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Data Sheets on Quarantine Pests

Phytophthora fragariae

IDENTITY

Name: *Phytophthora fragariae* Hickman
Taxonomic position: Fungi: Oomycetes: Peronosporales
Notes on taxonomy and nomenclature: *P. fragariae* has two varieties: var. *fragariae* Wilcox & Duncan and var. *rubi* Wilcox & Duncan. Records on diseases caused by *P. fragariae* var. *rubi* were previously referred to as *P. erythroseptica* (Converse & Schwartze, 1968; Seemüller *et al.*, 1986), *P. megasperma* (Duncan *et al.*, 1987) and *P. fragariae* (Wilcox, 1989). Wilcox & Duncan (1993) and Wilcox *et al.* (1993) consider it as a distinct variety of *P. fragariae*. Stammler *et al.* (1993) confirmed by RFLP analysis that the two varieties are homogeneous and distinct, but also resembled each other more than any other *Phytophthora* species.

- ***Phytophthora fragariae* var. *fragariae***
  Name:*Phytophthora fragariae* Hickman var. *fragariae* Wilcox & Duncan
  Common names: Red core, red stele, Lanarkshire disease (English)
  Coeur rouge des racines du fraisier (French)
  Rote Wurzelfäule der Erdbeere (German)
  Corazón rojo de la fresa (Spanish)
  Bayer computer code: PHYTFR
  EPPO A2 list: No. 79
  EU Annex designation: II/A2
- ***Phytophthora fragariae* var. *rubi***
  Name:*Phytophthora fragariae* Hickman var. *rubi* Wilcox & Duncan
  Common names: Root rot of raspberry (English)
  Dépérissement du framboisier (French)
  Himbeersterben, Wurzelfäule der Himbeere (German)
  Bayer computer code: PHYTFU
  EPPO A2 list: No. 79

HOSTS

- ***Phytophthora fragariae* var. *fragariae***
  The principal host is cultivated strawberries (*Fragaria* x *ananassa*). Only one other host, loganberries (*Rubus* hybrid), has been found naturally infected (McKeen, 1958), but a number of genera within the tribe Potentilleae in the Rosaceae have been infected artificially (Pepin, 1967).

  The potential host range in the EPPO region is all species of *Fragaria* and perhaps certain species of *Rubus*, such as loganberries and blackberries (*Rubus fruticosus*). Although a typical strain of the fungus causing strawberry red core has been isolated from loganberries, most serious outbreaks of severe root rot in *Rubus* are caused by the variety *P. fragariae* var. *rubi* (see below) (Wilcox, 1989).

- ***Phytophthora fragariae* var. *rubi***

Cultivated raspberries (*Rubus idaeus*) are the principal host, but hybrid berries such as loganberries and tayberries have been found naturally infected. In the last case the disease could not be reproduced in inoculation experiments. Some other genera within the tribe Potentilleae in the family Rosaceae may be susceptible but have not been tested. Strawberries are not susceptible to this variety of the pathogen, which does not cause typical red core symptoms.

The potential host range in the EPPO region would be raspberries (*Rubus idaeus*, *R. idaeus* hybrids and *R. occidentalis*) and perhaps other *Rubus* hybrid species such as loganberries and tayberries.

GEOGRAPHICAL DISTRIBUTION

- ***Phytophthora fragariae* var. *fragariae***

EPPO region: Austria, Belgium, Bulgaria (unconfirmed), Czech Republic, Cyprus, Denmark (Thinggaard, 1989), Egypt (Moustafa, 1986), France, Germany, Hungary (eradicated), Ireland, Italy, Lebanon, Luxembourg, Netherlands, Slovakia, Spain (unconfirmed), Sweden, Switzerland, UK (most parts including Scotland, England, Northern Ireland and Jersey; found but not established in Guernsey), Russia (European), Slovenia.

Asia: Cyprus, Japan, Lebanon. Also reported from Taiwan (Chang, 1988), but the high optimum temperature for growth (30°C) and the heterothallism (A2 mating type) of the isolate make this assignment doubtful.

North America: Canada (Alberta, British Columbia, New Brunswick, Nova Scotia, Ontario, Quebec), Mexico, USA (Arkansas, California, Colorado, Connecticut, Florida, Illinois, Iowa, Kentucky, Maine, Maryland, Michigan, New Jersey, New York, North Carolina, Oklahoma, Oregon, Virginia, Washingon, Wisconsin).

South America: Ecuador.

Oceania: Australia (South Australia), New Zealand.

EU: Present.

Distribution map: See CMI (1986, No. 62).

- ***Phytophthora fragariae* var. *rubi***

EPPO region: Austria, Denmark (Thinggaard, 1990), France (Nourrisseau & Baudry, 1987), Germany (Seemüller *et al.*, 1986), Ireland (Duncan *et al.*, 1987), Netherlands, Norway (Heiberg *et al.*, 1990), Slovenia, Sweden (Graaberg, 1994), Switzerland (Bolay & Lauber, 1989), UK (Scotland, England
and Northern Ireland; Duncan *et al.*, 1987).

North America: Canada (British Columbia and possibly Ontario), USA (New York, Ohio and the Midwest; Wilcox, 1989; Washington, Converse & Schwartze, 1968).

South America: Chile.

Oceania: There are reports of raspberry root rot from Australia (Washington, 1988) and New Zealand (Boesewinkel, 1982) but the species involved is *P. cryptogea*.

EU: Present.

Distribution map: See CMI (1986, No. 62).

BIOLOGY

- ***Phytophthora fragariae* var. *fragariae***

The fungus can survive for many years in soil as resistant oospores. There is experimental evidence that it can survive well in excess of 4 years and some field reports suggest that it remains viable for 13-15 years after a strawberry crop. There are no known

natural hosts other than strawberry and loganberry, although artificial infection of other members of the tribe Potentilleae may indicate a potential to survive on hosts such as raspberry and blackberry.

Oospores germinate to form one or occasionally several sporangia. The optimum temperature for germination is 10-15°C but germination can occur at 20°C and very slowly at 5°C. The sporangia release vigorously motile zoospores which swim to the root tips of the host plant where they encyst, attach themselves and form germ tubes which penetrate into the root. The fungus traverses the cortex inter- and intracellularly to the stele, mainly colonizing the pericycle and the phloem. Growth is mostly concentrated within the stele, with the fungus growing along it, but hyphae grow out from the roots to form new sporangia which release more zoospores and initiate new infections on other roots and plants. Non-papillate secondary sporangia are produced within a few days and the fungus can produce many cycles of infection 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 not uncommon and 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 2°C but not at 25°C (J.M. Duncan, unpublished results). 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. Thus, infection occurs most readily under wet, cool conditions, typically late autumn and early spring. Low temperatures favour the production of large amounts of secondary inoculum over a long period, so infection occurs readily.

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. The fungus is homothallic and only one strain is needed for oospore production. Several hundred oospores may be produced per cm length of infected root. Eventually infected roots rot, due in part to invasion by secondary organisms, leaving large numbers of new oospores in the soil. Planting diseased plants into clean soil contaminates the site for many years.

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 so intractable.

A number of races of the fungus have been recognized in the UK, in the past as many as 11 (Montgomerie, 1967), but more recently seven isolate clusters were detected, each of which probably corresponds to one race. In North America there are ten races and in Canada six. In a survey of different affected areas of Europe (Kennedy & Duncan, 1993), nine races were found of which three coincided with North American races. There is no internationally recognized system for classifying races.

- ***Phytophthora fragariae* var. *rubi***

The life cycle of the fungus is very similar to that of *P. fragariae* var. *fragariae*. It can probably survive for many years in soil as resistant oospores, and although there are no known natural hosts other than *Rubus* spp. it may be able to survive on other rosaceous hosts. Just as with *P. fragariae* var. *fragariae*, inoculum rapidly builds up and spreads, and several multiplication cycles occur within a year. The raspberry disease is thus just as intractable as strawberry red core. There are as yet no reports of races.

DETECTION AND IDENTIFICATION

Symptoms

- ***Phytophthora fragariae* var. *fragariae***

Disease outbreaks often start from small foci of infected strawberry plants. They increase in size, especially down slopes where spread in water can lead quickly 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 make only stunted growth. They may die just before fruiting or produce a few small fruit. Younger leaves can have a blue-green coloration and older ones turn yellow or red. Digging up the plants reveals a poorly developed and rotted root system.

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

- ***Phytophthora fragariae* var. *rubi***

As with *P. fragariae* var. *fragariae*, outbreaks often start from small foci, increasing in size, especially down slopes. Symptoms usually appear on the upper parts of plants that come under stress in late spring or early summer. Some fruiting canes, i.e. canes in their second year, do not break bud; others break bud but their fruiting laterals wilt and dry out before or at fruiting. When the periderm round the bases of these canes is removed the wood underneath is usually discoloured reddish-brown or brownish-black. There is a dearth of young, first-year canes (primocanes); a very early and useful symptom is the absence in spring of a flush of primocanes in the alleyways between the rows of plants. Young canes wilt to give the appearance of a shepherd's crook. Their foliage becomes bronzed or reddish long before autumn (premature autumn colouring). Blackish-purple lesions can be found at the base of many young canes, best seen by removing the periderm, and these can extend for 20-30 cm above soil level. The root systems of affected plants are badly rotted with few white feeder roots, and the thicker roots have internal discoloration often sharply demarcated from white unaffected regions of the root.

A number of other species of *Phytophthora* have been isolated from raspberries affected by root rot. *P. cambivora* and *P. citricola* may occasionally cause serious damage but most, such as *P. cactorum* and *P. drechsleri*, only cause significant damage in badly drained or waterlogged parts of a field (Duncan & Kennedy, 1989).

Plants attacked by these other species are rarely as severely affected as those attacked by *P. fragariae* var. *rubi* and lack some of its characteristic symptoms, e.g. the blackish-purple lesions on young canes and large oospores restricted to the stele. Apart from some atypical isolates of *P. cactorum* (see Morphology), the other species have been isolated only at low frequencies from raspberries affected by root rot; they are not a major problem except in diagnosis.

Morphology

- ***Phytophthora fragariae* var. *fragariae***

The disease is usually confirmed by finding red steles and typical oospores. The latter can be present in abundance but are restricted to the stelar region of rotted roots. Mature oogonia are usually golden-brown, 28-46 (mean 39) µm in diameter and contain a single

aplerotic oospore, 22-44 (mean 33) µm in diameter, mostly spherical but sometimes barrel-shaped where constricted by the host cell during their development. The non-papillate secondary sporangia are obpyriform in shape, 32-90 (mean 60) x 22-52 (mean 38) µm.

- ***Phytophthora fragariae* var. *rubi***

Oospores are best sought in young, soft, rotted roots collected from as high up on the base of the cane as possible. They are limited to the stelar region of rotted roots and are virtually identical to the oospores of *P. fragariae* var. *fragariae*, with mature oogonia usually golden-brown, 28-46 (mean 39) µm in diameter with a single aplerotic oospore, 22-44 (mean 33) µm in diameter.

It should be noted that oospores of somewhat atypical isolates of *P. cactorum* have been observed at very high frequency within the roots of many otherwise symptomless raspberry plants. They are smaller than the oospores of *P. fragariae* var. *rubi*, about 26 µm in diameter, and are located principally in the root cortex.

Detection and inspection methods

- ***Phytophthora fragariae* var. *fragariae***

The disease can be detected in fields even at very low

levels by the use of a sensitive bait test (Duncan *et al.*, 1986). Runners are dug 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 precise method of selecting samples and numbers of runners depends on the aim of the study, but samples of 500 plants from runner beds of 0.1-0.2 ha have detected levels of infection well below 1%. The root tips are mixed with a soilless compost and the mixture is planted with the alpine strawberry cultivar Baron Solemacher, 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. The root systems of the plants should be checked for oospores and, if necessary, isolations can be made to a selective medium (Montgomerie & Kennedy, 1983). This method is recommended by EPPO (OEPP/EPPO, 1984a).

ELISA tests have been developed for detection of *P. fragariae* (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. Cooke *et al.* (1995) expect that the use of PCR primers based on the rDNA of *Phytophthora* spp. will give the necessary specificity.

- ***Phytophthora fragariae* var. *rubi***

The disease can be detected by the use of a bait test.

Pieces of root, some with young buds attached, are collected in late autumn. They are mixed with a soilless compost and the mixture is used to fill flat planting trays. The trays are kept under good lighting and high temperatures and with just enough water to permit the development of the young buds into vigorous shoots. After about 5 weeks the trays are transferred to cool conditions with moderate lighting and copious watering (care should be taken to ensure that the pots drain freely and do not become stagnant). The new conditions encourage the development of the disease if present, typically wilting and yellowing of leaves, stem lesions and root rot with characteristic oospores in the stele.

The fungus can be isolated from infected plants using a selective medium (Montgomerie & Kennedy, 1983). Isolations should be attempted from a variety of parts: discoloured bases of stems, thick root pieces and fine rootlets. Brunner-Keinath & Seemüller (1992) have also described a selective medium.

MEANS OF MOVEMENT AND DISPERSAL

Both varieties of the fungus can spread in surface or drainage water, and this can be important for local spread. Caution must be exercised when irrigating crops as the fungus has been spread by irrigating with water which had drained from diseased fields, especially in very wet, mild winters. The fungus can also be moved in soil on implements 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 or raspberry.

PEST SIGNIFICANCE

Economic impact

- ***Phytophthora fragariae* var. *fragariae***

Red core is a cause of serious economic loss wherever it occurs, although it is generally most severe in cool, wet regions. Damage is most severe after wet winters (Reid, 1949) and can be considerable, with yields as low as 1 t/ha, mostly of small fruit of poor quality. In Nova Scotia (Canada), it was estimated that in one season 78% of the strawberry area was rendered unproductive with losses to growers in excess of 1500 Can$ per ha (Gourley & Delbridge, 1972). In the EPPO region, the disease is of great economic importance to strawberry production in all parts of Belgium, France, Germany, Italy, Netherlands, Russia, Switzerland and the UK, and of some importance in all countries where it is established.

- ***Phytophthora fragariae* var. *rubi***

The fungus causes an extremely serious disease which can result in complete loss of a raspberry plantation, as large areas are completely killed. Damage is most severe after wet winters. To establish raspberry plantations requires considerable capital investment which is recouped over the life of the plantation, usually 10-15 years. This investment is lost if severe outbreaks occur within 2-3 years of planting. The disease is of great importance in France, Germany, Norway, Switzerland and the UK. It has been increasing in importance in the Netherlands since 1993.

Control

- ***Phytophthora fragariae* var. *fragariae***

The main form of spread is in infected planting material and the best control is through strict legislation and certification schemes (perhaps involving a root tip/bait plant test, see below) for nursery stocks. EPPO has produced recommendations on a certification scheme for strawberries (OEPP/EPPO, 1994a). Nevertheless, such schemes have only controlled spread and have not prevented it within the EPPO region.

A number of fungicides are now approved for the control of red core. Fosetyl-aluminium and related chemicals are highly effective when applied in the autumn just before infection of new root systems begins. Various fungicides containing phenylamides have also been approved and when applied in autumn and spring give good control. However, phenylamide-tolerant strains have been isolated in Germany (Seemüller & Sun, 1989) and North America, where metalaxyl tolerance is causing serious problems (Nickerson & Maas, 1991).

Some control can also be obtained by cultural practices, especially by improving drainage. Good results have sometimes been achieved by growing plants on ridges or raised beds. Attempts to breed for resistance have resulted in the release of commercial cultivars with high levels of field resistance (Gooding, 1972), although for the most part they have not achieved wide commercial success. Moreover, their resistance may be race-specific and some strains attack them severely (Kennedy & Duncan, 1988). Many popular cultivars in Europe have race-specific resistance to the simpler races, but it is not clear

whether this contributes to disease control because races with virulence to 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.

- ***Phytophthora fragariae* var. *rubi***

A number of fungicides are now approved for the control of raspberry root rot. Fosetyl-aluminium and related chemicals have not proved effective and only fungicides containing phenylamides have so far been approved, such as mixtures of metalaxyl and copper oxychloride, or metalaxyl and mancozeb. Applications are made in autumn and spring as band sprays directed at the soil at the base of the canes.

Some control can also be obtained by good cultural practices, especially by improving drainage. Heiberg (1995) has proposed an integrated control system, based on raised beds, moderate cultivar resistance, fungicide treatment, mulching and organic amendment. In North America, a number of cultivars have useful levels of resistance: the red raspberries Newburgh, Meeker, Sumner (Barritt *et al.*, 1981) and Chilliwack (Daubeny, 1987) have some resistance while Latham and some black raspberry cultivars are highly resistant. In Europe, where the disease has appeared only recently, resistance breeding is still at an early stage. Some autumn-fruiting cultivars such as Autumn Bliss appear to have useful levels of resistance but all summer-fruiting cultivars are susceptible, in most cases extremely so. *Rubus spectabilis* and *R. parviflorus* have high levels of resistance (Bristow *et al.*, 1988), and are being used in breeding programmes. The resistance of Autumn Bliss probably comes from *R. spectabilis*. Most hybrid berries such as tayberry which have blackberry in their parentage are highly resistant or immune, but loganberry is moderately susceptible. *P. fragariae* var. *rubi* has been isolated from tayberry but when reinoculated it caused moderate symptoms only after prolonged waterlogging.

The disease can be introduced into new areas with planting material; Graaberg (1994) suggests that this is how it was introduced into Sweden. It could probably be covered by EPPO's recommended certification scheme for *Rubus* (OEPP/EPPO, 1994b).

Phytosanitary risk

P. fragariae is an EPPO A2 quarantine pest (OEPP/EPPO, 1982). The red core situation in the region was reviewed by EPPO in 1983 (OEPP/EPPO, 1984b). The original listing concerned the strawberry pathogen, but in 1991 the quarantine list entry was specifically extended to include *P. fragariae* var. *rubi*. IAPSC, JUNAC and NAPPO also consider the fungus to be of quarantine significance. 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 most such areas in the EPPO region, though not in Finland or Norway. It has also been recorded from the warmer, drier Mediterranean regions and extensive use of irrigation in such regions may increase the risk of more serious outbreaks in these regions. In any case, *P. fragariae* var. *fragariae* is of restricted distribution within several EPPO countries and subject to a compulsory certification scheme for planting material; on this basis, it should be regulated internationally as a quarantine pest.

The raspberry pathogen is a potential hazard where soils remain cool and damp for some part of the year. It presents a serious danger to all parts of the EPPO region where raspberries are grown, and is still of relatively limited distribution.

PHYTOSANITARY MEASURES

- ***Phytophthora fragariae* var. *fragariae***

EPPO recommends (OEPP/EPPO, 1990) that plants for planting of strawberries should have had root samples examined for *P. fragariae*, and that they and their mother plants should have been subjected to a growing-season inspection following EPPO's

recommended procedure (OEPP/EPPO, 1984a). In addition, it is suggested that some countries may require origin from a field where *P. fragariae* has never occurred. Use of certified strawberry planting material, according to OEPP/EPPO (1994a), could, however, provide adequate guarantees.

To implement this nationally and internationally, some European countries have legislation controlling the production of strawberry plants and the spread of red core (Navatel & Fournier, 1986). In England, the disease is notifiable to the authorities. Although the production of uncertified runners is permitted, land on which outbreaks occur is "scheduled" and the production of planting stock (certified or uncertified) of vegetatively propagated species on the land is prohibited. In Scotland, land is not scheduled but strawberry runners cannot be sold without an official certificate of health, a condition of which is the absence of red core. A certificate of health is only issued after the crop has been inspected and after it has passed a sensitive root tip / bait plant test of the type described under Detection and inspection methods. A similar test has also been used for a number of years in Sweden to test stocks and occasionally in other European countries such as Switzerland; an official but not obligatory certification scheme is operated in Switzerland and Belgium. Given the polycyclic nature of the disease, the severity of the damage which can occur and the long perennation period in infested soil, all certification schemes should place a zero tolerance on it, but some countries allow small percentages of root rot in certified stock (Navatel & Fournier, 1986). It is not clear whether "root rot" due to *P. fragariae* would be included in this category.

- ***Phytophthora fragariae* var. *rubi***

Raspberry root rot has occurred too recently to have attracted the same amount of controlling legislation as the very similar red core disease of strawberry, although the greater capital investment involved in raspberry production, and the losses which the disease can cause, makes the need for such legislation pressing. Similarly, EPPO has not yet recommended any requirements for it, though the EPPO recommendations for certification of *Rubus* planting material (OEPP/EPPO, 1994b) could provide an adequate basis. In Scotland its absence is now a condition for receipt of a phytosanitary certificate, and changes in legislation have been proposed which will make certification compulsory for all raspberry stocks produced in Scotland. Examination of stocks is undertaken in most other countries where the disease has become important.

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