DOI: https://doi.org/10.6092/issn.2531-7342/7817

Monilinia species of fruit decay: a comparison between biological and epidemiological data

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Abstract

The fungal genus *Monilinia* Honey includes parasitic species of *Rosaceae* and *Ericaceae*. The *Monilinia* genus shows a great heterogeneity, it is divided in two sections: *Junctoria*e and *Disjunctoriae*. These sections were defined by Batra (1991) on the basis of morphology, infection biology, and host specialization. *Junctoriae* spp. produce mitospore chains without disjunctors, they are parasites of *Rosaceae* spp.; *M. laxa*, *M. fructicola*, *M. fructigena* and recently *M. polystroma*, represent the principal species of the section, and they are responsible of economically important diseases of *Rosaceae*, new species such as *M. yunnanensis*, and *M. mumecola* could afflict European fruits in the future in absence of a strict phytosanitary control. The *Disjunctoriae* section includes species that produce mitospores intercalated by appendages (disjunctors); they parasitize *Rosaceae, Ericaceae*, and *Empetraceae*. The principal *Disjunctoriae* species are *M. vaccinii-corymbosi*, *M. urnula, M. baccarum, M. oxycocci*, and *M. linhartiana*. This study has the aim to underline the importance of *Monilinia* spp., and to describe their features.

Keywords: Monilinia spp; Junctoriae; Disjunctoriae; Prunus; Vaccinium

Riassunto

Il genere *Monilinia* Honey include diverse specie che attaccano in particolar modo le piante delle famiglie *Rosaceae* ed *Ericaceae*. *Monilinia* è un genere molto eterogeneo, infatti è suddiviso in due sezioni: *Junctoriae* e *Disjunctoriae*. Le due sezioni sono state definite da Batra (1991) sulla base della morfologia, della capacità infettiva e dell'ospite attaccato. La sezione *Junctoriae* è caratterizzata dalla produzione di catene di mitospore prive di setti di separazione fra una spora e l'altra. Essa comprende specie parassite di piante appartenenti alle *Rosaceae*. *M. laxa, M. fructicola*, *M. fructigena* e recentemente *M. polystroma*, appartengono a questa sezione e rappresentano la principale problematica fitosanitaria per drupacee e pomacee. Non vanno sottovalutate anche altre specie della sezione *Junctoriae* parassite del pesco e dell'albicocco, che al momento risultano essere presenti solo in Oriente: M. *yunnanensis* e *M. mumecola*. E' comunque necessario attuare severi controlli fitosanitari per evitarne la diffusione. La sezione *Disjunctoriae* include specie che producono mitospore intercalate da disgiuntori e che sono parassite di *Ericaceae, Rosaceae* ed *Empetraceae.* Le specie di *Monilinia* appartenenti a questa sezione sono *M. vaccinii-corymbosi*, *M. urnula, M. baccarum, M. oxycocci* e *M. linhartiana.* Questo lavoro ha lo scopo di sottolineare l'importanza delle specie di *Monilinia* e di descriverne le caratteristiche.

Parole chiave: Monilinia spp; Junctoriae; Disjunctoriae; Prunus; Vaccinium

DOI: https://doi.org/10.6092/issn.2531-7342/7817

Introduction

The genus *Monilinia* Honey includes several aggressive and economically important pathogens of the *Rosaceae, Ericaceae* and *Empetraceae.* They are present worldwide and affect in particular stone and pome fruits, and also berry fruits. These pathogens are often referred as "brown rot" agents. *Monilinia* spp. belong to the *Junctoriae* or *Disjunctoriae* section. These sections were defined on the basis of conidial morphology, fungal life cycle and host specialization (Batra, 1991).
M. fructicola, M. laxa, M. fructigena, M. polystroma, M. mumecola and *M. yunnanensis* constitute the *Junctoriae* section. They do not have disjunctors between the mature mitospores within the conidial chains. Other *Monilinia* species such as *M. oxycocci M. baccarum, M. urnula, M. vaccinii-corymbosi* and *M. linhartiana***,** have disjunctors, narrow barren separating cells. The endostromata occur in the young fruits, and the infection develops in the ovary chamber (Batra, 1991).
M. fructicola, M. laxa, M. fructigena and *M. polystroma* are well-known pathogens affecting rosaceous fruit production all over the world (Petroczy *et al*., 2012). The other species such as *M.* o*xycocc*i, *M. baccarum, M. urnula, M. vaccinii-corymbosi* inhabit *Vaccinium* hosts specially in North America. *M. fructicola* originates in America, Australia and New Zeland (EPPO/CABI, 2010). It was detected for the first time in French peach orchards (EPPO, 2002) and then in Spain (De Cal *et al*., 2009), Switzerland (Bosshard *et al*., 2006), Hungary (Petroczy and Palkovics, 2009), and Italy (Pellegrino *et al*., 2009; Montuschi *et al*., 2011; Marinelli *et al*., 2013) on peaches. This wide diffusion by *M. fructicola* could be related to sexual exchange for its ability to produce ascospores from mummified fruits (Byrde and Willets, 1977).
M. laxa is the most prevalent (85-90%) (Larena *et al.,* 2005) in Europe, but since *M. fructicola* was detected, in peach orchards both species easily can co-existed (Boehm *et al*., 2001; Villarino *et al*., 2013). These species can be distinguished for different growth characteristics. Nevertheless *M. laxa* remains a quarantine pathogen in China and in some areas of North America (Martini and Mari, 2014).
M. fructigena is prevalent on pome fruits, only 10% of isolates derived from stone fruits in Europe (Martini and Mari, 2014). *M. polystroma*, was found for the first time in Japan (Cotè *et al*., 2004) and later in Hungary (Petroczy and Palkovics, 2009), Czech Republic (EPPO, 2011), Italy (Martini e*t al*., 2014), and Croatia (Di Francesco *et al*., 2015). It shows similar morphological characteristics to *M. fructigena*. *M. mumecola* represents a new apricot pathogen that causes white rot; it resembles to *M. laxa*, but it differs from this and to the other brown rot fungi for conidia dimensions and colony characteristics (Harada *et al*., 2004).
Generally, *Monilini*a spp. hyphae differentiate melanised aggregates, the stromata (Holst-Jensen *et al*., 1997) which in early spring on mummified fruits could produce apothecia, the teleomorphic stage. The anamorphic stage is produced on infected leaves, blossoms, flowers and fruits.
Although the identification of *Monilinia* spp. has been based on morphological analysis, from '90s it was also realized by molecular diagnostics.
The objective of this review is to provide a deep analysis of *Monilinia* species, with respect to host specialization.

Taxonomy and morphology

Since 1928 the genus *Monilinia* belongs to the *Sclerotiniaceae* family, *Ascomycota*. These fungi are characterised by the apothecia originated from pseudosclerotia formed in mummified fruits or in debris. The apothecia are cup or disk-shaped with asci containing each eight ascospores. Apothecia are recorded more frequently in *M. fructicola* than *M. laxa*. (De Cal *et al*., 2014).
Monilinia spp. can also produced microconidia (spermatia), pyrose or globose no-germinative cells, may be involved in the fertilization process (Martini and Mari, 2014). The hyphae are septate, hyaline or variously pigmented: grey, tan, olive green or black. *Monilinia* species are difficult to distinguish because present

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similar life cycles, symptoms, and host range (Batra, 1991). They could be identified by morphological, and cultural characteristics, such as growth rate, growth pattern, colour, conidia and germ tube dimension (De Cal and Melgarejo, 1999).

As previously specified, Batra (1991) distinguished two section: *Disjunctoriae* and *Junctoriae*. The first includes most of *Monilinia* species with the characteristic mitospores intercalated by disjunctors (Holst-Jensen *et al*., 1997), and able of teleo and anamorphic reproduction. *Disjunctoriae* species could affect more than one host species, by vectors such as wind, rain, and insects (Batra, 1991).

The second section includes species that produce mitospores without disjunctors and no teleomorphic reproduction. These species affect principally *Rosaceae* hosts. Spores are dispersed by atmosphere factors and insects and produce the infection in pre or post ripening.

Monilinia taxonomic classification is complicated because this genus shares features with the *Sclerotinia* (Gjaerum, 1969; Penrose *et al*., 1976) and also *Ciboria* genera (Honey, 1936; Batra, 1991).

Disease cycle

The life cycle of brown rot diseases comprises the following three phases (Byrde and Willetts, 1977): (i) blossom blight and twig canker in early spring, (ii) brown rot in late spring and summer, and (iii) mummified fruits on trees and soil (Rungjindamai *et al*., 2014).

The pathogen overwinters in mummified fruits and twig cankers, and conidia from mummied fruits or ascospore from apothecia are blown on floral parts by wind, rain or insects.

The infected tissues turn dark and new masses of conidia are produced. The infection advances rapidly into blossoms and fruit spurs. Rot of fruits develops in clustered fruits, in fruit contact spots, and in insect or wind damaged fruits, under moist environmental conditions. The infection can remain latent until the fruit ripening. The pathogen quiescence capability and the brown rot incidence were often related to the fruit development stage (Lee and Bostock, 2007).

Latent infections present a typical pattern with the subcuticular infection of unripe fruit followed by the stop of the pathogen growth. As the fruit ripens, the fungal growth resumes resulting in post- harvest rot (Rungjindamai *et al*., 2014).

Monilinia spp. features

Monilinia laxa Aderhold & Ruhland

The disease caused by this fungus is usually known as European brown rot because it has been reported in almost all European countries. The disease is also present in Asia, America, Africa and Australia. In China and North America *M. laxa* is considered a quarantine pathogen.

Peach, apricot, plume, sweet cherry and sometimes apple are the principals *M. laxa* hosts. *M. laxa* shows on potato dextrose agar (PDA) at 22°C a lower growth (2-11 mm/24h) than *M. fructicola* (EPPO, 2002). The colony margin is lobed, and the sporulation is sparse, black rings and arcs associated with the formed rosette are visible in the bottom of the Petri dish. The stromata are greyish or hazel in colour (EPPO, 2002). Conidial size is 11.5-17 x 8-11 μm, and germ tubes are short and branching near spore (Martini and Mari, 2014). *S*ymptoms are visible since the blossom stage. *M. laxa* could cause on different parts of plant different disease known as: brown blossom bright, brown canker rot, twig blight, brown fruit rot. On blossoms the pathogen causes bud formation or petals fall; tissues become brown and necrotic. Blossoms seems to be the most susceptible in the phase of full bloom (Holb, 2008). Symptoms on fruits are small, circular, brown spots that under high temperatures and humidity completely invade tissues in a few days (Fig. 1.).

DOI: https://doi.org/10.6092/issn.2531-7342/7817

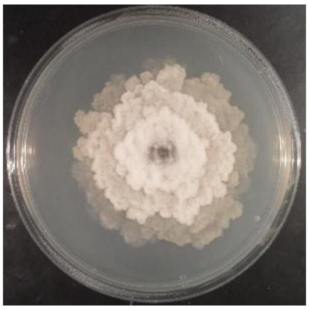

Fig. 1. *Monilinia laxa* strain (Criof Collection) grow on Potato Dextrose Agar (PDA).
Fig. 1. Ceppo di *Monilinia laxa* (Collezione Criof) allevato su substrato agarizzato PDA.

Monilinia fructicola Winter

M. fructicola is usually known as a North America fungus. It was also found in Asia and Oceania. In Europe is considered a quarantine pathogen by EPPO until 2001.
The species *Chaenomeles* Lindl., *Crataegu*s L., *Cydonia* Mill., *Eriobotrya* Lindl., *Malus* Mill., *Prunus* L. and *Pyrus* L. constitute only a part of the potential host plants of *M. fructicola* (EFSA, 2011). *M. fructicola* has a greater growth rate (9-20 mm/24h) respect to *M. laxa* on PDA at 22°C. The colony margin is entire and the sporulation is abundant, especially the production of microconidia. The stromata are greyish or hazelin in colour, with irregular crusts that may appear in old colonies (Fig.2.). The conidial and germ tube size are greater than those of *M. laxa* (14.5-16 x 9.5-11 μm) (Angeli *et al*., 2017).

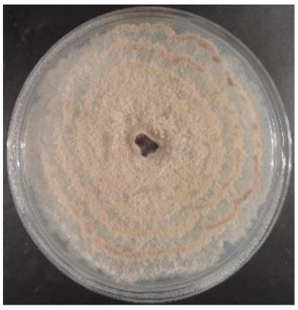

Fig. 2. *Monilinia fructicola* strain (Criof Collection) grow on Potato Dextrose Agar (PDA).
Fig. 2. Ceppo di *Monilinia fructicola* (Collezione Criof) allevato su substrato agarizzato PDA.

Symptoms are visible on blossoms, buds, branches, twigs and fruits. *M. fructicola* affects mainly fruits where the infection could remain latent if the environmental conditions are not favourable to the pathogen. The infection occurs through natural openings or during the ripening phase (Ogawa *et al*., 1995). Also young and immature fruits, especially peaches and plums, are very susceptible to this pathogen. Infected fruits that remain attached to the branches or fall to the soil, are the stroma substrate (mummies) where subsequently apothecia are formed.

Monilinia fructigena Aderhold & Ruhland

M. fructigena causes brown rot and blossom blight of stone and pome fruit trees worldwide. It has a more restricted distribution than the other species, it occurs in Europe and Asia, but not in North America. It is a quarantine pathogen in Canada, United States, Australia and New Zealand (USDA, 2010). Apple represents the principal *M. fructigena* host, but it was found also in peach, pear, sour cherry, plum and apricot (https://www.cabi.org/isc/datasheet/34747).

DOI: https://doi.org/10.6092/issn.2531-7342/7817

M. fructigena colonies show lower growth rate respect to the species mentioned above (Fig. 3.). Conidia are very large (17-21 x 10-13 µm) and form often two germs tube per conidia (van Leeuwen and van Kersten, 1998). Colonies are cream and yellow in colour, and could produce concentric rings with entire margins. The sporulation is less abundant respect to *M. fructicola*. Symptoms are rarely found on blossoms and twigs, they are more frequently found on fruits if the ripening phase is late.

The principal symptoms are the presence of circular and concentric brown spots on fruits. The pathogen is also known to be the cause of black rot, especially on fruits stored in the dark (Hrustic *et al*., 2012).

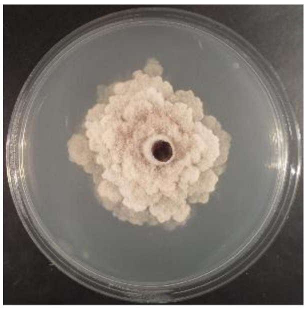

Fig. 3. *Monilinia fructigena* strain (Criof Collection) grow on Potato Dextrose Agar (PDA).
Fig. 3. Ceppo di *Monilinia fructigena* (Collezione Criof) allevato su substrato agarizzato PDA.

Monilinia polystroma van Leeuwen

M. polystroma has a more restricted distribution respect to *M. laxa* or *M. fructicola*; the pathogen was detected in Asia (China, Japan), and recently in Europe (Hungary, Serbia, Italy, Croatia, and Switzerland) (Petróczy and Palkovics, 2009; EPPO 2011; Vasić *et al.*, 2013, Martini *et al.* 2014, Di Francesco *et al.*, 2015). It causes a fruit rot on *Malus*, *Prunus*, *Pyrus* spp. and survives on mummified fruits.

M. polystroma colonies reach after 6 days on PDA at 20°C, 50-60 mm of diameter (Fig. 4.). Colony margins are regular, buff/pale luteous in colour (van Leeuwen *et al.*, 2002). The black stromata are firstly discrete but in time coalesce. Conidia are globose, ovoid or lemon shaped (12-21 x 8-12µm). The principal symptom is the presence of yellowish exogenous stromata on peaches, pears and apples 15 days after the ripening. The mantle of stromata formed by the host cuticle protects them against abiotic and biotic factors (van Leeuwen *et al*., 2002). Also under the field conditions, *M. polystroma* seems to colonize the fruits faster than *M. fructigena* (van Leeuwen *et al*., 2002) (Fif. 5.).

Fig. 4. *Monilinia polystroma* strain (Criof Collection) grow on Potato Dextrose Agar (PDA).
Fig. 4. Ceppo di *Monilinia polystroma* (Collezione Criof) allevato su substrato agarizzato PDA.

Fig. 5. *Monilinia polystroma* symptoms on *Cripps Pink* apple.
Fig. 5. Sintomi di *Monilinia polystroma* su mela *Cripps Pink*.

DOI: https://doi.org/10.6092/issn.2531-7342/7817

Monilinia yunnanensis Hu & Luo

M. yunnanensis is one of the *Monilinia* spp. detected in China on peaches. It is closely related to *M. fructigena* (Zhu *et al*., 2016). Colonies show regular margins with a daily growth of 8.5 mm, and are grey-green in coulor. After more than 10 days of incubation at 20°C, *M. yunnanensis* mycelium begins to develop stromata. Conidia are large and similar to those of *M. fructigena* (10–21×7–12 μm). *M. yunnanensis* produced indistinguishable symptoms from *M. fructigena* on peaches, and the lesions diameter on stone fruits reached 25.5 mm.

Monilinia mumecola Harada

M. mumecola is present only in Japan on Mume trees (*Prunus mume* Sieb. & Zucc.), a typical Japanese apricot. *M. mumecola* reaches its maximum mycelial growth (83 mm) at 20°C in 13 days (Harada *et al*., 2004). Colony is olive brown in colour, margins are slightly lobed, and the sporulation is scarce. The stromata on plates are greyish brown. Conidia are globose, sub-globose to broadly ellipsoid, hyaline (15-23 x 15-20 μm). The symptoms on infected fruits are a light brown rot, properly called "white rot" without sporodochia production (Harada *et al*., 2004).

Monilinia vaccinii-corymbosi Honey

M. vaccinii-corymbosi causes a serious disease of blueberry (*Vaccinium corymbosum*) in North America regions. In Europe it was firstly found in Austria (Gosch, 2003). The infection of open blueberry flowers, is followed by internal colonization and subsequent mummification of developing fruits. Symptoms consist of leaf and shoot blight. The highest incidence of infected shoots occurs on the lower part of canopy, more close to the soil. The blueberry fruits initially appear healthy, however they turn in dark bluish-purple colour. From late summer until early spring, the fungus overwinters as pseudosclerotia or "mummies" that produce apothecia which discharge the meiospores. Pseudosclerotia are dark brown, robust, hollow, distinctively ribbed, flattened and opened at both poles. Apothecia are reddish brown to umber, cup shaped with recurved margin when young. Ascospores are hyaline, ellipsoid measuring 15–19.2 μm x 8–10.7 μm. Macroconidia are observed in spring. They appear as a dense greyish covering on the convex side of bent current year twigs, on petioles, and along midribs of blighted leaves. Macroconidia are lemon shaped, hyaline, measuring 21.9–30.1 μm x 11.7 –15.3 μm (Munda, 2011). The colonies show a slow growth reaching 7-8 cm in diameter after 21 days at 20°C. The mycelium is white to beige in colour and compact, the reverse is brown, with yellow or honey pigmentation in some cultures. The production of macroconidia is scarce (Gosch, 2003).

Monilinia urnula Whetzel

This pathogen causes a disease of *Vaccinum vitis-idaea* called Mummy berry. It is widespread especially in Europe, mainly in Scandinavia, Austria and United Kingdom (Woronin, 1888; Dennis, 1968; Gjaerum, 1969;). It was reported also in Japan (Kobayashi, 2007). As *M. vaccinii-corymbosi* has a complicated life cycle. From harvesting time the mummies, compact masses of fungal tissue formed in infected berries, are found on the soil (Goheen, 1953).

Pseudosclerotia are reddish brown, hollow, open above and below. Apothecia could occurs in late spring depending on weather conditions, although were rare to find. They arose from mummified fruits (pseudosclerotia) that pass the winter in the field. Ascospores are hyaline, ellipsoid measuring 11.4 -15 μm x 5 –6.5 μm. Macroconidia are lemon shaped, hyaline measuring 25.6 –41.4 μm x 15.5 –27.5 μm. Mature macroconidia are separated by spindle like structures (disjunctors), firstly described by Woronin (1888) in *M. urnula,* and later found to be present in all species belonging to the *Disjunctoriae* section. The colonies on PDA are slow growing; at 25°C they reach 90 mm diameter in 21 days. Mycelium is white and beige on

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reverse, black stromata, buried in the agar medium, are observed in old colonies. Only microconidia are present especially in mature colonies. They are globose, hyaline, 2 -3 μm wide.

Monilinia baccarum Whetzel

M. baccarum is a pathogen of *Vaccinium myrtillus* L., typical of Scandinavia, Austria, Belgium, Germany and United Kingdom (Rehm, 1885; Woronin, 1888; Dennis, 1968; Gjaerum, 1969; Palmer, 1988; Batra, 1991). It causes the blight of newly emerging shoots; the infected berries turn pale, dry, shrivel, mummify and fall to the ground. They are called "white berries" due to the fine whitish layer of host cells that covers the berries (Batra, 1991).
Pseudosclerotia are light grey, sometimes greyish pink, apothecia are present from the end of May are dark brown. Ascospores are hyaline, ellipsoid measuring 14.5 –20.8 μm x 5.9 –7.3 μm. Macroconidia are lemon shaped, hyaline measuring 19–28 μm x 14 -21 μm, they are separated by disjunctors. The colonies are slow growing and reach the diameter of 50 mm in 21 days. The mycelium is white, greyish brown on reverse, black superficial stromata develop in old colonies.

Monilinia oxycocci Honey

M. oxycocci causes a disease of *Vaccinium macrocarpon* Ait. known as cranberry cotton ball . It is typical of Canada and North - East of United States.
The disease cycle includes both primary and secondary infection stages. In the spring as cranberry shoot growth resumes, pseudosclerotia germinate and produce apothecia. Ascospores infect young, succulent cranberry shoots. Conidia are carried by wind, or insects, to floral stigmata where secondary infection occurs. Conidia germinate on the stigma, germ tubes grow through the stylar canal, and white cotton-like mycelia fill the locules of developing fruit. The greatest numbers of conidia were produced at 16°C, but at 20°C conidia grow up better.The entire pericarp is colonized and develops into a pseudosclerotium in which the pathogen overwinters (Sanderson and Jeffers, 2001).
The colonies on PDA medium reach the diameter of 28 mm after 16 days at 20°C (Sanderson and Jeffers, 2001), the conidia production is generally low, less than 1000 conidia/ml, resulting similar to those of *M. fructigen*a.

Monilinia linhartiana Dennis

M. linhartiana represents the most important pathogen of quince fruits (*Cydonia oblonga* Mill.) in South of Spain, where it often destroys entire crops (Moral *et al.*, 2011). The life cycle of this pathogen is very similar to that of *M. vaccinii-corymbosi* on blueberry.
The *M. linhartiana* mycelium produces on fruits sporodochia with conidiophores and conidia arranged often in concentric zones. The conidia are one-celled, hyaline, lemon shaped. They have smooth walls and disjunctors, and are arranged in chains of up to 30 conidia (Pârvu and Pârvu, 2014).

Concluding remarks

Monilinia spp. are economically important pathogens, very difficult to control. The most studied *Monilinia* spp. are those responsible of the brown rot disease of stone fruit crops such as peach, apricot, apple, sweet and sour cherry (Tab. 1.). Brown rot disease is principally caused by *M. laxa*, *M. fructicola* and *M. fructigena* belonging to *Junctoriae* section.
This work focuses also on other *Monilinia* spp. less studied, because rare or restricted in their distribution (Munda, 2011), and responsible of less significant damage; the majority of these species belong to

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Disjunctoriae section. They need further studies to better understand their adaptive radiation in fungal speciation.

Between the *Disjunctoriae* spp., *M. urnula*, *M. baccarum*, *M. oxycocci* and *M. vaccinii-corymbosi* infect North America *Vaccinium* spp. causing a great economical impact on blueberry fruit production (Tab. 1.). Although morphological differences and host affinity, *M. oxycocci* and *M. vaccinii-corymbosi* are similar to *M. fructigena*; whereas *M. mumecola* is more closely related to *M laxa* on the base of symptoms on flowers and twigs of *Prunus* spp., cultural characteristics and sequence data in the ITS region of ribosomal DNA (Harada et al., 2004). Based upon comparison of sequence data for the ITS, glyceraldehyde-3-phosphate dehydrogenase (G3PDH) and β-tubulin genes and cultural characters (conidia size and stromatic tissue production), *M. yunnanensis* seems to be closely related to *M. fructigena* (Hu *et al*., 2011). Also *M. oxycocci*, *M. vaccinii-corymbosi* and *M. baccarum* that parasitize plants in the *Vaccinium* genus are similar to *M. fructigena* regarding endostromata structure.

Phylogenetic studies showed how these microorganisms could be genetically similar, and it represent a risk of high variability through their ability to adapt at different environmental conditions or sexual recombination (Holst –Jensen *et al*., 1997; Moral *et al*., 2011).

Tab. 1. Host affinity and morphological characteristics of *Monilinia* spp colonies.
Tab. 1. Pianta ospite e differenze morfologiche tra le specie di *Monilinia*.

Species	**Section**	**Host**	**Conidial dimension**	**Colony characteristicson nutrient medium**
M. fructicola	*Junctoriae*	Apple, peach pear	14.5-16 x 9.5-11 µm	Colour grey/hazel Entire margin and abundant sporulation
M. fructigena	*Junctoriae*	Pome and stone fruit	17-21 x 10-13 µm	Colour creamy/yellow Concentric rings with entire margin and not abundant sporulation
M. polystroma	*Junctoriae*	Peach, pear, apple	12-21 x 8-12 µm	Colour buff/pale Regular margin and black stromata
M. laxa	*Junctoriae*	Peach, apricot, plume, sweet cherry	11.5-17 x 8-11 µm	Colour grey/hazel Rosette with lobed margin and abundant sporulation
M. mumecola	*Junctoriae*	Mume (Japanese apricot)	15-23 x 15-20 µm	Colour olive/brown. Lobed margin, slightly sporulation
M. yunnanensis	*Junctoriae*	Peach	10–21 x 7–12 µm	Colour grey/green Regular margin and not abundant sporulation
M. linhartiana	*Disjunctoriae*	Quince fruit	10.5-17 x 8.5-11 µm	Colour white/grey Concentric zones with entire margin and not abundant sporulation
M. vaccinii-corymbosi	*Disjunctoriae*	Blueberry	15–19.2 x 8–10.7 µm	Colour white/beige with brown stromata, slight lobed margin and not abundant sporulation
M. baccarum	*Disjunctoriae*	Black raspberry	19–28 x 14-21 µm	Coulor white/greyish with black stromata, slight lobed margin and not abundant sporulation
M. urnula	*Disjunctoriae*	Cranberry	25.6–41.4 x 15.5–27.5 µm	Colour white/beige with buried black stromata, slight lobed margin. Only microconidia
M. oxycocci	*Disjunctoriae*	Cranberry	17-21 x 10-13 µm	Colour greyish, slight lobed margin. Not abundant sporulation

DOI: https://doi.org/10.6092/issn.2531-7342/7817

References

Angeli S.S., Amorim L. (2017). Comparative analysis of *Monilinia fructicola* and *M. laxa* isolates from Brazil: monocyclic components of peach brown rot. Ciencia rural, 47.

Batra L.R. (1991). World species of *Monilinia* (*Fungi*): their ecology, biosystematics and control. Mycologia Memoir, 16: 246.

Byrde R.J.W., Willets H.J. (1977). The brown rot fungi of fruit. Pergamon press, New York, 171.

Boehm E.W.A., Ma Z., Michailides T.J. (2001). Species-specific detection of *Monilinia fructicola* from California stone fruits and flowers. Phytopathology, 91: 428-439.

Bosshard E., Hilber-Bodmer M., Schärer H.J., Bünter M., Duffy B. (2006). First report of the quarantine brown rot pathogen *Monilinia fructicola* on imported stone fruits in Switzerland. Plant Disease, 90: 1554.

Côté M.J., Tardif M.C., Meldrum A.J. (2004). Identification of *Monilinia fuctigena*, *M. fructicola*, *M. laxa*, and *M. polystroma* on inoculated and naturally infected fruit using muliplex PCR. Plant Disease 88: 1219-1225.

Di Francesco A., Fruk M., Martini C., Jemric T., Mari M. (2015). First report of asiatic brown rot (*Monilinia polystroma*) on apple in Croatia. Plant Disease, 99: 1181.

De Cal A., Euguen B., Melgarejo P. (2014). Vegetative compatibility groups and sexual reproduction among ~~S~~spanish *Monilinia fructicola* isolates obtained from peach and nectarine orchards, but not *Monilinia laxa*. Fungal Biology, 118: 484-494.

De Cal A., Gell I., Usall J., Viñas I., Melgarejo P. (2009). First report of brown rot caused by *Monilinia fructicola* in peach orchards in Ebro Valley, Spain. Plant Disease, 93: 763.

De Cal A., Melgarejo P. (1999). Effects of long-wave UV light on *Monilinia* Growth and Identification of Species. Plant Disease, 83: 62-65.

Dennis R.W.G. (1968). British Ascomycetes. Lehre, Cramer, 445.

European Food Safety Authority (2011). Pest risk assessment of Monilinia fructicola for the EU territory and identification and evaluation of risk management options. European Food Safety Authority Journal, 9: 2119.

European and Mediterranean Plant Protection Organization (2002). First report of Monilinia fructicola in France. European and Mediterranean Plant Protection Organization Reporting Service 2002/003.

European and Mediterranean Plant Protection Organization (2011). https://gd.eppo.int/taxon/ MONIPO/ distribution/PL.

European and Mediterranean Plant Protection Organization/ European and Mediterranean Plant Protection Organization (2010). Monilinia fructicola. Distribution Maps of Plant Diseases, Map No. 50, Edition 8. CAB International, Wallingford, UK.

Gjaerum H.B. (1969). Some fruit inhabiting *Sclerotinias* in Norway. Friesia, 9: 18-28.

Goheen A.C. (1953). The cultivated highbush blueberry. U.S. Dept. Agr. Yearbook of Agriculture, 1953: 784-789. HALL.

Gosch C. (2003). *Monilinia vaccinii-corymbosi* on high bush blueberries (*Vaccinium corymbosum* L.): also in Europe. European Journal of Horticultural Science, 68: 238–241.

Harada Y., Nakao S., Sasaki M., Sasaki Y., Ichihashi Y.,Sano T. (2004). *Monilia mumecola*, a new brown rot fungus on *Prunus mume* in Japan. Journal of General Plant Pathology, 70: 297–307.

Holb I.J. (2008) Monitoring conidial density of *Monilinia fructigena* in the air in relation to brown rot development in integrated and organic apple orchards. European Journal of Plant Pathology, 120: 397–408

Holst-Jensen A., Kohn L.M., Schumacher T. (1997). Nuclear rDNA Phylogeny of the *Sclerotiniaceae*. Mycologia, 89: 885-899.

Honey E.E. (1936). North American species of *Monilinia*. I. Occurrence, grouping, and life-histories. American Journal of Botany, 23: 100-106.

Hrustic J., Mihajlović M., Tanović B., Delibašić G., Stanković I., Krstić B., Bulajić A. (2012). First Report of brown rot caused by *Monilinia fructicola* on nectarine in Serbia. Plant Disease, 97: 147.

Hu M.J., Cox K.D., Schnabel G., Luo C.X. (2011). *Monilinia* species causing brown rot of peach in China. Plos one, https://doi.org/10.1371/journal.pone.0024990.

Kobayashi T. (2007). Index of fungi inhabiting woody plants in Japan. Host, Distribution and Literature. Kyoiku, Kyokai Publishing Co., 1227.

Larena I., Torres R., De Cal A., Liñan M., Melgarejo P., Domenichini P. (2005). Biological control of postharvest brown rot (*Monilinia* spp.) of peaches by field applications of *Epicoccum nigrum*. Biological Control, 32: 305-310.

Lee M.H., Bostock R.M. (2007). Fruit exocarp phenols in relation to quiescence and development of *Monilinia fructicola* infections in *Prunus* spp.: A Role for Cellular Redox? Phytopathology, 97: 269-277.

Marinelli E., Vitale S., Valente M.T., Riccioni L. (2013). Segnalate in Lazio infezioni di *Monilinia fructicola* su drupacee. Informatore agrario, 2: 55-57.

Martini C., Lantos A., Di Francesco A., Guidarelli M., D'Aquino S., Baraldi E. (2014). First Report of Asiatic Brown Rot Caused by *Monilinia polystroma* on Peach in Italy. Plant Disease, 98: 1585.

Martini C., Mari M. (2014). *Monilinia fructicola*, *Monilinia laxa (Monilinia* rot, Brown rot). Postharvest decay-control strategies, Academic Press, 233-265.

Montuschi C., Ceredi G., Mari M. (2011). *Monilia fructicola* è arrivata anche in Emilia-Romagna. Agricoltura, 90-92.

Moral J., Muñoz-Díez C., Cabello D., Arquero O., Lovera M., Benítez M.J., Trapero A. (2011). Characterization of *Monilia* disease caused by *Monilinia linhartiana* on quince in southern Spain. Plant Pathology, 60: 1128–1139.

Munda A. (2011). *Monilinia* pathogens of cultivated *Vaccinium* species in Slovenia. Acta agricolturae Slovenica, 97: 99-104.

Ogawa J.M., Zehr E.I., Bird G.W., Ritchie D.F., Uriu K., Uyemoto J.K. (1995). Compendium of stone fruit diseases, APS, St. Paul, MN, 98.

Palmer J.T. (1988). Investigations into the *Sclerotiniaceae.* Lejunia , 127: 1–40.

Pârvu M., Pârvu A.E. (2014). Parasitic fungi *Sclerotiniaceae*: morphology and ultrastructure. Microscopy: advances in scientific research and education (A. Méndez-Vilas, Ed.), 530-537.

Pellegrino C., Gullino M.L., Garibaldi A., Spadaro D. (2009). First Report of brown rot of stone fruit caused by *Monilinia fructicola* in Italy. Plant Disease, 93: 668.

Penrose L.J., Tarran J., Wong A.L. (1976). First record of *Sclerotinia laxa* Aderh. & Ruhl. in New South Wales: differentiation from *S. fructicola* (Wint.) Rehm. by cultural characteristics and electrophoresis. Journal of Agriculturtal Research, 27: 547–55.

Petróczy M. and Palkovics L. (2009). First report of *Monilia polystroma* on apple in Hungary. European Journal of plant Pathology, 125: 343-347.

Petroczy M., Szigethy A., Palkovic L. (2012). *Monilinia* species in Hungary: morphology, culture characteristics, and molecular analysis. Trees, 26: 153–164.

Rehm H. (1885). Ascomyceten: *Sclerotinia baccarum*. Fasc. XVI. Hedwigia, 24: 7-17.

Rungjindamai N., Jeffries P., Xu X.M. (2014). Epidemiology and management of brown rot on stone fruit caused by *Monilinia laxa.* European Journal of Plant Pathology, 140: 1-17.

Sanderson P.G., Jeffers S.N. (2001). Vegetative growth and conidium production by *Monilinia oxycocci* in vitro. Mycologia, 93: 9-16.

United States department of agriculture (2010). Asian/European brown rot of Rosaceae - Monilinia fructigena. https://nt.ars-grin.gov/taxadescriptions/factsheets/index.cfm?thisapp=Moniliniafructigena

van Leeuwen G.C.M., Baayen R.P., Holb I.J., Jeger M.J. (2002). Distinction of the Asiatic brown rot fungus *Monilia polystroma* sp. nov. from *Monilia fructigen*a. Mycological Research, 106: 444–451.

DOI: https://doi.org/10.6092/issn.2531-7342/7817

van Leeuwen G.C.M., van Kersten H.A. (1998). Delineation of the three brown rot fungi of fruit crops (*Monilinia* spp.) on the basis of quantitative characteristics. Canadian Journal of Botany, 76: 2042–2050.

Vasić M., Duduk N., Ivanović M.S. (2013). First Report of Brown Rot Caused by *Monilia polystroma* on Apple in Serbia. Plant Disease, 97: 145.

Villarino M., Egüen B., Lamarca N., Segarra J., Usall J., Melgarejo P., De Cal A. (2013). Occurrence of *Monilinia laxa* and *M. fructigena* after introduction of *M. fructicola* in peach orchards in Spain. European Journal of Plant Pathology, 137: 835-845.

Woronin M. (1888). Uber die Sclerotienkrankheit der Vaccinieen-beeren. Mem. Acad. Imp. Sci. St. Petersbourg VII, 36: 1-49.

Zhu X.Q., Niu C.W., Chen X.Y., Guo L.Y. (2016). *Monilinia* species associated with brown rot of cultivated apple and pear fruit in China. Plant Disease, 100: 2240-2250.