

EPPO Datasheet: *Xanthomonas fragariae*

Last updated: 2023-06-19

IDENTITY

Preferred name: *Xanthomonas fragariae*

Authority: Kennedy & King

Taxonomic position: Bacteria: Proteobacteria:

Gammaproteobacteria: Lysobacterales: Lysobacteraceae

Common names: angular leaf spot of strawberry, leaf blight of strawberry, vascular collapse of strawberry

[view more common names online...](#)

EPPO Categorization: A2 list

[view more categorizations online...](#)

EU Categorization: RNQP ((EU) 2019/2072 Annex IV)

EPPO Code: XANTFR



[more photos...](#)

Notes on taxonomy and nomenclature

Xanthomonas fragariae is a phenotypically and genotypically homogeneous species and clearly distinct from the other xanthomonads (Vauterin *et al.*, 1995; Roberts *et al.*, 1996 and 1998; Rademaker *et al.*, 2000 and 2005; Parkinson *et al.*, 2007; Albuquerque *et al.*, 2011). Strains show a strong clonal relationship, although some variation in fatty acid, RFLP, rep-PCR and AFLP profiles, not related to geographic origin or virulence, was observed by Roberts *et al.*, 1998 and Stöger *et al.*, 2008. A deviating, virulent strain, causing crown infection was reported from Liaoning province in China (Li *et al.*, 2021). Maas *et al.* (2000) noted some difference in virulence between strains.

X. fragariae was the first xanthomonad where the CRISPR (clustered regularly interspaced short palindromic repeats) locus spacer typing and MLVA (Multilocus variable number of tandem repeats – VNTR - analysis), assisted in determining a (micro)-evolutionary trend among isolates. Two major groups and four subgroups were distinguished and data suggest that the two main groups were potentially responsible for the spread of the disease worldwide and the relative homogeneity of the species (Gétaz *et al.*, 2018).

A related bacterial pathogen, causing so-called bacterial leaf blight, in the early 1990s in strawberry cultivations in Northern Italy, was described in 2001 as *Xanthomonas arboricola* pv. *fragariae* (Janse *et al.* 2001). Subsequently, the pathogen was also found in strawberry plantlets in Türkiye (Ustun *et al.* 2007). Symptoms are necrotic, reddish-brown lesions on leaves that enlarge, often with a chlorotic halo, that are not water-soaked as in infections of *X. fragariae*. Moreover, often large brown V-shaped lesions, surrounded by a chlorotic halo develop along the leaf margin in *X. arboricola* pv. *fragariae* infections. In the final stages leaves may completely wither and die. As opposed to infections of *X. fragariae*, no small, water-soaked lesions in early stages of the infection and no bacterial exudate was observed. High humidity and lower temperatures are important for infections of *X. arboricola* pv. *fragariae* to appear. Sometimes, however, this pathogen has been co-isolated with *X. fragariae* (Scortichini and Rossi 2003; Vandroemme *et al.* 2013b). Vandroemme *et al.* (2013b) found genetic variability within a relatively small collection of *X. arboricola* pv. *fragariae* strains. In an apparent failure to obtain symptoms in their artificial inoculations with those strains (Vandroemme *et al.*, 2013b), they concluded, incorrectly (see below), that *X. arboricola* pv. *fragariae* was non-pathogenic. In some studies, other authors also failed to prove pathogenicity for certain strains of *X. arboricola* pv. *fragariae* (e.g. Fischer-Le Saux *et al.*, 2015; Gétaz *et al.*, 2020a). However, Ferrante & Scortichini (2018), using proper conditions during inoculation, unequivocally proved and reconfirmed pathogenicity using the pathovar type strain of *X. arboricola* pv. *fragariae*.

HOSTS

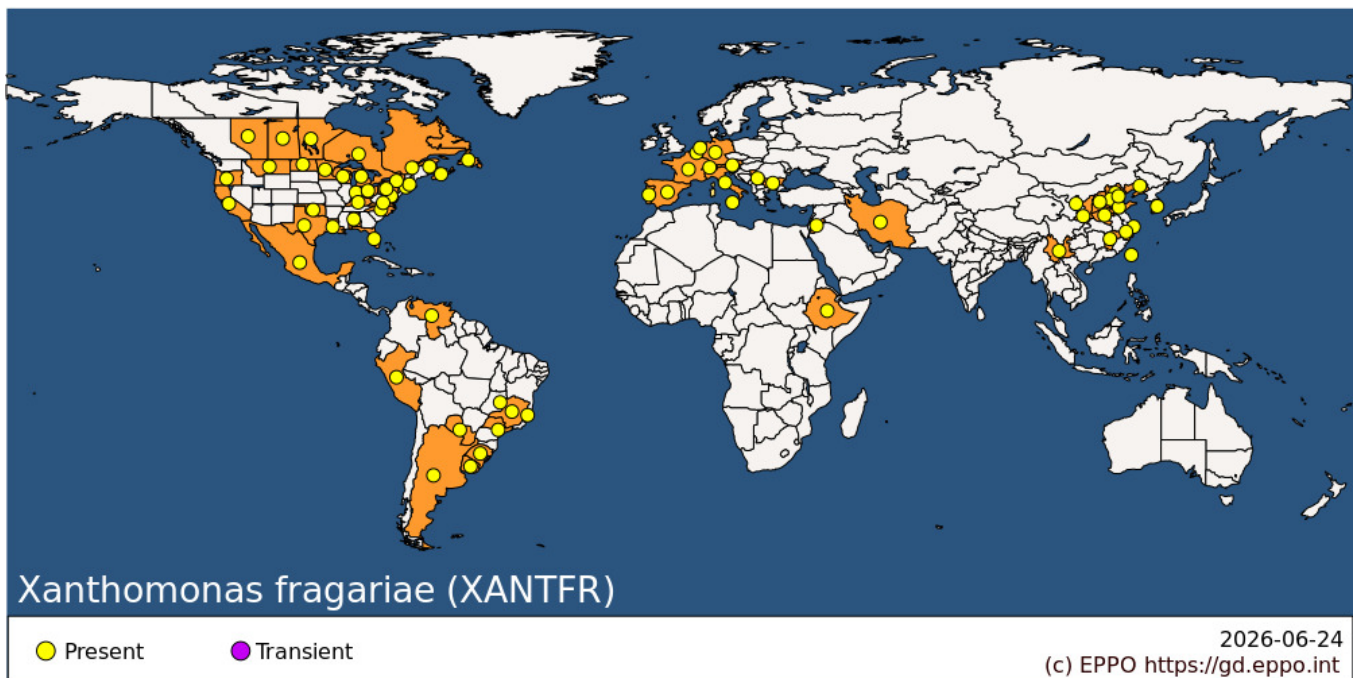
Fragaria x ananassa (the predominant cultivated strawberry, whose progenitors derive from hybridization between *F. chiloensis* and *F. virginiana*) is the main host, but its numerous cultivars vary a great deal in susceptibility (Desmet *et al.*, 2009).

Stöger *et al.* (2008) isolated *X. fragariae* from *F. vesca* (wild or European strawberry) and *F. chiloensis* in the field. *F. virginiana*, *Dasiphora fruticosa* and *Potentilla glandulosa* became infected only following experimental inoculation. Among *Fragaria* spp. only *F. moschata* (musk strawberry) was found to be resistant (Kennedy & King, 1962a; Kennedy, 1965; Maas, 1998). Cultivated strawberries (*Fragaria x ananassa*) are the host of concern throughout the EPPO region.

Host list: *Fragaria x ananassa*

GEOGRAPHICAL DISTRIBUTION

X. fragariae, was first observed in 1960 in Minnesota, USA (Kennedy & King, 1962a). The pathogen is easily transmitted to healthy material from asymptomatic plants. It probably spread within North America and from there to many other countries in different continents, with (latently) infected planting material (e.g., Mazzucchi *et al.*, 1973; Dye & Wilkie, 1973; McGechan & Fahy, 1976; López *et al.*, 1985; Bultreys *et al.*, 2000). In Australia angular leaf spot, after several outbreaks since 1976 (McGechan & Fahy, 1976; Gillings *et al.*, 1998), has been reported as eradicated (Young *et al.*, 2011). Eradication after some outbreaks was also reported from the United Kingdom (Matthews-Berry & Reed, 2009) as well as from Réunion island (FR) in the Indian Ocean (Pruvost *et al.*, 1988). The disease is widespread in North America and the EPPO region, less so in other continents such as South America, Asia and Africa, probably related to the spread and intensity of strawberry cultivation.



EPPO Region: Austria, Belgium, Bulgaria, France (mainland), Germany, Italy (mainland, Sicilia), Jordan, Netherlands, Portugal (mainland), Serbia, Spain (mainland), Switzerland

Africa: Ethiopia

Asia: China (Beijing, Hebei, Henan, Jiangxi, Liaoning, Ningxia, Shaanxi, Shandong, Shanghai, Shanxi, Tianjin, Yunnan, Zhejiang), Iran, Islamic Republic of, Jordan, Korea, Republic of, Taiwan

North America: Canada (Alberta, Manitoba, New Brunswick, Newfoundland, Nova Scotia, Ontario, Québec, Saskatchewan), Mexico, United States of America (Alabama, California, Connecticut, Florida, Indiana, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Montana, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Texas, Virginia, Wisconsin)

South America: Argentina, Brazil (Distrito Federal, Espirito Santo, Minas Gerais, Rio Grande do Sul, Sao Paulo), Paraguay, Peru, Uruguay, Venezuela

BIOLOGY

Residues of infected leaves and crown infections on runners used for planting are sources of inoculum for primary infections (Maas, 1998). In the residues of infected leaves, in or on soil, the bacterium survives from one crop to the next. Survival on the leaves is much shorter, a number of weeks only, even under high humidity conditions (Kastelein *et al.*, 2014). The bacterium exudes from primary lesions, and bacterial cells are spread in the form of aerosols, caused by rain and sprinkler irrigation (Hildebrand *et al.*, 2005; Kim *et al.*, 2016; van der Wolf *et al.*, 2018), that are transported by wind to healthy leaves. Penetration occurs through the stomata. Infections of the crowns occur through local wounds or downwards from the affected leaves. During the growing season several cycles of secondary infections may occur. The bacterium may attack flowers, and occasionally fruits. The early stages of infection and pathogenesis were studied using electron microscopy by Allan-Wojtas *et al.* (2010). From crown infection pockets, the bacterium causes lesions along the veins at the base of the youngest leaves, which develop in the apical crown region (Kennedy & King, 1962b; Hildebrand *et al.*, 1967; Maas, 1998 and 2004). In latent infections *X. fragariae* can move endophytically and systemically into the roots, crowns and runners. Occasionally this latent infection may lead to water-soaked areas at the base of newly emerged leaves with subsequent sudden plant collapse and death (Stefani *et al.*, 1989; Milholland *et al.*, 1996; Mahuku & Goodwin, 1997). This second type of symptoms, called ‘vascular collapse of strawberry’, led Hildebrand *et al.* (1967) to the conclusion that the disease would better be called bacterial blight of strawberry than just angular leaf spot.

Milholland *et al.* (1996) were able to isolate the pathogen from 100% of petioles 2 weeks after artificial leaf inoculation and from up to 83% of crown-tissue samples, 12 weeks after inoculation. They also detected the bacteria in xylem vessels using IF. Petiole tissues harboring bacteria were determined to be the main source of initial inoculum in strawberry fields (Wang *et al.*, 2018). Survival in soil under European conditions, in cases where crop residues were incorporated into the soil with or without haulm killing, appeared to be very limited (Kastelein *et al.*, 2009). Remarkably, Kong (2010) found that *X. fragariae* could still be isolated after almost 21 years of storage from air-dried leaf spots stored in tape-sealed Petri dishes at 5°C, and that these isolates were still virulent, causing typical symptoms after inoculation in strawberry plants.

During epidemics, when environmental conditions favor exudation and spread, the bacterium may cause systemic infections associated with crown pockets. These infections may also arise under damp nursery conditions. The conditions favoring infection are moderate daytime temperatures (about 20-23°C), low night-time temperatures and high humidities, up to 100% (Maas, 1998; Kastelein *et al.*, 2014). During the nursery stage in open fields in South Korea (from May to August), the pathogen was detected by PCR in mother plants, but not in soil or irrigation water. During the cultivation period, from September to March, the pathogen was detected in mother plants and their progeny, and also in soil, but not in water (Kim *et al.*, 2016). Infection of propagation material mainly occurs when strawberry plants are grown outdoors, when grown in glasshouses, screenhouses or polytunnels, disease incidence is much lower (Van der Gaag *et al.*, 2013).

In strawberry cultivation the (latently) infected planting material is the primary infection source, but contamination is also possible via contaminated machinery, tools, field workers and animals. Natural distribution of the bacterium in the field or glasshouse is (usually) limited to a few metres, due to splashing rain, wind or irrigation water, where (dried) exudates on leaves are also involved (Van der Gaag *et al.*, 2013; Kastelein *et al.*, 2009 and 2018; van der Wolf *et al.*, 2017). The pathogen can survive for up to 2 weeks on metal and wood (Vermunt & Van Beuningen, 2008). Survival of *X. fragariae* was determined by Turechek *et al.* (2023) on different materials used in nurseries (corrugated cardboard, cotton balls, cotton cloth, strawberry leaf, sheet metal, plastic, rubber, wood, glass, and latex glove) stored at c. 20°C or -4°C (the latter temperature being in use for dormant plants in nurseries) for up to 365 days after inoculation (DAI), using viability real-time PCR and a bioassay. *X. fragariae* could survive on all materials at -4°C up to 7 DAI, the longest survival was on cardboard (270 DAI). At 20 °C the bacterium survived in small numbers up to 14 DAI on cardboard, cotton and strawberry leaf tissue.

Cooper (2007) found a non-pathogenic *Pseudomonas* species often associated with *X. fragariae* and aggravating the symptoms to a certain extent. When *X. fragariae* is detected in rhizomes (in which bacterial exudates are sometimes found when cut transversely), this is often accompanied by other infections by *Verticillium* and/or *Phytophthora* spp. (Van der Gaag *et al.*, 2013).

Metabolic changes due to infections with *X. fragariae* and their underlying genetic basis, using ultra-performance liquid chromatography (UPLC)- quadrupole-time-of-flight (QTOF) mass-spectrometry and transcriptome analysis and gene expression of both pathogen and host, with high-throughput mRNA sequencing, were determined by Kim *et al.*

. (2016) and Gétaz *et al.* (2020b).

The whole genome sequences of two strains of *X. fragariae* (FaP21 and FaP29) isolated in 2011 from symptomatic strawberry leaf tissue in Siskiyou County, California, USA are available (Henry & Leveau, 2016). Other genome sequences were determined by Gétaz *et al.*, 2017b.

Pathogenicity of *X. fragariae* is mainly based a *hrp* gene cluster coding for structural elements of the type III secretion system (T3SS), T3SS effector s(T3E) and an essential part of the *gum* cluster coding for xanthan extracellular polysaccharide synthesis (Vandroemme *et al.*, 2013b). Furthermore, pathogenicity is also linked to a type IV (T4SS) and an *xps*-coded type II secretion system (T2SS) and the production of various toxins, including hemolytic and cytolytic RTX-toxins (Gétaz *et al.*, 2020b; Puławska *et al.*, 2020).

DETECTION AND IDENTIFICATION

Symptoms

On leaves, 1-4 mm, angular, shiny, water-soaked spots appear surrounded by the smallest veins. In the early stage, leafspots are only visible on the lower surface and appear translucent against the light. They enlarge, coalesce and after about 2 weeks are also visible on the upper leaf surface as water-soaked, angular spots, which subsequently become reddish-brown. They have a shiny appearance and are usually covered by bacterial exudate, which when dry, turns brown and appears as gum-like scales. Spots may coalesce along the primary and secondary veins. The dead tissues tear and break off, and the diseased leaf may show a ragged appearance.

In the most severe cases crown infection pockets may be seen inside after dissection. They appear as localized, water-soaked zones, frequently confined to one side of the crown, where bacterial exudate may also be formed.

For more information, see Kennedy & King (1962b), Hildebrand *et al.* (1967), Mazzucchi *et al.* (1973), Panagopoulos *et al.* (1978), Maas (1998) & Van der Gaag *et al.* (2013).

A blossom blight of strawberry caused by *X. fragariae* with blighting of entire flowers, or in less severe cases, water-soaked lesions on the lower surface of the calyx and pedicel of seemingly healthy green and ripe fruits was described by Gubler *et al.* (2007) from California, USA. Symptoms on calyxes and pedicels may be confused with those caused by *Erwinia pyrifoliae*, although in the latter case there is a more general blackening of the tissues, in some cases with bacterial slime formation. Fruits are usually infected, blackened and often malformed (Wenneker & Bergsma-Vlami, 2015).

Symptoms of angular leaf spot caused by *X. fragariae* may be confused with those caused by fungi, such as *Ramularia grevillea* (formerly *Mycosphaerella fragariae*) causing common spot of strawberry and *Diplocarpon fragariae*, causing leaf scorch, as well as with the symptoms caused by *X. arboricola* pv. *fragariae* (see Notes on taxonomy and nomenclature and Janse *et al.*, 2001). Definitive diagnosis should always be obtained through laboratory analysis (see below and EPPO, 2023).

Morphology

X. fragariae is an aerobic, Gram-negative, non-spore-forming, non-capsulated rod; size averaging 0.4 x 1.3 µm. Most cells are non-motile, but some have a single polar flagellum. On a suitable medium such as Wilbrink's medium colonies are circular, entire, convex, glistening, translucent to pale-yellow after 3-5 days incubation at 20 to 24°C (Bradbury, 1977; Roberts *et al.*, 1997; EPPO, 2023).

Detection and inspection methods

Rapid screening tests such as ELISA or IF and PCR/Nested PCR or a detached leaf assay (Civerolo *et al.*, 1997a and b; Randhawa & Civerolo, 2017) can be used for presumptive diagnosis of *X. fragariae*, as the bacterium is quite difficult to isolate, and its colonies are easily overgrown by those of secondary organisms. Use of purified agar (Difco) is recommended in all media because impurities from other commercial agars can inhibit the growth of *X. fragariae*

(Rowhani *et al.*, 1994; EPPO, 2023). The pure culture is distinguishable on agar media from other phytopathogenic xanthomonads, including *X. a. pv. fragariae* (EPPO, 2023).

Stöger & Ruppitsch (2004) developed a sensitive, PCR kit called REDEExtract-N-Ampk Plant PCR-Kit for the detection of *X. fragariae* in (a)symptomatic plant material. Several sensitive (nested/multiplexed) PCR detection tests, also in combination with immune-capture, targeting different loci in the *X. fragariae* genome, have been developed (Roberts *et al.*, 1996; Pooler *et al.*, 1996; Hartung & Pooler, 1997; Zimmermann *et al.*, 2004; Weller *et al.*, 2007; Vandroemme *et al.*, 2008; Turechek *et al.*, 2008; Vermunt and van Beuningen, 2008). These tests can be used to confirm the presence of *X. fragariae* in symptomatic plant material, and can be used for detection of (latent) infections in (symptomless) plants (Mahuku and Goodwin, 1997; Zimmerman *et al.*, 2004, EPPO, 2023; IPPC 2016). A real-time PCR was developed by Cubero *et al.* (2009), and another one, specifically tested for detection in crown tissue, by Turechek *et al.* (2008). A loop-mediated isothermal amplification assay (LAMP) and sample preparation procedure for detection was developed by Wang & Turechek (2016) and Gétaz *et al.* (2017a).

Rep-PCR has been used for identification of field isolates of *X. fragariae* (Opgenorth *et al.*, 1996) as well as MALDI-TOF mass spectrometry (Vandroemme *et al.*, 2013b).

Both PEMAX-PCR (a mix of nucleic acid intercalating dyes propidium monazide - PMA and ethidium-monazide - EMA) and PMA-real-time PCR have been recently developed for the detection of viable cells of *X. fragariae* in strawberry. This so-called viability PCR (vPCR) could be useful in testing of planting material entering a country (Wang & Turechek, 2020; Immanuel *et al.*, 2020).

An efficient spray-infiltration method of inoculation was published by Hazel *et al.* (1980), but also see EPPO (2023).

Details about presumptive diagnosis with rapid tests, detection and identification methods (including methods for extraction of bacterial cells and DNA), biochemical, serological and molecular and pathogenicity tests (using inoculation of bean plantlets or hilum injury/seed inoculation) for latent and symptomatic infected material, flow chart, culture media, chemicals and reference material) are provided in the EPPO Standard PM 7/65 (2) (EPPO, 2023) on *X. fragariae* and IPPC Diagnostic protocol DP 14 (IPPC, 2016).

PATHWAYS FOR MOVEMENT

Locally, *X. fragariae* can be spread by splashing water or via aerosols generated by precipitation, irrigation, or mowing (Van der Wolf *et al.*, 2017; 2018). The bacterium can also be spread via contact with contaminated machinery, clothes and by animals (Maas, 2004). For example, the spread of *X. fragariae* in a strawberry field by mowing and runner cutting machinery was studied in the Netherlands. The blades of a rotary mower became heavily contaminated after trimming leaves of symptomatic plants and could spread the bacterium to healthy plants up to a distance of 4 m (Kastelein *et al.*, 2018).

Within a field crop, *X. fragariae* is not free-living in the soil, but it can overwinter in the soil in association with previously infected plant material (Maas, 1998).

Over short and long distances, the movement of infected plants for planting is the main pathway. Commercial strawberry runners used for planting may spread the bacterium as they may still bear old, whole or torn, infected leaves or have crown infection pockets. Moreover, almost invisible fragments of infected leaves may be hidden in the apical crown region or between the roots (Kennedy & King, 1962a). Viable cells of *X. fragariae* could be detected in fruits produced for the fresh market (Immanuel *et al.*, 2020), but fruits are considered as a minor pathway.

PEST SIGNIFICANCE

Economic impact

Like in other strawberry leaf spot and blight diseases caused by e.g., *Phomopsis obscurans* and *X. arboricola* pv. *arboricola* and leaf blotch caused by *Zythia fragariae*, bacterial blight causes a certain reduction in yield, but generally, the disease is not destructive. However, heavy losses may occur under very wet weather conditions or

frequent overhead sprinkler irrigation. The highest losses (up to 75% fruit loss) were reported by Epstein (1966) in the USA, but in most cases losses are much lower, since only leaves and calices are infected, leading to a moderate reduction of photosynthesis and disfigured calices which very occasionally rendered fruits unmarketable (Legard *et al.*, 2003). Earlier substantial losses reported by Mazzucchi *et al.* (1973), López *et al.* (1985) and Bosshard & Schwind (1997) were not observed in later years, although the disease is widespread in Western Europe. In the USA, yield losses up to 25% were reported during some years in the 1990s, but the biggest impact was due to import restrictions from Mexico and the European Union for planting material (Roberts *et al.*, 1997; Van der Gaag *et al.*, 2013). In South Korea, the implementation of a strict control programme for several years reduced the disease incidence from 45% to 5% (Yoon *et al.*, 2016).

Control

The use of healthy planting material and avoidance of conditions favouring the disease (e.g. high humidity, high nitrogen fertilizing) are the main control methods. Crop operations, using machinery proved important for disease and pathogen spread in the field (Gigot *et al.*, 2017; Kastelein *et al.*, 2018) and should be taken into account when considering control measures. Other cultural measures include the use of drip irrigation and irrigation early in the morning to obtain faster drying of crop, as well as monitoring and removal of diseased plants. Treatments with copper-containing products have shown some effectiveness, but have to be applied very intensively, with a risk of phytotoxicity (Kennedy-Fisher, 1997).

Mixtures of copper compounds and the fungicide mancozeb were found to be effective against *X. fragariae*, but they may lead to phytotoxicity (Roberts *et al.*, 1997). Alternatives to copper such as acibenzolar-S-methyl, and kasugamycin showed lower disease severity than untreated controls (Cooper, 2007). An organic acid-based biopesticide (OAB, containing 10.73 g L⁻¹ of citric acid and 21.37 g L⁻¹ of lactic acid) could reduce disease incidence by up to 50% when 7 sprays were applied, in trials under natural field infection conditions, in Canada, where the product is registered (Dubois *et al.*, 2017). Oxidate (hydrogen dioxide 27%) was registered in the USA for control of angular leaf spot and has been used with varying success (Anco & Ellis, 2011). Braun & Hildebrand (2013) found that foliar applications of various antioxidants, such as α -tocopherol and mannitol, along with the plant activators acetylsalicylic acid and acibenzolar-S-methyl, and the fungicide fosetyl-Al, substantially reduced disease incidence. Kim *et al.* (2016) used oxolinic acid, with an 87% control during the nursery period, and the antibiotic validamycin-A, with a 95% control during the cultivation stage (control effect 95%). A post-harvest propylene oxide fumigation also had a control effect. Amino-thiazidol and zinc thiazidol alone or in low-rate combination with kasugamycin or copper compounds reduced disease incidence when applied pre-harvest to more than 90% (Haack *et al.*, 2019).

Henry *et al.* (2016) observed a strong reduction in symptom formation when *X. fragariae* was co-inoculated with tannic acid (a chelating agent of iron) onto strawberry plants, suggesting a kind of nutritional immunity and possibilities for control by restriction to iron access on or in the plant.

Dipping plants in a solution of 10% chlorine bleach and use of UV-C radiation and a concomitant removal or trimming remnant leaf and petiole tissue from nursery-trimmed plants, reduced disease significantly but not completely in planting stock (Turechek *et al.*, 2013).

Heat treatment was successfully applied to nursery stock where bacterial populations were exposed to 44°C for 4 h or 48°C for 2 h. These treatments minimally affected vegetative growth of plants bagged dry or wet (Turechek & Peres, 2009).

Hildebrand *et al.* (2005) found the cultivar Tristar as well as two clones, US 4808 and US 4809, that were derived from *F. virginiana*, to be much less susceptible than most of the cultivars tested. The latter two were released for resistance breeding. An important locus determining the resistance of the two wild genotypes mentioned above was found (designated *FarXf1*) which could play a role in marker-assisted selection in order to develop resistant cultivars (Roach *et al.*, 2016). Maas *et al.* (2002) used the above mentioned octoploid highly resistant clones US 4808 and US 4809, see also Jamieson *et al.* (2013). Recent breeding experiments with these genotypes showed that their resistance is based on three or four unlinked loci (Lewers *et al.*, 2003), leading to only limited inheritance.

A high level of plant host resistance to angular leafspot disease has been found in certain *Fragaria* species, such as *F. moschata* (2n=6x) and *F. vesca* (2n=2x) and occasionally in clones of *F. virginiana* (2n=8x) but not in octoploid

cultivated strawberries and in *F. x ananassa* cv. Tristar (Roberts *et al.*, 1997; Maas *et al.*, 2000, 2002; Hartung *et al.*, 2003; Xue *et al.*, 2005; Hildebrand *et al.*, 2005; Cooper, 2007; Pérez-Jiménez *et al.*, 2012; Jamieson *et al.*, 2013). In addition to *F. moschata* some accessions of *F. pentaphylla*, a tetraploid species of wild strawberry native to China showed resistance towards *X. fragariae* (Xue *et al.*, 2005).

The old German strawberry variety Sieger was found to be resistant against two strains of *X. fragariae* in Spain and could also be useful in breeding programs (Pérez-Jiménez *et al.*, 2012). To obtain more understanding and potential contributors to breeding for resistance Bestfleisch *et al.* (2015) screened 145 *Fragaria* genotypes of which 6, with variable ploidy showed moderate resistance, belonging to *Fragaria vesca* f. *alba*, *F. nilgerrensis* 'Yunnan', *F. vesca* 'Illa Martin' and *F. moschata* 'Bauwens'.

Phytosanitary risk

The main pathway for (international) spread of *X. fragariae* is via asymptomatic plants for planting with latent infections. Infected planting material is therefore the main risk for uncontaminated areas. However, over the years it has been observed that actual losses due to bacterial angular leaf spot remain generally low to very low and that current cultural methods, in combination with some preventive sprays of bactericidal compounds, can sufficiently limit its importance (Van der Gaag *et al.*, 2013). Based on this information the European Union changed the status of *X. fragariae* from a quarantine pest (Annex IIA2) to a regulated non-quarantine pest (RNQP) (EU, 2019).

PHYTOSANITARY MEASURES

It can be recommended that strawberry planting material from infested countries should be derived from mother plants kept free from *X. fragariae* as part of a certification scheme (EPPO, 2008a), and that the place of production should have been found free from the disease during the last five growing seasons. In addition, visual inspections during the dormant period can be useful. Inspectors should look for typical angular spots on old leaves or on their remains still attached to the runners. Samples from lots kept in cold storage must be inspected immediately after the runners are taken out and thawed. The spots can no longer be seen after only 1 day at room temperature.

Visual inspection and sampling methods for strawberry planting material (at import) are described in the commodity specific EPPO phytosanitary procedure PM 3/73 (1) (EPPO 2008b) and for places of production in PM 3/83(1) (EPPO, 2017). Certification for pathogen-tested material, including tests for *X. fragariae* are laid down in EPPO PM 4/11 (2) (EPPO, 2008a). Detailed risk management measures against *X. fragariae* have also been proposed on the use of non-certified and certified strawberry planting material during the RNQP project (EPPO, 2018). Detection of viable cells of *X. fragariae* using viability PCR (vPCR) has been suggested as a method that could be useful in post-entry quarantine and for detection in fresh fruits in New Zealand (Immanuel *et al.*, 2020).

REFERENCES

- Albuquerque P, Caridade CMR, Marcal ARS, Cruz J, Cruz L, Santos CL, Mendes MV & Tavares F (2011) Identification of *Xanthomonas fragariae*, *Xanthomonas axonopodis* pv. *phaseoli*, and *Xanthomonas fuscans* subsp. *fuscans* with novel markers and using a dot blot platform coupled with automatic data analysis. *Applied & Environmental Microbiology* **77**(16), 5619–5628.
- Allan-Wojtas P, Hildebrand PD, Braun PG, Smith-King HL, Carbyn S & Renderos WE (2010) Low temperature and anhydrous electron microscopy techniques to observe the infection process of the bacterial pathogen *Xanthomonas fragariae* on strawberry leaves. *Journal of Microscopy* **239**, 249-258. <https://doi.org/10.1111/j.1365-2818.2010.03373.x>
- Anco DJ & Ellis MA (2011) Angular leaf spot of strawberry (bacterial blight). Ohio State University Leaflet HYG - 3212, 2pp. <https://ohioline.osu.edu/factsheet/HYG-3212-11> (last accessed February 2023).
- Bestfleisch M, Richter K, Wensing A, Wünsche JN, Hanke M-V, Höfer M, Schulte E & Flachowsky H (2015) Resistance and systemic dispersal of *Xanthomonas fragariae* in strawberry germplasm (*Fragaria* L.). *Plant Pathology* **64**, 71-80. <https://doi.org/10.1111/ppa.12232>

- Bosshard E & Schwind M (1997) Detection of different bacterial and fungal pathogens in apparently healthy strawberry plants. In: Dehne HW *et al.* (eds) *Diagnosis and Identification of Plant Pathogens*. Kluwer, Dordrecht (NL), pp. 37-41. Bradbury JF (1977) *Xanthomonas fragariae*. *CMI Descriptions of Pathogenic Fungi and Bacteria* No. 558. CABI, Wallingford, UK.
- Braun PG & Hildebrand PD (2013) Effect of sugar alcohols, antioxidants and activators of systemically acquired resistance on severity of bacterial angular leaf spot (*Xanthomonas fragariae*) of strawberry in controlled environment conditions. *Canadian Journal of Plant Pathology* **35**, 20-26. <https://doi.org/10.1080/07060661.2012.751937>
- Bultreys A, Robbe A & Van Schingen JC (2000) Détection de *Xanthomonas fragariae* en culture de fraiser en Belgique. *Fruit Belge* **68**, 202-206
- Civerolo EL, Feliciano AJ, Melvin JA & Gubler WD (1997a) A detached leaf bioassay for *Xanthomonas fragariae*. In A. Mahadevin, ed. *Proceedings of the 9th International Conference of Plant Pathogenic Bacteria*, pp. 89–94. University of Madras, Madras, India.
- Civerolo EL, Roberts P, Feliciano AJ, Melvin JA, Buchner RP, Jones JB & Gubler WD (1997b) Comparative detection of *Xanthomonas fragariae* in strawberry plants by detached leaf inoculation, ELISA and PCR. In A. Mahadevin, ed. *Proceedings of the 9th International Conference of Plant Pathogenic Bacteria*, pp. 95–99. University of Madras, Madras, India.
- Cooper, GT (2007) Angular leaf spot of strawberry: disease control strategies and association of *Pseudomonas syringae* with lesions. 62pp. Thesis, University of Florida, USA.
http://ufdcimages.uflib.ufl.edu/UF/E0/02/14/57/00001/cooper_g.pdf (last accessed February 2023).
- Cubero J, Ayllon MA, Gell I, Melgarejo P, De Cal A, Martin-Sanchez PM, Perez-Jimenez RM, Soria C, Segundo E & Larena I (2009) Detection of strawberry pathogens by real-time PCR. *Acta Horticulturae* **842**, 263-266.
- Desmet E, Maes M, Vaerenbergh J, van Verbraeken L & Baets W (2009) Sensitivity screening of commonly grown strawberry cultivars towards angular leaf spot caused by *Xanthomonas fragariae*. *Acta Horticulturae* **842**, 275-278.
- Dubois C, Arsenault-Labrecque G & Pickford J (2017) Evaluation of a new biopesticide against angular leaf spot in a commercial operation system. *Acta Horticulturae* **1156**, 757-764.
<https://doi.org/10.17660/ActaHortic.2017.1156.111>
- Dye DW & Wilkie JP (1973) Angular leafspot of strawberry in New Zealand. *New Zealand Journal of Agricultural Research* **16**, 311-314. <https://doi.org/10.1080/00288233.1973.10421109>
- EPPO (2007) Minidatasheet on *Xanthomonas arboricola* pv. *fragariae*.
<https://gd.eppo.int/taxon/XANTAF/documents> (last accessed February 2023)
- EPPO (2008a) EPPO Standards. Schemes for the production of healthy plants for planting PM 4/11 (2) Certification scheme for strawberry. *EPPO Bulletin* **38**, 430–437.
- EPPO (2008b) EPPO Standards. Commodity-specific phytosanitary procedure PM 3/73 (1) Consignment inspection of *Fragaria* plants for planting. *EPPO Bulletin* **38**, 396–406.
- (EPPO (2017) *Fragaria* plants for planting – inspection of places of production. Phytosanitary procedure PM 3/83 (1). *EPPO Bulletin* **47**, 349–365.
- EPPO (2018) Regulated non-quarantine pest Project. An EU funded project for the benefit of the whole EPPO region . https://rnqp.eppo.int/recommendations/summarysheet_pest?pest=XANTFR (last accessed February 2023).
- EPPO (2023) EPPO Standards. Diagnostics PM 7/65(2) *Xanthomonas fragariae*. *EPPO Bulletin* **53**(2), 184–204.
- Epstein AH (1966) Angular leaf spot of Strawberry. *Plant Disease Reporter* **50**, 167.

- EU (2019) Commission Implementing Regulation (EU) 2019/2072 of 28 November 2019 establishing uniform conditions for the implementation of Regulation (EU) 2016/2031 of the European Parliament and the Council, as regards protective measures against pests of plants, and repealing Commission Regulation (EC) No 690/2008 and amending Commission Implementing Regulation (EU) 2018/2019. *Official Journal of the the European Union* L 319, **62**, 10 December 2019, <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L:2019:319:FULL&from=NL>
- Ferrante P & Scortichini M (2018) *Xanthomonas arboricola* pv. *fragariae*: a confirmation of the pathogenicity of the pathotype strain. *European Journal of Plant Pathology* **150**, 825–829.
- Fischer-Le Saux M, Bonneau S, Essakhi S, Manceau C & Jacques MAA (2015) Aggressive emerging pathovars of *Xanthomonas arboricola* represent widespread epidemic clones distinct from poorly pathogenic strains, as revealed by multilocus sequence typing. *Applied & Environmental Microbiology* **81**, 4651–4668. <https://doi.org/10.1128/AEM.00050-15>
- Gétaz M, Bühlmann A, Schneeberger PHH, Van Malderghem C, Duffy B, Maes M, Pothier JF & Cottyn B (2017a) A diagnostic tool for improved detection of *Xanthomonas fragariae* using a rapid and highly specific LAMP assay designed with comparative genomics. *Plant Pathology* **66**, 1094-1102. <https://doi.org/10.1111/ppa.12665>
- Gétaz M, Van der Wolf JM, Blom J & Pothier JF (2017b) Complete genome sequences of three isolates of *Xanthomonas fragariae*, the bacterium responsible for angular leaf spots on strawberry plants. *Genome Announcements* **5**, e00632-17. <https://doi.org/10.1128/genomeA.00642-17>
- Gétaz M, Krijger M, Rezzonico F, Smits THM, van der Wolf JM, Pothier JF (2018) Genome-based population structure analysis of the plant pathogen *Xanthomonas fragariae* indicates two potential sources and pathways of bacterial spread through plant material trade. *Microbial Genomics* **4**, e000189. <https://doi.org/10.1099/mgen.0.000189>
- Gétaz M, Blom J, Smits THM & Pothier JF (2020a) Comparative genomics of *Xanthomonas fragariae* and *Xanthomonas arboricola* pv. *fragariae* reveals intra- and interspecies variations. *Phytopathology Research* **2**, 17. <https://doi.org/10.1186/s42483-020-00061-y>
- Gétaz M, Puławska J, Smits THM & Pothier JF (2020b) Host-pathogen interactions between *Xanthomonas fragariae* and its host *Fragaria × ananassa* investigated with a dual RNA-Seq analysis. *Microorganisms* **18**, 1253. <https://doi.org/10.3390/microorganisms8081253>
- Gigot C, Turechek WW & McRoberts N (2017) Analysis of the spatial pattern of strawberry angular leaf spot in California nursery production. *Phytopathology* **107**, 1243-1255. <https://doi.org/10.1094/PHYTO-07-16-0275-R>
- Gillings MR, Fahy RC & Bradley J (1998) Identification of *Xanthomonas fragariae*, the cause of an outbreak of angular leaf spot on strawberry in South Australia, and comparison with the cause of previous outbreaks in New South Wales and New Zealand. *Australasian Plant Pathology* **27**, 97–103. <https://doi.org/10.1071/AP98012>
- Gubler WD, Feliciano AJ, Bordas AC, Civerolo EC, Melvin JA & Welch NC (2007) First report of blossom blight of strawberry caused by *Xanthomonas fragariae* and *Cladosporium cladosporioides* in California. *Plant Disease* **83**, 400. <https://doi.org/10.1094/PDIS.1999.83.4.400A>
- Haack SE, Walse SS, Nguyen K, Adaskaveg JE (2019) Management of *Xanthomonas fragariae* with pre- and postharvest treatments to overcome trade barriers for California strawberries. *Plant Disease* **103**, 1256-1263. <https://doi.org/10.1094/PDIS-08-18-1395-RE>
- Hartung JS, Gouin CC, Lewers KS, Maas JL & Hokanson S (2003) Identification of sources of resistance to bacterial angular leafspot disease of strawberry. *Acta Horticulturae* **626**, 155-159. <https://doi.org/10.17660/ActaHortic.2003.626.20>
- Hartung JS & Pooler MR (1997) Immunocapture and multiplexed-PCR assay for *Xanthomonas fragariae*, causal agent of angular leafspot disease. *Acta Horticulturae* **439**, 821–828.

- Hazel WJ, Civerolo EL & Bean GA (1980) Procedures for growth and inoculation of *Xanthomonas fragariae*, causal organism of angular leaf spot of strawberry. *Plant Disease* **64**, 178–181.
- Henry PM, Gebben SJ, Tech JJ, Yip JL & Leveau JHJ (2016) Inhibition of *Xanthomonas fragariae*, causative agent of angular leaf spot of strawberry, through iron deprivation. *Frontiers in Microbiology* **7**, 1589, 11 pp. <https://doi.org/10.3389/fmicb.2016.01589>
- Henry PM, Leveau JHJ (2016) Finished genome sequences of *Xanthomonas fragariae*, the cause of bacterial angular leaf spot of strawberry. *Genome Announcements* **4**, e01271-01216. <https://doi.org/10.1128/genomeA.01271-16>
- Hildebrand DC, Schroth MN & Wilhelm S (1967) Systemic invasion of strawberry by *Xanthomonas fragariae* causing vascular collapse. *Phytopathology* **57**, 1260-1261.
- Hildebrand PD, Braun PG, Renderos WE, Jamieson AR, McRae KB & Binns MR (2005) A quantitative method for inoculating strawberry leaves with *Xanthomonas fragariae*, factors affecting infection, and cultivar reactions. *Canadian Journal of Plant Pathology* **27**, 16-24. <https://doi.org/10.1080/07060660509507189>
- Immanuel T, Taylor R, Keeling S, Brosnahan C & Alexander B (2020) Discrimination between viable and dead *Xanthomonas fragariae* in strawberry using viability PCR. *Journal of Phytopathology* **168**, 363–373. <https://doi.org/10.1111/jph.12900>
- IPPC (2016) International standards for phytosanitary measures (ISPM) 27 - Diagnostic protocols for regulated pests DP 14: *Xanthomonas fragariae*, 26 pp. <https://www.ippc.int/coreactivities/standards-setting/ispms>
- Jamieson AR, Hildebrand PD & Renderos WE (2013) Breeding strawberry plants resistant to angular leafspot disease. *International Journal of Fruit Science* **13**, 28–35. <https://doi.org/10.1080/15538362.2012.696959>
- Janse JD, Rossi MP, Gorkink RFJ, Derks JHJ, Swings J, Janssens D & Scortichini M (2001) Bacterial leaf blight of strawberry (*Fragaria x ananassa*) caused by a pathovar of *Xanthomonas arboricola*, not similar to *Xanthomonas fragariae* Kennedy et King. Description of the causal organism as *Xanthomonas arboricola* pv. *fragariae* (pv. nov., comb. nov.). *Plant Pathology* **50**, 653-665. <https://doi.org/10.1046/j.1365-3059.2001.00644.x>
- Kastelein P, de Vries I, Krijger M & van der Wolf, J (2009) Effect van loofdoodmiddel op de overleving van *Xanthomonas fragariae* in ondergewerkte gewasresten in aardbei. (The effect of chemical haulm killer on the survival of *Xanthomonas fragariae* in incorporated crop residues in strawberry. Rapport (Report) **258** Plant Research International B.V., Wageningen, the Netherlands, 12 pp.
- Kastelein P, Krijger M, Czajkowski R, van der Zouwen PS, van der Schoor R, Jalink H & van der Wolf JM (2014) Development of *Xanthomonas fragariae* populations and disease progression in strawberry plants after spray-inoculation of leaves. *Plant Pathology* **63**, 255-263. <https://doi.org/10.1111/ppa.12090>
- Kastelein P, Evenhuis A, van der Zouwen PS, Krijger M & van der Wolf JM (2018) Spread of *Xanthomonas fragariae* in strawberry fields by machinery. *EPPO Bulletin* **48**, 569– 577. <https://doi.org/10.1111/epp.12497>
- Kennedy BW (1965) Infection of *Potentilla* by *Xanthomonas fragariae*. *Plant Disease Reporter* **49**, 491-492.
- Kennedy BW & King TH (1962a) Studies on epidemiology of bacterial angular leaf spot on strawberry. *Plant Disease Reporter* **46**, 360-363.
- Kennedy BW & King TH (1962b) Angular leaf spot of strawberry caused by *Xanthomonas fragariae* sp. nov. *Phytopathology* **52**, 873-875.
- Kennedy-Fisher SD (1997) The effect of copper sulphate and host variety on angular leaf spot (*Xanthomonas fragariae*) of strawberry. Thesis submitted in partial fulfilment of the requirements for the degree of Master of Agriculture. Dalhousie University Halifax, Nova Scotia, Canada, 83pp. Available at <http://www.collectionscanada.gc.ca/obj/s4/f2/dsk3/ftp04/mq24862.pdf> (last accessed February 2023).

- Kim DR, Gang GH, Jeon CW, Kang NJ, Lee SW & Kwak YS (2016) Epidemiology and control of strawberry bacterial angular leaf spot disease caused by *Xanthomonas fragariae*. *Plant Pathology Journal* **32**,290–299. <http://dx.doi.org/10.5423/PPJ.OA.01.2016.0007>
- Kong M (2010) Long-term survival of *Xanthomonas fragariae* in infected strawberry leaf tissue. *Phytopathology* **100**, no. 6 (supplement) S64 (abstract).
- Kwon J-H, Yoon H-S, Kim J-S, Shim C-K, & Nam M-H (2010) Angular leaf spot of strawberry caused by *Xanthomonas fragariae*. *Research in Plant Disease* **16**, 97-100. <https://doi.org/10.5423/rpd.2010.16.1.097>
- Legard DE, Ellis, M, Chandler CK & Price JF (2003) Integrated management of strawberry diseases in winter fruit production areas, p 111-124. In: The strawberry: a book for growers. N. Childers (ed.). Institute of Food and Agricultural Sciences, Horticultural Sciences Department, University of Florida, Gainesville. Norm Childers Publications, USA. 246 pp.
- Li Y-L, Wang D-J, Ma Y-Y, Cai X-L, Xiao S, Y-Q Wen & J-Y Feng (2021) first report of *Xanthomonas fragariae* strain yl19 causing crown infection pockets in strawberry in Liaoning Province, China. *Plant Disease* **105**, 2237. <https://doi.org/10.1094/PDIS-12-20-2560-PDN>
- López MM, Aramburu JM, Cambra M & Borrás V (1985) Detección e identificación de *Xanthomonas fragariae* en España. [Detection and identification of *Xanthomonas fragariae* in Spain]. *Anales del Instituto Nacional de Investigaciones Agrarias. Serie Agrícola* **28**, 245-259
- Maas JL (1998) Compendium of Strawberry Diseases. Second Edition, 98p. APS Press, St Paul (MN), USA. <https://doi.org/10.1094/9780890546178>
- Maas JL, Gouin-Behe C, Hartung JS & Hokanson SC (2000) Sources of resistance for two differentially pathogenic strains of *Xanthomonas fragariae* in *Fragaria* genotypes. *HortScience* **35**, 128-131.
- Maas JL, Gouin CC, Hokanson SC & Hartung JS (2002) Strawberry parent clones US 4808 and US 4809 resistant to bacterial angular leafspot disease caused by *Xanthomonas fragariae*. *HortScience* **37**, 716-717.
- Maas JL (2004) Strawberry disease management. In Diseases of fruits and vegetables, diagnosis and management, Vol. II, (ed. Naqvi SAMH), pp. 441–483. Kluwer academic publishers, Dordrecht (NL).
- Mahuku GS & Goodwin PH (1997) Presence of *Xanthomonas fragariae* in symptomless strawberry crowns in Ontario detected using a nested polymerase chain reaction (PCR). *Canadian Journal of Plant Pathology* **19**, 366-370.
- Matthews-Berry SS & Reed PJ (2009) Eradication of the first outbreak of *Xanthomonas fragariae* in the United Kingdom. *EPPO Bulletin* **39**, 171-174. <https://doi.org/10.1111/j.1365-2338.2009.02284.x>
- Mazzucchi U, Alberghina A & Dalli A (1973) Occurrence of *Xanthomonas fragariae* Kennedy & King in Italy. *Phytopathologische Zeitschrift* **76**, 367-370.
- McGechan JK & Fahy (1976) Angular leaf spot of strawberry, *Xanthomonas fragariae*: first record of its occurrence in Australia, and attempts to eradicate the disease. *Australian Plant Pathology Society Newsletter* **5**, 57-59.
- Milholland RD, Ritchie DF, Dayking ME & Gutierrez WA (1996) Multiplication and translocation of *Xanthomonas fragariae* in strawberry. *Advances in Strawberry Research* **15**, 13–17.
- Opgenorth DC, Smart CD, Louws FJ, de Bruijn FJ & Kirkpatrick BC (1996) Identification of *Xanthomonas fragariae* field isolates by rep-PCR genomic fingerprinting. *Plant Disease* **80**, 868–873.
- Panagopoulos CG, Psallidas PG & Alivizatos AS (1978) A bacterial leaf spot of strawberry in Greece caused by *Xanthomonas fragariae*. *Phytopathologische Zeitschrift* **91**, 33-38.
- Parkinson N, Aritua V, Heeney J, Cowie C, Bew J & Stead D (2007) Phylogenetic analysis of *Xanthomonas* species

- by comparison of partial gyrase B gene sequences. *International Journal of Systematic and Evolutionary Microbiology* **57**, 2881–2887. <https://doi.org/10.1099/ijs.0.65220-0>
- Pérez-Jiménez RM, De Cal A, Melgarejo P, Cubero J, Soria C, Zea-Bonilla T & Larena I (2012) Resistance of several strawberry cultivars against three different pathogens. *Spanish Journal of Agricultural Research* **10**, 502–512. <https://doi.org/10.5424/sjar/2012102-345-11>
- Pruvost O, Fabrègue C & Luisetti J (1988) Mise en évidence de la maladie des taches angulaires du fraisier à l'île de la Réunion. *Fruits (France)* **43**, 369–373.
- Pooler MR, Ritchie DF & Hartung JS (1996) Genetic relationships among strains of *Xanthomonas fragariae* based on random amplified polymorphic DNA PCR, repetitive intergenic consensus PCR data and generation of multiplexed PCR primers useful for the identification of this phytopathogen. *Applied and Environmental Microbiology* **62**, 3121–3127.
- Pużawska J, Kaluzna M, Warabieda W, Pothier JF, Gétaz M & van der Wolf JM (2020) Transcriptome analysis of *Xanthomonas fragariae* in strawberry leaves. *Scientific Reports* **10**, 20582. <https://doi.org/10.1038/s41598-020-77612-y>
- Rademaker JLW, Hoste B, Louws FJ, Kersters K, Swings J, Vauterin L, Vauterin P & De Bruijn FJ (2000) Comparison of AFLP and rep-PCR genomic fingerprinting with DNA-DNA homology studies: *Xanthomonas* as a model system. *International Journal of Systematic and Evolutionary Microbiology* **50**, 665–677.
- Rademaker JLW, Louws FJ, Schultz MH, Rossbach U, Vauterin L, Swings J & de Bruijn FJ (2005) A comprehensive species to strain taxonomic framework for *Xanthomonas*. *Phytopathology* **95**, 1098–1111.
- Randhawa P & Civerolo E (2017) Detection of *Xanthomonas fragariae* in strawberry planting stock. Chapter 34. *In* Detection of Plant-Pathogenic Bacteria in Seed and Other Planting Material, 2nd Edition. January 2017, 249–254. <https://doi.org/10.1094/9780890545416.034>
- Roach JA, Verma S, Peres NA, Jamieson AR, van de Weg WE, Bink MC, Bassil NV, Lee S & Whitaker VM (2016) FaRXf1: a locus conferring resistance to angular leaf spot caused by *Xanthomonas fragariae* in octoploid strawberry. *Theoretical and Applied Genetics* **129**, 1191–1201. <https://doi.org/10.1007/s00122-016-2695-1>
- Roberts PD, Jones JB, Chandler CK, Stall RE & Berger RD (1996) Survival of *Xanthomonas fragariae* on strawberry in summer nurseries in Florida detected by specific primers and nested polymerase chain reaction. *Plant Disease* **80**, 1283–1288.
- Roberts PD, Berger RD, Jones JB, Chandler CK & Stall RE (1997) Disease progress yield loss, and control of *Xanthomonas fragariae* on strawberry plants. *Plant Disease* **81**, 917–921.
- Roberts PD, Hodge NC, Bouzar H, Jones JB, Stall RE, Berger RD & Chase AR (1998) Relatedness of strains of *Xanthomonas fragariae* by restriction fragment length polymorphism, DNA-DNA reassociation, and fatty acid analyses. *Applied and Environmental Microbiology* **64**, 3961–3965.
- Rowhani A, Feliciano AJ, Lips T & Gubler WD (1994) Rapid identification of *Xanthomonas fragariae* in infected strawberry leaves by enzyme-linked immunosorbent assay. *Plant Disease*, **7**, 248–250.
- Scortichini M & Rossi MP (2003) Genetic diversity of *Xanthomonas arboricola* pv. *fragariae* strains and comparison with some other *X. arboricola* pathovars using repetitive PCR genomic fingerprinting. *Journal of Phytopathology* **151**, 113–119. <https://doi.org/10.1046/j.1439-0434.2003.00591.x>
- Stefani E, Mazzucchi U & Calzolari A (1989) Evidence of endophytic movement of *Xanthomonas fragariae* Kenn. and King in strawberry. *Phytopathologia Mediterranea* **28**, 147–149.
- Stöger A, Ruppitsch W (2004) A rapid and sensitive method for the detection of *Xanthomonas fragariae*, causal agent of angular leafspot disease in strawberry plants. *Journal of Microbiological Methods* **58**, 281–4. <https://doi.org/10.1016/j.mimet.2004.04.002>

- Stöger A, Barionovi D, Calzolari, Gozzi, A, Ruppitsch W & Scortichini M (2008) Genetic variability of *Xanthomonas fragariae* strains obtained from field outbreaks and culture collections as revealed by repetitive-sequence PCR and AFLP. *Journal of Plant Pathology* **90**, 469-473.
- Turechek WW & Peres NA (2009) Heat treatment effects on strawberry plant survival and angular leaf spot, caused by *Xanthomonas fragariae*, in nursery production. *Plant Disease* **93**, 299-308. <https://doi.org/10.1094/PDIS-93-3-0299>
- Turechek WW, Hartung JS & Mc Callister J (2008) Development and optimization of a real-time detection assay for *Xanthomonas fragariae* in strawberry crown tissue with receiver operation characteristic curve analysis. *Phytopathology* **98**, 359-368. <https://doi.org/10.1094/PHTO-98-3-0359>
- Turechek WW, Wang S, Tiwari G & Peres NA (2013) Investigating alternative strategies for managing bacterial angular leaf spot in strawberry nursery production. *International Journal of Fruit Science* **13**(1-2), 234-245. <https://doi.org/10.1080/15538362.2012.698181>
- Turechek WW, Jertberg M, Winterbottom C & Wang H (2023) Survival of *Xanthomonas fragariae* on common materials. *Plant Disease* **107**, 116-124 <https://doi.org/10.1094/PDIS-03-22-0719-RE>
- Ustun N, Tjou-Tam-Sin NNA, Janse JD (2007) First report of bacterial leaf blight of strawberry caused by *Xanthomonas arboricola* pv. *fragariae* Janse *et al.* in Turkey. *Journal of Plant Pathology* **89**, 109-112.
- Van den Mooter M & Swings J (1990) Numerical analysis of 295 phenotypic features of 266 *Xanthomonas* strains and related strains and an improved taxonomy of the genus. *International Journal of Systematic Bacteriology* **40**, 348-369.
- Van der Gaag DJ, Bergsma-Vlami M, Van Vaerenbergh J, Vandroemme J & Maes M (2013) Pest risk analysis for *Xanthomonas fragariae*. Netherlands Food and Consumer Product Safety Authority, Utrecht, the Netherlands - Institute for Agricultural and Fisheries Research, Merelbeke, Belgium - available at https://www.nvwa.nl/txmpub/files/?p_file_id=2203331 (last accessed February 2023).
- Van der Wolf J, Kastelein P, Evenhuis B & Moene A (2017) Dissemination of *Xanthomonas fragariae* in a strawberry field crop. 12th European Foundation for Plant Pathology & 10th French Society for Plant Pathology, 29 May 2017 to 2 June 2017, Dunkerque, France, Abstract.
- Van der Wolf JM, Evenhuis A, Kastelein P, Krijger MC, Funke VZ, van den Berg W & Moene AF (2018) Risks for infection of strawberry plants with an aerosolized inoculum of *Xanthomonas fragariae*. *European Journal of Plant Pathology* **152**, 711-722. <https://doi.org/10.1007/s10658-018-1513-9>
- Vandroemme J, Baeyen S, Van Vaerenbergh J, De Vos P & Maes M (2008) Sensitive real-time PCR (TaqMan®) detection of *Xanthomonas fragariae* in strawberry plants. *Plant Pathology* **57**, 438-444. <https://doi.org/10.1111/j.1365-3059.2007.01813.x>
- Vandroemme J, Cottyn B, Pothier JF, Pflüger V, Duffy B & Maes M (2013a) *Xanthomonas arboricola* pv. *fragariae* : what's in a name? *Plant Pathology* **62**, 1123-1131. <https://doi.org/10.1111/ppa.12028>
- Vandroemme J, Cottyn B, Baeyen S, De Vos P & Maes M (2013b) Draft genome sequence of *Xanthomonas fragariae* reveals reductive evolution and distinct virulence-related gene content *BMC Genomics* **14**, 829.
- Vauterin L, Rademaker J & Swings J (2000) Synopsis on the taxonomy of the genus *Xanthomonas*. *Phytopathology* **90**, 677-682.
- Vauterin L, Hoste B, Kersters K, Swings J (1995) Reclassification of *Xanthomonas*. *International Journal of Systematic and Evolutionary Microbiology* **45**(3), 472-489.
- Vermunt A, van Beuningen A (2008) Monitoring van *Xanthomonas fragariae* in de aardbeiteelt en de ontwikkeling van een hygiëne protocol. <https://edepot.wur.nl/290364> (last accessed January 2023).

Wang H, McTavish C & Turechek WW (2018) Colonization and movement of *Xanthomonas fragariae* in strawberry tissues *Phytopathology* **108**, 681-690. <https://doi.org/10.1094/PHYTO-10-17-0356-R>

Wang H & Turechek WW (2016) A loop-mediated isothermal amplification assay and sample preparation procedure for sensitive detection of *Xanthomonas fragariae* in strawberry. *PLoS ONE* **11**, e0147122. <https://doi.org/10.1371/journal.pone.0147122>

Wang H & Turechek WW (2020) Detection of viable *Xanthomonas fragariae* cells in strawberry using propidium monoazide and long-amplicon quantitative PCR. *Plant Disease* **104**, 1105–1112. <https://doi.org/10.1094/PDIS-10-19-2248-RE>

Weller SA, Beresford-Jones NJ, Hall J, Thwaites R, Parkinson N & Elphinstone JG (2007) Detection of *Xanthomonas fragariae* and presumptive detection of *Xanthomonas arboricola* pv. *fragariae*, from strawberry leaves, by real-time PCR. *Journal of Microbiological Methods* **70**, 379–83. <https://doi.org/10.1016/j.mimet.2007.05.018>

Wenneker M & Bergsma-Vlami M (2015) *Erwinia pyrifoliae*, a new pathogen on strawberry in the Netherlands. *Journal of Berry Research* **5**, 17-22. <https://doi.org/10.3233/JBR-140086>

Xue S & Bors RH (2005) Resistance sources to *Xanthomonas fragariae* in non-octoploid strawberry species. *HortScience* **40**, 1653-1656.

Yoon M-J, Myung I-S, Lee J-Y, Kim Y-S, Lee Y-H, Kim D-Y, Lee Y-K (2016) Distribution of bacterial angular leaf spot of strawberry and characterization of *Xanthomonas fragariae* strains from Korea. *Research in Plant Disease* **22**, 9-17. <https://doi.org/10.5423/RPD.2016.22.1.9>

Young AJ, Marney TS, Herrington M, Hutton D, Gomez AO, Villiers A, Campbell PR & Geering ADW (2011) Outbreak of angular leaf spot, caused by *Xanthomonas fragariae* in a Queensland strawberry germplasm collection. *Australasian Plant Pathology* **40**, 286-292. <https://doi.org/10.1007/s13313-011-0045-y>

Zimmermann C, Hinrichs-Berger J, Moltmann E & Buchenauer H (2004) Nested PCR (polymerase chain reaction) for detection of *Xanthomonas fragariae* in symptomless strawberry plants. *Journal of Plant Disease and Protection* **111**, 39–51.

ACKNOWLEDGEMENTS

This datasheet was extensively revised in 2023 by Dr Jaap D. Janse, independent consultant, bacteriologist. His valuable contribution is gratefully acknowledged.

How to cite this datasheet?

EPPO (2026) *Xanthomonas fragariae*. EPPO datasheets on pests recommended for regulation. Available online. <https://gd.eppo.int>

Datasheet history

This datasheet was first published in the EPPO Bulletin in 1986 and revised in the two editions of 'Quarantine Pests for Europe' in 1992 and 1997, as well as in 2023. It is now maintained in an electronic format in the EPPO Global Database. The sections on 'Identity', 'Hosts', and 'Geographical distribution' are automatically updated from the database. For other sections, the date of last revision is indicated on the right.

CABI/EPPO (1992/1997) *Quarantine Pests for Europe (1st and 2nd edition)*. CABI, Wallingford (GB).

EPPO (1986) Data sheets on quarantine organisms No. 135, *Xanthomonas fragariae*. *EPPO Bulletin* **16**(1), 17-20. <https://doi.org/10.1111/j.1365-2338.1986.tb01128.x>



Co-funded by the
European Union