Fungicidal Activity

Chemical and Biological Approaches to Plant Protection

Edited by

David Hutson
Junshi Miyamoto

WILEY SERIES IN AGROCHEMICALS AND PLANT PROTECTION

Fungicidal Activity

Chemical and Biological Approaches to Plant Protection

Edited by
DAVID HUTSON
Falmouth, Cornwall, UK

and

JUNSHI MIYAMOTO
Sumitomo Chemical Company, Osaka, Japan

JOHN WILEY & SONS
Chichester · New York · Weinheim · Brisbane · Singapore · Toronto

National 01243 779777
International (+44) 1243 779777
e-mail (for orders and customer service enquiries): cs-books@wiley.co.uk
Visit our Home Page on http://www.wiley.co.uk
or http://www.wiley.com

Other Wiley Editorial Offices

John Wiley & Sons, Inc., 605 Third Avenue,
New York, NY 10158-0012, USA

WILEY-VCH Verlag GmbH, Pappelallee 3,
D-69469 Weinheim, Germany

Jacaranda Wiley Ltd, 33 Park Road, Milton,
Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01,
Jin Xing Distripark, Singapore 129809

John Wiley & Sons (Canada) Ltd, 22 Worcester Road,
Rexdale, Ontario M9W 1L1, Canada

Library of Congress Cataloging-in-Publication Data

Fungicidal activity : chemical and biological approaches to plant protection / edited by D. H. Hutson and Junshi Miyamoto.
p. cm. — (Wiley series in agrochemicals and plant protection)
Includes bibliographical references and index.
ISBN 0-471-96806-4 (hardback : alk. paper)
1. Fungicides. I. Hutson, D. H. (David Herd), 1935– .
II. Miyamoto, J. (Junshi) III. Series.
SB951.3.F8 1988 98-3121
632′.952—dc21 CIP

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 0 471 96806 4

Typeset in 10/12 pts Times by Thomson Press (India) Ltd, New Delhi.
Printed and bound in Great Britain by Biddles Ltd, Guildford and Kings Lynn.
This book is printed on acid-free paper responsibly manufactured from sustainable forestry, in which at least two trees are planted for each one used for paper production.

Wiley Series in Agrochemicals and Plant Protection

Previous Titles in the Wiley Series in Agrochemicals and Plant Protection:

The Methyl Bromide Issue (1996), ISBN 0 471 95521 3. *Edited by* C. H. Bell, N. Price *and* B. Chakrabarti
Pesticide Remediation in Soils and Water (1998), ISBN 0 471 96805 6. *Edited by* P. Kearney *and* T. R. Roberts
Chirality in Agrochemicals (1998), ISBN 0 471 98121 4. *Edited by* N. Kurihara *and* J. Miyamoto

Forthcoming Titles in the Wiley Series in Agrochemicals and Plant Protection:

Metabolism of Agrochemicals in Plants. *Edited by* T. R. Roberts
Optimizing Pesticide Use. *Edited by* M. F. Wilson

Fungicidal Activity

Contributors

J. M. Clough
ZENECA Agrochemicals, Jealott's Hill Research Station, Bracknell, Berkshire RG42 6EY, UK

H.-W. Dehne
Institut für Pflanzenkrankheiten, Universität Bonn, Nussallee 9, D-53115, Bonn, Germany

C. R. A. Godfrey
ZENECA Agrochemicals, Jealott's Hill Research Station, Bracknell, Berkshire RG42 6EY, UK

J. A. Gracia-Garza
Biocontrol of Plant Diseases Laboratory, USDA-ARS, BARC-West, Beltsville, MD 20705, USA

D. W. Hollomon
IACR-Long Ashton Research Station, Department of Agricultural Sciences, University of Bristol, Long Ashton, Bristol BS18 9AF, UK

S. J. Kendall
IACR-Long Ashton Research Station, Department of Agricultural Sciences, University of Bristol, Long Ashton, Bristol BS18 9AF, UK

R. P. Larkin
Biocontrol of Plant Diseases Laboratory, USDA-ARS, BARC-West, Beltsville, MD 20705, USA

E.-C. Oerke
Institut für Pflanzenkrankheiten, Universität Bonn, Nussallee 9, D-53115, Bonn, Germany

D. Roberts
Biocontrol of Plant Diseases Laboratory, USDA-ARS, BARC-West, Beltsville, MD 20705, USA

Y. Uesugi
1-28-9-903 Kaidori, Tama-shi, Tokyo 206, Japan

I. Yamaguchi
The Institute of Physical and Chemical Research (RIKEN), Wako, Saitama 3510106, Japan

K. Yoneyama
Faculty of Agriculture, Meiji University, 1-1-1, Higashimita, Tama, Kawasaki, Kanagawa 214, Japan

Series Preface

There have been tremendous advances in many areas of research directed towards improving the quantity and quality of food and fibre by chemical and other means. This has been at a time of increasing concern for the protection of the environment, and our understanding of the environmental impact of agrochemicals has also increased and become more sophisticated thanks to multi-disciplinary approaches.

Wiley has recognized the opportunity for the introduction of a series of books within the theme 'Agrochemicals and Plant Protection' with a wide scope that will include chemistry, biology and biotechnology in the broadest sense. This series will effectively be a replacement for the successful 'Progress in Pesticide Biochemistry and Toxicology' edited by Hutson and Roberts which has run to nine volumes. In addition, it will complement the international journals *Pesticide Science* and *Journal of the Science of Food and Agriculture* published by Wiley on behalf of the Society of Chemical Industry.

The scope of the new series encompasses all major areas of interest and will reflect the advances made during half a century after World War II and, more importantly, look to further successful developments in agricultural chemistry and biotechnology in the 21st century. The objective is to publish a series of books that will be complementary and will become a collectable series for those involved in research, development and registration of agrochemicals as well as more general aspects.

SCOPE OF 'AGROCHEMICALS AND PLANT PROTECTION'

As indicated, the scope is very broad and the following topics are illustrative:

- Discovery of new agrochemicals/QSAR approaches/other structure activity relationships
- Mode of action of all classes of agrochemicals and PGRs as well as natural products
- Synergy
- Safeners
- Chirality in agrochemical development
- Formulation technologies
- Biopesticides
- Resistance and resurgence/molecular mechanisms of resistance
- Toxicology/metabolism/human risk assessment/extrapolation from animals to man

- Environmental fate and effects/risk assessment/simulation modelling/predicted environmental concentrations
- Residues analysis/formulations analysis/instrumentation
- Remediation/waste management
- Regulation of agrochemicals
- Modern biotechnology and agriculture/genetic modification/plant breeding/regulatory implications of biotechnology
- IPM and ICM
- Plant protection in the 21st century.

There will also be scope for specific monographs on classes of agrochemical (e.g. triazole fungicides, sulphonylurea herbicides) and for broad tests on global issues of world food supply and environmental concerns.

THE SERIES EDITORS

Dr Terry Roberts is Director of Scientific and Regulatory Affairs at JSC International based in Harrogate, UK. He joined JSC in March 1996 and provides scientific and regulatory consulting services to the agrochemical, biocides and related industries with the emphasis on EU registrations.

Dr Roberts was formerly with Corning Hazleton as Director of Agrochemical and Environmental Services (1990–1996) and with Shell Research Ltd for the previous 20 years.

He has been active in international scientific organizations, notably OECD, IUPAC and ECPA, over the past 25 years and was recently appointed Secretary to the Division of Chemistry and the Environment within IUPAC. He has published extensively and is now Editor-in-Chief of the new Wiley series on 'Agrochemicals and Plant Protection'.

Dr Junshi Miyamoto is Corporate Advisor to the Sumitomo Chemical Company, where he has worked since 1957 after graduating from the Department of Chemistry, Faculty of Science, Kyoto University. After a lifetime of working in the chemical industry, Dr Miyamoto has acquired a wealth of knowledge in all aspects of mode of action, metabolism and toxicology of agrochemicals and industrial chemicals. He was previously Director General of Takazuka Research Center of the Company covering the areas of agrochemicals, biotechnology as well as environmental health sciences. He is currently President of the Division of Chemistry and the Environment, IUPAC, and in 1985 he received the Burdick Jackson International Award in Pesticide Chemistry from the American Chemical Society and in 1995, the Award of Distinguished Contribution to Science from the Japanese Government. He has published over 190 original papers and 50 books in the area, and is on the editorial board of several international journals, including *Pesticide Science*.

Preface

Fungicides have the longest history of the three main groups of crop protection agents (insecticides, herbicides and fungicides). Some 150 different compounds are now in use with a global end-user market value of some $6 billion, accounting for almost 20% of the agrochemicals market. Fungicides appear to fall into rather less well-defined groups than do, for example, the insecticides and they encompass a wide range of varied chemical structures. A major development in the 1960s was the successful commercialization of systemic fungicides (absorbed and transported within the plant) allowing more effective protection than did the earlier compounds. More efficient spray technology and formulation have similarly improved the efficiency of the non-systemic materials. With systemic fungicides, and with very specific modes of action and with intensive use situations (e.g. high value glass house crops), resistance has appeared. This in turn has provided a stimulus for the search for new modes of action. The development of compounds with low environmental impact and favourable mammalian toxicology has similarly been an impetus to further research. The search is also increasingly being extended to exploit biological control methods.

The size and scope of the fungicides market are presented by H.-W. Dehne and E.-C. Oerke in the introductory Chapter 1. This is followed by Y. Uesugi's description (Chapter 2) of the current status of the various groups of chemical fungicides, their modes of action and their uses. The debt owed to natural products research in the discovery of fungicides is then described by I. Yamaguchi in Chapter 3. The problem of resistance is discussed in Chapter 4 by D. W. Hollomon and S. J. Kendall. This chapter emphasizes the prediction and avoidance of the problem and also deals with its management and amelioration of its effects when encountered.

The detailed description by J. M. Clough and C. R. A. Godfrey in Chapter 5 of the discovery and development of the strobilurins provides an excellent example of the development of such a chemical class based on a novel mode of action. The remaining three chapters concentrate on biological aspects of control. Biological control methods are already successful in insect control; the biological control of fungal diseases is a relatively recent development and there are many difficulties yet to be overcome. The prospects are assessed by R. P. Larkin, D. P. Roberts and J. A. Gracia-Garza (Chapter 6). Chapter 7 on Systemic Acquired Resistance (I. Yamaguchi) commences with the far-from-obvious statement: 'Disease is a rare outcome in the spectrum of plant–microbe interaction'. The author then describes this remarkable phenomenon, akin in ways to the mammalian immune system, and its manipulation by chemical and other stimulae. Such manipulation affords a novel approach to disease control. The enhancement of natural protection by breeding and by gene transfer techniques is another promising field of research which will become increasingly important. K. Yoneyama, in Chapter 8, describes the various endogenous protection systems and how these may be modulated to improve the resistance of plants to fungal attack. The use of these techniques raises further important issues such as the toxicological aspects of natural fungicides and the public acceptance of genetically engineered agricultural commodities. These latter aspects perhaps deserve treatment in a separate volume.

D. H. HUTSON
Falmouth, Cornwall, UK

J. MIYAMATO
Osaka, Japan

January 1998

Contents

1 Impact of Diseases and Disease Control on Crop Production

H.-W. DEHNE and E.-C. OERKE
Bonn University, Germany

INTRODUCTION

It has become evident over the centuries that diseases caused by fungi can lead to high, sometimes complete losses of crops. This is most striking when the epidemic is spread over large areas and if all plants are more or less susceptible to the devastating pathogens. Since plants have been cultivated, fungal pathogens have found opportunities to spread epidemically and can cause a

Fungicidal Activity. Edited by D. H. Hutson and J. Miyamoto

biological threat to entire crops. Furthermore, fungal diseases especially can result not only in a quantitative yield loss but also in qualitative losses due to lower food quality and to decreased potential for storage and mycotoxin contamination. Most crops are attacked by several fungal pathogens—some are adapted to more moist conditions, such as downy mildews or fruit rots, others need only limited periods of wetness, such as rust fungi, others are even independent of high moisture, such as powdery mildews or smut fungi. Besides the leaf pathogens, high risks of latent damage also arise from soil-borne diseases.

There are several examples of disease epidemics that have caused remarkable food deficiencies or the depletion of a complete crop out of a particular area. The late blight of potato caused by *Phythophthora infestans* has led to periods of starvation by epidemic spread in Ireland during 1845 and 1846; a similar severe epidemic caused big problems with the food supply in Germany during 1916 and 1917. Since then frequent outbreaks of this disease have led to repeated problems wherever potatoes are grown. Additionally, the outbreak of coffee rust caused by *Hemileia vastatrix* led to a depletion of coffee from India and Ceylon, which then became substituted by tea. Another example of an epidemic spread shows the influence of cultivation on these particular problems: the leaf spot disease caused by *Cochiobolus heterostrophus* (*Helminthosporium maydis*) was endemic in maize growing areas, but it became devastating when cytoplasmic male sterility—used for the production of hybrid seed maize—was introduced into almost all maize varieties. When this high susceptibility to the leaf spot pathogen was introduced, the epidemic spread of the disease led to high rates of damage during the early 1970s in the USA and later in South America.

The detrimental outbreak of diseases and the permanent presence of plant pathogens leading to losses in quantity and quality of plant production, have stimulated research to inhibit the development of fungal plant pathogens. The first plant protection chemicals were fungicides introduced as Bordeaux mixture against downy mildew of grapes. A milestone in cereal production was the introduction of seed dressings based on mercury compounds early this century. The organotin chemicals, due to their broad spectrum of activity, led to a general introduction of fungicides in plant production. Since the 1960s the development of fungicides has been improved by the invention of systemic, more specific fungicides that have also offered the development of integrated disease control.

IMPACT OF DISEASES IN MAJOR CROPS

The impact of plant diseases and the most important plant pathogens can be differentiated by crops and the crop losses they cause (Figure 1, Table 1). Key pathogens causing yield-limiting diseases, major pathogens regularly causing

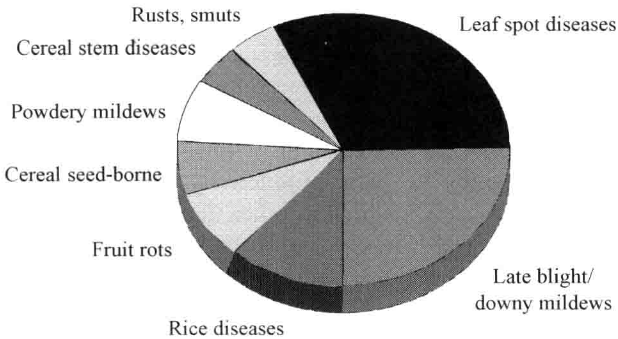

Figure 1 Relative importance of the major diseases based on market potentials (modified from Schwinn, 1992)

Table 1 Area harvested and production of the most important crops/crop groups in 1995

			Share (%) in area/production		
Crop	Area (1000 ha)	Production (1000 t)	Europe	North America/Oceania	East Asia
Wheat	220 605	541 120	12.0/22.9	20.8/18.8	13.2/19.0
Rice	149 151	550 193	0.3/0.4	0.9/1.6	23.4/38.0
Maize	136 245	514 506	7.9/10.7	20.1/37.9	17.3/22.3
Pulses	70 317	55 997	3.4/10.4	6.0/11.2	7.1/10.6
Barley	69 378	142 746	20.8/39.0	14.7/18.7	2.3/2.9
Soybeans	62 285	125 930	0.8/1.0	41.4/48.3	13.9/11.3
Oilseed rape	24 635	34 685	16.1/30.7	22.1/19.3	28.0/28.2
Cotton[a]	34 014	57 244	1.4/2.3	19.7/19.2	16.0/25.0
Peanuts[b]	22 476	27 990	0.1/0.1	2.9/5.8	17.2/37.0
Sunflower[c]	21 476	26 186	21.2/24.0	7.2/7.7	3.8/4.8
Potato	18 480	280 679	20.8/28.6	4.1/9.0	20.1/18.3
Coffee[d]	10 494	5 603	—/—	0.0/0.0	0.2/0.8
Sugarbeets	7 832	265 963	38.2/53.1	7.6/9.9	9.8/6.6
Vegetables	—	487 287	—/13.7	—/7.9	—/32.1
Fruits	—	396 873	—/15.7	—/8.9	—/11.9
Grapes	7 706	53 255	56.7/48.0	4.9/11.5	2.6/4.5

[a] Cottonseed [b] Groundnut in shell [c] Sunflower seed [d] Green coffee

(Source: FAO, 1996)

economic losses, and minor pathogens of lower importance have been differentiated. In some cases major pathogens from one region are not present in other areas. Regional differences for agricultural crops are given according to the intensity of production: Europe, dominated by the EU, with high productivity; North America and Oceania with lower productivity in cereals; East Asia with moderate to high productivity; Rest of world with low productivity. On a local basis, pathogens other than those listed may also be of economic importance. Yield levels and losses have been estimated from literature data as described earlier (Oerke *et al.*, 1994).

CEREALS

Cereals can be infected by a great number of pathogens, dominated by *Ascomycetes* and *Basidiomycetes*. Bacteria are of minor importance, however, they may reduce yields in some regions (e.g. *Xanthomonas campestris* pv *undulosa* in Brazil, etc.). Wheat and barley are highly susceptible to biotrophic pathogens such as rusts caused by *Puccinia* spp. and powdery mildew due to *Erysiphe graminis*. These diseases are especially important when they are

Table 2 Ranking of diseases in wheat, rice and maize in order of importance, by region

Europe	North America and Oceania	East Asia	Rest of world
Wheat			
Rusts	Rusts	Bunts	Bunts
Leaf and glume blotch	Common root rot	Rusts	Rusts
Powdery mildew	Bunts	Smuts	Smuts
Foot rot, eye spot	Take-all	Leaf and glume blotch	Foot rot, head blight
Smuts	Leaf and glume blotch	Powdery mildew	Leaf and glume blotch
Rice			
Rice blast	Sheath blight	Rice blast	Rice blast
Sheath blight	Rice blast	Sheath blight	Brown spot
Brown spot	Brown spot	Bacterial leaf blight	Sheath blight
Bacterial leaf blight	*Cercospora* leaf spot	Brown spot	*Cercospora* leaf spot
Leaf scald	Stem rot	Sheath rot	Bacterial leaf blight
Maize			
Foot rot, stalk rot	Leaf blight	Foot rot, ear rot	Foot rot, stalk rot
Head smut	Rusts	Rusts	Rusts
Common smut	Foot rot, stalk rot	Downy mildew	Downy mildew
Leaf blight	Head blight	*Aspergillus* spp.	Leaf blight
Head blight, ear rot	Head smut	Leaf blight	*Aspergillus* spp.

grown at high fertilization level (Table 2). In low input farming systems of wheat, smuts (*Ustilago* spp.), bunts (*Tilletia* spp.) and necrotrophic leaf pathogens such as *Mycosphaerella graminicola* (anam. *Septroria tritici*), *Phaeosphaeria nodorum* (anam. *Septoria nodorum*) are predominant. Seedling diseases due to *Fusarium* spp. and *Septoria* spp. can be controlled efficiently by seed dressing. The chemical control of soil-borne pathogens such as *Gaeumannomyces graminis* and *Cochliobolus sativus* causing take-all and common root rot/spot blotch, respectively, is often insufficient and production losses can only be reduced by long-term crop rotations. In barley, the pathogen spectrum is similar, however, leaf spot diseases such as net blotch (*Pyrenophora teres*) and scald (*Rhynchosporium secalis*) are among the most important yield-limiting factors in Europe, Oceania and North America. In South America *Puccinia striiformis* is very destructive.

Due to the high input-cultivation of wheat in Western Europe the loss potential of diseases is higher than in all other regions (Figure 2). Intensive disease control practices mainly in Western and Central Europe reduce losses by almost two-thirds to 7%. Soil-borne diseases still pose some control problems. In other regions disease control is rather low and, on a global level, the loss potential is reduced only from 16% to 12%. As world-wide yields currently average about 2.5 t/tha a higher use of fungicides would not be cost-effective in many areas.

RICE

More than 90% of actual production is harvested in Asia. Production systems vary from deepwater rice to upland rice, from intensive cultivation of irrigated lowland rice in East Asia to extensive production systems of upland rice. World-wide rice blast caused by *Magnaporthe grisea* (anam. *Pyricularia oryzae*) is considered to be the most damaging disease followed by sheath blight due to *Thanatephorus cucumeris* (anam. *Rhizoctonia solani*) (Table 2). Bacterial leaf blight caused by *Xanthomonas campestris* pv. *oryzae* has increased during the last decades especially in lowland rice. Besides brown spot (*Cochliobolus miyabeanus*), narrow brown leaf spot (*Cercospora oryzae*), stem rot (*Magnaporthe salvinii*), Bakanae (*Gibberella fujikuroi*), sheath rot (*Sarocladium oryzae*), kernel smut (*Tilletia barclayana*) and leaf scald (*Rhynchosporium oryzae*) and insect-transmitted viral diseaes are reported to cause economic losses.

In rice production the loss potential of pathogens exceeds 20% in Europe, North America/Oceania and East Asia where productivity is high. The infection pressure is lower in all other regions (Figure 2). Current disease control practices effectively reduce losses to an actual level of 8% in the USA, to about 12% in East Asia where China is the main rice producer. In Southeast Asia, South Asia, Latin America and Africa disease control is poor and current losses remain at a high level.