasaki, T., Fujie, M., Yamada, T., Vol. 77, No. 12. Biocontrol of Ralstonia solanacearum by Treatment with Lytic Bacteriophages. Appl. Environ. Microbiol. 77.
Gill, J., Abedon, S.T., 2003. Bacteriophage ecology and plants. APS Net Feature doi: 10.1094/APSnetFeature-2003-1103.
Iriarte, F.B., Obradović, A., Wernsing, M.H., Jackson, L.E., Balogh, B., Hong, J.A., Momol, M.T., Jones, J.B., Vallad, G.E., 2012. Soil-based systemic delivery and phyllosphere in vivo propagation of bacteriophages. Bacteriophage 2, e23530.
Johnson, K., 2016. Non-antibiotic fire blight control that minimizes fruit russet risk. Tree Fruit Research Commission, Wenatchee, WA.
Johnson, K.B., Smith, T.J., Temple, T.N., Gutierrez, E., Elkins, R.B., Castagnoli, S.P., 2016. Integration of acibenzolar-S-methyl with antibiotics for protection of pear and apple from fire blight caused by Erwinia amylovora. Crop Protection 88, 149-154.
Johnson, K.B., Temple, T.N., 2014. Therapeutic SAR-inducing branch paints aid the restoration of pear and apple tree health after fire blight infection. Phytopathology 104, 56-56.
Nagy, J.K., Schwarczinger, I., Kunstler, A., Pogany, M., Kiraly, L., 2015. Penetration and translocation of Erwinia amylovora-specific bacteriophages in apple - a possibility of enhanced control of fire blight. European Journal of Plant Pathology 142, 815-827.
Shane, B., Sundin, G.W., 2011. Copper formulations for fruit crops. In: Pathology, D.o.P. (Ed.). MSU Extension, Michigan State University.
Smith, T., 2012. Improving the management of two critical pome fruit diseases. Tree Fruit Research Commission Final Report.
Smith, T., 2015. Improving the management of two critical pome fruit diseases. Tree Fruit Research Commission Final Report.