Fire Blight of Apple and Pear in Washington

Fire blight is an important disease affecting pear and apple. Infections commonly occur during bloom or on late blooms during the three weeks following petal fall. Increased acreage of highly susceptible apple varieties on highly susceptible rootstocks has increased the danger that infected blocks will suffer significant damage. In Washington there have been minor outbreaks annually since 1991 and serious damage in over 5% to 10% of orchards in 1993, 1997, 1998, 2005, 2009, 2012, 2015, 2016, 2017, and 2018. Controlling fire blight is a significant expense for pome fruit producers. For example, in epidemic outbreaks in Washington in 2017 and 2018 growers reported spending an average of $250 an acre on preventative sprays and $27 to $864 per acre for removal of cankered wood as well as removal of more than 300 acres of apples and 200 acres of pears.

Causal Organism

Fire blight is caused by *Erwinia amylovora*, a gram-negative, rod-shaped bacterium. The bacterial population grows via cell division, and the rate of division is regulated by temperature, among other factors. Cell division is minimal below 50°F and relatively slow at air temperatures between 50°F and 70°F. At air temperatures above 70°F, the rate of cell division increases rapidly and is fastest (optimal) at 80°F. Above 95°F cell density on and in the plant can actually decline (Pusey and Curry 2004).

Host Range

Considered a problem for apple and pear, *E. amylovora* has a wide host range infecting about 200 rosaceous plant species (Momol and Aldwincklke 2000). Most strains are able to infect commercial, ornamental, and wild plants from the subfamily Amygdaloideae, which includes apple, pear, quince, crab apple, hawthorn, mountain ash, and Bradford pear. However, some *E. amylovora* strains exclusively infect plants of the genus *Rubus* (Rosoideae subfamily), like blackberries and raspberries (Momol and Aldwincklke 2000; Bluhm and Stover 2016).

Signs and Symptoms

Overwintering cankers can appear black, grey, violet, or brown (Figure 1). Older cankers may have dry, sunken tissue. If the bark is cut from the edge of an active canker, reddish flecking can be seen in the wood near the canker margin (Teviotdale 2011).

Figure 1. Canker on apple (top photo), and overwintering canker on young Anjou pear (bottom photo). Photos: S. Tianna DuPont, WSU.

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Blossom symptoms become apparent one to two weeks after infection. The floral receptacle, ovary, and peduncles become water-soaked and dull, grayish green in appearance (Figure 2). Later tissues shrivel and turn brown to black. During periods of high humidity, small droplets of bacterial ooze form on water-soaked and discolored tissues. Ooze droplets appear creamy white when new and become amber tinted as they age (Johnson 2000).

Figure 2. Bloom symptoms 12 days after infection. Photo: S. Tianna DuPont, WSU.

Shoot symptoms include the characteristic "shepherd's crook" formed from rapidly wilting shoot tips. Leaves on diseased shoots often show blackening along the midrib and veins before becoming fully necrotic and will cling firmly to the host after death (a key diagnostic feature) (Figure 3). Numerous diseased shoots give a tree a burnt, blighted appearance (hence the disease name).

Figure 3. Characteristic shepherds crook symptoms of fire blight. Notice ooze. Photo: S. Tianna DuPont, WSU.

Rootstock infections usually develop near the graft union as a result of internal movement of the pathogen through the tree or from infection of root suckers. The bark of infected rootstocks may show water-soaking, purplish to black discoloration, cracking, or signs of bacterial ooze. Red-brown streaking may be apparent in the cambium just under the bark (Figure 4). Symptoms of rootstock blight can be confused with Phytophthora collar rot. Malling 26 and 9 rootstocks are highly susceptible to fire blight (Johnson 2000).

Figure 4. Rootstock infections may appear water-soaked under the bark. Photo S. Tianna DuPont, WSU.

Transmission and Disease Cycle

Erwinia amylovora survives winter in the living tissue around canker margins and underneath the dark canker surface (Biggs 1994; Teviotdale 2011; Santander et al. 2022a). Live cells can survive the winter in 7% to 62% of cankers (van der Zwet and Beer 1991; Santander et al. 2022b), and as few as one canker in a block can cause a new infection (Tullis 1929). When humidity is high in the spring the pathogen emerges from cankers as ooze and oozeless colonies (Figure 5). This ooze is attractive to bees, flies, and other insects who transfer the pathogen to flowers (Van Der Zwet and Keil 1979). Pathogen cells can also be moved from old cankers to flowers and other susceptible tissues by water splash and wind-blown rain. Pathogen cells multiply quickly on nutrient rich floral stigma when temperatures are warm (70°F to 80°F is optimal for the pathogen) (Ogawa and English 1991; Pusey and Curry 2004). Bacterial cells can then be washed down the style into the floral cup by water (usually from rain or heavy dew) where they can invade flowers through the nectaries (Thomson 1986). Once initial blossoms are infested, ooze droplets form with as many as a billion bacterial cells per droplet (Slack et al. 2017). Insects and rain can move the pathogen to additional flowers and susceptible young leaves (Johnson et al. 1993; Pattemore et al. 2014). If the pathogen is successful in infecting the developing fruitlet, the disease spreads through the intercellular spaces and then the vascular system of the tree (xylem) (Momol et al. 1998), and more ooze can form on flower and fruitlet surfaces. The pathogen kills young host tissues as it progresses, creating characteristic lesions often called a strike. After invading woody tissues, it forms fire blight cankers. Pathogen cells migrate inside the tree well ahead of visible symptoms. They can accumulate in susceptible tissue such as one-year old shoot tips and susceptible rootstocks causing infections distant from the original infection (Bogs et al. 1998). For example, in a Michigan study, *E. amylovora* moved an average of two inches per day in new growth and one-and-a-half inches per day in woody growth in five-year-old Gala, which equates to approximately 11 inches per week (Olive and Sundin 2023).

Erwinia amylovora can also infect susceptible one- and two-year-old tissue directly through wounds (e.g., insect feeding and hail injury) and natural openings (e.g., stomata, hydathodes) causing shoot blight infections (Vanneste 2000; Millet et al. 2022).

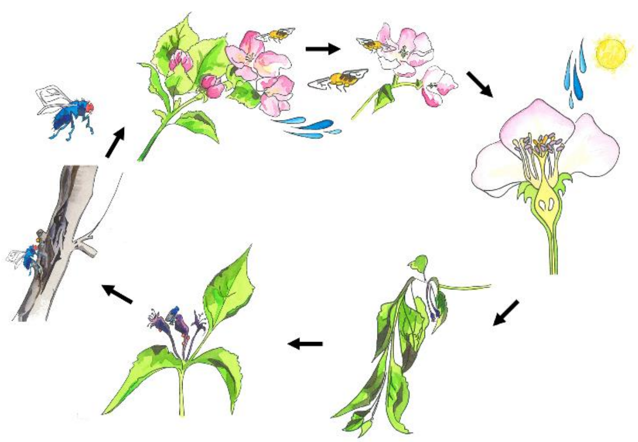

Figure 5. Fire blight disease cycle. Ooze from overwintering cankers is moved to flowers by insects or water splash where it can then be spread through the orchard by bees, wind-blown rain, and water splash. When conditions are warm, *E. amylovora* multiplies quickly on the flower stigma. Rain and dew can wash the bacteria into the flower where it can enter the plant through the nectaries. Illustration credit: S. Tianna DuPont.

Cultural Controls

Plant on resistant rootstock. Resistant rootstocks (e.g., Geneva series for apples) can help prevent tree death from rootstock blight (Norelli et al. 2003; Russo et al. 2007). However, resistant rootstocks generally do not prevent the scion from becoming infected (Russo et al. 2007). Some data suggest that rootstock characteristics (root surface area and gene expression) can reduce the size of lesions which develop (Singh et al. 2019).

Winter sanitation. In winter, prune out old fire blight cankers as thoroughly as possible. Ideally, cut blight before you prune for tree structure so that the blighted cuttings can be removed from the orchard. Compared to cuts made in summer, winter removal cuts can be made closer to the visible canker edge. In winter the pathogen is confined to the cankered area. Cut at the next "horticulturally sensible" site below the canker to fulfill the requirements of the training system. You do not need to sterilize tools when you are cutting on fully dormant trees. Late dormant copper applications can enhance orchard sanitation, further reducing pathogen inoculum levels going into spring (Elkins et al. 2015).

Manage the orchard environment. In addition to warm temperatures, moisture is required to initiate infections. As little as two to three hours of wetting from dew or light rain is sufficient to trigger infection. Manage weeds and cover crops to limit relative humidity. Do not irrigate during bloom.

Flower removal in young blocks. Flower removal in young blocks and removal of late blooms limits the numbers of flowers and thus reduces potential points of infection. In two 2020 trials flower removal at pink bud stage for young nonbearing trees reduced infections to zero, compared to 71 to 77 per 100 clusters in water treated checks and 5 to 17 per 100 clusters in soluble copper treated trees (DuPont et al. 2022).

Keep tree vigor moderate. By limiting nitrogen fertilizer application, tree vigor is reduced. Moderating vigor will not prevent infection, but it can reduce damage to the tree by limiting the amount of new and more susceptible plant tissue.

Summer sanitation. Timely cutting of fire blight infected material soon after infections occur is recommended to reduce the spread of the pathogen throughout the orchard and to limit the advance of the disease in the tree, which can lead to plant death. Remove infected branches 12 to 18 inches below the visibly infected tissue in wood that is two years old or older (Figure 6). Timely removal reduces the number of trees that die from fire blight (DuPont et al. 2023). Moreover, this practice reduces the number of new infections which must be removed after initial pruning (DuPont et al. 2023). Although sanitizing pruning shears has been long considered important to prevent dissemination of fire blight infections (Van Der Zwet and Keil 1979), in multiple studies sterilizing shears made no difference in preventing canker formation as long as the cuts are made at the recommended distance below the visible canker (Travis and Kleiner 1997; Toussaint and Philion 2008; DuPont 2023). Canker removal cuts made four inches from where the branch joins structural wood ("ugly" stub cutting) can significantly reduce the number of cankers that redevelop on structural wood, which sustains fruiting area for future years (Steiner 2000; DuPont et al. 2023). While small cankers will reform on many of these cuts, these cankers can be removed during winter pruning. Breaking off infected flower clusters and diseased current season growth by hand can provide a rapid removal method, but it can result in a greater number of cankers in the orchard at the end of the season, with more cankers on structural wood (DuPont et al. 2023).

Applying a concentrated solution of Actigard as part of pruning therapies can reduce the severity of reoccurring fire blight cankers. In trees with Actigard applied, when removing fire blight infection, both the proportion of trees in which fire blight reoccurred and the rate of canker expansion was reduced in five years of field trials (Johnson and Temple 2016; Johnson and Temple 2017). Apply concentrated Actigard in water with an up and down motion to a one to one-and-a-half foot section of the central leader or major scaffold near where the fire blight infection was removed (Figure 7). Use the labeled rate of one ounce Actigard per one quart of water with one percent silicone-based penetrant.

Figure 6. Remove infected branches 12 to 18 inches below the visibly infected tissue into wood that is two years old or older. Photo credit S. Tianna DuPont, WSU.

Very young infected trees, first to third leaf, should be removed and destroyed. In young, vigorous trees, bacteria move quickly through the tree, and pruning therapies are unlikely to be effective. Apply Actigard to trees neighboring removed trees, to reduce canker occurrence risk.

Temperature Risk Models

The risk of fire blight infection during bloom can be calculated based on the temperature and moisture. In Washington Cougar Blight is available at WSU Decision Aid System for Tree Fruit (https://decisionaid.systems/) or in Excel format (https://treefruit.wsu.edu/crop-protection/disease-management/fire-blight/). This model calculates fire blight risk based on the temperature of the previous four days using the documented growth rate of the bacteria; for example, higher risk with multiple hours above 70°F (Pusey and Curry 2004). The model then projects risk for the next three days based on predicted temperatures. The model also includes an inoculum component that helps to estimate risk at specific sites. Maryblyt (http://grapepathology.org/maryblyt) is another commonly used model for predicting fire blight risk (Turechek and Biggs 2015). Growers can use model information to decide when to spray. If trees are likely to be blooming during an upcoming high-risk period, protective sprays *before* an infection event are recommended (Smith and Pusey 2010).

Chemical Controls

Chemical Control Programs

There is a risk of fire blight infection any time there are open flowers on the tree, the weather is warm, and wetting occurs. Watch for and protect secondary flowers during the three weeks after petal fall, a common time for fire blight infection in Washington. Most sprays only protect the flowers that are open. Protect new flowers as they open. In warm weather follow-up sprays are needed every two to three days rotating the mode of action. See Tables 3 and 4 at the end of the publication for more information.

Figure 7. Application of concentrated Actigard in water using a one-liter sprayer to a one-foot section of leader. Photo: A. Baro-Sabe, WSU.

Conventional Management

Consider temperature and moisture to assess infection risk. After a period of warm weather (high infection risk) best results are obtained when antibiotics are applied within the 24-hour window *before* flower wetting (e.g., streptomycin, kasugamycin, oxytetracycline). Products used must contact the interior of the flowers in sufficient water and approved wetting agent to completely cover the tree crown interior. Antibiotic sprays every two to three days may be necessary during extended high or extreme risk periods. Rotate between materials with differing modes of action. In high risk blocks, or if fire blight was in the orchard last year, consider applications of Blossom Protect with Buffer Protect during early bloom. Lime sulfur applied for thinning is also antimicrobial and reduces blight pressure. See Tables 1 and 2.

Organic Management

Nonantibiotic control programs for fire blight which contain Blossom Protect and soluble copper products during the bloom period (e.g., Previsto, Cueva) followed by *Bacillus* based biorationals (e.g., Serenade Opti) at petal fall have performed well, suppressing fire blight with low russet risk in Oregon trials 2013 to 2021 (Johnson et al. 2022) as well as Washington and New York (Cox et al. 2015; Cox et al. 2016; DuPont et al. 2023). In difficult-to-thin apple varieties where multiple lime sulfur applications reduce Blossom Protect efficacy, soluble coppers can be an effective choice. Integrated programs with Blossom Protect or soluble coppers during high-risk bloom periods followed by essential oils or peracetic acid-peroxide products (e.g., Thyme Guard, Cinnerate, Oxidate 5.0, Jet-Ag) at petal fall have also had control similar to Blossom Protect/Serenade programs in several trials (DuPont et al. 2023). Consider drying times and rotations, and limit post petal fall applications of essential oils and peracetic acid-peroxides products to moderate russet risk. See Tables 1 and 2.

Nonbearing Trees

Young nonbearing trees with high vigor in high-risk varieties or locations may require season-long protection from shoot blight. In recent trials for protection of young nonbearing trees, flower removal performed best followed by weekly applications of soluble copper at 3 to 4 quarts per acre or fixed copper at 1.5 pounds per acre (DuPont et al. 2022). Flower removal at pink for young nonbearing trees reduced infections to zero infections per 100 flower clusters in Pennsylvania and zero per 100 flower clusters in New York in 2020 trials (DuPont et al. 2022). Three applications of soluble copper (Previsto 3 qt., or Cueva 4 qt.) reduced infections per 100 flower clusters from 77 to 5.5 in New York and 71 to 17 in Pennsylvania, and three applications of fixed copper (1.5 lb) reduced infections per 100 flower clusters from 77 to 27 in New York and 71 to 8 in Pennsylvania (DuPont et al. 2022).

Antibiotic Resistance Management

Fire blight pathogen resistance to streptomycin was first detected in California in 1971 and in Oregon and Washington in the 1970s and 1980s (Coyier and Covey 1975). It was believed to be widespread in the western United States in 1991 and in other parts of the US including Idaho, Utah, Missouri, Michigan (2003), and New York (2002, 2016, 2021) (Loper et al. 1991a; McGhee and Sundin 2011; Forster et al. 2015a; Tancos et al. 2016). In an ongoing antibiotic resistance survey, researchers did not find isolates from collected samples to be resistant to streptomycin and tetracycline, but some isolates exhibited resistance and tolerance to kasugamycin (Zhao 2023). To minimize the risk of resistance development, it is recommended to apply streptomycin in combination with oxytetracycline and limit streptomycin application to once per season. Kasugamycin could be applied in a mixture with oxytetracycline or rotation with oxytetracycline.

Strategies for Improving Protective Programs

Coverage. Product efficacy is based on thorough coverage of flowers. Use tree row volume to apply appropriate volumes to cover the tree architecture in your orchard. Products applied every other row or at high speeds may have insufficient coverage and lower efficacy.

Timing. Antibiotics have the highest efficacy when applied shortly *before* a moisture event. Nonetheless, kasugamycin and streptomycin can also be applied up to 12 hours after a moisture event, but with reduced effectiveness. Streptomycin has locally systemic activity and kasugamycin is effective on bacteria which have been washed into the floral cup but have not yet invaded the flower.

pH of Spray Tank Water. It is important to appropriately acidify spray tank water when using antibiotics (especially oxytetracycline and kasugamycin). Antibiotic efficacy reported in WSU trials is with spray tank water buffered to pH 5.6. At higher pH the antibiotic degradation rate is faster and thus efficacy is often lower. For example, in one trial kasugamycin reduced the bacterial population by 86% to 96% at pH 5.1 but only 21% to 35% at pH 7.3 (Adaskaveg et al. 2011). Johnson and KC (2021) found that buffering oxytetracycline products to a pH 4 can further improve efficacy.

Use Appropriate Rates. Quantity of active ingredient is important to obtain efficacy. For example, recent work looking at rates of copper products demonstrated that as metallic copper content increases, copper product efficacy increases up to approximately 0.2 lb metallic copper per 100 gal per acre (DuPont 2019) (Figure 8). This is equivalent to approximately 3 qt of Previsto or 4 qt of Cueva per acre.

Mixtures. A full rate of kasugamycin (100 ppm) with a full rate of oxytetracycline (200 ppm), as well as streptomycin (100 ppm) mixed with a full rate of oxytetracycline (200 ppm) have provided improved efficacy in some trials (Oregon 2015–2018) (Johnson, unpublished data). Actigard (2 oz per 100 gal) plus an antibiotic applied during bloom has improved the efficacy of antibiotics an average of 5% to 6% per application of Actigard in trials in Washington and Oregon (Johnson et al. 2016).

Table 1. Example plans for different blocks and conditions—apple.

Apples				
Conventional		**Organic**		
Cut and remove fire blight cankers. Good sanitation is essential for successful fire blight management.				
Low to Moderate Risk	**High Risk** high value varieties, history of blight	**Easy to Thin Varieties**	**Hard to Thin Varieties / Short Bloom Period**	**Hard to Thin Varieties / Long Bloom Period**
• Watch the model. • *If* an infection event is projected, apply an antibiotic within 24 hours *before* wetting. • Repeat every 2–3 days during warm, wet risk periods to cover newly opening flowers *rotating* FRAC.[a] • Continue weekly applications 1–2 weeks post petal fall.[b]	• Use antibiotic mixes: oxytetracycline + kasugamycin or antibiotic + Actigard.[a] • Cover every 2–3 days during warm conditions during bloom *rotating* FRAC.[a] • Acidify spray tanks to 5.5 to improve antibiotic efficacy. New research shows 4.0 may further improve efficacy.[c] • Continue weekly applications 1–2 weeks post petal fall.[b]	• Blossom Protect + Buffer Protect early.[d] • Lime sulfur (+ oil). • Blossom Protect + Buffer Protect. • Depending on the model and cultivar russet risk/drying conditions, soluble copper (Previsto 3 qt, Cueva 4 qt, Cueva 3 qt + Serenade Opti, Instill, Mastercop). • Petal fall + 1–2 weeks Serenade Opti/Aso (most fruit safe) or 2% lime sulfur (red apples), essential oils (Cinnerate, Thyme Guard), peracetic acids (Oxidate 5.0, Jet-Ag).[e,f,g]	• Lime sulfur (+ oil) 2–3 applications. • Depending on the model and cultivar russet risk/drying conditions, soluble copper (Previsto 3 qt, Cueva 4 qt, Cueva 3 qt + Serenade Opti, Instill, Mastercop).[g] • Petal fall + 1–2 weeks Serenade Opti/Aso (most fruit safe) or 2% lime sulfur (red apples), essential oils (Cinnerate, Thyme Guard), peracetic acids (Oxidate 5.0, Jet-Ag).[e,g]	• Lime sulfur (+ oil). • Blossom Protect + Buffer Protect. • Lime sulfur + oil. • Blossom Protect + Buffer Protect. • Depending on the model and cultivar russet risk/drying conditions, soluble copper (Previsto 3 qt, Cueva 4 qt, Cueva 3 qt + Serenade Opti, Instill, Mastercop). • Petal fall + 1–2 weeks Serenade Opti/Aso (most fruit safe) or 2% lime sulfur (red apples), essential oils (Cinnerate, Thyme Guard), peracetic acids (Oxidate 5.0, Jet-Ag).[e]

[a] Rotate modes of action using fungicide resistance action committee (FRAC) codes. Rotation is necessary to prevent emergence of resistant *E. amylovora*. Rotate as necessary to comply with application intervals for individual products. Do not apply Actigard at closer than seven-day interval (label restriction).
[b] Kasumin 2L. Do not make more than four applications per year. Post petal fall restriction has been removed (March 2021).
[c] Spray tank acidification has increased efficacy of oxytetracycline products (e.g., Mycoshield).
[d] Blossom Protect yeast need about 12 hours to grow on the flower to protect against infection before a wetting event.
[e] Lime sulfur at this timing can interfere with oil sprays for mites.
[f] Blossom Protect+ Buffer Protect, then Previsto (full bloom), then Serenade Opti/Aso (petal fall) was the best organic combination in 13 trials in Oregon at 83% relative control (Johnson et al. 2022) similar to antibiotics.
[g] Consider drying conditions. Fruit marking may occur under slow drying conditions.

Table 2. Example plans different blocks and conditions—pear.

<table>
<tr><th colspan="4">Pears</th></tr>
<tr><th colspan="2">Conventional</th><th colspan="2">Organic</th></tr>
<tr><td colspan="4">Cut and remove fire blight cankers. Good sanitation is essential for successful fire blight management.</td></tr>
<tr><td>Low to Moderate Risk</td><td>High Risk
sensitive varieties,
history of blight</td><td>Easy to Mark Varieties
Anjou/Comice</td><td>Marking Tolerant Varieties
Bosc</td></tr>
<tr><td>• Watch the model.
• If an infection event is projected apply an antibiotic less than 24 hours before wetting.
• Repeat every 2–3 days during warm, wet risk periods to cover newly opening flowers rotating FRAC.[a]
• Continue weekly applications 1–2 weeks post petal fall during warm wet risk periods.[b]</td><td>• Use antibiotic mixes: oxytetracycline + kasumamycin or antibiotic + Actigard.[a]
• Cover every 2 days during warm conditions during bloom, rotating FRAC.[a]
• Acidify spray tanks to at least 5.5 to improve antibiotic efficacy. New research shows that 4.0 may further improve efficacy.[c]
• Continue weekly applications 1–2 weeks post petal fall.[b]</td><td>• 2 applications of Blossom Protect + Buffer Protect during early bloom to petal fall (70%–80% bloom if single treatment).[d]
• Follow with Serenade Opti/Aso at petal fall to reduce russet risk from Blossom Protect yeast.</td><td>• 2 applications of Blossom Protect + Buffer Protect during early bloom to petal fall (70%–80% bloom if single treatment).
• Follow with soluble copper (Cueva 4 qt, Previsto 3 qt) if the model indicates risk (warm/wet).
• Petal fall plus options also include essential oils (Cinnerate, Thyme Guard), peracetic acids (Oxidate 5.0, Jet-Ag).</td></tr>
</table>

[a] Rotate modes of action. Rotation is necessary to prevent emergence of antibiotic resistant *E. amylovora*. Rotate as necessary to comply with application intervals for individual products. Do not apply Actigard at closer than seven-day interval (label restriction).
[b] Kasumin 2L. Do not make more than four applications per year. The post petal fall restriction has been removed (March 2021).
[c] Spray tank acidification has increased efficacy of oxytetracycline products (e.g., Mycoshield).
[d] Blossom Protect yeast need about 12 hours to grow on the flower to protect against infection before a wetting event.

Antibiotics

Kasugamycin (Kasumin) is a recently labeled antibiotic that provides *excellent* levels of control. For example, in eight trials in Michigan relative control averaged 92% (Sundin and McGhee 2010). In an ongoing antibiotic resistance survey in Washington, some isolates exhibited resistance and tolerance to kasugamycin (Zhao 2023) but no field level failures were reported. There is an intermediate risk of resistance developing to this antibiotic (Adaskaveg et al. 2011). Kasumin controls streptomycin-resistant strains of fire blight. Kasumin provides forward control for two to three days prior to rain events (on flowers open when applied) and will be partially effective for blossom blight control if applied within 12 hours after a rain event. Kasumin is not locally systemic like streptomycin. Thus, Kasumin will not penetrate into the nectaries and will not be able to control an infection once the fire blight pathogen reaches the nectaries. Acidifying spray tanks (target 5) is important to reduce antibiotic break down and extend activity. Kasugamycin is ultraviolet (UV) sensitive, and spraying at night and reduced pH can help improve residual time. The use of a nonionic surfactant enhances deposition of the antibiotic on flowers.

Oxytetracycline (Mycoshield, FireLine) generally provide *good* levels of control in Washington trials (average 74% control) and has a low risk of resistance development (DuPont et al. 2023). Oxytetracycline products should be applied within 12 to 24 hours *prior* to a moisture event for best results. Oxytetracycline is considered bacteriostatic (inhibits bacterial growth). Thus, to be effective it must be applied prior to wetting events where it can prevent growth on stigmas. Oxytetracycline is also sensitive to UV degradation, and much of the activity is lost within one to two days after application. Acidifying spray tanks (target pH 5) is important to reduce antibiotic break down and extend activity. The use of a nonionic surfactant enhances deposition of the antibiotic on flowers.

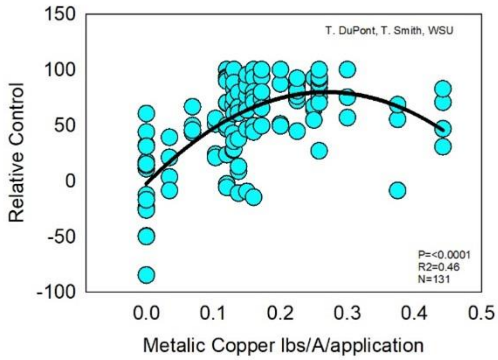

Figure 8. Relative control from coppers WSU trials 2013 to 2017 (DuPont 2019).

Streptomycin (Agri-Mycin, FireWall) resistant strains of the fire blight pathogen have been present in Washington orchards since 1975 (Coyier and Covey 1975; Loper et al. 1991b). Recent tests have indicated that the proportion of the pathogen population resistant to this antibiotic has dropped and expected control levels have improved (Forster et al. 2015). In an ongoing survey in Washington no fire blight strains resistant to streptomycin were detected (Zhao 2023). This product should only be used in combination with oxytetracycline and should not be used unless a high-to-extreme risk infection period is expected. Limit use to once per season. Repeat application has a high risk of resistant bacteria being uncontrolled. The use of a nonionic surfactant enhances deposition of the antibiotic in and on flowers. Acidifying spray tanks (target pH 5) is important to reduce antibiotic break down and extend activity.

Nonantibiotic Products

In summary analysis of eight Washington trials Alum (potassium aluminum sulfate), Blossom Protect (*A. pullulans*) and several copper products (Previsto, Mastercop, Instill) provided good disease suppression of 70% to 73% similar to antibiotic treatments (DuPont et al. 2023) (Figure 9). Several essential oil, copper, peracetic acid-peroxide and biological products (Serenade Opti, Cueva, Oxidate 5.0, Jet-Ag, Thyme Guard, Thymox and Cinnerate) provided intermediate disease suppression between 45% to 62% significantly better than the water-treated trees.

Blossom Protect. *Blossom Protect* is a combination of two strains of *Aureobasidium pullulans*, a yeast that occurs naturally in the Pacific Northwest pome fruit flowers. It is applied in combination with a buffer, Buffer Protect. Relative efficacy of Blossom Protect plus Buffer Protect in Washington averaged 72% across six orchard trials with two to three applications (DuPont et al. 2023). High relative efficacy has also been documented in Oregon with control comparable to antibiotic standards, in Michigan where two applications resulted in between 85% and 92% relative control, and in Germany where Blossom Protect provided an average of 79% efficacy across 11 trials (Kunz et al. 2011; Johnson and Temple 2013; Sundin et al. 2018; Outwater et al. 2019).

Recommendations for Blossom Protect use include applications to every tree row (Temple et al. 2020). It may also be important to apply with at least 12 to 24 hours between application and an impending rain event in order to give sufficient time for *A. pullulans* populations to colonize flowers (Temple et al. 2020).

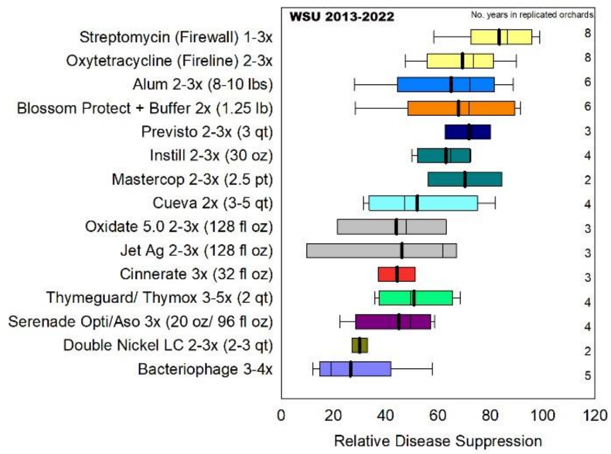

Figure 9. Relative fire blight suppression from biopesticides compared to antibiotic standards in fire blight inoculated apple and pear orchards in Wenatchee, Washington, between 2013 and 2022 (DuPont et al 2023). For each treatment, the dark line indicates the mean, the narrow line the median, the box indicates the upper and lower quartile, and the whiskers indicate the minimum and maximum. Treatment application timings for antibiotics, coppers (Previsto, Instill, Mastercop*, Cueva), potassium aluminum sulfate (Alum), biologicals (Serenade Aso/Opti, Double Nickel LC Bacteriophage), and essential oils (Cinnerate, Thyme Guard) included 12 hours before inoculation, 12 hours after inoculation, and petal fall (generally 3 days after inoculation). Peracetic acid-peroxide products (Jet-Ag, Oxidate 5.0) were applied two to three times post bloom. Blossom Protect and Buffer Protect (*Aureobasidium pullulans*) were applied at 20% and 80% bloom or 70% and 90% bloom. *Note*: Alum, Mastercop at 2.5 pt and Cueva at 5 qt were applied under an experimental use permit. See labels for legal use.

*Important! Some of the pesticides discussed in Figure 9 were tested under an experimental use permit granted by Washington State Department of Agriculture (WSDA). Application of a pesticide to a crop or site that is not on the label is a violation of pesticide law and may subject the applicator to civil penalties up to $7,500. In addition, such an application may also result in illegal residues that could subject the crop to seizure or embargo action by WSDA or the US Food and Drug Administration. It is your responsibility to check the label before using the product to ensure lawful use and obtain all necessary permits in advance.

Coppers. Coppers are generally effective disease control products. Free copper ions are taken up by pathogen cells and cause toxicity by nonselectively denaturing proteins in cells. New soluble copper formulations are designed to have lower plant phytotoxicity. For example, copper octanoate (Cueva) is a copper soap, copper hydroxide product (Previsto) is formulated with a polymer matrix designed to lessen toxicity of copper ions on the plant surface, and copper sulfate pentahydrate products (e.g., Instill) are generally highly soluble but may be formulated to reduce plant phytotoxicity. Soluble coppers are used during bloom in semiarid Washington but can cause phytotoxicity in wetter areas in Oregon and California (Smith 2012, 2015; Johnson 2016).

In Washington trials relative disease suppression resulting from use of soluble coppers (e.g., Previsto, Instill, Mastercop, Cueva) ranged from a median of 47% to 73% in 2013 to 2022 trials (DuPont et al. 2023). These results are similar to field trials from other regions of the United States, such as New York, Virginia, and Oregon, where soluble coppers provided between 50% and 80% relative control, depending on type, timing, and rate of application (Yoder et al. 2013; Cox et al. 2014; Choi et al. 2018; DeShields and DeShields 2020). The amount of metallic copper in a product will determine in part the appropriate rate for optimum efficacy. 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 lb per 100 gal per acre of metallic copper equivalent ($p < 0.001$; $R^2 = 0.46$) (DuPont 2019) (Figure 8).

Concern about fire blight resistance to coppers has been raised due in part to resistance documented in *Pseudomonas syringae* strains affecting almonds (Andersen et al. 1991). However, none of 138 isolates tested in Washington in 1991 by Loper et al. (1991a) grew in copper at 0.16 mM, while 15 of 80 isolates in nearby British Columbia, Canada, had a reduced response at 0.16 mM. No tolerance was found at field rates of 1.10 mM (Sholberg et al. 2001).

Due to relatively high disease suppression rates, soluble coppers fit well in an integrated nonantibiotic program following early bloom Blossom Protect plus Buffer Protect applications (Johnson et al. 2022).

Bacillus Products. Serenade Opti/Aso is considered a “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. *Bacillus subtilis* strain QST 713 (Serenade) has provided an average of 60% control in Oregon and is best used as part of an integrated program (Smith 2012; Johnson and Temple 2013; Smith 2015). In four Washington trials from 2014 to 2022 Serenade Opti/Aso provided 50% median relative control (DuPont et al. 2023).

Oxidizing Agents. Several peracetic acid-peroxide products are available (e.g., Jet-Ag, Oxidate 5.0) for fire blight. These low residue oxidative agents have the potential to damage microbial structures, such as membrane layers, and disrupt microbial cellular processes, like DNA or protein synthesis, leading to cell death (Wagner et al. 2002; Finnegan et al. 2010). Oxidizing agents (Jet-Ag and Oxidate 5.0) produced median relative disease suppression of 53% and 62% in Washington with two to three applications post inoculation (four trials: 2019–2022). When multiple post petal fall applications were made under slow-drying conditions, fruit marking occurred. In order to limit fruit marking potential, peracetic acid-peroxide products should be applied only in fast-drying conditions and up until the early post petal fall period.

Plant Extracts. Plant essential oils of thyme and cinnamon have antibacterial activity against *E. amylovora* (Chizzola et al. 2008; Kokoskova et al. 2011; Tawfik and Shahin 2011; Akhlaghi et al. 2020). In Washington trials essential oil products Cinnerate, Thyme Guard and Thymox provided a median of 45% to 49% relative disease suppression comparable to recent trials in other states (DeShields and DeShields 2020; DuPont et al. 2023).

Other Biologicals. Bacteriophages are viruses that kill bacteria (Meile et al. 2017). Bacteriophages are an attractive option for integrated disease management due to their target specificity; however, sensitivity to environmental conditions have thus far made application challenging (Gill and Abedon 2003; Nagy et al. 2012; Nagy et al. 2015). In Washington trials, relative disease suppression of bacteriophage products against *E. amylovora* has been variable, with control below 20% observed in 2019 and 2020, while in 2022 three applications provided 58% relative disease suppression (DuPont et al. 2023). This variability has also been seen in other regions. For example, bacteriophages provided 35% and 39% relative suppression in Michigan 2019 trials and 74% and 42% in 2018 trials (Sundin et al. 2018; Outwater et al. 2019).

Plant Defense Inducers. Acibenzolar-S-methyl (Actigard 50WG) is a synthetic inducer of systemic acquired resistance (SAR). Its mode of action mimics the plant hormone salicylic acid, which is responsible for priming the plant’s defense system. The level of protection is smaller compared to an antibiotic, but it lasts longer—approximately a week (Maxson-Stein et al. 2002). Actigard (two oz per acre) plus an antibiotic applied during bloom improved the efficacy of antibiotics an average of 5% to 6% per application in trials in Washington and Oregon (Johnson et al. 2016). Therapeutic applications of Actigard to a one-foot section of the scaffold where fire blight cankers were removed have reduced the size of canker expansion and the number of trees which died (Johnson and Temple 2016; Johnson and Temple 2017).

Additional Resources

Decision Aid System

WSU Crop Protection Guide for Tree Fruits in Washington

Organic Fire Blight Management in the Western US

Cougar Blight Model

Table 3. Materials available for control of fire blight in *apple*. See the *WSU Crop Protection Guide for Tree Fruits in Washington* for annually updated information. Efficacy numbers denote the relative efficacy of a pesticide against a given pest on a 1 to 4 scale with 1 being low and 4 being high efficacy. This information is based primarily on research conducted with WSU researchers in Washington. Re-entry interval (REI), preharvest interval (PHI), mode of action (MOA). Times of application: bloom (b), early bloom (eb), petal fall (pf).

Chemical	Rate per Acre	REI	PHI	MOA	Efficacy	Notes
Actigard 50WG acibenzolar-s-methyl	2 fl oz	12 hr	60 d	P01	NR	For bloom applications: Apply 2 oz/acre in a tank mix with a fire blight treatment (generally an antibiotic) that is standard in your area. This is generally 2–3 applications between 20% bloom and petal fall, depending on the environmental conditions. Do not apply closer than a 7-day interval. Also used to reduce reoccurrence of blight after cutting out infected strikes. Apply concentrate to a 1-foot section of the main leader after cutting strikes.
Blossom Protect *Aureobasidium pullulans* strains DSM 14940 & 14941	1.25 lb	4 hr	none listed	NC	4	Apply with Buffer Protect. 50% and 80% bloom. Yeasts need 1–2 days before an infection to colonize the flower before bacteria invade to be effective.
Cinnerate cinnamon oil	32 fl oz	none listed	0 d	unknown	2	Essential oil products provided median relative disease suppression (45%–49%) in 3 WA trials with repeat applications. Use as part of an integrated program. Consider drying times to minimize marking risk.
Cueva copper octanoate	4.00 qt	4 hr	0 d	M1	3	Little russet in semiarid WA trials. Some russet risk in wetter OR. Tank mix compatible with *Bacillus*-based biopesticides. Soluble copper efficacy 47% to 73%. From WSU trials 2013 to 2022 (DuPont et al. 2023).
DoubleNickel 55 *Bacillus amyloliquefaciens* strain D747	See label	4 hr	0 d	BM02	2	See label and space between rows to select the corresponding rate. Efficacy may vary based on disease pressure. Can be used with copper fungicides to increase control. Relative disease suppression in Washington trials average 30%.
FireLine 17WP oxytetracycline	See label	12 hr	60 d	41	4	Best activity within 24 hr before wetness event. Check spray tank pH, 5.5–6.0 optimal. Best activity at 200 ppm: 1.0 lb/100 gal. Label allows up to 1.5 lb/acre. Do not go above 150 gal/acre to maintain 200 ppm.
Instill copper sulfate pentahydrate (metallic copper 5.4%)	30 fl oz	48 hr	0 d	M1	3	Consider drying conditions to minimize marking risk. Soluble copper efficacy 47% to 73%. From WSU trials 2013 to 2022 (DuPont et al. 2023).
Instill-O copper sulfate pentahydrate	51 fl oz	48 hr	0	M1	3	Consider drying conditions to minimize marking risk.
Jet-Ag hydrogen peroxide, peroxyacetic acid	128 fl oz	4 hr	none listed		2	Median relative disease suppression between 48% and 62% in WA trials with repeat applications. Use as part of an integrated program. Consider drying times to minimize marking risk.
Kasumin 2L kasugamycin	64.00 oz	12 hr	90 d	24	4	Best control when applied less than 24 hr before wetness event. Control up to 12 hr after wetness event.
Mastercop Copper sulfate pentahydrate	40 fl oz	48 hr			3	Consider drying conditions to minimize marking risk.
Mycoshield calcium oxytetracycline	See label	12 hr	60 d	41	4	Best activity within 24 hr before wetness event. Check spray tank pH, 5 optimal. 200 ppm: 1.0 lb/100 gal.
NovaSource Lime Sulfur lime sulfur/calcium polysulfide	2% v/v	48 hr	none listed		NR	Early bloom applications plus oil are antimicrobial. 20% and 70% bloom timings. Reapply biologicals after lime sulfur if used.
OxiDate 5.0 hydrogen peroxide, peroxyacetic acid	128 fl oz				2	Provided moderate relative disease suppression (median 48%–62%) in WA over 3 trials with repeat applications. Use as part of an integrated program. Consider drying times to minimize marking risk.
Previsto copper hydroxide	3–4 qt	48 hr	none listed	M1	3	Pay attention to drying times. Do not combine with acidifying products to reduce fruit finish risks. Label restricts tank mixing. Soluble copper efficacy 47% to 73% in WSU trials 2013 to 2022 (DuPont et al. 2023).
Serenade Opti *Bacillus subtilis* strain QST 713	20.00 oz	4 hr	0 d	44	2	Efficacy may vary based on disease pressure.
Thyme Guard thyme oil	2 qt	4 hr			2	Essential oil products provided moderate relative disease suppression (46%–49%) in 4 WA trials with repeat applications. Use as part of an integrated program. Consider drying times to minimize marking risk.

Table 4. Materials available for control of fire blight in *pear*. See the *WSU Crop Protection Guide for Tree Fruits in Washington* for annually updated information. Efficacy numbers denote the relative efficacy of a pesticide against a given pest on a 1 to 4 scale with 1 being low and 4 being high efficacy. This information is based primarily on research conducted with WSU researchers in Washington. Re-entry interval (REI), preharvest interval (PHI), mode of action (MOA). Times of application: bloom (b), early bloom (eb), petal fall (pf).

Chemical	Rate per Acre	REI	PHI	MOA	Efficacy	Notes
Actigard 50WG acibenzolar-s-methyl	1.0–2.0 fl oz	12 hr	60 d	P01	NR	For bloom applications: Apply 1–2 oz/acre in a tank mix with a fire blight treatment (generally an antibiotic) that is standard in your area. This is generally 2–3 applications between 20% bloom and petal fall, depending on the environmental conditions. Do not apply closer than a 7-day interval. Also used to reduce reoccurrence of blight after cutting out infected strikes. Apply concentrate to a 1-meter section of the main leader after cutting.
Blossom Protect *Aureobasidium pullulans* strains DSM 14940 & 14941	1.25 lb	4 hr	none listed	NC	4	Apply with Buffer Protect. 50% and 80% bloom. Yeasts need 1–2 days before an infection to colonize the flower before bacteria invade to be effective. Russet potential on sensitive varieties in humid conditions.
Cinnerate cinnamon oil	32 fl oz	none listed	0 d	unknown	2	Essential oil products provided median relative disease suppression (45%–49%) in 3 WA trials with repeat applications. Use as part of an integrated program. Consider drying times to minimize marking risk.
Cueva copper octanoate	4 qt	4 hr	0 d	M1	3	Little russet in semiarid WA trials. Some russet risk in wetter OR. Tank mix compatible with *Bacillus*-based biopesticides. Soluble copper efficacy 47% to 73%. From WSU trials 2013 to 2022 (DuPont et al. 2023).
DoubleNickel 55 *Bacillus amyloliquefaciens* strain D747	3.00 lb	4 hr	0 d	BM02	2	See label and space between rows to select the corresponding rate. Efficacy may vary based on disease pressure. Can be used with copper fungicides to increase control. Relative disease suppression in Washington trials average 30%.
FireLine 17WP oxytetracycline	16 oz	12 hr	60 d	41	4	Best activity within 24 hr before wetness event. Check spray tank pH, 5.5–6.0 optimal. Best activity at 200 ppm: 1.0 lb/100 gal. Label allows up to 1.5 lb/acre. Do not go above 150 gal/acre to maintain 200 ppm.
Jet-Ag hydrogen peroxide, peroxyacetic acid	128 fl oz	4 hr	none listed		2	Median relative disease suppression between 48% and 62% in WA trials with repeat applications. Use as part of an integrated program. Consider drying times to minimize marking risk.
Kasumin 2L kasugamycin	64.00 fl oz	12 hr	90 d	24	4	Best control when applied less than 24 hr before wetness event. Control up to 12 hr after wetness event.
Mycoshield calcium oxytetracycline	16.00 oz	12 hr	60 d	41	4	Best activity within 24 hr before wetness event. Check spray tank pH, 5 optimal. 200 ppm: 1.0 lb/100 gal.
OxiDate 5.0 hydrogen peroxide, peroxyacetic acid	128 fl oz				2	Provided moderate relative disease suppression (median 48%–62%) in WA over 3 trials with repeat applications. Use as part of an integrated program. Consider drying times to minimize marking risk.
Previsto copper hydroxide	3–4.00 qt	48 hr	none listed	M1	3	Pay attention to drying times. Do not combine with acidifying products to reduce fruit finish risks. Label restricts tank mixing. Soluble copper efficacy 47% to 73% in WSU trials 2013 to 2022 (DuPont et al. 2023).
Serenade Opti *Bacillus subtilis* strain QST 713	20.00 oz	4 hr	0 d	44	2	Efficacy may vary based on disease pressure. Median relative disease suppression 50% in WA trials 2017 to 2021, 60% WA and OR 2012–2015.
Thyme Guard thyme oil	2 qt	4 hr			2	Essential oil products provided moderate relative disease suppression (46%–49%) in 4 WA trials with repeat applications. Use as part of an integrated program. Consider drying times to minimize marking risk.

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