EPPO Datasheet: *Fusarium circinatum*

Last updated: 2021-01-28

IDENTITY

Preferred name: *Fusarium circinatum*
Authority: Nirenberg & O'Donnell
Taxonomic position: Fungi: Ascomycota: Pezizomycotina: Sordariomycetes: Hypocreomycetidae: Hypocreales: Nectriaceae
Other scientific names: *Fusarium lateritium f. sp. pini* Hepting, *Fusarium subglutinans f. sp. pini* Hepting, *Gibberella circinata* Nirenberg & O'Donnell
Common names: pitch canker of pine
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EPPO Categorization: A2 list
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EU Categorization: Emergency measures, Quarantine pest ((EU) 2019/2072 Annex II B)
EPPO Code: GIBBCI



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HOSTS

Fusarium circinatum infects mainly *Pinus* spp. It has been reported to infect 106 different host species, including 67 Pinus species, 18 Pinus hybrids, 6 non-pine tree species, and 15 grass and herb species which are hosts under natural conditions or show symptoms after artificial inoculation (Drenkhan *et al.*, 2020). In North America, its main native hosts are *Pinus elliottii*, *P. palustris*, *P. patula*, *P. radiata*, *P. taeda*, *P. virginiana* and *P. muricata*. Host species are available throughout the European territory, including the European and Mediterranean species *Pinus halepensis*, *Pinus pinaster*, *Pinus sylvestris*, and various North American species planted in Europe such as *Pinus contorta* and *Pinus strobus*, and certain Asian species (e.g. *Pinus densi?ora*, *Pinus thunbergii*). There is an isolated record on *Pseudotsuga menziesii*, not apparently associated with any damage, while infection on *Larix* spp. is based on greenhouse data.

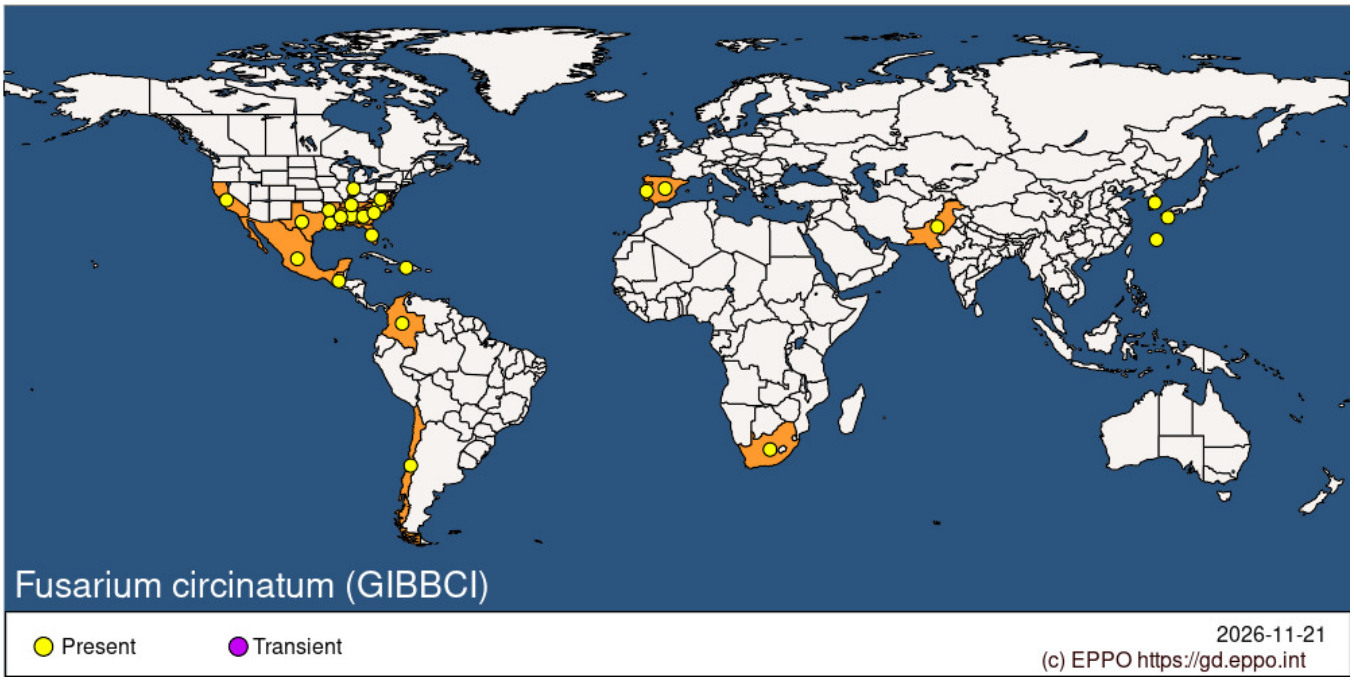
Host list: *Agrostis capillaris*, *Arrhenatherum longifolium*, *Briza maxima*, *Bromus carinatus*, *Centaurea decipiens*, *Cymbidium sp.*, *Ehrharta erecta*, *Holcus lanatus*, *Hypochaeris radicata*, *Lolium arundinaceum*, *Musa acuminata*, *Pentameris pallida*, *Pinus arizonica*, *Pinus armandii*, *Pinus attenuata*, *Pinus ayacahuite*, *Pinus canariensis*, *Pinus cembroides*, *Pinus contorta*, *Pinus coulteri*, *Pinus densiflora*, *Pinus discolor*, *Pinus douglasiana*, *Pinus durangensis*, *Pinus echinata*, *Pinus elliottii var. densa*, *Pinus elliottii var. elliottii*, *Pinus elliottii*, *Pinus glabra*, *Pinus greggii*, *Pinus halepensis*, *Pinus hartwegii*, *Pinus kesiya*, *Pinus leiophylla*, *Pinus luchuensis*, *Pinus maximinoi*, *Pinus montezumae*, *Pinus muricata*, *Pinus nigra*, *Pinus occidentalis*, *Pinus palustris*, *Pinus patula*, *Pinus pinaster*, *Pinus pinea*, *Pinus ponderosa*, *Pinus pringlei*, *Pinus pseudostrobus*, *Pinus radiata*, *Pinus rigida*, *Pinus sabiniana*, *Pinus strobus*, *Pinus sylvestris*, *Pinus taeda*, *Pinus tecunumanii*, *Pinus teocote*, *Pinus thunbergii*, *Pinus torreyana*, *Pinus virginiana*, *Pinus wallichiana*, *Pseudotsuga menziesii*, *Rubus ulmifolius*, *Sonchus oleraceus*, *Teucrium scorodonia*, *Zea mays*

GEOGRAPHICAL DISTRIBUTION

The origin and spread of *F. circinatum* are obscure. Older records from various parts of the world may be based on inadequate identification. Outside America, records in Japan, South Africa and Spain are considered to result from introductions. Based on genetic diversity indices, the fungus is probably native in North America, most likely Mexico (Wikler & Gordon, 2000), with further range expansion first in Eastern North America (Hepting and Roth, 1946) and then in the Western USA, specifically California (McCain *et al.*, 1987). The fungus has probably been moved around the world with pine planting stock, seedlings and especially infected seed. Until 2005, there have been no reliable records in the EPPO region. In Spain and Portugal, outbreaks were first detected in nurseries, and in

France it has been found in conifer seeds imported from the USA. In Northern Spain and some areas of Portugal, where the pest is now established, it has been found both in nurseries and in forest stands of *Pinus radiata*, *P. pinaster*, *P. nigra*, *P. pinea* and *P. sylvestris* (Landeras *et al.*, 2005, Pérez-Sierra *et al.*, 2007; Bragança *et al.*, 2009; EPPO, 2019a). The outbreaks in Italy (Carlucci *et al.*, 2007) and France (EPPO, 2006) have now been officially eradicated. Spanish populations are significantly differentiated and structured into two distinct groups suggesting two independent introductions (Berbegal *et al.*, 2013).

The world distribution of pitch canker is largely confined to Mediterranean and sub-tropical climates, with some extension into temperate climates, suitability tends to decrease from the coastal areas to the centre of Europe, being most suitable or optimal in parts of Northern and Eastern Spain, Central and Northern Portugal and the coastal areas of France, Italy and Greece (Ganley *et al.*, 2009; EFSA, 2010; Möykkynen *et al.*, 2015). In the EPPO region, host availability is not a limiting factor for the spread of *F. circinatum*, however the pathogen is reported to stop its growth and sporulation as temperatures approach zero Celsius. For this reason, it is presumed that areas with Mediterranean and warm Oceanic climates may be more favourable to the pathogen than continental climates.



EPPO Region: Portugal (mainland), Spain (mainland)
Africa: South Africa
Asia: Japan (Kyushu, Ryukyu Archipelago), Korea, Republic of, Pakistan
North America: Mexico, United States of America (Alabama, Arkansas, California, Florida, Georgia, Indiana, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Virginia)
Central America and Caribbean: Guatemala, Haiti
South America: Chile, Colombia

BIOLOGY

F. circinatum is a pathogen which is seed-borne, airborne and also found on insects. It can infect vegetative and reproductive parts at all ages of the host. In *Pinus halepensis* in California, the pathogen was found causing significant resin soaked cankers on the primary roots and root collars of planted adult trees (Garbelotto & Schweigkofler, 2007). It can also infect pine seeds internally or be present as a superficial contaminant (Barrows-Broaddus & Dwinell, 1985; Storer *et al.*, 1998, Elvira-Recuenco *et al.*, 2015), but it is not known how this infestation occurs. Seed-borne inoculum can infect and kill pine seedlings. Since perithecia have not been observed in nature, it is presumed that ascospores are not of great importance for infection of the host, however sexual reproduction may imply genetic recombination, which can lead to the emergence of strains with enhanced virulence. Most infection is by macroconidia and/or microconidia, carried by splashed rain, wind or insects. Bark-feeding insects (e.g. *Pityophthorus* sp., *Ips* sp., *Conophthorus* sp.) commonly breed in affected branches and emerging adults commonly

carry the pathogen although their vectoring potential is still undemonstrated, given that most papers prove phoresy and not vectoring (Brockerhoff *et al.*, 2016). Nonetheless it has been suggested that these insects may increase infection by wounding their hosts (Sakamoto & Gordon, 2005). Wound-associated infection is reported to be important, however a recent study demonstrated that *F. circinatum* is also able to colonize seedlings stem and tree branches that were artificially inoculated without wounds (Swett *et al.*, 2018). *F. circinatum* is mainly characterized by necrotrophic behaviour but also displays hemibiotrophic behaviour, being capable of living inside the host remaining symptomless in seedlings for more than a year and in the roots of mature trees (Elvira-Recuenco *et al.* 2015; Swett *et al.*, 2016; Hernandez-Escribano *et al.*, 2018a).

Moisture is required for an infection to occur, and infections appear to be associated with locations or seasons where atmospheric moisture is readily available and temperatures are relatively warm, such as in the South-Eastern USA during summer thunderstorms (Dwinell *et al*., 1985). In California, the disease is most severe in close proximity to the coast. The distribution of the disease also suggests that cooler temperatures are restrictive (Gordon *et al*., 2001). At moderate temperatures, the pathogen can survive for 1 year or more in infected wood, although new sporulation is greatly decreased or non-existent when trees are dead (Garbelotto *et al.*, 2008) The highest density of the aerial inoculum in Northern California was found during the warm (15-20 °C), rainy months of the year (Garbelotto *et al.* 2008), but sporulation stops as minimum temperatures approach freezing. It seems that the positive effect of temperature on spore germination is opposite to the effect on spore production in Galicia, Northern Spain (Dvorák *et al.*, 2017). In established infestations most new infections occur via microconidia (Schweigkofler *et al.* 2004).

DETECTION AND IDENTIFICATION

Symptoms

In seedlings, the pathogen typically rots the hypocotyl at or near the soil-line, so that the seedling collapses. Seedlings may also show necrosis, chlorosis, wilting and dieback. Seedlings may also be infected by soil-borne inoculum. In either case, the symptoms are not particularly distinctive, differing little from those caused by other damping-off pathogens. Root infections are most often observed on seedlings in nurseries or Christmas tree farms, but can also occur on exposed roots of larger trees in landscape plantings. In Christmas tree farms, the pathogen may extensively colonize the root system, causing a brown discoloration and disintegration of the cortex. Above-ground symptoms are generally not apparent until the pathogen has reached the root crown and girdled the stem (Garbelotto & Schweigkofler, 2007). This disease stage results in a uniform loss of colour in the foliage, which fades first to a dull green, then yellow and finally brown. Removal of the bark on the main stem near the soil-line may reveal resin-soaked tissue with a honey-brown to dark-brown discoloration (pitching).

Branches and stems of pine trees of any age may also be infected. Infection usually begins as a canker and dieback of small branches in the top or middle part of the tree. Needles wilt above the infection site becoming chlorotic, then turn red and brown and resin accumulates on the branch surface. Repetition of these symptoms throughout the canopy may lead to extensive dieback. Branch infection always precedes trunk infection, however, the trunk and larger branches may in due course be infected, producing copious amounts of resin and accelerating the decline of the tree. Girdling of the main stem may lead to death of the tree. Death of infected trees can be hastened by bark beetle attacks. In California, a significant percentage of *P. radiata* trees can recover, hence, the presence of canopies in clear remission among dead and dying canopies can also be taken as a stand-level trait associated with established outbreaks of itch Canker (Bonello *et al.*, 2001).

Morphology

In culture, *F. circinatum* produces macro- and microconidia (Nirenberg & O'Donnell, 1998). Macroconidia are typically 3-septate, with slightly curved walls, 32–48 × 3.3–3.8 µm, resembling those of numerous other anamorphs in the form-genus *Fusarium*. Microconidia, typically single-celled, ovoid (or nearly oval or allantoid), are borne in false heads on aerial polyphialides. The proliferation of microconidiophores, coupled with a slight twisting of the aerial mycelium on which they are borne, gives a distinctive colony morphology. Aerial mycelium is white or slightly violet. Colonies are frequently sectored. These characters do not clearly separate *F. circinatum* from other fungi with anamorphs of the *Fusarium subglutinans* group. The sterile hyphae (coiled or not distinctively coiled) are characteristic of *F. circinatum* and are observed clearly on Spezieller-Nährstoffarmer Agar (SNA) medium. The

epithet ‘circinatum’ refers to these typical coiled hyphae, also called ‘circinate’ hyphae (EFSA, 2010; EPPO 2019b). However recent studies show that coiled hyphae are not a fully reliable attribute for the diagnostic of the species (Vainio *et al.*, 2019). Perithecia are also readily produced in culture: dark purple to black, ovoid to obpyriform, 332–396–453 µm high and 288–337–358 µm wide (Britz *et al.*, 2002), asci are cylindrical, 88–100 × 7.5–8.5 µm, released by oozing; ascospores, 1-septate, are 8 per ascus and ellipsoidal to fusiform shaped. This description is close to that of many related species.

Detection and inspection methods

Since some pathogens cause symptoms very similar to *F. circinatum*, laboratory analysis should always be carried out to identify and confirm its presence. Correll *et al*. (1991) describe a suitable selective medium. The COST Action Field Guide of Pine Pitch Canker (2017) provides an overview of damage that is similar to the symptoms caused by *F. circinatum*. Sampling protocols for seeds, seedlings, twigs, branches, shoots, soil samples, spore traps and insects from different studies are collated and compiled by Vainio *et al.*, 2019 as well as morphological and molecular identification methods. Identification of *F. circinatum* from samples of *Pinus* spp. or *Pseudotsuga menziesii* (plant tissue or seeds), morphological and molecular methods are available also and described in detail in the IPPC Diagnostic Protocol (Annex 22) of ISPM 27 (FAO, 2017) and EPPO Diagnostic Protocol PM 7/91 (EPPO, 2019b). Molecular methods are the preferred methods for the identification of *F. circinatum* because of their sensitivity and accuracy. However, Ioos *et al.* (2019) highlighted that the use of protocols using conventional or real-time PCR outside their initial development and validation conditions should require careful characterization of the performance data prior to use under modified conditions.

A standard way of determining presence of the pathogen in an infested stand is that of performing tree bark spore washes followed by culturing on selective media: at that point identification can be done either by morphology or using molecular assays. Early detection based on symptoms is almost impossible in a forest stand, given the rarity of symptoms. Methods based on the trapping of spores on filter paper, followed by PCR-based detection performed directly on washes of the filter have proven to be among the most effective methods for early detection of the pathogen (Schweigkofler *et al.* 2004). This method has been employed with success by many national phytosanitary agencies around the world.

PATHWAYS FOR MOVEMENT

F. circinatum is spread locally by splashing water, wind and insects, but its rate of spread in newly infested areas does not appear to be very high. Garbelotto *et al.* (2008) report a distance of 2 km/year as the potential of spread in California, based on spore detection. In general, the natural spread of the pathogen may be limited due to the short dispersal distances of the spores and possibly by the fairly short flight distances of disseminating insects (Zamora-Ballesteros *et al.*, 2019).

Over long distances, *F. circinatum* can be carried by consignments of pine seeds or pine cones, or by plants for planting. In California, the pathogen was established in San Diego County tens of kms away from any known natural infestations due to the planting of young Aleppo Trees in a parking lot (Garbelotto *et al.*, 2007). These trees were about 10 years old when planted, and, at the time of planting, showed no obvious symptoms. The movement of infected Christmas trees has also been identified as significant pathway for the spread of the pathogen in California (Gordon *et al.*, 2001). The long distance (California to New Zealand) movement of the pathogen was detected and eradicated in a lot of Douglas-fir seedlings, indicating that movement of non-pine live hosts could effectively move the pathogen long distances. Interestingly, the nursery of origin was, at the time of discovery, outside the official zone of infestation by the pathogen (Vogler *et al.*, 2004).

One significant pathway for the medium and medium-to-long range dispersal of the pathogen has been identified in the use of contaminated tools and equipment, in the movement of infected green waste and possibly in the use of contaminated pots and potting racks. Soil has also been shown to be infectious at least for short periods of time (Swett and Gordon, 2013; Camilli *et al.*, 2013).

In principle, the pathogen could remain viable and be carried by infected wood, but this is most likely for particle wood made from small branches and their bark, in which spores of the fungus can survive. Round wood and sawn wood, especially if debarked, are less likely to carry the fungus. Additionally, in view of the substantial trade in pine wood, and the limited distribution of the fungus, the likelihood of a timber pathway of movement is low but not nil

(EFSA, 2010; Kopinga *et al.*, 2010). Wood packaging material made of coniferous wood also presents a risk because the wood used for packaging is usually of lower quality in terms of physical imperfections and presence of bark (Vainio *et al.*, 2019). Long-range dispersal through the movement of soil is unlikely as the fungus cannot survive for long periods in the soil (Nirenberg and O'Donnell, 1998; Serrano *et al.*, 2017). Numerous insect species that commonly occur in pine nurseries and forests throughout Europe and elsewhere have the potential to spread the fungus as either vectors, carriers or wounding agents. Most of the evidence is, however, circumstantial and ambiguous (Fernandez-Fernandez *et al.*, 2019)

PEST SIGNIFICANCE

Economic impact

F. circinatum is a chronic problem in the South-Eastern USA, where it affects pine production in plantations, nurseries (Barnard & Blakeslee, 1980) and seed orchards (Dwinell *et al*., 1981; Dwinell *et al*., 1985), but does not have significant impacts on native forests. It regularly adds to the cost of production but does not result in large financial losses in most years. Most southern pines are affected to some extent, including *P. taeda*, which typically sustains only minor damage and *P. elliottii*, which can be more severely affected. Major epidemics were reported for this species in Florida in the 1970s, with an estimated loss of between 0,4 and 0,9 million cubic meters annually in the period from 1974 through 1979 (Dwinell *et al*., 1985). However, in recent times, the use of less susceptible genotypes and changes in silvicultural techniques have greatly reduced the impact of the disease in the South eastern USA.

F. circinatum also occurs throughout the coastal regions of California, from San Diego in the south, to Mendocino County north of San Francisco (Gordon *et al.*, 2001) Since *F. circinatum* was introduced into California in 1986, it has caused damage and mortality of *P. radiata* in urban areas and in native forests. Costs of tree removal and replacement may eventually amount to several million USD in severely affected areas (Templeton *et al.*, 1997). Other *Pinus* spp. are also affected. In California, the disease has had a mild impact on all three native mainland stands of *P. radiata*. These represent the majority of the 5 native stands of this globally important pine species, hence this impact, even if limited, is of major concern. Pitch Canker has however had significant negative impacts on planted Monterey pines in urban settings, along roads, in golf courses and even in National Parks. It has also severely affected entire stands of *P. muricata* naturally regenerated after wildfires in Marin County (Swett and Gordon, 2013). Genetic diversity has been identified as an important aspect limiting damage by this pathogen (Aegerter *et al.* 2006), together with climatic (Garbelotto *et al.*, 2008) and ecological factors. The impact has also been significant in plant nurseries and Christmas tree farms in California (Gordon *et al.* 2001).

The disease is considered as one of the most important diseases of conifers globally (Wingfield *et al.*, 2008), Since its introduction into South Africa, *F. circinatum* has caused serious problems in seedling nurseries (Viljoen *et al*., 1994, 1995). The appearance of *F. circinatum* in plantations in Spain, South Africa, along with its presence in nurseries in Chile, substantially enhances this threat since these countries have large areas of *P. radiata*, and/or *P. patula*, both known to be very susceptible to the pathogen. In Europe, Spain has the largest area planted with this species (ca. 287 000 ha) which provides 25% of Spanish conifer timber. In Spain the disease is causing damage in forests and nurseries in five regions: Galicia, Asturias, Cantabria, País Vasco and Castilla y León. When dealing with native European species, Scots pine (*P. sylvestris*), *P pinaster* and Aleppo pine (*P. halepensis*) have been reported to be more susceptible than Austrian pine (*P. nigra*) and Italian stone pine (*P. pinea*) based on lab tests (Eneback & Stanosz 2003, Itturixta *et al.*, 2012, 2013), however in the Iberian peninsula where both the exotic P. *radiata* and the native *P. pinaster* have been exposed to the pathogen, damage is significant only on the exotic, while it is minor on the native one. In Japan, Pitch Canker has been reported from *Pinus luchuensis* (Muramoto and Dwinell 1990), while *P. densiflora* appears to be less susceptible based on lab tests (Kim *et al.* 2008)

Control

In the South-eastern USA, the *F. circinatum* problem is addressed by controlling the disease as far as possible in well managed seed nurseries, using less susceptible planting material, and preventing the spread of inoculum from infested areas by sanitary precautions (Dwinell *et al*., 1985). Chemical and biological control methods are ineffective or uneconomic, and have at present no particular role to play (except possibly seed treatment with fungicides).

Nurseries and Christmas tree farms should be carefully sited. Clean, preferably local, seeds should be used. Wounding and over-fertilization should be avoided. In general, good hygiene should be maintained, and precautions taken for movement of equipment and soil. In plantations, infected material (logs, firewood) should not be moved: chipping or debarking may be used to reduce the risk that the pathogen may bespread by insects. Insecticide use to limit spread by insects is not environmentally appropriate nor was it effective when tried (Swett & Gordon, 2013).

Disease resistance and tolerance are key elements for the control of the disease, and resistant clones of *P. radiata* are available for replanting in areas of California affected by the disease (Aegerter 2003). Likewise, very susceptible species should not be planted where risk of infection is high. -Large scale studies of American *Pinus* spp. (Hodge & Dvorak, 2000) have shown considerable differences among species in susceptibility. *P. radiata* and the close relatives *P. muricata* and *P. attenuata* are very susceptible, while pines of subsection Oocarpa were extremely resistant. Within *P. radiata*, variation in susceptibility has been observed in California populations of both planted and naturally regenerated trees (Storer *et al*., 1999, 2002), and similar variation is found among susceptible pine species from the southern USA: *P. elliottii* (Dwinell & Phelps, 1977) *P. taeda* and *P. virginiana* (Kelley & Williams, 1982; Kuhlman *et al*., 1982; Barrows-Broaddus & Dwinell, 1984). Based on lab tests, *P. echinata* and *P. virginiana* native to the Eastern USA are rather susceptible to the pathogen (Kim *et al.* 2008). The Mexican *Pinus patula*, widely used in South Africa is extremely susceptible, but other pine species from Mexico and their hybrids with *P. patula* are much less so (Mitchell *et al.* 2012).

If individual valuable amenity trees are affected, pruning with appropriate hygienic precautions can restore the value of the tree. In the case of isolated infected trees in an otherwise pest-free area, it may be more appropriate to remove and destroy the tree. In general, in affected areas, it is preferable to use trees other than *Pinus*, or less susceptible *Pinus* spp., in amenity plantings. For example, in California, several exotic pine species that are suitable for a Mediterranean climate and less susceptible than the native species (Gordon *et al*., 1998a,b) have been (should be? could be?) used.

Phytosanitary risk

F. circinatum has shown its capacity to spread to new areas on pine seedlings (California, Mexico, South Africa, Chile, Spain, Portugal, Japan). It could readily be further spread by international movement of infected *Pinus* seeds and seedlings. However, it could also be moved by international trade of non-pine seedlings as it has occurred for Douglas-fir (Vogler *et al.* 2004). In addition to pathogen sources outside the EPPO region, it should be clearly stated that the pathogen is also present within the EPPO region, and that these outbreaks represent a possible source for further movement of the pathogen within the EPPO region. The pathogen in fact was first reported in Asturias, Spai (Landeras *et al.*, 2005) and it has subsequently become established in restricted areas of northern Spain and Portugal (Iturritxa et 2013, Bragança *et al.*, 2009; EPPO, 2019). There have also been occurrences of *F. circinatum* in France and Italy, now reportedly eradicated (EPPO, online). The areas to which it has spread have Mediterranean-type climates, so that, within the EPPO region, the Mediterranean area is clearly at risk since *Pinus* spp. are widely planted there. However, oceanic warm regions such as the entire West Coast of the Iberian Peninsula, of France and of the British Isles and Ireland may also be at risk.

Pitch pine canker probably presents most danger to forest nurseries. Damage to plantations or native forests seem more likely to arise in cool and humid regions of Europe or in Mediterranean regions.

PHYTOSANITARY MEASURES

Quarantine regulations are crucial to minimize the risk of new introductions into disease-free countries. Seed lots should be tested using molecular methods already developed for *F. circinatum*. The cryptic presence of *F. circinatum* in pine seedlings or herbaceous plants (Hernandez-Escribano *et al.*, 2018b) could increase the risk of non-detection of infected material in pine nurseries which could lead to spread of the disease in the nursery and to forests and, consequently, increase the management costs (Vettraino *et al.*, 2018). Breeding for resistance appears to be the best option for control in the field (Martin-Garcia *et al.*, 2019) and other measures may be integrated for Pitch Canker control.

Since the first reported outbreaks of *F. circinatum* in 2005 in Spain, specific emergency measures were adopted to prevent the introduction into and the spread of *F. circinatum* within the EU. The emergency measures indicate that

the Member States shall conduct annual surveys for the presence of *F. circinatum*. These surveys should consist of visual examinations and if there is any suspicion of infection, the collection of samples and performance of tests. The emergency measures also enforce special requirements for the import and internal movement of some of the host plants and plant products of *F. circinatum* (EFSA 2020).

Seeds of *Pinus* sp. imported from countries where *F. circinatum* is present should be free from the pest. Seed-testing methods are presented by Anderson (1986), Correll *et al.* (1991) and ISTA (2020). There is a certain risk of introduction with soil but, in general, most EPPO countries prohibit the import of soil, and restrict the import of plants with soil (EPPO, 1994), from other continents. These measures should be effective against *F. circinatum*. Host plants for planting should be free from the pest. Seed and plants of other confirmed hosts from countries where the pest is present, in particular Douglas-fir should be screened as well, based on the precedent of an infected Douglas-fir seedling resulting in intercontinental movement of the pathogen (Vogler *et al.*, 2004).

Based on the experience in California, the discovery of infections in nurseries and/or in forest stands should trigger a whole suite of phytosanitary measures. In plant nurseries, the following should be implemented: soil exposed to inoculum should be pasteurized, growing containers should be sterilized, infected plants and plants within the same lot should be culled and autoclaved, raised planting beds and walkways should be disinfected. In forest stands, wood and foliage from cut trees should be burned or piled locally and not moved to different sites, while tools and equipment should be sterilized at the end of operations in each infected site. Approaches employed for sterilization, disinfection or sanitation of equipment/soil and destruction of infected plant material approaches may vary, as long as proven effective (Vettraino *et al.*, 2018).

REFERENCES

Aegerter BJ & Gordon TR (2006) Rates of pitch canker induced seedling mortality among Pinus radiata families varying in levels of genetic resistance to *Gibberella circinata* (anamorph *Fusarium circinatum*). *Forest Ecology and Management* 235, 14-7.

Aegerter BJ (2003) Pitch Canker: A technical review. UCANR Publications.

Anderson RL (1986) New method for assessing contamination of slash and loblolly pine seeds by *Fusarium moniliforme* var. *subglutinans. Plant Disease* 70, 452–453.

Barnard EL & Blakeslee GM (1980) Pitch canker of slash pine seedlings: a new disease in forest tree nurseries. *Plant Disease* 64, 695–696.

Barrows-Broaddus J & Dwinell LD (1984) Variation in susceptibility to the pitch canker fungus among half-sib and full-sib families of Virginia pine. *Phytopathology* 74, 438–444.

Barrows-Broaddus J & Dwinell LD (1985) Branch dieback and cone and seed infection caused by *Fusarium moniliforme* var. *subglutinans* in a loblolly pine seed orchard in South Carolina. *Phytopathology* 75, 1104–1108.

Berbegal M, Pérez-Sierra A, Armengol J & Grünwald NJ (2013). Evidence for multiple introductions and clonality in Spanish populations of *Fusarium circinatum*. *Phytopathology* 103(8), 851–861.

Bonello P, Gordon TR & Storer AJ (2001) Systemic induced resistance in Monterey pine. *Forest Pathology* 31, 99-106.

Bragança H, Diogo E, Moniz F & Amaro P (2009) First report of pitch canker on pines caused by *Fusarium circinatum* in Portugal. *Plant Disease* 93, 1079

Britz H, Coutinho TA, Wing?eld MJ & Marasas WFO (2002) Validation of the description of *Gibberella circinata* and morphological differentiation of the anamorph *Fusarium circinatum*. *Sydowia* 54, 9–22.

Brockerhoff EG, Dick M, Ganley R, Roques A, Storer AJ (2016) Role of insect vectors in epidemiology and invasion risk of *Fusarium circinatum*, and risk assessment of biological control of invasive *Pinus contorta. Biological Invasions* 18, 1177-90.

CABI/EPPO (1998) *Gibberella circinata*. *Distribution Maps of Plant Diseases No. 753*. CAB International, Wallingford (GB).

Camilli KS, Marshall J, Owen D, Gordon T & Wood D (2013) Pitch Canker Disease in California. Sacramento: California Department of Forestry and Fire Protection. *Tree Notes* 32

Carlucci A, Colatruglio L & Frisullo S (2007) First report of pitch canker caused by *Fusarium circinatum* on *Pinus halepensis* and *Pinus pinea* in Apulia (Southern Italy). *Plant Disease* 91(12), 1683.

Carter JW & Gordon TR (2020). Infection of the Native California Grass, *Bromus carinatus*, by *Fusarium circinatum* , the Cause of Pitch Canker in Pines. *Plant Disease* 104, 194-197

Correll JC, Gordon TR, McCain AH, Fox JW, Koehler CS, Wood DL & Schultz ME (1991) Pitch canker disease in California: pathogenicity, distribution, and canker development on Monterey pine (*Pinus radiata*). *Plant Disease* 75, 676–682

COST (European Cooperation in Science and Technology). Action FP1406 PINESTRENGTH (2017) Pine Pitch Canker Field Guide. Available online:

https://www.planthealthcentre.scot/sites/www.planthealthcentre.scot/files/inlinefiles/FieldGuidePitchCankerSept2017.pdf [Accessed: 15 September 2020]

COST Action FP1406 PINESTRENGTH (2017). Available online: http://www.pinestrength.eu/ (accessed on 10 October 2020).

Drenkhan R, Ganley B, Martín-García J, Vahalík P, Adamson K, Adam?íková K, Ahumada R, Blank L *et al.* (2020) Global Geographic Distribution and Host Range of *Fusarium circinatum*, the Causal Agent of Pine Pitch Canker. *Forests* 11, 724

Dvo?ák M, Janoš P, Botella L, Rotková G & Zas, R (2017) Spore Dispersal Patterns of *Fusarium circinatum* on an Infested Monterey Pine Forest in North-Western Spain. *Forests* 8, 432.

Dwinell LD, Barrows-Braddus JB & Kuhlman EG (1985) Pitch canker: a disease complex of southern pines. *Plant Disease* 69, 270–276.

Dwinell LD, Kuhlman EG & Blakeslee GM (1981) Pitch canker of southern pines. In: *Fusarium: Diseases, Biology, and Taxonomy* (Eds Nelson PE, Toussoun TA & Cook RJ), p. 457. Pennsylvania State University Press, University Park (US).

Dwinell LD & Phelps WR (1977) Pitch canker of slash pine in Florida. *Journal of Forestry* 75, 488–489.

EFSA (European Food Safety Authority) Panel on Plant Health (PLH): Risk assessment of *Gibberella circinata* for the EU territory and identification and evaluation of risk management options (2010) *EFSA Journal* 8(6), 1620.

EFSA, Kinkar M, Vos S (2020) Pest survey card on *Fusarium circinatum*. EFSA supporting publication 2020:EN-1842.

Elvira-Recuenco M, Iturritxa E & Raposo R (2015) Impact of seed transmission on the infection and development of pitch canker disease in *Pinus radiata*. *Forests* 6, 3353–3368.

Enebak SA & Stanosz GR (2003) Responses of conifer species of the Great Lakes region of North America to inoculation with the pitch canker pathogen *Fusarium circinatum Forest Pathology* 33, 333-8.

EPPO (1994) EPPO Standard PM 3/54 Growing plants in growing medium prior to export. Bulletin OEPP/EPPO Bulletin 24, 326–327.

EPPO (European and Mediterranean Plant Protection Organization) (2006) First Report of *Gibberella Circinata* in

France; EPPO Reporting Service; EPPO Global Database: Paris, France, p. 104.

EPPO (2019a) Update of the Situation of *Fusarium circinatum* in Portugal; EPPO Reporting Service; EPPO Global Database: Paris, France, p. 170.

EPPO (2019b) Diagnostic Protocol PM 7/91 (2). EPPO Global Database. Available online https://www.eppo.int/RESOURCES/eppo_standards/pm7_diagnostics (accessed on 7 October 2020).

Fernández-Fernández M, Naves, P, Witzell J, Musolin DL, Selikhovkin AV, Paraschiv M, Chira D, Martínez-Álvarez P, Martín-García J, Muñoz-Adalia EJ, Altunisik A, Cocuzza GEM, Silvestro SD, Zamora C, Diez JJ (2019) Pine Pitch Canker and Insects: Relationships and Implications for Disease Spread in Europe. *Forests* 10, 627.

Ganley RJ, Watt M, Manning L & Iturritxa E (2009) A global climatic risk assessment of pitch canker disease. *Canadian Journal of Forest Research* 39, 2246–2256.

Garbelotto M, Smith T & Schweigkofler W (2008) Variation in rates of spore deposition of *Fusarium circinatum*, the causal agent of pine pitch canker, over a 12-month-period at two locations in Northern California. *Phytopathology* 98, 137–143.

Garbelotto M, Schweigkofler W, Shaw D (2007) First report of *Fusarium circinatum*, causal agent of pitch canker disease, from the roots of mature Aleppo pines in California *Plant Health Progress*, 55.

Gordon TR, Okamoto D, Storer AJ & Wood DL (1998a) Susceptibility of ?ve landscape pines to pitch canker disease, caused by *Fusarium subglutinans* f. sp. *pini*. *Hortscience* 33, 868–871.

Gordon TR, Storer AJ & Wood DL (2001) The pitch canker epidemics in California. *Plant Disease* 85, 1128–1139.

Gordon TR, Wikler KR, Clark L, Okamoto D, Storer AJ & Bonello P (1998b) Resistance to pitch canker disease, caused by *Fusarium subglutinans* f. sp. *pini*, in Monterey pine (*Pinus radiata*). *Plant Pathology* 47, 706–711.

Hepting GH and Roth ER (1946) Pitch canker, a new disease of some southern pines. *Journal of Forestry* 44, 742–744.

Hernandez-Escribano L, Iturritxa E, Aragonés A, Mesanza N, Berbegal M. Raposo R & Elvira-Recuenco, M (2018a) Root infection of canker pathogens, *Fusarium circinatum* and *Diplodia sapinea*, in asymptomatic trees in *Pinus radiata* and *Pinus pinaster* plantations. *Forests* 9, 128.

Hernandez-Escribano L, Iturritxa E, Elvira-Recuenco M, Berbegal M, Campos JA, Renobales G, García I & Raposo R (2018b) Herbaceous plants in the understory of a pitch canker-affected Monterey pine plantation are endophytically infected with *Fusarium circinatum*. *Fungal Ecology*, 32, 65–71.

Hodge GR & Dvorak WS (2000) Differential responses of Central American and Mexican pine species and *Pinus radiata* to infection by the pitch canker fungus. *New Forests* 19, 241–258.

Ioos R, Fourrier C, Iancu G and Gordon TR (2009) Sensitive detection of Fusarium circinatum in pine seed by combining an enrichment procedure with a real-time polymerase chain reaction using dual-labeled probe chemistry. *Phytopathology* 99, 582–590.

Ioos R, Aloi F, Piskur B, Guinet C, Mullett M, Berbegal M, Bragança H, Cacciola SO, Oskay F, Cornejo C, Adamson K, Douanla-Meli C, Ka?ergius A, Martínez-Álvarez P, Nowakowska JA, Luchi N, Vettraino AM, Ahumada R, Pasquali M, Fourie G, Kanetis L, Alves A, Ghelardini L, Dvo?ák M, Sanz-Ros M, Diez JJ, Baskarathevan J & Aguayo J (2019) Transferability of PCR-based diagnostic protocols: an international collaborative case study assessing protocols targeting the quarantine pine pathogen Fusarium circinatum. *Scientific Reports* 9, 1–17.

IPPC (International Plant Protection Convention) (2017) Diagnostic Protocol (Annex 22) of ISPM 27 (FAO, 2017).

ISTA (International Seed Testing Association) (2020). 7-009: Detección de Fusarium circinatum en semillas de

Pinus spp. (pino) y Pseudotsuga menziesii. International rules for seed testing 7-009. Bassersdorf, Switzerland, ISTA.

Iturritxa E, Ganley RJ, Raposo R, García?Serna I, Mesanza N, Kirkpatrick SC, Gordon TR (2013) Resistance levels of Spanish conifers against *Fusarium circinatum* and *Diplodia pinea* 2013. *Forest Pathology* 43, 488-95.

Iturritxa E, Mesanza N, Elvira-Recuenco M, Serrano Y, Quintana E & Raposo R (2012) Evaluation of genetic resistance in *Pinus* to pitch canker in Spain. *Australasian Plant Pathology* 41 601–607.

Kelley WD & Williams JC (1982) Incidence of pitch canker among clones of loblolly pine in seed orchards. *Plant Disease* 66, 1171–1173.

Kim YS, Woo KS, Koo YB, Yeo JK (2008) Variation in susceptibility of six pine species and hybrids to pitch canker caused by *Fusarium circinatum*. *Forest Pathology* 38, 419-28.

Kopinga J, Moraal LG, Verwer CC & Clerkx APPM (2010). Phytosanitary Risks of Wood Chips; Alterra: Wageningen, The Netherlands.

Kuhlman EG, Dianis SD & Smith TK (1982) Epidemiology of pitch canker disease in a loblolly pine seed orchard in North Carolina. *Phytopathology* 72, 1212–1216.

Landeras E, García P, Fernández Y, Braña M, Fernández-Alonso O, Méndez-Lodcs S, Pérez-Sierra A, León M, Abad-Campos P, Berbegal M, Beltrán R, García-Jiménez J & Armengol J (2005) Outbreak of pitch canker caused by *Fusarium circinatum* on *Pinus* spp. in northern Spain. *Plant Disease* 89, 1015.

Martín-García J, Zas R, Solla A, Woodward S, Hantula J, Vainio EJ, Mullett M, Morales-Rodríguez C., Vannini A, Martínez-Álvarez P *et al.* (2019) Environmentally friendly methods for controlling pine pitch canker. *Plant Pathology* 68, 843–860.

McCain A, Koehler C, Tjosvold S (1987) Pitch canker threatens California pines. *California Agriculture* 41, 22-3.

Mitchell RG, Coutinho TA, Steenkamp E, Herbert M, Wingfield MJ (2012). Future outlook for *Pinus patula* in South Africa in the presence of the pitch canker fungus (*Fusarium circinatum*). *Southern Forests: A Journal of Forest Science* 74, 203-10.

Möykkynen T, Capretti P and Pukkala T (2015) Modelling the potential spread of *Fusarium circinatum*, the causal agent of pitch canker in Europe. *Annals of Forest Science* 72, 169–181.

Muramoto H & Dwinell LD (1990) Pitch canker of *Pinus luchuensis* in Japan. *Plant Disease* 7 4, 530.

Nirenberg HI & O'Donnell K (1998) New *Fusarium* species and combinations within the *Gibberella fujikuroi* species complex. *Mycologia* 90, 434–458.

Peréz-Sierra A, Landeras E, Leon M, Berbegal M, García-Jiménez J and Armengol J (2007) Characterization of *Fusarium circinatum* from *Pinus* spp. in northern Spain. *Mycological Research*, 832–839.

Pfenning LH, da Silva Costa S, Pereira de Melo M, Costa H, Ventura JA, Auer CG & dos Santos AF (2014) A First report and characterization of *Fusarium circinatum*, the causal agent of pitch canker in Brazil. *Tropical Plant Pathology* 39, 3.

Sakamoto JM & Gordon TR (2005). Factors influencing infection of mechanical wounds by *Fusarium circinatum* on Monterey pines (Pinus radiata). *Plant Pathology*, 55, 130–136.

Serrano Y, Iturritxa E, Elvira-Recuenco M and Raposo R (2017) Survival of *Fusarium circinatum* in soil and *Pinus radiata* needle and branch segments. *Plant Pathology* 66, 934–940.

Steenkamp ET, Rodas CA, Kvas M & Wingfield MJ (2012) *Fusarium circinatum* and pitch canker of *Pinus* in Colombia. *Australasian Plant Pathololog*y 41, 483–491.

Storer AJ, Bonello P, Gordon TR & Wood DL (1999) Evidence of resistance to the pitch canker pathogen (*Fusarium circinatum*) in native stands of Monterey pine (*Pinus radiata*). *Forest Science* 45, 500–505.

Storer AJ, Gordon TR & Clark L (1998) Association of the pitch canker fungus, *Fusarium subglutinans* f. sp. *pini*, with Monterey pine seeds and seedlings in California. *Plant Pathology* 47, 649–656.

Storer AJ, Wood DL & Gordon TR (2002) The epidemiology of pitch canker of Monterey pine in California. *Forest Science* 48, 694–700.Schweigkofler W, O'Donnell K, Garbelotto M (2004). Detection and quantification of airborne conidia of *Fusarium circinatum*, the causal agent of pine pitch canker, from two California sites by using a real-time PCR approach combined with a simple spore trapping method. *Applied and Environmental Microbiology*, 70, 3512-20.

Swett CL and Gordon TR (2012) First report of grass species (Poaceae) as naturally occurring hosts of the pine pathogen *Gibberella circinata. Plant Disease* 96, 908.

Swett CL and Gordon TR (2013) Pest Notes: Pitch Canker, UC ANR Publication 74107

Swett CL, Kirkpatrick SC and Gordon TR (2016) Evidence for a Hemibiotrophic Association of the Pitch Canker Pathogen *Fusarium circinatum* with *Pinus radiata*. *Plant Disease*,100, 79–84.

Swett CL, Reynolds GJ and Gordon TR (2018) Infection without wounding and symptomless shoot colonization of Pinus radiata by Fusarium circinatum, the cause of pitch canker. *Forest Pathology* 48, e12422.

Templeton SR, Wood DL, Storer AJ & Gordon TR (1997) Economic damages of pitch canker. *Fremontia* 25, 10–14.

Vainio EJ, Bezos D, Bragança H, Cleary M, Fourie G, Ghelardini MGL, Hannunen S, Ioos R, Martín-García J, Martínez-Álvarez P, Mullett M, Oszako T, Papazova-Anakieva I, Piškur B, Romeralo C, Sanz-Ros AV, Steenkamp ET (2019) Sampling and Detection Strategies for the Pine Pitch Canker (PPC) Disease Pathogen Fusarium circinatum in Europe. *Forests* 10, 723.

Vettraino AM, Potting R & Raposo R (2018) EU legislation on forest plant health: An overview with a focus on *Fusarium circinatum Forests* 9, 568.

Viljoen A, Wing?eld MJ, Kemp GHJ & Marasas WFO (1995) Susceptibility of pines in South Africa to the pitch canker fungus *Fusarium subglutinans* f. sp. *pini. Plant Pathology* 44, 877–882.

Viljoen A, Wing?eld MJ & Marasas WFO (1994) First report of *Fusarium subglutinans* f. sp. *pini* on pine seedlings in South Africa. *Plant Disease* 78, 309–312.

Vogler DR, Gordon TR, Aegerter BJ, Kirkpatrick SC, Lunak GA, Stover P, Violett P (2004) First report of the pitch canker fungus (*Fusarium circinatum*) in the Sierra Nevada of California. *Plant Disease* 88, 772.

Wikler K & Gordon TR (2000) An initial assessment of genetic relationships among populations of Fusarium circinatum in different parts of the world. *Canadian Journal of Botany*, *78*(6)709-717.

Wing?eld MJ, Jacobs A, Coutinho TA, Ahumada R & Wing?eld BD (2002) First report of the pitch canker fungus, *Fusarium circinatum*, on pines in Chile. *New Disease Reports*, Vol. 4 August 2001 – January 2002. http://www.bspp.org.uk/ndr/.

Wingfield MJ, Hammerbacher A, Ganley RJ, Steenkamp ET, Gordon TR, Wingfield BD, Coutinho TA.(2008) Pitch canker caused by Fusarium circinatum—A growing threat to pine plantations and forests worldwide. Australas. *Plant Pathology*, 37, 319–334.

Zamora-Ballesteros C, Diez JJ, Martín-García J, Witzell J, Solla A, Ahumada R, Capretti P, Cleary M, Drenkhan R, Dvo?ák M, Elvira-Recuenco M, Fernández-Fernández M, Ghelardini L, Gonthier P, Hernández-Escribano L, Ioos R, Markovskaja S, Martínez-Álvarez P, Muñoz-Adalia EJ, Nowakowska JA, Oszako T, Raposo R, Santini A and Hantula J, 2019. Pine Pitch Canker (PPC): Pathways of Pathogen Spread and Preventive Measures. *Forests*, 10, 1158.

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