

Chapter 2

Morphology and Ultrastructure of *Piriformospora indica*

Gerhard Kost and Karl-Heinz Rexer

2.1 History

The first finding of the fungus *Piriformospora indica* is like it happened sometimes in science; when you want to investigate and solve an unclear problem, you reveal another new phenomenon. During a routine isolation of AM fungi in the desert Thar (Rajasthan, India), *P. indica* was isolated for the first time from the rhizospheres of *Prosopis juliflora* (Schwartz) DC. and *Ziziphus nummularia* (Burm. fil.) Wt. & Arn. as a contaminant (Verma et al. 1998). Some AM spores of *Glomus mosseae* were picked from these roots. At the first superficial view, this spore looked very similar to some vesicular spore-types of Glomerales. It seems that the isolated spore is a vesicle of an AM fungus and belongs to a fungus of the Glomeromycota. But this spore was well growing on artificial complex media. Therefore this species could not be a member of the Glomeromycota because Glomeromycota are growing in biotrophic interaction with plants only. A detailed ultrastructural and molecular genetic analysis (Verma et al. 1998) elucidated, that the systematic position of this species is in the lower Agaricomycotina (Basidiomycota). It was necessary to describe the isolated fungus as a new species of the order Sebaciniales, Basidiomycota. Because of the pear-like form of the spores and the geographic origin of the first collection of this fungus, we selected the name *P. indica* (Verma et al. 1998; Varma et al. 1999, 2001).

First experiments with *P. indica* revealed that the cocultivation of the fungus together with young maize seedlings causes a strong support for the growth of their shoots. Further experiments using a broad spectrum of interacting plants documented a broad growth-supporting effect of *P. indica*. Several studies revealed the different ways of the interaction between the mycelium and the host plant.

G. Kost (✉) • K.-H. Rexer

Philipps University of Marburg, FB Biology, Systematic Botany and Mycology, Karl-von-Frisch
Str. 8, 35032 Marburg, Germany

e-mail: kost@biologie.uni-marburg.de; rexer@biologie.uni-marburg.de

A deeper knowledge about the morphological structures of *P. indica* is necessary and important for a better understanding of the biology of this fungus and its interactions. This species is very important for basic science and technology and it has a broad spectrum of applications in agriculture and biotechnology. After the description of *P. indica*, many scientific projects have been started. Recently a new species, *Piriformospora williamsii*, of the genus *Piriformospora* was described (Basiewicz et al. 2012).

After 15 years of intensive investigations in several labors around the world, much information is revealed about this fungus. Now it is obvious that *Piriformospora* is a model species in science, but additionally it is also a very important and useful one for application in biotechnology and agriculture.

In this chapter, the morphological and ultrastructural data about this member of the Sebaciales—*P. indica*—is collected from own studies, and others are compiled from literature to give a complete overview about this quite interesting fungus.

2.2 Morphological Structures

Until now no fruit bodies and no basidia are found formed by the mycelium within the cultures. The propagation of *P. indica* is only done by chlamydospores or by mycelium.

2.2.1 Hyphal Cells

The hyphal cells of *Piriformospora* are thin walled, and they are always hyaline and not pigmented. They have an obvious small diameter in comparison to other hyphal types of the Basidiomycota. The dimensions of the hyphae strongly depend on the culture conditions. In water agar or under low nutrient conditions, the hyphal cells are very long and extremely small. Cultivating *Piriformospora* in complex media, the hyphal diameter ranges from 0.6 μm up to 3.5 μm . The hyphal length in MOM-agar is (10) 12–18 μm (20) but in water agar the hyphal cells can obtain a length of 50 μm and more. The form of the hyphae is tubular but very often the hyphae are strongly moniliform. The hyphae are regularly septated but the number of nuclei per cell is not fixed. The hyphal cells are multinucleate. There is no formation of clamp connection at the septa. Sometimes the hyphae are coiled in several layers. It is not rare that the hyphae are interconnected by several anastomoses.

Within the hyphal cells, the highest number of observed nuclei was up to 8, but in the most case, 2–6 nuclei per cell only. The single nucleus is regularly distributed within the hyphal cell. In the apical, hyphal-tip, cell, only one nucleus was observed mostly. Because no conjugated nuclei (dicaryon) could be examined within the hyphae, the nuclear stages of the hyphal cells were considered to be haploid.

But actual molecular studies revealed that *P. indica* is heterokaryotic (Zuccaro et al. 2009, 2011).

2.2.2 Mycelium

Piriformospora indica can be cultured on several synthetic and complex media; it grows under solid and liquid culture conditions. The morphology of the mycelium strongly varies depending on the composition of the nutrients of the culture medium and the conditions of cultivation (solid or liquid media). The mostly used media for *P. indica* is MYP and MA. Most of the mycelium of *P. indica* grows under the surface of the agar media. Using solid culture media, only few aerial hyphae are formed. The mycelium grows concentric and covers the agar media homogenously. Sometimes the mycelium forms rhythmic rings in the petri dishes. Young mycelium cultures are white but in age the color turns to cream yellow. The structure of the mycelium is homogenous, no specialized hyphae could be observed, but some hyphae are arranged in coils. The patterns of the hyphal ramification are regular with the branching of acute and up to 90° angled hyphae. In submerse shaking cultures the mycelia are conglomerated to small wadding like globose balls (see Fig. 2.3a).

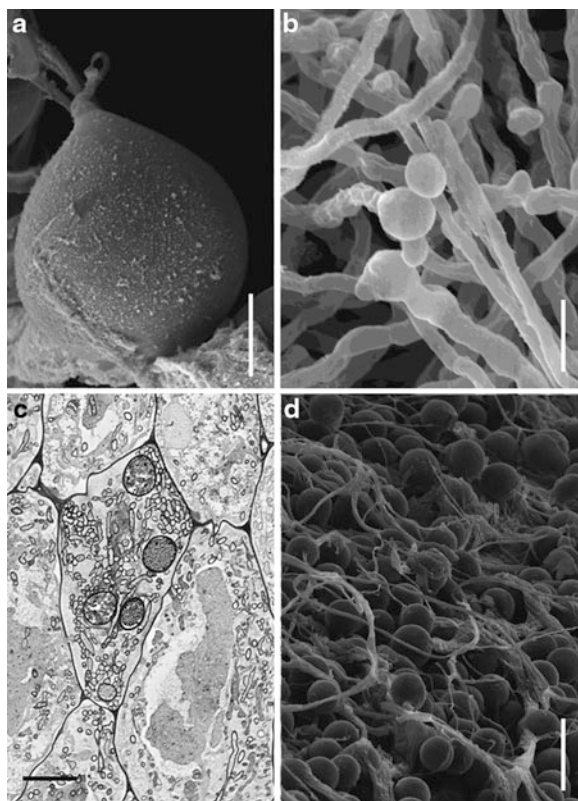
During our infection experiments with *Populus* saplings of the *Populus* hybrid (Esch5) and *P. indica* the mycelium shows a more aggressive behavior against host plant (Kaldorf et al. 2005). This was actuated by the media conditions during the experiments. This violent effect to the poplar shoots seems to depend on nitrogen concentration of media. The mycelium overgrows the shoots of the plant, invades into the plant cell like a phytopathogenic fungus, and destroys them by infection of their plant cells of aerial parts (Kaldorf et al. 2005).

The hyphae of the mycelium never formed basidia. Warcup (1981, 1988) used several species of lower Agaricomycotina also members of the Sebaciniales for his mycorrhizal experiments with orchids. He described advanced techniques for the induction of basidia of these orchid inhabiting fungal mycelia (Warcup & Talbot 1967). But all tests to induce the forming of basidia of *P. indica* failed until today. Therefore only the anamorphic stage of *P. indica* and no teleomorph are known.

2.2.3 Chlamydospores (Fig. 2.1)

The hyphae form colorless chlamydospores in culture. The chlamydospores emerge from terminal hyphal tips. Their development starts with a swollen thin-walled vesicle separated by a cell wall. The mature spores are almost globular, but one side is a little bit smaller and they look similar to the shape of a pear. The size of the mature chlamydospores varies between (14) 16 and 25 (33) µm in length and (9) 10

Fig. 2.1 (a) Chlamydospore bar = 5 μm . (b) Ontogenies of chlamydospores bar = 10 μm . (c) Endocellular formed chlamydospores bar = 30 μm . (d) Chlamydospore formation on petri dish culture bar = 30 μm



and 17(20) μm in width. Because of this shape of the spores, the genus name of the fungus was selected. The chlamydospore-forming hyphae are irregularly swollen near the point of the first spore formation and a little bit inflated. Young developing spores are clavate. Successively some more chlamydospores are developed at the end of short branching hyphae. Therefore, the chlamydospores are very often clustered in groups.

Their surface is smooth and at the beginning uncolored. The spore wall is thickening during the maturing process up to max 1.5 μm , and the color of the wall changes to light yellowish. The surface structure of the chlamydospores was revealed by scanning electron microscopy. The cytoplasm of the spores is refracting in the LM because it is completely filled with granular material. Many strongly refracting lipid bodies can be observed inside the spores. The chlamydospores contain many nuclei (8–25), which can be seen after staining with DAPI by fluorescence microscopy.

On suitable media but also on water agar, the chlamydospores form a germination tube and grow with very small hyphae. The growth rate of these primary hyphae is depending on the composition of the media. In media with water or in low concentrated nutrient, the germination hyphae are unbranched over a longer distance, but in normal concentrated media, many branching hyphae can be seen.

2.3 Interaction Structures

One of the specific features of *P. indica* is the ability to interact with the roots of many plant species of different taxa. The morphology of the interacting structures depends on the involved partners. These interacting partners could be mosses, ferns, gymnosperms, and angiosperms. Depending on the taxa of the angiosperms, *P. indica* interacts with quite different modes of interaction. The behavior of *Piriformospora* during the interaction with the roots is depending on the host plant. All plant species, which are able to form one of the different mycorrhizal types, can be used by *Piriformospora* as a host. The morphological structures during the interaction with *P. indica* are quite similar to that what it is known from their common interaction structures. These different types will be described below.

Together with ectomycorrhiza-forming plants, *P. indica* promotes the plant growth also, but the fungus is not able to build up a well-developed ectomycorrhiza with mantle and Hartig net. Only a loose net of hyphae covers the surface of the roots and some intercellular growing hyphae penetrate into the roots of such plants. The root cells react to the endophytic growing mycelium with thickened walls of the adjacent cells.

In these cases, where *P. indica* penetrates the root cells, two different modes of reactions caused by the invading hyphae are known.

2.3.1 Endophytic and Necrotrophic Mode of Life

P. indica is able to destroy the cells at the beginning of the interaction and behave itself like a necrotrophic parasite in some cases (Deshmukh et al. 2006; Kogel et al. 2006; Schäfer et al. 2007). If hyphae of *Piriformospora* invade into a plant cell, the hyphal tip forms a small inconspicuous appressorium on the surface of the outer wall of the rhizoids or root cells. During the contact phase of the hyphae of *Piriformospora*, the living plant cells rarely respond by accumulating additional cell wall material near the infection site. After the plant cell wall is locally dissolved by fungal enzymes, the hyphal tip intrudes into plant cell. But only in few cases the plant cells are able to stop the infection by the fungus. Regularly these root cells die very quickly. Mostly the invaded root cells of plant species are killed before infection, or they die off during the contact phase of the hyphae. Therefore no additional cell wall material could be seen at the infection point. The fungal hyphae cross the cell wall with thin penetration peg. The cell content will be saprophytically decomposed by the fungus. Using FDA staining, which distinguishes living and dead cell, it can be observed that many cortex cells of the interacting root have died after an infection of the root by *P. indica*, while uninfected root cells are still alive. Very often *P. indica* develops its chlamydospores inside these dead root cells.

Table 2.1 List of some selected and tested host plants of *Piriformospora indica* compiled by literature and own results

<i>Acacia nilotica</i>	<i>Abrus precatorius</i>	<i>Adhatoda vasica</i>
<i>Aneura pinguis</i>	<i>Arabidopsis thaliana</i>	<i>Artemisia annua</i>
<i>Azadirachta indica</i>	<i>Bacopa monnieri</i>	<i>Brassica rapa</i>
<i>Cassia angustifolia</i>	<i>Chlorophytum borivillianum</i>	<i>Chlorophytum tuberosum</i>
<i>Cicer arietinum</i>	<i>Coffea arabica</i>	<i>Coleus forskohlii</i>
<i>Cymbopogon martinii</i>	<i>Dactylorhiza fuchsii</i>	<i>Dactylorhiza incarnata</i>
<i>Dactylorhiza maculata</i>	<i>Dactylorhiza majalis</i>	<i>Dactylorhiza purpurella</i>
<i>Daucus carota</i>	<i>Dalbergia sissoo</i>	<i>Foeniculum vulgare</i>
<i>Glycine max</i>	<i>Helianthus annuus</i>	<i>Hordeum sativum</i>
<i>Linum album</i>	<i>Medicago truncatula</i>	<i>Mentha piperita</i>
<i>Nicotiana tabacum</i>	<i>Nicotiana attenuata</i>	<i>Oryza sativa</i>
<i>Oryza granulata</i>	<i>Panicum virgatum</i>	<i>Petroselinum crispum</i>
<i>Picea abies</i>	<i>Pinus sylvestris</i>	<i>Piper nigrum</i>
<i>Pisum sativum</i>	<i>Populus tremula</i>	<i>Populus tremuloides</i>
<i>Prosopis chilensis</i>	<i>Prosopis juliflora</i>	<i>Quercus robur</i>
<i>Saccharum officinarum</i>	<i>Setaria italica</i>	<i>Solanum lycopersicum</i>
<i>Solanum melongena</i>	<i>Sorghum vulgare</i>	<i>Spilanthes calva</i>
<i>Tectona grandis</i>	<i>Tephrosia purpurea</i>	<i>Terminalia arjuna</i>
<i>Thymus vulgaris</i>	<i>Vigna mungo</i>	<i>Withania somnifera</i>
<i>Zea mays</i>	<i>Ziziphus nummularia</i>	

2.3.2 Biotrophic Interaction with Living Plant Cells

In contrast to the widely distributed necrotrophic type of interaction between the hyphae of *Piriformospora* and the root cells of plants, a small group of plants have developed an equilibrated biotrophic interaction between the hyphae of *Piriformospora* and the living cells of the plant. In case of this interaction, the invading hyphae of *P. indica* do not destroy the invaded cells of orchids and liverworts. *P. indica* establishes a typical orchid mycorrhiza or a mycothallus together with some bryophytes. This interaction could be interpreted as biotrophic and mutualistic.

Piriformospora has a wide spectrum of hosts. During the last years many plant species are tested under defined conditions. A list of tested plant species is given below (Table 2.1):

2.4 Mycorrhiza Types of *P. indica*

The members of the order Sebaciales are able to form different mycorrhizal types depending on the interacting plant species. In this book, some of these different interaction types are described in detail. During the last decade, we have studied the

wide spectrum of host plants forming different types of mycorrhiza together with *P. indica* (Glen et al. 2002).

2.4.1 Interactions with VA-Mycorrhiza-Forming Plants

The first interaction studies of *P. indica* were done with *Zea mays*, where the plant-supporting effect was observed for the first time. At the first glance the chlamydospores of *P. indica* within the root cells and outside of the roots of the plants remind to the interacting structures of an arbuscular mycorrhiza. The chlamydospores appear inside the root cortex cells and outside of the root. The hyphae penetrate the cell walls and most of the infected cells are dead. But during this infection process, the central cylinder of the root will not be invaded by hyphal cells. Many of the tested plants belongs to this interaction type.

2.4.2 Orchid Mycorrhiza (Fig. 2.2)

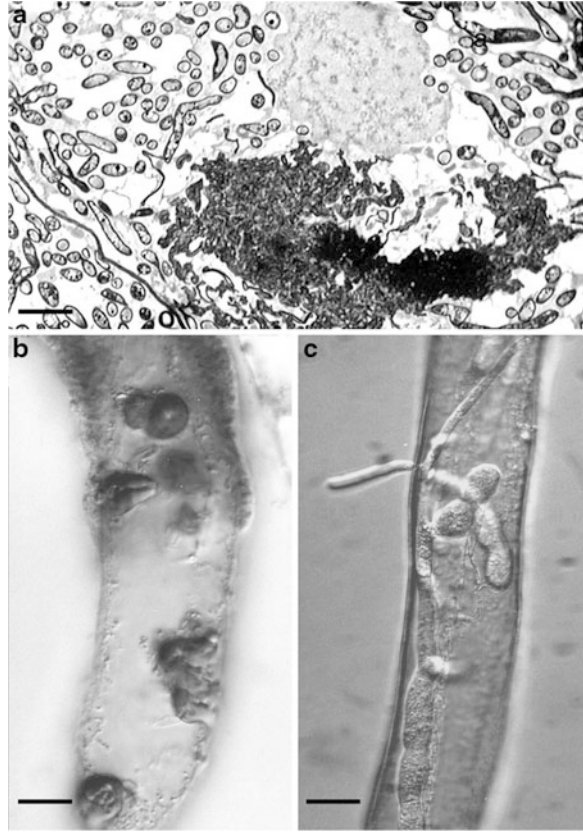
Under defined conditions it is tested that *P. indica* promotes the germination of orchid seeds and promotes the formation of the protocorm (Blechert et al. 1999). During the experiments it could be shown that the developing protocorm has the same morphology and anatomy during the interaction together with *P. indica* as with autochthonic fungal species. The orchids' cell is completely filled up with hyphae; the nucleus of these cells expands during the higher cell activity (Fig. 2.2a).

In some cases, especially in orchids, the root hairs of the orchids show a defense reaction against the intruding hyphae. Around the point of invasion, a small lignotuber is visible. These lignotubers are only formed if the infected plant cells are living and active during the first phase of the invasion processes (Fig. 2.2b, c). During the interaction between *P. indica* and the root cells of *Dactylorhiza majalis*, the protoplast of the rhizoid seems to be influenced by the penetration of the hyphae (Fig. 2.2a, c).

2.4.3 Ectomycorrhiza-Forming Plants (ECM Plants)

During cocultivation experiments with the ECM-forming species *Quercus robur*, an undeveloped network of hyphae covers the surface of the roots, and few intercellular hyphae that live inside the roots were observed here. Very thin hyphae intercellularly grow, but the typical hyphal arrangements such as a Hartig net and palmetti structures were not formed during our experiments.

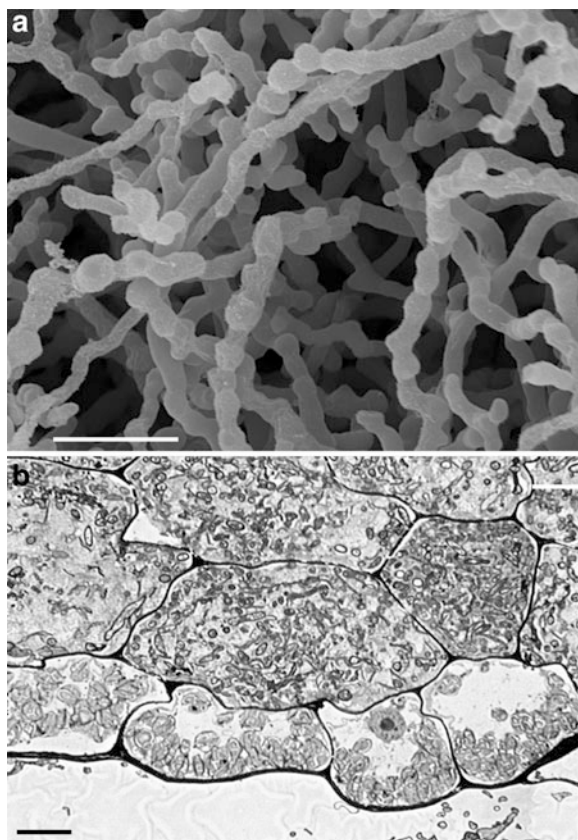
Fig. 2.2 (a) Infected root cells of *Dactylorhiza majalis* by *Piriformospora indica*, swollen nucleus of the orchid cell, dark material remains of a former fungal infection of *Piriformospora indica*; bar = 30 μ m. (b) Lignotuber of a rhizoid of *Dactylorhiza majalis* after infection of *Piriformospora indica*; bar = 20 μ m. (c) Infected rhizoid of *Dactylorhiza* with moniliform hyphae of *Piriformospora indica*; bar = 20 μ m



2.4.4 *Piriformospora* and *Arabidopsis thaliana* (*Brassicaceae*)

The morphological structures which appear during the interaction between the hyphae *P. indica* and the root cells *Arabidopsis thaliana* are very similar to those described from other AM-forming plants (Peřkan-Berghöfer et al. 2004). Although many species of the Brassicaceae are not always living together with Glomerales, *P. indica* interacts with these members of the Brassicaceae. The growth rate of the specimens, which interact with *Piriformospora*, is obviously higher. During the interaction, the hyphae of *P. indica* destroy some cortex cells of the root. Cocultivation studies of both partners revealed that *Arabidopsis thaliana* forms interacting structures similar to those which are described from other AM plants. The roots are loosely covered by the mycelium of *Piriformospora*. Some infected outer root cells are dead, but the hyphae of *P. indica* do not cross the pericycle and do not invade into the internal parts of the roots.

Fig. 2.3 (a) Moniliform hyphae of *Piriformospora indica* on solid culture medium; bar = 10 μ m. (b) Infected thallus cells of *Aneura pinguis* by *Piriformospora indica*; bar = 20 μ m



2.4.5 Interactions with Aneuraceae (Fig. 2.3)

By testing the host spectrum of *P. indica*, we cocultivated liverwort *Aneura pinguis* together with *P. indica* under sterile conditions. After a short time, both partners intensively interacted. The hyphae of *P. indica* invaded the moss thalli. The hyphae seem to be accumulated in a layer under the epidermic cells. The living moss cells are completely filled with hyphae (Kottke et al. 2003, Preussing et al. 2010).

2.4.6 Interactions with Ericaceae

The different groups of the family of Ericaceae are able to establish quite diverse interaction types depending on the taxonomic position within the Ericaceae. Field experiments also demonstrated the growth-supporting effect of *P. indica* in

cocultivation experiments. A special chapter in this book is attended to this type of interaction (Selosse et al. 2007).

2.5 Ultrastructure

Whereas the light microscopy gave no indication to the systematic relationship, the studies of the ultrastructural characters of the hyphae of *Piriformospora* clearly revealed the relationship to Basidiomycota by transmission electron microscopy. Later molecular genetic studies affirmed this interpretation of the taxonomic position. Ultrathin sections of the hyphal wall showed that the hyphal wall is multifaceted by different opacity of the layers of the cell wall. At the septa, the cell wall is swollen around the septal pore forming a distinct dolipore. These both characters are typical for Basidiomycota. To recognize the correct classification within the Basidiomycota the analyses of the specific structures of the cell wall and the septa were very useful (Verma et al. 1998). The parenthesomes cover both sides of the dolipore like a flat membranaceous disc without any detectable perforations. The membrane of the parenthesomes is arranged by different electron opaque layers. Both outer layers are electron dense and appear as a dark line. The inner layer is less dense and appears much lighter. Additionally to these structures, a small darker line can be observed in the middle of the inner layer. All these characters can be found in the order of the Sebaciales.

Although the morphology of *P. indica* does not show so quite different structures and specializations like fruit body forming Asco- and Basidiomycota, it is very interesting to observe the different adaptations and specializations of the mycelium of *P. indica* during the interaction processes with the different hosts. With this fungus it can be proved that interacting structures formed by one strain of *P. indica* together with different host plants belong to quite diverse mycorrhizal types. These data impressively prove again that the host plants induce the type of mycorrhization. Several publications of the last years documented that species of Sebaciales are overlooked (Selosse et al. 2009; Weiß et al. 2004) and they are underestimated in their importance of the influence of the composition of the vegetation on the earth.

References

- Basiewicz M, Weiß M, Kogel K-H, Langen G, Zorn H, Zuccarod A (2012) Molecular and phenotypic characterization of Sebacia vermifera strains associated with orchids, and the description of *Piriformospora williamsii* sp. nov. Fungal Biol 116:204–213
- Blechert O, Kost G, Hassel A, Rexer RH, Varma A (1999) First remarks on the symbiotic interactions between *Piriformospora indica* and terrestrial orchid. In: Varma A, Hook B (eds) Mycorrhizae, 2nd edn. Springer, Germany, pp 683–688

- Deshmukh S, Hückelhoven R, Schäfer P, Imani J, Sharma M, Weiss M, Waller F, Kogel KH (2006) The root endophytic fungus *Piriformospora indica* requires host cell death for proliferation during mutualistic symbiosis with barley. *Proc Natl Acad Sci USA* 103:18450–18457
- Glen M, Tommerup IC, Bougher NL, O'Brien PA (2002) Are Sebacinaceae common and widespread ectomycorrhizal associates of Eucalyptus species in Australian forests? *Mycorrhiza* 12:243–247
- Kaldorf M, Koch B, Rexer KH, Kost G, Varma A (2005) Patterns of interaction between *Populus* Esch5 and *Piriformospora indica*: a transition from mutualism to antagonism. *Plant Biology* 7:210–218
- Kogel KH, Franken P, Hückelhoven R (2006) Endophyte or parasite-what decides? *Curr Opin Plant Biol* 9:358–363
- Kottke I, Beiter A, Weiss M, Haug I, Oberwinkler F, Nebel M (2003) Heterobasidiomycetes form symbiotic associations with hepatics: Jungermanniales have sebacinoid mycobionts while *Aneura pinguis* (Metzgeriales) is associated with a *Tulasnella* species. *Mycol Res* 107:957–968
- Peškan-Berghöfer T, Shahollari B, Giang PH, Hehl S, Markert C, Blanke V, Varma AK, Oelmüller R (2004) Association of *Piriformospora indica* with *Arabidopsis thaliana* roots represents a novel system to study beneficial plant–microbe interactions and involves early plant protein modifications in the endoplasmic reticulum and at the plasma membrane. *Physiologia Plantarum* 122:465–477
- Preussing M, Nebel M, Oberwinkler F, Weiss M (2010) Diverging diversity patterns in the *Tulasnella* (Basidiomycota, Tulasnellales) mycobionts of *Aneura pinguis* (Marchantiophyta, Metzgeriales) from Europe and Ecuador. *Mycorrhiza* 20:147–159
- Schäfer P, Khatabi B, Kogel KH (2007) Root cell death and systemic effects of *Piriformospora indica*: a study on mutualism. *FEMS Microbiol Lett* 275:1–7
- Selosse MA, Setaro S, Glatard F, Richard F, Urcelay C, Weiss M (2007) Sebacinaleae are common mycorrhizal associates of Ericaceae. *New Phytol* 174:864–878
- Selosse MA, Dubois MP, Alvarez N (2009) Do Sebacinaleae commonly associate with plant roots as endophytes? *Mycol Res* 113:1062–1069
- Varma A, Singh A, Sudha, Sahay N, Sharma J, Roy A, Kumari M, Rana D, Thakran S, Deka D, Bharti K, Franken P, Hurek T, Bleichert O, Rexer K-H, Kost G, Hahn A, Hock B, Maier W, Walter M, Strack D, Kranner I (2001) *Piriformospora indica*: a cultivable mycorrhiza-like endosymbiotic fungus. In: Hock B (ed) *Mycota IX*. Springer, Germany, pp 123–150
- Varma A, Verma S, Sahay NS, Bütehorn B, Franken P (1999) *Piriformospora indica*, a cultivable plant growth promoting root endophyte. *Appl Environ Microbiol* 65:2741–2744
- Verma SA, Varma A, Rexer K-H, Hassel A, Kost G, Sarbhoy A, Bisen P, Bütehorn B, Franken P (1998) *Piriformospora indica*, gen. et sp. nov., a new root-colonizing fungus. *Mycologia* 90:898–905
- Warcup JH (1981) The mycorrhizal relationships of Australian orchids. *New Phytologist* 87:371–381
- Warcup JH (1988) Mycorrhizal associations of isolates of *Sebacina vermifera*. *New Phytologist* 110:227–231
- Warcup JH, Talbot PHB (1967) Perfect states of rhizoctonias associated with orchids. *New Phytologist* 66:631–641
- Weiß M, Sykora Z, Garnica S, Riess K, Martos F, Krause C, Oberwinkler F, Bauer R, Redecker D (2011) Sebacinaleae everywhere: previously overlooked ubiquitous fungal endophytes. *PLoS One* 6:16793
- Weiß M, Selosse M-A, Rexer K-H, Urban A, Oberwinkler F (2004) Sebacinaleae: a hitherto overlooked cosm of heterobasidiomycetes with a broad mycorrhizal potential. *Mycol Res* 108:1003–1010

- Zuccaro A, Lahrmann U, Guldener U, Langen G, Pfiffi S, Biedenkopf D, Wong P, Samans B, Grimm C, Basiewicz M, Murat C, Martin F, Kogel K-H (2011) Endophytic life strategies decoded by genome and transcriptome analyses of the mutualistic root symbiont *Piriformospora indica*. PLoS Pathog 7:1–26
- Zuccaro A, Basiewicz M, Zurawska M, Biedenkopf M, Kogel K-H (2009) Karyotype analysis, genome organization, and stable genetic transformation of the root colonizing fungus *Piriformospora indica*. Fungal Genet Biol 46:543–550

Piriformospora indica

Sebacinales and Their Biotechnological Applications

Varma, A.; Kost, G.; Oelmüller, R. (Eds.)

2013, XIII, 397 p. 124 illus., 38 illus. in color., Hardcover

ISBN: 978-3-642-33801-4