

FOOD AND INDUSTRIAL BIOPRODUCTS AND BIOPROCESSING

Edited by
Nurhan Turgut Dunford



Food and Industrial Bioproducts and Bioprocessing

Edited by

Nurhan Turgut Dunford

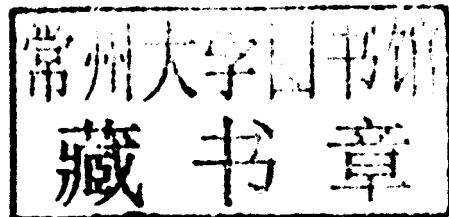
Department of Biosystems and Agricultural
Engineering and Robert M. Kerr Food & Agricultural
Products Center

Oklahoma State University

Stillwater

Oklahoma

USA



 **WILEY-BLACKWELL**

A John Wiley & Sons, Ltd., Publication

This edition first published 2012 © 2012 by John Wiley & Sons, Inc.

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.

Authorization to photocopy items for internal or personal use, or the internal or personal use of specific clients, is granted by Blackwell Publishing, provided that the base fee is paid directly to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923. For those organizations that have been granted a photocopy license by CCC, a separate system of payments has been arranged. The fee codes for users of the Transactional Reporting Service are ISBN-13: 978-0-8138-XXXX-X/2007.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book. This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

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

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, Thrander 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

<i>Preface</i>	xi
<i>Contributors</i>	xiii
<i>Abbreviations</i>	xvii

1 Traditional and Emerging Feedstocks for Food and Industrial Bioproduct Manufacturing	1
Nurhan Turgut Dunford	
1.1 Introduction	1
1.2 Grain crops	2
1.2.1 Wheat	2
1.2.2 Corn	5
1.2.3 Barley	8
1.2.4 Sorghum	10
1.3 Oil and oilseeds	13
1.3.1 Rapeseed/Canola	14
1.3.2 Soybeans	15
1.3.3 Other Oilseeds	19
1.4 Lignocellulosic biomass	24
1.5 Conclusions	25
References	26
2 Recent Processing Methods for Preparing Starch-based Bioproducts	37
George F. Fanta, Frederick C. Felker and Randal L. Shogren	
2.1 Introduction	37
2.2 Annealing and heat-moisture treatment	40
2.3 High-pressure treatment	41
2.4 Microwave processing	46
2.5 Processes using ultrasound	50
2.6 Processing using supercritical fluids	56
2.7 Extrusion processing	63
2.8 Processing by steam jet cooking	67
2.9 Conclusions	71
References	72

3 Protein Processing in Food and Bioproduct Manufacturing and Techniques for Analysis	85
Joyce Irene Boye and Chockry Barbana	
3.1 Introduction	85
3.2 General properties of proteins	86
3.3 Protein separation processes in food and bioproduct manufacturing	87
3.3.1 Dry processing	88
3.3.2 Wet processing	89
3.4 Calculating protein yields and recovery	101
3.5 Processing effects on yield and protein quality	101
3.5.1 Protein characterization	102
3.6 Conclusion	108
References	108
4 Advancements in Oil and Oilseed Processing	115
Nurhan Turgut Dunford	
4.1 Introduction	115
4.2 Oilseed pretreatment	116
4.2.1 Handling and storage	116
4.2.2 Preparation of seeds for oil extraction	117
4.2.3 Size reduction and flaking	118
4.2.4 Cooking/Tempering	118
4.3 Oil extraction	119
4.3.1 Solvent extraction	119
4.3.2 Mechanical oil expression	122
4.3.3 Aqueous extraction	124
4.3.4 Enzyme and surfactant-aided oil extraction	124
4.3.5 Supercritical fluid technology	126
4.4 Oil refining	127
4.4.1 Degumming	127
4.4.2 Deacidification/Refining	131
4.4.3 Bleaching	135
4.4.4 Deodorization	136
4.4.5 Winterization	137
4.5 Conclusions	137
References	138
5 Food-grade Microemulsions As Nano-scale Controlled Delivery Vehicles	145
Natasha Berry, Rickey Yada and D��rick Rousseau	
5.1 Introduction	145
5.2 Winsor classification/phase behavior	146
5.3 Theories of microemulsion formation	147
5.3.1 Mixed film theory	147
5.3.2 Solubilization theory	147
5.3.3 Thermodynamic theory	147
5.4 What makes microemulsions thermodynamically stable?	148
5.5 Methods of microemulsion formation	148
5.6 Polydispersity	149

5.7	Composition	149
5.7.1	Organic phase	149
5.7.2	Aqueous phase	150
5.7.3	Surfactants	150
5.7.4	Co-surfactants	151
5.8	Factors affecting phase behavior	151
5.9	Parameters that modify microemulsion structure	152
5.9.1	Critical micelle concentration	152
5.9.2	Critical packing parameter	152
5.9.3	Hydrophile–lipophile balance	153
5.9.4	Ingredient compatibility	153
5.10	Characterization techniques	154
5.10.1	Ternary phase diagrams	154
5.10.2	Small angle scattering techniques	155
5.10.3	Cryo-transmission electron microscopy	156
5.10.4	Dynamic light scattering	157
5.10.5	Nuclear magnetic resonance	158
5.11	Applications	158
5.11.1	Solubilization of poorly-soluble drugs	158
5.11.2	Emulsified microemulsions	159
5.11.3	Protection against oxidation/light	159
5.11.4	Controlled release delivery systems	159
5.11.5	Microemulsions as nano-reactors	160
5.12	Conclusions	160
	References	161
6	Emulsions, Nanoemulsions and Solid Lipid Nanoparticles as Delivery Systems in Foods	167
	Umut Yucel, Ryan J. Elias and John N. Coupland	
6.1	Delivery systems in foods	167
6.2	Structure of emulsions	168
6.3	Localization of BLI in emulsions	169
6.4	Emulsions as delivery systems	172
6.5	Crystallization in emulsions	174
6.5.1	Kinetics of crystallization in fine droplets	175
6.5.2	Structure of crystalline fat droplets	177
6.6	Localization of BLI in solid lipid nanoparticles	178
6.7	Conclusions	180
	Acknowledgement	181
	References	181
7	Fermentation	185
	Mark R. Wilkins and Hasan Atiyeh	
7.1	Introduction	185
7.2	Fermentative pathways	186
7.3	Microbial growth	188
7.4	Reactor design	189
7.4.1	Types of reactors	190

7.5	Fermentation schemes	194
7.5.1	Batch fermentation	194
7.5.2	Fed-batch fermentation	194
7.5.3	Continuous fermentation	194
7.6	Fermentation Products	195
7.6.1	Acetone–Butanol–Ethanol (ABE) fermentation	195
7.6.2	Glycerol	196
7.6.3	Propionate	197
7.6.4	Succinate	197
7.6.5	1,3 Propanediol	197
7.6.6	Butanediol	198
7.7	Separation	199
7.7.1	Separation of acids	199
7.7.2	Separation of alcohols	199
7.7.3	Separation of diols and triols	200
7.8	Future application areas and emerging developments	200
	References	201
8	Fungal Cell Factories	205
	Sue A. Karagiosis and Scott E. Baker	
8.1	Fungi and fungal biotechnology	205
8.2	Historical perspective	206
8.2.1	Koji	206
8.2.2	Penicillin	207
8.2.3	Citric acid	208
8.3	Industry	208
8.3.1	Organic acids	208
8.3.2	Enzymes	211
8.3.3	Lovastatin	211
8.4	Genomics and the future	213
8.4.1	Citric acid and <i>Aspergillus niger</i>	213
8.4.2	Cellulase production	214
8.4.3	Bioactive secondary metabolites	215
8.5	Conclusions	215
	References	216
9	Microalgae: A Renewable Source of Bioproducts	221
	Susan I. Blackburn and John K. Volkman	
9.1	Introduction	221
9.2	Microalgae and their global importance	221
9.3	Cultured microalgae	223
9.4	Algal culture collections	224
9.5	Microalgal production systems	225
9.5.1	Plastic bags and tanks	225
9.5.2	Open ponds	225
9.5.3	Photobioreactors	226
9.5.4	Hybrid or combination growth systems	227
9.5.5	Fermentation systems	227

9.6	Historical natural foods	228
9.7	Live feedstocks for aquaculture	228
9.8	Bioproducts	229
9.8.1	Bioactive compounds	229
9.8.2	Lipids	230
9.8.3	Proteins and carbohydrates	233
9.8.4	Vitamins and antioxidants	233
9.8.5	Pigments	234
9.9	Pharmaceuticals	235
9.10	Microalgae in cosmetics and skin care	236
9.11	Microalgae bioproducts: Future potential	236
	References	237
10	Bioprocessing Approaches to Synthesize Bio-based Surfactants and Detergents	243
	Douglas G. Hayes	
10.1	Bio-based surfactants: Overview	243
10.2	Feedstocks for bio-based surfactants	244
10.3	Industrial bio-based surfactants	246
10.4	Advantages of bioprocessing to prepare bio-based non-ionic surfactants	248
10.5	Preparation of bio-based surfactants via enzymes in non-aqueous media	249
10.5.1	Lipase-catalyzed synthesis of monoacylglycerols (MAGs)	251
10.5.2	Lipase-catalyzed synthesis of saccharide–fatty acid esters	252
10.5.3	Lipase-catalyzed synthesis of polyglycerol polyricinoleate	254
10.5.4	Enzyme-catalyzed synthesis of alkylpolyglucosides (APGs)	254
10.5.5	Enzyme-catalyzed synthesis of amino acid derivatives	255
10.5.6	Enzymatic production of lysophospholipids and structured phospholipids	256
10.6	Preparation of biosurfactants via fermentation	258
10.7	Conclusions	261
	References	262
11	Biopolymers	267
	Oğuz Türlünç and Michael A. R. Meier	
11.1	Introduction	267
11.2	Carbohydrate-based polymers	267
11.2.1	Polymers from starch	267
11.2.2	Polymers from cellulose	270
11.2.3	Polymers from lactic acid and lactide	272
11.2.4	Polyhydroxyalkanoates	275
11.2.5	Polymers from chitin or chitosan	276
11.3	Fat- and oil-based polymers	277
11.3.1	Polymers from triglycerides	277
11.3.2	Polymers from fatty acids	282
11.4	Conclusion	286
	References	286

12	Lignocellulosic Biomass Processing	293
	Fei Yu and Jonathan Y. Chen	
12.1	Introduction	293
12.2	Availability of lignocellulosic biomass	293
12.2.1	Southern pine wood	294
12.2.2	Corn stover	295
12.2.3	Bast fiber crops	295
12.2.4	Other lignocellulosic feedstocks	296
12.3	Processing	297
12.3.1	Biological conversion	297
12.3.2	Thermochemical conversion	297
12.3.3	Bast fiber production	305
	References	308
13	Recent Developments in Non-thermal Processess	313
	Fernando Sampedro and Howard Q. Zhang	
13.1	Introduction	313
13.2	Recent advances in non-thermal technologies	314
13.2.1	High Pressure Processing (HPP)	314
13.2.2	Ultra High Pressure Homogenization (UHPH)	315
13.2.3	High Pressure Carbon Dioxide (HPCD)	317
13.2.4	Pulsed Electric Fields (PEF)	318
13.2.5	Ultraviolet Light (UV)	320
13.2.6	Irradiation	321
13.2.7	High Intensity Ultrasounds	323
13.2.8	Hurdle approach	324
13.3	Future trends	325
	Acknowledgements	325
	References	326
14	Enzymes as Biocatalysts for Lipid-based Bioproducts Processing	333
	Ling-Zhi Cheong, Zheng Guo, Sergey N. Fedosov, Bena-Marie Lue, Ram C.R. Jala, Gündüz Güzel, and Xuebing Xu	
14.1	Introduction	333
14.2	Enzyme characteristics	333
14.3	Enzyme kinetics in industrial applications	334
14.4	Enzymes in industrial applications	338
14.4.1	Enzymatic processing of partial acylglycerols	339
14.4.2	Enzymatic processing of bioactive compounds	343
14.4.3	Enzymatic processing of phospholipids	346
14.4.4	Enzymatic processing of fatty acid alkyl esters	348
14.5	Conclusions and future trends	351
	References	353

<i>Index</i>	359
--------------	-----

A color plate section falls between pages 222 and 223

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 Gavrillescua 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 (Gavrillescua 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