PLANT BIOTECHNOLOGY

Comprehensive Biotechnology
Second Supplement

Editors
MICHAEL W. FOWLER & GRAHAM S. WARREN

Editor-in-Chief
MURRAY MOO-YOUNG

PERGAMON PRESS

PLANT BIOTECHNOLOGY

Comprehensive Biotechnology
Second Supplement

PERGAMON MAJOR REFERENCE WORKS

Comprehensive Inorganic Chemistry (1973)

Comprehensive Organic Chemistry (1979)

Comprehensive Organometallic Chemistry (1982)

Comprehensive Heterocyclic Chemistry (1984)

International Encyclopedia of Education (1985)

Comprehensive Insect Physiology, Biochemistry & Pharmacology (1985)

Comprehensive Biotechnology (1985)

Physics in Medicine & Biology Encyclopedia (1986)

Encyclopedia of Materials Science & Engineering (1986)

World Encyclopedia of Peace (1986)

Systems & Control Encyclopedia (1987)

Comprehensive Coordination Chemistry (1987)

Comprehensive Polymer Science (1989)

Comprehensive Electrocardiology (1989)

Comprehensive Medicinal Chemistry (1990)

Comprehensive Organic Synthesis (1991)

Comprehensive Rock Engineering (1993)

PLANT BIOTECHNOLOGY

Comprehensive Biotechnology
Second Supplement

VOLUME EDITORS

MICHAEL W. FOWLER

University of Sheffield, UK

&

GRAHAM S. WARREN

University of Sheffield, UK

EDITOR-IN-CHIEF

MURRAY MOO-YOUNG

University of Waterloo, Ontario, Canada

PERGAMON PRESS

OXFORD · NEW YORK · SEOUL · TOKYO

U.K. Pergamon Press plc, Headington Hill Hall, Oxford OX3 0BW, England

U.S.A. Pergamon Press, Inc., 395 Saw Mill River Road, Elmsford, New York 10523, USA

KOREA Pergamon Press Korea, KPO Box 315, Seoul 110-603, Korea

JAPAN Pergamon Press Japan, Tsunashima Building Annex, 3-20-12 Yushima, Bunkyo-ku, Tokyo 113, Japan

---

First edition 1992

Library of Congress Cataloging in Publication Data

Plant biotechnology: Comprehensive biotechnology. Second supplement volume editors, Michael W. Fowler & Graham S. Warren; editor-in-chief, Murray Moo-Young.
p. cm.
Includes bibliographical references and index.
1. Plant biotechnology. I. Fowler, Michael W. II. Warren, Graham S., 1952– . III. Moo-Young, Murray. IV. Comprehensive biotechnology.
TP248.27.P55P56 1991 91-16681
631—dc20

British Library Cataloguing in Publication Data

Fowler, Michael W.
Plant biotechnology. – (Comprehensive biotechnology supplement series; no. 2) I. Title II. Warren, Graham S. III. Series
660.6

ISBN 0-08-034731-2

♾™The paper used in this publication meets the minimum requirements of the American National Standard for Information Sciences – Permanence of Paper for Printed Library Materials, ANSI Z39.48-1984.

Printed and bound in Great Britain by BPCC Wheatons Ltd, Exeter

Contents

Foreword

In 1985, *Comprehensive Biotechnology* was published as a major reference work (four volumes; 3764 pages) for effective 'one stop shopping' in a diverse, multidisciplinary field which had previously been treated only in specialist publications. It was well received by the international audience, as shown by citations from *Nature*, the American Chemical Society, the Society for Industrial Microbiology and the Institution of Chemical Engineers, among others.

Since 1985, the biotechnology field has grown significantly, especially in the agriculture-related aspects. To address the changes, the supplement *Animal Biotechnology* was published in 1989 and this year (1992), a complementary supplement *Plant Biotechnology* is being released. As with the first supplement, the editors of *Plant Biotechnology* (M. Fowler and G. Warren) undertook the difficult task of capturing, in an authoritative way, the current status and future trends in this important aspect of biotechnology. We owe them both a word of appreciation for their dedication.

In the future, Pergamon intends to keep the four volume foundation work of *Comprehensive Biotechnology* updated on an ongoing basis with review articles in its quarterly journal, *Biotechnology Advances.*

MURRAY MOO-YOUNG
Waterloo, Canada
June 1991

This page intentionally left blank

Preface

oduction

ome 10 to 15 years ago when the first stirrings of what might be termed 'modern' biotechnology an to take shape, and organizations such as the European Federation of Biotechnology were ned to nurture its development, great doubts were expressed as to the applicability of what ht be loosely termed plant sciences to biotechnology. What a difference a decade has made. lay it is generally accepted that one of the key areas of biotechnology for the next century will n plant-based biotechnology, with implications ranging from improved crops and food provision, alternative bioremediation systems and novel high value chemicals, including enzymes. mendous progress has been made in all aspects of plant physiology, biochemistry and molecular ogy over the last decade, much of it driven from a biotechnological standpoint.

'he application of novel techniques aimed at improving the performance of plants or plant cells been a particular growth area in modern biotechnology. Such growth has been directed largely the needs of agriculture and fuelled by the rapid development of the central techniques of :neration from plant cell and tissue cultures, gene vector design and plant transformation. Other ors have also been key, notably the interest of many multinational companies who have been :k to see the commercial potential of engineered crop species. Equally, organizations such as European Commission and World Bank have seen the wider impact upon farming economies Third World development, and have been instrumental in assembling multinational research grammes focusing on plant biotechnology. In parallel, plant biotechnologists have also ›gnized that recently unreachable goals have almost overnight come within their grasp, enabling n to reach towards opportunities both scientific and commercial.

ike every branch of biotechnology, plant biotechnology is an ever-broadening subject that is cult to characterize. We have attempted for ease of presentation to divide this volume into five ject areas.

ogy of Plant Cells

1uch that is fundamental to the development of plant biotechnology in the future lies in the cture, composition and functionality of plant cells and genes. It is on this area that the first ion focuses, with particular emphasis on the cellular and molecular biology of plants and cultured s. An appreciation of these basic aspects is important in the recognition of new possibilities and limitations of many of the individual techniques currently in use. The pursuit of applied aims 1out due attention to the underlying mechanisms involved is likely to be a self-limiting and ficient process. This is seen in molecular biology where, while protocols for cloning genes have ɔme almost routine, the question 'which gene shall we clone?' has become commonplace. Plant echnology at present is greatly limited by the lack of basic understanding of most of the useful racters we wish to manipulate.

he state of knowledge of plant systems has always lagged far behind that of microorganisms animals. This to some extent reflects the smaller number of researchers working with plants, also reflects the technical problems associated with experimentation on plant systems. The new 1niques, especially recombinant DNA methods, linked to cell and tissue culture offer great scope elieve this situation, leading to a deeper and wider appreciation of plant cell and molecular ogy.

tems for the Exploitation of Cell Cultures

his section is concerned with the direct exploitation of cell cultures for the production of useful stances. In principle, this area of research should be perhaps the most immediately fruitful

because engineered or selected cells can be produced with characteristics that do not need to be compatible with plantlet regeneration or plant fertility, constraints that have limited progress in certain agricultural applications. However, other obstacles have been encountered, in particular the failure of many cell lines in culture to express those genes coding for secondary metabolite synthesis, genetic instability of cells maintained in culture and the lack of basic information about the biochemistry of biosynthetic pathways. Largely for these reasons, progress in the development of plant cell cultures for industrial use has generally been disappointing. In addition to more basic research, the more widespread adoption of gene transfer methods for the manipulation of pathways may alter this situation. Most likely, plant cell culture will prove to be a feasible route to the production of specific substances in particular, favourable circumstances, for example novel products unique to cultured cells, and the formation of protein products from foreign genes. The alternative strategy of the transfer of plant genes to microorganisms for heterologous expression is also being actively pursued.

Regeneration and Propagation Systems

Central to the application of novel techniques to the improvement of plants is the ability to regenerate whole, fertile plants from individual cells and protoplasts. Although this process was first described some 40 years ago, it has long been restricted to a relatively small range of species. Extensive research has resulted in an improvement in this situation to the point that at least low levels of regeneration are now possible from most of the important crop species. However, much of the progress has been empirically based, and plant regeneration is still devoid of a satisfactory theoretical foundation. The desired applications of cell fusion and transformation techniques have placed extra demands on regeneration systems. The requirement that newly developed plant varieties must be compatible with breeding programmes necessitates high fertility of the regenerants. This situation is usually the exception rather than the norm. It has been found that, although transformation and regeneration can often be readily achieved separately, transformation of regeneration competent cells is much rarer, and therefore the frequency of transgenic plants recovered can be very low. New developments are occurring rapidly in this area, however, and the recent reports of fertile, transgenic rice and maize perhaps indicate that these problems are near to a general solution.

Plant regeneration has long been exploited commercially for the micropropagation of ornamentals and disease-free stock. However, tissue culture techniques are labour intensive and time consuming and careful planning is required to ensure that a micropropagation scheme is economically viable. There is currently increasing interest in the mechanization of certain culture manipulations with a view to reducing the cost of the process.

Genetic Manipulation of Plant Cells

The next section considers the increasingly central area of genetic manipulation of plant cell systems. For a number of years, manipulation of the genetic make-up of plants by protoplast fusion, mutagenesis and culture-induced variation has resulted in steady but relatively slow progress towards improved plant varieties. Now specific gene transfer has moved to centre stage. The ability to add just the desired genes to a plant, without the near certainty of downgrading previously optimized characters, gives special appeal to this approach. However, the other novel methods will continue to be useful in specific instances, especially in cases in which there is little understanding of the molecular mechanisms governing the desired characters. Traditional methods will probably remain central to crop improvement but will be increasingly complemented by the new technology. Biotechnology is all about application and commercialization. The technique that achieves the desired aim most cheaply will be adopted and not necessarily that which is novel, or technically most elegant or sophisticated.

Genetic engineering has already been responsible for the production of plants with enhancement in a range of desirable traits, notably disease resistance, insect resistance, ripening properties and nutritional and commercial value. Progress is also being made towards longer term aims such as improvement of the efficiency of photosynthesis and other polygenic mechanisms. Enthusiasm for transgenesis is currently high. The bounds of the possible have been radically widened. However, this enthusiasm is being tempered by the growing debate on the potential hazards of releasing transgenic plants, the ethical and emotional concerns associated with changing our flora, and whether there is an actual need to create certain new plant varieties.

This book is a survey of these various facets of plant biotechnology. The individual chapters and the follow-up literature cited should allow a relatively easy access to the various subject areas and hopefully stimulate interest in these rapidly moving and exciting fields of research.

MICHAEL W. FOWLER
Sheffield, UK
June 1991

GRAHAM S. WARREN
Sheffield, UK
June 1991

This page intentionally left blank

Contributors

Dr P. G. Alderson
Nottingham University School of Agriculture, Sutton Bonington, Loughborough, Leicestershir
LE12 5RD, UK

Dr C. A. Cullis
Department of Biology, Case Western Reserve University, Cleveland, OH 44106, USA

Dr A. G. Day
MRC Unit for Protein Function and Design, Cambridge IRC for Protein Engineering, Departmen
of Chemistry, University of Cambridge, Lensfield Road, Cambridge CB2 1EW, UK

Professor M. W. Fowler
Department of Molecular Biology & Biotechnology, University of Sheffield, Sheffield S10 2TN, UK

Dr C. H. Foyer
Laboratoire de Métabolisme, INRA, Route de St Cyr, F-78026 Versailles Cedex, France

Dr R. T. Furbank
Division of Plant Industry, CSIRO, PO Box 1600, Canberra, 2601 ACT, Australia

Dr J. Hall
Leicester Polytechnic School of Life Sciences, Scraptoft Campus, Scraptoft, Leicester LE7 9SU, UK

Dr C. P. Lichtenstein
Centre for Biotechnology, Imperial College of Science, Technology and Medicine, London SW7 2AZ
UK

Dr W. H.-T. Loh
Applied Molecular Genetics & Oilseeds, DNA Plant Technology Corporation, Cinnaminsor
NJ 08077, USA

Dr F. Mavituna
Department of Chemical Engineering, University of Manchester Institute of Science and Technology
Sackville Street, PO Box 88, Manchester M60 1QD, UK

Dr H. Morikawa
Research Centre for Cell & Tissue Culture, Kyoto University, Kyoto 606, Japan

Dr S. J. Ochatt
INRA, Station d'Amelioration des Espèces Fruitières et Ornamentales, Domaine de Bois l'Abb
Beaucouze, F-49000 Angers, France

Dr G. Ooms
AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Hert
AL5 2JQ, UK

Dr N. Overbeeke
Unilever Research Laboratorium Vlaardingen, PO Box 114, 3130 AC Vlaardingen, The Netherlands

Dr J. B. Power
Department of Botany, Plant Genetic Manipulation Group, University of Nottingham, University Park, Nottingham NG7 2RD, UK

Mr A. Ranchhod
Management Centre, Southampton Institute, East Park Terrace, Southampton SO9 4WW, UK

Dr R. D. Rice
11 Cloysters Green, St Katherine by the Tower, London E1 9LU, UK

Dr A. H. Scragg
Bristol Polytechnic, Coldharbour Lane, Frenchay, Bristol BS16 1QY, UK

Dr A. M. Stafford
Department of Molecular Biology & Biotechnology, University of Sheffield, Sheffield S10 2TN, UK

Dr C. T. Verrips
Unilever Research Laboratorium Vlaardingen, PO Box 114, 3130 AC Vlaardingen, The Netherlands

Dr G. S. Warren
Department of Molecular Biology & Biotechnology, University of Sheffield, Sheffield S10 2TN, UK

Professor G. Wenzel
Federal Biology Research Centre for Agriculture & Forestry, Institute for Resistance Genetics, D-8059 Grünbach, Germany

Dr P. D. Williams
Department of Chemical Engineering, University of Manchester Institute of Science and Technology, Sackville Street, PO Box 88, Manchester M60 1QD, UK

Professor Y. Yamada
Research Centre for Cell & Tissue Culture, Kyoto University, Kyoto 606, Japan

Contents of All Volumes

COMPREHENSIVE BIOTECHNOLOGY

Volume 1

Section 1: Genetic and Biological Fundamentals

Section 2: Chemical and Biochemical Fundamentals

Volume 2

Section 1: Bioreactor Design, Operation and Control

Section 2: Upstream and Downstream Processing

Volume 3

Section 1: Healthcare Products

Volume 4

Section 1: Specialized Activities and Potential Applications

Section 2: Governmental Regulations and Concerns