

Penicillium subgenus *Penicillium*: new taxonomic schemes, mycotoxins and other extrolites

Studies in Mycology

The *Studies in Mycology* is an international journal which publishes systematic monographs of filamentous fungi and yeasts, and in rare occasions the proceedings of special meetings related to all fields of mycology, biotechnology, ecology, molecular biology, pathology and systematics. For instructions for authors see www.cbs.knaw.nl.

EXECUTIVE EDITOR

Prof. dr Robert A. Samson, Centraalbureau voor Schimmelcultures, Fungal Biodiversity Centre, P. O. Box 85167, 3508 AD Utrecht, The Netherlands.
E-mail: samson@cbs.knaw.nl

EDITORS

Prof. dr Uwe Braun, Martin-Luther-Universität, Institut für Geobotanik und Botanischer Garten, Herbarium, Neuwerk 21, D-06099 Halle, Germany.
E-mail: braun@botanik.uni-halle.de

Prof. dr Pedro W. Crous, Centraalbureau voor Schimmelcultures, Fungal Biodiversity Centre, P. O. Box 85167, 3508 AD Utrecht, The Netherlands.
E-mail: crous@cbs.knaw.nl

Dr John C. David, CABI Bioscience, Bakeham Lane, Egham, Surrey TW20 9TY, UK.
E-mail: j.david@cabi.org

Prof. dr Walter Gams, Centraalbureau voor Schimmelcultures, Fungal Biodiversity Centre, P. O. Box 85167, 3508 AD Utrecht, The Netherlands.
E-mail: gams@cbs.knaw.nl

Prof. dr David M. Geiser, Department of Plant Pathology, 121 Buckhout Laboratory, Pennsylvania State University, University Park, PA, USA 16802.
E-mail: dgeiser@psu.edu

Dr Lorelei L. Norvell, Pacific Northwest Mycology Service, 6720 NW Skyline Blvd, Portland, OR, United States 97229-1309.
E-mail: lnorvell@pnw-ms.com

Dr Erast Parmasto, Institute of Zoology & Botany, 181 Riia Street Tartu, Estonia EE-51014.
E-mail: e.parmasto@zbi.ee

Prof. dr Alan J. L. Phillips, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Quinta de Torre, 2829-516 Caparica, Portugal.
E-mail: alp@mail.fct.unl.pt

Dr Amy Y. Rossman, Rm 304, Bldg 011A, Systematic Botany & Mycology Laboratory, Beltsville, MD, USA 20705.
E-mail: amy@nt.ars-grin.gov

Dr Keith A. Seifert, Eastern Cereal & Oilseed Centre, Agriculture & Agri-Food Canada KW Neatby Bldg, 960 Carling Ave, Ottawa, ON, Canada K1A 0C6.
E-mail: seifertk@em.agr.ca

Prof. dr Jeffrey K. Stone, Department of Botany & Plant Pathology, Cordley 2082, Oregon State University, Corvallis, OR, USA 97331-2902.
E-mail: stonej@bcc.orst.edu

Dr Richard C. Summerbell, Centraalbureau voor Schimmelcultures, Fungal Biodiversity Centre, P. O. Box 85167, 3508 AD Utrecht, The Netherlands.
E-mail: summerbell@cbs.knaw.nl

Copyright 2004 Centraalbureau voor Schimmelcultures, P.O. Box 85167, 3508 AD UTRECHT, The Netherlands

All rights reserved. No part of this work covered by the copyright herein may be reproduced or used in any form or by any means — graphic, electronic, or mechanical, including photocopying, recording, taping or information storage and retrieval systems — without permission of the publisher.

Published and distributed by Centraalbureau voor Schimmelcultures, P.O. Box 85167, 3508 AD UTRECHT, The Netherlands. Internet: www.cbs.knaw.nl. Email: info@cbs.knaw.nl.

ISBN 90-70351-53-6

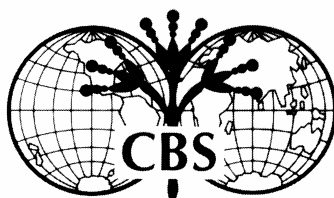
***Penicillium* subgenus *Penicillium*: new taxonomic schemes and
mycotoxins and other extrolites**

Robert A. Samson and Jens C. Frisvad

*Centraalbureau voor Schimmelcultures,
PO Box 85167, 3508 AD, Utrecht, the Netherlands*

and

*Center for Microbial Biotechnology, Biocentrum-DTU,
Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark*



Centraalbureau voor Schimmelcultures,
Utrecht, The Netherlands

An institute of the Royal Netherlands Academy of Arts and Sciences

FOREWORD

The terverticillate *Penicillia* are among the most common fungi worldwide and they influence the everyday life of many people. These *Penicillia* have given us penicillin, mycophenolic acid, compactin, fungal steroid transformations, white and blue mould cheeses, fermented salamis, and extra cellular enzymes, but they have also been the cause of severe mycotoxicoses, allergy and indoor air problems. Thus a correct predictive classification and correct identifications are of paramount importance. If this classification also reflects phylogeny, the resulting polyphasic taxonomy would be of value for all biologists, food technologists and biotechnologists. We are proposing such predictive polyphasic taxonomy for these important *Penicillia*.

Our cooperation started in 1985, when Rob Samson invited Jens Frisvad to collaborate on *Penicillium* taxonomy, simply because the classical morphological approach of Melie Stolk and Rob Samson was so different from the physiological/biochemical approach of Jens Frisvad, that cooperation could only be synergistic. We believe that the taxonomy presented here is truly polyphasic, and that our suggested classification is supported by phylogenetic data made possible by the PCR revolution in molecular biology. Our approach presents a dialogue between classification and cladification with an emphasis on the former and apparently the two widely different approaches points to the same species and species series!

In our studies we have extensively used the profiles of secondary metabolites. We prefer the term extrolites for these fungal compounds which are defined as follows: *An extrolite is an outwardly directed chemical compound produced during differentiation of a living organism. An extrolite is usually excreted, but can also be accumulated in the cell wall or membrane. All extrolites are of a limited taxonomic distribution, while intralites (= primary metabolites = general metabolites) are widely distributed, examples of intralites being ergosterol in fungi and oxaloacetate in all living organisms. Since extrolites are outwardly directed, they are always involved in interactions between the organism producing it and any other organism or the abiotic environment. Extrolism is the metabolism of extrolites and their regulation. Organismal extrolism is regulated both by the genome and the biotic and abiotic environment [the developmental norm of reaction, see Schlichting and Pigliucci, 1998 Phenotypic evolution. A reaction norm perspective. Sinauer Associates, Inc. Publishers, Sunderland, Massachusetts (388 pp.)]*

The authors are extremely grateful to Jos Houbraken and Ellen Kirstine Lyhne who carried out numerous measurements and observations of the *Penicillium* cultures. Also Angelina Kuijpers, Karin van den Tweel, Mariette Pouw, Flemming Lund, Lisette Knoth Nielsen are thanked for investing so much enthusiasm in collecting data for this study. Ole Filtenborg, Ulf Thrane, Jørn Smedsgaard, Thomas Larsen, Anne Svendsen, Ellen Hoekstra have all made important contributions to the knowledge on these important species. We also thank the late Amelia C. Stolk for inspiration and support. Walter Gams helped us with the Latin diagnosis. Jos Houbraken collected numerous data for the electronic key for the CBS website and together with Vincent Robert created the *Penicillium* electronic database. We thank the Danish Technical Research Council for support for Program for Predictive Biotechnology and the Centre for Advanced Food Studies (LMC) for additional financial support.



This publication is dedicated to the memory of Amelia C. Stolk.

CONTENTS

Polyphasic taxonomy of *Penicillium* subgenus *Penicillium*. A guide to identification of food and air-borne terverticillate *Penicillia* and their mycotoxins –

Jens C. Frisvad and Robert A. Samson

Introduction	1
History	2
Materials and methods.....	3
Taxonomy.....	10
Excludes taxa.....	10
Species concept	11
Sectional classification in <i>Penicillium</i> subgenus <i>Penicillium</i>	12
Taxonomic and nomenclatorial notes on series, species and synonymy in <i>Penicillium</i> subgenus <i>Penicillium</i>	14
Ecology and distribution of species in <i>Penicillium</i> subgenus <i>Penicillium</i>	33
Mycotoxins produced by <i>Penicillium</i> subgenus <i>Penicillium</i>	36
Pharmaceuticals produced by <i>Penicillium</i> subgenus <i>Penicillium</i>	37
List of accepted in subgenus <i>Penicillium</i>	39
Keys to species	40
Species descriptions	52
References	168
Phylogenetic analysis of <i>Penicillium</i> subgenus <i>Penicillium</i> using partial β-tubulin sequences - Robert A. Samson, Keith A. Seifert, Angelina F.A. Kuijpers, Jos A.M.P. Houbraken and Jens C. Frisvad	175
Mycotoxins, drugs and other extrolites produced by species in <i>Penicillium</i> subgenus <i>Penicillium</i> - Jens C. Frisvad, Jørn Smedsgaard, Thomas O. Larsen and Robert A. Samson.....	201
Classification of Terverticillate <i>Penicillia</i> by Electrospray Mass Spectrometric Profiling - Jørn Smedsgaard, Michael Edberg Hansen and Jens C. Frisvad	243