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# Phylogeny and nomenclature of the genus *Talaromyces* and taxa accommodated in *Penicillium* subgenus *Biverticillium*

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**Abstract:** The taxonomic history of anamorphic species attributed to *Penicillium* subgenus *Biverticillium* is reviewed, along with evidence supporting their relationship with teleomorphic species classified in *Talaromyces*. To supplement previous conclusions based on ITS, SSU and/or LSU sequencing that *Talaromyces* and subgenus *Biverticillium* comprise a monophyletic group that is distinct from *Penicillium* at the generic level, the phylogenetic relationships of these two groups with other genera of *Trichocomaceae* was further studied by sequencing a part of the *RPB1* (RNA polymerase II largest subunit) gene. *Talaromyces* species and most species of *Penicillium* subgenus *Biverticillium sensu* Pitt reside in a monophyletic clade distant from species of other subgenera of *Penicillium*. For detailed phylogenetic analysis of species relationships, the ITS region (incl. 5.8S nrDNA) was sequenced for the available type strains and/or representative isolates of *Talaromyces* and related biverticillate anamorphic species. Extrolite profiles were compiled for all type strains and many supplementary cultures. All evidence supports our conclusions that *Penicillium* subgenus *Biverticillium* is distinct from other subgenera in *Penicillium* and should be taxonomically unified with the *Talaromyces* species that reside in the same clade. Following the concepts of nomenclatural priority and single name nomenclature, we transfer all accepted species of *Penicillium* subgenus *Biverticillium* to *Talaromyces*. A holomorphic generic diagnosis for the expanded concept of *Talaromyces*, including teleomorph and anamorph characters, is provided. A list of accepted *Talaromyces* names and newly combined *Penicillium* names is given. Species of biotechnological and medical importance, such as *P. funiculosus* and *P. marneffeii*, are now combined in *Talaromyces*. Excluded species and taxa that need further taxonomic study are discussed. An appendix lists other generic names, usually considered synonyms of *Penicillium sensu lato* that were considered prior to our adoption of the name *Talaromyces*.

**Key words:** anamorph, DNA phylogeny, single name nomenclature, teleomorph, *Trichocomaceae*.

**Taxonomic novelties:** **Taxonomic novelties: New species** – *Talaromyces apiculatus* Samson, Yilmaz & Frisvad, sp. nov. **New combinations and names** – *Talaromyces aculeatus* (Raper & Fennell) Samson, Yilmaz, Frisvad & Seifert, *T. albobiverticillius* (H.-M. Hsieh, Y.-M. Ju & S.-Y. Hsieh) Samson, Yilmaz, Frisvad & Seifert, *T. allahabadensis* (B.S. Mehrotra & D. Kumar) Samson, Yilmaz & Frisvad, *T. aurantiacus* (J.H. Mill., Giddens & A.A. Foster) Samson, Yilmaz, & Frisvad, *T. boninensis* (Yaguchi & Udagawa) Samson, Yilmaz, & Frisvad, *T. brunneus* (Udagawa) Samson, Yilmaz & Frisvad, *T. calidicanus* (J.L. Chen) Samson, Yilmaz & Frisvad, *T. cecidicola* (Seifert, Hoekstra & Frisvad) Samson, Yilmaz, Frisvad & Seifert, *T. coalescens* (Quintan.) Samson, Yilmaz & Frisvad, *T. dendriticus* (Pitt) Samson, Yilmaz, Frisvad & Seifert, *T. diversus* (Raper & Fennell) Samson, Yilmaz & Frisvad, *T. duclauxii* (Delacr.) Samson, Yilmaz, Frisvad & Seifert, *T. echinosporus* (Nehira) Samson, Yilmaz & Frisvad, comb. nov. *T. erythromellis* (A.D. Hocking) Samson, Yilmaz, Frisvad & Seifert, *T. funiculosus* (Thom) Samson, Yilmaz, Frisvad & Seifert, *T. islandicus* (Sopp) Samson, Yilmaz, Frisvad & Seifert, *T. loliensis* (Pitt) Samson, Yilmaz & Frisvad, *T. marneffeii* (Segretain, Capponi & Sureau) Samson, Yilmaz, Frisvad & Seifert, *T. minioluteus* (Dierckx) Samson, Yilmaz, Frisvad & Seifert, *T. palmae* (Samson, Stolk & Frisvad) Samson, Yilmaz, Frisvad & Seifert, *T. panamensis* (Samson, Stolk & Frisvad) Samson, Yilmaz, Frisvad & Seifert, *T. paucisporus* (Yaguchi, Someya & Udagawa) Samson & Houbraken *T. phialosporus* (Udagawa) Samson, Yilmaz & Frisvad, *T. piceus* (Raper & Fennell) Samson, Yilmaz, Frisvad & Seifert, *T. pinophilus* (Hedgcock) Samson, Yilmaz, Frisvad & Seifert, *T. pittii* (Quintan.) Samson, Yilmaz, Frisvad & Seifert, *T. primulinus* (Pitt) Samson, Yilmaz & Frisvad, *T. proteolyticus* (Kamyschko) Samson, Yilmaz & Frisvad, *T. pseudostrumaticus* (Hodges, G.M. Warner, Rogerson) Samson, Yilmaz, Frisvad & Seifert, *T. purpurogenus* (Stoll) Samson, Yilmaz, Frisvad & Seifert, *T. rademirici* (Quintan.) Samson, Yilmaz & Frisvad, *T. radicus* (A.D. Hocking & Whitelaw) Samson, Yilmaz, Frisvad & Seifert, *T. ramulosus* (Visagie & K. Jacobs) Samson, Yilmaz, Frisvad & Seifert, *T. rubicundus* (J.H. Mill., Giddens & A.A. Foster) Samson, Yilmaz, Frisvad & Seifert, *T. rugulosus* (Thom) Samson, Yilmaz, Frisvad & Seifert, *T. sabulosus* (Pitt & A.D. Hocking) Samson, Yilmaz & Frisvad, *T. siamensis* (Manoch & C. Ramirez) Samson, Yilmaz & Frisvad, *T. sublevisporus* (Yaguchi & Udagawa) Samson, Yilmaz & Frisvad, *T. variabilis* (Sopp) Samson, Yilmaz, Frisvad & Seifert, *T. varians* (G. Sm.) Samson, Yilmaz & Frisvad, *T. verruculosus* (Peyronel) Samson, Yilmaz, Frisvad & Seifert, *T. viridulus* Samson, Yilmaz & Frisvad.

## INTRODUCTION

The modern concept of *Penicillium* (referred to in this paper as *Penicillium sensu lato*), was derived from the pioneering monographic revisions of Thom (1930), Raper & Thom (1949), and formalised by the recognition of four subgenera, *Aspergilloides*, *Furcatum*, *Penicillium* and *Biverticillium* by Pitt (1980). Over the past decade, the realisation has grown that *Penicillium* subgenus *Biverticillium* is phylogenetically distinct from other subgenera of *Penicillium* and that this distinctiveness should be reflected in its formal taxonomy. Because of their usually symmetrical, biverticillate conidiophores, the group has been recognised since Wehmer (1914) segregated them in an informal subdivision of

*Penicillium* that he called "Verticillatae". The delineation, species composition and taxonomic rank of this group were modified in subsequent monographs by Thom (1930), Raper & Thom (1949), Pitt (1980), and Ramirez (1982), culminating in the widespread recognition of subgenus *Biverticillium* and the use of this name in many taxonomic and phylogenetic studies. Malloch (1985), based on a consideration of morphological and ecological factors, and anamorph-teleomorph connections, may have been the first to speculate that subgenus *Biverticillium* should be removed from *Penicillium* as a separate genus.

The teleomorph genera historically associated with *Penicillium sensu lato* are *Talaromyces* and *Eupenicillium* (in single name nomenclature, the latter is now considered a synonym of

*Penicillium sensu stricto*, see Houbraken & Samson 2011). The teleomorphs of these two groups produce distinctive ascomata. In *Talaromyces*, the soft ascomatal walls are comprised of multiple layers of interwoven hyphae and the ascomata mature quickly, usually within a few weeks in agar culture. In *Penicillium sensu stricto*, the sclerotium-like ascomata have rigid walls of thick-walled, isodiametric cells and the ascomatal maturity can take months and often ascospores do not form at all. Furthermore, in *Talaromyces* the ascus initials sometimes have morphologically distinguishable gametangia and the mature asci are produced in chains (Stolk & Samson 1972), while the ascomatal initials in *Penicillium sensu stricto* are irregularly interwoven, loosely branched hyphae masses (Emmons 1935), and the mature asci are single. Raper & Thom (1949) already recognised that there was considerable evidence that *Penicillium* subgenus *Biverticillium* constituted a natural and homogenous group. A comparison of the anamorphs of these two teleomorph types reveals a correlation with phialide shape, with anamorphs of *Talaromyces* (until now classified in *Penicillium* subgenus *Biverticillium*) having narrower phialides that are aculeate or lanceolate, and anamorphs in *Penicillium sensu stricto* having broader, ampulliform or flask-shaped phialides. One consequence of the differences in phialide shape is that the symmetrical nature of the conidiophores of species allied with *Talaromyces* tends to be emphasised, because in general the phialides are more densely packed. The colonies of subgenus *Biverticillium* can often be distinguished from those of *Penicillium sensu stricto* by the naked eye. They often have darker green conidia, more or less yellow pigmented and encrusted aerial hyphae, and colony reverses in yellow, orange or red to purplish red shades.

Once DNA-based studies of fungal phylogeny began, it quickly became apparent that the differences between *Penicillium sensu stricto* and *Talaromyces* were more than a matter of degree, and that there might be a significant problem with the generic concept of *Penicillium sensu lato*. *Penicillium sensu stricto* and *Talaromyces* occur as distinct clades within *Trichocomaceae*, which could be considered subfamilies (LoBuglio *et al.*, 1993, LoBuglio & Taylor 1993). Using small subunit nuclear ribosomal DNA sequences (18S), Berbee *et al.* (1995) showed that *Penicillium* is polyphyletic if subgenus *Biverticillium* is included, a conclusion reconfirmed in one of the first reviews of the impact of molecular phylogenetics on Ascomycete taxonomy (Sugiyama 1998) using an analysis of 18S rDNA sequences. Removal of subgenus *Biverticillium* transforms *Penicillium sensu stricto* into a monophyletic group. This dichotomy between *Penicillium sensu stricto* and *Talaromyces* was shown repeatedly in studies employing nuclear ribosomal RNA genes, for example by Peterson (2000), who analysed a combination of the nuclear ribosomal internal transcribed spacer regions (ITS) and large subunit ribosomal DNA (28S) sequences (Ogawa *et al.* 1997, Ogawa & Sugiyama 2000), and by Wang & Zhuang (2007) in a phylogeny based on calmodulin sequences. The results of these analyses are all confirmed in the multigene phylogenetic analyses presented elsewhere in this volume by Houbraken & Samson (2011), using genes selected for their ability to accurately reflect molecular phylogeny. As indicated by Houbraken & Samson (2011), when other genera assigned to *Trichocomaceae* are included in phylogenetic analyses, the division between subgenus *Biverticillium* and *Penicillium sensu stricto* becomes even clearer. In that study, intervening genera include *Aspergillus*, *Paecilomyces sensu stricto* (with *Byssochlamys* as a synonym), and several small and less well-known genera such as *Thermoascus*, *Penicilliopsis*, *Thermomyces* and the recently described *Rasamsonia* (Houbraken *et al.* 2011).

In a molecularly defined, phylogenetically accurate taxonomic system, maintaining subgenus *Biverticillium* in *Penicillium sensu stricto* is untenable. However, almost every aspect of the biology, biochemistry, and physiology of these two groups emphasises their fundamental distinctiveness, although sometimes with limited taxon sampling. For example, Pitt (1980) emphasised the distinctiveness of subgenus *Biverticillium* by using a low water-activity medium, G25N (which includes 25 % glycerol) in his standard plating regime. Strains assigned to this subgenus grow slowly on this medium, less than 10 mm diam at 25 °C in 7 d, whereas species of the other subgenera are more xerophilic and grow faster. Cell-wall components seem to differ significantly. Leal & Bernabé (1998) reported on the complex glucomannogalactan components of the water soluble polysaccharide fraction of several species of *Trichocomaceae*, suggesting that a characteristic heteropolysaccharide composed of 4 galactose: 1 mannose: 1 glucose was unique to species of subgenus *Biverticillium*. Species of *Penicillium sensu stricto* species were characterised by the presence of a  $\beta$ -(1-5)(1-6)-galactofuran polysaccharide in the same fraction. Cell wall components as reflected by their exoantigens were screened in about 50 species of *Penicillium sensu lato* using an ELISA reaction to antibodies raised to *P. digitatum* (subgenus *Penicillium*). These antibodies reacted well with all the species of subgenera *Furcatum*, *Penicillium* and *Aspergilloides*, but did not react with the four species of subgenus *Biverticillium* tested (*P. funiculosum*, *P. islandicum*, *P. rubrum*, and *P. tardum*) (Notermans *et al.* 1998). Kuraishi *et al.* (1991) first noted that the pattern of ubiquinones in *Penicillium sensu lato* and showed a distinct pattern in subgenus *Biverticillium*. Paterson (1998) examined 335 strains and 118 species of *Penicillium sensu lato* and determined that the Q9 ubiquinone type was predominant in the species of *Penicillium sensu stricto*. In contrast, species of *Talaromyces*, *Trichocoma* and subgenus *Biverticillium* had different versions of the Q10 ubiquinone type. Exceptions to these patterns can be explained by the small number of species whose classification in, or elimination from, subgenus *Biverticillium* has been uncertain or controversial. Frisvad *et al.* (1990a) provided an overview of the extrolites of *Talaromyces* species, and demonstrated the occurrence of characteristic extrolites such as mitorubins, bisanthaquinones such as rugulosin and skyrin, vermicellin, vermistatin, vermiculine, duclauxin and glauconic acid. None of these compounds were found in cultures of *Penicillium sensu stricto* (Frisvad *et al.* 1990b).

The soon to be published *International Code of Nomenclature for Algae, Fungi and Plants* removes the primacy of teleomorph-over anamorph-typified names, leaving both kinds of names competing equally for priority (Norvell 2011). Because of these changes, we apply the principle of 'one fungus - one name' and in the nomenclatural revision, priority is given to the oldest genus and species name irrespective of whether they were originally described for teleomorphs or anamorphs (Hawksworth *et al.* 2011). In this respect, *Penicillium* returns to the single named, but pleomorphic, nomenclatural and taxonomic system used by many of the founders of its taxonomy, and actively promoted by the Peoria school (Thom 1930, Raper & Thom 1949). *Talaromyces*, now also defined as a pleomorphic genus, is adopted for the anamorphic species formerly included in *Penicillium* subgenus *Biverticillium*. In this study, the phylogenetic relationships of species of subgenus *Biverticillium* and other members of the *Trichocomaceae* were studied by sequencing a part of the *RPB1* (RNA polymerase II largest subunit) gene. Furthermore, we discuss the taxonomy and nomenclature of species of this expanded concept of *Talaromyces*, based on phylogenetic, phenotypic and extrolite data. For detailed



phylogenetic analysis below genus level, the ITS regions (including the 5.8S nrDNA) of ex-type strains and/or representatives were sequenced. As discussed below, this paper is not meant as a monographic treatment, because many complexes have not yet been studied comprehensively.

## MATERIALS AND METHODS

### Sources of cultures

The fungi examined include type strains or representatives of all available species of *Talaromyces* and *Biverticillium*. The strains are maintained in the CBS-KNAW Fungal Biodiversity Centre (CBS) culture collection and an overview of strains used for phylogenetic analysis is shown in Table 1. In a few cases, the ex-type strain was unavailable and sequence data present in GenBank were used.

### Morphology and physiology

Cultures were grown for 7 d on Czapek agar, Czapek yeast autolysate agar (CYA), oatmeal agar (OA) and/or malt extract agar (MEA) plates at 25 °C or, if required, another temperature. Medium compositions follow Samson *et al.* (2010). Cultures were grown for up to 3 wk for ascospore production.

### Extrolite analysis

Nearly all species described in the genera *Penicillium sensu lato* (including those formerly classified in *Eupenicillium*), *Penicillium* subgenus *Biverticillium*, *Talaromyces*, *Aspergillus* and its many associated teleomorphic genera, and *Paecilomyces* (including those formerly or still classified in the associated teleomorph genus *Byssochlamys*) were analysed qualitatively for their profiles of secondary metabolites as determined by HPLC with diode array detection. Many strains of each species were examined, whenever available, but in some cases only the ex-type culture was available. Cultures were inoculated on the media CYA, MEA (Blakeslee formula, using Difco malt extract), YES agar (Samson *et al.* 2010, Difco yeast extract) and OA. All cultures were analysed chemically using three agar plugs from a 7 d old culture grown at 25 °C (Smedsgaard 1997). Different methods were used for HPLC analysis, but the methods were essentially based on Frisvad & Thrane (1987, 1993). Since 1997, the method for Nielsen & Smedsgaard (2003) was used and after 2010 the UPLC method of Nielsen *et al.* (2011) was applied. Metabolites were identified via their diode-array based UV-VIS spectra and in some cases by their mass spectra, and by comparison to authenticated standards (Nielsen *et al.* 2011).

For the extrolites analyses, the biosynthetic families of the sampled genera were compared using UPGMA cluster analysis (NTSYS version 2.11). All metabolites were classified according to biosynthetic families; for example the viridicatin biosynthetic family consists of cyclophenol, cyclophenin, cycloheptin, dehydrocycloheptin, viridicatin, viridicatol and 3-methoxyviridicatin (Turner & Aldridge 1983). This family was scored as one character in the cluster analysis. The exometabolites were also combined into biosynthetic families and tabulated as such. For example, many species of *Talaromyces* and *Penicillium* subgenus *Biverticillium* produce the azaphilones mitorubrin, mitorubrinol, mitorubrinolol, mitorubrinolol acetate, mitorubrinic acid, funicone, deoxyfunicone, actofunicone,

3-O-methylfunicone, kasanosin A and B, diazaphilonic acid, and wortmin; they are here collectively called the mitorubrins, while the related metabolites vermistatins and penicidones are called vermistatins (see Šturdíková *et al.* 2000, Nicoletti *et al.* 2009, Osmanova *et al.* 2010). Some chlorinated azaphilones such as helicisins (Yoshida *et al.* 1995) and luteusins (Fujimoto *et al.* 1990, Yoshida *et al.* 1996a, b) are epimers of the sclerotiorins from *P. sclerotiorum*, and are treated as two families, albeit closely related to the mitorubrins.

### DNA extraction, amplification and sequencing

Isolates used for molecular studies were grown on MEA for 7–14 d at the required temperature prior to DNA extraction. DNA was extracted from the cells using the UltraClean™ Microbial DNA Kit (MoBio Laboratories), following the protocols of the manufacturer. A part of the *RPB1* gene was amplified to study the phylogenetic relationships among *Penicillium* and other related genera. This fragment was amplified using the primer pair RPB1-F1843 5'-ATTTYGAYGGTGAYGARATGAAC-3' and RPB1-R3096 5'-GRACRGTDCRCATAYTTRACC-3' (Houbraken & Samson 2011). Primer RPB1-F1843 corresponds with position 1490–1512 of GenBank no. XM\_002146871 (*P. marneffei*, ATCC 18224) and RPB1-R3096 corresponds with position 2610–2633. An additional primer, RPB1-R2623 5'-GCRTTGTTTSARATCCTTMARRCTC-3' was occasionally used as an internal primer for sequencing (Houbraken & Samson 2011). The ITS regions were sequenced to study the relationship among *Talaromyces* and the related biverticillate anamorphic species. Fragments containing the ITS region were amplified using primers V9G (de Hoog & Gerrits van den Ende 1998) and LS266 (Masclaux *et al.* 1995). Sequencing reactions were performed with the Big Dye Terminator Cycle Sequencing Ready Reaction Kit v. 3.1 (Applied Biosystems) and carried out for both strands to ensure consistency of the consensus sequence.

### Data analyses

For the DNA sequence analyses, alignments were performed using the software Muscle as implemented in the MEGA5 programme (Tamura *et al.* 2011). The RAxML (randomised accelerated maximum likelihood) software (v. 7.2.8, Stamatakis *et al.* 2008) was used for the Maximum Likelihood (ML) analysis. The robustness of trees in the ML analyses was evaluated by 100 bootstrap replications. The phylogram based on *RPB1* sequences is rooted with *Coccidioides immitis* (strain RS; full genome strain), and *Trichocoma paradoxa* (CBS 788.83) is used as an outgroup in the ITS analysis.

## RESULTS

### Phylogenetic generic delimitation of *Talaromyces* and biverticillate anamorphic species

The phylogenetic relationships of *Talaromyces* and species of *Penicillium* subgenus *Biverticillium* among other related genera were studied using partial *RPB1* sequences. One-hundred fifty-six strains were included in this analysis. The length of the alignment was 496 characters (exon data only, no introns observed) and 323 of those characters were variable. The proportion of gaps and

**Table 1.** Strains used in phylogenetic analysis of *Talaromyces*.

Name	Collection no.	Origin	GenBank Accession number	
			RPB1	ITS
" <i>Aphanoascus cinnabarinus</i> "	CBS 267.72 = ATCC 26215	Soil, Japan	JN121625	JN899376
<i>Aspergillus aculeatus</i>	CBS 172.66 <sup>T</sup> = ATCC 16872 = IMI 211388	Tropical soil	JN121590	
<i>Aspergillus clavatoflavus</i>	CBS 473.65 <sup>NT</sup> = ATCC 16866 = IMI 124937	Rain forest soil, Tulley, Queensland, Australia	JN121686	
<i>Aspergillus flavus</i>	NRRL 3357 = CBS 128202 = ATCC 200026	Peanut cotyledons, USA	Unpublished	
<i>Aspergillus fumigatus</i>	Af293	Patient with invasive aspergillosis	Nierman <i>et al.</i> (2005)	
<i>Aspergillus niger</i>	CBS 513.88	Derived from NRRL 3122 and currently used as enzyme production strain	Pel <i>et al.</i> (2007)	
<i>Aspergillus ochraceoroseus</i>	CBS 101887 = ATCC 42001 = IBT 14580	Soil, Tai National Forest, Ivory Coast	JN121557	
<i>Aspergillus ochraceus</i>	CBS 108.08 <sup>NT</sup> = ATCC 1008 = CBS 547.65 = IMI 016247 = IMI 016247iii = IMI 016247iv = NRRL 1642 = NRRL 398	Unknown source	JN121562	
<i>Aspergillus penicillioides</i>	CBS 130294	Indoor environment, Germany	JN121578	
<i>Aspergillus robustus</i>	CBS 649.93 <sup>T</sup> = CBS 428.77 = IBT 14305	Surface soil from thorn-forest, near Mombasa, Kenya	JN121711	
<i>Aspergillus sparsus</i>	CBS 139.61 <sup>NT</sup> = ATCC 16851 = IMI 019394 = IMI 019394ii = MUCL 31314 = NRRL 1933	Soil, Costa Rica	JN121586	
<i>Aspergillus steynii</i>	CBS 112812 <sup>T</sup> = IBT 23096	Dried arabica green coffee bean, on parchment, internal infection, Chamumdesheran Estata, Karnataka, district Giris, India	JN121569	
<i>Aspergillus sydowii</i>	CBS 264.81	Grains and milling fractions, <i>Triticum aestivum</i> , India	JN121624	
<i>Aspergillus versicolor</i>	CBS 245.65 = ATCC 11730 = ATCC 16020 = IMI 045554 = IMI 045554ii = IMI 045554iii = IMI 045554iv = MUCL 19008	Cellophane, Indiana, USA	JN121614	
<i>Aspergillus zonatus</i>	CBS 506.65 <sup>NT</sup> = ATCC 16867 = IMI 124936	Forest soil, Province of Linon, Fortuna, Costa Rica	JN121691	
<i>Byssoschlamys nivea</i>	CBS 100.11 <sup>T</sup> = ATCC 22260	Unknown source	JN121511	
<i>Byssoschlamys spectabilis</i>	CBS 101075 <sup>T</sup> = ATCC 90900 = FRR 5219	Heat processed fruit beverage, Tokyo, Japan	JN121554	
<i>Byssoschlamys verrucosa</i>	CBS 605.74 <sup>T</sup> = ATCC 34163	Nesting material of <i>Leipoa ocellata</i> (Malleefowl), Pulletop Nature Reserve, New South Wales, Australia	JN680311	
<i>Chrysosporium inops</i>	CBS 132.31 <sup>T</sup> = IMI 096729 = UAMH 802	Skin of man, Italy	JN121584	
<i>Coccidioides immitis</i>	Strain "RS"	Vaccine strain - origin unknown	Sharpton <i>et al.</i> (2009)	
<i>Emericella nidulans</i>	FGSC A4 (= ATCC 38163 = CBS 112.46)	Unknown source	Galagan <i>et al.</i> (2005)	
<i>Eurotium herbariorum</i>	CBS 516.65 <sup>NT</sup> = ATCC 16469 = IMI 211383 = NRRL 116	Unpainted board, Washington, USA	JN121693	
<i>Geosmithia viridis</i>	CBS 252.87 <sup>T</sup> = FRR 1863 = IMI 288716	Soil, bank of creek flowing into Little River, New South Wales	JN680284	JN899314
<i>Hamigera avellanea</i>	CBS 295.48 <sup>T</sup> = ATCC 10414 = IMI 040230 = NRRL 1938	Soil, San Antonio, Texas, USA	JN121632	
<i>Hamigera striata</i>	CBS 377.48 <sup>NT</sup> = ATCC 10501 = IMI 039741 = NRRL 717	Canned blueberries, USA	JN121665	
<i>Monascus purpureus</i>	CBS 109.07 <sup>T</sup> = ATCC 16365 = ATCC 16426 = IMI 210765 = NRRL 1596	Fermented rice grain, 'ang-quac' (purple coloured rice), Kagok-Tegal, imported from China, Prov. Quouan-toung, Java, Indonesia	JN121563	
<i>Paecilomyces aeruginus</i>	CBS 350.66 <sup>T</sup> = IMI 105412	Debris of <i>Glyceria maxima</i> , Attenborough, Notts., UK	JN121657	JN899388
<i>Paecilomyces pascuus</i>	CBS 253.87 <sup>T</sup> = FRR 1925	Pasture grass, Otara, New Zealand	JN899292	JN899321

Table 1. (Continued).

Name	Collection no.	Origin	GenBank Accession number	
			RPB1	ITS
<i>Penicillioopsis clavariiformis</i>	CBS 761.68 = CSIR 1135	Unknown source, Pretoria, South Africa	JN121716	
<i>Penicillium aculeatum</i>	CBS 100105 = CBS 289.48 = ATCC 10409 = IMI 040588 = NRRL 2129 = NRRL A-1474	Textile, USA		JN899389
	CBS 289.48 <sup>NT</sup> = ATCC 10409 = IMI 040588 = NRRL 2129 = NRRL A-1474	Textile, USA		JN899378
<i>Penicillium aculeatum</i> var. <i>apiculatum</i>	CBS 312.59 <sup>T</sup> = ATCC 18315 = FRR 635 = IMI 068239	Soil, Japan	JN680293	JN899375
<i>Penicillium allahabadense</i>	CBS 453.93 <sup>T</sup> = ATCC 15067 = CBS 304.63	Soil of cultivated field, pH 6.9, Allahabad, India	JN680309	JN899345
<i>Penicillium arenicola</i>	CBS 220.66 <sup>T</sup> = ATCC 18321 = ATCC 18330 = IMI 117658 = NRRL 3392	Soil from pine forest, Kiev, Ukraine	JN121601	
<i>Penicillium aurantiacum</i>	CBS 314.59 <sup>T</sup> = ATCC 13216 = IMI 099722 = NRRL 3398	Soil, Georgia		JN899380
<i>Penicillium aureocephalum</i>	CBS 102801 <sup>T</sup>	<i>Quercus ruber</i> , Gerona, Selva de Mar, Catalonia, Spain		JN899392
<i>Penicillium brunneum</i>	CBS 227.60 <sup>T</sup> = ATCC 18229 = FRR 646 = IFO 6438 = IHEM 3907 = IMI 078259 = MUCL 31318	Milled rice imported into Japan, Thailand	JN680281	JN899365
<i>Penicillium calidicanium</i>	CBS 112002 <sup>T</sup>	Soil, Nantou County, Taiwan	JN899305	JN899319
<i>Penicillium canescens</i>	CBS 300.48 <sup>NT</sup> = ATCC 10419 = IMI 028260 = MUCL 29169 = NRRL 910	Soil, England	JN121636	
<i>Penicillium catenatum</i>	CBS 352.67 <sup>T</sup> = ATCC 18543 = IMI 136241	Desert soil, Upington, Cape Province, South Africa	JN121659	
<i>Penicillium cinnamopurpureum</i>	CBS 490.66 = ATCC 18337 = IMI 114483	Cultivated soil, South Africa	JN121690	
<i>Penicillium citrinum</i>	CBS 139.45 <sup>T</sup> = ATCC 1109 = IMI 091961 = MUCL 29781 = NRRL 1841	Unknown source	JN121585	
<i>Penicillium coalescens</i>	CBS 103.83 <sup>T</sup>	Soil under <i>Pinus</i> sp., near Vulladolid, Spain		JN899366
<i>Penicillium concavorugulosum</i>	CBS 898.73 <sup>T</sup> = ATCC 20202	Unknown substrate, Japan	JN899304	JN899390
<i>Penicillium crateriforme</i>	CBS 184.27 <sup>T</sup> = FRR 1057 = IMI 094165 = LSHB P164 = MUCL 29224 = NRRL 1057	Soil, Louisiana	JN680270	JN899373
<i>Penicillium dendriticum</i>	CBS 660.80 <sup>T</sup> = IMI 216897	Leaf litter of <i>Eucalyptus pauciflora</i> , Kosciusko National Park, New South Wales, Australia	JN121714	JN899339
<i>Penicillium diversum</i>	CBS 320.48 <sup>T</sup> = ATCC 10437 = DSM 2212 = IMI 040579 = IMI 040579ii = NRRL 2121	Leather, USA	JN680297	JN899341
<i>Penicillium duclauxii</i>	CBS 322.48 <sup>T</sup> = ATCC 10439 = IMI 040044 = MUCL 28672 = MUCL 29094 = MUCL 29212 = NRRL 1030	Canvas, France	JN121643	JN899342
<i>Penicillium echinosporum</i>	CBS 293.62 <sup>T</sup> = ATCC 18319 = DSM 2230 = FRR 3411 = IMI 080450 = IMI 101214	Wood pulp, Surrey, Kenley, UK		JN899363
<i>Penicillium erythromellis</i>	CBS 644.80 <sup>T</sup> = FRR 1868 = IMI 216899	Soil from creek bank, Little River, New South Wales, Australia	JN680315	JN899383
<i>Penicillium euglaucum</i>	CBS 323.71 <sup>NT</sup>	Soil, Argentina	JN121644	
<i>Penicillium expansum</i>	CBS 325.48 = ATCC 7861 = IBT 5101 = IMI 039761 = MUCL 29192 = NRRL 976	Fruit of <i>Malus sylvestris</i> , USA	JN121645	
<i>Penicillium fellutanum</i>	CBS 229.81 <sup>NT</sup> = ATCC 10443 = CBS 326.48 = FRR 746 = IFO 5761 = IMI 039734 = IMI 039734iii = NRRL 746	Unknown source, USA	JN121605	
<i>Penicillium funiculosum</i>	CBS 272.86 <sup>NT</sup> = IMI 193019	<i>Lagenaria vulgaris</i> , India	JN680288	JN899377
<i>Penicillium glabrum</i>	CBS 125543 <sup>NT</sup> = IBT 22658 = IMI 91944	Unknown source	JN121717	

Table 1. (Continued).

Name	Collection no.	Origin	GenBank Accession number	
			RPB1	ITS
<i>Penicillium herquei</i>	CBS 336.48 <sup>T</sup> = ATCC 10118 = FRR 1040 = IMI 028809 = MUCL 29213 = NRRL 1040	Leaf, France	JN121647	
<i>Penicillium ilderdanum</i>	CBS 168.81 <sup>T</sup> = IJFM 5596 = IMI 253793	Air, Madrid, Spain		JN899311
<i>Penicillium isariiforme</i>	CBS 247.56 <sup>T</sup> = ATCC 18425 = IMI 060371 = MUCL 31191 = MUCL 31323 = NRRL 2638	Woodland soil, Zaire	JN121616	
<i>Penicillium islandicum</i>	CBS 338.48 <sup>NT</sup> = ATCC 10127 = IMI 040042 = MUCL 31324 = NRRL 1036	Unknown source, Cape Town, South Africa	JN121648	JN899318
<i>Penicillium janthinellum</i>	CBS 340.48 <sup>NT</sup> = ATCC 10455 = IMI 040238 = NRRL 2016	Soil, Nicaragua	JN131650	
<i>Penicillium javanicum</i>	CBS 341.48 <sup>T</sup> = ATCC 9099 = IMI 039733 = MUCL 29099 = NRRL 707	Root of <i>Camellia sinensis</i> , Indonesia, Java	JN121651	
<i>Penicillium kewense</i>	CBS 344.61 <sup>T</sup> = ATCC 18240 = IMI 086561 = MUCL 2685 = NRRL 3332	Culture contaminant of mineral oil CMI 1959; Kew, Surrey, UK	JN121654	
<i>Penicillium korosum</i>	CBS 762.68 <sup>T</sup>	Rhizosphere, India		JN899347
<i>Penicillium lapidosum</i>	CBS 343.48 <sup>T</sup> = ATCC 10462 = IMI 039743 = NRRL 718	Canned blueberry, Washington, USA	JN121653	
<i>Penicillium liani</i>	CBS 225.66 <sup>T</sup> = ATCC 18325 = ATCC 18331 = IMI 098480 = NRRL 3380 = VKM F-301	Soil, China	JN680280	JN899395
<i>Penicillium loliense</i>	CBS 643.80 <sup>T</sup> = ATCC 52252 = FRR 1798 = IMI 216901 = MUCL 31325	<i>Lolium</i> , Palmerston North, New Zealand	JN680314	JN899379
<i>Penicillium marneffeii</i>	CBS 388.87 <sup>T</sup> = ATCC 18224 = CBS 334.59 = IMI 068794ii = IMI 068794iii	<i>Rhizomys sinensis</i> (bamboo rat), Vietnam	JN899298	JN899344
<i>Penicillium minioluteum</i>	CBS 642.68 <sup>T</sup> = IMI 089377 = MUCL 28666	Unknown source	JN121709	JN899346
<i>Penicillium mirabile</i>	CBS 624.72 <sup>T</sup> = CCRC 31665 = FRR 1959 = IMI 167383 = MUCL 31206	Forest soil, Crimea, Ukraine	JN680312	JN899322
<i>Penicillium namylovskii</i>	CBS 353.48 <sup>T</sup> = ATCC 11127 = IMI 040033 = MUCL 29226 = NRRL 1070	Soil under <i>Pinus</i> sp., Puszcza Bialowieska, square "652", Poland	JN121660	
<i>Penicillium oblatum</i>	CBS 258.87 <sup>T</sup> = FRR 2234	Spoiled baby food, Sydney, New South Wales, Australia	JN680285	JN899364
<i>Penicillium ochrosalmoneum</i>	CBS 489.66 = ATCC 18338 = IMI 116248ii	Cornmeal, South Africa	JN121689	
<i>Penicillium osmophilum</i>	CBS 462.72 <sup>T</sup> = IBT 14679	Agricultural soil, Wageningen, Netherlands	JN121683	
<i>Penicillium palmae</i>	CBS 442.88 <sup>T</sup> = IMI 343640	Seed, Wageningen, Netherlands	JN680308	JN899396
<i>Penicillium panamense</i>	CBS 128.89 <sup>T</sup> = IMI 297546	Soil, Barro Colorado Island, Panama	JN899291	JN899362
<i>Penicillium phialosporum</i>	CBS 233.60 <sup>T</sup> = ATCC 18481 = FRR 203 = IMI 078256	Milled Californian rice, California, USA	JN680282	JN899340
<i>Penicillium piceum</i>	CBS 361.48 <sup>T</sup> = ATCC 10519 = IMI 040038 = NRRL 1051	Unknown source		JN899370
<i>Penicillium pinophilum</i>	CBS 631.66 <sup>NT</sup> = ATCC 36839 = CECT 2809 = DSM 1944 = IAM 7013 = IMI 114933	PVC, Centre d'Études du Bouchet, M. Magnoux, France	JN680313	JN899382
<i>Penicillium pittii</i>	CBS 139.84 <sup>T</sup> = IMI 327871	Clay soil, under poplar trees, bank of Duero River, Valladolid, Spain	JN680274	JN899325
<i>Penicillium primulinum</i>	CBS 321.48 <sup>T</sup> = ATCC 10438 = CBS 439.88 = FRR 1074 = IMI 040031 = MUCL 31321 = MUCL 31330 = NRRL 1074	USA	JN680298	JN899317
<i>Penicillium proteolyticum</i>	CBS 303.67 <sup>T</sup> = ATCC 18326 = NRRL 3378	Granite soil, Ukraine	JN680292	JN899387
<i>Penicillium pseudostromaticum</i>	CBS 470.70 <sup>T</sup> = ATCC 18919 = FRR 2039	Feather, near Itasca State Park, Hubbard Co., Minnesota, USA	JN899300	JN899371

Table 1. (Continued).

Name	Collection no.	Origin	GenBank Accession number	
			RPB1	ITS
<i>Penicillium purpurogenum</i>	CBS 286.36 <sup>T</sup> = IMI 091926	Unknown source	JN680271	JN899372
<i>Penicillium purpurogenum</i> var. <i>rubisclerotium</i>	CBS 274.95	Sculpture, castle Troja, Prague, Czech Republic	JN899295	JN899316
	CBS 270.35 <sup>T</sup> = ATCC 4713 = ATCC 52244 = FRR 1064 = IBT 4302 = MUCL 29225 = NRRL 1064 = NRRL 1142	<i>Zea mays</i> , Castle Rock, Virginia, USA	JN680287	JN899381
<i>Penicillium rademirici</i>	CBS 140.84 <sup>T</sup> = CECT 2771 = IMI 282406 = IMI 327870	Air under willow tree, bank of river Duero, Herrera, Valladolid, Spain		JN899386
<i>Penicillium radicum</i>	CBS 100489 <sup>T</sup> = FRR 4718	Root of seedling of <i>Triticum aestivum</i> , Wagga Wagga, New South Wales, Australia		JN899324
<i>Penicillium rotundum</i>	CBS 369.48 <sup>T</sup> = ATCC 10493 = IMI 040589 = NRRL 2107	Wood, Chiriqui Prov., Panama		JN899353
<i>Penicillium rubicundum</i>	CBS 342.59 <sup>T</sup> = ATCC 13217 = IMI 099723 = NRRL 3400	Soil, Georgia, USA	JN680301	JN899384
" <i>Penicillium rubrum</i> "	CBS 196.88 = FRR1714	Unknown source	JN680278	JN899312
	CBS 206.89 = IFO 6580	Japan	JN680279	JN899313
	CBS 263.93	Bronchoalveolair lavage of immunocompetent female patient with pneumonia by <i>Nocardia</i>	JN680286	JN899315
<i>Penicillium rugulosum</i>	CBS 371.48 <sup>T</sup> = ATCC 10128 = IMI 040041 = MUCL 31201 = NRRL 1045	Tuber ( <i>Solanum tuberosum</i> ), Connecticut, USA	JN680302	JN899374
<i>Penicillium sabulosum</i>	CBS 261.87 <sup>T</sup> = FRR 2743	Spoiled pasteurized fruit juice, New South Wales, Sydney, Australia	JN899294	
<i>Penicillium samsonii</i>	CBS 137.84 <sup>T</sup> = CECT 2772 = IMI 282404 = IMI 327872	Fruit, damaged by insect, Valladolid, Spain	JN680273	JN899369
<i>Penicillium shearii</i>	CBS 290.48 <sup>T</sup> = ATCC 10410 = IMI 039739 = IMI 039739iv = NRRL 715	Soil, Tela, Honduras	JN121631	
<i>Penicillium siamense</i>	CBS 475.88 <sup>T</sup> = IMI 323204	Forest soil, Lampang, Thum District, Ban Daen Tham, Thailand		JN899385
<i>Penicillium simplicissimum</i>	CBS 372.48 <sup>NT</sup> = ATCC 10495 = IMI 039816	Flannel bag, Cape, South Africa	JN121662	
<i>Penicillium stipitatum</i>	CBS 375.48 <sup>T</sup> = ATCC 10500 = NRRL 1006 = IMI 39805	Rotting wood, Louisiana, USA	JN680303	JN899348
<i>Penicillium stolckiae</i>	CBS 315.67 <sup>T</sup> = IMI 136210 = ATCC 18546	Peaty forest soil, Eastern Transvaal, South-Africa	JN680295	
<i>Penicillium tardum</i>	CBS 258.37 <sup>T</sup> = NRRL 2116	Unknown source	JN899293	
	CBS 378.48 <sup>T</sup> = ATCC 10503 = IMI 040034 = NRRL 1073	Dead twig, France	JN899297	
<i>Penicillium tularense</i>	CBS 430.69 <sup>T</sup> = ATCC 22056 = IMI 148394	Soil, under <i>Pinus ponderosa</i> and <i>Quercus kelloggii</i> , Tulare Co., Pine Flat, California, USA	JN121681	
<i>Penicillium variabile</i>	CBS 385.48 <sup>NT</sup> = ATCC 10508 = IMI 040040 = NRRL 1048	Cocos fibre, Johannesburg, South Africa	JN680304	JN899343
<i>Penicillium varians</i>	CBS 386.48 <sup>T</sup> = ATCC 10509 = IMI 040586 = NRRL 2096	Cotton yarn, UK	JN680305	JN899368
<i>Penicillium verruculosum</i>	CBS 388.48 <sup>NT</sup> = ATCC 10513 = DSM 2263 = IMI 040039 = NRRL 1050	Soil, Texas, USA		JN899367
<i>Penicillium victoriae</i>	CBS 274.36 <sup>T</sup> = IMI 058412 = MUCL 9651	Dried leaf, Tobaheide, Sumatra	JN680289	JN899393
<i>Penicillium viridicatum</i>	CBS 390.48 <sup>NT</sup> = ATCC 10515 = IBT 23041 = IMI 039758 = IMI 039758ii = NRRL 963	Air, District of Columbia, Washington D.C., USA	JN121668	
<i>Phialosimplex caninus</i>	CBS128032 <sup>T</sup> = UAMH 10337	Bone marrow aspirate ex canine, San Antonio, Texas, USA	JN121587	
<i>Phialosimplex chlamydosporus</i>	CBS 109945 <sup>T</sup> = FMR 7371 = IMI 387422	Disseminated infection in a dog	JN121566	
<i>Phialosimplex sclerotialis</i>	CBS 366.77 <sup>T</sup> = IAM 14794	Fodder of ray-grass and lucerne, France	JN121661	
<i>Rasamsonia eburnea</i>	CBS 100538 <sup>T</sup> = IBT 17519	Soil, Taipei, Taiwan	JN680325	



Table 1. (Continued).

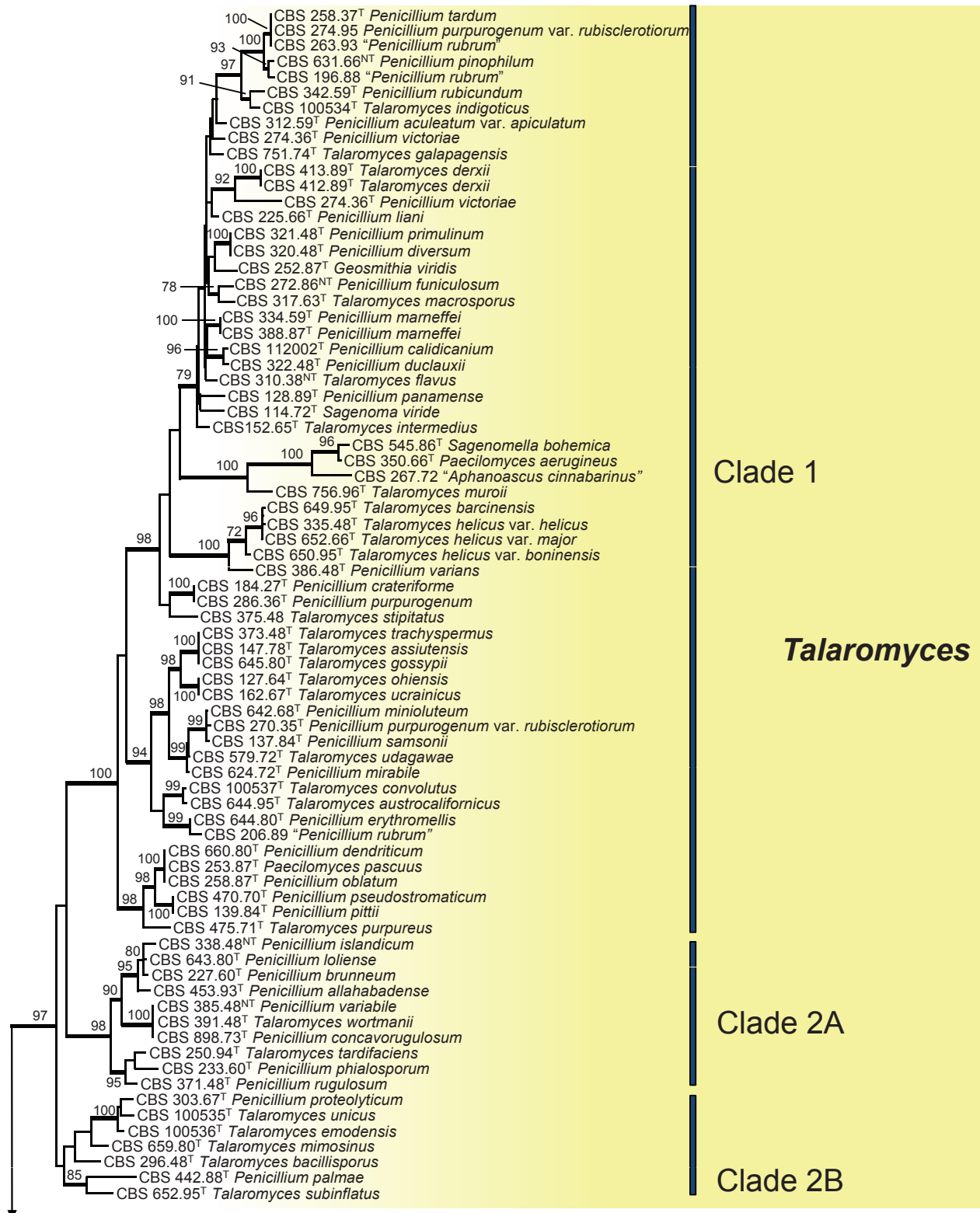
Name	Collection no.	Origin	GenBank Accession number	
			RPB1	ITS
<i>Rasamsonia argillacea</i>	CBS 101.69 <sup>T</sup> = IMI 156096 = IBT 31199	Mine tip with a very high surface temperature; Staffordshire, UK	JN121556	
<i>Rasamsonia byssochlamydoides</i>	CBS 413.71 <sup>T</sup> = IBT 11604	Dry soil under Douglas fir, Oregon, USA	JN121675	
<i>Rasamsonia emersonii</i>	CBS 393.64 <sup>T</sup> = DTO 4811 = IBT 21695 = ATCC 16479 = IMI 116815 = IMI 116815ii	Compost, Italy	JN121670	
<i>Sagenoma viride</i>	CBS 114.72 <sup>T</sup> ATCC 22467 = NRRL 5575	Soil, Australia	JN121571	
<i>Sagenomella bohémica</i>	CBS 545.86 <sup>T</sup> = CCF 2330 = IAM 14789	Peloids for balneological purposes, Frantiskovy Lázně Spa, West Bohemia, Czech Republic	JN121699	JN899400
<i>Sagenomella diversispora</i>	CBS 398.69	Forest soil under <i>Populus tremuloides</i> , Petawawa, Ontario, Canada	JN121673	
	CBS 399.69 = MUCL 15012	Forest soil under <i>Thuja occidentalis</i> , Aberfoyle, Ontario, Canada	JN121674	
<i>Sagenomella griseoviridis</i>	CBS 426.67 <sup>T</sup> = ATCC 18505 = IMI 113160	Unknown source	JN121677	
<i>Sagenomella humicola</i>	CBS 427.67 <sup>T</sup> = ATCC 18506 = IMI 113166	Forest soil under <i>Thuja occidentalis</i> , Ontario, Canada	JN121678	
<i>Sagenomella striatispora</i>	CBS 429.67 <sup>T</sup> = ATCC 18510 = IMI 113163	Soil, Guelph, Ontario, Canada	JN121679	
<i>Sagenomella verticillata</i>	CBS 415.78A	Gymnosperm forest soil, Sweden	JN680307	
<i>Sclerocleista ornata</i>	CBS 124.53 <sup>NT</sup> = ATCC 16921 = IMI 055295 = MUCL 15643 = NRRL 2256	Soil in oak forest, Dane Co., Madison, Wisconsin, USA	JN121581	
<i>Talaromyces assiutensis</i>	CBS 118440	Soil, Fes, Morocco		JN899320
	CBS 147.78 <sup>T</sup>	Soil, amended with crushed buffalo hoofs and incubated for 5 months at 35 °C, Egypt	JN680275	JN899323
<i>Talaromyces austrocalifornicus</i>	CBS 644.95 <sup>T</sup> = IBT 17522	Soil, campus Univ. South California, Los Angeles, USA	JN680316	JN899357
<i>Talaromyces bacillisporus</i>	CBS 296.48 <sup>T</sup> = ATCC 10126 = IMI 040045 = NRRL 1025	Begonia leaf, New York City, New York, USA	JN121634	JN899329
<i>Talaromyces barcinensis</i>	CBS 649.95 <sup>T</sup> = IBT 17518	Soil, Barcelona, Spain	JN680318	JN899349
<i>Talaromyces brevicompactus</i>	CBS 102661 <sup>T</sup> = AS 3.4676	Moulded vegetables, Prov. Sechuan, Wolong, China	JN680326	
<i>Talaromyces convolutus</i>	CBS 100537 <sup>T</sup> = IBT 14989	Soil, Kathmandu, Nepal	JN121553	JN899330
<i>Talaromyces cyanescens</i>	CBS 114900 = FMR 8388	Tortosa, Catalina, Spain		JN899391
<i>Talaromyces derxii</i>	CBS 412.89 <sup>T</sup> = NHL 2981	Cultivated soil, Okayama Prefecture, Kurashiki City, Higashitomi, Japan	JN680306	JN899327
	CBS 413.89 <sup>T</sup> = NHL 2982	Cultivated soil, Okayama Prefecture, Kurashiki City, Higashitomi, Japan	JN899299	JN899326
<i>Talaromyces emodensis</i>	CBS 100536 <sup>T</sup> = IBT 14990	Soil, Kathmandu, Nepal	JN121552	JN899337
<i>Talaromyces flavus</i>	CBS 310.38 <sup>NT</sup> = IMI 197477 = NRRL 2098	Unknown substrate, New Zealand	JN121639	JN899360
<i>Talaromyces galapagensis</i>	CBS 751.74 <sup>T</sup> = IFO 31796	Shaded soil under <i>Maytenus obovata</i> , Isla Santa Cruz, Galapagos Islands, Ecuador	JN680321	JN899358
<i>Talaromyces gossypii</i>	CBS 645.80 <sup>T</sup> = FRR 1966 = IMI 198365	<i>Gossypium</i> , India	JN680317	JN899334
<i>Talaromyces helicus</i> var. <i>boninensis</i>	CBS 650.95 <sup>T</sup> = IBT 17516	Lawn soil, Kominato, Chichijima, Ogasawara-mura, Tokyo-to, Japan	JN680319	JN899356
<i>Talaromyces helicus</i> var. <i>helicus</i>	CBS 335.48 <sup>T</sup> = ATCC 10451 = DSM 3705 = IMI 040593 = NRRL 2106	Soil, Sweden	JN680300	JN899359
<i>Talaromyces helicus</i> var. <i>major</i>	CBS 652.66 <sup>T</sup> = IMI 100914	Swamp soil, near Attenborough, Nottingham, UK	JN680320	JN899335
<i>Talaromyces indigoticus</i>	CBS 100534 <sup>T</sup> = IBT 17590	Soil, Nagasaki-ken, Minamikushiyama-mura, Japan	JN680323	JN899331
<i>Talaromyces intermedius</i>	CBS 152.65 <sup>T</sup> = BDUN 267 = IFO 31752 = IMI 100874	Alluvial pasture and swamp soil, Attenborough, Nottingham, England	JN680276	JN899332

Table 1. (Continued).

Name	Collection no.	Origin	GenBank Accession number	
			RPB1	ITS
<i>Talaromyces leycettanus</i>	CBS 398.68 <sup>T</sup> = ATCC 22469 = IMI 178525	Coal spoil tip soil, Leycett, Staffordshire, England, UK	JN121672	
<i>Talaromyces luteus</i>	CBS 348.51 <sup>NT</sup> = IMI 089305	Soil, UK	JN121656	
<i>Talaromyces macrosporus</i>	CBS 317.63 <sup>T</sup> = FRR 404 = IMI 197478	Apple juice, Stellenbosch, South Africa	JN680296	JN899333
<i>Talaromyces mimosinus</i>	CBS 659.80 <sup>T</sup> = FRR 1875 = IMI 223991	Soil from creek bank, Nattai River, New South Wales, Australia	JN899302	JN899338
<i>Talaromyces muroii</i>	CBS 756.96 <sup>T</sup> = PF 1153	Soil, Hualien County, Chingpu, Taiwan	JN680322	JN899351
<i>Talaromyces ocotl</i>	CBS 102855 <sup>T</sup>	Heat-treated soil from forest of <i>Pinus hartwegii</i> , Veracruz, Mexico	JN680327	
<i>Talaromyces ohioensis</i>	CBS 127.64 <sup>T</sup>	Soil treated with cyanamide, Germany	JN680272	JN899355
<i>Talaromyces purpureus</i>	CBS 475.71 <sup>T</sup> = ATCC 24069 = ATCC 52513 = FRR 1731 = IMI 181546	Soil, near Esterel, France	JN121687	JN899328
<i>Talaromyces subinflatus</i>	CBS 652.95 <sup>T</sup> = IBT 17520	Copse soil, Hahajima, Ogasawara-mura, Tokyo-to, Japan	JN899301	JN899397
<i>Talaromyces tardifaciens</i>	CBS 250.94 <sup>T</sup>	Unknown source	JN680283	JN599361
<i>Talaromyces thermophilus</i>	CBS 236.58 <sup>T</sup> = ATCC 10518 = IMI 048593 = NRRL 2155	<i>Parthenium argentatum</i> , decaying plant; California, USA	JN121611	
<i>Talaromyces trachyspermus</i>	CBS 373.48 <sup>T</sup> = ATCC 10497 = IMI 040043 = NRRL 1028	Unknown source, USA	JN121664	JN899354
<i>Talaromyces ucrainicus</i>	CBS 162.67 <sup>T</sup> = ATCC 22344 = FRR 3462	Unknown source	JN680277	JN899394
<i>Talaromyces udagawae</i>	CBS 579.72 <sup>T</sup> = FRR 1727 = IMI 197482	Soil, Misugimura, Japan	JN680310	JN899350
<i>Talaromyces unicus</i>	CBS 100535 <sup>T</sup> = CCRC 32703 = IBT 18385	Soil, Chiayi County, Funlu, Taiwan	JN680324	JN899336
<i>Talaromyces wortmanii</i>	CBS 391.48 <sup>T</sup> = ATCC 10517 = IMI 040047 = NRRL 1017	Unknown source	JN121669	JN899352
<i>Thermoascus aurantiacus</i>	CBS 396.78	Sawdust, in lumber yard, Toronto, Ontario, Canada	JN121671	
	CBS 891.70 = IMI 173037	Wood, Firenze, Italy	JN121719	
<i>Thermoascus crustaceus</i>	CBS 181.67 <sup>T</sup> = ATCC 16462 = IMI 126333	<i>Parthenium argentatum</i> , decaying plant; Salinas, California, USA	JN121591	
<i>Thermoascus thermophilus</i>	CBS 528.71 <sup>NT</sup> = IMI 123298 = NRRL 5208	Wood and bark of <i>Pinus</i> , Sweden	JN121697	
<i>Thermomyces lanuginosus</i>	CBS 218.34 = MUCL 8338	Fruit shell of <i>Theobroma cacao</i>	JN121599	
	CBS 224.63 = MUCL 8337	Mushroom compost; Gossau-Zürich Switzerland	JN121602	
	CBS 288.54 = MUCL 8340	Stomach of bovine foetus, Netherlands	JN680291	
<i>Trichocoma paradoxa</i>	CBS 103.73	Unknown source, Japan	JN121558	
	CBS 247.57 = MUCL 39666 = IBT 31159	Unknown source, Hachijō, Japan	JN121617	
	CBS 788.83	Rotting stump of cut down tree, Myoji Temple near Hakui Noto Park, Ishikawa Pref., Japan	JN121718	JN899398
<i>Warcupiella spinulosa</i>	CBS 512.65 <sup>NT</sup> = ATCC 16919 = IMI 075885 = NRRL 4376	Jungle soil, Berakas-Muara, Brunei	JN121692	

completely undetermined characters in the alignment was 0.60 %. Figure 1 shows that members of the subgenus *Biverticillium* and *Talaromyces* are accommodated in a well-supported (97 % bs), monophyletic clade (= *Talaromyces* s. str.) and that species of the *Penicillium* subgenera *Aspergilloides*, *Furcatum* and *Penicillium* form an independent, well-supported clade (*Penicillium* s. str.). The majority of described *Talaromyces* species belong to *Talaromyces* s. str., but some species are dispersed in other clades, including *Talaromyces ocotl*, *T. luteus*, *T. thermophilus*, *T.*

*eburneus*, *T. emersonii*, *T. byssochlamydoides*, *T. spectabilis*, *T. brevicompactus*, *T. striatus* and *T. leycettanus*. *Talaromyces ocotl* is in a well-supported clade with the type species of *Sagenomella*, *S. diversispora*, and other *Sagenomella* species. The former *T. emersonii*, *T. eburneus* and *T. byssochlamydoides* form a clade recently recognised and described as the genus *Rasamsonia* (Houbraken *et al.* 2011). *Talaromyces thermophilus* is also excluded from *Talaromyces* s. str. and is closely related to the type species of *Thermomyces*, *Therm. lanuginosus*. Basal to *Therm. lanuginosus*



**Fig. 1.** Best-scoring Maximum Likelihood tree calculated using RAxML, based on partial *RPB1* sequences showing the relationships among members of *Talaromyces* and *Penicillium* subgenus *Biverticillium* and related genera. The bootstrap support percentages of the maximum likelihood (ML) analysis are presented at the nodes. Bootstrap support values less than 70 % are not shown and branches with bootstrap support values > 70 % are thickened. The bar indicates the number of substitutions per site. The tree is rooted with *Coccidioides immitis* (strain RS).

and *T. thermophilus* is *Talaromyces luteus*. This species is on a separate branch and no other closely related species were found in our analysis. The uniqueness of the species is supported by the production of large amounts of the prenylated diketopiperazines talathermophilins A and B, not found in any other species (Chu *et al.* 2010). The phylogenetic position of *T. leycettanus* is not convincingly defined. This species is positioned near *Warcupiella*

*spinulosa* and *Hamigera striata* (= *Talaromyces striatus*), but bootstrap support is lacking. *Talaromyces brevistipitatus* occurs on a well-supported branch with *H. avellanea*. Comparison of ITS and calmodulin sequences shows that this species is closely related to NRRL 2108, an undescribed, phylogenetically distinct *Hamigera* species (ITS 100 % bs, calmodulin 99 % bs) (Peterson *et al.* 2010). The majority of members of subgenus *Biverticillium sensu*

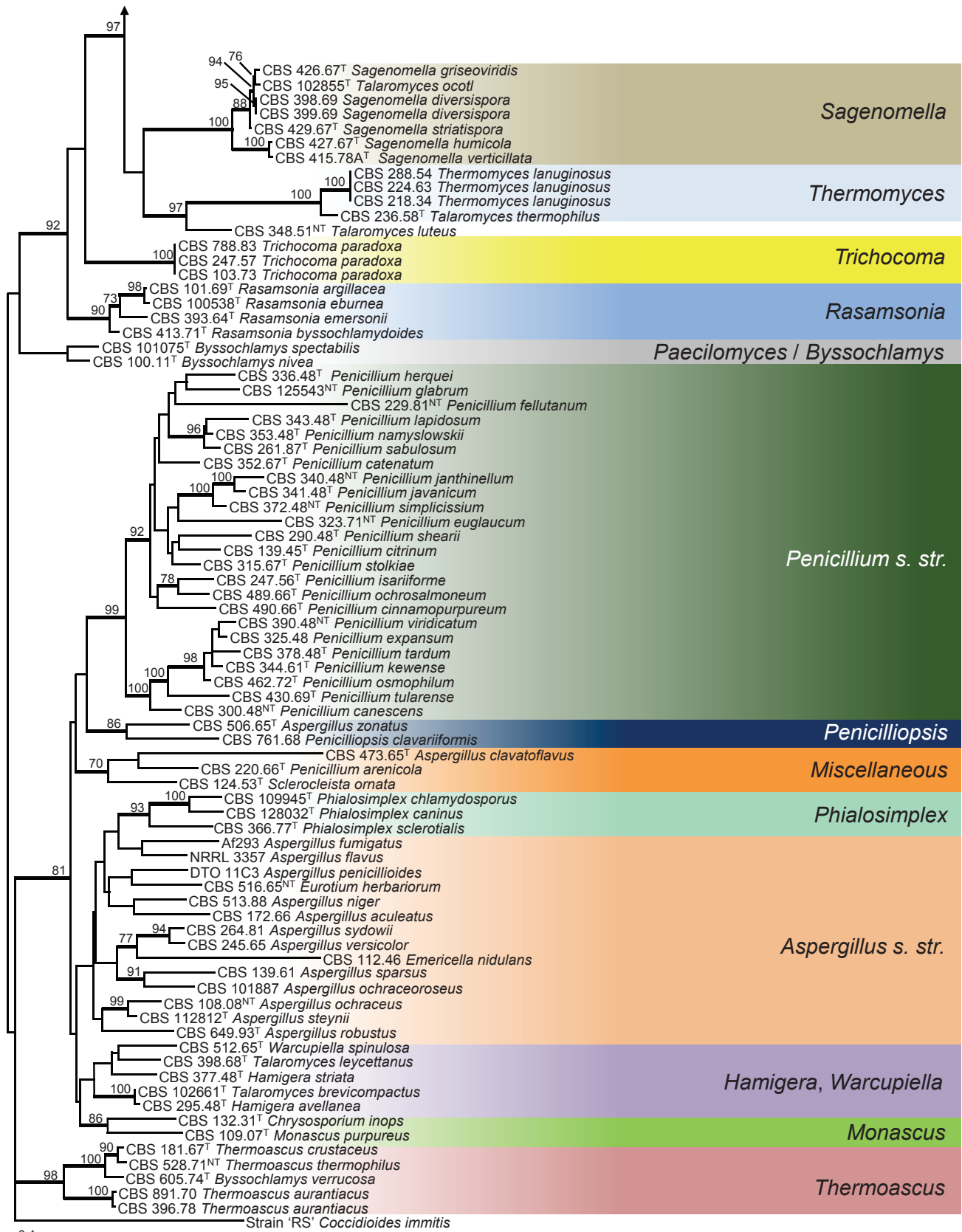


Fig. 1. (Continued).

Pitt (1980) are phylogenetically placed within *Talaromyces* s. str., with *P. isariiforme* as the only exception. This species belongs to *Penicillium* s. str. and is closely related to *P. ochrosalmoneum*. This relationship was also confirmed by extrolite data (see below).

Figure 1 indicates that the following species phylogenetically belong in *Talaromyces*: *Aphanoascus cinnabarinus* (CBS 267.72),

*Sagenomella bohémica* (CBS 545.86<sup>T</sup>), *Paecilomyces aerugineus* (CBS 350.66<sup>T</sup>), *Geosmithia viridis* (CBS 252.87<sup>T</sup>) and *Sagenomella viride* (CBS 114.72<sup>T</sup>). The former three strains are on a well-supported sister clade basal to *Talaromyces muroii* CBS 756.96.



## Species delimitation and synonymies within *Talaromyces*

The ITS analysis (Fig. 2) was used in this study to provide a preliminary circumscription of the species belonging to the *Talaromyces* clade. Ninety-seven strains were included in the ITS analysis. The used primer pair V9G and LS266 also amplifies a part of the 18S and 28S rDNA; however, for analysis, only the span including the ITS regions and 5.8S rDNA was used. The length of the alignment was 483 characters and 221 characters were variable.

Most bootstrap support values in the ITS analysis are low, less than 70 %. Only a few branches are supported with values higher than 70 %. The majority of *Talaromyces* species are on a branch with 96 % bootstrap support (clade 1, Fig. 2). This clade is also present in the *RPB1* analysis (100 % bs). Another large clade was present in the ITS phylogram and this clade is supported with 96 % bootstrap (clade 2). This clade can be divided in two subclades (2A and 2B), both present in the *RPB1* analysis; however, the relationship among these subclades is not supported statistically. *Talaromyces dendriticus*, *T. oblatus*, and *Paecilomyces pascuus* are in the same lineage and the former two species share the same ITS sequence. *Talaromyces assiutensis* and *T. gossypii* also have similar ITS sequences and are phenotypically similar (Frisvad et al. 1990a).

## Extrolite analysis

In general, *Talaromyces* species produce many biosynthetic families of polyketides and meroterpenoids, but rather few families of nonribosomal peptides and terpenes. By examining HPLC-DAD results from all described species of *Penicillium*, *Aspergillus* and their teleomorphs, and by searching the literature for families of exometabolites produced by these fungi, it is obvious that *Talaromyces* species have unique and specific extrolites (Table 2). Figure 3 shows the common exometabolite families in *Talaromyces*/*Biverticillium*, *Penicillium*, *Aspergillus* and other genera. *Aspergillus* and *Penicillium* share 91 biosynthetic families, but shares more of these with other fungal genera than with *Talaromyces*. A few exometabolites are shared among *Talaromyces*, *Penicillium* and *Aspergillus* including alternariols, asperphenamate, botryodiploidin, dehydrocarolic acid, emodins, geodins, gregatins, herqueinone, 3-hydroxyphthalic acid, italinic acid, lichexanthones, mellein, monordens, pinselin, rugulosuvines, rugulovasines, secalonic acids and zeorins. Most of these metabolites have relatively simple structures, and many occur in other genera less related phylogenetically to any of the penicilloid and aspergilloid genera. Considering the large number of shared exometabolite biosynthetic families in common between *Penicillium* and *Aspergillus*, *Talaromyces* is clearly different, which corresponds with all other data for these genera.

Among the few extrolites shared by *Penicillium*, *Aspergillus* and *Talaromyces* are the ergochromes, secalonic acid D & F. These anthraquinone derived metabolites are found in *P. isariiforme*, *P. chrysogenum*, *Aspergillus aculeatinus*, *P. dendriticum* and *P. pseudostromaticum* (Samson et al. 1989, Frisvad & Samson 2004, Houbraken et al. 2011). It is also possible that there are optical antipodes of these compounds produced in these genera, as was found in *Aspergillus versicolor* ((+) versicolamide) and *A. sclerotiorum* ((-)-versicolamide) (Williams 2011). If this is so, it may indicate that the extrolites of *Talaromyces* and *Penicillium* /

*Aspergillus* may also differ in stereochemical aspects. Another example of shared yet different extrolites is the azaphilones, which are common in species of *Talaromyces* and related biverticillate anamorphic species (Frisvad et al. 1990a, Nicoletti et al. 2009, Osmanova et al. 2010), but could not be found in *Aspergillus* and *Penicillium sensu stricto*. When similar compounds were found in *Talaromyces*, stereoisomers of the compounds were found in *Aspergillus* and *Penicillium*. For example, while sclerotiorins occur in *P. sclerotiorum*, the epimers are found in *Talaromyces helicus* and *T. luteus* (Yoshida et al. 1995, 1996a, b). Austdiol was isolated from *Aspergillus pseudoustus* (Vleggaar et al. 1974, Samson et al. 2011), but 7-epi-austdiol from a *Talaromyces* species (Liu et al. 2010).

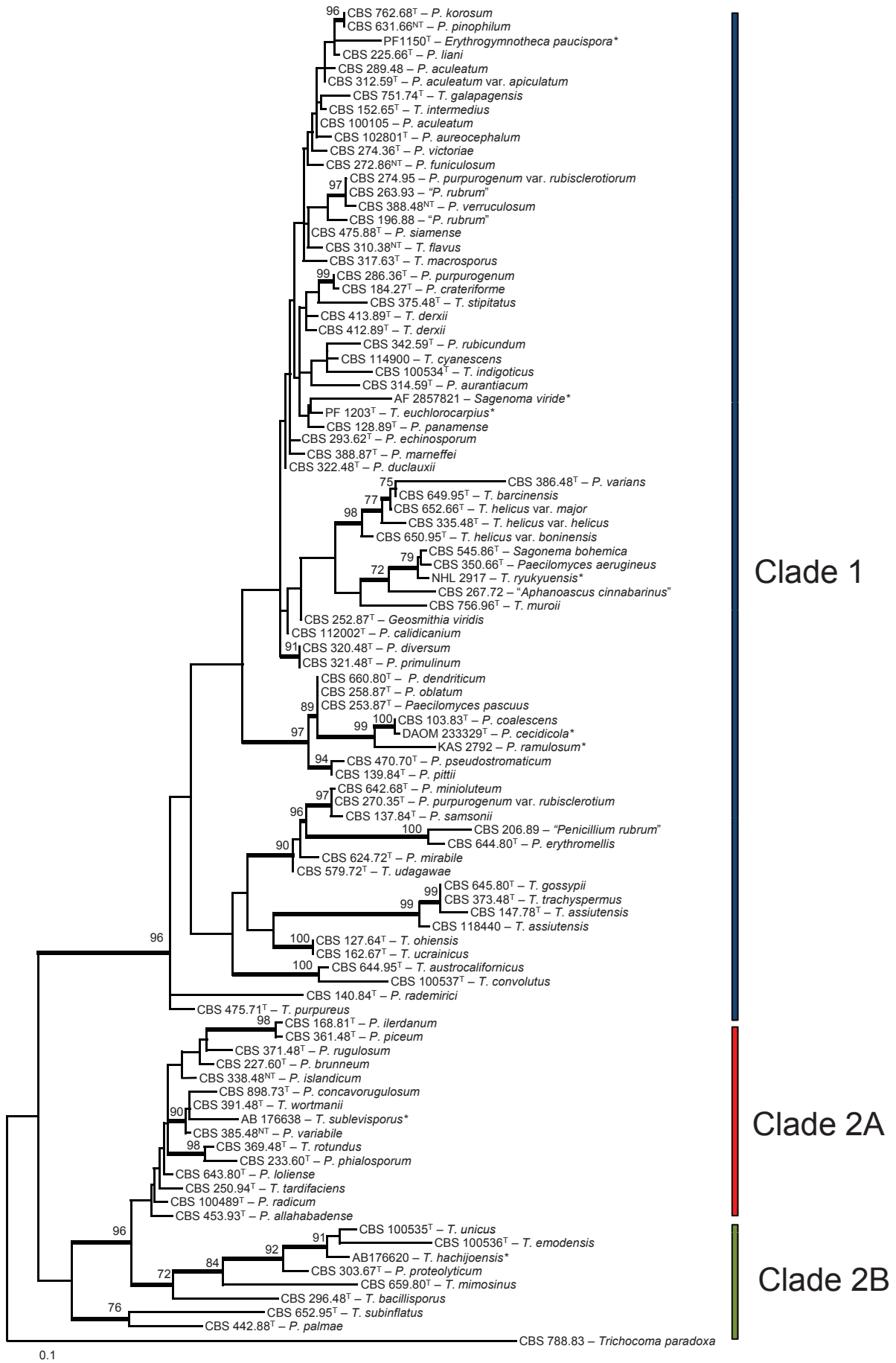
Misidentifications of strains can make these comparisons difficult, but the overwhelming majority of extrolites found in *Talaromyces* are not found in *Aspergillus* or *Penicillium*. Although vermistatins, penisimplisins, penisimplicissins were reported from *Penicillium simplicissimum* (Komai et al. 2005), the producing strain was misidentified and actually represents a species of *Talaromyces*. The opposite has also happened, and metabolites attributed to a species of subgenus *Biverticillium* are later found to be produced by species of *Penicillium sensu stricto*. *Penicillium verruculosum* was reported to produce verruculogen, hence the name (Cole et al. 1972, Cole & Kirksey 1973), but the strain was later reidentified as *P. brasilianum* (Frisvad 1989).

*Penicillium isariiforme* (Samson et al. 1989) and *P. ochrosalmoneum* (Wicklow & Cole 1984) both produce large amounts of citreoviridin, supporting their close relationship indicated by the phylogenetic analyses, as noted above (Fig. 1).

## DISCUSSION

The symmetrical, biverticillate penicillus was used as a defining character by Wehmer (1914), and Thom (1915a, b). Wehmer (1914) proposed to call this group the Verticillata, while Thom (1915a) referred to it as the *Penicillium luteum-purpurogenum* group. Biourge (1923) was the first who named this group as the subgenus *Biverticillium*, but included species such as *P. citrinum* (as *P. aurifluum*), *P. atramentosum* etc., which are no longer regarded as members of this subgenus (Houbraken et al. 2010). The characteristic lanceolate or acrose phialides was used as a more definitive morphological character of subgenus *Biverticillium* and related *Talaromyces* anamorphs (Raper & Thom 1949), because biverticillate branched conidiophores with flask-shaped phialides are mainly found in unrelated species such as *P. citrinum*. Although the lanceolate phialides occur in most species of subgenus *Biverticillium*, some species, e.g. *P. rugulosum*, have phialides that are not slender and have an apical portion tapering into a long acuminate point.

Thom (1930) treated some of the *Penicillia* in his *Biverticillate-Symmetrica* group and distinguished four sections: *Ascogena*, *Coremigena*, *Luteo-virida* (*Funiculosa* and *Luteo-purpurogena*) and *Miscellanea*. Later Raper & Thom (1949) subdivided the group into the *P. luteum* series, *P. duclauxii* series, *P. funiculosum* series, *P. purpurogenum* series, *P. rugulosum* series and *P. herquei* series. This grouping is inconsistent with our phylogenetic analysis of the biverticillate group. The classification proposed by Pitt (1980) is more in concordance with the phylogenetic and taxonomic treatment proposed here, although he included a few species in *Penicillium* subgenus *Biverticillium*, namely *P. isariiforme*, *P. clavigerum* and



**Fig. 2.** Best-scoring Maximum Likelihood tree calculated using MEGA 5.0 based on ITS sequences showing the relationship among members of the *Talaromyces* and members of *Penicillium* subgenus *Biverticillium*. The bootstrap support percentages of the maximum likelihood (ML) analysis are presented at the nodes. Bootstrap support values less than 70 % are not shown and branches with bootstrap support values > 75 % are thickened. The bar indicates the number of substitutions per site. The tree is rooted with *Trichocoma paradoxa* (CBS 788.83). *T.* = *Talaromyces*; *P.* = *Penicillium*. Strains indicated with \* are ITS sequencing obtained from GenBank.

**Table 2.** Secondary metabolite (exometabolite) biosynthetic families known from *Talaromyces* and *Penicillium* subgenus *Biverticillium*. (P) means also found in *Penicillium* and its teleomorphic state *Eupenicillium*, (A) means also found in species of *Aspergillus*. (Others) means also found in other fungi outside *Penicillium*, *Aspergillus*, *Talaromyces* and related genera.

Secondary metabolite (exometabolite) biosynthetic families		
AF-110	5-Hydroxymethylfurfural	Purpurogenones
Alternariols * (P and others)	Hydromethylmaltol	Rasfonin
Anthglutin	4-Hydroxy-4,5-dicarboxy pentadecanoic acid ( <i>T. spiculisporus</i> )	Rubratoxins
Apiculides (incl. NG-011's * (others))	7-Hydroxy-2,5-dimethylchromane	Rugulosins (& flavoskyrin) * (others)
AS-186-G	3-Hydroxymethyl-6,8-dimethoxycoumarin	Rugulotrosins
Asperphenamates & asperglauclid * (A, P)	3-Hydroxyphthalic acid * (P)	Rugulosuvine * (P)
Atrovetinin methyl acetal ( <i>P. verruculosum</i> )	Islandic acids	Rugulovasines * (P)
Epi-Austdiols (7-epiaustdiol & 8-O-methylepiaustdiol) (the stereoisomer austdiol found in <i>Aspergillus</i> )	(+)-Isocitric acid + Decylcitric acid ( <i>T. spiculisporus</i> )	Secalonic acids * (A, P, others)
Austins * (A, P)	Italinic acids * (P)	Speciferone* (others)
BE-24811	Juglones	Spiculisporic acids (= minioluteic acids)
BE-31405's	Lichexanthone * (others)	SQ 30957
Berkeleyamides	Luteusins	Stemphyperylene
Botryodipoidin * (P & others)	Maculosin * (others)	Stipitatic acids
Chrodinanine A	Mellein * (A)	Talaperoxides
Cordyanhydrides	Methyl-4-carboxy-5-hydroxyphthalaldehyde	Talaroconvolutins
Cyclochlorotines & islanditoxin	3-Methyl-6-hydroxy-8-methoxy-3,4-dihydroisocoumarins	Talaroderxine
Dehydrocarolic acids * (A, P)	Miniolutelides, berkeleydione, berkeleytriones, berkeleyacetals, dhilirolides	Talaroflavones
Diethylphthalate (Artefact?)	Mitorubins & kasanosins & funicones	Talaromycins
5,6-Dihydro-3,5-dihydroxy-6-hydroxymethyl-2H-pyran-2-one	Monascins & monascorubramin	Talarotoxins
4,6-Dihydroxy-5-methylphthalide	Monordens * (A, others)	TAN-931
(2E,2E',7S,7'E)-4,9-Dioxo-7-(4',9'-dioxo-2',7' decadienoyloxy)-2-decanoic acid	NG-061	Thailandolides
Diversonols	NK-374200	Trachyspermic acids
Duclauxins	OF-4949's	Trachyspic acid
Emodins * (A, P, others)	Penicillipsin * (others)	Triacetic lactone
Erythroskyrins	Penisimplicins	(-)-2,3,4-Trihydroxy-butanamide
Flavomannin	Penisimplicissins	Vermicellins
Funiculosic acids	Penitric acid & penitricins	Vermiculins
Funiculosin	Pevalic acid	Vermilutins
Geodins * (A, P)	PF-1092A	Vermistatins & penicidones
Glauconic acids	Pinselic acid	Vertoskyrin
Gregatins and penicilliois * (A, P)	Pinselins * (A, others)	Wortmannilactones
Helicusins	Purpactins (= penicillides = vermioxocins)	Wortmannins * (others)
Herqueinones* (P)	Purpuride	Xanthoradones
		Zeorins * (A, others)

*P. vulpinum* (as *P. claviforme*) that are now classified in *Penicillium sensu stricto*. The same conclusion was shown by the early molecular results of LoBuglio & Taylor (1993), and subsequently supported by the physiological, morphological and extrolite characters reviewed in the Introduction, and generated during this study.

In general, *Penicillium sensu stricto* and *Aspergillus* share many more features with each other than they do with *Talaromyces*. This includes micro- and macro-morphology, good growth on low water activity media, and the many shared exometabolite families. *Talaromyces* produces a series of metabolites that are apparently unique to this genus (J.C. Frisvad unpubl. data). The characteristic yellow and red colony and mycelial colours in *Talaromyces* are often caused by accumulation of mitorubins and other azaphilones

and unique anthraquinones and mitorubins that are not found in *Aspergillus* and *Penicillium*. Some azaphilones are found in *Penicillium sclerotiorum* and *Penicillium hirayamae*, but only their optical antipodes are found in *Talaromyces*.

### ***Penicillium* and *Talaromyces* species excluded from the revised *Talaromyces* genus**

Figure 1 shows that a number of species described in the genus should be excluded from *Talaromyces s. str.* Phylogenetically, *T. ocofl* CBS 102855<sup>T</sup> belongs to *Sagenomella*, as also suggested using phenotypic characters (Heredia *et al.* 2001). The anamorph of this species was not formally named, described only as



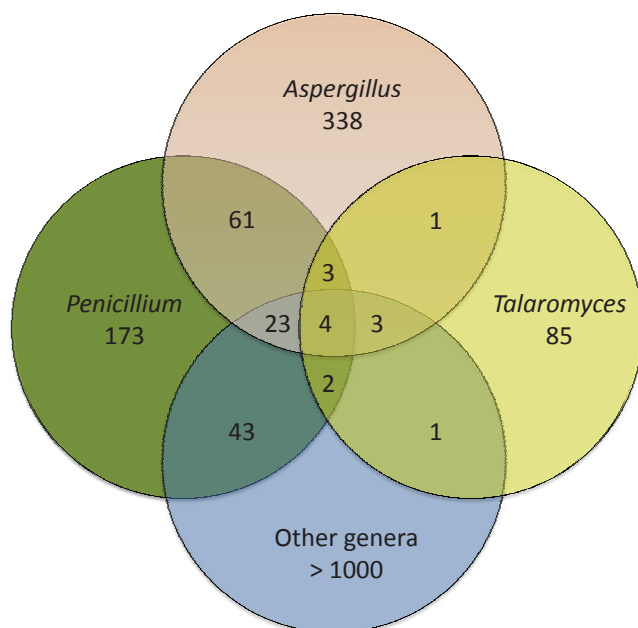


Fig. 3. Common exometabolite families in *Talaromyces/Biverticillium*, *Penicillium*, *Aspergillus* and other genera.

*Sagenomella* sp., and thus the new combination *Sagenomella ocofl* is proposed in the taxonomy section below.

Our analysis confirms the distinctiveness of the recently described genus *Rasamsonia* erected for thermotolerant or thermophilic species with distinctly rough-walled conidiphore stipes, olive-brown conidia, and ascomata, if present, with a scanty hyphal covering. *Talaromyces eburneus*, *T. emersonii*, *T. byssochlamydoides* were assigned to this genus, together with the anamorphic species originally described as *Geosmithia argillacea* and *G. cylindrospora* (Houbraken *et al.* 2011).

*Talaromyces thermophilus* is the only member of *Talaromyces* section *Thermophila* (Stolk & Samson 1972). LoBuglio *et al.* (1993) already noted that this species is the most divergent *Talaromyces* species, occupying a basal position to the major *Talaromyces* clade. Houbraken *et al.* (2011) showed that this species is closely related to *Thermomyces lanuginosus* and our partial *RPB1* sequence data confirm this relationship (Fig. 1). We did not examine type material of *Talaromyces thermocitrinus* (as '*thermocitrinum*') and the conclusion of Mouchacca (2007), who tentatively placed this species in synonymy with *T. thermophilus*, is not followed here. *Talaromyces luteus* is further basal to *T. thermophilus* and *Therm. lanuginosus* and this species might represent a distinct genus. For the present, *T. thermophilus* and *T. luteus* will be retained in *Talaromyces*. More research is needed to confirm whether the assignment of these species to *Thermomyces* is warranted.

Udagawa & Suzuki (1994) described *Talaromyces spectabilis* with a *Paecilomyces* anamorph. Houbraken *et al.* (2008) transferred this species to *Byssochlamys* and showed that it is the teleomorph of *Paec. variotii*. In a single name system, *Paec. variotii* is the oldest genus and species name for this taxon, and thus the correct name for the holomorph.

*Talaromyces brevicompactus*, *T. striatus* (= *Hamigera striata*) and *T. leycettanus* are distant from *Talaromyces s. str.* and phylogenetically more closely related to *Penicillium s. str.* and *Aspergillus*. Figure 1 shows that *H. striata* and *T. leycettanus* are closely related. Further phylogenetic support for this relationship was presented in the studies of Ogawa & Sugiyama (2000) and Houbraken & Samson (2011). These two species are phylogenetically distant from

*Talaromyces s. str.* and more closely related to *Hamigera*. Peterson *et al.* (2010) delimited *Hamigera* phylogenetically but stated that *T. leycettanus* and *H. striata* do not belong to this genus, and followed Benjamin's (1955) placement of *H. striata* in *Talaromyces*. In this study, we retain *H. striata* and *T. leycettanus* in *Hamigera* and *Talaromyces*, respectively. A thorough study on *Hamigera* and related genera is needed to clarify the correct placement of these species. Kong (1999) described *Talaromyces brevicompactus*, stating that this species is closely related to *Hamigera avellanea* (as *Talaromyces avellaneus*). The anamorph of this species was described in *Merimbla*, thus confirming the relationship with *Hamigera*. Sequence comparisons of this species showed that it is similar to NRRL 2108, a phylogenetically undescribed *Hamigera* species (J. Houbraken, unpubl. data, Peterson *et al.* 2010). We wait with combining this species in *Hamigera* until a more data and strains become available.

### Species described in other genera but phylogenetically within *Talaromyces*

Phylogenetic analysis shows that "*Aphanoascus cinnabarinus*", *Sagenomella bohemica*, *Paecilomyces aerugineus*, *Geosmithia viridis* and *Sagenoma viride* belong to *Talaromyces*. The genus *Sagenoma* is typified with *S. viride*, and therefore this genus can be considered as a synonym of *Talaromyces*. Our data support the conclusions of von Arx (1987), who correctly transferred this species in *Talaromyces*, and this is reflected in the taxonomy section below.

Houbraken & Samson (2011) discussed the confusion over *Aphanoascus cinnabarinus*, which has persisted since the description of the genus *Aphanoascus* by Zukai (1890). Most authors follow Apinis (1968) and consider the genus *Aphanoascus* to be typified by *A. fulvescens* Zukai. In addition, the neotypification of *A. cinnabarinus* by Udagawa & Takada (1973) was incorrect, because their neotype strain had a *Paecilomyces* anamorph, whereas Zukai's original description and illustrations clearly showed a *Chrysosporium*-like anamorph (Stolk & Samson 1983). Based on morphological features, Stolk & Samson (1983) indicated that *Chromocleista cinnabarina* (as *A. cinnabarinus sensu* Udagawa & Takada) belongs to the *Eurotiales* and suggested that this species is intermediate between *Thermoascus* and *Talaromyces*. Our phylogenetic study, and that of Houbraken & Samson (2011), clarified that *C. cinnabarina* belongs to *Talaromyces s. str.* The taxonomic position of *Chromocleista cinnabarina* (as *A. cinnabarinus sensu* Udagawa & Takada) will be discussed in a forthcoming paper. *Paecilomyces aerugineus* was proposed by Samson (1974) for *Spicaria silvatica* Oudemans *sensu* Apinis. This species resembles the anamorph of *A. cinnabarinus sensu* Udagawa & Takada and a more detailed study is necessary to clarify this relationship.

### TAXONOMY

*Penicillium* itself has a long list of generic synonyms (see Seifert *et al.* 2011) that must be considered for the species formerly included in subgenus *Biverticillium*. These synonyms of *Penicillium* are discussed in the Appendix to this paper. As it turns out, none of these are appropriate for subgenus *Biverticillium*, leaving the comparatively young *Talaromyces* as the oldest well-known generic name as the new home for the anamorphic species of subgenus *Biverticillium*.



Yaguchi *et al.* (1994a) introduced *Erythrogymnotheca* for the single species *E. paucispora*. No specimens of *E. paucispora* were studied; however, examination of the available ITS data on GenBank and the original description shows that this species belongs in *Talaromyces*. As a consequence, *Erythrogymnotheca* is synonymised with *Talaromyces*. Comparison of an ITS sequence of *E. paucispora* (AB176603) shows that it is related to *P. korosum*, *P. pinophilum* and *P. liani* in *Talaromyces* (Fig. 2). The original description suggests that *Talaromyces* and *Erythrogymnotheca* differ in ascus characteristics and ascospore morphology. However, these genera also share characters. The ascomatal initials of *E. paucispora* approximate those of *Talaromyces flavus* and other species of *Talaromyces*. Furthermore, *E. paucispora* produces a loose hyphal yellow- or red-pigmented ascomata similar to those of other *Talaromyces* species and the main ubiquinone systems are Q-10 and Q-10 (H<sub>2</sub>), also indicating a relationship with *Talaromyces* (Paterson 1998, Yaguchi *et al.* 1994a).

Matsushima (2001) described *Paratalaromyces* from soil collected in Taiwan, distinguishing it by a distinct *textura epidermoidea* layer in the ascomatal wall, and the presence of spinulose marginal hyphae. We have not seen the type but the description of *Paratalaromyces lenticularis* is similar to that of *Talaromyces unicus* (Tzean *et al.* 1992). We consider the genus a synonym here.

Visagie & Seifert (unpubl. data) report on the generic name *Lasioderma* Mont., typified by *L. flavo-virens* Durieu & Mont., which is conspecific with *Penicillium aureocephalum* Munt.-Cvetk., Hoyo & Gómez-Bolea. The name *Lasioderma* is widely used as an insect genus, and a formal proposal for the conservation of *Talaromyces* against this older name is being prepared.

#### **Talaromyces** C.R. Benj., Mycologia 47: 681. 1955.

- = *Penicillium* Link subgenus *Biverticillium* Dierckx *apud* Biourge Cellule 33: 31. 1923.
- = *Penicillium* subg. *Biverticillata-Symmetrica* Thom, The Penicillia: 158. 1930.
- = *Sagenoma* Stolk & G.F. Orr, Mycologia 66: 676. 1974.
- = *Erythrogymnotheca* Yaguchi & Udagawa, Mycoscience 35: 219. 1994.
- = *Paratalaromyces* Matsush., Matsush. Mycol. Mem. 10: 111 (2003) [2001].

*Ascomata* cleistothecial, usually with a distinctly hyphal exterior wall, often yellow, occasionally white, creamish, pinkish or reddish. *Asci* 8-spored, globose to ellipsoidal, ascus initials sometimes with morphologically distinguishable gametangia, mature asci produced in chains. *Ascospores* one-celled, rarely smooth-walled, but often with surface ornamentation and wings, hyaline to yellow, in strains producing abundant red pigment occasionally red. *Conidiophores* comprising smooth or rough-walled elements, with long hyaline stipes, generally terminating in a single whorl of 3–10 metulae, appearing symmetrical in face view (in some species with a single subterminal lateral branch that afterwards repeats the branching pattern of the main axis, but then with the whole conidiophore appearing asymmetrical), each metula with a terminal whorl of phialides. *Conidiogenous cells* phialidic, aculeate or acerose, rarely ampulliform, periclinal thickening usually visible in the conidiogenous aperture, with or without a cylindrical collarette. *Conidia* aseptate, green in mass, in basipetal connected chains, usually ellipsoidal to fusiform.

*Type species:* *Talaromyces vermiculatus* (P.A. Dang.) C.R. Benj., Mycologia 47: 684. 1955.

The name *Talaromyces* was introduced by Benjamin (1955), and the type species is *T. vermiculatus* (P.A. Dang.) C.R. Benj. One of

the authors (RAS) personally visited several herbaria in Paris to locate holotype or other original material of *Penicillium vermiculatum* P.A. Dang. Dangeard (1907) described and illustrated both the anamorph and teleomorph under this name, but his material could not be located. To repair the shortcoming of the typification of *Talaromyces*, the lectotype for *P. vermiculatum* is here designated as Plate XVIII in Dangeard (1907, available at the Biodiversity Heritage Library, www.biodiversitylibrary.org). It was selected from among the plates XVI–XX because it includes the most detailed drawings of the anamorph, but also includes elements of the teleomorph. Herb. IMI 197477 is here designated as the epitype of *Penicillium vermiculatum* P.A. Dang. This specimen, which is also the holotype of *Penicillium dangeardii* J. Pitt, the seldom-used name for the anamorph of *T. flavus*, is derived from the equivalent cultures CBS 310.38, IMI 19447, and NRRL 2098. The latter strain was considered typical of *P. vermiculatum* by Raper & Thom (1949), the last major treatment to use this *Penicillium* name as a distinct species.

#### **List of species**

The following list includes previously accepted species of *Talaromyces* and proposals to transfer the species of *Penicillium* subgenus *Biverticillium* to *Talaromyces*.

Our phylogenetic studies demonstrate that several taxa represent complexes of morphologically cryptic phylogenetic species, requiring further study. For example, we analysed members of the *Penicillium purpurogenum* complex (including *P. purpurogenum*, *P. rubrum*, *P. crateriforme*, *P. sanguineum*) and found that several species group could be distinguished by sequencing certain genes (N. Yilmaz, unpubl. data) and had distinct macromorphological features and unique extrolite profiles. The full phylogenetic diversity of the *P. purpurogenum* species complex requires more investigation, and a more detailed account will be published elsewhere.

#### **ACCEPTED SPECIES IN TALAROMYCES**

***Talaromyces aculeatus*** (Raper & Fennell) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560639.

*Basionym:* *Penicillium aculeatum* Raper & Fennell, Mycologia 40: 535. 1948.

***Talaromyces albobiverticillius*** (H.-M. Hsieh, Y.-M. Ju & S.-Y. Hsieh) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560683.

*Basionym:* *Penicillium albobiverticillium* H.-M. Hsieh, Y.-M. Ju & S.-Y. Hsieh, Fung. Sci. 25: 26. 2010.

***Talaromyces allahabadensis*** (B.S. Mehrotra & D. Kumar) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560640.

*Basionym:* *Penicillium allahabadense* B.S. Mehrotra & D. Kumar, Canad. J. Bot. 40: 1399. 1962.

***Talaromyces apiculatus*** Samson, Yilmaz & Frisvad, **sp. nov.** MycoBank MB560641.

= *Penicillium aculeatum* var. *apiculatum* Abe, S., 1956, J. Gen. Appl. Microbiol., Tokyo 2: 124. 1956 (*nom. inval.*, Art. 36).

*Penicillio aculeato* simile, sed conidiis apiculatis distinguuntur.

*Typus*: **Japan** from soil (CBS H-20755 Holotype, culture ex-type CBS 312.59)

*Note*: Species similar to *Penicillium aculeatum* but differing by apiculate conidia.

*Talaromyces assiutensis* Samson & Abdel-Fattah, *Persoonia* 9: 501. 1978.

*Anamorphic synonym*: *Penicillium assiutense* Samson & Abdel Fattah (simultaneously published, identical holotype).

***Talaromyces aurantiacus*** (J.H. Mill., Giddens & A.A. Foster) Samson, Yilmaz, & Frisvad, **comb. nov.** MycoBank MB560642.

*Basionym*: *Penicillium aurantiacum* J.H. Mill., Giddens & A.A. Foster, *Mycologia* 49: 797. 1957.

*Talaromyces austrocalifornicus* Yaguchi & Udagawa *Trans. Mycol. Soc. Japan* 34: 245. 1993.

*Anamorphic synonym*: *Penicillium austrocalifornicum* Yaguchi & Udagawa (simultaneously published, identical holotype).

*Talaromyces bacillisporus* (Swift) C. R. Benj., *Mycologia* 47: 682. 1955.

= *Penicillium bacillisporum* Swift, *Bull. Torrey Bot. Club* 59: 221, 1932.

***Talaromyces boninensis*** (Yaguchi & Udagawa) Samson, Yilmaz, & Frisvad, **comb. nov.** MycoBank MB560643.

*Basionym*: *Talaromyces helicus* var. *boninensis* Yaguchi & Udagawa, *Transactions Mycological Society Japan* 33: 511. 1992.

***Talaromyces brunneus*** (Udagawa) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560644.

*Basionym*: *Penicillium brunneum* Udagawa, *J. Agric. Sci. (Tokyo) Nogyo Daigaku* 5: 16. 1959.

***Talaromyces calidicanus*** (J.L. Chen) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560645.

*Basionym*: *Penicillium calidicanium* J.L. Chen, *Mycologia* 94(5): 870. 2002.

***Talaromyces cecidicola*** (Seifert, Hoekstra & Frisvad) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560646.

*Basionym*: *Penicillium cecidicola* Seifert, Hoekstra & Frisvad, *Stud. Mycol.* 50: 520. 2004.

***Talaromyces coalescens*** (Quintan.) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560647.

*Basionym*: *Penicillium coalescens* Quintan., *Mycopathol.* 84: 115. 1984.

*Talaromyces convolutus* Udagawa, *Mycotaxon* 48: 141. 1993.

*Anamorphic synonym*: *Penicillium convolutum* Udagawa (simultaneously published, identical holotype).

***Talaromyces dendriticus*** (Pitt) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560648.

*Basionym*: *Penicillium dendriticum* Pitt, *The Genus Penicillium*: 413. 1980.

*Talaromyces dextrii* Takada & Udagawa, *Mycotaxon* 31: 418. 1988.

*Anamorphic synonym*: *Penicillium dextrii* Takata & Udagawa (simultaneously published, identical holotype).

***Talaromyces diversus*** (Raper & Fennell) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560649.

*Basionym*: *Penicillium diversum* Raper & Fennell, *Mycologia* 40: 539. 1948.

***Talaromyces duclauxii*** (Delacr.) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560650.

*Basionym*: *Penicillium duclauxii* Delacr., *Bull. Soc. Mycol. France* 7: 107. 1891.

***Talaromyces echinosporus*** (Nehira) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560651.

*Basionym*: *Penicillium echinosporum* Nehira, *J. Ferment. Technol., Osaka* 11: 861. 1933.

*Note*: *Penicillium asperosporum* G. Smith, *Trans. Brit. Mycol. Soc.* 48: 275. 1965. (= *Penicillium echinosporum* G. Sm., *Trans. Brit. Mycol. Soc.* 45: 387. 1962 (non Nehira in *J. Ferment. Technol.* 11: 849. 1933) belongs in *Penicillium* section *Aspergilloides* (Houbraken & Samson 2011).

*Talaromyces emodensis* Udagawa, *Mycotaxon* 48: 146. 1993.

*Anamorphic synonym*: *Penicillium emodense* Udagawa (simultaneously published, identical holotype).

***Talaromyces erythromellis*** (A.D. Hocking) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560652.

*Basionym*: *Penicillium erythromellis* A.D. Hocking *apud* Pitt, *The Genus Penicillium*: 459. 1980.

*Talaromyces euchlorocarpus* Yaguchi, Someya & Udagawa, *Mycoscience* 40: 133. 1999.

*Anamorphic synonym*: *Penicillium euchlorocarpium* Yaguchi, Someya & Udagawa (simultaneously published, identical holotype).

*Note*: We have not seen the type, but the description and the ITS sequences available in GenBank (AB176617) show that this is a distinct species of *Talaromyces*.

***Talaromyces flavo-virens*** (Durieu & Mont.) Visagie, Llimona & Seifert, *ined.*

*Note*: A manuscript on this species and its relationship to *Penicillium aureocephalum* Munt.-Cvetk., Hoyo & Gómez-Bolea is being prepared for publication in *Mycotaxon*.

*Talaromyces flavus* (Klöcker) Stolk & Samson, *Stud. Mycol.* 2: 10. 1972.

*Anamorphic synonym*: *Penicillium dangeardii* Pitt, *The Genus Penicillium*: 472. 1980.

***Talaromyces funiculosus*** (Thom) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560653.

*Basionym:* *Penicillium funiculosum* Thom, Bull. Bur. Anim. Ind. U.S. Dep. Agric. 118: 69. 1910

*Talaromyces galapagensis* Samson & Mahoney, Trans. Brit. Mycol. Soc. 69: 158. 1977.

*Anamorphic synonym:* *Penicillium galapagense* Samson & Mahoney (simultaneously published, identical holotype).

*Talaromyces hachijoensis* Yaguchi, Someya & Udagawa, Mycoscience 37: 157. 1996.

*Note:* We have not seen the type but the description and the ITS sequences available in GenBank (AB176620) show that this is a distinct species of *Talaromyces*. It is unusual in the genus for its apparent lack of an anamorph.

*Talaromyces helicus* (Raper & Fennell) C.R. Benj., Mycologia 47: 684. 1955.

≡ *Penicillium helicum* Raper & Fennell, Mycologia 40: 515. 1948.

*Talaromyces indigoticus* Takada & Udagawa, Mycotaxon 46: 129. 1993.

*Anamorphic synonym:* *Penicillium indigoticum* Takada & Udagawa (simultaneously published, identical holotype).

*Talaromyces intermedius* (Apinis) Stolk & Samson, Stud. Mycol. 2: 21. 1972.

*Anamorphic synonym:* *Penicillium intermedium* Stolk & Samson, Stud. Mycol. 2: 21. 1972.

***Talaromyces islandicus*** (Sopp) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560654.

*Basionym:* *Penicillium islandicum* Sopp, Skr. Vidensk.-Selsk. Christiania, Math.-Naturvidensk. Kl. 11: 161. 1912.

***Talaromyces loliensis*** (Pitt) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560655.

*Basionym:* *Penicillium loliense* Pitt, The Genus *Penicillium*: 450. 1980

*Talaromyces macrosporus* (Stolk & Samson) Frisvad, Samson & Stolk, Ant. van Leeuwenhoek J. Microbiol. Serol. 57: 186. 1990.

*Anamorphic synonym:* *Penicillium macrosporum* Frisvad, Filt., Samson & Stolk. *nom. illegit.* Art. 53 (non *P. macrosporum* Berk. & Broome 1882).

***Talaromyces marneffei*** (Segretain, Capponi & Sureau) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560656.

*Basionym:* *Penicillium marneffei* Segretain, Capponi & Sureau *apud* Segretain, Bull. Soc. Mycol. France 75: 416. 1959 [1960].

*Talaromyces mimosinus* A.D. Hocking *apud* Pitt, The Genus *Penicillium*: 507. 1980.

*Anamorphic synonym:* *Penicillium mimosinum* A. D. Hocking (simultaneously published, identical holotype).

***Talaromyces minioluteus*** (Dierckx) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560657.

*Basionym:* *Penicillium minioluteum* Dierckx, Ann. Soc. Sci. Bruxelles 25: 87. 1901.

*Talaromyces muroii* Yaguchi, Someya & Udagawa, Mycoscience 35: 252. 1994.

*Note:* This species is unusual in *Talaromyces* because of its lack of a known anamorph.

***Talaromyces palmae*** (Samson, Stolk & Frisvad) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560658.

*Basionym:* *Penicillium palmae* Samson, Stolk & Frisvad, Stud. Mycol. 31: 135. 1989.

***Talaromyces panamensis*** (Samson, Stolk & Frisvad) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560659.

*Basionym:* *Penicillium panamense* Samson, Stolk & Frisvad, Stud. Mycol. 31: 136. 1989.

***Talaromyces paucisporus*** (Yaguchi, Someya & Udagawa) Samson & Houbraken, **comb. nov.** MycoBank MB560684.

*Basionym:* *Erythrogymnotheca paucispora* Yaguchi, Someya & Udagawa, Mycoscience 35: 219. 1994.

***Talaromyces phialosporus*** (Udagawa) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560660.

*Basionym:* *Penicillium phialosporum* Udagawa, J. Agric. Sci. (Tokyo) Nogyo Daigaku 5: 11. 1959.

***Talaromyces piceus*** (Raper & Fennell) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560661.

*Basionym:* *Penicillium piceum* Raper & Fennell, Mycologia 40: 533. 1948.

***Talaromyces pinophilus*** (Hedgcock) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560662.

*Basionym:* *Penicillium pinophilum* Hedgcock *apud* Thom, Bull. Bur. Anim. Ind. US Dept. Agric. 118: 37. 1910.

***Talaromyces pittii*** (Quintan.) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560663.

*Basionym:* *Penicillium pittii* Quintan., Mycopathol. 91: 69. 1985.

***Talaromyces primulinus*** (Pitt) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560664.

*Basionym:* *Penicillium primulinum* Pitt, The Genus *Penicillium*: 455. 1980.

***Talaromyces proteolyticus*** (Kamyschko) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560665.

*Basionym:* *Penicillium proteolyticum* Kamyschko, Nov. Sist. niz. Rast. Sist. niz. Rast. 14: 227. 1961.

***Talaromyces pseudostromaticus*** (Hodges, G.M. Warner, Rogerson) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560666.



*Basionym:* *Penicillium pseudostromaticum* Hodges, G.M. Warner & Rogerson, *Mycologia* 62: 1106. 1970.

*Talaromyces purpureus* (E. Müll. & Pacha-Aue) Stolk & Samson, *Stud. Mycol.* 2: 57. 1972.

*Anamorphic synonym:* *Penicillium purpureum* Stolk & Samson, *Stud. Mycol.* 2: 57. 1972.

*Talaromyces purpurogenus* (Stoll) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560667.

*Basionym:* *Penicillium purpurogenum* Stoll, *Beitr. Charakt. Penicillium-Arten*: 32. 1904.

*Talaromyces rademirici* (Quintan.) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560668.

*Basionym:* *Penicillium rademirici* Quintan., *Mycopathol.* 91: 69. 1985.

*Talaromyces radicus* (A.D. Hocking & Whitelaw) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560669.

*Basionym:* *Penicillium radicum* A.D. Hocking & Whitelaw, *Mycol. Res.* 102: 802. 1998.

*Talaromyces ramulosus* (Visagie & K. Jacobs) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560670.

*Basionym:* *Penicillium ramulosum* Visagie & K. Jacobs, *Mycologia* 101: 890. 2009.

*Talaromyces rotundus* (Raper & Fennell) C.R. Benj., *Mycologia* 47: 683. 1955.

≡ *Penicillium rotundum* Raper & Fennell, *Mycologia* 40: 518. 1948.

*Talaromyces ryukyensis* (S. Ueda & Udagawa) Arx, *Persoonia* 13: 282. 1987.

≡ *Sagenoma ryukyense* S. Ueda & Udagawa, *Mycotaxon* 20: 499. 1984.

*Note:* We have not seen the type but the description and the ITS sequences available in GenBank (AB176628) show that this is a distinct species of *Talaromyces*.

*Talaromyces rubicundus* (J.H. Mill., Giddens & A.A. Foster) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560671.

*Basionym:* *Penicillium rubicundum* J.H. Mill., Giddens & A.A. Foster, *Mycologia* 49: 797. 1957.

*Talaromyces rugulosus* (Thom) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560672.

*Basionym:* *Penicillium rugulosum* Thom, *Bull. Bur. Anim. Ind. US Dept. Agric.* 118: 60. 1910.

*Talaromyces sabulosus* (Pitt & A.D. Hocking) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560673.

*Basionym:* *Penicillium sabulosum* Pitt & A. D. Hocking, *Mycologia* 77: 818. 1985.

*Talaromyces siamensis* (Manoch & C. Ramírez) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560674.

*Basionym:* *Penicillium siamense* Manoch & C. Ramírez, *Mycopathol.* 101: 32. 1988.

*Talaromyces stipitatus* (Thom) C.R. Benj., *Mycologia* 47: 684. 1955.

≡ *Penicillium stipitatum* Thom, *Mycologia* 27: 138. 1935.

*Talaromyces sublevissporus* (Yaguchi & Udagawa) Samson, Yilmaz & Frisvad, **comb. et stat. nov.** MycoBank MB560675.

*Basionym:* *Talaromyces wortmannii* var. *sublevissporus* Yaguchi & Udagawa, *Mycoscience* 35: 63. 1994.

*Note:* We have not examined the ex-type of this species but from the ITS data (GenBank AB176638), this seems to be a separate species.

*Talaromyces tardifaciens* Udagawa, *Mycotaxon* 48: 150. 1993.

*Anamorphic synonym:* *Penicillium tardifaciens* Udagawa (simultaneously published, identical holotype).

*Talaromyces trachyspermus* (Shear) Stolk & Samson, *Stud. Mycol.* 2: 32. 1972.

*Anamorphic synonym:* *Penicillium spiculisporum* Leman, *Mycologia* 12: 268. 1920

*Talaromyces ucrainicus* Udagawa, in Stolk & Samson, *Stud. Mycol.* 2: 34. 1972.

*Anamorphic synonym:* *Penicillium ucrainicum* Panasenko, *Mycologia* 56: 59. 1964.

*Talaromyces udagawae* Stolk & Samson, *Stud. Mycol.* 2: 36. 1972.

*Anamorphic synonym:* *Penicillium udagawae* Stolk & Samson (simultaneously published, identical holotype).

*Talaromyces unicus* Tzean, J.L. Chen & Shiu, *Mycologia* 84: 739. 1992.

*Anamorphic synonym:* *Penicillium unicum* Tzean, J.L. Chen & Shiu (simultaneously published, identical holotype).

*Talaromyces variabilis* (Sopp) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560676.

*Basionym:* *Penicillium variabile* Sopp, *Skr. Vidensk.-Selsk. Christiania, Math.-Naturvidensk. Kl.* 11: 169. 1912.

*Talaromyces varians* (G. Sm.) Samson, Yilmaz & Frisvad, **comb. nov.** MycoBank MB560677.

*Basionym:* *Penicillium varians* G. Sm., *Trans. Brit. Mycol. Soc.* 18: 89. 1933.

*Talaromyces verruculosus* (Peyronel) Samson, Yilmaz, Frisvad & Seifert, **comb. nov.** MycoBank MB560678.

*Basionym:* *Penicillium verruculosum* Peyronel, *Germi Atmosf. Fung. Micel.*: 22. 1913.

*Talaromyces viridis* (Stolk & G.F. Orr) von Arx, *Persoonia* 13(3): 2821. 1987

≡ *Sagenoma viride* Stolk & G.F. Orr, *Mycologia* 66: 677. 1974.

*Talaromyces viridulus* Samson, Yilmaz & Frisvad, **nom. nov.** MycoBank MB560679.

*Basionym:* *Geosmithia viridis* Pitt & A.D. Hocking, *Mycologia* 77: 822. 1985 = *P. viride* (Pitt & A.D. Hocking) Frisvad, Samson &



Stolk, *Persoonia* 14: 229. 1990, *nom. illegit.* Art. 53 (non Fres. 1851 nec Rivera 1873 nec Sopp 1912 nec (Matr.) Biourge 1923). Non *Talaromyces viridis* (Stolk & G.F. Orr) Arx.

*Talaromyces wortmannii* (Klöcker) C.R. Benjamin, *Mycologia* 47: 683. 1955

≡ *Penicillium wortmannii* Klöcker, *Compt-Rend. Trav. Carlsberg Lab.* 6: 100. 1903.

## EXCLUDED SPECIES AND TAXA, WHICH NEED FURTHER TAXONOMIC STUDY

*Penicillium concavorugulosum* S. Abe, *J. Gen. Appl. Microbiol.* Tokyo 2: 127. 1956 (*nom. inval.* Art. 36).

*Note:* This species was invalidly described, but our ITS data (Fig. 2) show that it is related to *T. wortmannii*. Further study is required but extrolite data indicate that this species is unique (J.C. Frisvad, unpublished data).

*Penicillium crateriforme* J.C. Gilman & E.V. Abbott, *Iowa State Coll. J. Sc.* 1: 293. 1927.

*Note:* Our ITS data (Fig. 2) show that this species is a synonym of *P. purpurogenum*.

*Penicillium ilerdanum* C. Ramírez, A.T. Martínez & Berer., *Mycopathol.* 72: 32. 1980.

*Note:* Frisvad *et al.* (1990b) considered this species synonymous with *Penicillium piceum* Raper & Fennell, which is confirmed by our ITS data (Fig. 2)

*Penicillium isariiforme* Stolk & J.A. Mey., *Trans. Brit. Mycol. Soc.* 40: 187. 1957.

*Note:* According to Houbraken & Samson (2011), this species, included in subgenus *Biverticillium* by Pitt (1980), is correctly classified in *Penicillium sensu lato*.

*Penicillium korosum* J.N. Rai, Wadhvani & J.P. Tewari, *Ant. van Leeuwenhoek* 35: 430. 1969.

*Note:* This species requires further investigation, but our ITS sequence (Fig. 2) indicates that it is similar to *P. pinophilum*.

*Penicillium krugeri* C. Ramírez, *Mycopathol.* 110: 23. 1990.

*Note:* We have been unable to examine authentic material, and the correct classification of this species is uncertain.

*Penicillium lignorum* Stolk, *Ant. van Leeuwenhoek* 35: 264. 1969.

*Note:* A preliminary phylogenetic analysis indicates that this species does not belong to *Talaromyces* and might represent a new genus (J. Houbraken, unpubl. data).

*Penicillium mirabile* Beliakova & Milko, *Mikol. Fitopatol.* 6: 145. 1972.

*Note:* The ex-type culture is in poor condition and although our ITS data (Fig. 2) indicate that it is a distinct species, it should be further investigated.

*Penicillium oblatum* Pitt & A.D. Hocking, *Mycologia* 77: 810. 1985.

*Note:* In our ITS phylogeny (Fig. 2), this species is close to *Paecilomyces pascuus* and *Penicillium dendriticum* and needs further study.

*Penicillium pascuum* (Pitt & A.D. Hocking) Frisvad, Samson & Stolk, *Persoonia* 14: 229. 1990

≡ *Paecilomyces pascuus* Pitt & A. D. Hocking, *Mycologia* 77: 822. 1985.

*Note:* See on the position of this species under *P. oblatum* above.

*Penicillium rubrum* Stoll, *Beitr. Charakt. Penicillium-Arten:* 35. 1904.

*Note:* Although the name is well-known, the taxonomic position of the taxon remains doubtful because no type material has been located. A possible solution would be lectotypification from Stoll's illustrations, followed by epitypification to become a usable name.

*Penicillium purpurogenum* var. *rubrisclerotium* Thom, *Mycologia* 7: 137. 1915.

*Note:* Our ITS data (Fig. 2) indicate that this species is synonymous with *P. minioluteum*.

*Penicillium samsonii* Quintan., *Mycopathol.* 91: 69. 1985.

= *Talaromyces minioluteus* (Dierckx) Samson, Yilmaz, Frisvad & Seifert (see above).

*Penicillium tardum* Thom, *The Penicillia:* 485. 1930.

*Note:* Raper & Thom (1949) pointed out that there is confusion about the type culture and the status of this species will be subject of further studies.

*Penicillium victoriae* Szilv., *Archiv. Hydrobiol.* 14, Suppl. 6: 535. 1936

= *Penicillium janthinellum* Biourge, *Cellule* 33: 258. 1923 (Pitt, 1980).

*Note:* Pitt (1980) synonymised this species under *Penicillium janthinellum*, but our studies showed that it clearly belongs in *Talaromyces*. Because there is only one strain, the exact identity of this fungus requires further study.

*Talaromyces barcinensis* Yaguchi & Udagawa, *Trans. Mycol. Soc. Japan* 34: 15. 1993.

*Anamorphic synonym:* *Penicillium barcinense* Yaguchi & Udagawa (simultaneously published, identical holotype).

*Note:* Our ITS sequence data show that this species is close to *Talaromyces helicus* and further study should determine its correct taxonomic position.

*Talaromyces brevicompactus* Kong, *Mycosystema* 18: 9. 1999.

*Anamorphic synonym:* *Merimbla brevicompacta* Kong, *Mycosystema* 18: 9. 1999 (simultaneously published, identical holotype).

*Note:* Fig. 1 shows that this species belongs in *Hamigera*. Comparison of partial  $\beta$ -tubulin and calmodulin sequences of the ex-type strain of *T. brevicompactus* with recent published data shows that this species represents a distinct species (J. Houbraken, unpubl. data). The new combination in *Hamigera* will be made elsewhere.

*Talaromyces byssochlamydoides* Stolk & Samson, *Stud. Mycol.* 2: 45. 1972.

*Anamorphic synonym:* *Paecilomyces byssochlamydoides* Stolk & Samson (simultaneously published, same holotype).

= *Rasamsonia byssochlamydoides* (Stolk & Samson) Houbraken & Frisvad, *Ant. van Leeuwenhoek*, *in press*.

*Talaromyces eburneus* Yaguchi, Someya & Udagawa, *Mycoscience* 35: 249. 1994.

*Anamorphic synonym:* *Geosmithia eburnea* Yaguchi, Someya & Udagawa (simultaneously described, holotype identical)

= *Rasamsonia eburnea* (Yaguchi, Someya & Udagawa) Houbraken & Frisvad, *Ant. van Leeuwenhoek*, *in press*.

*Talaromyces emersonii* Stolk, *Ant. van Leeuwenhoek* 31: 262. 1965.

*Anamorphic synonym:* *Penicillium emersonii* Stolk (simultaneously described, holotype identical), *Ant. van Leeuwenhoek* 31: 262. 1965.

= *Rasamsonia emersonii* (Stolk) Houbraken & Frisvad, *Ant. van Leeuwenhoek*, *in press*.

*Talaromyces gossypii* Pitt, *The Genus Penicillium*: 500. 1980

= *T. assiutensis*, Samson & Abdel-Fattah, *Persoonia* 9: 501. 1978 (*vide* Frisvad *et al.* 1990a).

*Talaromyces lagunensis* Udagawa, Uchiy. & Kamiya, *Mycoscience* 35: 403. 1994.

*Anamorphic synonym:* *Penicillium lagunense* Udagawa, Uchiy. & Kamiya (simultaneously published, identical holotype).

*Note:* We have been unable to examine authentic material, and the correct classification of this species is uncertain.

*Talaromyces leycettanus* H.C. Evans & Stolk, *Trans. Brit. Mycol. Soc.* 56: 45. 1971.

*Anamorphic synonym:* *Penicillium leycettanus* H.C. Evans & Stolk (simultaneously published, identical holotype)

= *Paecilomyces leycettanus* (H.C. Evans & Stolk) Stolk, Samson & H.C. Evans, *Persoonia* 6: 342. 1971.

*Note:* Houbraken & Samson (2011) showed that this species is phylogenetically unrelated to *Talaromyces* and close to *Hamigera*. Its taxonomic position requires further investigation.

*Talaromyces luteus* (Zukal) C.R. Benj., *Mycologia* 47: 681. 1955.

= *Penicillium luteum* Zukal, *Sitzungsber Kaiserl. Akad. Wiss. Math-Naturwiss. C1., Abt. 1*, 98: 561. 1890.

*Note:* Although the phenotype of this species resembles species of *Talaromyces*, our molecular analysis shows that it is phylogenetically unique and basal to *T. thermophilus*.

*Talaromyces malagensis* (Thüm.) Stalpers & Samson 1984, in Stalpers, *Stud. Mycol.* 24: 69. 1984.

*Note:* Stolk & Samson (1972) considered *Sporotrichum malagense* a dubious synonym of *T. udagawae*, based on their failure to find ascospores and conidia in the type material (herb. W). Later, Stalpers (1984) studied material preserved in herb. BR which is authentic and labelled as "type". It agrees with Thümen's original diagnosis and contains both fertile *Talaromyces* cleistothecia and a sporulating biverticillate anamorph. Therefore, the new combination to *Talaromyces* was proposed. The species resembles *T. udagawae* or *T. luteus*, but in the absence of a living culture we cannot determine its precise taxonomic identity.

*Talaromyces ocotl* Bills & Heredia, *Mycologia* 90: 533. 1998.

*Note:* Figure 1 shows that this species belongs to *Sagenomella* and the new combination is proposed here:

*Sagenomella ocotl* (Bills & Heredia) Samson, Houbraken & Frisvad, **comb. nov.** MycoBank MB560681.

*Basionym:* *Talaromyces ocotl* Bills & Heredia, *Mycologia* 93: 533. 1998.

*Talaromyces ohioensis* Pitt, *The Genus Penicillium*: 502. 1980.

*Anamorphic synonym:* *Penicillium ohioense* L. H. Huang & J. A. Schmitt, *Ohio J. Sci.* 75: 78. 1975.

*Note:* Pitt (1980) considered this species to be related to *T. luteus*, but our ITS data clearly show that is synonymous with *T. ucrainicus*.

*Talaromyces panasenkoi* Pitt, *The Genus Penicillium*: 482. 1980.

*Anamorphic synonym:* *Penicillium panasenkoi* Pitt (simultaneously published, identical holotype).

*Note:* Pitt (1980) proposed *T. panasenkoi* as a new species for the invalidly published *P. ucraininum* Panasenko; however, Stolk & Samson (1972) had already proposed *Talaromyces ucrainicus* Udagawa for this taxon. *T. panasenkoi* Pitt is therefore a synonym of *T. ucrainicus*.

*Talaromyces retardatus* Udagawa, Kamiya & Kaori Osada, *Trans. Mycol. Soc. Japan* 34: 9. 1993.

*Anamorphic synonym:* *Penicillium retardatum* Udagawa, Kamiya & Kaori Osada (simultaneously published, identical holotype).

*Note:* No strain was available for examination and the status of this species is thus unknown.

*Talaromyces spectabilis* Udagawa & Suzuki, *Mycotaxon* 50: 82. 1994.

= *Byssochlamys spectabilis* (Udagawa & Suzuki) Houbraken & Samson, *Appl. Environ. Microbiol.* 74: 1618. 2008.

= *Paecilomyces variotii* Bainier *Bull. Soc. mycol. Fr.* 23: 27. 1907.

Note: The oldest generic and species name for this species is *P. variotii*, which becomes the correct name for the holomorph.

*Talaromyces striatus* (Raper & Fennell) C.R. Benj., Mycologia 47: 682. 1955

= *Hamigera striata* (Raper & Fennell) Stolk & Samson, Persoonia 6: 347. 1971.

*Talaromyces thermocitrinus* Subrahm. & Gopalkr., Ind. Bot. Reporter 35: 35. 1984 (as '*T. thermocitrinum*').

Note: We have not seen the type, but judging from the substrate (dust on books), and the mention of yellow cleistothecia, it is possible that this species is a *Eurotium* species, a typical contaminant of books and other material in archives. However, its reported thermophily is different from known species of the mesophilic *Eurotium* species.

*Talaromyces thermophilus* Stolk, Ant. van Leeuwenhoek 31: 268. 1965.

Basionym: *Penicillium dupontii* Griffon & Maubl., Bull. Trimest. Soc. mycol. Fr. 27: 73. 1911.

Note: Figure 1 shows that this species is related to *Thermomyces lanuginosus*, and should be transferred to *Thermomyces* (Houbraken *et al.* 2011, Houbraken & Samson 2011).

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## APPENDIX: OTHER POSSIBLE GENERIC NAMES

As noted above in the Taxonomy section, in order to adopt *Talaromyces* as the generic name for the former *Penicillium* subgenus *Biverticillium*, older genera considered synonyms of *Penicillium sensu lato* had to be considered. These are treated below.

*Aspergillopsis* Sopp, Vid.-Selsk. Skr. I. Math.-naturv. Kl. 11: 201. 1912. (Taf. xx, Fig. 149, Taf. xxiii, Fig. 31).

Type species: *A. fumosus* Sopp 1912.

Note: This generic name is illegitimate (Art. 53), being a later homonym of *Aspergillopsis* Speg. 1910. Pitt (1980) considered Sopp's genus a tentative synonym of *Merimbla* Pitt.

*Citromyces* Wehmer, Ber. dt. Bot. Ges. 11: 338. 1893.

Type species: *C. pfefferianus* Wehmer 1893

= *Penicillium glabrum* (Wehmer) Westling 1911, *vide* Pitt 1980.

Note: Wehmer's genus was considered a synonym of *Penicillium* by many authors, including Raper & Thom (1949) and Pitt (1980), with *C. pfefferianus* considered a probable synonym of *P. glabrum* (subgenus *Aspergillioides*) by Pitt (1980). Therefore, the genus remains a synonym of *Penicillium sensu stricto*.

*Coremium* Link : Fr., Mag. Ges. naturf. Freunde, Berlin 3: 19. 1809 : Fries, Syst. mycol. 1: xviii, 1821.

Type species: *C. glaucum* Link 1809.

Note: This genus was described in the same publication as *Penicillium*. Raper & Thom (1949) and Seifert & Samson (1985) both considered the type species to be a synonym of the type species of *Penicillium*, *P. expansum* Link 1809. Therefore, *Coremium* remains a synonym of *Penicillium sensu stricto*.

*Eladia* G. Sm., Trans. Br. mycol. Soc. 44: 47. 1961.

Type species: *Eladia saccula* (Dale) G. Sm. 1961 = *Penicillium sacculum* Dale 1926.

Note: This genus was considered a synonym of *Penicillium* by Stolk & Samson (1985), but was considered distinct by Pitt (1980), and von Arx (1981). In the multigene phylogenetic study by Houbraken & Samson (2011), *Eladia* is clearly included in *Penicillium sensu stricto* and that synonymy is accepted here.

*Floccaria* Grev., Scott. Crypt. Fl., Vol. 6, Pl. 301. 1828.

Type species: *F. glauca* Grev. 1828.

Note: There is no known extant type according to Seifert & Samson (1985), who searched for it in K and E. The illustration shows a synnematus fungus that could well be *P. expansum*, but there are no microscopic details. Therefore, this name can be discounted as a possible generic name for the species formerly ascribed to subgenus *Biverticillium*.

*Geosmithia* Pitt, Can. J. Bot. 57: 2021. 1980.

Type species: *Geosmithia lavendula* (Raper & Fennell) Pitt 1980 = *Penicillium lavendulum* Raper & Fennell 1948.

Note: Although von Arx (1981) considered *Geosmithia* a synonym of *Penicillium*, it is polyphyletic as presently circumscribed. Using SSU sequences, Ogawa *et al.* (1997) showed that *G. lavendula*, and a second common species *G. putterilli*, belong to the *Bionectriaceae*, *Hypocreales*. Similar results were obtained using ITS sequences by Kolařík *et al.* (2004), using LSU sequences by Schroers *et al.* (2005) and then multigene phylogenies by Kolařík & Kirkendall (2010). Despite this, some anamorphs attributed to *Geosmithia* have been described recently in *Talaromyces* (e.g. Yaguchi *et al.* 2005). Because the type species is not associated with the same order as *Penicillium*, *Geosmithia* need not be considered as a possible home for species of subgenus *Biverticillium*, but neither should it be considered a synonym of *Penicillium*.

*Hormodendrum* Bonord., Handbuch allg. Mykol.: 76. 1851.

Type species: *Amphitrichum olivaceum* Corda 1837 = *Hormodendrum olivaceum* (Corda) Bonord. 1851, lectotype selected by Clements & Shear 1931.

Note: *Hormodendron* has variously been treated as a synonym of *Penicillium* by von Arx (1974) and de Hoog & Hermanides-Nijhoff (1977) but more often as a synonym of *Cladosporium* Link, following



the study of the type specimen by Hughes (1958). There is no reason to consider this name further as a synonym of *Penicillium* or as a possible receptacle for the species of subgenus *Biverticillium*.

*Merimbla* Pitt, Can. J. Bot. 57: 2394. 1980.

*Type species: M. ingelheimensis* (F.H. Beyma) Pitt 1980  
= *Penicillium ingelheimense* F.H. Beyma 1942.

*Note:* *Merimbla* was considered a possible synonym of *Penicillium* by von Arx (1981), but this has not generally been accepted. *Merimbla ingelheimensis* was considered the anamorph of *Hamigera avellanea* by Stolk & Samson (1971), but is now known to be a closely related but phylogenetically distinct species (Peterson *et al.* 2010). The *Hamigera* clade is phylogenetically distinct from subgenus *Biverticillium* in the multigene analyses of Peterson *et al.* (2010) and Houbraken & Samson (2011). In a single name system, we consider *Merimbla* a synonym of the older genus *Hamigera*.

*Monilia* Fr., Syst. mycol. 3: 409. 1832.

*Type species: M. caespitosa* (L. : Fr.) Fr. 1832 / *Mucor caespitosus* L. 1753.

*Note:* Donk (1963) suggested that *M. caespitosa* might be a species of *Penicillium* based on the protologue. However, this generic name was formally rejected to conserve usage of *Monilia* Bonorden for the well-known genus of fruit pathogens. Therefore, it is unavailable as a possible generic name for species included in subgenus *Biverticillium*.

*Moniliger* Letell., Fig. Champ., Pl. 668. 1839. Figs 3, 4.

*Type species:* not designated, two original species.

*Note:* According to Seifert *et al.* (2011), Letellier included two species, with illustrations clearly representing *Aspergillus*. The synonymy of *Moniliger* with *Penicillium* proposed by Kirk *et al.* (2008) thus seems unlikely, and the genus is better listed as a synonym of *Aspergillus*.

*Penicillium* Link : Fr., Mag. Ges. naturf. Freunde, Berlin 3: 16. 1809. : Fries, Syst. mycol. 3: 406.1832.

*Type species: P. expansum* Link 1809, *vide* Thom 1910.

*Note:* With this revision, and that of Houbraken & Samson (2011), *Penicillium* is now used exclusively for the nominal Clade including *P. expansum*, and species in the now synonymous genus *Eupenicillium* F. Ludw. 1892 (Houbraken & Samson 2011).

*Pritzeliella* Henn., Hedwigia Beibl. 42: 88. 1903.

*Type species: P. caerulea* Henn. 1903.

*Note:* Clements & Shear (1931) suggested that *Pritzeliella* should be considered a synonym of *Penicillium* without further commenting on the identity of its type species. Seifert & Samson (1985) examined the holotype of *P. caerulea* and considered it a synonym of *Penicillium coprophilum* (subgenus *Penicillium*). Its status as a synonym of *Penicillium sensu stricto* thus remains unchanged.

*Rhodocephalus* Corda, Ic. Fung. 1: 21. 1837 (Tab. vi, Fig. 282).

*Type species: R. candidus* Corda 1837 *Type species: Penicillium leucocephalum* Rabenh. 1844.

*Note:* Corda (1837) illustrated and described his species as having aseptate stipes, a branched, asymmetrical penicillate head, with long chains of asexual conidia. Rabenhorst (1844) renamed the species in *Penicillium*, changing the epithet, a conclusion followed by Lindau (1907). Thom (1930) and Raper & Thom (1949) disagreed, stating that the illustration in the protologue has branched conidial chains that would exclude the fungus from *Penicillium*. This a debatable conclusion, because the chains are simply overlapping in the illustration and there is no clear indication of branching. Pitt (1980) evidently did not examine the protologue when he suggested a synonymy with *Aspergillus candidus*. Hughes (1958) did not report on the type, and according to Holubová (in litt. to Seifert, 1991), there is no material of *Rhodocephalus* in the Corda herbarium (PRM). The asymmetrical conidiophores illustrated by Corda discount this as a possible genus for species of subgenus *Biverticillium*, but its exact identity is unknown.

*Torulomyces* Delitsch, Systematik der Schimmelpilze: 91. 1943 (Taf. 30, Figs 232–235).

*Type species: T. lagena* Delitsch 1943 = *Monocillium lagena* (Delitsch) Hashmi, W.B. Kendr. & Morgan-Jones 1972 = *Penicillium lagena* (Delitsch) Stolk & Samson 1983.

*Note:* *Torulomyces* was included as a synonym of *Penicillium sensu stricto* in the phylogenetic study of Houbraken & Samson (2011).

*Yunnania* H.-Z. Kong, Mycotaxon 69: 320. 1998.

*Type species: Y. penicillata* H.-Z. Kong 1998.

*Note:* Houbraken & Samson (2011) sequenced the ITS of authentic cultures of *Y. penicillata*, showing a relationship with the *Microascales*, suggesting a synonymy with *Scopulariopsis* or *Scedosporium* might be appropriate.

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