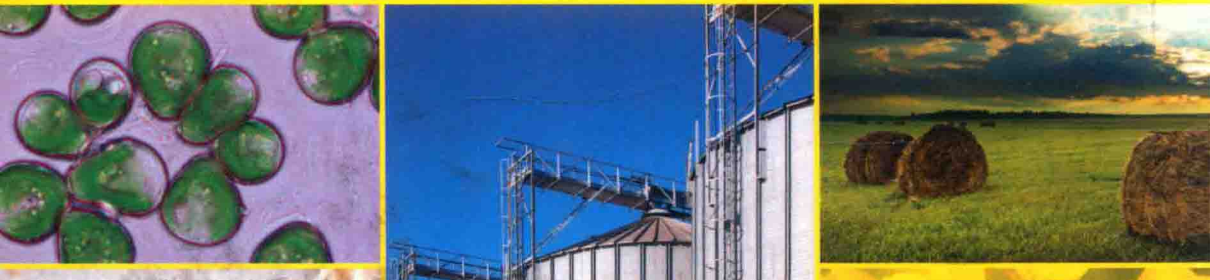
FOOD AND INDUSTRIAL BIOPRODUCTS AND BIOPROCESSING

Edited by
Nurhan Turgut Dunford



WILEY-BLACKWELL

Food and Industrial Bioproducts and Bioprocessing

Edited by

Nurhan Turgut Dunford
Department of Biosystems and Agricultural Engineering and Robert M. Kerr Food & Agricultural Products Center
Oklahoma State University
Stillwater
Oklahoma
USA

WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

Wiley-Blackwell is an imprint of John Wiley & Sons, formed by the merger of Wiley's global Scientific, Technical and Medical business with Blackwell Publishing.

Editorial Offices
2121 State Avenue, Ames, Iowa 50014-8300, USA
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
9600 Garsington Road, Oxford, OX4 2DQ, UK

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell.

Library of Congress Cataloging-in-Publication Data

Food and industrial bioproducts and bioprocessing / edited by Nurhan Turgut Dunford.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-8138-2105-4 (hard cover : alk. paper)
1. Biological products. 2. Biotechnology. 3. Biomass. I. Dunford, Nurhan Turgut, 1953–
TP248.2.F725 2012
660.6–dc23
2011035806

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

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Set in 10/12pt Times by SPi Publisher Services, Pondicherry, India
Printed and bound in Malaysia by Vivar Printing Sdn Bhd

1 2012

Food and Industrial Bioproducts and Bioprocessing

Preface

Petroleum-derived products have dominated the markets for decades because of the ease of production and economies of scale. In recent years diminishing petroleum resources, volatile political environments in some of the major petroleum producing countries and environmental concerns inspired a paradigm shift. Today significant resources have been dedicated to the development of bioproducts from renewable sources. Research and development efforts to harness the unique chemical and physical properties of plants and microorganisms to produce ecologically benign products that outperform their non-renewable counterparts have accelerated. Ever increasing consumer demand for "chemical free", "healthy" and "natural" foods incited the food industry to reevaluate the conventional food ingredients and processing techniques and adapt new and advanced production systems.

This book, which contains 14 chapters, provides a comprehensive review of the latest developments in food and industrial bioproducts and bioprocessing techniques. Although it is an important topic, biofuels are not covered in the book. This book is designed as a reference source for scientists, students, and government and industry personnel who are interested in the recent developments and future opportunities in food and industrial bioproducts and relevant bioprocessing techniques. The contributing authors of the book from Australia, Canada, Denmark, Germany and the USA are internationally renowned experts in their fields and their contributions to the book are invaluable. I would like to express my sincere gratitude to the authors for accepting my invitation to contribute and completing their chapters in a timely manner. The comments received from the external reviewers, James T.C. Yuan, Ibrahim Banat, Sue, Nokes, David Cowan, Randy Berka, Mark R. Marten, B. Dave Oomah, J.L. Willett, Laurent Bazinet, Dan Farkas, Richard Ashby, Thrandur Helgason, Donghai Wang, Cristina Sabliov, Wenqiao (Wayne) Yuan, Michael J. Haas, Sang-Hyun Pyo, Krister Holmberg, Aaron L. Brody, Amos Richmond and Mike Packer, were extremely helpful. I would like to thank all the reviewers for generously spending time to review the chapters. Certainly their contributions enhanced the quality of the book.

I would also like to thank the staff at Wiley-Blackwell for their help and guidance which made the successful completion of this project possible. I am grateful to my son, Michael John, for his patience, understanding and encouragement during the preparation of this book.

Nurhan Turgut Dunford

Contributors

Hasan Atiyeh
Department of Biosystems
and Agricultural Engineering
Oklahoma State University
Stillwater, Oklahoma, USA

Scott E. Baker
Chemical and Biological Process
Development Group
Pacific Northwest National Laboratory
Richland, Washington, USA

Chockry Barbana
Food Research and Development Centre
Agriculture and Agri-Food Canada
Saint-Hyacinthe, Quebec, Canada

Natasha Berry
Department of Chemistry and Biology
Ryerson University
Toronto, Ontario, Canada

Susan I. Blackburn
CSIRO Marine and Atmospheric Research
and Energy Transformed Flagship
Hobart, Tasmania, Australia

Joyce Irene Boye
Food Research and Development Centre
Agriculture and Agri-Food Canada
Saint-Hyacinthe, Quebec, Canada

Jonathan Y. Chen
School of Human Ecology
Texas Materials Institute Material
Science & Engineering Program
The University of Texas at Austin
Austin, Texas, USA

Ling-Zhi Cheong
Department of Engineering
Aarhus University
Aarhus, Denmark

John N. Coupland
Department of Food Science
The Pennsylvania State University
University Park, Pennsylvania, USA

Nurhan Turgut Dunford
Department of Biosystems and
Agricultural Engineering and
Robert M. Kerr Food & Agricultural
Products Center
Oklahoma State University
Stillwater, Oklahoma, USA

Ryan J. Elias
Department of Food Science
The Pennsylvania State University
University Park, Pennsylvania, USA

George F. Fanta
US Department of Agriculture
Agricultural Research Service
National Center for Agricultural
Utilization Research
Peoria, Illinois, USA

Sergey N. Fedosov
Department of Engineering
Aarhus University
Aarhus, Denmark

Frederick C. Felker
US Department of Agriculture
Agricultural Research Service
National Center for Agricultural
Utilization Research
Peoria, Illinois, USA

Zheng Guo
Department of Engineering
Aarhus University
Aarhus, Denmark

Gündüz Güzel
Department of Engineering
Aarhus University
Aarhus, Denmark

Douglas G. Hayes
Department of Biosystems Engineering and Soil Science
University of Tennessee
Knoxville, Tennessee, USA

Ram C.R. Jala
Department of Engineering
Aarhus University
Aarhus, Denmark

Sue A. Karagiosis
Chemical and Biological Process Development Group
Pacific Northwest National Laboratory
Richland, Washington, USA

Bena-Marie Lue
Department of Engineering
Aarhus University
Aarhus, Denmark

Michael A. R. Meier
Karlsruhe Institute of Technology
Institute of Organic Chemistry
Karlsruhe, Germany

Dérick Rousseau
Department of Chemistry and Biology
Ryerson University
Toronto, Ontario, Canada

Fernando Sampedro
USDA ARS Eastern
Regional Research Center
Wyndmoor, Pennsylvania, USA

Randal L. Shogren
US Department of Agriculture
Agricultural Research Service
National Center for Agricultural Utilization Research
Peoria, Illinois, USA

Oğuz Türünç
Karlsruhe Institute of Technology
Institute of Organic Chemistry
Karlsruhe, Germany

John K. Volkman
CSIRO Marine and Atmospheric Research and Energy Transformed
Hobart, Tasmania, Australia

Mark R. Wilkins
Department of Biosystems and Agricultural Engineering
Oklahoma State University
Stillwater, Oklahoma, USA

Xuebing Xu
Department of Engineering
Aarhus University
Aarhus, Denmark

Rickey Yada
Department of Food Science
University of Guelph
Guelph, Ontario, Canada

Fei Yu
Department of Agricultural and Biological Engineering
Mississippi State University
Mississippi State, Mississippi, USA

Umut Yucel
Department of Food Science
The Pennsylvania State University
University Park, Pennsylvania, USA

Howard Q. Zhang
USDA ARS Western Regional
Research Center
Albany, California, USA

Abbreviations

ADMET	Acyclic diene metathesis polymerization
AOT	Sodium dioctyl sulfosuccinate
CALA	Candida antarctica lipase A
CALB	Candida antarctica lipase B
DAG	Diacylglycerol
DVB	Divinyl benzene
E	Enzyme
EP	Enzyme-product complex
ES	Enzyme-substrate complex
ESBO	Epoxidized Soybean Oil
FA	Fatty acid
FAME	Fatty acid methyl ester
G (or GLY)	Glycerol
HAP	Hazardous air pollutant
hPL	Human pancreatic lipase
IPN	Interpenetrating network
KmS	Michaelis constant
LOI	Limiting oxygen index
LPL	Lysophospholipids
MAG	Monoacylglycerol
METU	Methyl undec-10-enoate
NMMO	N-methylmorpholine-N-oxide
P	Product
PC	Phosphatidylcholine
PG	Partial Acylglycerol
PGA	Poly(glycolic acid)
PHA	Polyhydroxyalkanoate
PHB	Poly(3-hydroxybutyrate)
PHBV	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)
PL	Phospholipid
PLA	Poly(lactic acid)
PLA_1	Phospholipase A_1
PLA_2	Phospholipase A_2
PLC	Phospholipase C
PLCD	Phospholipase D
PLLA	Poly(l-lactic acid)
PU	Polyurethane

PVA	Poly(vinyl alcohol)
RM	Rhizomucor meihei
S	Substrate
S*	Micellar substrate
TAG	Triacylglycerol
TLL	Thermomyces lanuginosum
UA	Undec-10-enoic acid
V	Velocity
VOC	Volatile organic compounds

Contents

1 Traditional and Emerging Feedstocks for Food and Industrial Bioproduct Manufacturing

Nurhan Turgut Dunford

1.1 INTRODUCTION

Many industrial products, such as dyes, inks, paints and plastics, were made from biomass generated by trees, vegetables or other crops during the early 1900s. By 1970, petroleum-based products had largely replaced bio-based products. The utilization of plant-based materials decreased from about 35% to less than 16% between 1925 and 1989 (Forward, 1994). Waning interest in bio-based products was due to the relative ease and lower cost of manufacturing similar products from petrochemicals.

The petrochemical industry has been very successful in developing new products (more than 100 000 commercial products) (Metzger and Eissen, 2004). About 2.6 million barrels per day of petroleum equivalent are used for production of chemicals and industrial building blocks. More than 95% of the world's petrochemical production is derived from oil or natural gas (Weissermel and Arpe, 1997). Excessive reliance on non-renewable energy and resources is the major problem facing petrochemical industry today. In 2001 it was projected that the global oil reserves would last for about 40 years (Metzger and Eissen, 2004). Oil production is expected to reach its maximum in this decade, at the latest by 2015–2020, and then slowly decrease. According to Gavrilescua and Chisti, the issues that make the petrochemical industry unsustainable in the long run are: (1) utilization of manufacturing techniques that are not environmentally benign or safe, (2) production of toxic by-products and waste, (3) products are not readily recyclable and biodegradable after their useful life, and (4) social benefits of the production are not broadly accessible due to excessive regional concentration of production (Gavrilescua and Chisti, 2005).

Nearly one billion of the current world population (the total is about six billion) live in the industrialized countries. The world population is expected to reach to about nine billion by 2050. It is anticipated that the population growth will mainly soar in the developing countries (Metzger and Eissen, 2004). As the population and the standard of living increase, demand for food and other goods will substantially grow, consequently exerting tremendous pressure on resources. Today it is true that "hunger is a problem of poverty rather than absolute food scarcity" (Koning *et al.*, 2008). Yet, the global demand for food production will more than double by 2050, competing for resources needed to grow biomass for other purposes, including biofuels and bio-based non-food industrial products (Koning *et al.*, 2008). A combination of further increases in crop yields (about 2% per year) and doubling

Food and Industrial Bioproducts and Bioprocessing, First Edition. Edited by Nurhan Turgut Dunford.