

DISEASES

Armillaria mellea

Other scientific names: *Agaricus melleus* Vahl; *Agaricus sulphureus* Weinm.; *Armillaria mellea* var. *glabra* Gillet; *Armillaria mellea* var. *maxima* Barla; *Armillaria mellea* var. *minor* Barla; *Armillaria mellea* var. *sulphurea* (Weinm.) Fr.; *Armillariella mellea* (Vahl) P. Karst.; *Clitocybe mellea* (Vahl) Ricken; *Lepiota mellea* (Vahl) J.E. Lange

Phylum, Order and Family: Basidiomycota: Agaricales: Marasmiaceae

Common names: Armillaria root disease; honey mushroom; shoestring root rot

Armillaria mellea (Vahl) P. Kummer is a common worldwide pathogen of trees, woody shrubs and herbaceous plants causing root rot, root-collar rot and butt rot. A natural component of forest ecosystems, it can cause wood decay, growth reduction and even mortality, particularly in trees stressed by other factors, or in young trees planted on sites from which infected hosts have been removed.



Armillaria mellea fruiting bodies

DISTRIBUTION

Global, found throughout temperate and tropical regions of the world.

IDENTIFICATION

The following description refers to *Armillaria* species in general (Williams *et al.*, 1986). *Armillaria* can be detected by removing the bark covering an infected area to expose characteristic, fan-like sheets of white mycelium or rhizomorphs that grow between the wood and the bark. The hyphae grow together in bundles that give this mycelial mat a striated appearance. The bundles can enlarge, darken and harden into rhizomorphs. The rhizomorphs are flat, black to reddish brown in colour, up to 5 mm in width with an outer layer of dark mycelium and an inner core of white mycelium. Rhizomorphs can also grow through the soil although these tend to be

more cylindrical than and approximately half as wide as those produced beneath the bark. The rhizomorphs and mycelial fans can leave impressions on the inner bark, allowing diagnosis even after they decompose.

Mushrooms growing in clusters around the bases of infected trees or stumps may indicate the presence of *Armillaria*. These short-lived mushrooms, produced sporadically in late summer or autumn, are most abundant during moist periods. They are approximately 5 cm tall with yellow or brown stalks and a ring around the stalk just below the gills is sometimes evident. The caps are honey-yellow or tan-brown in colour, 5 to 12.5 cm in diameter with slightly sticky, brown tufted hairs and light-coloured gills beneath which produce millions of white to light yellow basidiospores.

HOSTS

Armillaria mellea has a very wide host range of both broadleaf and conifer trees and also herbaceous plants.

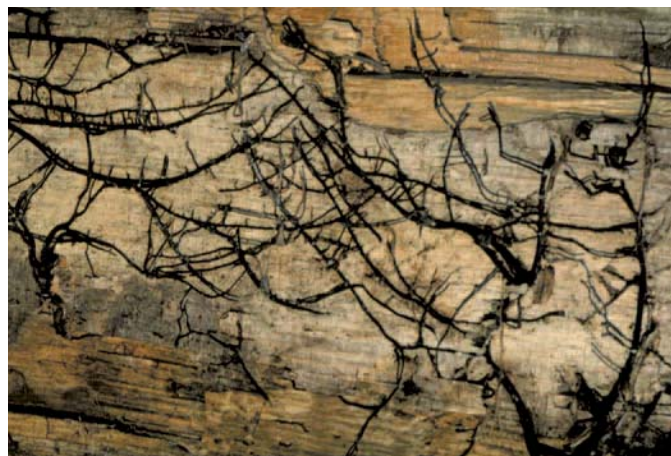
BIOLOGY

The following description refers to *Armillaria* species in general (Sinclair and Lyon, 2005). The fungus survives as rhizomorphs and vegetative mycelium on and in the dead wood of tree stumps and roots. It has sometimes been found living several feet above the soil line on the trunk of trees several years after they are killed by *Armillaria*.

In late autumn, mushrooms may arise from the rhizomorphs and release millions of basidiospores which are carried by the wind to dead stumps or injured bark on living plants. Under favourable conditions of moisture and temperature, the basidiospores germinate and produce a mycelium that first infects the bark and then the sapwood and cambial regions. White mycelial mats develop on the sapwood, followed by the formation of rhizomorphs which can grow for distances of up to 3 m through the soil. Infection occurs when the mycelium comes in contact with and adheres to the roots of a susceptible host by means of a gelatinous secretion. The rhizomorph penetrates the root by a combination of mechanical pressure and enzymes that partially digest the root's cell walls and then grows into the root tissue between the cells. Once a host tree or plant has been invaded, the fungus continues to spread through the root and trunk tissues even several years after it has died; a large stump can support the growth of rhizomorphs for decades. Depending on environmental conditions and vigour, host trees or shrubs may die one to several years after the initial infection.



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Peeling back the bark of trees infected with *Armillaria mellea* exposes mycelial fans (L) and rhizomorphs (R)

SYMPTOMS AND DAMAGE

Since *Armillaria mellea* commonly inhabits the roots of host trees and plants, detection of this species and differentiation of aboveground symptoms from other root and trunk fungi is difficult. However the presence of characteristic mushrooms growing around the bases of host trees or obvious symptoms in the crown or on the lower stem help to identify this pathogen (Williams *et al.*, 1986).

Symptoms of *A. mellea* infestation include premature autumn colouration and leaf drop, stunting of growth, yellowing or browning of the foliage, a general decline in the vigour of the host tree or plant, and dieback of twigs, branches and main stems (University of Illinois Extension, 2000). Large, vigorous or lightly infected trees can develop crown symptoms over a number of years until the trees die while small, extensively infected or low vigour trees develop symptoms rapidly, foliage quickly discolours and the host tree often dies within a year (Williams *et al.*, 1986). Conifers frequently produce a larger cone crop (stress cones) shortly before they die. As host tree decline progresses, rotting of the buttress roots and the lower trunk becomes evident and severely infected trees exude resin, gum or a fermenting watery liquid from the lower trunk (University of Illinois Extension, 2000).

On conifers, lower stem infections appear as enlarged areas with large amounts of resin flow while on broadleaved trees they sometimes develop as sunken cankers covered with loose bark or a combination of bark, gum and other resins (Williams *et al.*, 1986). Root infections are frequently heavily coated with resin, soil and sometimes fungal tissue.

DISPERSAL AND INTRODUCTION PATHWAYS

Armillaria can live for decades in suitable live host material, stumps and root fragments, and can disperse naturally through the spread of rhizomorphs in the soil (Williams *et al.*, 1986). The movement of infected plants, trees and soil can spread the pathogen to new areas.

CONTROL MEASURES

Due to the worldwide distribution and wide host range of *Armillaria mellea*, eradication is not feasible. Control measures focus on limiting the buildup of the disease or reducing its impact (Williams *et al.*, 1986). Cultural practices, such as reforesting stands with a mixture of suitable, *Armillaria* free species, maintaining vigorous tree growth, minimizing tree stress, preventing tree damage, and reducing the availability of food by uprooting and burning infected or susceptible root systems and stumps, may help with managing *Armillaria* in commercial forests and urban landscapes (Williams *et al.*, 1986). Individual high value trees can be treated with fungicides around the base of infected stems or in holes left after trees have been uprooted (Williams *et al.*, 1986).

Botryosphaeria dothidea

Other scientific names: *Caumadothis dothidea* (Moug.) Petr.; *Dothiorella mali* var. *fructans* Dearn.; *Sphaeria dothidea* Moug.

Phylum, Order and Family: Ascomycota: Dothideales: Botryosphaeriaceae

Common names: Botryosphaeria canker

Botryosphaeria dothidea (Moug.) Ces. & De Not. (1863) is known in many parts of the world and is commonly associated with cankers and dieback on hundreds of different woody plants, including eucalypts. Eucalypt species are planted around the world which makes this species a major concern to the forest sector. This pathogen is an opportunistic pathogen that attacks stressed trees. The entire taxonomy of the genus *Botryosphaeria* has undergone changes in the last few years (see Crous *et al.*, 2006 for more information). This species was previously considered synonymous with *Botryosphaeria ribis*, so literature on both species is inextricably intertwined, but these are now considered two distinct species.



Cankers caused by *Botryosphaeria dothidea* on apple (*Malus sp.*) (L) and Leyland cypress (*X Cupressocyparis leylandii*) with bark removed (R)

DISTRIBUTION

Botryosphaeria dothidea has a worldwide distribution. The origin of this species is unknown although it has been suggested that it is native to the Northern Hemisphere since it occurs on native and cultivated hosts there (Slippers *et al.*, 2005).

IDENTIFICATION

A more detailed description of the morphology of *Botryosphaeria dothidea* can be found in Slippers *et al.* (2004), Crous *et al.* (2006) or CREM (2008).

Asci are produced in fruiting bodies called stroma that erupt through the bark and have multi-layered walls. The fruiting bodies occur singly or in clusters, often intermixed with conidiomata, and are 200 to 500 µm in diameter (Slippers *et al.*, 2004; Crous *et al.*, 2006). Asci have two layers (bitunicate) and the inner layer is quite thick.

They can be stalked or not stalked, club-shaped, with a well-developed apical chamber, eight-spored, septate and rarely branched toward the tip (Slippers *et al.*, 2004; Crous *et al.*, 2006). Ascospores are unicellular, hyaline, fusoid to ovoid and sometimes have tapered ends giving a spindle-shaped appearance (Slippers *et al.*, 2004; Crous *et al.*, 2006). Once germinated, they turn brown and become septate and even slightly bumpy (Crous *et al.*, 2006).

The pathogen is often diagnosed by the conidial state, *Fusicoccum aesculi* Corda. Conidiomata are flask-shaped and morphologically indistinguishable from the ascomata (Slippers *et al.*, 2004). Conidia are hyaline, unicellular, narrowly fusiform or irregularly fusiform with subtruncate to bluntly rounded bases, 23 to 25 μm in length and 4 to 5 μm in diameter and rarely have septums (Slippers *et al.*, 2004). Conidiogenous cells are holoblastic, hyaline, subcylindrical and 6 to 20 μm in length and 2 to 5 μm in diameter (Slippers *et al.*, 2004).

Spermatia are unicellular, hyaline, allantoid to rod-shaped and 3 to 6 μm in length and 1.5 to 2 μm in diameter (Slippers *et al.*, 2004). Spermatophores are hyaline, cylindrical to subcylindrical, 4 to 10 μm in length and 1 to 2 μm in diameter (Slippers *et al.*, 2004).



Crown thinning and dieback in American sycamore (*Platanus occidentalis*) and apple (*Malus sp.*) caused by *Botryosphaeria dothidea* infection

HOSTS

Botryosphaeria dothidea has a very wide host range of trees and shrubs. It is a major problem in planted forests particularly those planted with eucalypts, but susceptibility differs among the eucalypt species.

BIOLOGY

Botryosphaeria dothidea is an opportunistic pathogen that becomes more of a problem to stressed hosts. The pathogen infects through wounds or natural openings in the bark, and survives endophytically until the host becomes stressed by drought, late frosts, cold or hot winds, insect damage or pruning (TPCP, 2002a; Sinclair and Lyon, 2005).

Botryosphaeria dothidea overwinters in dead and infected stems. Spores are dispersed by wind, rain and possibly insects to new hosts where they germinate and invade the

host tissues. Pruning wounds are a common infection court. Fungal fruiting bodies produced just under the surface of stems release spores which spread to adjacent hosts. Except for a few weeks in winter, spores are released year-round although infections occur more frequently in early summer.



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Discolouration of the vascular tissue of American sycamore (Platanus occidentalis) caused by Botryosphaeria dothidea infection; only the light-coloured section (1/4) is alive

SYMPTOMS AND DAMAGE

Botryosphaeria dothidea causes dieback and canker in hundreds of woody plants and trees. On some hosts, only small twigs die, especially if the host is vigorous. Stressed trees may be unable to compartmentalize the infection, and the dieback progresses into larger branches and trunk.

In *Eucalyptus* spp. infection can result in the death of tree tops and a discolouration of the stem core which can extend throughout the tree (TPCP, 2002a). Stem and branch cankers are very serious symptoms of *B. dothidea* infection; the stems and branches often break at the site of the cankers (TPCP, 2002a).

DISPERSAL AND INTRODUCTION PATHWAYS

Spores are dispersed by wind, rain and possibly insects to new hosts. Movement of infected trees, plants and wood products is a possible pathway of introduction.

CONTROL MEASURES

Encouraging vigorous growth and reducing damage to susceptible host trees can help avoid infection by *Botryosphaeria dothidea*. Removal of pruned or fallen branches can reduce inoculum. Early detection and the planting of disease tolerant species or clones can help reduce losses in forest plantations (TPCP, 2002a).

Chrysoporthe cubensis

Phylum, Order and Family:: Ascomycota: Diaporthales: Incertae sedis

Common names: *Eucalyptus* canker; *Eucalyptus* canker disease

Chrysoporthe cubensis (Bruner) Gryzenhout & M.J. Wingfield, previously named *Cryphonectria cubensis* (Bruner) Hodges, is a widespread fungus well known for the canker disease it causes, particularly in *Eucalyptus* spp. The cankers result in limb and trunk breakages, stunted and distorted growth, and often mortality. This is a very important disease in eucalypt plantations as it is known to kill significant numbers of trees, particularly those in young plantations, and as a result it is a major constraint to the successful establishment of eucalypt plantations.



Fruiting bodies of Chrysoporthe cubensis: perithecia embedded in and protruding from bark removed from cankered tissues of Eucalyptus grandis

DISTRIBUTION

The geographic origin of this pathogen is unknown. The original host is thought to be clove (*Syzygium aromaticum*) which is native to Indonesia (Myburg, Wingfield and Wingfield, 1999). However, others have suggested that *C. cubensis* is native to South and Central America based upon its wide occurrence in the region, its high phenotypic diversity in various South America countries and the discovery of this pathogen on native *Miconia* species in Colombia (Gryzenhout *et al.*, 2006).

It is found throughout tropical and subtropical regions of the world including Brazil, Colombia, Cuba, Mexico, Suriname, Venezuela, United States (Florida, Hawaii, Puerto Rico), Cameroon, Democratic Republic of Congo, Republic of Congo, United Republic of Tanzania (Zanzibar), Australia, China, India, Indonesia, Malaysia, Singapore and Western Samoa (Gryzenhout *et al.*, 2004).

IDENTIFICATION

Detailed descriptions of the morphology of *Chrysoporthe cubensis* can be found in Gryzenhout *et al.* (2004) and Myburg *et al.* (2004).

Conidiomata of *Chrysoporthe cubensis* occur separately or on the top of an ascostroma and are distinguishable from ascomata by their pyriform shape, attenuated necks, conidiomatal locules and distinct stromatic tissue (Gryzenhout *et al.*, 2004). They are generally superficial, black, pyriform to globose with attenuated necks (Gryzenhout *et al.*, 2004; Myburg *et al.*, 2004). Conidiophores are hyaline and consist of a globular to rectangular basal cell that branches irregularly at the base or above into cylindrical cells (Gryzenhout *et al.*, 2004). Conidia are hyaline, non-septate, oblong, and secreted as bright spore tendrils or droplets (Gryzenhout *et al.*, 2004).

Ascomata are semi-immersed in the bark and are recognizable by extending, fuscous-black, cylindrical perithecial necks (Gryzenhout *et al.*, 2004; Myburg *et al.*, 2004). Ascstroma stand 120 to 230 µm above the level of bark and are 280 to 490 µm in diameter (Gryzenhout *et al.*, 2004). Ascospores are fusoid to oval with a septum that is usually central and tapered apices (Gryzenhout *et al.*, 2004; Myburg *et al.*, 2004).

HOSTS

Species from the Myrtaceae, Melastomataceae and Lythraceae families including *Syzygium aromaticum*, *Melastoma malabathricum*, *Lagerstroemia indica*, *Clidemia sericea*, *Rhynchanthera mexicana*, *Psidium cattleianum* and species of *Eucalyptus*, *Tibouchina* and *Miconia*.

BIOLOGY

Chrysoporthe cubensis infects trees through wounds, particularly at the bases of young trees. The most common method of infection is believed to be through asexual spores that are dispersed by rain splash although wind disseminated sexual spores are also common (TPCP, 2002b). Infection is favoured by warm temperatures and rainfall (Myburg, Wingfield and Wingfield, 1999). Lesions expand more rapidly in plants that are well-watered than in those where the soil or climate is relatively dry (Sinclair and Lyon, 2005).



Symptoms and damage caused by *Chrysoporthe cubensis* on *Eucalyptus grandis*: bark fissures at the base of infected tree (L) and advanced canker development (R)

SYMPTOMS AND DAMAGE

Chrysosporthe cubensis causes a canker disease which results in girdling of stems, limb and trunk breakages, stunted and distorted growth, wilting and often mortality (Gryzenhout *et al.*, 2004; Nakabonge *et al.*, 2006). This is a very important disease in eucalypt plantations as it is known to kill significant numbers of eucalypts, particularly those in young plantations. The cankers can be found at the bases of hosts or higher up on the trunks (Nakabonge *et al.*, 2006).

DISPERSAL AND INTRODUCTION PATHWAYS

The movement of infected plants and trees can spread the pathogen to new areas.

CONTROL MEASURES

Breeding for disease-tolerant eucalypt hybrids has been successful in managing the disease caused by *Chrysosporthe* spp. in some countries, such as Brazil and South Africa (Nakabonge *et al.*, 2006). Planting of disease tolerant eucalypts, and avoiding planting in high risk areas, can help reduce losses in plantations (TPCP, 2002b).

Mycosphaerella pini

Other scientific names: *Cytosporina septospora* Dorog.; *Dothistroma pini* Hulbary; *Dothistroma pini* var. *keniense* M.H. Ivory [as 'keniensis']; *Dothistroma pini* var. *lineare* Thyr & C.G. Shaw; *Dothistroma septosporum* (Dorog.) M. Morelet [as 'septospora']; *Dothistroma septosporum* var. *keniense* (M.H. Ivory) B. Sutton; *Dothistroma septosporum* var. *lineare* (Thyr & D.E. Shaw) B. Sutton; *Dothistroma septosporum* var. *septosporum* (Dorog.) M. Morelet; *Eruptio pini* (Rostr.) M.E. Barr; *Mycosphaerella pini* (A. Funk & A.K. Parker) Arx; *Scirrhia pini* A. Funk & A.K. Parker; *Septoria septospora* (Dorog.) Arx; *Septoriella septospora* (Dorog.) Sacc.

Phylum, Order and Family: Ascomycota: Capnodiales: Mycosphaerellaceae

Common names: pine needle blight; dothistroma needle blight; needle fungus; red band needle blight

Mycosphaerella pini Rostrup, 1957 is a fungus that infects and kills the needles of *Pinus* spp. resulting in significant defoliation, stunted growth and eventually death of host trees. It is a major pest in both naturally regenerated and planted forests and probably the most important foliage disease of exotic pines. Susceptibility among pine species does vary. The widely planted *P. radiata* is particularly susceptible and many forests planted with this species in the Southern Hemisphere, particularly in East Africa, New Zealand and Chile, have been devastated by this needle blight. This pathogen has forced managers in some areas to abandon the planting of *P. radiata* and depend more on other tree species.



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Red transverse bands on pine needles are a characteristic symptom of Mycosphaerella pini infection

DISTRIBUTION

Mycosphaerella pini is believed to be native to the cloud forests of Central America though it now has a worldwide distribution (EPPO/CABI, 1997).

IDENTIFICATION

Ascstromata are black, multiloculate, subepidermal, erumpent, 200 to 600 x 95 to 150 µm in size and densely aggregated in red bands (EPPO/CABI, 1997; Hildebrand, 2005).

Asci are cylindric or clavate, bitunicate, apex rounded, eight-spored, and 46 to 52 x 8 to 10 µm in size (Hildebrand, 2005). Ascospores are hyaline, with one septum, fusiform to cuneate, and 13 to 16 x 3 to 4 µm in size (Hildebrand, 2005).

The conidial state is known as *Dothistroma septosporum*. Conidial stromata are linear, subepidermal, erumpent, dark brown or black, 125 to 1500 µm long, 5 to 45 µm wide and up to 600 µm high (Hildebrand, 2005). Conidial locules are parallel to the longitudinal axis of stromata and lack a distinct wall (Hildebrand, 2005). Conidiophores are numerous, hyaline or amber, dense, unbranched and are approximately the same size as the conidia which they produce at their tips (Hildebrand, 2005). Conidia are hyaline, one- to five- but usually three-septate, blunt at the ends, straight, slightly curved or bent and 16 to 64 x 3.5 µm in size (Hildebrand, 2005).

HOSTS

The main hosts are pines, such as *Pinus contorta*, *P. echinata*, *P. jeffreyi*, *P. monticola*, *P. muricata*, *P. pinaster*, *P. ponderosa*, *P. radiata*, *P. resinosa*, and *P. sylvestris*, although other species such as *Picea abies*, *Picea sitchensis*, *Pseudotsuga menziesii* and *Larix decidua* have been infected (EPPO/CABI, 1997).

BIOLOGY

Mycosphaerella pini produces both conidia and ascospores although the conidial state is most frequently encountered (Hildebrand, 2005). Numerous conidia are produced in the stromata (fruiting bodies) which develop below the epidermis of infected needles (Peterson, 1982). Stromata can remain viable on dry infected foliage for many months and will produce conidia when suitable moist conditions arise (Hildebrand, 2005). Conidia are dispersed short distances by rain splash and longer distances by wind-dispersed moisture droplets, mist and low clouds (EPPO/CABI, 1997; Hildebrand, 2005). Optimum temperatures for spore germination are between 18 and 24 °C (Hildebrand, 2005). After germination, germ tubes grow toward the stomata through which infection occurs. The fungus grows within the needle tissue and kills cells with the toxin, dothistromin, in advance of the growing hyphae (Hildebrand, 2005). Dead needles remain attached to the host tree and produce spores for approximately one year (Hildebrand, 2005).

SYMPTOMS AND DAMAGE

Mycosphaerella pini is a fungus that infects and kills the needles of many *Pinus* spp. resulting in premature loss of needles and significant defoliation. Damage by *Mycosphaerella pini* has significant impacts on commercial forests, Christmas tree plantations and nurseries. This pathogen can spread rapidly when environmental conditions, mild climate with high rainfall or frequent fog or mist, favour infection.



Symptoms of *Mycosphaerella pini* infection on *Pinus nigra*

Infected host trees typically have thin crowns with discoloured and dead needles, especially on the lower crown (Hildebrand, 2005). Early symptoms are the presence of yellow to tan spots on needles which later turn brown or reddish brown and enlarge to produce the characteristic red band around the needle (Peterson, 1982; Hildebrand, 2005). These red bands are diagnostic for this disease and are caused by the presence of dothistromin, a toxin produced by *M. pini* (Hildebrand, 2005). The ends of infected needles eventually turn brown but the bases of the needles remain green (Peterson, 1982; Hildebrand, 2005). Small black fruiting bodies break through the needle epidermis in the centre of the red band (Hildebrand, 2005). Infected needles die and drop prematurely typically leaving branches with only terminal needles remaining (Hildebrand, 2005). Older needles are typically cast before younger needles. The development of epicormic shoots on the stem and major branches of infected host trees may also occur (EPPO/CABI, 1997). Host trees can be defoliated within weeks and successive years of infection results in stunted growth and eventual mortality.

DISPERSAL AND INTRODUCTION PATHWAYS

Mycosphaerella pini produces numerous conidia that can be dispersed short distances by rain splash; long distance dispersal is often through wind dispersed moisture droplets, mist and low cloud (EPPO/CABI, 1997; Hildebrand, 2005). Ascospores can also be wind-dispersed long distances.

Longer distance spread can occur through the movement of infected planting stock, seed mixed with small infected needle pieces and logs which have infected needles lodged in the bark crevices (EPPO/CABI, 1997; Hildebrand, 2005). Once the pathogen has been transported to new areas, it is capable of producing spores and thereby spreading to nearby suitable hosts as long as there is sufficient moisture for spore germination and infection (Hildebrand, 2005).

CONTROL MEASURES

Mycosphaerella pini has been successfully controlled through the use of copper fungicides although over large areas their use is not always economically feasible (EPPO/CABI, 1997; Hildebrand, 2005). In nurseries and Christmas tree plantings, however, fungicides can be effective and economical (Hildebrand, 2005). Pruning and the planting of less susceptible pine species or pest tolerant varieties can also help in the control of this pathogen (EPPO/CABI, 1997; Hildebrand, 2005).

Phytophthora ramorum

Phylum, Order and Family: Oomycota: Pythiales: Pythiaceae

Common names: sudden oak death (SOD); sudden oak death syndrome (SODS); ramorum blight; ramorum dieback; ramorum leaf blight; ramorum shoot blight

Phytophthora ramorum S. Werres, A.W.A.M. de Cock & W.A. Man in't Veld causes a very serious disease called sudden oak death which causes extensive mortality of tanoak and oaks. It is also associated with disease on ornamental plants and other broadleaf and conifer trees. This pathogen has been a significant problem in North American and European forests and nurseries.



Cankers and bleeding on coast live oak (*Quercus agrifolia*) resulting from *Phytophthora ramorum* infection

DISTRIBUTION

Native: The geographic origin of *P. ramorum* is unknown.

Introduced: It is believed that it has been introduced independently to Europe and North America from an unidentified third country.

North America: Canada (nursery report now eradicated); United States (14 counties in coastal California, one county in southwest Oregon)

Europe: Nursery reports only from Belgium, Denmark, France, Germany, Ireland, Italy, Norway, Poland, Slovenia, Spain, Switzerland, and Sweden; nursery as well as wildland reports from the Netherlands and the United Kingdom

IDENTIFICATION

In culture, *P. ramorum* hyphae are highly branched, contorted and dendritic (GISD, 2007). Chlamydospores are mostly terminal occurring on hyphal tips, 22 to 72 µm in length and at first are translucent but darken to a cinnamon brown colour (Kliejunas, 2001; GISD, 2007). Sporangia are oval-shaped, semi-papillate, deciduous and 30 to 90 µm in length (Kliejunas, 2001; GISD, 2007).

HOSTS

In the United States, *Phytophthora ramorum* attacks a variety of tree species including coast live oak (*Quercus agrifolia*), California black oak (*Q. kelloggii*), shreve oak (*Q. parvula* var. *shrevei*), canyon live oak (*Q. chrysolepis*) and tanoaks (*Lithocarpus densiflorus*) (Thomas, 2005). It is also known to infect several other plant and tree species such as Pacific madrone (*Arbutus menziesii*), poison oak (*Toxicodendron diversilobatum*), big leaf maple (*Acer macrophyllum*), coast redwood (*Sequoia sempervirens*), Douglas fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), rhododendron and azalea species (*Rhododendron*), Pacific huckleberry/evergreen huckleberry (*Vaccinium ovatum*), lingonberry (*V. vitis-idaea*), strawberry tree (*Arbutus unedo*), mountain laurel (*Kalmia latifolia*), manzanita (*Arctostaphylos manzanita*), English yew (*Taxus baccata*), dwarf rose (*Rosa gymnocarpa*), salmonberry (*Rubus spectabilis*), California coffeeberry (*Rhamnus californica*), cascara buckthorn (*Rhamnus purshiana*), beaked hazelnut (*Corylus cornuta*), Victorian box (*Pittosporum undulatum*), California buckeye (*Aesculus californica*), California bay laurel (*Umbellularia californica*), California honeysuckle (*Lonicera hispidula*), toyon/Christmasberry (*Heteromeles arbutifolia*), western starflower (*Trientalis latifolia*), *Syringa* spp., *Viburnum* spp., *Pieris* spp. and *Camellia* spp. (Kliejunas, 2001; EPPO, 2008).

In Europe, *P. ramorum* is mainly found on *Rhododendron* and *Viburnum* species, but has also been isolated from *Arbutus*, *Camellia*, *Hamamelis*, *Kalmia*, *Leucothoe*, *Pieris* and *Syringa* species (EPPO, 2008). In the United Kingdom, an isolated finding was reported on one *Quercus falcata* tree and on a few trees of *Fagus sylvatica*, *Quercus ilex*, *Q. cerris*, *Castanea sativa* and *Aesculus hippocastanum* (EPPO, 2008). In the Netherlands, infections on one *Q. rubra* and two *Fagus sylvatica* have been reported; all were located near infected *Rhododendron* (EPPO, 2008).

An updated list of *P. ramorum* hosts can be found on the USDA's Animal and Plant Health Inspection Service (APHIS) Web site at: www.aphis.usda.gov

BIOLOGY

Phytophthora ramorum exists as two separate mating types: the A1 mating type (found primarily in Europe); and the A2 type (found primarily in North America) (Kliejunas, 2001). Sexual reproduction can only occur if these two types come together.

Two types of asexual fruiting structures, sporangia and chlamydospores, are produced on the foliage of non-oak hosts (Kliejunas, 2005; DEFRA, 2005a). Infected oak produce few spores while other hosts such as bay laurel and tanoak produce prolific sporulation, and are believed important in the epidemiology of the disease. The sporangia hold and produce zoospores which can swim by means of flagellae. Warm temperatures of approximately 18 to 20 °C and/or a water film facilitate infection. Leaves and twigs then develop black lesions where, in conditions of very high humidity and moderate temperature, new sporangia and chlamydospores are produced typically within two days (GISD, 2007). Chlamydospores form inside the leaf tissue, and provide a resting/survival structure that remains viable in the organic material or soil for over one year. Infectious propagules accumulate in water bodies in the soil beneath the host (GISD, 2007). Infection of the main stems of tanoaks and oaks generally occurs only under high spore pressure, usually provided by nearby sporulation hosts, such as rhododendron or bay laurel (GISD, 2007).

SYMPTOMS AND DAMAGE

Symptoms vary depending on host type. On oaks and tanoak, infection results in stem bark lesions, basal cankers which produce reddish, black or dark brown sappy exudates ('bleeding'), and crown dieback (Kliejunas, 2001; Thomas, 2005). Cankers are typically found on the lower trunk, although they may occur up to 20 m above the ground; they do not extend into the roots below the soil line (Kliejunas, 2001).

Branch cankers also occur, especially on tanoak. On tanoak, infection of terminal twigs can lead to tip dieback, leaf flagging or the formation of shepherd's crooks (Kliejunas, 2001). Exudations do not always develop on tanoak, especially on smaller diameter branches. Infected host trees die relatively quickly once crown symptoms develop although the severity of damage varies considerably between sites. On other hosts, infection typically results in leaf lesions, small branch cankers, and stem and branch dieback (Kliejunas, 2001).



Symptoms of Phytophthora ramorum infection on tanoak (Lithocarpus densiflorus) and coast live oak (Quercus agrifolia)

DISPERSAL AND INTRODUCTION PATHWAYS

Phytophthora ramorum is dispersed locally by rain splash, wind-driven rain, irrigation or ground water, soil and soil litter (Kliejunas, 2001; DEFRA, 2005a). The deciduous nature of the sporangia opens the possibility for air dispersal. Bark and ambrosia beetles are commonly found on infected trees but their potential role of vectors has not yet been investigated (EPPO, 2008).

Spread over longer distances occurs through the movement of contaminated plant material, growing media and nursery stock as well as in soil carried on vehicles, machinery, footwear or animals (Kliejunas, 2001; DEFRA, 2005a).

CONTROL MEASURES

Trunk painting with Agri-Fos, a systemic fungicide, has effectively prevented infection on high value trees. This material provides some curative action, if the infection is not too far advanced. An active eradication program, requiring the removal of all host material with a buffer strip of 30 m has greatly reduced the spread of the pathogen in Oregon. In California, and in nurseries, the focus is on preventing the further spread through careful monitoring and detection methods and quarantine procedures.

In natural areas heavily infested with *P. ramorum* eradication is not feasible. Small infestations can be eradicated if the pathogen is detected early enough, by removing all infected or suspect host material, with a large buffer zone, treating

stumps to prevent resprouting, and broadcast burning to kill inoculum in the plant debris and leaf litter (COMTF, 2008). In nurseries, the application of fungicides, the planting of host resistant plants and cultural control methods such as pruning, destruction of affected plants, avoiding standing water and careful examination of plants can help to decrease the incidence of *P. ramorum* (DEFRA, 2005b; Benson, 2003).