Nondigestible Carbohydrates and Digestive Health

Editors
Teri M. Paeschke
William R. Aimutis

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

IFT PRESS
Nondigestible Carbohydrates and Digestive Health
The *IFT Press* series reflects the mission of the Institute of Food Technologists – to advance the science of food contributing to healthier people everywhere. Developed in partnership with Wiley-Blackwell, *IFT Press* books serve as leading-edge handbooks for industrial application and reference and as essential texts for academic programs. Crafted through rigorous peer review and meticulous research, *IFT Press* publications represent the latest, most significant resources available to food scientists and related agriculture professionals worldwide.

Founded in 1939, the Institute of Food Technologists is a nonprofit scientific society with 22,000 individual members working in food science, food technology, and related professions in industry, academia, and government. IFT serves as a conduit for multidisciplinary science thought leadership, championing the use of sound science across the food value chain through knowledge sharing, education, and advocacy.

**IFT Press Advisory Group**
(formerly, Book Communications Committee)
Casimir C. Akoh
Christopher J. Doona
Jung Hoon Han
David B. Min
Ruth M. Patrick
Syed S. H. Rizvi
Fereidoon Shahidi
Christopher H. Sommers
Yael Vodovotz
Mark Barrett
Karen Nachay
Margaret Kolodziej

**IFT Press Editorial Advisory Board**
Malcolm C. Bourne
Dietrich Knorr
Theodore P. Labuza
Thomas J. Montville
S. Suzanne Nielsen
Martin R. Okos
Michael W. Pariza
Barbara J. Petersen
David S. Reid
Sam Saguy
Herbert Stone
Kenneth R. Swartzel
Nondigestible Carbohydrates and Digestive Health

Editors
Teri M. Paeschke
William R. Aimutis
Titles in the IFT Press series

- Accelerating New Food Product Design and Development (Jacqueline H. Beckley, Elizabeth J. Topp, M. Michele Foley, J.C. Huang and Witoon Prinyawiwatkul)
- Advances in Dairy Ingredients (Geoffrey W. Smithers and Mary Ann Augustin)
- Bioactive Proteins and Peptides as Functional Foods and Nutraceuticals (Yoshinori Mine, Eunice Li-Chan and Bo Jiang)
- Biofilms in the Food Environment (Hans P. Blaschek, Hua H. Wang, and Meredith E. Agle)
- Calorimetry in Food Processing: Analysis and Design of Food Systems (Gönül Kaletüncü)
- Coffee: Emerging Health Effects and Disease Prevention (YiFang Chu)
- Food Carbohydrate Chemistry (Ronald E. Wrolstad)
- Food Ingredients for the Global Market (Yao-Wen Huang and Claire L. Kruger)
- Food Irradiation Research and Technology (Christopher H. Sommers and Xuetong Fan)
- Foodborne Pathogens in the Food Processing Environment: Sources, Detection and Control (Sadhana Ravishankar, Vijay K. Juneja and Divya Jaroni)
- High Pressure Processing of Foods (Christopher J. Doona and Florence E. Feeherry)
- Hydrocolloids in Food Processing (Thomas R. Laaman)
- Improving Import Food Safety (Wayne C. Ellefson, Lorna Zach and Darryl Sullivan)
- Microbial Safety of Fresh Produce (Xueteong Fan, Brendan A. Niemira, Christopher J. Doona, Florence E. Feeherry and Robert B. Gravani)
- Microbiology and Technology of Fermented Foods (Robert W. Hutkins)
- Multiphysics Simulation of Emerging Food Processing Technologies (Kai Knoerzer, Pablo Juliano, Peter Roupas and Cornelis Versteeg)
- Multivariate and Probabilistic Analyses of Sensory Science Problems (Jean-François Meullenet, Rui Xiong, and Christopher J. Findlay)
- Nanoscience and Nanotechnology in Food Systems (Hongda Chen)
- Natural Food Flavors and Colorants (Mathew Attokaran)
- Nondestructive Testing of Food Quality (Joseph Irudayaraj and Christoph Reh)
- Nondigestible Carbohydrates and Digestive Health (Teresa M. Paeschke and William R. Aimutis)
- Nonthermal Processing Technologies for Food (Howard Q. Zhang, Gustavo V. Barbosa-Cánovas, V.M. Balasubramaniam, C. Patrick Dunne, Daniel F. Farkas, James T.C. Yuan)
- Nutraceuticals, Glycemic Health and Type 2 Diabetes (Vijai K. Pasupuleti and James W. Anderson)
- Organic Meat Production and Processing (Steven C. Ricke, Michael G. Johnson and Corliss A. O’Bryan)
- Packaging for Nonthermal Processing of Food (Jung H. Han)
- Preharvest and Postharvest Food Safety: Contemporary Issues and Future Directions (Ross C. Beier, Suresh D. Pillai, and Timothy D. Phillips, Editors; Richard L. Ziprin, Associate Editor)
- Processing and Nutrition of Fats and Oils (Ernesto M. Hernandez, and Afaf Kamal-Eldin)
- Processing Organic Foods for the Global Market (Gwendolyn V. Wyard, Anne Plotto, Jessica Walden and Kathryn Schuett)
- Regulation of Functional Foods and Nutraceuticals: A Global Perspective (Clare M. Hasler)
- Resistant Starch: Sources, Applications and Health Benefits (Yong-Cheng Shi and Clodualdo Maningat)
- Sensory and Consumer Research in Food Product Design and Development (Howard R. Moskowitz, Jacqueline H. Beckley, and Anna V.A. Resurreccion)
- Sustainability in the Food Industry (Cheryl J. Baldwin)
- Thermal Processing of Foods: Control and Automation (K. P. Sandeep)
- Trait-Modified Oils in Foods (Frank T. Orthoefer and Gary R. List)
- Water Activity in Foods: Fundamentals and Applications (Gustavo V. Barbosa-Cánovas, Anthony J. Fontana Jr., Shelly J. Schmidt, and Theodore P. Labuza)
- Whey Processing, Functionality and Health Benefits (Charles I. Onwulata and Peter J. Huth)
Table of Contents

| Preface | ix |
| Contributors | xi |

**Chapter 1**  
Introduction to Fiber and Nondigestible Carbohydrates: Definition, Health Aspects, and Perspectives  
*Teri M. Paeschke and William R. Aimutis*  
1

**Chapter 2**  
The Gastrointestinal Tract and Its Microflora  
*William R. Aimutis and Kayla Polzin*  
15

**Chapter 3**  
The Immunomodulatory Effects of Dietary Fiber and Prebiotics in the Gastrointestinal Tract  
*Marie-Claire Arrieta, Jon Meddings, and Catherine J. Field*  
37

**Chapter 4**  
Lower Gut Hormones and Health Effects Associated with Consumption of Fermentable Fibers  
*Michael J. Keenan, Jun Zhou, Reshani Senevirathene, Marlene Janes, and Roy J. Martin*  
79

**Chapter 5**  
Animal, In Vitro, and Cell Culture Models to Study the Role of Dietary Fibers in the Gastrointestinal Tract of Humans  
*Trevor A. Faber and George C. Fahey, Jr.*  
97
# Table of Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Impact of Fiber on Gastrointestinal Microbiota</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td><em>Koen Venema</em></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Fermentable Carbohydrates and Digestive Health</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td><em>Joanne Slavin</em></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Overview of Dietary Fiber and its Influence on Gastrointestinal Health</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td><em>Devin J. Rose and Bruce R. Hamaker</em></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Toward Second-Generation Carbohydrate Functional Food Ingredients</td>
<td>223</td>
</tr>
<tr>
<td></td>
<td><em>Robert A. Rastall</em></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Whole Grains and Digestive Health</td>
<td>245</td>
</tr>
<tr>
<td></td>
<td><em>Isabel Bondia-Pons, Jenni Lappi, Emilia Selinheimo, Marjukka Kolehmainen, Hannu Mykkänen, and Kaisa Poutanen</em></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Fermentability of Polydextrose, Resistant Maltodextrin, and Other Soluble Fibers: Prebiotic Potential</td>
<td>273</td>
</tr>
<tr>
<td></td>
<td><em>Maria Stewart</em></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Development and Evaluation Bimuno® , a Novel Second-Generation Prebiotic Galactooligosaccharide Mixture</td>
<td>295</td>
</tr>
<tr>
<td></td>
<td><em>George Tzortzis</em></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Concluding Remarks: Gastrointestinal Health and Nondigestible Carbohydrates</td>
<td>313</td>
</tr>
<tr>
<td></td>
<td><em>William R. Aimutis and Teri M. Paeschke</em></td>
<td></td>
</tr>
</tbody>
</table>

Appendix Nondigestible Carbohydrates: Structure and Sources  321

Index  331
Preface

Carbohydrates are a diverse set of compounds that are well known as nutritive ingredients to provide energy such as sugars and starches. Lesser known, but emerging, are carbohydrates that provide digestive health benefits such as enhanced immune system, mineral adsorption, and colonic health in general. These types of carbohydrates are not digested by either the stomach or small intestine and reach the colon intact or only partially digested. The chemical structure and bonding arrangement of these carbohydrates play a key role in their efficacy as prebiotic or fermentable substrates. Evolving science regarding prebiotics such as fructo-, galacto-, and xylooligosaccharides, as well as fermentable carbohydrates such as pectin, arabinoxylans, and resistant starch demonstrates the diversity of carbohydrates and their function in digestive health. This book features authors from academia as well as industry to provide a broad view of carbohydrates for digestive health.

This book evolved from several Symposia we organized at the 2008 Institute of Food Technologists (IFT) Annual Meeting in Las Vegas. The Symposia covered the importance of carbohydrates and digestive health in one manner or another, and provided a good start to this book. All of the contributors are internationally recognized experts in their fields that have spoken and published on these topics numerous times in the past. We intentionally challenged the authors to give us different perspectives in their areas, and even to add a “little edge” to some theories if they so chose. We think some did accomplish this in the end. This text is a useful reference for all who are interested in carbohydrates and digestive health including food scientists (product developers) whom are often called upon to formulate products with “fiber”
Preface

and need a background to understand the nutritional aspects and implications. Additionally, nutrition scientists will find this book useful as it provides a good background for understanding carbohydrates and their function in digestive health for nutrition scientists that have little background in this area.

Our deepest appreciation and respect goes to the chapter authors who contributed significant amounts of time, knowledge, talents, and expertise to bring this book from a concept to hardcover in a very rapidly changing field of study. We also thank Mr. Mark Barrett and Ms. Susan Engelken at Wiley-Blackwell for their guidance, advice, and assistance in the preparation and completion of this book.

We also must give our most heartfelt thanks and appreciation to our spouses for their understanding while we were trying to finish this book. They sacrificed many hours of family time in the process.

Finally, we dedicate the book to all those who have researched and devoted their talents and instincts to understanding the interactions of carbohydrates and the intestinal tract in healthy and diseased individuals. A special dedication to those patients that have suffered from some of the debilitating diseases discussed in this book. You have sacrificed your comfort at times in the name of science to better understand if carbohydrates were friend or foe to your digestive problems. We thank you for this graciousness.

Teri M. Paeschke
William R. Aimutis
Contributors

Aimutis, William R.
Cargill, Inc., Wayzata, MN, USA

Arrieta, Marie-Claire
Department of Medicine, University of Alberta, Edmonton, Canada

Bondia-Pons, Isabel
Department of Clinical Nutrition, University of Eastern Finland, Kuopio, Finland

Faber, T.A.
Department of Animal Sciences, University of Illinois, Urbana, IL, USA

Fahey, G. Jr.
Department of Animal Sciences, University of Illinois, Urbana, IL, USA

Field, Catherine
Department of Agricultural, Food and Nutritional Science, University of Alberta, East Edmonton, Canada

Hamaker, Bruce R.
Department of Food Science, Purdue University, West Lafayette, IN, USA
Contributors

Janes, Marlene
Department of Food Science, Louisiana State University AgCenter, Baton Rouge, LA, USA

June Zhou
Laboratory of Geriatric Endocrinology and Metabolism, Veterans Affairs Medical Center, Washington, DC, USA

Keenan, Michael
Department of Human Nutrition and Food, Louisiana State University AgCenter, Baton Rouge, LA, USA

Kolehmainen, Marjukka
Department of Clinical Nutrition, University of Eastern Finland, Kuopio, Finland

Lappi, Jenni
Department of Clinical Nutrition, University of Eastern Finland, Kuopio, Finland

Martin, Roy J.
Pennington Biomedical Research Center, Louisiana State University System, Baton Rouge, LA, USA

Meddings, Jon
Faculty of Medicine, University of Calgary, Calgary, Canada

Mykkänen, Hannu
Department of Clinical Nutrition, University of Eastern Finland, Kuopio, Finland

Paeschke, Teri
Des Plaines, IL, USA

Polzin, Kayla
Cargill, Inc., Waukesha, WI, USA

Poutanen, Kaisa
VTT Technical Research Centre of Finland, Espoo, Finland
Contributors

Rastall, R.A.
Department of Food Biosciences, University of Reading, Whiteknights, Reading, UK

Rose, Devin J.
Department of Food Science and Technology, University of Nebraska, NE, USA

Selinheimo, Emilia
VTT Technical Research Centre of Finland, Espoo, Finland

Senevirathne, Reshani
Department of Food Science, Louisiana State University AgCenter, Baton Rouge, LA, USA

Slavin, Joanne
Department of Food Science and Nutrition, University of Minnesota, St. Paul, MN, USA

Stewart, Maria
Department of Human Nutrition, Food and Animal Science, University of Hawaii at Manoa, Honolulu, HI, USA

Tzortzis, George
Clasado Ltd, Milton Keynes, England, UK

Venema, Koen
Department of BioSciences, TNO Quality of Life, AJ Zeist, The Netherlands