EPPO Datasheet: *Phytophthora fragariae*

Last updated: 2022-02-15

IDENTITY

Preferred name: *Phytophthora fragariae*
Authority: C.J. Hickman
Taxonomic position: Chromista: Oomycota: Oomycetes: Peronosporales: Peronosporaceae
Other scientific names: *Phytophthora fragariae var. fragariae* C.J. Hickman
Common names: Lanarkshire disease of strawberry, red core of strawberry, red stele 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: PHYTFR

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Notes on taxonomy and nomenclature

Phytophthora fragariae was previously considered to have two varieties: var. *fragariae* Wilcox & Duncan and var. *rubi* Wilcox & Duncan, which shared similar morphology and growth/temperature responses but differed in their host specificities; *P. fragariae* var. *fragariae* causing red core of strawberry, and *P. fragariae* var. *rubi* being associated with root rot of raspberry (Wilcox & Duncan, 1993). In 2007, *P. fragariae* var. *rubi* was separated from *P. fragariae* and re-described as *Phytophthora rubi* (Wilcox & Duncan, 1993 and Man in't Veld, 2007), as analyses of isozyme profiles and cox1 sequences demonstrated the absence of gene flow between both taxa (Man in 't Veld, 2007). This was subsequentially supported by whole genome analyses (Tabima *et al.*, 2018). Phylogenetically, both species belong to Clade 7a, with *Phytophthora attenuata* from Taiwan being the most closely related species (Jung *et al.*, 2017).

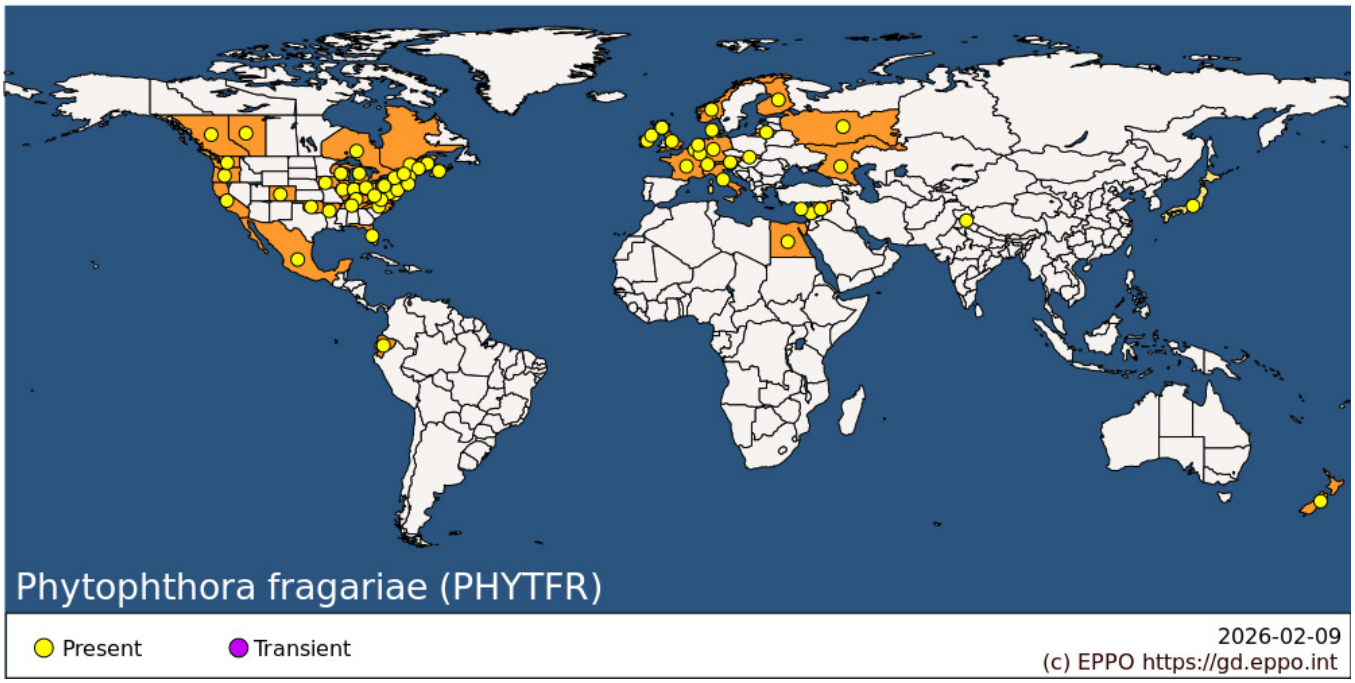
HOSTS

Fragaria × *ananassa* and *Rubus* × *loganobaccus* are the only known hosts under natural conditions. Infection of *P. fragariae* can occur via artificial inoculation on other genera in the families *Rosaceae*, *Amaranthaceae* and *Solanaceae* (Erwin & Ribeiro 1996).

Host list: *Fragaria x ananassa*, *Rubus x loganobaccus*

GEOGRAPHICAL DISTRIBUTION

Phytophthora fragariae is currently present in all five continents, although its distribution is concentrated in Europe and North America. Since its first report in Scotland in 1920, the pathogen has spread in many countries where strawberry is grown, except China and the Southern Mediterranean countries of Europe (Van de Weg, 1997) where the pathogen distribution is still restricted. The climate of most European countries is favorable to the requirements of the pathogen for growth and sporulation; conditions are apparently most conducive in the western part of Northern Europe, with a temperate, oceanic climate, and least so in the southern Mediterranean regions, where high soil temperatures would inhibit pathogen establishment and disease development. Disease outbreaks are so far known only in commercial strawberry production, and it is reported in several EPPO member countries. In two EPPO member countries (Hungary, Sweden) *P. fragariae* is reported as eradicated.



EPPO Region: Austria, Belgium, Cyprus, Denmark, Finland, France (mainland), Germany, Ireland, Italy (mainland), Lithuania, Luxembourg, Netherlands, Norway, Russian Federation (Central Russia, Southern Russia), Slovakia, Switzerland, United Kingdom (England, Northern Ireland, Scotland)
Africa: Egypt
Asia: India (Himachal Pradesh), Japan, Lebanon, Syrian Arab Republic
North America: Canada (Alberta, British Columbia, New Brunswick, Nova Scotia, Ontario, Québec), Mexico, United States of America (Arkansas, California, Colorado, Connecticut, Delaware, Florida, Illinois, Indiana, Iowa, Kentucky, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, Tennessee, Vermont, Virginia, Washington, West Virginia, Wisconsin)
South America: Ecuador
Oceania: New Zealand

BIOLOGY

Phytophthora fragariae can survive in the soil for at least 12 years without host plants as resistant oospores (Newton *et al*. 2010), whereas hyphae and other asexual structures persist for a few months only (Duncan & Cowan, 1980).

Oospores germinate and form a new sporangiophore on which, depending on the environmental conditions, one or occasionally several sporangia are produced. The optimum temperature for germination is 10-15°C but germination can occur also at 20°C and very slowly at 5°C. Minimum growth temperature is 3°C, while optimum and maximum temperatures are 18°C and 27°C, respectively. Sporangia release motile, biflagellate zoospores into the soil water. These zoospores are then chemotactically attracted by the root tips of the host plant where they attach themselves, encyst, and form germ tubes which penetrate into the root. The pathogen traverses the cortex inter- and intracellularly to the stele, mainly colonizing the pericycle and the phloem. Growth is mostly concentrated within and along the stele, but hyphae grow out from the roots to form new sporangia which release more zoospores, and the cycle starts again. Secondary sporangia are produced within a few days and thus many cycles of infection can occur over the winter months. Sporangia can often be seen on recently infected roots, generally concentrated around root tips and at the points where lateral roots are emerging from the main root. Internal proliferation of the sporangia is a common feature, which presumably contributes to the rapid production of large numbers of zoospores. Zoospores are negatively geotropic and, by swimming upwards, become concentrated in the water at the surface of the soil. Movement in surface or drainage water, especially down slopes, can spread the zoospores very rapidly. The optimum temperature for infection is 10-17°C; infection can occur at temperatures down to 3°C but not at 25°C (Erwin & Ribeiro, 1996). It proceeds more slowly below 10°C but more secondary inoculum is produced over longer periods at these low temperatures, which explains why the disease is more severe after a wet winter. The infection

occurs most readily under wet, cool conditions, typically in late autumn and early spring and the low temperatures favour the production of large amounts of secondary inoculum over a long period.

The stele of infected roots turns red in response to infection and later the root starts to rot from the tip upwards. As the infection progresses, oospores are formed in close association with the stele, probably in the sieve tubes of the phloem. *Phytophthora fragariae* has a homothallic breeding system and forms oogonia, containing thick-walled oospores, and amphigynous and/or paragynous antheridia in single culture. Several hundred oospores may be produced per cm length of infected root. Eventually infected roots rot, and are invaded by secondary organisms, leaving a large number of new oospores in the soil.

A number of distinct pathogenicity races of *P. fragariae* have been reported in the United Kingdom, United States, and Canada, although there is no internationally recognized system for classifying races. A total of 27 races have been described, however some of which were shown to be the same as other described races (Kennedy & Duncan, 1993). Recent studies using genomic approach allowed the resolution of *P. fragariae* race schemes between different countries, Canadian race 1 is equivalent to United Kingdom race 1, Canadian race 2 is equivalent to United Kingdom race 3 and both Canadian race 3 and United States race 4 are equivalent to United Kingdom race 2 (Adams *et al.* 2020).

DETECTION AND IDENTIFICATION

Symptoms

Disease outbreaks often start from small foci of infected strawberry plants. They increase in size, especially down slopes where spread in water can quickly lead to large areas being affected. Symptoms can be apparent on the roots from late autumn onwards but generally do not become noticeable on the above-ground parts of the plants until late spring or early summer, at which time it can be difficult to find confirmatory evidence of the pathogen in the roots.

Symptoms usually appear on the upper parts of plants that come under stress in late spring or early summer, especially in low-lying, wet areas. Plants often fail to develop or have only stunted growth. They may die just before fruiting or produce a few small fruits. Younger leaves can have a blue-green coloration and older ones turn yellow or red. Digging up the plants reveals a poorly developed and rotten root system.

Lateral feeder roots are usually badly rotten and are commonly lost by the time plants are dug up. The adventitious roots rot from the tips upwards and often are grey to brown at their distal ends, giving the characteristic 'rat-tail' symptom. Cutting open the upper, white, unrotten parts of such roots reveals steles which are wine-red to brick-red in colour - hence the name red core. The colour can extend for quite long distances above the rotten parts of the roots, right into the crown in highly susceptible cultivars.

Morphology

The disease is usually confirmed by finding red steles and the presence of the typical oospores in the infected tissues. The oospores can be abundant but are restricted to the stelar region of rotten roots.

Sporangia non-papillate; persistent; obpyriform, ovoid, ellipsoid (28–56 × 27–49 µm), often very markedly obpyriform in shape; with internal and nested proliferation and originated in unbranched or simple sympodial sporangiophores. Hyphal swellings coralloid, irregular shapes, globose, subglobose, some solitary, and others catenulate in chains. Chlamydospores absent. Oogonia smooth-walled, originated in very short stalks; frequently globose (28–46 µm diam) with tapering base; antheridia amphigynous and some paragynous (16–30 × 12–22 µm); oospores plerotic and aplerotic, many showing a single globule and turning golden brown with age (Abad *et al*., 2023).

Detection and inspection methods

Infection of strawberry roots by *P. fragariae* can be difficult to detect, especially in summer when the fungus is largely inactive and is present principally as oospores.

The disease can be detected in fields even at very low levels by the use of a sensitive root tip bait test (Duncan *et al.*, 1986). Runners are dug up at regular intervals across the field and samples of root tips, 2-5 cm in length, are cut from the ends of the roots and collected in a polythene bag. The root tips are mixed with a soilless compost and the mixture is planted with the alpine strawberry cultivar Baron Solemacher (*Fragaria vesca* var. *alpina*), grown from seed. The plants are then kept under cool conditions with moderate lighting in a glasshouse and watered copiously (care should be taken to ensure that the pots drain freely and do not become stagnant). Deep-red coloration of stems and leaves and wilting of leaves often become apparent within 5 weeks, when the test is normally terminated (Duncan, 1979). The root systems of the plants should be checked for oospores and, if present, isolation can be carried out on a selective medium (Erwin & Ribeiro, 1996). The root tip bait test is highly sensitive and can detect <1% infection levels, however it is time-consuming and requires the tester to have mycological expertise, taxonomic experience and must be done at about 12°C.

Other methods of detecting *P. fragariae* have been developed. ELISA tests have been developed (Amouzou-Alladaye *et al*., 1988; Mohan, 1988; Werres, 1988; Pscheidt *et al*., 1992) but these are not suitable for critical diagnosis since they are only specific at the level of the genus *Phytophthora*. Burns & George (1995) tried to obtain monoclonal antibodies specific for the two varieties of *P. fragariae*, but these again were specific only at the genus level.

A Polymerase Chain Reaction (PCR) technique has been developed in the Netherlands and Scotland. Sequences of the internal transcribed spacer region of the ribosomal gene repeat (rDNA) were used to develop specific primers in a nested PCR (Cooke *et al.*, 2000). With this technique, it was possible to detect specifically *P. fragariae* in infected but symptomless roots, and also to detect zoospores in contaminated water samples. The method is highly sensitive and is at least as sensitive as the root tip bait test. Although this work was mainly done on *P. fragariae*, the PCR method can also be used for *P. rubi* (Bonants *et al.* 2004).

Recently, Munawar *et al.* (2020) developed a rapid recombinase polymerase amplification (RPA) assay for *P. fragariae* targeting the *Phytophthora* mitochondrial DNA intergenic atp9-nad9 marker, which was shown to be more reliable than the baiting test to detect the pathogen from the soil.

More generally, other fast and reliable methods have been developed for DNA extraction from soil and zoospores trapped from water on filters making it possible to follow the activity and spread of *Phytophthora* species throughout the year (Prigigallo *et al*., 2016).

EPPO recommends that plants for planting of strawberries imported from affected parts of the world (e.g. USA, South America) should fulfil the phytosanitary procedures described in the EPPO Standard PM 3/73 (EPPO, 2008b). This guideline describes the procedure by which consignments of *Fragaria* spp. plants for planting are subjected to import control including sampling and pathogen identification.

Inspection can be made both at the point of entry in the importing country or may be applied in the exporting country, just before transporting the consignment. Inspections are made visually for detection of specific disease symptoms, such as root and crown rot, and through sampling and pathogen testing.

EPPO Standard PM 3/83 (EPPO, 2017) describes the procedure for inspection of places of production of *Fragaria* plants for planting.

PATHWAYS FOR MOVEMENT

Phytophthora fragariae can spread in surface or drainage water, and this can be important for local spread. Caution must be exercised when irrigating crops as the pathogen has been spread by irrigating with water which had drained from infested fields, especially in very wet, mild winters. The pathogen can also be moved in soil on equipment and machinery. However, the most important means of spread which has undoubtedly resulted in the movement of the disease within countries and throughout much of Europe, is in planting material of strawberry (EPPO, 2017).

PEST SIGNIFICANCE

Economic impact

Red core is a cause of serious economic loss wherever it occurs, although it is generally most severe in cool, wet regions (Pinkerton *et al*., 2002). Damage is most severe after wet winters and can be considerable, with yields as low as 1 tonne/ha, mostly of small fruit of poor quality (Wilcox *et al*. 1999). In Nova Scotia (Canada), it was estimated that in one season 78% of the strawberry area was rendered unproductive with significant losses to growers (Gourley & Delbridge, 1972). Montgomerie and Kennedy (1982) demonstrated that the relationship between red core disease incidence and severity and yield was highly significant and negatively correlated. In the EPPO region, the disease is of great economic importance to strawberry production in Belgium, France, Germany, Italy, Netherlands, Russia, Switzerland and the United Kingdom, and of some importance in all countries where it is established.

Control

The rapid build-up and spread of inoculum, the polycyclic nature of the disease, and the production and subsequent survival of oospores are the main factors which make this disease difficult to control and eradicate.

The main means of spread is via infected planting material and the best control measure is through strict legislation and certification schemes (ideally involving a root tip bait test see above) for nursery stocks. EPPO has produced recommendations on a certification scheme for strawberries (EPPO, 2008a) providing detailed guidelines to produce pathogen tested material of vegetatively propagated strawberry plants.

Several fungicides are known to be effective in controlling red core disease. Both metalaxyl and fosetyl aluminium gave satisfactory control of red core disease (McIntyre & Walton, 1981; O'Neill & Griffin, 1987). Various fungicides containing phenylamides when applied in autumn and spring also gave significant disease control. However, in addition to environmental consequences arising from the use of fungicides, there is a risk of selecting fungicide-resistant strains of the pathogen. Metalaxyl-resistant strains of *P. fragariae* have been reported from Germany (Seemüller & Sun, 1989) and North America, where metalaxyl tolerance is causing serious problems (Nickerson & Maas, 1991).

Control can also be obtained by appropriate use of cultural practices, especially by improving drainage. Good results have sometimes been achieved by growing plants on ridges or raised beds. The presence of *P. fragariae* seems to cause more damage under perennial cultivation systems than annual cultivation systems. In the case of a transfer from perennial to annual cultivation systems, *P. fragariae* would possibly cause less damage, provided that disease-free plants were used for planting (EPPO, 2008).

Attempts to breed for resistance have resulted in the release of commercial cultivars with high levels of field resistance (Gooding, 1972), however, their resistance was shown to be race-specific (Kennedy & Duncan, 1988). Many popular cultivars in Europe have race-specific resistance, but it is not clear whether this contributes to disease control because races, which are virulent on these cultivars, have been recorded from several countries. In North America, breeders have selected cultivars with race-specific resistance (Scott *et al.*, 1984), and have had some success in controlling the disease. Attempts to breed for resistance have resulted in the production of commercial cultivars with high levels of field resistance. Van de Weg (1997) suggested that resistance of strawberry and virulence of *P. fragariae* behaves according to a gene-for-gene system with at least five race-specific resistance and avirulence genes. In Europe, Canada and the USA there are a number of red core-resistant varieties grown (Milholland, 1994), although, in Europe they are not widely cultivated. Due to the increasing concern about the use of pesticide, the use of resistant cultivars represents an important disease management alternative to prevent establishment of the pathogen in new strawberry production sites.

Biological control of red stele could be an alternative to the use of agrochemicals. Plant growth promoting rhizobacteria (PGPR) showed positive results both in *in vitro* and *in vivo* experiments in reducing red core and crown rot caused by *P. fragariae,* exhibiting similar level of control as the chemical fungicides (Anandhakumar & Zeller 2008).

Phytosanitary risk

Phytophthora fragariae is well established in the EPPO region and could potentially spread further. Strawberry red

core is a potential hazard where soils remain cool and damp for some part of the year. In fact, the disease now occurs in several countries in the EPPO region, particularly in central and northern Europe. It has also been recorded in countries of the warmer and drier Mediterranean region and extensive use of irrigation in such regions may increase the risk of more serious outbreaks in that region. *P. fragariae* is however of restricted distribution within several EPPO countries.

PHYTOSANITARY MEASURES

To prevent the introduction and spread of *P. fragariae*, import requirements for *Fragaria* plants for planting apply worldwide. It may be required that host plants are produced in a pest-free area, or, as suggested by some countries, in a pest free place of production (EFSA, 2014). Use of certified strawberry planting material, according to EPPO (2008a), can, however, provide adequate guarantees and the probability that *Fragaria* spp. plants imported through this scheme may carry *P. fragariae* is considered to be low. In the European Union, when *P. fragariae* was deregulated as a quarantine pest (EU, 2019), the pathogen was recommended for regulation as a RNQP for *Fragaria* plants for planting (other than seeds) during the EU Quality pest project (Picard *et al*., 2018). ISPM 40 (IPPC, 2017) also provides useful guidance for phytosanitary measures to be applied to growing media associated to plants for planting.

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ACKNOWLEDGEMENTS

This datasheet was extensively revised in 2022 by Bruno Scanu of the University of Sassari (Italy). His valuable contribution is gratefully acknowledged.

How to cite this datasheet?

EPPO (2026) *Phytophthora 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 1982 and revised in the two editions of 'Quarantine Pests for Europe' in 1992 and 1997, as well as in 2021. 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.

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Co-funded by the
European Union