Fire Blight, An Economically Important Disease of Apple and Pear: A Review of the Pathogen (*Erwinia amylovora*), Disease Occurrence, Biology and Management

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Introduction

Fire blight, caused by the bacterium *Erwinia amylovora*, is a potentially devastating disease of apples (*Malus* spp.) and pears (*Pyrus* spp.). The pathogen infects the family Rosacea, which also includes ornamental pear (*Pyrus* spp.), crab apple, hawthorn (*Crataegus* spp.), mountain ash (*Sorbus* spp.), cotoneaster (*Cotoneaster* spp.), quince (*Cydonia* spp.), ornamental quince (*Chaenomeles* spp.), firethorn (*Pyrancantha* spp.), medlar (*Mespilus* germanica), loquat (*Eriobotrya japonica*), *Stranvaesia davidiana*, and raspberry (*Rubus* spp.)(van der Zwet and Beers 1999). The disease is native to North America with the first incidence of the disease reported on this continent in New York State in the late 18th century (Bonn and van der Zwet 2000). Fire blight was introduced into Europe following WWII and first detected in England in 1957 (Billing 2000). Today it is present in many apple-growing regions around the world (see section below entitled "Global Incidence of Fire Blight).

Fire blight was first noted in Canada in the Niagara Peninsula in 1840 (Bonn and van der Zwet 2000). Today, fire blight is found in all the apple-growing provinces with the most severe incidences occurring in the warmer, humid climate of southern Ontario, and periodic outbreaks in the Okanagan Valley in British Columbia. Occasional outbreaks also occur in the other apple-producing provinces of Québec, Nova Scotia, New Brunswick and Prince Edward Island. It also occurs in the Prairie Provinces where it can be a problem in Saskatoon berry production (Bonn and van der Zwet 2000, Jesperson, pers. comm.).

Outbreaks of fire blight occur periodically and are related to presence of bacteria (inoculum) and weather conditions conducive to infections (warm, wet and humid weather during bloom, or severe thunderstorm and hail activity during the summer). In susceptible varieties of apple and pear, the fire blight bacteria can move rapidly throughout the tree resulting in the death of large limbs or even the entire tree. It is the most damaging and economically serious disease of pome fruit due to its potential to cause the death, and subsequent need for removal, of infected trees, or in the most severe cases, whole sections of orchard blocks. The impact of such an economic disaster becomes one that some growers have difficulty ever recovering from as their production is set back for many years (van der Zwet and Beer 1999).

Although fire blight has always been a major threat to pear plantings, it's importance in apple production has taken on a new dimension with the shift toward the more lucrative fresh fruit market involving the planting of new, fire blight-susceptible cultivars like Gala, Fuji, Gingergold, and Ambrosia. Orchards are also being planted at higher tree densities using 600 to 2,000 trees per acre instead of 100 to 300 trees per acre. Higher tree densities require smaller trees and this is accomplished by using dwarfing rootstocks and tree training techniques that promote more bearing surface and less overall structure. The favoured rootstocks are M.26 and M.9, which are also very susceptible to fire blight. Tree training methods may contribute to the problem by reducing some of the inherent physiological resistance in apples to the progress of infections. In all, the risks for major limb and tree losses following even a modest outbreak of fire blight is much greater now than it was 10 to 20 years ago (Smith 2001, Steiner 1998).

In North America and around the world an integrated management program (chemical, biological, cultural) for fire blight has been the most effective. The options for controlling fire blight are few – antibiotics, copper, and some biological control agents and growth regulators. Streptomycin, an antibiotic, and to a lesser extent oxytetracycline, have consistently provided the most effective and consistent control of this important disease (Alwinkle *et al*. 2000, Smith 2001, Steiner 1998). However, the overuse of streptomycin has led to resistance in many countries, including the USA and Canada (BC), leaving apple and pear growers very vulnerable with limited and less effective options (Jones and Schnabel 2000, Scholberg et al. 2001, Smith 2001). Regulatory restrictions and bans on the use of streptomycin in some countries have put further pressure on the tree fruit industry (Psilladas and Tsiantos 2000). With the changes in orchard production and the corresponding increase in susceptibility to fire blight, the highly erratic nature of the disease and it destructive potential, mitigating the risks for antibiotic resistance and suppressing the damage caused by fire blight over the long term is paramount for the long-term viability of the pome fruit industry. The development of more advanced integrated approaches, using antibiotics, other materials, predictive models, and cultural management practices, must be used in combination to provide protection, which is both economical and effective (Solymár *et al*. 1999, Steiner 2000, van der Zwet and Beer 1999, Wilcox 1994).

<u>Global Incidence of Fire Blight</u>

Native to North America, it is widely believed that fire blight spread to England and to Egypt in the 1950s through infested bud wood or trees from North America (Bonn and van der Zwet 2000). Fire blight was not reported on the European mainland until 1966 (initially the Netherlands and Poland, followed in subsequent years by West Germany, Belgium and France). Other than in North America, Europe and Mediterranean countries, fire blight is also present in some Pacific Rim countries (Japan, South Korea and New Zealand). The following is a listing of countries in which fire blight has been recorded and reported (van der Zwet 2002) [1].

<u>Note</u>: Numbers in brackets indicate first records of the disease in that country as according to Bonn and van der Zwet (2000).

North America-
Bermuda (1938), Canada (1890, 1943 – first outbreak in Niagara area), Guatemala (1968), Mexico (1921), United States (1794, earliest observation)
Europe –
Albania (1993), Austria (1993), Belgium (1972), Bulgaria (1990), Croatia (1993), Czech Republic (1987), Denmark (1968), England (1958), France (1972), Germany (1971), Great Britain (1957), Greece (1987), Hungary (1996), Ireland (1986), Italy (1992), Luxemburg, Macedonia (1990), Moldavia, Netherlands (1966), Norway, Poland (1967), Romania (1993), Serbia (1993), Slovenia (1993), Spain (1996), Sweden, Switzerland (1989), Ukraine.

Eastern Mediterranean –
Armenia (1990), Cyprus (1986), Egypt (1964), Iran (1995), Israel (1985), Jordan (1990), Lebanon (1988), Turkey (1985)
Pacific Rim –
Japan (1903), New Zealand (1919), South Korea (1999 – *E. pyrifolia*)

[1]Several other significant apple-producing countries, including Chile, Brazil, China, South Africa and Australia, are still considered fire blight-free.

Economic Importance

Fire blight is a serious disease of apple and pear in any given year, where climactic conditions are favourable. The economic losses to apple and pear industries in countries with fire blight present can be devastating. Bonn and van der Zwet (2000) have summarized some examples of these losses, which are bulleted below (all crop loss figures in U.S. dollars):

- USA (CA), 1976, losses of $4.7 million, mostly pear trees.
- The Netherlands, 1982, cost of eradication and control to nurseries and fruit trees was estimated at $6 million.
- Cyprus, 1986, 29,000 trees (100 ha) destroyed.
- Greece, 1988, 300 ha of infected pear trees destroyed. Total cost of removal and replanting estimated at $7 million.
- USA (MI), 1991, estimated $3.8 million crop loss and apple tree removal.
- Germany (Rheinland-Pfalz), 1993-1996, 600 ha of fruit trees removed.
- Belgium, 1996, $70,000 for removal of 20,0000 fruit trees in one nursery.
- Hungary, 1996, almost 65,000 apple, pear, quince and ornamentals destroyed at cost of $1.1 million.
- Australia, 1997, eradication program in Royal Botanic Garden in Melbourne and subsequent industry losses to trade restrictions were estimated at $15 million.
- USA (MI), 2000, over 1000 acres destroyed – lost revenue (long-term) estimated at over $30 million (Longstroth 2000, 2003).

There are no industry or government figures available for losses to fire blight in Canada, however economic losses have sometimes been substantial for individual growers. The major epidemic that affected Michigan in 1991 also affected many orchards in southwestern and southcentral Ontario industry, particularly of some of the most susceptible cultivars planted at that time (e.g. Golden Russet, Paula Red, and Mutsu) (Solymár, pers. obs.). In subsequent years more blocks of apple and pear were removed as overwintering high inoculum levels continued to impact the most susceptible cultivars. Examples include removal of a 5-acre block of Golden Russet and 10-acre block of Gala and Mutsu in Norfolk County, and 15 acres of apples in the Milton area. In Québec an apple grower was forced by the provincial government to remove approximately 10 acres of trees infected by fire blight, to attempt to avoid spread to adjoining orchards (Jalbert, pers. comm.). In 2002-2003, 25 acres of young (5th leaf) Gala and Gingergold trees, planted on M.9 rootstock, were ripped out by a grower in Essex County after fire blight infected his trees (Frankis, pers. comm.).

Biology

(Summarized from Solymár *et al*. 2002, van der Zwet and Beer 1999, and Wilcox 1994)

E. amylovora bacteria overwinter in living tissue at the margins of cankers on the trunk and main branches and become active in the spring when temperatures get above 18°C. Relatively few overwintering cankers become active and produce bacteria in the spring, but a single active canker may produce millions of bacteria, enough to infect an entire orchard.

The fire blight bacterium is too small to be seen without the aid of a microscope. However, in the spring liquid masses of the bacterium can sometimes be seen oozing from infected tissues. Open blossoms are the most susceptible tissues on both apple and pear trees. Bacteria move to blossoms via wind, rain and insects, where they can multiply to very high numbers in the nectar of the floral cup. Further spread of the pathogen occurs when pollinating insects (mainly bees) carry it from infected to non-infected blossoms. Rain, heavy dews, and pesticide sprays wash the bacteria into the base of the floral cup where bacteria enter natural openings and cause infections. Once infection occurs, bacteria move quickly in succulent tissues (1-4 yr old tissues), especially under conditions of warm temperatures and high humidity. Early symptoms of blossom blight can be expected 5 to 30 days after infection depending upon daily temperatures.

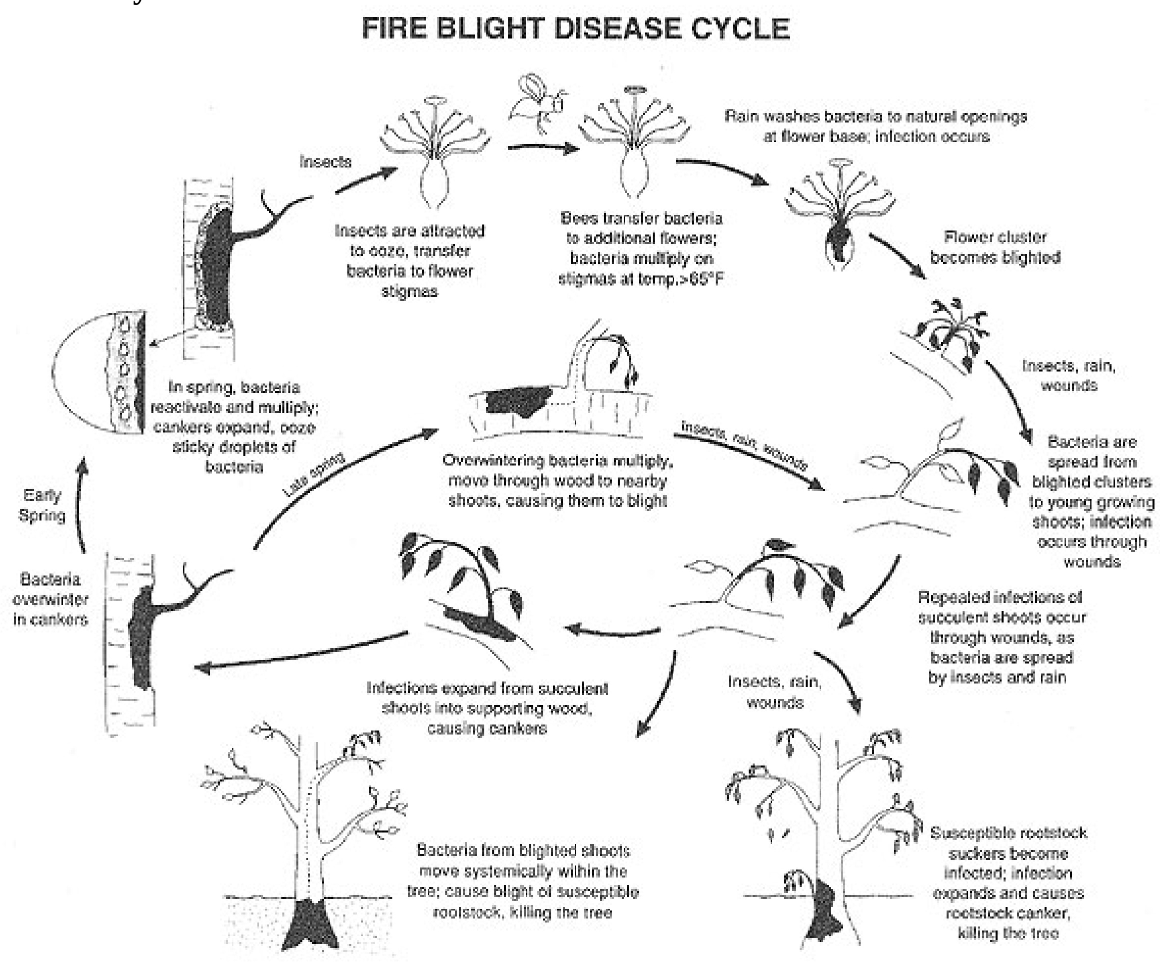
Secondary infections can occur throughout the growing season and inoculum produced from infected blossoms can be further spread by wind, rain, and insects. Shoot tip infections are likely to occur when shoots are actively growing and daily temperatures average 16°C or more. Invasion can occur directly through natural openings, such as lenticels and stomata, under conditions of prolonged rain and high humidity. However, shoot infection more commonly occurs through wounds created by sucking insects, such as aphids, leafhoppers, leaf curling midge, and tarnished plant bugs; by wind whipping; blowing sand; or by hail. Pruning using contaminated equipment can also hasten the spread of fire blight. Fire blight bacteria multiply rapidly within an infected shoot. Droplets of ooze can form on the shoots within 3 days. Shoots remain highly susceptible to infection until vegetative growth ceases and the terminal bud is formed.

Secondary infections also occur from secondary blossoms or “rat-tail” blossoms, which develop through the growing season (Smith 2001). This is a characteristic of pears and some apple cultivars (e.g. Gala).
Secondary infections are usually the most serious and can result in eventual tree losses. As the growing season progresses, infections slow down and cankers develop in the bark. Cankers tend to be sunken with indefinite margins at first but later develop cracks and become sealed off from healthy tissues

In years when blossom infections do not occur, the primary sources of inoculum for the shoot blight phase are the overwintering cankers. Particularly, young water shoots near infected cankers become infected as the bacteria move into them systemically from the canker margins. In the absence of blossom infections, the development of shoot blight infections is often localized around areas with overwintering cankers.

Although mature shoot and limb tissues are generally resistant to infection by *E. amylovora*, injuries caused by hail, late frosts of -2°C or lower, and high winds that damage the foliage breach the normal defence mechanisms in mature tissues. Instances of fire blight that originate with infections at sites of injury are called trauma blight and may affect even normally resistant cultivars like 'Delicious'.

Disease Cycle



Disease cycle of *Erwinia amylovora* - E. Gotham, Cornell University.

<u>Symptoms</u>

Fire blight bacteria can attack all parts of the tree, so disease symptoms are referred to by the plant part affected. These have been described widely in the literature (Solymar *et al*. 1999, Steiner 2000, van der Zwet and Beer 1999, Wilcox 1994) and are provided below:

Blossom blight starts in spring when flowers become infected. Infected flowers first appear water soaked, and then begin to shrivel, wilt and eventually turn brown to black. Individual flowers or entire clusters may be affected in a given cluster. The bacteria typically progress into young spur growth, leaves, and developing fruit. The bacteria travel along the midveins and the leaves soon wilt, shrivel, and turn black. Infected leaves cling to the infected stem and will often remain attached throughout the season. Young fruit will often become infected from bacterial invasion through the fruit spur. Infected fruit appear black and shrivelled, and will remain attached to the tree. The blossom blight phase of fire blight includes shoot death that develops as a result of bacterial invasion from the flower clusters. “Rattail bloom”, the late bloom that may occur on terminal buds of one-year old shoots, and secondary bloom (often present in pears) are critical factors in late season infections.

Shoot blight develops from secondary infections that originate on young terminal shoots, including suckers and water sprouts. Shoot blight usually develops in late spring or early summer. Infected shoots may at first become oily in appearance and turn dark green. Shoot blight can progress very rapidly under favourable conditions, moving 15-30 cm over the course of a few days. Blighted shoots will often form the characteristic "Shepard's crook" at their tip. When infection is severe, the appearance of blighted shoots gives the impression that the tree has been scorched by fire, hence the name fire blight.

Canker blight is also referred to as "limb", "trunk", or "body" blight depending on where the infection occurs. Cankers form as result of the bacteria traveling systemically into the woody tissue of the tree. The cankers appear sunken and dark and, when the outer bark is cut away, the underlying tissue appears water soaked. The water soaked tissue will be redder in color in young, active cankers, eventually turning a darker brown as the canker ages.

Trauma blight is a term used to describe infections that occur when blight is initiated at leaf or bark injuries resulting from hail or severe windstorms. This type of infection can often be confused with shoot blight because of the similarity between symptoms. Often, the only diagnostic that helps to determine whether a shoot is suffering from shoot blight or trauma blight depends upon the origin of the infection. If the infection appears to have originated from the tip of the shoot it is assumed that one is dealing with shoot blight.

Rootstock blight occurs when bacteria from infected blossoms or shoots moves internally through trunks and infects roots. Rootstock blight is associated primarily with the highly susceptible rootstocks such as M.26 and M.9 (apple) and Bartlett and Quince (pear). On these trees, just a few blossom or shoot infections on the scion cultivar can supply bacteria that move systemically into the rootstock where a canker may develop and girdle the tree. Infected rootstock turns dark brown to black depending on the severity of the infection and susceptibility of the rootstock and a stark contrast between the scion and graft union is often noticeable. Trees affected by rootstock blight generally show symptoms of decline and early death by mid to late season. Sometimes symptoms may not be apparent until the following spring.

Factors Affecting Disease Development

The development of fire blight is dependent on the interaction between the host, the pathogen and ambient environmental conditions. The degree of susceptibility of the host (both scion and rootstock), orchard location, soil type and drainage, tree nutrition, irrigation management, cultural practices, and weather all impact host susceptibility. The following are summarized from more extensive descriptions by Thomson (2000) and van der Zwet *et al*. (1999):

Cultivar Susceptibility

Apple and pear cultivars vary in their susceptibility to fire blight infections. Additionally, those cultivars that have a late or prolonged blossom period are more likely to have blossoms open on the tree when the weather warms up, and are therefore more likely to suffer from blossom blight. Even relatively resistant trees, such as Red Delicious, may get fire blight after a hail storm if the pathogen is found in high numbers in the orchard or if they are in a mixed planting with susceptible apple cultivars or pears.

Note that susceptibility/resistance ratings in Table 1 are not exact, and can be influenced by growing conditions and management practices (e.g. fertilizer programs, pruning practices, pest management programs for sucking insects, etc.). It is also important to remember that “resistance” does not mean “immunity”. Note also that younger trees have a greater risk of being severely damaged or killed than older trees.

Table 1. Fire Blight Susceptibility of North American Apple & Pear Cultivars and Rootstocks

	Least Susceptible	**Moderately Susceptible**	**HighlySusceptible**
Apple	Enterprise[1] Freedom[1] Jonafree[2,3] Liberty[1,2] Macfree [2] Northern Spy[2,3] Red Delicious[1,2] Redfree[2,3]	Ambrosia[5] Cameo[4] Cortland[2] Creston[4] Empire[1] Golden Delicious[1,2,3] GoldRush[1] Golden Supreme[5] Granny Smith[2] Gravenstein[2] Honeycrisp[5] Jerseymac[2] Macoun[2] McIntosh[1,2,3] Nova Easygro[1] Nova Mac[5] Pioneer Mac[4] Sansa[4] Spartan[1,2] Summerred[1] Sunrise[4] Yataka[4]	Braeburn[1,3] Fuji[1,3] Gala[1,3] Ginger Gold[1,3] Golden Russet[5] Idared[1,2] Jonagold[1,2] Jonathan[2] Lodi[2] Mutsu[1,2] Northern Spy[1] Paula Red[2,3] Pink Lady[5] Rome Beauty[1] Spigold[2] Tydeman[2] Wealthy[2] Yellow Transparent[5]
Crabapple		Dolgo[1]	Manchurian[1] Snowdrift[1]
Malus Rootstock	B.9[5] M.7[1] Robusta 5 Considered resistant: Cornell Geneva (CG® series)[5] – see also Table 2	MM.106[1] MM.111[1] M.4[1]	M.9[1] M.26[1] M.27[1] Mark[1] Ottawa 3[1]
Pear	Considered resistant: Harrow Crisp[1] Harrow Delight[1] Harrow Gold[1] Harrow Sweet[1] Harvest Queen[1]	Kiefer[5] Magness[5] Moonglow[5] Seckel[1] Spartlett[5]	Anjou[1] Bartlett[1] Bosc[1] Cascade[1] Clapp's Favorite[5] Comice[5] Flemish Beauty[1] Starkrimson[1]
Asian Pear		Kosui[1] Chojoro[1] Seuri[1] Shinko[1] Shinsui[1] Singo[1]	Hosui[1] Shinseiki[1] 20th Century[1]
Pyrus Rootstock	Old Home (OH) [1] OH x Farmingdale[1]	OHF 51[1]	Bartlett seedling[1] Quince rootstocks[1]

[1]from OMAF and BC websites
[2]from MSU web site, Nancy J. Butler, "Diseases on Apples"
[3]from WV University, Kearneysville website, Keith Yoder and Alan Biggs
[4]from Drs. Steven Miller and Alan Biggs in NE183 plot, WV
[5]from other field observations

Cornell University has had an apple rootstock breeding program at Geneva, NY since 1968. The objectives of the project are to develop rootstocks with improved nursery and orchard characteristics and that are better adapted to fire blight, crown rot and replant disease. Several new, dwarfing rootstocks have been released for commercial use over the last several years. The biggest hurdle in widespread adoption by the apple industry is the lack of availability of significant quantities of these rootstocks from commercial nurseries at the present. Other characteristics (strengths and weaknesses) are described in Table 2 (Robinson *et al.* 2004).

Table 2. Characteristics of Commercially Available CG® Rootstocks (Norelli *et al*. 2000)

CG Rootstock	Vigour	Yield Efficiency	Fire Blight Resistance	Phytopthora Resistance	Woolly Apple Aphid Resistance	Winter Hardiness
Geneva®65	Size is 60% of M.9	High, but fruit size only 90% of M.9	Yes	Yes	No	?
Geneva®16	Similar to vigorous M.9	Similar/slightly better than M.9	Yes	Yes	No	Very good
Geneva®41	Similar to M.9	Yield and size better than M.9	Yes	Yes	No	Very good
Geneva®11	Similar to M.26	Similar to M.9, fruit size similar to M.26	Yes	Yes	No	?
Geneva®202	Slightly larger than M.26		Yes	Yes	Yes	
Geneva®935	Slightly larger than M.26	Similar to M.9, excellent fruit size	Yes	Yes	No	High
Geneva®30	Similar to M.7	High	Yes	Yes	?	High

Plant Organs and Age

Infection by fire blight may be initiated in blossoms, foliage, succulent stems, or fruit. The most common route for bacterial infection is through the blossom hypenthium. The flowers are susceptible from the point in time when they open until petal fall. Rapidly growing shoots and suckers (vegetative growth) in late spring and early summer is also very susceptible to initiation, development and spread of infections. Spread of infection on slow-growing or non-growing tissue is minimal.

Soil Conditions

Soil type, soil moisture content, pH of the soil and nutrient content (particularly nitrogen) all affect tree growth and, consequently, susceptibility to fire blight infection. Heavy (clay) soils are usually poorly drained, acid and excessively fertilized. Trees are stressed and become more susceptible to the disease. Lighter, well-drained soils with a pH range of 5.5. to 6.5 results in healthier trees, better able to withstand infection.

Cultural Practices

Excessive winter pruning may make trees more susceptible to fire blight bacteria since it encourages lush regrowth. Late spring pruning cuts and pruning of sucker growth during the spring and early summer provide open wounds for fire blight to enter. Contaminated pruning tools can also spread the bacterium. Use of sharpened metal or wooden limb spreaders may cause wounds to the bark allowing fire blight bacteria to enter the tree. Other mechanical damage (e.g. from farm machinery) may also cause wounds, which are entry points for the bacterium.

Fruit trees that are provided with a balanced fertilizer program are less susceptible to fire blight infections. Several studies have indicated that higher levels of potassium in the soil result in lower levels of fire blight in Bartlett pear (Lewis and Kenworthy 1962).

Tree Nurseries

Inadvertent spread of fire blight from scion wood and rootstocks in tree nurseries has long been suspected as a route for fire blight to move to new orchards, and possibly spread to established plantings. Especially serious is the movement of pathogen infested nursery stock from areas where Streptomycin-resistant bacteria occur to areas where resistance is not present.

Environmental Conditions

Weather greatly affects the establishment of the bacterial infection and the development of fire blight symptoms. Growth and multiplication of the bacterium is highly dependent on temperature and the presence of free. Free moisture, in the form of rain, dew or high relative humidity, is also positively correlated with bacterial growth.

"Multiplication of *E. amylovora* occurs most rapidly between 24°C and 29°C . However the pathogen can grow over a much wider temperature range of 4°C to 32°C. The disease has occurred when temperatures did not exceed 19°C and some infections have been observed in orchards in which temperatures did not exceed 13°C during the critical blossoming period. Warm (>25°C), moist conditions induce rapid growth of tissues that are highly susceptible" (van der Zwet and Beer 1999).

Hailstorms are significant meteorological events that can trigger massive spread of fire blight. Hailstones, especially jagged hail, can cause tears in the plant tissue, providing entry sites for the pathogen. Rain accompanying the hailstorm can carry bacteria to the wounds. Even severe windstorms that shred leaves or blow sand against leaves, causing microscopic tissue injury have been implicated in the spread of fire blight (Solymár, personal observation).

Insects

Researchers believe that insects probably play a major role in the dissemination of fire blight. Some insects act as vectors, picking up inoculum through their feeding activities and carrying it to other plants, while others, during feeding activity, cause small punctures in the plant tissue, allowing the pathogen to enter. Smith (pers. comm.) believes that flies (Musicidae, etc.) are one of the major vectors early in the season. He has observed flies attracted to, and feeding on, the ooze that develops from overwintering fire blighted cankers. Individual flies may then visit open blossoms to feed on pollen and nectar, thereby transferring the bacteria. Honeybees and other pollinators have been identified as a significant vector in carrying fire blight bacteria from blossom to blossom during bloom (Thomson 2000). The following is a partial list of insects that have been implicated in spread of fire blight.

Table 3. Insects that have been implicated in the primary and/or secondary dissemination of fire blight

Common Name	Scientific Name
Ambrosia beetles	*Xylosandrus germanus*
Ants	*Formica* spp.
Green apple aphid	*Aphis pomi*
Woolly apple aphid	*Eriosoma lanigerum*
White apple leafhopper	*Yyphlocyba pomaria*
Potato leafhopper	*Empoasca fabae*
Pear Psylla	*Cacopsylla pyricola*
Plant bugs	Mirid species
Stink bugs	Pentatomyid species
Apple leaf curling midge	*Dasineura mali*
Honeybees	*Apis mellifera*
Flies	Various species

Fire Blight Management

Fire blight is best controlled using an integrated approach that combines: (a) horticultural practices that minimize tree susceptibility and disease spread; (b) reduction in the amount of inoculum in the orchard; (c) use of predictive models to determine blossom infections potential and (d) application of well-timed sprays of bactericides to protect against infection under specific sets of conditions.

Horticultural Practices (Preventative)

Horticultural practices to help prevent occurrence and spread of fire blight have been widely described in the literature. Because fire blight is native to North America and relatively new in most parts of the world (e.g. 1980's) many of these practices were first tested and described in the U.S. and Canada. The following are summarized, from Solymar *et al*. (2002), Steiner *et al*. (2000) and van der Zwet and Beers (1999).

- A fire blight control strategy should be a part of the planning process for all new plantings of susceptible cultivars **or** rootstocks. Recognize that the risk to such plantings will be even greater if they are planted within one-half mile of apple or pear blocks with a prior history of fire blight, and try to isolate new at-risk blocks from current inoculum sources to whatever extent is possible.

- Plant new orchards on well-drained loam or sandy-loam soils
- Maintain a soil pH of 5.5. to 6.5
- Maintain a balanced tree nutrition program by conducting soil and leaf analysis on a regular basis, and adding nutrients as required
- Avoid over-fertilizing with nitrogen. Excess nitrogen promotes lush, succulent vegetative growth, which is more susceptible to fire blight.
- Avoid excessive winter pruning which otherwise stimulates vegetative growth the following season. Regular annual pruning, and minimizing the number of cuts made, will keep the tree "calmer".
- Delay summer pruning until terminal bud set has occurred (i.e. terminals "hardened off"), generally by early to mid-August. Summer prune when the forecast calls for 2 to 3 consecutive days of sunny, dry weather.
- Sucker growth (water sprouts) should be broken out periodically during the season. In pears this also decreases the incidence of pear psylla, which is a vector of fire blight.
- If using an irrigation system avoid overhead irrigation to prevent excessive period of wet foliage and unregulated vegetative growth. Wet foliage and cankers are more conducive to infection and spread of the bacteria. Drip or trickle irrigation is preferable.
- Maintain a sound integrated pest management (IPM) program for insects that are implicated in the spread of fire blight (particularly those with piercing-sucking mouthparts)
- Apogee (prohexadione calcium) is a growth regulator that has demonstrated potential for managing shoot blight infection in experimental trials conducted in Canada and the U.S. *Apogee is ineffective for control of the blossom blight phase of the disease and is registered only for apples, not for pears*. Apogee works by slowing down the growth of a tree and, therefore, is used primarily to control overly vigorous trees and reduce the need for seasonal pruning. Apogee has value in fire blight management because when trees stop growing, they become relatively resistant to new blight infections and further expansion of established infections is arrested.

Horticultural Practices (Managing infections)

Because fire blight is native to North America and relatively new in most parts of the world (e.g. 1980's) many of these practices were first tested and described in the U.S. and Canada. The following are summarized, from BCMAFF (2000), Solymar *et al*. (2002), Steiner *et al*. (2000) and van der Zwet and Beers (1999).

- Overwintering cankers should be cut out during the dormant season to reduce sources of bacteria for the next season. Fire blight cankers have either smooth or cracked margins. Both types of cankers should be removed. One or more separate operations to prune out cankers are recommended. Since cankers may be hard to locate, it is always best to go over the orchard several times. Cankers are most visible on bright, sunny days. Make cuts 15-30 cm below the canker margins. It is not considered necessary to sterilize pruning tools during the dormant season. Do, however, disinfect your tools if spring pruning is extended into late spring when temperatures have warmed up and/or the budburst stage has arrived. These conditions may also reactivate the infectious bacteria in cankers. In fact, an additional inspection for cankers around the budburst stage may reveal cankers that were missed earlier.

- In orchards with a history of fire blight, the yellow-orange shoots characteristic of canker blight infections should be scouted for and pruned out 1-2 weeks after petal fall; this is particularly useful when blossom blight is well controlled and canker blight infections are thus the main source of inoculum for disease spread during the summer. Pruning out new shoot blight infections as they appear can also help limit disease spread, but will be most effective if practiced rigorously during the first few weeks after bloom; pruning will do little to slow disease spread if delayed until a large number of infections are visible.
- Prune out infected branches at least 30-40 cm below the visibly diseased part. This is necessary as bacteria are usually present beyond the discoloured area. Dip tools in a disinfectant between each cut. Large pruning cuts may also be treated with dilute disinfectant. Flag trees that have been pruned, and watch for further symptoms or the development of cankers. Prunings should be removed and burned immediately.
- Scout for new fire blight strikes every 3 or 4 days. Frequent scouting will aid removal of new infections before they have a chance to invade the structural wood.
- Where infections occur on shoots attached to scaffold limbs or the trunk, it is not always possible to cut back 30 cm without sacrificing the limb or even the tree. An option on large trees is to scrape out discoloured inner bark using a hatchet or knife, down to clean wood, and disinfect the cut surface.
- Cankers often form at the sites of pruning wounds, where blight was cut out during the summer. Such cankers may be hard to detect. To overcome this problem, it is sometimes recommended that a short (10 cm) stub be left beyond the next healthy spur or branch union when pruning out strikes ("ugly stub method"). Remove the stub later, during dormant pruning. Marking the stubs with bright paint will make them more visible.
- During severe epidemics, give priority to young trees and high-density plantings. Concentrate on salvaging as much of the tree structure and bearing surface as possible. Excessive pruning during the summer will encourage a late flush of growth, which will be susceptible to continued infections.
- Summer pruning (other than removal of strikes) should be avoided during a serious outbreak, due to the danger of spreading the disease. If there is any fire blight in the area, disinfect your tools while summer pruning. Avoid pruning during wet weather or when storms are expected within the next 24 hours.

- Do not cut root suckers or rootstock sprouts during a blight outbreak, because the wounds may become infected. They may be safely removed during the dormant season.

  Disinfectants:
  Good disinfectants for tools include a 10% household bleach (e.g. Javex, Chlorox) solution, Lysol Concentrated Disinfectant, and PineSol. The latter can be diluted up to 1:5 with water. Bleach needs to be mixed fresh every day. Tools can either be dipped into, or sprayed with the disinfectant solution. If you use bleach, be aware that it will corrode metal tools and damage your clothing. Ideally, tools should be disinfected after every cut. Dilute disinfectant can also be sprayed on the bark after cutting out an infected branch. A less harsh alternative on pruning tools is denatured alcohol (70%), available at pharmacies.

Eradication

Fire blight is native to North America, but since the 1950s has spread to most European countries, Mediterranean countries and some Pacific Rim countries. Hawthorn (*Crataegus* spp.) and cotoneaster (*Cotoneaster salicifolius* floccosus), planted as ornamentals, and used in windbreaks and hedgerows, are found throughout Europe. Both are extremely susceptible to fire blight (van der Zwet and Beer 1999) and are implicated as a major reservoir host for the fire blight pathogen. Many European countries implemented eradication programs in the 1960s and 1970s to attempt to halt the spread of fire blight to commercial crops such as apple, pear and quince. For example, in 1966 The Netherlands initiated an eradication program for hawthorn hedges and windbreaks, and ornamental cotoneasters, in an attempt to reduce sources of inoculum. In 1982 the country lost as estimated US$6 million worth of nursery stock and fruit trees to severe fire blight outbreaks (Bonn and van der Zwet 2000). Similar programs were attempted in Belgium, Germany, Denmark, and other countries with little success in eradicating the disease (Bonn and van der Zwet 2000). Spain, however, has successfully controlled the spread of fire blight in that country through eradication of identified infested plants and creation of buffer zones around these sites (Lopez, pers. comm.)

In April 1997, fire blight-like symptoms were observed on three different roseaceous plants in the Royal Botanic Garden in Melbourne, Australia (Rodini *et al*. 1999), a country considered free of fire blight. A massive eradication program was implemented followed by extensive detection surveys, diagnostics and media management at an estimated cost of A$2.2 million. The total cost to the Australian pome and nursery industries was estimated at A$20 million in lost revenue. (Rodoni *et al*. 2004). The disease is considered eradicated from that country.

Fire Blight Management in Nurseries

Steiner (2002) reviewed management practices in nurseries to manage fire blight. He comments that "while blossom blight is particularly damaging in commercial orchards, it is not generally a problem in nursery fields, but the abundance of succulent vegetative growth and the wounding that occurs as part of routine nursery practices, such as bud and

shoot removal, provide ample opportunities for shoot and trauma blight incidences. In addition, since the pathogen is readily transported as aerosols with even modest, wind-driven rains at 3-6 m/sec, the presence of even a few sources of inoculum can be enough to initiate major epidemics of secondary shoot blight in large nursery fields planted at high densities of more than 20,000 trees/ha."
Recommendations set out by Steiner (2000) include:

- Locating nursery fields in isolation, away from orchards and alternate hosts
- Maintain bud wood sources orchards separate from production orchards
- Select bud wood from fire blight-free trees
- Deflower nursery trees
- Use hail netting
- Always disinfect hand towels when moving from nursery to nursery
- Monitor regularly for appearance of symptoms
- Immediately remove and dispose of any trees showing symptoms, and immediate trees next to infected trees
- Maintain a sound IPM program for insects with sucking-piercing mouthparts (e.g. aphids, leafhoppers, etc)
- Use antibiotics and copper as required

Predictive Models

Predictive models can be very effective in forecasting when orchards are at risk of infection, in timing bactericide sprays, and in potentially reducing unnecessary applications. There are over a half dozen risk assessment models developed in the world. The principal factors in assessing fire blight risk are: temperature, moisture (precipitation, dew, humidity), phenology (e.g. open blossoms, terminal shoot growth), host susceptibility, pathogen inoculum levels, and trauma events (frost, hail, strong winds, insects) (Billings 2000).

In North America there are 2 predictive models used by the tree fruit industry. The Maryblyt™ model, was developed by Dr. Paul Steiner in Maryland, USA (Steiner and Lightner 1992). Since 1990 this computer-based model has been widely used in different countries and under different climactic conditions. Maryblyt™ is designed to predict blossom blight infection potential and symptom development of most phases of fire blight (e.g. shoot blight, trauma blight, etc.). The model assumes an abundance of inoculum in the orchard. It predicts the potential risk of infection based on the occurrence of certain environmental conditions in sequence. These conditions include:

1. The presence of blossoms
2. The accumulation of 198 degree hours (>18°C) from start of bloom
3. A wetting event including rain, dew, or a spray application, or 2 mm of rainfall the previous day.
4. The average temperature of 15°C the day of infection.

There is agreement that Maryblyt™ generally gives useful guidance on optimal timing of protective (streptomycin) sprays during bloom, especially if used with consideration of field risks (Jones 1992, Bonn 1993, van der Zwet *et al.* 1994).

The second model, Cougarblight, was developed by Tim Smith at Washington State University (Smith 1993, 1999). It is not a computer model, but, instead, can be set up as a spreadsheet. The model uses a “look up” chart to determine daily degree hours (DDH) accumulated based on maximum and minimum temperatures. Since hourly values are used to accumulate heat units rather than the daily high and low temperatures Cougarblight arguably provides a more accurate calculation of DDH. The user then calculates the sum of DDH over four days during bloom leading up to a potential wetting period. The user must select the appropriate inoculum potential based on proximity to the inoculum source. The biggest advantage of this model is its ease of use. It can be used in conjunction with regional weather data and the user-friendly tabulated guides. Spring weather is usually cooler and drier in the Pacific Northwest than in the East, and the model is considered more sensitive to fire blight events under low inoculum levels.

When comparing Cougarblight and MaryBlyt, both models track heat units (DDH above a base of 15°C) on days leading up to a wetting event, using slightly different methods to do so. Only days with open blossoms count towards the accumulation. Both models require some type of wetting to initiate infection, and allow for heavy dew in the absence of rain as sufficient to cause such wetting. Dew that only affects the orchard grass is not enough to cause infection. As there is no independent measure of heavy dew, an observation of 3 or more hours of leaf wetness is used as a proxy to represent the possibility of heavy dew. This is an imperfect measure, but it is the best we have. MaryBlyt also allows for infection on the day after a day with more than 2 mm rain even if that day has no rain or heavy dew.

Comparisons of the two models by Deb Breth of Cornell University over 3 years have shown that they are very similar in identifying possible fire blight infection periods (Breth *et al*. 2000). In Canada, the eastern apple growing provinces have generally used the Maryblyt model, in BC the Cougarblight model is preferred. Those IPM practitioners that have compared the models generally agree that, ultimately, the choice of model is much less important than actually using at least one of the two to forecast possible infection conditions (Breth and Aldwinkle 2002).

Several systems and models were developed in Europe in the 1980’s and 1990’s, including Firescreens in France, Feuerbra in Germany and the Billing’s integrated system (BIS) in England (Billings 2000). Many of these systems used the concept of potential daily doublings of the pathogen (based on daily temperature values), plus daily rainfall and storm records, in conjunction with field risks (Billings 2000). In the last few years, components of the Maryblyt™ model were incorporated in an integrated system (BIS), which also retains elements of earlier European systems. Agreement between the Maryblyt™ model and BIS is often good for predicting blossom blight infections (Billings 2000).

Israel developed it’s own prediction system, the Fire Blight Control Advisory (FBCA) system in 1999. (Schtienberg *et al*. 1999). The FBCA uses phenology, temperature, wetness duration, 3-day weather forecast, and monitoring of early visible fire blight symptoms in orchards. This prediction system was tested against Western models, including BIS and Maryblyt™, but it was found that they were not suited to Israeli conditions (Schtienberg et al. 2002).

Chemical Control

A large number of chemicals have been tested against fire blight (Van der Zwet and Keil 1979; Psillidas and Tsiantos 2000). Most of the earlier work was conducted in North America, with an increase in studies out of Europe and New Zealand after the disease was discovered there. Few of these chemicals ever received registration. The two groups of chemicals that have played the most important role in controlling fire blight (re. efficacy) on apples and pears are copper compounds and antibiotics.

Copper compounds

Copper compounds have been established as effective bactericides and have been used against fire blight on apples and pears since 1900. These are protectant chemicals and therefore must be applied before infection occurs. They will not cure diseased tissue or active infections. The real role for copper in controlling fire blight is to provide an inhibitory barrier over all bark and bud surfaces in the orchard that will prevent the bacteria from colonizing these areas.

The active ingredient is the copper ion, which is toxic to all plant life, causing burning of leaves and russeting of fruit. The phytotoxicity of copper compounds is a limiting factor when applying it to apple and pear trees, limiting its use to delayed dormant and green tip application timings. The use of Bordeaux mixtures (copper sulphate + hydrated lime as a safener), in correct proportions and properly prepared, can reduce the phytotoxicity of copper when applied to fruit trees. In Canada the following copper compounds are registered:

Table 4. Registered copper products in Canada[1]

Product Name	Active Ingredient	Registered on Apple	Registered on Pear	Recommended rate of formulated copper in rate of hydrated lime (kgs)
Clean Crop Copper 53W	Cu from tribasic copper sulphate 53%	Yes	Yes	1:6
Griffin Basicorp	Cu in basic copper sulphate 53%	Yes	Yes	1:6
Copper Spray	Cu for copper oxychloride 50%	Yes	No	N/A
Triangular Brand Copper Sulfate	Cupric sulphate pentahydrate (metallic Cu 25.2%)	Yes	Yes	2:6

[1] from OMAF 2004

Comments and cautions on the use of copper products and Bordeaux mixtures (from BCMAFF website):

- Due to phytotoxicity risks copper formulations should be used only at budbreak (green tip) to reduce or delay the production of inoculum in overwintering cankers.

- Applying copper during bloom may cause blossom burn and fruit russet, especially on Bartlett and Anjou pears and susceptible apple cultivars.
- Copper oxychloride should not be used on wet foliage. Bartletts sprayed with copper during wet weather have suffered russeting.
- Since the dispersal and colonization of the bacteria is random and independent from the resistance or susceptibility of the trees, *all of the trees in a treated block must be sprayed, not just those of susceptible varieties.*
- The addition of spray oil to dormant copper spray has been shown to increase the effectiveness of the treatment.
- Bordeaux mixtures reduce risk of phytotoxicity but caution must still be exercised. Apply as a dilute spray only, using 3000 L/ha. Do not use as a concentrate. Do not use Streptomycin after using Bordeaux mixture, as the high pH of the Bordeaux will break down the Streptomycin.
- Bordeaux mixture is corrosive. Sprayers should be washed thoroughly after use. A protective coat of oil will make clean up easier by preventing Bordeaux from sticking to paint.

Antibiotics

Antibiotics are organic compounds produced by microorganisms, which selectively inhibit the growth of other microorganisms. Fire blight was one of the first bacterial diseases against which antibiotics were used in agriculture (Morgan and Goodman 1955). Although many antibiotics were found to be active *in vitro*, only a few had practical value for field applications. Other materials had high plant or mammalian toxicity, lack of systemic activity and short persistence on plant surfaces in the field (Psillidas and Tsiantos 2000). The only materials of any commercial value are streptomycin and, to some extent, oxytetracycline and kasugamycin.

<u>Streptomycin</u>

Streptomycin is an aminoglycoside produced by certain strains of *Streptomyces griseus*. In repeated field testing it has proven itself to be an effective material to fight fire blight, without any phytotoxic effects on leaves and no fruit russeting (van der Zwet and Keil 1979). At a rate of 100 to 150 p.p.m., applied during the blossom period on apple and pear, at 3 to 5 day intervals, good control of fire blight is exhibited. In cases where secondary bloom occurs or weather conditions favour infections, more applications are recommended (Bonn and Morand 1980).

Prior to 2001, streptomycin was also registered in Canada post-bloom for control of trauma blight infection events (i.e. hail storms). The effectiveness of streptomycin for this type of infection was contingent on applying the material just prior to an anticipated trauma event or within 12 hours of the start of the event.

Comments and cautions on the use of streptomycin (BCMAFF website):
It is most effective for blossom blight control during warm (over 18^{o}C) temperatures.

It only provides 2 to 3 days of protection because it breaks down quickly when exposed to sunlight.
Streptomycin is most effective when applied as a dilute spray to open blossoms.
Better absorption is obtained during slow drying conditions.
For best results, streptomycin should not be tank mixed with other pesticides.
Do not use streptomycin after symptoms develop or to control shoot blight, since it is not effective and increases the risk for developing resistance.
Streptomycin has a 50-day pre-harvest interval on apple, and 30 days on pear.
Streptomycin should always be stored in a refrigerator, or effectiveness will decline rapidly. Refrigerated product will keep well for two years, with a gradual decline in effectiveness from two to five years.

Streptomycin resistance in bacteria can occur either as a result of chromosomal mutation or through gene acquisition (Davies 1986). Strains of *E. amylovora* that are resistant to streptomycin were confirmed in California pear orchards in 1971, followed by reports of resistance in Oregon and Washington in subsequent years. Today, streptomycin-resistant strains are widespread in pear and apple orchards in the Pacific Northwest (WA and OR) (Jones and Schnabel 2000), including British Columbia (Sholberg *et al*. 2001), and in California (Moller *et al.* 1981). Contrary to the situation in western North America, most apple orchards in eastern states and provinces, even after more than 40 years of streptomycin usage, have not developed resistance. Although streptomycin-sensitive strains of *E. amylovora* are present in most eastern states (e.g. New York, New England states), resistant strains have been identified in Michigan, Missouri, and Idaho (McManus and Jones 1994, Shaffer and Goodman 1985). Ontario and other eastern provinces have not reported any streptomycin-resistance.

Recently, streptomycin-resistant strains of *E. amylovora* were found outside of North America, in New Zealand (Thomson *et al*. 1993), Lebanon (Saad *et al*. 2000), and Israel (Manulis *et al*. 1996).

The existence of streptomycin-resistant *E. amylovora* makes control very difficult, if not impossible, because streptomycin is considered the only effective, plant-safe pesticide available in many countries for the control of fire blight (Psallidas and Tsiantos 2000). The less effective oxytetracycline (see below for description) can be substituted for streptomycin, or used in combination with streptomycin, on pears in the US.

Streptomycin use has been banned in several E.U. countries. Residues of streptomycin found in honey led to a ban in Belgium (Deckers and Schoofs 2004), and strict use regulations in Germany (Moltmann *et al*. 2004). It is also banned in France and Switzerland (Broggini *et al*. 2004).

<u>Oxytetracycline</u>

Oxytetracycline is an antibiotic produced by the actinomycete, *Streptomyces rimosus*. In the United States oxytetracycline is sold as Terramycin or Mycoshield. It is not registered for use in Canada. Various studies have shown that this antibiotic is somewhat less effective than streptomycin (85-95%), but has proven useful in US states where resistance to streptomycin exists (e.g. WA, OR, MI). In fact, in Pacific Northwest pear and apple orchards oxytetracycline has been used since the late 1970's to control fire blight (Moller *et al.* 1981). Resistance has not developed. The EPA must approve its use for fire blight control annually.

<u>Kasugamycin</u>

Kasugamycin is an aminoglycoside produced by *Streptomyces kasugaensis*. It is not registered in North America due to high phytotoxicity on pears and apples at effective rates (Aldwinkle and Norelli 1990). However, Kasumin (trade name) has been registered in the Netherlands for use on ornamental hosts of fire blight (Coster and Waalkens 1989).

Other Chemicals

<u>Oxolinic acid</u>

Oxolinic acid is a synthetic bactericide belonging to the quinoline family and developed by Sumitomo Chemical Co. in Japan, and marketed through Valent as Starner®. It was tested in the 1980's against fire blight with variable results (Hikichi *et al*. 1989). More recent testing in the U.S. showed it to have good efficacy of fire blight (Jesperson, pers. comm.) It has been registered in Israel since 1997 (Shtienberg *et al*. 2001), but does not have registration in the U.S. or Canada.

<u>Fosetyl- aluminum</u>

Fosetyl – Al, or Aliette™, is registered in North America for *Phytopthora* collar and root rots of apple. Research indicates that this material does not directly inhibit target organisms, but that it induces defence mechanisms in the host. The material has been tried for several years in Europe, the U.S. and Canada. Test results show that Alliette is never better than streptomycin, often affords significantly less control and, sometimes, appears to be ineffective (Steiner 1998, Psillidas and Tsiantos 2000). The product is registered for fire blight control in France and Turkey. In Canada and the U.S. it is registered for *Phytopthora* spp. and for blister spot, *Pseudomonas syringae*.

Biological Agents

"Biological control of fire blight occurs when a bacterial antagonist establishes and develops a large population on the stigmatic surface (of the flower). Biological control agents (BCAs), through a combination of mechanisms, then suppress establishment and growth of the pathogen. Suppression of the increase in population size of *E. amylovora* on stigmatic surfaces reduces the probability of floral infection and spread of the pathogen to other blossoms. Effective biological control requires that the BCAs colonize the stigmatic surface of the blossom, and the population of the antagonist on those surfaces is large. A sufficiently large BCA population is usually in the range of 10^5 to 10^6

colony-forming units/mL (cfu/mL), for which the latter number is considered the upper limit (carrying capacity) of population size for BCAs on an apple or pear blossom. Fire blight is a good candidate for biological control because the bacterial antagonists need to persist on the nutrient-rich, stigmatic surfaces for only about a week to suppress blossom infection effectively" (Johnson and Stockwell 2000).

Establishment of populations of bacterial antagonists in blossoms is the most critical step in implementing biological control of fire blight in commercial orchards. The initial process of establishment of bacterial antagonists in the orchard appears to be quite variable, and potentially influenced by the complex methods of inoculum preparation (e.g. freeze-drying and re-suspension), application methods, insect activity, and orchard temperatures (Stockwell *et al*. 1992, 1998). Honeybees have been experimented with as dispersal agents of bacterial antagonists using pollen inserts, which are attached to the hive entrance. As honeybees enter and leave the hive they contact the pollen insert, which has been inoculated with bacterial antagonists, and are then carried to blossoms (Johnson *et al*. 1993a, 1993b). Best control is achieved if the antagonist is applied to newly opened flowers, prior to fire blight infections, to allow for establishment (Lindow *et al*. 2004).

Once established, there is a good amount of evidence that populations are relatively resilient and that they become partially self-sustaining by spreading from blossom to blossom by insects and rain (Nuclo *et al*. 1998). The antagonistic bacteria must then stay active for at least 5 to 7 days while trees are in bloom. Most fire blight researchers tend to use the term "suppression" rather than "control" when discussing the use of antagonistic bacteria for management of fire blight.

Blight Ban™, *Pseudomonas fluorescens*, strain A506

Blight Ban™ has been marketed since 1995 in the US. *Pseudomonas fluorescens*, strain A506 multiplies rapidly and colonizes open flowers to the extent that it excludes any significant subsequent colonization by the fire blight organism (Vanneste 1996). Tests in many locations, however, show that if this antagonist is applied after *Erwinia amylovora* is already present or even as a mixture with the pathogen, it is not effective (Johnson and Stockwell 2000).

Blight Ban™ C9-1, *Pantoea agglomerans*, strain C9-1

Pantoea agglomerans, strain C9-1, formerly known as *Erwinia herbicola*, is a common epiphyte found in apple and pear orchards. In addition to the competition for space that occurs with *P. fluorescens* A506, *P. agglomerans* C9-1 also produces an antibiotic that inhibits the multiplication of the pathogen (Wilson and Lindow 1993). Like *P. fluorescens* A506, *P. agglomerans* C9-1 must also be present in the flower before the arrival of the pathogen for it to be effective. *P. agglomerans* C9-1 has not yet been approved by the EPA in the USA.

Note: Both *P. fluorescens* A506 and *P. agglomerans* C9-1 provide a moderate level of control against fire blight in most trials conducted across the U.S. (e.g. Aldwinkle 1999, 2000; Hickey *et al*. 2001b). However, neither provides the overall control for blossom blight that is as dependable, or as effective, as streptomycin. Typically, levels of control for BCAs are significantly less than is generally obtained with streptomycin (Aldwinkle *et al.* 2000, Hickey *et al*. 2001b, Steiner 1998).

Serenade®, *Bacillus subtilis*

Serenade® is registered in the EU and the USA is, which has shown generally mixed results and is not considered a strong bacterial antagonist on it's own (only up to 40% control), but when used with streptomycin in rotation provides control comparable with use of streptomycin alone (Edgecomb 2004). New York recommends, " that Serenade be used in a rotational program with streptomycin and not as a sole bactericide for fire blight management. Research at Geneva suggests that streptomycin should be the first product applied during bloom, particularly when conditions are very favourable for the development of fire blight. Serenade should be applied 24 hr after the infection event" (Cornell Cooperative Extension 2004).

Johnson and Stockwell (2000) conclude that " given current antagonist strains, biocontrol of fire blight, in most cases, should be viewed as a complimentary disease control strategy, where the benefits of use will be most significant when integrated with orchard sanitation and the application of antibiotics during periods of high infection risk".

Since BCAs are resistant to streptomycin (gene lies on the chromosome and not on a transmissible plasmid, so this type of resistance should be safe in that it is not likely to be transferred to pathogen strains), the best treatment time for these bioantagonists is at the beginning of bloom and at full bloom along with streptomycin treatments scheduled in response to predicted infection events. At the present stage of development, BCAs are probably a less attractive alternative to streptomycin in the mid-Atlantic region than in the western U.S. where it is reported that up to 85% of the pathogen isolates are already resistant to streptomycin (Stockwell *et al*. 1996).

Systemic Acquired Resistance (SAR) Inducers

SAR inducers are materials that boost plant systemic acquired resistance. Unlike antibiotics and copper, SAR inducers do not affect the bacteria directly, but turns on the plants own defence mechanisms. SAR inducer technology is targeted at shoot blight prevention (Psallidas and Tsiantos 2000).

Messenger™ (harpin protein) has a U.S. Environmental Protection Agency (EPA) label. Messenger™ must be applied several days before infection takes place. That is, before the grower really knows how high the risk of infection will be. It may be useful in high-value orchards of susceptible varieties and rootstocks where fire blight has occurred in previous years, and especially where streptomycin resistance is present (Aldwinkle 1999).

Results were promising in New York trials for several consecutive years, however the level of control was not as good as by streptomycin in seasons with high disease pressure during bloom, suggesting Messenger™ may not provide sufficient control in fire blight-prone years (Aldwinkle 1999). Hickey *et al*. (2001b) found no significant difference between shoots treated with Messenger™ and untreated shoots. No russeting of fruit has been recorded to date (Aldwinkle 1999).

Another product, Actigard (enzothiadiazole), mimics salicylic acid to stimulate the SAR pathway, which induces pathogenesis-related proteins and diseases resistance expression (Ward *et al*. 1991). also turns on plant defenses. In New York trials control was not as good as with Messenger™ although other researchers have had acceptable results with Actigard (Aldwinkle *et al*. 2000). It does not have a US label for fire blight at the present.

Gibberellin Inhibitors

Prohexadione-calcium (Apogee™) is a growth regulator that inhibits gibberellin biosynthesis thereby stunting actively growing shoots (Rademacher 2000). It helps reduce shoot blight symptoms of fire blight by reducing terminal shoot growth and earlier "hardening" thereby reducing the desirability of shoots to sucking insects such as aphids and leafhoppers. Apogee™ is very effective in preventing shoot blight in mature, bearing trees at appropriate rates and when considering shoot vigour and seasonal growing conditions (Aldwinkle *et al*. 2000, Hickey *et al*. 2001a, 2001b; Jones and Ehret 1999). Apogee™ treatments, unlike antibiotics, need to be applied 2 weeks prior to infections occurring (Deckers and Schoofs 2004). Recent work by Norelli and Miller (2004) showed that Apogee™ could be used to help manage fire blight in young trees in the 4th to 6th season of growth. Further research is needed on younger trees (as reducing shoot growth is not desirable when the aim is optimizing growth for earlier bearing) and in cooler climates where lower tree vigour is often experienced and Apogee™ may stunt growth that is needed. Apogee™ has been registered in the US and in EU countries for several years and is expected to receive registration in Canada for the 2005 growing season.

Summary of Registered Products in Different Countries

Table 5. Bactericides registered for use against fire blight in different countries

Common Names	Commercial Name	Crop(s) Registered On	Country

A. Copper Compounds			
basic copper sulphate	Basicop, Triangle Brand, etc.	apple	BE, BG, **CA**, FR, GR, TR, US
tri-basic copper sulphate	Copper 53W, etc.	apple, pear	**CA** (pear only), US, GE
copper hydroxide	Kocide, Blue Shield, Cupravit, etc.	apple, pear	BE, BG, CY, GR, NZ, US
copper oxide	Nordox 50 WP	apple, pear	GR
copper oxychloride	Coperil, Cupravit, Guardsman, etc.	apple, pear	BE, **CA**, CY, GR, NL, US
copper oxychloride + mancozeb	Mancozide	pear	US
copper oxychloride + maneb	Herkul	apple, pear	TR
copper oxyquinolate	Quinolate 40%	apple, pear	CY
B. Antibiotics			
streptomycin	Streptomycin, Agri-strep, Agrimycin	Apple, pear	**CA**, GE, GR, IL, NL, NZ, US
oxytetracycline	Mycoshield, Terramycin	Apple, pear	US
kasugamycin	Kasumin	ornamentals	NL, SP
oxolinic acid	Starner	apple, pear	IL
C. Other Chemical Compounds			
flumequin	Firestop	apple, pear	BE, CY
fosetyl-al	Aliette	apple, pear	FR, TR
D. Biologicals			
Pantoea agglomerans, strain C9-1	Blightban C9-1		US
Pantoea agglomerans strain P10c	Blossom Bless	Apples, pears	NZ
Pseudomonas flourescens, strain A506	Blightban A506		TR, US
Bacillus subtillus	Serenade		US
E. Growth Regulators and SAR Inducers			
prohexadione calcium	Apogee		US
harpin protein	Messenger		US

This table adapted, in part, from Psallidas and Tsiantos 2000, and other sources: Vanneste *et al*. 2002; Paulin, pers. comm..; Lopez, pers. comm.
Country codes according to ISO 3166 : 1988

Breeding for Resistance

Traditional plant breeding programs for resistance of pear and apple to fire blight and other diseases have been underway for many years and are summarized by van der Zwet and Keil (1979) and by Lespinasse and Aldwinkle (2000). Traditionally, crosses of rootstocks or scions are evaluated for resistance by observing seedlings or young trees under nursery, greenhouse or experimental orchard conditions. Artificial inoculations with the fire blight pathogen are made *in vivo* and lesion development on roots is observed and recorded. Fire blight resistance is controlled polygenetically so breeding for fire blight resistance is necessarily a long-term strategy.

Breeding programs for fire blight resistance currently exist in France, Italy, Germany, the United States and New Zealand, and are described by Lespinase and Aldwinkle (2000). In Canada, the pear breeding program at AAFC Harrow, which produced a number of fire blight resistant varieties of pear through traditional breeding programs (e.g. Harrow series and Harvest Queen) was discontinued in the late 1990's.

Due to the heterozygosis of *Malus* and *Pyrus*, long generation time, and self-incompatibility, backcross programs of several generations are prohibitively long term and expensive. This makes traditional breeding programs where an attempt is made to introduce disease-resistance genes by conventional breeding into a commercially accepted cultivar, while maintaining all its desirable traits (appearance, quality, flavour storability, horticultural aspects, etc.), almost impossible (Alwinkle *et al*. 2000). For example, although several disease-resistant selections have been commercialized in Europe and in the United States (e.g. Liberty, Goldrush, Enterprise, Freedom), these cultivars often lack in those same desirable traits that have led to the success of current commercial cultivars. Combined with the difficulty in getting retailers and consumers to accept new cultivars in the marketplace, uptake of these disease-resistant cultivars has not had a significant impact on global apple production trends (O'Rourke, pers. comm.). Rather, most of the cultivars are grown for organic markets and for smaller speciality markets (e.g. health food stores, pick-your-own).

Transgenics

The use of biotechnology can overcome many of the obstacles to traditional breeding programs described in the previous section (Norelli and Aldwinkle 2000). Genetic engineering offers a viable alternative to conventional breeding for the creation of resistant varieties since it is faster, can use genes from many sources, and will preserve the desirable qualities of the transformed variety or rootstock (Alwinkle *et al*. 2000).

Several researchers, particularly David James at East Malling, United Kingdom, pioneered methods to transfer genes into apple. The Department of Plant Pathology at Cornell University drew upon his work and their own early efforts to develop the techniques they now use for efficient genetic transformation of several varieties. They currently use modified strains of the common soil bacterium, *Agrobacterium tumefaciens,* which transfers genes into plants in nature, as the gene delivery system (Aldwinkle *et al*. 2000).

Initial testing of fire blight resistance of two- and three-year-old trees of Royal Gala transgenic lines in the field, containing lytic proteins (attacin, cecropins, or avian lysozyme), showed that several lines had significantly increased resistance. This was the first demonstration in a well replicated test of increased shoot resistance of transgenics in the field. The greatest level of fire blight resistance was observed with transgenics containing the attacin protein (Norelli and Aldwinkle 2000).

Besides the lytic protein genes, other genes derived from apple, other plants, and also the fire blight bacterium itself, are being tested for their ability to make apple plants more resistant to fire blight. These new genes should act to enhance apple's own natural defenses against pathogens, rather than acting directly against the fire blight bacterium by producing proteins that are antimicrobial. Orchard trials conducted by the Cornell group have also shown that when apple trees are sprayed with SAR inducers, such as benzothiadiazole (Actigard) or harpin protein (Messenger), significant reductions (40-50 percent) in the amount of blossom blight of apple can result. By expressing the harpin protein transgenically in apple they hope to either pre-activate its natural defenses against fire blight and apple scab, or activate them earlier in the infection process to render apple plants more resistant to these diseases. The Harpin gene has been transferred to M.26 apple rootstock and is being evaluated for its effect on fire blight resistance (Norelli and Aldwinkle 2000).

The transgenic lines currently being developed in the Cornell program are considered experimental. Transgenic lines designed for use in commercial apple growing will likely differ in genes, promoters, and regulatory sequences from those described here. Before being commercialized, transgenic apple varieties will have to go through rigorous regulatory requirements to demonstrate their complete safety for humans and the environment (Aldwinkle *et al*. 2000).

Summary

Fire blight has plagued pear and apple orchardists for many decades, but perhaps today, more than at any other time in history, the economic threat is being magnified by the trend towards higher density plantings, using fire blight-susceptible dwarfing rootstocks and new, popular cultivars that also are even more susceptible to *E. amylovora* than older, less valuable cultivars. Streptomycin, long the stalwart for controlling fire blight in orchards, is no longer a viable option in the Pacific Northwest (including BC) and some Eastern States due to the development of resistance.

Many years of experience has shown that the best way to manage this devastating disease is through an integrated approach using horticultural methods, predictive models for forecasting infections, and combinations of antibiotics, biologicals, and growth regulators. In the long-term bioengineering of commercial cultivars, with genes coded for fire blight resistance, is a solution apple and pear growers are eagerly anticipating.

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