Handbook of Research on Bioenergy and Biomaterials

Consolidated and Green Processes

Leopoldo Javier Ríos González
Jośe Antonio Rodríguez-De La Garza
Miguel Ángel Medina Morales
Cristóbal Noé Aguilar
Editors

CRC Press
Taylor & Francis Group
APPLE ACADEMIC PRESS

HANDBOOK OF RESEARCH ON BIOENERGY AND BIOMATERIALS

Consolidated and Green Processes

HANDBOOK OF RESEARCH ON BIOENERGY AND BIOMATERIALS

Consolidated and Green Processes

Edited by

Leopoldo Javier Ríos González

Jośe Antonio Rodríguez-De La Garza

Miguel Ángel Medina Morales

Cristóbal Noé Aguilar

APPLE ACADEMIC PRESS

First edition published 2022

Apple Academic Press Inc.
1265 Goldenrod Circle, NE,
Palm Bay, FL 32905 USA

4164 Lakeshore Road, Burlington,
ON, L7L 1A4 Canada

CRC Press
6000 Broken Sound Parkway NW,
Suite 300, Boca Raton, FL 33487-2742 USA

2 Park Square, Milton Park,
Abingdon, Oxon, OX14 4RN UK

Apple Academic Press exclusively co-publishes with CRC Press, an imprint of Taylor & Francis Group, LLC

Library and Archives Canada Cataloguing in Publication

Title: Handbook of research on bioenergy and biomaterials : consolidated and green processes / edited by Leopoldo Javier Ríos González, Jośe Antonio Rodríguez-De La Garza, Miguel Ángel Medina Morales, Cristóbal Noé Aguilar.

Names: Ríos González, Leopoldo Javier, editor. | Rodríguez-de la Garza, Jośe Antonio, editor. | Medina Morales, Miguel Ángel, editor. | Aguilar, Cristóbal Noé, editor.

Description: First edition. | Includes bibliographical references and index.

Identifiers: Canadiana (print) 20210163666 | Canadiana (ebook) 20210163887 | ISBN 9781771889551 (hardcover) | ISBN 9781774639351 (softcover) | ISBN 9781003105053 (ebook)

Subjects: LCSH: Biomass conversion. | LCSH: Biomass energy. | LCSH: Biomass. | LCSH: Biomass—Refining. | LCSH: Biomolecules. | LCSH: Green chemistry.

Classification: LCC TP248.B55 H36 2022 | DDC 662/.88—dc23

Library of Congress Cataloging-in-Publication Data

Names: Ríos González, Leopoldo Javier, editor.

Title: Handbook of research on bioenergy and biomaterials : consolidated and green processes / edited by Leopoldo Javier Ríos González, José Antonio Rodríguez-de La Garza, Miguel Ángel Medina Morales, Cristóbal Noé Aguilar.

Description: First edition. | Palm Bay, FL : Apple Academic Press, 2021. | Includes bibliographical references and index. | Summary: "The Handbook of Research on Bioenergy and Biomaterials: Consolidated and Green Processes provides an understanding of consolidated processing and biorefinery systems for the production of bio-based chemicals and value-added bioproducts from renewable sources. The chapters look at a variety of bioenergy technological advances and improvements in the energy and materials sectors that aim to lower our dependence of fossil fuels and consequently reduce greenhouse gas (GHG) emissions. The volume looks at a selection of processes for the production of energy and biomaterials, including the Fischer-Tropsch process, gasification, pyrolysis, combustion, fermentation from renewable sources (such as, plants, animals and their byproducts), and others. Applications that are explored include transportation fuels, biodiesel production, wastewater treatment, edible packaging, bioplastics, physical rehabilitation, tissue engineering, biomedical applications, thermal insulation, industrial value compounds, and more. All of the topics covered in this publication address consolidated processes that play a pivotal role in the production of bioenergy and biomaterials because these processes require fewer unitary operations needed in the process, leading to a more direct method of production. This type of production system contributes to decreasing negative effects on the environment, lowering costs, saving energy and time, and improving profitability and efficiency. This volume will be valuable for the industrial sector, for researchers and scientists, as well as for faculty and advanced students"-- Provided by publisher.

Identifiers: LCCN 2021011437 (print) | LCCN 2021011438 (ebook) | ISBN 9781771889551 (hardback) | ISBN 9781774639351 (paperback) | ISBN 9781003105053 (ebook)

Subjects: LCSH: Biotechnology. | Biomass energy.

Classification: LCC TP248.15 .H36 2021 (print) | LCC TP248.15 (ebook) | DDC 660.6--dc23

LC record available at https://lccn.loc.gov/2021011437

LC ebook record available at https://lccn.loc.gov/2021011438

ISBN: 978-1-77188-955-1 (hbk)
ISBN: 978-1-77463-935-1 (pbk)
ISBN: 978-1-00310-505-3 (ebk)

About the Editors

Leopoldo Javier Ríos González, PhD

Leopoldo J. Ríos-González, PhD, is a full-time Professor at the School of Chemistry, Autonomous University of Coahuila, México. He is biologist chemist specializing in microbiology and holds a PhD in biotechnology. He is expert in the production of liquid and gas biofuels from biomass and is a member of the Bioenergy Thematic Network (REMBIO). In 2016, he was granted the Environmental Merit Award by the Autonomous University of Coahuila, and in 2017, he received the Environmental Award of Coahuila. Dr. Rios-Gonzalez has developed research funded by the Secretariat of Agricultural, National Council of Research and Technology (CONACyT) through the International Cooperation Programs CONACyT/CONICyT, Secretariat of Economy and different projects with industry. Dr Rios-Gonzalez has published over 25 original research papers in indexed journals and is member of National Researchers System in México (SNI) from 2018 (Level I).

Jośe Antonio Rodríguez-De La Garza, PhD

Jose A. Rodríguez-De la Garza, PhD, has been a full-time Professor since 2008 at the School of Chemistry, Autonomous University of Coahuila, Mexico. in the area Environmental Biotechnology. He currently is head of the Biotechnology PhD program at the same institution. He is member of the Mexican Society of Biotechnology and Bioengineering. Dr. Rodriguez-De la Garza currently develops a research project funded by the State Council of Science and Technology of Coahuila He has been a Thesis Director of PhD, MSc, and BSc theses. He is became a mechanical engineer at the Autonomous University of Nuevo Leon, Mexico. He earned his MSc and PhD degrees in biotechnology from the Autonomous University of Coahuila. He has been in two academic stays, in the USA (Washington State University, Pullman) and in Chile (Pontificia Universidad Católica de Valparaíso). Dr Rodriguez-De la Garza has published over 15 original research papers in indexed journals and five book chapters and has participated and contributed in over 40 scientific meetings.

Miguel Ángel Medina Morales, PhD

Miguel Ángel Medina Morales, PhD, is a full-time Professor at the School of Chemistry, Autonomous University of Coahuila, Mexico, in the area environmental biotechnology. He is a member of National Researchers System (SNI) from 2017 (candidate level). In 2017 he was part of a research team that were honored with the Tritio Award given by the Autonomous University of Coahuila. He has published over 14 papers in scientific journals and several book chapters. He graduated as Biologist Chemist at the Autonomous University of Coahuila. He obtained his MSc Degree in Food Science and Technology by the same institution. In 2012 he obtained his PhD in Food Science and Technology at the Autonomous University of Coahuila.

Cristóbal Noé Aguilar, PhD

Cristóbal Noé Aguilar, PhD, is Director of Research and Postgraduate Programs at the Universidad Autonoma de Coahuila, Mexico. He is also a member of the Bioprocesses and Bioproducts Research Group and Professor in the Food Research Department in the School of Chemistry at the Universidad Autónoma de Coahuila, Saltillo, Mexico. Dr. Aguilar is Associate Editor of *Heliyon* (Microbiology) and *Frontiers in Sustainable Food Systems* (Food Processing) and has published more than 330 papers in indexed journals, more than 40 articles in Mexican journals, and 250 contributions in scientific meetings. He has also published many book chapters, several Mexican books, four editions of international books, and more. He has been awarded several prizes and awards, the most important of which are the National Prize of Research 2010 from the Mexican Academy of Sciences; the Prize "Carlos Casas Campillo 2008" from the Mexican Society of Biotechnology and Bioengineering; National Prize AgroBio–2005; and the Mexican Prize in Food Science and Technology. Dr. Aguilar is a member of the Mexican Academy of Science, the International Bioprocessing Association, Mexican Academy of Sciences, Mexican Society for Biotechnology and Bioengineering, and the Mexican Association for Food Science and Biotechnology. He has developed more than 21 research projects, including six international exchange projects.

Contents

Contributors ..... *xi*

Abbreviations ..... *xix*

Preface ..... *xxv*

PART I: Green Chemistry and Biorefinery 1

1. Merging Green Chemistry and Biorefinery: Consolidating Processes 3

A.G. Reyes, C. Rivera-Pérez, A. Sáenz-Galindo, J.J. Fuentes-Avilés, C. Salinas-Salazar, and R. Parra-Saldívar

2. Design of Green Chemical Processes 39

Lorena Farías-Cepeda, Lucero Rosales Marines, Karina Reyes Acosta, Adolfo Romero Galarza, and Anilú Rubio Ríos

3. Catalytic Routes in Biomass Conversion: Synthesis of Furfural and HMF 65

Denis A. Cabrera-Munguia, Horacio González, Adolfo Romero-Galarza, L. Farías-Cepeda, Lucero Rosales-Marines, and Sandra L. Castañón-Alonso

4. Conversion of Biomass to Liquid Transportation Fuels Through Fischer–Tropsch Synthesis: A Global Perspective 101

C. Leyva, A. Romero-Galarza, S. L. Castañón-Alonso, L. Farías-Cepeda, L. Rosales-Marines, and A. Rubio Ríos

5. Tailoring the Suitable Solid Catalyst for Biodiesel Production Using Second-Generation Feedstocks 127

D. A. Cabrera-Munguia, A. Romero-Galarza, H. González, L. Farías-Cepeda, K. Reyes-Acosta, and L. E. Serrato-Villegas

6. Anaerobic Digestion as Consolidated Process Platform for Gaseous Biofuels Production and Other Value-Added Products 165

Salvador Carlos Hernández, Diana Sofía Segovia Arévalo, and Lourdes Díaz Jiménez

7. Microbial Butanol Production From Lignocellulosic Biomass: Consolidated Bioprocessing (CBP) 203

José A. Rodríguez-De la Garza, Thelma K. Morales-Martínez, Miguel A. Medina-Morales, Adolfo Romero Galarza, Mayela Moreno-Dávila, Cristóbal N. Aguilar, and Leopoldo J. Ríos-González

8. Consolidated Process for Bioenergy Production and Added Value Molecules from Microalgae 229

B. A. Ayil-Gútierrez, Y. J. Tamayo-Ordoñez, M.C. Tamayo-Ordoñez, A. V. Córdova-Quiroz, L. J. Rios-González, and I. M. M. Moreno-Davila

9. Bioelectrochemical Systems for Wastewater Treatment and Energy Recovery 253

S. Y. Martínez-Amador, L. J. Ríos-Gonzalez, M. M. Rodríguez-Garza, I. M. M. Moreno-Dávila, T. K. Morales-Martinez, M. A. Medina-Morales, and J. A. Rodríguez-de la Garza

10. Valorization of Nonnative Aquatic Weeds Biomass Through Their Conversion to Biofuel 271

Fernando Méndez-González, Alejandra Pichardo-Sánchez, Ben Hur Espinosa-Ramírez, Nubia R. Rodríguez-Durán, Guadalupe Bustos-Vázquez, and Luis V. Rodríguez-Durán

11. Engineering Microorganisms for Chemicals and Biofuels Production 283

Y. J. Tamayo-Ordoñez, B. Ayíl-Gútierrez, A. Ruiz-Marín, V. M. Interián-Ku, W. Poot-Poot, G. J. Sosa-Santillán, V. H. Ramos-Garcia, and M. C. Tamayo-Ordoñez

12. Development of Useful Microbial Strains by Genetic Engineering 305

María Tamayo-Ordoñez, Humberto Martínez Montoya, L. Margarita López-Castillo, Paola Angulo-Bejarano, Rodolfo Torres-de los Santos, and Erika Acosta-Cruz

PART II: Biomaterials and Biomolecules 337

13. Biotechnological Production of Biomaterials and Their Applications 339

Mauricio Carrillo-Tripp, Rodolfo Torres-de los Santos, Miguel A. Medina-Morales, Leopoldo Ríos-González, María Antonia Cruz-Hernández, Salvador Castell-González, Gerardo de Jesús Sosa-Santillán, and Erika Acosta-Cruz

14. Biopolymer Extraction and Its Use in Edible Packaging 391

Thalía A. Salinas-Jasso, María L. Flores-López, J.M. Vieira, Ana V. Charles-Rodríguez, Armando Robledo-Olivo, Olga B. Álvarez Pérez, Romeo Rojas Molina, and Miguel A. De León-Zapata

15. Bioplastics from Plant Oils and Sugars 441

Alma Berenice Jasso-Salcedo, Araceli Martínez Ponce, Christian Javier Cabello Alvarado, Marlene Lariza Andrade Guel, and Carlos Alberto Ávila Orta

16. Biofibers for Polymer Reinforcement: Macro- and Micromechanical Points of View 479

F. J. Alonso-Montemayor, R. I. Narro-Céspedes, M. G. Neira-Velázquez, D. Navarro-Rodríguez, and C. N. Aguilar

17. Trends in the Modification and Obtaining of Biomaterials Used in Physical Rehabilitation and Tissue Engineering 499

L. F. Mora-Cortes, R. I. Narro-Céspedes, A. Sáenz-Galindo, J. C. Contreras-Esquivel, M. G. Neira-Velázquez, and F. Ávalos-Belmontes

18. Hydrogel Systems Based on Collagen and/or Fibroin for Biomedical Applications 529

Jesús A. Claudio-Rizo, Claudia M. López-Badillo, and Brenda R. Cruz-Ortiz

19. Understanding Consolidated Processes in the Design of Sustainable Biomaterials as Thermal Insulators 573

Luis Fernando Sánchez Terán, Salvador Carlos Hernández, Arturo I. Martínez Enríquez, and Lourdes Díaz Jiménez

20. Catabolic Regulation of CCM in Bacteria for the Accumulation of Products of Commercial Interest 601

M. C. Tamayo-Ordoñez, B. A. Ayil-Gútierrez, F. A. Tamayo-Ordoñez, E. A. De la Cruz-Arguijo, J. C. Contreras-Esquivel, E. Cázares-Sánchez, and Y. J. Tamayo-Ordoñez

21. Limonene Biotransformation: An Efficient Strategy for the Production of Industrial Value Compounds. 629

H. A. Luna-García, P. Villarreal Quintero, A. Iliná, J. L. Martínez-Hernández, E. P. Segura-Ceniceros, C. N. Aguilar, and M. L. Chávez-González

22. Mangiferin: Biological Diversity, Properties, and Biotechnological Applications. 645

J. C. Tafolla-Arellano, R. Rojas Molina, J. M. Tirado-Gallegos, E. Ochoa-Reyes, R. Baeza-Jiménez and J. J. Buenrostro-Figueroa

23. Release and Production of Phenolic Biomolecules by Fungal Enzymes From Biomass.....671

Erika Acosta-Cruz, Luis Víctor Rodríguez-Durán, Leonardo Sepúlveda, Fernando Jasso-Juarez, Marisol Cruz-Requena, José Antonio Rodríguez-De la Garza, Leopoldo J. Ríos-González, and Miguel A. Medina-Morales

Index*..... *701

Contributors

Karina Reyes Acosta
Chemical Engineering Department, Faculty of Chemical Sciences, Autonomous University of Coahuila, Saltillo, Coahuila, Mexico

Erika Acosta-Cruz
Departamento de Biotecnología. Facultad de Ciencias Químicas. Universidad Autónoma de Coahuila, Blvd. Venustiano Carranza, 25280 Saltillo, Coahuila, México

Cristóbal N. Aguilar
Bioprocesses and Bioproducts Research Center, FCQ-UAdeC, 25280 Saltillo, México

F. J. Alonso-Montemayor
PhD Program in Materials Science and Technology, School of Chemistry (FCQ), Autonomous University of Coahuila (UAdeC), 25280 Saltillo, México

Christian Javier Cabello Alvarado
CONACYT—Consorcio de Investigación Científica, Tecnológica y de Innovación del Estado de Tlaxcala, Calle 1 de mayo No. 22, Col. Centro, C.P. 90000, Tlaxcala de Xicothenccatl Tlaxcala, México

Olga B. Álvarez Pérez
Greencorp Biorganiks de México S.A. de C.V., Blvd Luis Donaldo Colosio, Col. San Patricio, Saltillo 25204, México

Paola Angulo-Bejarano
Tecnologico de Monterrey, Centre of Bioengineering, School of Engineering and Sciences, Campus Queretaro, Querétaro, Qro, Mexico

Diana Sofía Segovia Arévalo
Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional Unidad Saltillo, México

F. Ávalos-Belmontes
Departament of Polymers, FCQ-UAdeC, 25280 Saltillo, Mexico

B. A. Ayil-Gútierrez
CONACYT—Centro de Biotecnología Genómica, Instituto Politécnico Nacional, Blvd. del Maestro, s/n, Esq. Elías Piña 88710. Reynosa, Tamaulipas, México

R. Baeza-Jiménez
Research Center in Food and Development, A.C. Av. 4ta Sur 3820, Fracc. Vencedores del Desierto, 33089, Cd. Delicias, Chihuahua, México

J. J. Buenrostro-Figueroa
Research Center in Food and Development, A.C. Av. 4ta Sur 3820, Fracc. Vencedores del Desierto, 33089, Cd. Delicias, Chihuahua, México

Guadalupe Bustos-Vázquez
Departamento de Ingeniería Bioquímica, Universidad Autónoma de Tamaulipas, Unidad Académica Multidisciplinaria Mante, Blvd. Enrique Cárdenas González No. 1201 Pte. Col. Jardín, C.P. 89840 Ciudad Mante, Tamaulipas, México

Denis A. Cabrera-Munguia
Advanced Materials, School of Chemistry, Autonomous University of Coahuila, México

Mauricio Carrillo-Tripp
Laboratorio de la Diversidad Biomolecular, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional Unidad Monterrey, Apodaca, Nuevo León, México

Sandra L. Castañón-Alonso
Chemistry Department, Universidad Autónoma Metropolitana-Iztapalapa, Ciudad de México, México

Salvador Castell-González
Colegio de Posgraduados en Ciencias Ambientales y Biotecnología del Sureste, A.C. Mérida, Yucatán, México

E. Cázares-Sánchez
Instituto Tecnológico de la Zona Maya, carretera Chetumal Escárcega Km. 21.5. C.P. 77960 Ejido Juan Sarabia, México

Ana V. Charles-Rodríguez
Department of Food Science and Technology, Universidad Autónoma Agraría Antonio Narro, Colonia Buenavista, Saltillo, México

M. L. Chávez-González
Nanobioscience Group, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México
Bioprocesses & Bioproducts Group, Food Research Department, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México

Jesús A. Claudio-Rizo
Advanced Materials Department, School of Chemical Sciences, University Autonomous of Coahuila, Saltillo, Mexico

J. C. Contreras-Esquivel
Glycobiology Research Center, FCQ-UAdeC, 25280 Saltillo, Mexico

A. V. Córdova-Quiroz
Facultad de Química, Dependencia Académica de Ciencias Química y Petrolera, Universidad Autónoma del Carmen, Carmen, México

E. A. De la Cruz-Arguijo
Centro de Biotecnología Genómica, Instituto Politécnico Nacional, Blvd. del Maestro, s/n, Esq. Elías Piña, Reynosa 88710, México

Brenda R. Cruz-Ortiz
Ceramic Materials Department, School of Chemical Sciences, University Autonomous of Coahuila, Saltillo, Mexico

Marisol Cruz-Requena
Departamento de Investigación en Alimentos, Facultad de Ciencias Químicas, Universidad Autónoma de Coahuila, 25280 Saltillo, México

Leopoldo María Antonia Cruz-Hernández
Laboratorio de Interacción Ambiente-Microorganismo, Centro de Biotecnología Genómica, Instituto Politécnico Nacional, Reynosa, Tamaulipas, México

Ben Hur Espinosa-Ramírez
División de Electromecánica Industrial, Universidad Tecnológica de Tecámac, Tecámac, Estado de México, México

Lorena Farías-Cepeda
Chemical Engineering Department, Faculty of Chemical Sciences, Autonomous University of Coahuila, Saltillo, Coahuila, Mexico

María L. Flores-López
Department of Research and Development, Biocampo S.A. de C.V., Blvd. Dr. Jesús Valdés Sánchez Km. 10, Fracc. Presa de las Casas, Arteaga 25350, México

J. J. Fuentes-Avilés
Facultad de Ciencias Químicas, Universidad Autónoma de Coahuila. Blvd., Venustiano Carranza y José Cárdenas Valdés, C.P. 25280 Saltillo, Coahuila, México

Adolfo Romero Galarza
Chemical Engineering Department, Faculty of Chemical Sciences, Autonomous University of Coahuila, Saltillo, Coahuila, Mexico

Horacio González
Faculty of Chemical Engineering, Universidad Michoacana de San Nicolás de Hidalgo, México

A. Iliná
Nanobioscience Group, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México

Fernando Jasso-Juarez
Departamento de Biotecnología, Facultad de Ciencias Químicas, Universidad Autónoma de Coahuila, Blvd. Venustiano Carranza, 25280 Saltillo, México

Arturo I. Martínez Enríquez
Centro de Investigación y Estudios Avanzados del Instituto Politécnico Nacional, CINVESTAV-Saltillo, 25900 Ramos Arizpe, México

J. L. Martínez-Hernández
Nanobioscience Group, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México

Marlene Lariza Andrade Guel
Department of Advanced Materials, Centro de Investigación en Química Aplicada, Blvd.

Salvador Carlos Hernández
Centro de Investigación y Estudios Avanzados del Instituto Politécnico Nacional, CINVESTAV-Saltillo, 25900 Ramos Arizpe, México Enrique Reyna Hermosillo No. 140 C.P. 25294 Saltillo, Coahuila, México

V. M. Interián-Ku
Instituto Tecnológico de la Zona Maya, carretera Chetumal Escárcega Km. 21.5, Ejido Juan Sarabia, C.P. 77960 Quintana Roo, México

Alma Berenice Jasso-Salcedo
CONACYT—Centro de Investigación en Química Aplicada, Blvd. Enrique Reyna Hermosillo No. 140 C.P. 25294 Saltillo, Coahuila, México

Lourdes Díaz Jiménez
Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional Unidad Saltillo, México

C. Leyva
Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada-IPN-Unidad Legaria, Ciudad de México, México

Miguel A. De León-Zapata
Research Center for the Conservation of Biodiversity and Ecology of Coahuila (CICBEC), Autonomous University of Coahuila, Saltillo 25280, Mexico

Claudia M. López-Badillo
Ceramic Materials Department, School of Chemical Sciences, University Autonomous of Coahuila, Saltillo, Mexico

L. Margarita López-Castillo
Centro de Biotecnología Femsa. Escuela de Ingeniería y Ciencias, Tecnológico de Monterrey, Monterrey, Nuevo León, México

Claudia M. López-Badillo
Ceramic Materials Department, School of Chemical Sciences, University Autonomous of Coahuila, Saltillo, Mexico

H. A. Luna-García
Nanobioscience Group, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México
Bioprocesses & Bioproducts Group, Food Research Department, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México

Lucero Rosales Marines
Chemical Engineering Department, Faculty of Chemical Sciences, Autonomous University of Coahuila, Saltillo, Coahuila, Mexico

S. Y. Martínez-Amador
Botany Department, Agronomic Division, Universidad Autónoma Agraria Antonio Narro, Mexico

Humberto Martínez Montoya
Laboratory of Genetics and Comparative Genomics, UAM Reynosa Aztlán—Universidad Autónoma de Tamaulipas, Reynosa, Tamaulipas, México

Fernando Méndez-González
Departamento de Biotecnología, Universidad Autónoma Metropolitana-Iztapalapa, Ciudad de México, México

Miguel A. Medina-Morales
Department of Biotechnology, School of Chemistry, Autonomous University of Coahuila, Mexico

Romeo Rojas Molina
School of Agronomy, Universidad Autónoma de Nuevo León, Monterrey, México

Thelma K. Morales-Martínez
Bioprocess and Microbial Biochemistry Group, School of Chemistry, Autonomous University of Coahuila, Mexico

I. M. M. Moreno-Davila
Laboratorio de Biotecnología Ambiental. Departamento de Biotecnología.
Facultad de Ciencias Químicas. Universidad Autónoma de Coahuila, Ing J. Cardenas Valdez S/N, República, 25280 Saltillo, Coahuila, México

Mayela Moreno-Dávila
Department of Biotechnology, School of Chemistry, Autonomous University of Coahuila, Mexico

L. F. Mora-Cortes
PhD Program in Materials Science and Technology, School of Chemistry (FCQ), Autonomous University of Coahuila (UAdeC), 25280 Saltillo, Mexico

R. I. Narro-Céspedes
Departament of Polymers, FCQ-UAdeC, 25280 Saltillo, México

D. Navarro-Rodríguez
Department of Polymers Synthesis, Research Center for Applied Chemistry (CIQA) 25294, Saltillo, Coahuila, México

M. G. Neira-Velázquez
Department of Polymers Synthesis, Research Center for Applied Chemistry (CIQA) 25294, Saltillo, Coahuila, México

E. Ochoa-Reyes
Research Center in Food and Development, A.C. Av. 4ta Sur 3820, Fracc. Vencedores del Desierto, 33089, Cd. Delicias, Chihuahua, México

Carlos Alberto Ávila Orta
Department of Advanced Materials, Centro de Investigación en Química Aplicada, Blvd. Enrique Reyna Hermosillo No. 140 C.P. 25294 Saltillo, Coahuila, México

R. Parra-Saldívar
Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Ave. Eugenio Garza Sada 2501, 64849 Monterrey, NL, México

Alejandra Pichardo-Sánchez
Departamento de Biotecnología, Universidad Autónoma Metropolitana-Iztapalapa, Ciudad de México, México

Araceli Martínez Ponce
Escuela Nacional de Estudios Superiores, Unidad Morelia, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro No. 8701, Col. Ex Hacienda de San José de la Huerta, 58190 Morelia, Michoacán, México

W. Poot-Poot
Laboratorio de Biotecnología, Facultad de Ingeniería y Ciencias, Universidad Autónoma de Tamaulipas, Centro Universitario, 87120 Ciudad Victoria, Tamaulipas, México

P. Villarreal Quintero
Nanobioscience Group, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México
Bioprocesses & Bioproducts Group, Food Research Department, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México

V. H. Ramos-Garcia
Biotecnologia Vegetal. Centro de Biotecnología Genómica, Instituto Politécnico Nacional, Blvd. del Maestro, s/n, Esq. Elías Piña, 88710 Reynosa, México

A. G. Reyes
CONACYT—CIBNOR, Instituto Politécnico Nacional 195, Playa Palo de Santa Rita Sur, 23096 La Paz, BCS, México

Leopoldo J. Ríos-González
Department of Biotechnology, School of Chemistry, Autonomous University of Coahuila, Mexico

C. Rivera-Pérez
CONACYT—CIBNOR, Instituto Politécnico Nacional 195, Playa Palo de Santa Rita Sur, 23096 La Paz, BCS, México

Armando Robledo-Olivo
Department of Food Science and Technology, Universidad Autónoma Agraría Antonio Narro, Colonia Buenavista, Saltillo, México

José A. Rodríguez-de la Garza
Department of Biotechnology, School of Chemistry, Autonomous University of Coahuila, Mexico

Luis Víctor Rodríguez-Durán
Departamento de Ingeniería Bioquímica, Universidad Autónoma de Tamaulipas, Unidad Académica Multidisciplinaria Mante, Blvd. Enrique Cárdenas González No. 1201 Pte. Col. Jardín, C.P. 89840 Ciudad Mante, Tamaulipas, México

Nubia R. Rodríguez-Durán
Departamento de Ingeniería Bioquímica, Universidad Autónoma de Tamaulipas, Unidad Académica Multidisciplinaria Mante, Blvd. Enrique Cárdenas González No. 1201 Pte. Col. Jardín, C.P. 89840 Ciudad Mante, Tamaulipas, México

M. M. Rodríguez-Garza
Department of Biotechnology, School of Chemistry, Universidad Autonoma de Coahuila, Mexico

Adolfo Romero-Galarza
Department of Chemical Engineering, School of Chemistry, Autonomous University of Coahuila, México

Lucero Rosales-Marines
Department of Chemical Engineering, School of Chemistry, Autonomous University of Coahuila, México

Anilú Rubio Ríos
Chemical Engineering Department, Faculty of Chemical Sciences, Autonomous University of Coahuila, Saltillo, Coahuila, Mexico

A. Ruiz-Marín
Facultad de Química, Dependencia Académica de Ciencias Química y Petrolera, Universidad Autónoma del Carmen, Carmen, México

A. Sáenz-Galindo
Facultad de Ciencias Químicas, Universidad Autónoma de Coahuila. Blvd., Venustiano Carranza y José Cárdenas Valdés, C.P. 25280 Saltillo, Coahuila, México

C. Salinas-Salazar
Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Ave. Eugenio Garza Sada 2501, 64849 Monterrey, NL, México

Thalía A. Salinas-Jasso
Department of Chemical Metrology, Universidad Politécnica de Ramos Arizpe (UPRA), Ramos Arizpe, México

Rodolfo Torres-de los Santos
Unidad Académica Multidisciplinaria Mante Centro. Universidad Autónoma de Tamaulipas, Cd. Mante, Tamaulipas, México

Gerardo de Jesús Sosa-Santillán
Departamento de Biotecnología. Facultad de Ciencias Químicas, Universidad Autónoma de Coahuila, Ing J. Cardenas Valdez S/N, República, 25280 Saltillo, Coahuila, México

E. P. Segura-Ceniceros
Nanobioscience Group, School of Chemistry, Universidad Autónoma de Coahuila, Blvd. V. Carranza esquina con José Cárdenas Valdés s/n Col, República Oriente, 25280 Saltillo, México

Leonardo Sepúlveda
Grupo de Bioprocesos y Bioquímica Microbiana, Facultad de Ciencias Químicas, Universidad Autónoma de Coahuila, 25280 Saltillo, México

L. E. Serrato-Villegas
Department of Chemical Engineering, School of Chemistry, Autonomous University of Coahuila, México

J. C. Tafolla-Arellano
Departamento de Ciencias Básicas, Laboratorio de Biotecnología y Biología Molecular. Núcleo Básico del Doctorado en Ciencias en Recursos Fitogenéticos para Zonas Áridas, Universidad Autónoma Agraria Antonio Narro, 25315. Buenavista, Saltillo, Coahuila, México

M. C. Tamayo-Ordoñez
Laboratorio de Ingeniería Genética, Departamento de Biotecnología. Facultad de Ciencias Químicas. Universidad Autónoma de Coahuila, Ing J. Cardenas Valdez S/N, República, 25280 Saltillo, Coahuila, México

Y. J. Tamayo-Ordoñez
Estancia Posdoctoral Nacional-CONACyT, Posgrado en Ciencia y Tecnología de Alimentos. Facultad de Ciencias Químicas. Universidad Autónoma de Coahuila, Ing J. Cardenas Valdez S/N, República, 25280 Saltillo, Coahuila, México

Luis Fernando Sánchez Terán
Centro de Investigación y Estudios Avanzados del Instituto Politécnico Nacional, CINVESTAV-Saltillo, 25900 Ramos Arizpe, México

J. M. Tirado-Gallegos
School of Animal Science and Ecology, Universidad Autónoma de Chihuahua. 31453, Chihuahua, Chihuahua, México

J. M. Vieira
Department of Food Engineering, Faculty of Food Engineering, University of Campinas (UNICAMP), Campinas, Brazil

Preface

In recent years, an increasing interest in products of natural origin has taken root in the population. Several processes are being developed to address the need for these products and, in particular, biotechnology and green chemistry are the leading areas due to its considerably lower implications of harming the environment. The specific cases of bioenergy, biomaterials, and biomolecules extraction and production have a strong relation with biotechnology, which along with green chemistry, contribute to develop technology that leads to the creation of useful compounds.

The *Handbook of Research on Bioenergy and Biomaterials: Consolidated and Green Processes* will give an insight and an understanding of consolidate processing-biorefinery systems for biofuels production using tools of biotechnology, chemical engineering, among other branches of science.

Bioenergy produced by Fischer–Tropsch, gasification, pyrolysis, combustion, and fermentation from renewable sources (such as plants, animals, and their byproducts) is considered a great technological improvement in the energy sector in regard to lower our dependence of fossil fuels and consequently the greenhouse gas (GHG) emissions. In addition to produce biofuels, researchers are looking for the biorefinery concept perceiving agro-industrial value chains. As a result, the subject of biorefinery engineering science may need to grow as a discipline in regard of converting biomass into useful liquid fuels in an attempt to replace totally or partially the fossil fuels consumption.

Biomolecules comprise a wide array of compounds with a wide area of applications. These biomolecules can be included with those with bioactivities such as antioxidants, antimicrobials, anticancer, among many others. Enzymes are among these biomolecules and are important to many processes such as biofuels production, high added-value compounds release, enzymatic synthesis of useful compound, degradation of residual materials, and along many other processes. Production of these types of biomolecules are significant factors for quality improvement in the way of life of humans and to increase production in the meat and agricultural industry sector.

Biomaterials are defined as any material that can interact with biological systems and is also an interesting topic that will be covered in our book. There are several examples that have been used as a treatment, augmentation, and

replacement in certain type of tissue or surface. Organic molecules of biological origin such as polysaccharides or proteins have been used to interact with other compounds or polymers to give way to a different material with new or different features. Also, inorganic molecules have been applied to interact with living tissues or biological molecules to be applied in several fields ranging from medicine to industrial processes. Another interesting aspect in this regard is the fact that microorganisms are able to produce high molecular weight compounds that can be applied in biomaterials and also produce precursors that apply in the same manner.

In all the topics that are covered in this publication, the term "consolidated process" plays a pivotal role due to the fact that it means that fewer unitary operations will be used in a process and in obtaining a more direct method of production. This type of production systems can contribute to decrease the negative effects on the environment, lower costs, energy and time, improving profitability and efficiency.

The editors

CHAPTER 14

Biopolymer Extraction and Its Use in Edible Packaging

THALÍA A. SALINAS-JASSO[1], MARÍA L. FLORES-LÓPEZ[2], J. M. VIEIRA[3], ANA V. CHARLES-RODRÍGUEZ[4], ARMANDO ROBLEDO-OLIVO[4], OLGA B. ÁLVAREZ PÉREZ[5], ROMEO ROJAS MOLINA[6], and MIGUEL A. DE LEÓN-ZAPATA[7*]

[1]*Department of Chemical Metrology, Universidad Politécnica de Ramos Arizpe (UPRA), Ramos Arizpe, México*

[2]*Department of Research and Development, Biocampo S.A. de C.V., Blvd. Dr. Jesús Valdés Sánchez Km. 10, Fracc. Presa de las Casas, Arteaga 25350, México*

[3]*Department of Food Engineering, Faculty of Food Engineering, University of Campinas (UNICAMP), Campinas, Brazil*

[4]*Department of Food Science and Technology, Universidad Autónoma Agraría Antonio Narro, Colonia Buenavista, Saltillo, México*

[5]*Greencorp Biorganiks de México S.A. de C.V., Blvd Luis Donaldo Colosio, Col. San Patricio, Saltillo 25204, México*

[6]*School of Agronomy, Universidad Autónoma de Nuevo León, Monterrey, México*

[7]*Research Center for the Conservation of Biodiversity and Ecology of Coahuila (CICBEC), Autonomous University of Coahuila, Saltillo 25280, Mexico*

[*]*Corresponding author. E-mail: miguel.leon@uadec.edu.mx.*

ABSTRACT

This chapter is about methods to obtain biopolymers and their application in edible packaging for foods. Different processes to extract biopolymers and obtain edible coatings and films have been developed to increase the postharvest shelf life of food products and minimally

processed. This chapter included a description of processes focused on extracting natural biopolymers, as polysaccharides, proteins, lipids. The properties (e.g., gases and humidity barrier ability) of edible coatings and films to reduce the deterioration of vegetable products are acutely examined. Also, this work reviews the parameters that alter the stability of edible packaging.

14.1 INTRODUCTION

The reduction in the use of nonrenewable synthetic materials has promoted research and development of packaging with lower environmental impact.

Even so, the packaging must provide the physical and mechanical properties necessary for food preservation. To achieve this purpose, the promising materials for the manufacture of packaging from renewable sources are biopolymers (Avérous and Poller, 2012). A fundamental characteristic of biopolymers is that its degradation occurs in short periods, from weeks to a few months (Shimao, 2001).

Edible packaging can encapsulate antioxidant (Cheng et al., 2015), antimicrobial (Arismendi et al., 2013), or nutrients (Vanderroost et al., 2014). Packaging must be effective and economically feasible.

Its characteristics depend on the food product application, which might be coated. Vegetable products are perishable (Barbosa-Pereira et al., 2014), affecting the products quality, causing losses during storage due to various metabolic reactions that promote the growth of microorganisms (Bosquez-Molina et al., 2003). The biopolymers must present thermal stability, flexibility, a barrier to gases and water, should be nontoxic, and biodegradable (Ali et al., 2010).

In this chapter, the processes for biopolymers extraction and its use in edible packaging to improve the quality and prolong the postharvest shelf life of produce and minimally processed foods are described, as well as its properties, factors influencing the stability, and the elaboration methods of edible coatings and films.

14.2 BIOPOLYMERS-BASED EDIBLE FILMS AND COATINGS

Biopolymers have properties for film formation and can be used as cost-effective constituents in the food industry for encapsulation of natural bioactive compounds. Moreover, they exhibit useful functional properties, including gelation, emulsification, and water-holding properties. These properties enable them to exert specific characteristics, such as appropriate appearance and texture, which promote consumer acceptance.

14.2.1 BIOPOLYMERS

According to European Bioplastics (2018), the term "biopolymer" is synonymous with the term "bioplastic." The oil's resources scarcity and the gradual decline in synthetic plastics have allowed to strive toward environmental sustainability (Bilal and Iqbal, 2019). Renewable biomaterials are safer and green options to reduce waste generation and environmental pollution. The development of innovative products from biopolymers has promoted the growth and development of ecological and sustainable processes allowing a sustainable economy (Bilal and Iqbal, 2019). Biopolymers, like polysaccharides, proteins, and lipids, are an alternative to traditional plastics and to produce edible coating and films (Espitia et al., 2014). Globally, consumers demand high-quality natural products obtained through economic processes that do not affect the environment. Biotechnology companies and researchers have proposed to develop biodegradable technologies with food principles from biopolymers (Mahalik and Nambiar, 2010) as composite films and coatings (Galus et al., 2013; Kurek et al., 2014). Food packagings are biodegradable technologies from hydrophilic and hydrophobic biopolymers with moisture and gas barrier properties.

14.2.2 POLYSACCHARIDES

Polysaccharides are composed of monosaccharides and glycosidic bonds, in addition to insoluble fibers (lignin, galactomannans, cellulose, and xylans) and soluble fibers (arabinoxylans, pectins, and arabinogalactans) (Caprita et al., 2010). Polysaccharides (NSP) without starch are principally without α-glucan polysaccharid.

Table 14.1 describes the parameters of the polysaccharides involved in film-forming.

All these factors (Table 14.1) influence the main functions, such as thickening, gelling, film-forming, foaming, and emulsification, which contributes to obtaining high-quality products with applications in the pharmaceutical and food industry.

Polysaccharides are widely available in nature, are not toxic, and inedible films have selective permeability to gases (Erginkaya et al., 2014).

14.2.3 PROTEINS

Proteins cover a large amount of polymeric type compounds that fulfill specific functions within plants and animals as the contribution of biological activity in addition to providing structure. Proteins are biomolecules made up of carbon, nitrogen, hydrogen, and oxygen,

TABLE 14.1 Factors that Affect the Film-Forming Properties

Factors	Film-Forming Properties
Structural conformation	Polysaccharide ordered conformations depends on the sugar residues and the glycosidic linkages. The linear polysaccharides produce good film because assume conformations ranging from a twofold helix to a sixfold helix that determines how extended the polymer is and how much can be associated to form hydrogen bonds, which are responsible for gelling, film formation, or thickening
Molecular weight	High molecular weight polysaccharides form stronger films
Ionic charge on the molecule	Ionic groups allow polysaccharides to be more polar by providing greater capacity to form hydrogen bonds
Steric groups	OH groups of the polysaccharides are esterified by ether substitution, altering the hydrogen bonds, and influencing the ability of the polysaccharides to form films

Sources: Patra et al. (2012), Sudo (2011).

which can also contain sulfur, phosphorus, iron, magnesium, and copper, among other elements. They are made up of amino acids, alpha-amino and alpha carboxyl groups, and a side chain with different functional groups. Present multiple functional properties due to intermolecular binding capacity to different bond types can be classified based on the ability of proteins to interact with water molecules. Protein structure can be modified through heat, modifying pH, pressure, mechanical treatments, and among others (Chiralt et al., 2017). Biodegradable materials have been sought for inclusion in the food industry, mainly of plant and animal origin, for its biodegradability and film-forming (Calva-Estrada et al., 2019). Proteins, in general, have various properties, including that they are edible and can carry nutrients. When combined with some other components, they become materials with great advantages due to the networks that manage to develop when undergoing modifications (Gnanasekaran, 2019). Not only can these biopolymers be used in the food area but also in different aspects such as in medicine and engineering to rebuild or reinforce. In the food packaging industry, proteins from milk, gelatin, gluten, egg, zein, soy, among other sources are the most used because they can be consumed directly on food; however, despite the multiple studies that exist in this regard to improve and find the best alternatives that are biodegradable.

14.2.3.1 PLANT PROTEINS

14.2.3.1.1 Soy Protein

Its origin is agricultural and has been known since the 1930s. The main feature it has is its emulsifying and texturing capacity. Its grains contain approximately 40% protein, among which two main fractions have been identified: albumins that are water-soluble and globulins that are soluble in saline solutions, representing 80% of total proteins. Remaining proteins are composed of intracellular enzymes, hemaglutinins, protein inhibitors, and membrane lipoproteins (Kinsella, 1979), and major components are classified according to their sedimentation properties. Due to biodegradability and a nutritional mixture of proteins, soy proteins promote film-forming. Several studies have been reported on its use in the food industry and recently as packaging materials.

14.2.3.1.2 Wheat Proteins

Wheat proteins are classified for their solubility and functionality. These include albumins, globulins, gliadins, and glutenins (De la Vega, 2009). They can also be found classified as proteins belonging to or without gluten. Gluten proteins account for 80%–85% of total wheat proteins. Gluten proteins can be used for the manufacture of transparent and homogeneous packaging with mechanical properties of interest.

14.2.3.1.3 Corn Zein

Zein is a natural protein generated by wet milling as a bioproduct. It is a protein derived from corn endosperm and is a biodegradable component. Zein is formed by polypeptides such as leucine, proline, alanine, serine and glutamine, and ϒ-zine that has a high cysteine content. Jornet-Martínez et al. (2016) mentioned the amphipathic structure that is created and combines a helical structure with the polyproline, this results in a hydrophobic material, making it an alternative for food packaging.

14.2.3.2 ANIMAL PROTEINS

14.2.3.2.1 Whey Protein

The FDA reports that milk proteins must have all the proteins found naturally in milk and that they must be in the same relationships, while in the whey protein, isolates and concentrate are obtained by the elimination of nonprotein components and are casein free. These milk proteins have properties that can provide desirable textures and other attributes to the final product. They have multiple applications in traditional food products. Various types of milk protein, such as whey protein

concentrates, whey protein isolates, caseins and caseinates, and among others, can be obtained from waste generated by industrial complexes. Whey contains β-Lactoglobulins that are obtained as a residue from the cheese and casein industry (Fox et al., 2015), which provide the properties of solubility, thermal stability, emulsifying, and nutritional value (Walstra et al., 2005). Protein interactions that occur between chains determine the network formation of films and their properties.

14.2.3.2.2 Meat Proteins

They can be classified into three types: sarcoplasmic, stromal, and myofibrillar. Collagen is classified as a fibrous protein and is present in the skin, tendons, bones, and vascular and connective tissue of animals. Due to the presence of covalent bonds, it is said to form intermolecular bridges inside, and disulfide bonds are few due to the low amount of cysteine present. It consists of three parallel chains of the alpha type, which combine to give rise to a triple-stranded superhelical structure (Montalvo et al. 2012). Amino acid sequence is formed by a repeating chain of glycine-proline-hydroxyproline and has been used as packaging for sausages. Gelatin is generated when collagen is subjected to hydrolysis under acidic or alkaline conditions. Gelatin has large amounts of proline, hydroxyproline, lysine, and hydroxylysine. It is used primarily as a texturing agent. Packaging from this component is usually clear and flexible but very hydrophilic. Moreover, in short, myofibrillar proteins are found in mammals and fish; they have a secondary structure, generating packaging with properties of permeability when subjected to previous denaturation processes (Dangaran et al., 2009).

14.2.4 LIPIDS

Lipids are a set of materials used in the manufacture of food packaging due to their hydrophobic properties. Within the components called hydrophobic substances, we find waxes, oils, and resins. Natural waxes such as candelilla wax, carnauba, bees, and among others are used in the industry. Oil-based waxes such as paraffin, petroleum-derived oils and vegetables, and resins are also found.

14.2.4.1 WAXES

In recent years, waxes have been used to give food, especially those of immediate consumption such as fruits and vegetables, a better look compared to the consumer. Waxes are known to several nonpolar components that can be synthetic or natural. Chemically they are esters

of fatty acids and long-chain fatty acids and are characterized by a high hydrocarbon content (approximately 50%) and a relatively low amount of volatile esters. Due to their nonpolar components, they form materials against humidity (Aguirre-Joya et al., 2017).

14.2.4.2 ANIMAL AND INSECT WAXES

They are as the name indicates the waxes that come from the segregation of certain insects or animals. Within this classification, they are distinguished into two subgroups: wax that comes from terrestrial and marine animals. From terrestrial animals, we find the lanolin that comes from wool and marine animals the Spermaceti, which is no longer marketed. However, the wax of greater industrial importance is beeswax. This compound is the final product of bee metabolism and is segregated by worker bee glands (Rhim and Shellhammer, 2005)

14.2.4.3 VEGETABLE WAXES

Vegetable waxes are the result of the climatic conditions in the regions where many plants are found. Generally, plants store waxes in the epidermis of their leaves as protection against water evaporation, especially in drought season. They are classified into waxes of trees and shrubs and in turn from the section where the wax is found as leaves, stems, root, and among others. The most used commercial waxes are the carnaúba wax for the production of preservation agents, cleaning, emulsions, and among others. Another, the widely used waxes for the manufacture of cosmetics, foods, and pharmaceuticals is candelilla wax, which is generated in semidesert plants and is found in stems and leaves (Rhim and Shellhammer, 2005).

14.2.4.4 FATS

Fats are polar and neutral lipids insoluble in water with the ability to form a stable hydrophobic layer on a surface. They are used as emulsifiers and dispersing agents forming interfacial micelles. The classification of this group of lipids is given by two fractions: either by the degree of saturation (saturated and unsaturated) or by the length of the chain (short, medium, and long) (Isabel Castro-González, 2002). Saturated fats have a higher melting point and greater water permeability than unsaturated fats.

14.2.4.5 RESINS

Resin is a viscous substance from vegetable (hydroaromatic structure) or of synthetic origin (higher degree

of polymerization) with mechanical, emulsifying, and adhesive properties.

14.3 BIO-BASED POLYMERS EXTRACTION METHODS

Currently, there are several conventional and innovative methods for biopolymers extraction, where the yield depends mainly on geographical conditions of the raw material, physical, and chemical parameters, used solvent, and its polarity. Therefore, the different methods of extracting the main biopolymers as proteins, polysaccharides, and lipids are described below.

14.3.1 POLYSACCHARIDES

Natural polysaccharides such as mucilage, starch, and pectin, present selective permeability to gases (Ergincaya et al., 2014). The extraction of the polysaccharides is based on methods that use solvents, water, salts, and acids (Table 14.2).

14.3.2 PROTEINS

Proteins and peptides are obtained during the technological process, and many extraction methods involving enzymatic hydrolysis, and among others. Protein extraction methods are shown in Table 14.3.

14.3.3 LIPIDS

Lipids such as vegetable oils and waxes are a very heterogeneous family of compounds that minimize moisture loss, provide gloss, and flexibility, in addition to reduce complexity, and cost of films and edible coatings. They present hydrophobicity as a common characteristic and dissolve in organic solvents. In order to carry out the extraction of the most used lipids in films and edible coatings for its application in foods, several methods have been proposed (Tables 14.4–14.9).

14.3.3.1 VEGETABLE OILS

Vegetable oils as sunflower oil, jojoba oil, palm oil, coconut oil, and cocoa butter are mainly composed of triglycerides as palmitic acid, stearic acid, oleic acid, and linolenic acid. They are used in films and edible coatings with the aim of decrease intramolecular forces.

14.3.3.2 SUNFLOWER OIL

Sunflower oil is obtained from the sunflower seed and contains a high concentration of vitamin E and low levels of saturated fat. The pressing method is commonly used to extract sunflower oil. New methods have been developed for the extraction

TABLE 14.2 Main Methods of Polysaccharides Extraction

Polysaccharide	Extraction Method	Parameters (Weight, Volume, Pretreatment, Solvent, pH, Time, Temperature)	Yield (%)	Reference
Starch	Extraction with water	Potato (kg) = 1 Pretreatment process = sliced and crushed The solid residue was washed several times with distilled water to remove all the starch, was filtered and sedimented at the bottom, and finally drying the resulting paste on trays at room temperature	8.6–19.2	Zárate-Polanco et al. (2014)
Starch	Extraction with water	Banana flour (g) = 100 Pretreatment process = shelled, sliced, frozen, lyophilized and milled Solvent = distilled water	56.5	Bello-Lara et al. (2014)
Pectin	Extraction with salts	Banana flour (g) = 100 Pretreatment process = shelled, sliced, frozen, lyophilized and milled Salt = ammonium oxalate (0.05%%) pH = 5.6 in a water bath and constant agitation	9.7	Bello-Lara et al. (2014)
Mucilage	Extraction with solvents	Opuntia ficus-indica (g) = 100 Pretreatment process = washed and milled Centrifuged for the aqueous phase = 5000 rpm for 30 min. Solvent ratio (aqueous phase: solvent (acetone)) = 1: 3	0.8	Abraján-Villaseñor (2008)
Mucilage	Extraction with solvents	Opuntia ficus-indica (g) = 100 Pretreatment process = washing, grinding and blanching Centrifuged for the aqueous phase = 5000 rpm for 30 min Solvent ratio (aqueous phase: solvent (acetone)) = 1: 3	0.6	Abraján-Villaseñor (2008)
Mucilage	Extraction with solvents	Opuntia ficus-indica (g) = 100 Pretreatment process = washed, ground and cooked Centrifuged for the aqueous phase = 5000 rpm for 30 min Solvent ratio (aqueous phase: solvent (acetone)) = 1: 3 Washing the precipitate with ethanol and dried under vacuum	0.3	Abraján-Villaseñor (2008)
Pectin	Extraction with acids and solvents	Pretreatment process = chopped, blanched, filtered, solid washed with ethanol, dried and weighed Dry and ground loquat (g) = 25 Acid = HCl 0.003 N T = 90 °C t = 75 min 98% ethanol was added to the pectic solution to precipitate the pectin, leaving it at rest for 1 h The floating pectin was filtered and washed with ethanol	21–23	Chasquibol-Silva et al. (2008)

TABLE 14.3 Protein Extraction Methods

Extraction Method	Food	Reference
Cell disruption methods		
Homogenization		
Milling and homogenization	Rice	Toldra and Nollet (2013)
	Olive tree seeds	
	Green Alga	Wang et al. (2015)
Ultrasonic homogenization	Peanut	Wang (2017)
	Milk	Ashokkumar et al. (2010)
Pressure homogenization	Milk	(Doona and Feeherry (2008)
	Microalgae	Mulchandani, Kar and Singhal (2015)
Temperature treatments		
	Whey proteins	Schmid and Muller (2018)
Enzymatic treatments	Soybean	Ndlela et al. (2012)
		De Moura et al. (2011a)
	Algae	Wang et al. (2015)
	Lentelis and White beans	Bildstein et al. (2008)
Osmotic and chemical lysis	Spiruline	Hadiyanto and Adetya (2018)
	Ginseng roots	Jiang et al. (2014)
Protein Solubilization/ Precipitation	Bovine serum	McArt et al. (2006)
	Soybean	De Moura et al. (2011b)
Aqueous solutions	Almond	Ge et al. (2016)

of sunflower oil, the most used is the extraction with solvents such as hexane, isopropyl alcohol, and petroleum ether (Table 14.4), where the hexane shows high yield at the 12 h of extraction. However, there are many environmental limitations regarding the use of solvents. It is also highlighting the use of solvents as the hexane and ultrasound irradiation, with the aim of decrease the extraction time in the process (90 min) in comparison with solvents extraction, obtaining high yields similar to those obtained in hexane extraction (Table 14.4).

14.3.3.3 JOJOBA OIL

Jojoba oil is obtained from seeds of the jojoba *Simmondsia chinensis*. Jojoba oil is of light color and contains a mixture of triglycerides

TABLE 14.4 Methods to Extract Sunflower Oil

Extraction Method	Parameters (w:v, Solvent, Temperature, Time)	Yield (%)	Reference
Extraction with solvents	Seed = 5 g Hexane = 200 mL T = 100 °C t = 8 h	37.9	Fornasari et al. (2017)
Extraction with solvents	Seed = 5 g Petroleum ether = 200 mL T = 100 °C t = 8 h	36.8	Fornasari et al. (2017)
Extraction with solvents	Seed = 50 g Hexane = 300 mL T = 50 °C t = 24 h	54.3	Rai et al. (2015, 2016)
Extraction with solvents	Seed = 10 g Hexane = 200 mL T = Normal boiling point t = 4 h	46.2	Ravber et al. (2015)
Extraction with solvents	Seed = 10 g Particle size = 2.0 mm Hexane = 100 mL t = 12 h T= 85 °C	99.0	Luque-García and Luque de Castro (2004)
Extraction with solvents	Seed = 50 g Hexane = 189 mL T = 69.5 °C	44.4	Gallegos-Infante et al. (2003)
Extraction with solvents	Seed = 50 g Isopropyl alcohol = 159 mL T = 82 °C	43.4	Gallegos-Infante et al. (2003)
Ultrasound-assisted Soxhlet	Seed = 10 g Particle size = 2.0 mm Hexane = 100 mL T= 85 °C Ultrasound irradiation of the cartridge for 30 cycles (90 min, output amplitude 40% of the nominal amplitude of the converter, applied power 100 W)	99.0	Luque-García and Luque de Castro (2004)

and long-chain esters of unsaturated fatty acids. Commonly, jojoba oil is obtained by pressing the seeds obtaining yields between 30% and 43% (Table 14.5), depending on the number of pressures that are applied during the process. The use of solvents such as hexane, chloroform, and petroleum ether, allows us to obtain yields of 52%–94.2%, 32.5%, and 92.2%, respectively, thus hexane being the most used solvent. The most recent method of extraction is a supercritical fluid, which uses a mixture of solvents as CO_2 + propane, CO_2 + ethanol, and hexane, obtaining yields of 98%, 80%, and 94%, respectively, and showing the highest yields (Table 14.5). CO_2 is also used; however, this method shows lower yields (44%–50.6%) in comparison with the disolvents mixture (Table 14.5). Therefore, the yields obtained by the supercritical fluid method depend on the polarity of the solvent, as well as the temperature and pressure applied in the process.

14.3.3.4 PALM OIL

Palm oil is rich in triglycerides and is extracted from the palm Elaeis guineensis Jacq. Yield depends on the variety of the palm (Table 14.6). Commonly palm oil is extracted by manual pressing with yields of 33%–35% of palmitic acid and 42.2%–43.3% of oleic acid (Table 14.6), which are lower than those obtained by hydraulic and mechanical pressure (Table 14.6). Where the mechanical pressure of the seed pretreated with preheating, cracking, and flaking turned out to be the process with the highest oil yield (Table 14.6) compared to the hydraulic pressure process of the seed pretreated with preheating, cracking, and flaking (Table 14.6).

14.3.3.5 COCONUT OIL

Coconut oil is obtained from *C. nucifera*. Also, this oil does not undergo degradation at high temperatures. Coconut oil is commonly obtained by heating, where the coconut undergoes a process of cracking, flaking, and scratching of the pulp, to subsequently boil the pulp in water, and separate by density, with this process the highest oil yield is obtained (Table 14.7). The solvent extraction method, mainly with hexane, has the lowest oil yield (Table 14.7). Another innovative method for coconut oil extraction is the method of extraction with saline solution (sodium chloride salt) using temperature, which proved to obtain a yield of 60% (Table 14.7).

14.3.3.6 COCOA BUTTER

Cocoa bean (*Theobroma cacao*) consists mainly of cocoa butter,

TABLE 14.5 Main Methods of Jojoba Oil Extraction

Extraction Method	Parameters (Pressure, Solvent, Time, Number of Pressing, Temperature, Particle Size and Pretreatment Process)	Yield (%)	Reference
Supercritical fluid	Solvent = 30%CO_2 + propane *P* (bar) = 70 *T* (K) = 313	98	Palla et al. (2014)
Supercritical fluid	Solvent = 30%CO_2 + ethanol *P* (MPa) = 35 y 45 *T* (K) = 363	80	Salgin (2007)
Supercritical fluid	Solvent = $ScCO_2$ *P* (bar) = 450 *T* (K) = 343	44	Salgin (2007)
Supercritical fluid	Solvent = $ScCO_2$ *P* (bar) = 600 *T* (K) = 363	50.6	Salgin et al. (2004)
Extraction with solvents	Particle size (mm) = 0.48 mm Solvent = Hexane	55	Allawzi et al. (2005)
Extraction with solvents	Particle size (mm) ≤ 1 mm Solvent = Chloroform *t* = 18 h	32.5	Salgin et al. (2004)
Extraction with solvents	Relation Disolvent/solid (L/Kg) = 15 Solvent = Hexane *t* = 30 min *T* = 55 °C	94.2	Zaher et al. (2004)
Extraction with solvents	Relation disolvent/solid (L/kg) = 15 Solvent = Petroleum ether *t* = 30 min *T* = 55 °C	92.2	Zaher et al. (2004)
Extraction with solvents	Particle size (mm) ≤ 1 mm Solvent = Hexane *t* = 18 h	52	Abu-Arabi et al. (2000)
Traditional	Type of press = Hydraulic Number of pressing = 1 Pretreatment process = none	35.4	Abu-Arabi et al. (2000)
Traditional	Type of press = Hydraulic Number of pressing = 2 Pretreatment process = Breaking	43.8	Abu-Arabi et al. (2000)
Traditional	Type of press = Rosedowns Number of pressing = 1 Pretreatment process = Preheating	38.2	Rawles, (1978)
Traditional	Type of press = Hander Number of pressing = 1 Pretreatment process = Preheating	35–39	Rawles, (1978)

TABLE 14.5 *(Continued)*

Extraction Method	Parameters (Pressure, Solvent, Time, Number of Pressing, Temperature, Particle Size and Pretreatment Process)	Yield (%)	Reference
Traditional	Type of press = Hander Number of pressing = 2 Pretreatment process = Preheating	40–42	Rawles, (1978)
Traditional	Type of press = Hander Number of pressing = 3 Pretreatment process = Preheating	43	Rawles, (1978)
Traditional	Type of press = Hydraulic Number of pressing = 1 Pretreatment = Cracking and flaking	30.8	Spadaro and Lambou (1972)

TABLE 14.6 Methods to Extract Palm Oil

Extraction Method	Parameters (Variety of Plant Species, Type of Press, Pretreatment)	Yield (%)	Reference
Traditional	Variety of plant species = *D. x Ekona* Type of press = Manual Number of pressing = 1 Pretreatment process = none	Palmitic acid = 33.1 Oleic acid = 43.3	Sandoval-García et al. (2016)
Traditional	Variety of plant species = *D. x Ghana* Type of press = Manual Number of pressing = 1 Pretreatment process = none	Palmitic acid = 35.4 Oleic acid = 42.2	Sandoval-García et al. (2016)
Traditional	Variety of plant species = *D. x Nigeria* Type of press = Manual Number of pressing = 1 Pretreatment process = none	Palmitic acid = 34.2 Oleic acid = 43.3	Sandoval-García et al. (2016)
Pressing	Variety of plant species = *E. guineensis* Jacq. Type of press = Mechanic Number of pressing = 1 Pretreatment process = Preheating, cracking, flaking	97 y 99	Jaimes-M. et al. (2012)
Pressing	Variety of plant species = *Acrocomia aculeata* Type of press = Hydraulic Number of pressing = 1 Pretreatment = Cracking and flaking	Lauric acid = 51.0	Hernández and Mieres-Pitre (2005)

TABLE 14.7 Main Methods of Coconut Oil Extraction

Extraction Method	Extraction Conditions (w: v, Pretreatment Process, Temperature, Time, Solvent)	Yield (%)	Reference
Traditional	Coconut pulp = 1350 g Pretreatment process = cracking, flaking, striped coconut T = 98 °C t = 2 h	222	Da Silva-Rodríguez (2017)
Extraction with solvents	Relation disolvent/solid (mL/g) = 300/80 Solvent = Hexane t = 1.5–2 h T = 62 °C	57–64	Rivera-Hernández et al. (2001)
Extraction with saline solution	Relation water/solid (mL/g) = 1000/75 sodium chloride salt (g) = 90 t = 1 h T = 60 °C	60	Ramos-Ramírez and Salazar-Montoya (1995)

which is considered as unique, due to its chemical composition. Cocoa beans pretreated by fermentation, drying, and toasted give yields of 50% (Table 14.8). New methods have been implemented for the extraction of cocoa butter, as the supercritical method, that used pressure (35 MPa), temperature (60 °C), and mixture of solvents as CO_2 + 25% ethanol, CO_2 + 25% isopropanol, and CO_2 + 15% acetone obtaining yields of 100%, 96.7%, and 84%, respectively (Table 14.8). Other methods with high yield consist of the extraction with solvents as the *t*-butanol mixed with a solution of ammonium sulfate, where the system adjusts to pH 2, and it is heated at 45 °C for 2 h (Table 14.8). Therefore, there is a demand for green technologies as the ultrasound-assisted supercritical method and supercritical method, using CO_2 as an extraction solvent, obtaining yields of 37.5% and 30.6%, respectively (Table 14.8).

14.3.4 WAXES

Waxes refer to a wide variety of substances of vegetable and animal origin because they comprise a mixture of several long-chain fatty acids and other components. Consumers prefer natural and sustainable

TABLE 14.8 Processes to Extract Cocoa Butter

Extraction Method	Extraction Conditions (w:v, Solvent, Pressure, Temperature, Time, Type of Press, Number of Pressing, Pretreatment Process)	Yield (%)	Reference
Supercritical	Cocoa beans (g) = 100 Solvent = CO_2 *P* (bar) = 550 *T* (°C) = 40 *t* = 360 min	30.6	Rodríguez et al. (2014)
Supercritical	Cocoa beans (g) = 10 Solvent = CO_2 + 25% ethanol *P* (MPa) = 35 *T* (°C) = 60 Flow rate = 2 mL/min	100	Asep et al. (2013)
Supercritical	Cocoa beans (g) = 10 Solvent = CO_2 + 25% isopropanol *P* (Mpa) = 35 *T* (°C) = 60 Flow rate = 2 mL/min	96.7	Asep et al. (2013)
Supercritical	Cocoa beans (g) = 10 Solvent = CO_2 + 15% acetone *P* (MPa) = 35 *T* (°C) = 60 Flow rate = 2 mL/min	84	Asep et al. (2013)
Supercritical	Cocoa beans (g) = 30 Solvent = ethane *P* (MPa) = 28.3 *T* (K) = 343.2	100	Saldaña et al. (2002)
Ultrasound-assisted supercritical	Cocoa beans (g) = 100 Solvent = CO_2 *P* (bar) = 550 *T* (°C) = 40 *t* = 360 min Ultrasound irradiation (resonance frequency of 30 kHz and constant energy of 58 W)	37.5	Rodríguez et al. (2014)
Extraction with solvents	kokum kernel powder (g) = 1 Three phase partitioning system = distilled water (16 mL), ammonium sulphate (50% w/v) and t-butanol (0.5:1–3:1) pH = 2 *t* = 2 h *T* = 45 °C	95	Vidhate and Singhal (2013)
Traditional	Type of press = Mechanic Number of pressing = 1 Pretreatment process = Fermentation, drying, toasted	50	Codini et al. (2004)

products, which increased the demand for natural waxes global (Attard et al., 2018), mainly the carnauba wax, candelilla wax, and beeswax.

14.3.4.1 CARNAUBA WAX

Carnauba wax is obtained the dried and crushed the palm leaves of *Copernicia prunifera* (Dantas et al., 2013). There are many environmental limitations regarding the use of dangerous solvents. There have been many efforts in order to find cleaner methods, one of these methods is the use of supercritical fluids (Table 14.9), such as CO_2 as a solvent which is inexpensive and completely inert (Palla et al., 2014). Also, obtaining a performance of carnauba wax superior (97%) to that obtained with the use of solvents (3.4%), due to the use of high pressures.

14.3.4.2 CANDELILLA WAX

Candelilla wax is obtained from Euphorbia antisyphilitica Zucc. The common name of the plant "candelilla" comes from the particular form of the stems of the bush, which are long, straight, erect, covered, with wax, and with the appearance of small candles (De León-Zapata, 2008; Rojas-Molina et al., 2013). Traditionally, candelilla wax is extracted with concentrated sulfuric acid to separate the wax in the form of foam (Table 14.9). Candelilla wax is also obtained by solvent extraction as aliphatic and aromatic hydrocarbons, but it is flammable and not renewable. Hence, an efficient, economical, and eco-friendly method is required as the extraction method with citric acid in combination with temperature and presion obtaining yields of 4–6% of wax (Table 14.9). Another method is the accelerated drying and scraping of candelilla stems obtaining a yield of 4% of wax (Table 14.9). However, it takes a lot of work and time since it is necessary to scrape stem by stem.

14.3.4.3 BEESWAX

The physicochemical properties of the wax depend on the bee species (Reybroeck et al., 2010). Commonly, the wax is extracted by methods that use heat to melt the wax (Table 14.9). In order to produce high-quality wax, it is recommended not to heat at too high temperature and for too long time, because that may damage darken its color. Wax should be heated in containers made of stainless steel. Combs containing fermented honey should not be melted in order to prevent wax off odor, and water with a low mineral content should be used to avoid the formation of water-wax emulsions (Bogdanov, 2004).

TABLE 14.9 Main Methods of Waxes Extraction

Wax	Extraction Method	Extraction Conditions (w:v, Solvent, Pressure, Temperature, Time, Flow Rate)	Yield	Reference
Carnauba wax	Supercritical fluid	Milled date palm leaves (g) = 100 Solvent = CO_2 *P* (bar) = 400 *T* (°C) = 100 Flow rate = 40 g/min *t* = 2 h	97	Al Bulushi et al. (2018)
Carnauba wax	Extraction with solvents	Milled date palm leaves (g) = 10 Solvent = Heptane *t* = 5 h	3.4	Al Bulushi et al. (2018)
Carnauba wax	Dried and crushed	The leaves are collected, dried and crushed to open the plant tissue and then beaten to separate the wax as a powder	–	Morales-Hernandez (2015)
Candelilla wax	Organic acids	Candelilla stems (kg) = 1 Acid = 0.05% citric acid *P* (kg/cm^2) = 1.05 *t* = 5 min *T* = 100 °C	4–6	De León-Zapata et al. (2016)
Candelilla wax	Accelerated drying and scraping	Candelilla stems (kg) = 0.5 Drying = for 48 h at 40 °C	4	Ahumada-Lazo (2012)
Candelilla wax	Traditional	Candelilla stems (kg) = 1 Acid = concentrated sulfuric acid *t* = 30 min *T* = 90–100 °C	4	De León-Zapata (2008)
Candelilla wax	Extraction with solvents	Solvent = aliphatic and aromatic hydrocarbons or a mixture of both *t* = 50 min *T* = 100 °C	–	Taboada-Reyes (1992)
Candelilla wax	Pressing	Type of press = Mechanic Number of pressing = 1 Pretreatment process = None	–	Treviño-García (1929)
Beeswax	Traditional	Extraction with hot water, steam, heat from electrical or solar power, to melt the wax	–	Bogdanov (2004)

14.4 EDIBLE PACKAGING FOR FOOD APPLICATION

The challenge of the agrifood industry is to maintain the quality and organoleptic properties of the fresh vegetable products. In this context, edible coatings have been incorporated in food processing, because they protect them from water loss during the transpiration in postharvest. Typically, the major constituents are biopolymers, mainly polysaccharides (e.g., chitosan), proteins (e.g., whey protein), and lipids (e.g., beeswax) that can be extracted from products and by-products of the agrifood industry. This section discusses the properties, qualities, and effect on shelf life extension that different materials used in the formation of edible coatings.

14.4.1 POLYSACCHARIDES, PROTEINS, AND LIPIDS FOR VEGETABLE PRODUCTS IN POSTHARVEST

Hydrocolloids (protein and polysaccharides), lipids (fatty acids, waxes, oils, and resins), and composites (interaction between hydrocolloids and lipids) (Dhall, 2013; Valencia-Chamorro et al., 2011) must be selected according to the ripening profile and the surface characteristics of the fruits and vegetables to be coated (Flores-López et al., 2016; Yousuf et al., 2018).

14.4.2 HYDROCOLLOIDS

Whey protein (Schmid et al., 2017), chia protein (Capitani et al., 2016), gelatin (Ahmad et al., 2012), soy protein (Yousuf and Srivastava, 2019), corn-zein (Boyacı et al., 2019), and among others are widely used for food packaging. Protein-based materials form coatings/films (Hassan et al., 2018) pliable, and translucent (Yousuf et al., 2018), and also present mechanical properties due to the possibility of forming different types of linkages; although their hydrophilic nature results in high water vapor permeability (Feng et al., 2018; Flores-López et al., 2016).

Polysaccharides have a selective permeability to gases (O_2 and CO_2); however, their hydrophilicity also influences their water vapor permeability. The most commonly used polysaccharides are alginate (Valero et al., 2013), chitosan (Vieira et al., 2016), pectin and cellulose (Moalemiyan et al., 2012; Pastor et al., 2010), starch (García et al., 2012), carrageenan (Hamzah et al., 2013) and, so on. The research into novel natural sources of polysaccharides for the build of edible coatings/films with improved properties has received world attention. Cerqueira et al. (2009) designed edible coatings based on galactomannans from *Adenanthera pavonina* and *Caesalpinia pulcherrima* seeds, to be applied in tropical fruits. Also,

Dick et al. (2015) investigated the effect of glycerol on the physicochemical and mechanical properties of chia mucilage-based film. The films were found to have a uniform and transparency appearance as the glycerol concentration increased. The use of residues from the agrifood industry has also allowed us to obtain polysaccharides with properties to form bio-packaging. For instance, Torres-León et al. (2018) developed a new edible film based on mango (var. Ataulfo) by-products to extend the shelf life of peach. This improved surface properties and reduced gas transfer rates of the fruit.

14.4.3 LIPIDS

Lipids repel water due to its hydrophobic property (Hassan et al., 2018), in addition, its low gas permeability and its protective capacity in refrigeration conditions allow them to be an excellent alternative for nonclimacteric fruits (Flores-López et al., 2016). Within this group, the application of waxes and oils (synthetic and natural) has been a recurring activity since ancient times (Dhall, 2013). Paraffin wax and beeswax are the most effective lipid materials but alternative naturals waxes have become more acceptable in recent years, as in the case of candelilla wax. Candelilla wax based coating formulations have been shown to prevent senescence of strawberries (Oregel-Zamudio et al., 2017) and avocados (Saucedo-Pompa et al., 2009). However, lipid-based coatings are characterized by improperly adhering to the surface, promote anaerobiosis, and altering the appearance and taste of the product to be coated (Hassan et al., 2018; Flores-López et al., 2016; Perez-Gago et al., 2002).

14.4.4 COMPOSITES

Composites are defined as a blend of hydrocolloids (i.e., polysaccharides or proteins) and lipids (Dhall, 2013), in order to improve their characteristics (e.g., mechanical properties or permeability) while minimizing their drawbacks (Tharanathan, 2003; Valencia-Chamorro et al., 2009; Chiumarelli and Hubinger, 2014; Oliveira et al., 2018). Also, the use of composites can reduce the costs of the final coating/film.

14.4.5 USE OF NATURAL ADDITIVES IN EDIBLE PACKAGING

Fresh vegetable products coated with edible films are a reality (Hassan et al., 2018; Yousuf et al., 2018; Zhao, 2019) forming a barrier against microbial attack and growth, and gas exchange control (the main postharvest problems) (Ortega-Toro et al.,

2017; Ncama et al., 2018). Promoting the retention of nutritional quality (Figure 14.1). Also, these systems are capable of carrying natural bioactive compounds, for example, antimicrobial, antioxidant, nutrients, and flavorings, from various sources within their matrix (Hassan et al., 2018), limiting the use of synthetic chemicals due to their possible agrotoxicological effects on environment and consumers (Ponce et al., 2008; Vieira et al., 2016). Minimally processed vegetable products are extremely perishable, being more susceptible to the physical, enzymatic, microbiological, and consequently at organoleptic level (Yousuf and Srivastava, 2019; Thakur et al., 2019). The use of edible coatings/films becomes an indispensable alternative in their preservation and this reality is triggered by the consumers' demand for durable, safe, and stable food without compromising the environment through nonbiodegradable packaging. Table 14.10 shows some recently developed works, with examples of base compositions with and without incorporation of bioactive/antimicrobial agents and their effects when applied to a determined fresh or minimally processed fruit or vegetable.

14.5 PRODUCTION OF EDIBLE COATINGS AND FILMS

Edible packaging can be edible films or coatings, edible coatings are liquid produced by wet methods, and films are solid laminates produced by dry methods.

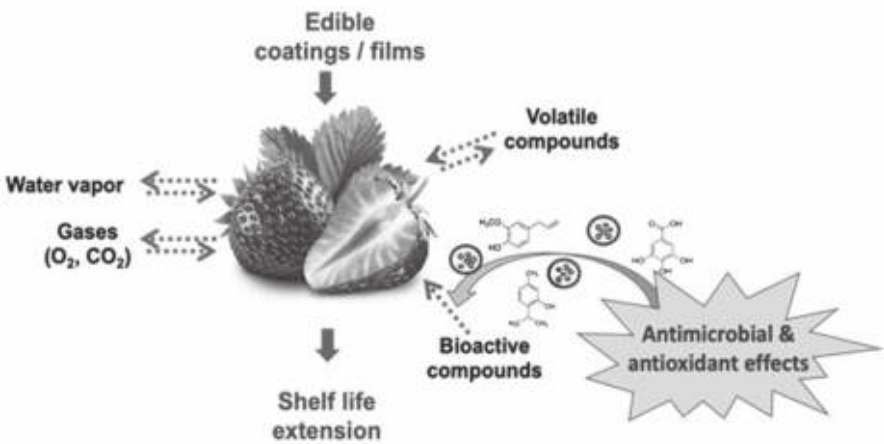

FIGURE 14.1 Edible coatings/films as gas and water vapor barrier and vehicle of natural additives to protect fresh vegetable products.

TABLE 14.10 Coatings/Films Applied in Fresh Vegetable Products

Base Composition	Bioactive Agent	Treatment Conditions	Microorganism Inhibited	Fruit/Vegetable		Shelf-life Improvement	References
				Fresh	Fresh-cut		
Starch	*Aloe vera*	Storage at 10 °C/85% RH for 7 days, then stored at 25 °C/85% RH for more 7 days	*Fusarium oxysporum; Bipolaris spicifera; Curvularia hawaiiensis*	Cherry tomatoes		Weight loss reduction, fungal inhibition, and good appearance promotion	Ortega-Toro et al. (2017)
Isolated soy protein	Honey	4 °C/16 days. Honey was applied in combination with coating	Total yeast and mold		Pineapple	Physicochemical and microbiological quality maintenance, extending shelf life up to two weeks	Yousuf and Srivastava (2019)
Shellac and gelatin		Storage at 25 °C for 30 days	Total yeast and mold	Banana		Physicochemical and microbiological quality maintenance, ripening process retarding, weight loss prevention, and good texture promotion	Soradech et al. (2017)
Starch and glucose	–	Storage at 4 °C for 30 days	–	Cucumber		Ripening process retarding, weight loss prevention, partial barrier to O_2 and CO_2, and WVP control. Also, antioxidant activity, proline, and soluble sugar content increased, while catalase and peroxidase activities and protein content decreased	Patel and Panigrahi (2019)
Chitosan and guar gum	–	4 °C/16 days	–	Shiitake mushroom (*Lentinus edodes*)		Higher tissue firmness, rate of declines in soluble protein and ascorbic acid slowed, increased the total soluble solids and reducing sugars, malondialdehyde and electrolyte leakage. Sensory evaluation confirmed the positive effects of coating	Huang et al. (2019)
Beetroot, corn, and pectin	–	Storage at 25 °C/80–85% RH for 30 days	–	Tomato		Prevents dehydration and senescence. Improves firmness and appearance. Retains the antioxidant content	Sucheta et al. (2019)

TABLE 14.10 *(Continued)*

Base Composition	Bioactive Agent	Treatment Conditions	Microorganism Inhibited	Fruit/Vegetable		Shelf-life Improvement	References
				Fresh	Fresh-cut		
Chitosan	*Aloe vera*	Storage at 5 °C/90% RH for 25 days	*Botritys cinerea*	Blueberry		Weight loss prevention, additional barrier to reduce fungal contamination and good appearance promotion. The use of coating extended the shelf life for about 5 days	Vieira et al. (2016)
Cactus (*Opuntia dilleniid*) polysaccharide	–	Storage at 5 °C for 5 days	Total viable counts		Potato	Browning suppression. Weight loss and microbial growth prevention. Respiration rate and total sugars control	Wu (2019)
Cassava starch and beeswax	–	Storage at 15 °C/90% RH for 15 days	–	Guavas		High WVP reduction. Delay in mass loss and chlorophyll. Physicochemical and organoleptic characterization indicated a quality maintenance and an extended shelf life	Oliveira et al. (2018)
Gellan	Geraniol and pomegranate extract	Storage at 5 °C for 7 days	Mesophilic bacteria, yeast and molds, and psychrophilic bacteria		Strawberry	Geraniol into gellan-based coatings improved the microbiological stability. Gellan-based coatings were found to be good vehicle of natural antimicrobials compatible with organic fresh food	Tomadoni et al. (2018)
Whey protein isolate nanofibrils	Trehalose	Storage at 4 °C for 10 days	–		Apple	Colorless transparent film on the apple surface. It delayed the browning process, the weight loss, and inhibited the total phenolics decreasing. Promotion of greater antioxidant activity and reduction of respiration rate, resulting in an increase of the shelf life.	Feng et al. (2018)

14.5.1 DRY PROCESSING

Biopolymers extracted from biomass, such as proteins, that behaves as thermoplastic materials which they are excellent for processing packaging by dry processing (Table 14.11).

Sustainable use of natural resources for the development of edible coatings and films has taken important global. The most used biopolymers for its elaboration are pectin (Lei et al., 2013; Younis and Zhao, 2019), starch (Galindez et al., 2019; Yildirim-Yalcin et al., 2019), cellulose, zein (Spasojevic et al., 2019), carboxymethyl cellulose (Ruan et al., 2019), methylcellulose (Matta et al., 2019), chitosan (Younis and Zhao, 2019), agar (Wang et al., 2018), alginate (Salama et al., 2018; Fabra et al., 2018), konjac (Lei et al., 2019), carragenans (Tavassoli-Kafrani et al., 2015), gelatin (Dou et al., 2018), Cassia gum (Cao et al., 2018), mucilage (Gheribi et al., 2018), maltodextrin (Zhang et al., 2019), egg yolk (Fuertes et al., 2017), Tara gum (Ma et al., 2016), and many others. However, the methodology for its preparation is variable from the use of different temperatures, times, stirring, and concentration is according to each polymer used (Table 14.12).

Edible film production consists of solubilizing the base polymer and adding some plasticizer (glycerol)

TABLE 14.11 Main Methods for Obtaining Edible Films by Dry Processing

Methods	Process	Finality	Reference
Thermoforming	The biopolymer is heated and transformed	Elaboration of containers	Hernandez-Izquierdo and Krochta (2008)
Thermopressing	The biopolymer is subjected to high and low temperatures	Elaboration of multilayer materials	Hernandez-Izquierdo and Krochta (2008)
Extrusion	The biopolymer is subjected to shear, high-temperature compression, and cooling	Edible films manufacturing	Ullsten et al. (2006) Barone et al. (2006) Hernandez-Izquierdo et al. (2008) Krishna et al. (2012) Rouilly et al. (2006) Arvanitoyannis and Biliaderis (1999) Fishman et al. (2000) Flores et al. (2010) Li et al. (2011)

TABLE 14.12 Methods for Preparation of Edible Films

Polymer(s)	Concentration	Plasticizer	Time (min)	Temperature	Stirring (rpm)	Drying	Additives	Reference
Ulluco starch	2.0, 2.5, and 3.0% (w/v)	Glycerol (1.0% w/v)	5	95	NR	8 ºC	NR	Galindez et al. (2019)
Sodium alginate Carboxymethyl cellulose	1:1 w/w	Glycerol (2.0% v/v)	90	50	NR	50 ºC/12 h	Epigallocatechin gallate	Ruan et al. (2019)
Carboxymethyl cellulose	2% (w/v)	NR	NR	NR	NR	50 ºC/15 h	Lactobacillus rhamnosus	Singh et al. (2019)
Chitosan	1.5% (w/v) in 1% v/v or acetic acid	Glycerol 18% (w/w)	4–6 h	30	8000	40 ºC/36 h	Tween 80	Zheng et al. (2019)
Mucilage	2% (w/v)	Glycerol 25% (w/w)	15	25	500	35 ºC/48 h	Tween 80	Ekrami et al. (2019)
Agar	1.5% (w/v)	Glycerol 30% (w/w)	30	95	20,000/2 min	40 ºC/72 h	Cellulose	Wang et al. (2018)
Starch and protein	100:0, 90:10, 80:20, 70:30 60:40 and 50:50	Glycerol 20% (w/w)	5	90 ºC	NR	35 ºC	NR	Chinma et al. (2015)
Chitosan in lactic acid solution	2%; 1% v/v	NR	NR	NR	NR	NR	Essential oil of Thymus zygis	Ballester-Costa et al. (2016)
NaCas	7.5 g/100 g	Glycerol 0.32 (w/w)	2 h	25 ºC	NR	23 ºC/48 h (50%RH)	NR	Caprioli et al. (2009)
Alyssum homolocarpum seed gum	1.2% (w/v)	Glycerol (25, 35 and 45% w/w)	30	50 ºC	400 rpm	40 ºC/24 h (30% RH)	NR	Mohammadi-Nafchi et al. (2017)

NR: nonreported.

to prevent the film from fracturing once it dehydrates. The agitation and temperature depend on the polymer. The incorporation of additives depends on the use and application of the film and ranges from pure compounds, raw extracts, oils, waxes (to reduce permeability). Finally, they are dehydrated at temperatures not exceeding 50 °C for up to 48 h.

14.5.2 WET PROCESSING

Wet processing consists of dissolving the biopolymers with additives and conditioners; this is applied by immersion in the food promoting its spreading over the surface, and finally, it dried by solvent evaporation (29.13). However, this procedure is not feasible at the industrial scale, mainly by the long drying time (24 h).

An alternative to overcome the various problems of food preservation is the development and application of composite coatings from polysaccharides (Formiga et al., 2019), proteins (Ananey-Obiri et al., 2018), or lipids (Rojas et al., 2015) on their blends. The main production processes of edible coatings are shown in Table 14.14.

In general, the production of edible coatings consists solubilize the polymer by up to 5% (depends on its solubility and its water retention

TABLE 14.13 Wet Processing to Produce Edible Coatings

Methods	Process	Finality	Reference
Tape casting	Film-forming solution is cast as a thin layer on a tape and is dried by heat conduction	Manufacturing of paper, plastic, ceramic, paint and edible, or synthetic films to coat paper, improved the barrier to transmission of oxygen, carbon dioxide, water vapor and UV radiation, in addition to the adherence, transparency, and oil resistance	De Moraes et al. (2013) Guillaume et al. (2010) Farris et al. (2010) Gastaldi et al. (2007) Han and Krochta (2001)
Edible coatings	Consists of dipping the food in the coating solution. The main parameters for the elaboration of the edible coating are the density, viscosity, superficial characteristics of product, and the surface tension	Preserve fresh products of vegetable and animal origin	Cisneros-Zevallos and Krochta (2003) Vargas et al. (2008) Kim et al. (2008)

TABLE 14.14 Methods for Preparation of Edible Coatings

Ingredients	Plasticizer	Conditions	Additives	Reference
Arabic gum, candelilla wax	NR	15,000 rpm/15 min	Tarbush extract (500 ppm)	Rojas et al. (2015)
Laquer wax 2%	Tefose® 2000	Dissolving wax in water at 60 °C/5 min	NR	Hu et al. (2019)
Corn starch 4%	Glycerol 1% v/v	Microwave heating (700 W) 10 min, stirring 5 min and pH 5.6	$CaCl_2$ (2%)	De Oliveira Alves Sena et al. (2019)
Beeswax, hydroxypropyl methylcellulose, and stearic acid 5:1 (BW:SA)	Glycerol 2:1 (HPMC:Gly)	Microwave (90 °C), 1 min at 968 g and 3 min at 3871 g.	NR	Formiga et al. (2019)
Guar gum (0.8%, candelilla wax (0.2%),	Glycerol (0.3%)	Hot water (80 °C), 20,500 rpm/20 min	Gallic acid (0.15%)	Oregel-Zamudio et al. (2017)
Chitosan (1%) and carboxymethyl cellulose (1.5%)	NR	Solubilization at 80 °C (Chitosan) and stirring in acetic acid (0.7% w/v)//2h to CMC. pH 5.6	NR	Yan et al. (2019)
Carnauba wax (10 g), oleic acid (7.5 mL/100g)	NR	90–95 °C at 1200 rpm/3 min, pH 7 and finally dissolved	NR	Singh et al. (2016)
Carnauba and beeswax (20 g), ammonia solution (30%)	NR	Stirring 30 min/90 °C. add 20 mL water (100 °C) and finally stirring 60 min with hot water (150 mL)	NR	Motamedi et al. (2018)
Soy protein 5% (w/v)	Glycerol 3.5% (w/v)	Solubilization in hot water (90 °C)/30 min. pH adjusted at 10	Essential oil from thyme and oregano (1, 2, or 3%)	Yemis and Candogan (2017)
Peach gum (1%)	NR	90 °C/6 h, centrifugued 5000 g/10 min	NR	Li et al. (2017)

NR: nonreported.

capacity). The use of surfactants is more common. In the case of coatings, the particle size of the emulsion is of great importance, as it is homogenizes at up to 25,000 rpm. The use of additives depends on the purpose (antimicrobial and antioxidant).

14.6 STABILITY OF EDIBLE PACKAGING

The short shelf life of fresh and processed foods has been a human concern since food is scarce and population growth. Because of their physical structure (water activity, nutrients as carbohydrates, proteins, and minerals), foods are susceptible to microbial spoilage and degradation. Thus, microbiological and physiological activities play a role in quality degradation during storage. Nowadays there are some serious environmental and health problems due to plastic packaging uses and their disposal conditions (Haward, 2018; Chae and An, 2018; Windsor, 2019; Lebreton and Andrady, 2019). Promoting an environmental mentality and the development of various scientific studies to obtain edible and biodegradable packagings from natural sources like fruits and vegetables peels and kernels (Wu et al., 2019; Nawab et al., 2018) with good sensory attributes; high barrier and mechanical properties; biochemical, physicochemical, and microbial stability (Brody, 2011).

14.6.1 REORGANIZATIONS OF THE FILM MATRIX AND COATING

The contact of the packaging with the food depends on the molecular size of the biopolymer, the chemical nature of the compounds, the temperature and process conditions, and the film structure. When a coating is in contact with food, the film-coating evaporation flux at the interface between the film-coating/environment should be evaluated, as well as the coating absorption flux on the food due to the interface between the food/film-coating (Montero-Garcia, 2016). Edible films-coating needs one or more additives in order to carry functional compounds intended to provide the improved characteristics (sensory, nutritional, microbiological, enzymatic, color, and other chemical reactions). Reorganizations of the matrix depend on the type of polymer and its functional groups, the concentrations of plasticizers and additives added. A high concentration of additives could generate undesirable odors, turbidity, and promote lipid oxidation (Wambura et al., 2011). The dose of the active compounds needs to be relatively low (Silva-Weiss et al., 2013). The selection of natural additives and their application depends on their properties (antioxidant, antimicrobial, antibrowning), cost-effectiveness, and effect on the sensory attributes of the final product

(Perumalla and Hettiarachchy, 2011). The reorganization of the edible matrix is related to the wounding-to response of the biological material (starch crystallization, protein aggregation, and plasticizer migration), chemical degradation (lipid oxidation, nonenzymatic browning, degradation of active compounds), and enzymatic degradation (proteolysis). The starch crystallizes due to the plasticizers content (Perez Sira and Dufour, 2017) and has low stability upon storage due to retrogradation (recrystallization) process of starch. Retrogradation can be minimized by adding cellulose as a matrix filler (Benito-González et al., 2019). Plasticizers provide greater flexibility to the polymeric matrix and reduce the original brittleness of biopolymers. Plasticizers do not chemically interact with the backbone chain but position themselves between the polymer molecules to reduce polymer chain-to-chain interaction (Kadzińska et al., 2019). The most studied and suitable plasticizer is glycerol, due to its marked hydrophilic nature as compared to sorbitol (Jiménez et al., 2018). Nowadays the research has been focused on finding other sources of plasticizers, in order to fulfill the main limitations of glycerol use (high hydrophilicity, low thermal stability, and surface migration over time) (Blanco-Pascual, 2016). Gheribi et al. (2018) developed an edible film with a mixture of mucilage from Opuntia ficus-indica cladodes and sorbitol as plasticizer, reaching water vapor permeability values up to three times lower than the other films evaluated. Other research works have a focus in using different materials, like chia seed mucilage (Dick et al., 2015), chitosan (Sabbah et al., 2019), epigallocatechin gallate and carboxymethyl cellulose (Ruan et al., 2019), and among others. Proteins can also have a similar function as a plasticizer, either both plant and animal sources, the amino acid functional groups in proteins can improve the stability and form an extended structure of the films. Formulations from polysaccharides and proteins show better structural properties than individual proteins (Cerqueira et al., 2011; Jiménez et al., 2018).

14.6.2 CHEMICAL DEGRADATION

Lipids used as hydrophobic material is well-known and is not strange its use as the barrier in foodstuffs; however, the inconvenience lays in the lipid oxidation. Lipid oxidation is a process that results in rancidity and deterioration of fats and progresses via free-radical propagated chain reactions, which yields hydroperoxides that cause a variety of secondary reactions with the evolution of aldehydes, ketones, acids, and other

low-molecular-weight volatile substances (Ramis-Ramos, 2003).

14.6.3 ENZYMATIC DEGRADATION

Minimally processed foods as fruits and vegetables (Yoruk and Marshall, 2003), meat and meat products (Hernandez-Hernandez, 2009) rich in phenolic components are subjected to the action of antioxidant enzymes. Postharvest oxidative stress occurs during storage, causing an imbalance between the production and removal of reactive oxygen species, such as H_2O_2, O_2-, and OH- radicals, from the tissues. The protection of fruit or vegetable cells from oxidative injury depends on the enzymes and polyphenols level which scavenge the reactive oxygen species, and prevent harmful effects (Amiot et al., 1992; Zeng et al., 2010). Antioxidants and enzymatic inhibitors are used to prevent browning by the chemical reduction of quinones to colorless ortho-diphenol reduction agents (McEvily and Iyengar, 1992). Millard reactions take place if the temperature is increased and reducing sugars are present. Some reducing agents have been investigated to prevent the antioxidant reaction (Table 14.15). Butylated hydroxyanisole and butylated hydroxytoluene are the most commonly used synthetic antioxidants; therefore, natural antioxidants such as phenolic compounds are alternatives to synthetic antioxidants (Chan et al., 2007; Jongjareonrak et al., 2008; Yen et al., 2008).

14.6.4 MICROBIAL GROWTH

Microbial growth in food products promotes deterioration and reduce the shelf life (Ding et al., 2013). Packaging provides some level of protection to food products from external and internal unfavorable conditions (Mihindukulasuriya and Lim, 2014). Those films have nutrients as substrates for microbial growth. In order to improve the efficiency and stability of edible coating-films, it is essential to find adequate materials (Flores-López, 2015). The incorporation of antimicrobial agents into the used in edible films could enhance its functional properties by retarding microorganism (Soares et al., 2009; Sirelkhatim et al., 2015; Malhotra et al., 2015). Essential oils and polyphenols (tannins, flavonoids, phenolic acids, secondary plant metabolites (Espitia et al., 2014) are listed in Table 14.2, as natural antimicrobials. A concern regarding some functional additives is their flavor and aroma. Sensory evaluation of edible films and foodstuffs packaged is scarce; however, many active compounds are known to be accepted by consumers (Otoni et al., 2017).

TABLE 14.15 Edible Coatings and Films with Natural Antioxidants.

Films Coating	Reduction agent	Application	Reference
Carboximethyl cellulose-based coating	Ascorbic acid	Apple	Saba (2016)
Apple-pectin edible coating		Persimmon	Sanchis (2016)
Aloe vera gel coating		Strawberry	Sogvar (2016)
Carrot puree, carboximethyl cellulose, corn starch, and gelatin edible films	Acetic acid and sodium bicarbonate	Carrot	Wang (2011)
Carrot puree-chitosan-starch	Cinnamaldehyde	Carrot	Wang (2015)
Starch coating	Yerba mate extracts and mango pulp	Mango	Reis (2015)
Xanthan gum nano-coating	Tocopherol	Apple	Zambrano-Zaragoza (2014)
		Apple	Galindo-Perez (2015)
	Cinamic acid	Pear	Sharma (2015)
Nanocapsules-xanthan gum coating	b-carotene	Melon	Zambrano-Zaragoza (2017)
Gum arabic, Aloe vera, chitosan coating	Thyme oil	Avocado	Sivakumar (2014)
Chitosan, carboxymethyl cellulose edible coating	Moringa leaf extract	Avocado	Tesfay (2017)
	Pineapple fruit extract	Apple	Supapvanchi (2012)
Alginate edible coating	Plum extract	*Prunus salicina Lindl.*	Valero (2013)
	Sunflower oil	Kent mangoes	Robles-Sanchez (2013)
	Cinnamon and rosemary essential oils	Apple	Chiabrando (2015)
	Malic acid	Mango	Salinas-Roca (2016)
	Mango peel	Papaya	Valderrain-Rodriguez (2015)
	Lemon grass essential oil	Pineapple	Azaraksh (2014)

TABLE 14.15 *(Continued)*

Films Coating	Reduction agent	Application	Reference
Chitosan coating	chitosan	Strawberry	Petriccione (2015)
	Rosemary extract	Pear	Xiao (2010)
	cinnamon oil	Sweet pepper (Capsicum annum L)	Xing (2011)
	cinnamon oil	Peach	Ayala-Zavala (2013)
	Trans-cinnamaldehyde	Melon	Carvalho (2016)
	Sodium chloride	Pear	Xiao (2011)
	Shrimp waste	Shrimp	Arancibia (2015)
	Pomegranate peel extract	Shrimp	Yuan (2016)
	chitosan	Kiwifruit	Drevinskas (2017)
Chitosan-aloe vera coating	NA	Blueberry *(vaccinium corymbosum*)	Vieira (2016)
Starch-gelatin edible film	NA	Grapes	Fakhouri (2015)
Pectin	Geraniol	Strawberry	Badawy (2016)
Hidroxymethyl cellulose, chitosan	Bergamot essential oil	Grapes	Sanchez-Gonzalez (2011)
Poly (butylene adipate co-terephalate) PBAT	Oregano essential oil	Fish	Cardoso (2017)
Basil seed gum	Oregano essential oil	Apricot	Hashemi (2017)
Soy protein edible coating	Ferulic acid	Apple	Alvez (2017)
	Honey	Melon	Yousuf (2017)
Whitemouth croaker protein isolate	Oregano-clay	Papaya	Cortez-Vega (2014)

TABLE 14.16 Recent Antimicrobial Film-coating Studies

Film or Edible Coating	Antimicrobial Agent	Application	Target Microorganism	Reference
Chitosan-aloe vera coating	Aloe vera	Blueberry	*B. cinérea, P. expansum, A. niger*	Vieira (2016)
Chitosan, pectin	Trans-cinnamaldehyde	Papaya	Total aerobic, pshycrotrophics, yeast, and molds count	Brasil (2012)
Chitosan edible film	Berberis crataeginas fruit extract and seed oil			
Soy protein film	Thyme and oregano essential oil	Beef	*E. coli* 0H157:H7, *S. aureus, P. Aeruginosa, L. plantarum*	Emiroglu (2010)
Gelatin-chitosan edible film	Guarana seeds *(Paullinia cupana),* leaves of boldolochile (*Peumus boldus Molin*), cinnamon barks *(Cinnamomum* sp), leaves of rosemary (*Rosmarinus officinalis*)	Laboratory level	*S. aureus* and *E. coli*	Bonilla (2016)
Zein films	*Zataria multiflora Boiss* essential oil and monolaurin	Meat	*E. coli* and *L. monocytogenes*	Moradi (2016)
Pectin-papaya puree	cinnamaldehyde	Laboratory level	*E. coli, S. aureus, L. monocytogenes, S. entérica, Choleraesuis*	Otoni (2014)
LLDPE	Clove essential oil	Chicken	*S. entérica, L. monocytogenes*	Mulla (2017)
Chitosan	Green tea extracts	Pork sausages	Total viable count, yeast, mold	Siripatrawa (2012)
	Titanium dioxide	Tomato	fungal	Kaewklin (2018)

KEYWORDS

- **natural polymers**
- **extraction**
- **properties**
- **stability**
- **food packaging**

REFERENCES

Abraján-Villaseñor, M.A. Efecto del método de extracción en las características químicas y físicas del mucílago del nopal (Opuntia ficus indica) y estudio de su aplicación como recubrimiento comestible. Degree Dissertation, Universidad Politécnica de Valencia, Valencia, España. 2008.

Abu-Arabi, M.K.; Allawzi, M.A.; Al-Zoubi, H.S.; Tamimi, A. Extraction of Jojoba oil by pressing and leaching. Chem. Eng. J. 2000, 76, 61–65.

Aguirre-Joya, J.A. et al. Edible coatings and films from lipids, waxes, and resins. In Edible Food Packaging: Materials and Processing Technologies. Taylor & Francis Group: Oxfordshire, 2017, 121–152.

Ahmad, M.; Benjakul, S.; Prodpran, T.; Agustini, T.W. Physico-mechanical and antimicrobial properties of gelatin film from the skin of unicorn leatherjacket incorporated with essential oils. Food Hydrocoll. 2012, 28, 189–199.

Ahumada-Lazo, R., Jr. Secado acelerado y raspado del tallo de candelilla (Euphorbia antisyphilitica) y su relación con el rendimiento en la extracción de cera. Degree Dissertation, Universidad Autónoma de Chihuahua, Chihuahua, Chihuahua, 2012.

Al Bulushi, K.; Attard, T.M.; North, M.; Hunt, A.J. Optimisation and economic evaluation of the supercritical carbon dioxide extraction of waxes from waste date palm (Phoenix dactylifera) leaves. J. Clean. Prod. 2018, 186, 988–996.

Ali, A.; Maqbool, M.; Ramachandran, S.; Alderson, P.G. Gum arabig as a novel edible coating for enhancing shelf life and improving postharvest quality of tomato (*Solanum lycopersicum* L.) fruit. Postharv. Biol. Technol. 2010, 58, 42–47.

Allawzi, M.A.; Abu-Arabi, M.K.; Al-Taher, F.A. Parametric study on the batch leaching process of Jojoba oil. Eur. J. Lipid Sci. Technol. 2005, 107, 469–475.

Alves, M.M.; Gonçalves, M. P.; Rocha, C.M.R. Effect of ferulic acid on the performance of soy protein isolate-based edible coatings applied to fresh-cut apples. LWT—Food Sci. Technol. 2017, 80, 409–415.

Amiot, M.J.; Tacchini, M.; Aubert, S.; Nicolas, J. Phenolic composition and browning susceptibility of various apple cultivars at maturity. J. Food Sci. 1992, 57, 4, 958–962.

Ananey-Obiri, D.; Matthews, L.; Azahrani, M.H.; Ibrahim, S.A.; Galanakis, C.M.; Tahergorabi, R. Application of protein-based edible coatings for fat uptake reduction in deep-fat fried foods with an emphasis on muscle food proteins. Trends Food Sci. Technol. 2018, 80, 167–174.

Arancibia, M.Y.; Lopez-Caballero, M.E.; Gomez-Guillen, M.C.; Montero, P. Chitosan coatings enriched with active shrimp waste for shrimp preservation. Food Control. 2015, 54, 259–266.

Arismendi, C.; Chillo, S.; Conte, A.; Del Nobile, M.A.; Flores, S.; Gerschenson, L.N. Optimization of physical properties of xanthan gum/tapioca starch edible matrices containing potassium sorbate and evaluation of its antimicrobial effectiveness. LWT—Food Sci. Technol. 2013, 53, 290–296.

Arvanitoyannis, I.; Biliaderis, C.G. Physical properties of polyol-plasticized edible blends made of methyl cellulose and soluble starch. Carbohydr. Polym. 1999, 38(1), 47–58.

Asep, E.K.; Jinap, S.; Jahurul, M.H.A.; Zaidul, I.S.M.; Singh, H. Effects of polar cosolvents on cocoa butter extraction using supercritical carbon dioxide. Innov. Food Sci. Emerg. Technol. 2013, 20, 152–160.

Ashokkumar, M. et al. The ultrasonic processing of dairy products—an overview. Dairy Sci. Technol. 2010, 90 (2/3), 147–168.

Attard, T.M.; Bukhanko, N.; Eriksson, D.; Arshadi, M.; Geladi, P.; Bergsten, U.; Budarin, V.L.; Clark, J.H.; Hunt, A.J. 2018. Supercritical extraction of waxes and lipids from biomass: a valuable first step towards an integrated biorefinery. J. Clean. Prod. 2018, 177, 684–698.

Avérous, L.; Poller, E. Biodegradable polymers. In Environmental Silicate Nano-Biocomposites. Springer: New York, NY, 2012; 13–39.

Ayala-Zavala, J.F.; Silva-Espinoza, B.A.; Cruz-Valenzuela, M.R.; Leyva, J.M.; Ortega-Ramírez, L.A.; Carrazco-Lugo, D.K.; Miranda, M.R.A. Pectin–cinnamon leaf oil coatings add antioxidant and antibacterial properties to fresh-cut peach. Flavour. Fragr. J. 2013, 28, 1, 39–45.

Azarakhsh, N.; Osman, A.; Ghazali, H.M.; Tan, C.P.; Adzahan, N.M. Lemongrass essential oil incorporated into alginate-based edible coating for shelf-life extension and quality retention of fresh-cut pineapple. Postharvest Biol. Technol. 2014, 88, 1–7.

Badawy, M.E.; Rabea, E.I.; AM El-Nouby, M.; Ismail, R.I.; Taktak, N.E. Strawberry shelf life, composition, and enzymes activity in response to edible chitosan coatings. Int. J. Fruit Sci. 2017, 17, 2, 117–136.

Ballester-Costa, C.; Sendra, E.; Fernández-López, J.; Viuda-Martos, M. Evaluation of the antibacterial and antioxidant activities of chitosan edible films incorporated with organic essential oils obtained from four Thymus species. J. Food Sci. Technol. 2016, 53, 3374–3379.

Barbosa-Pereira, L.; Angulo, I.; Lagarón, J.M.; Paseiro-Losada, P.; Cruz, J.M. Development of new active packaging films containing bioactive nanocomposites. Innov. Food Sci. Emerg. Technol. 2014, 26, 310–318.

Barone, J.R.; Schmidt, W.F.; Gregoire, N.T. Extrusion of feather keratin. J. Appl. Polym. Sci. 2006, 100(2), 1432–1442.

Bello-Lara, J.E., Balois-Morales, R., Sumaya-Martínez, M.T., Juárez-López, P., Rodríguez-Hernández, A.I., Sánchez-Herrera, L.M., Jiménez-Ruíz, E.I. Extracción y caracterización reológica de almidón y pectina en frutos de plátano 'Pera' (Musa ABB). Rev. Mex. Cienc. Agríc. 2014, 5, 1–6.

Benito-Gonzalez, I.; López-Rubio, A.; Martinez-Sanz, M. High-performance starch biocomposites with celullose from waste biomass: film properties and retrogradation behaviour. Carbohydr. Polym. 2019, 216, 180–188.

Bilal, M.; Iqbal, H.M.N. Naturally-derived biopolymers: potential platforms for enzyme immobilization. Int. J. Biol. Macromol. 2019, 130, 462–482.

Bildstein, M. et al. An enzyme-based extraction process for the purification and enrichment of vegetable proteins to be applied in bakery products. Eur. Food Res. Technol. 2008, 228 (2), 177–186.

Bill, M.; Sivakumar, D.; Korsten, L.; Thompson, A.K. The efficacy of combined application of edible coatings and thyme oil in inducing resistance components in avocado (Persea americana Mill.) against anthracnose during post-harvest storage. Crop Prot. 2014, 64, 159–167.

Blanco-Pascual, N.; Gómez-Estaca, J. Production and processing of edible packaging. Edible Food Packag. Mater. Process Technol. 2016, 36, 153.

Bogdanov, S. Quality standards of pollen and beeswax. Apiacta 2004, 38, 334–341.

Bonilla, J.; Sobral, P.J. Investigation of the physicochemical, antimicrobial and antioxidant properties of gelatin-chitosan edible film mixed with plant ethanolic extracts. Food Biosci. 2016, 16, 17–25.

Bosquez-Molina, E.; Guerrero-Legarreta, I.; Vernon-Carter, E.J. Moisture barrier properties and morphology of mesquite gum: candelilla wax based edible emulsion coatings. Food Res. Int. 2003, 36, 885–893.

Boyacı, D.; Iorio, G.; Sozbilen, G.S.; Alkan, D.; Trabattoni, S.; Pucillo, F.; Farris, S.; Yemenicioğlu, A. Development of flexible antimicrobial zein coatings with essential oils for the inhibition of critical pathogens on the surface of whole fruits: test of coatings on inoculated melons. Food Packag. Shelf Life. 2019, 20, 100316.

Brasil, I.M.; Gomes, C.; Puerta-Gomez, A.; Castell-Perez, M.E.; Moreira, R.G. Polysaccharide-based multilayered antimicrobial edible coating enhances quality of fresh-cut papaya. LWT—Food Sci. Technol. 2012, 47, 1, 39–45.

Brecht, J.K. Physiology of lightly processed fruits and vegetables. HortScience 1995, 30, 1, 18–22.

Brody, A.L. Packaging innovation-past, present, and future. Food Technol. 2011, 65, 80–82.

Calva-Estrada, S.J.; Jiménez-Fernández, M.; Lugo-Cervantes, E. Protein-based films: advances in the development of biomaterials applicable to food packaging. Food Eng. Rev. 2019, 11, 78–92.

Cao, L.; Liu, W.; Wang, L. Developing a green and edible film from Cassia gum: the effects of glycerol and sorbitol. J. Clean. Prod. 2018, 175, 276–282.

Capitani, M.I.; Matus-Basto, A.; Ruiz-Ruiz, J.C.; Santiago-García, J.L.; Betancur-Ancona, D.A.; Nolasco, S.M.; Tomás, M.C.; Segura-Campos, M.R. Characterization of biodegradable films based on Salvia hispanica L. Protein and Mucilage. Food Bioprocess Technol. 2016, 9, 1276–1286.

Caprioli, I.; O'Sullivan, M.; Monahan, F.J. Use of sodium caseinate/glycerol edible films to reduce lipid oxidation in sliced turkey meat. Eur. Food Res. Technol. 2009, 228, 433–440.

Caprita, R.; Caprita, A.; Julean, C. Biochemical aspects of non-starch polysaccharides. J. Anim. Sci. Biotechnol. 2010, 43, 368–375.

Cardoso, L.G.; Santos, J.C.P.; Camilloto, G.P.; Miranda, A.L.; Druzian, J.I.; Guimarães, A.G. Development of active films poly (butylene adipate co-terephthalate)–PBAT incorporated with oregano essential oil and application in fish fillet preservation. Ind. Crops Prod. 2017, 108, 388–397.

Carpiné, D. et al. Development and characterization of soy protein isolate emulsion-based edible films with added coconut oil for olive oil packaging: barrier, mechanical, and thermal properties. Food Bioproc. Tech. 2015, 8(8), 1811–1823.

Carvalho, R.L.; Cabral, M.F.; Germano, T.A.; Carvalho, W.M.; Brasil, I.M.; Gallão, M.I.; Miranda, M.R.A. Chitosan coating with *trans*-cinnamaldehyde improves structural integrity and antioxidant metabolism of fresh-cut melon. Postharvest Biol. Technol. 2016, 113, 29–39.

Cerqueira, M.A.; Bourbon, A.I.; Pinheiro, A.C.; Martins, J.T.; Souza, B.W.S.; Teixeira, J.A.; Vicente, A.A. Galactomannans use in the development of edible films/coatings for food applications. Trends Food Sci. Technol. 2011, 22, 12, 662–671.

Cerqueira, M.A.; Lima, Á.M.; Teixeira, J.A.; Moreira, R.A.; Vicente, A.A. Suitability of novel galactomannans as edible coatings for tropical fruits. J. Food Eng. 2009, 94, 372–378.

Chae, Y.; An, Y.J. Current research trends on plastic pollution and ecological impacts on the soil ecosystem: a review. Environ. Pollut. 2018, 240, 387–395.

Chan, E.W.C.; Lim, Y.Y.; Chew, Y.L. Antioxidant activity of Camellia sinensis leaves and tea from a lowland plantation in Malaysia. Food Chem. 2007, 102, 4, 1214–1222.

Chasquibol Silva, N., Arroyo Benites, E., Morales Gomero, J.C. Extracción y caracterización de pectinas obtenidas a partir

de frutos de la biodiversidad peruana. Ing. Ind. 2008 26, 175–199.

Chelikani, P.; Fita, I.; Loewen, P.C. Diversity of structures and properties among catalases. Cell. Mol. Life Sci. 2004, 61, 192–208.

Cheng, S.Y.; Wang, B.J.; Weng, Y.M. Antioxidant and antimicrobial edible zein/chitosan composite films fabricated by incorporation of phenolic compounds and dicarboxylic acids. LWT—Food Sci. Technol. 2015, 63, 115–121.

Chiabrando, V.; Giacalone, G. Effect of essential oils incorporated into an alginate-based edible coating on fresh-cut apple quality during storage. Qual. Assurance Safety Crops Foods 2014, 7, 3, 251–259.

Chinma, C.E.; Ariahu, C.C.; Alakali, J.S. Effect of temperature and relative humidity on the water vapour permeability and mechanical properties of cassava starch and soy protein concentrate based edible films. J. Food Sci. Technol. 2015, 52, 2380–2386.

Chiralt, A. et al. Edible films and coatings from proteins. In Proteins in Food Processing. 2nd ed. Elsevier Ltd.: London, 2017.

Chiumarelli, M.; Hubinger, M.D. Evaluation of edible films and coatings formulated with cassava starch, glycerol, carnauba wax and stearic acid. Food Hydrocoll. 2014, 38, 20–27.

Cisneros-Zevallos, L.; Krochta, J.M. Dependence of coating thickness on viscosity of coating solution applied to fruits and vegetables by dipping method. J. Food Sci. 2003, 68(2), 503–510.

Codini, M.; Díaz-Vélez, F.; Ghirardi, M.; Villavicencio, I. Obtención y utilización de la manteca de cacao. Invenio [Online] 2004, 7. http://www.redalyc.org/articulo.oa?id=87701213 (accessed June 17, 2019).

Cortez-Vega, W.R.; Pizato, S.; Andreghetto De Souza, J.T.; Prentice, C. Using edible coatings from whitemouth croaker (Micropogonias furnieri) protein isolate and organo-clay nanocomposite for improve the conservation properties of fresh-cut 'Formosa' papaya. Innov. Food Sci. Emerg. Technol. 2014, 22, 197–202.

Cosgrove, J. Emerging edible films: dissolving strips have made minor supplement inroads, but advancing technologies point to progress. [Online 2008]. Available online at: http://www.nutraceu ticals-world.com/contents/view_online-exclusives/2008-01-01/ emerging-edible-films/ (accessed January 7, 2013).

Cui, Z. et al. Effects of rutin incorporation on the physical and oxidative stability of soy protein-stabilized emulsions, Food Hydrocoll. 2014, 41, 1–9.

Da Silva-Rodríguez, C.P. Extracción de aceite de Coco (Cocos nuciferas) como estrategias de aprovechamiento de los productos locales de Mitú. Vaupes Innova. 2017, 83–89.

Dangaran, K.; Tomasula, P.M.; Qi, P. Edible Films and Coatings for Food Applications. Springer Science & Business Media: Berlin, 2009.

Dantas, A.N.D.S.; Magalhães, T.A.; Matos, W.O.; Gouveia, S.T.; Lopes, G.S. Characterization of carnauba wax inorganic content. J. Am. Oil Chem.' Soc.. 2013, 90, 1475–1483.

De la Vega, G. Proteínas de la harina de trigo. Temas de Ciencia y Tecnología. 2009, 13, 27–32.

De León-Zapata, M.A., Jr. Mejoras tecnológicas al proceso de extracción de cera de candelilla (Euphorbia antisyphilitica Zucc.). Degree Dissertation, Universidad Autónoma de Coahuila, Saltillo, Coahuila, 2008.

De León-Zapata, M.A.; Rojas-Molina, R.; Saucedo-Pompa, S.; Ochoa-Reyes, E.; De La Garza-Toledo, H.; Rodríguez-Herrera, R.; Aguilar-González, C.N. Proceso de extracción de cera de candelilla (Euphorbia antisyphilitica Zucc.). Mexican Patent 347121, 10 February 2016.

De Moraes, J.O.; Scheibe, A.S.; Sereno, A.; Laurindo, J.B. Scale-up of the production of cassava starch based films using

tape-casting. J Food Eng. 2013, 119, 4, 800–808.

De Moura, J.M.L.N. et al. Protein extraction and membrane recovery in enzyme-assisted aqueous extraction processing of soybeans. J. Am. Oil Chem. Soc. 2011a, 88, 6, 877–889.

De Moura, J.M.L.N. et al. Protein recovery in aqueous extraction processing of soybeans using isoelectric precipitation and nanofiltration. J. Am. Oil Chem. Soc. 2011b, 88, 9, 1447–1454.

De Oliveira Alves Sena, E.; Oliveira Da Silva, P.S.; De Aragão Batista, M.C.; Alonzo Sargent, S.; Ganassali De Oliveira Junior, L.F.; Almeida Castro Pagani, A.; Gutierrez Carnelossi, M.A. Calcium application via hydrocooling and edible coating for the conservation and quality of cashew apples. Sci. Hortic. (Amsterdam). 2019, 256.

Dhall, R.K. Advances in edible coatings for fresh fruits and vegetables: a review. Crit. Rev. Food Sci. Nutr. 2013, 53, 435–450.

Dick, M.; Costa, T.M.H.; Gomaa, A.; Subirade, M.; De Oliveira Rios, A.; Flores, S.H. Edible film production from chia seed mucilage: effect of glycerol concentration on its physicochemical and mechanical properties. Carbohydr. Polym. 2015, 130, 198-205.

Ding, H.; Fu, T.J.; Smith, M.A. Microbial contamination in sprouts: how effective is seed disinfection treatment. J. Food Sci.. 2013, 78, 4, R495–R501.

Dou, L.; Li, B.; Zhang, K.; Chu, X.; Hou, H. Physical properties and antioxidant activity of gelatin-sodium alginate edible films with tea polyphenols. Int. J. Biol. Macromol. 2018, 118, 1377–1383.

Drevinskas, T.; Naujokaitytė, G.; Maruška, A.; Kaya, M.; Sargin, I.; Daubaras, R.; Česonienė, L. Effect of molecular weight of chitosan on the shelf life and other quality parameters of three different cultivars of Actinidia kolomikta (kiwifruit). Carbohydr. Polym. 2017, 173, 269–275.

Ekrami, M.; Emam-Djomeh, Z.; Ghoreishy, S.A.; Najari, Z.; Shakoury, N. Characterization of a high-performance edible film based on Salep mucilage functionalized with pennyroyal (Mentha pulegium). Int. J. Biol. Macromol. 2019, 133, 529–537.

Emiroğlu, Z.K.; Yemiş, G.P.; Coşkun, B.K.; Candoğan, K. Antimicrobial activity of soy edible films incorporated with thyme and oregano essential oils on fresh ground beef patties. Meat Sci. 2010, 86, 2, 283–288.

Erginkaya, Z.; Kalkan, S.; Unal, E. Use of antimicrobial edible films and coatings as packaging materialsfos food safety. In Food Processing: Strategies for Quality Assessment. Food Engineering Series. Malik, A. et al., eds. Springer: New York, 2014.

Espitia, P.J.P.; Du, W.X.; De Jesús Avena-Bustillos, R.; Soares, N.D.F.F.; McHugh, T.H. Edible films from pectin: physical-mechanical and antimicrobial properties—a review. Food hydrocoll. 2014, 35, 287–296.

European Bioplastics. What are bioplastics. https://www.europeanbioplastics.org/bioplastics/(accessed September 14, 2018).

Fabra, M.J.; Falcó, I.; Randazzo, W.; Sánchez, G.; López-Rubio, A. Antiviral and antioxidant properties of active alginate edible films containing phenolic extracts. Food Hydrocoll. 2018, 81, 96–103.

Fakhouri, F.M.; Martelli, S.M.; Caon, T.; Velasco, J.I.; Mei, L.H.I. Edible films and coatings based on starch/gelatin: film properties and effect of coatings on quality of refrigerated red crimson grapes. Postharvest Biol. Technol. 2015, 109, 57–64.

Farris, S.; Cozzolino, C.A.; Introzzi, L.; Piergiovanni, L. Development and characterization of a gelatin-based coating with unique sealing properties. J. Appl. Polym. Sci. 2010, 118(5), 2969–2975.

Feng, Z.; Wu, G.; Liu, C.; Li, D.; Jiang, B.; Zhang, X. Edible coating based on whey protein isolate nanofibrils for antioxidation and inhibition of product browning. Food Hydrocoll. 2018, 79, 179–188.

Fishman, M.L.; Coffin, D.R.; Konstance, R.P.; Onwulata, C.I. Extrusion of pectin/starch blends plasticized with glycerol. Carbohydr. Polym. 2000, 41(4), 317–325.

Flores, S.K.; Costa, D.; Yamashita, F.; Gerschenson, L.N., Grossmann, M.V. Mixture design for evaluation of potassium sorbate and xanthan gum effect on properties of tapioca starch films obtained by extrusion. Mater. Sci. Eng.: C. 2010, 30(1), 196–202.

Flores-López, M.L.; Cerqueira, M.A.; De Rodríguez, D.J.; Vicente, A.A. Perspectives on utilization of edible coatings and nano-laminate coatings for extension of postharvest storage of fruits and vegetables. Food Eng. Rev. 2016, 8, 3, 292–305.

Formiga, A.S.; Pinsetta, J.S.; Pereira, E.M.; Cordeiro, I.N.F.; Mattiuz, B.-H. Use of edible coatings based on hydroxypropyl methylcellulose and beeswax in the conservation of red guava 'Pedro Sato.' Food Chem. 2019, 290, 144–151.

Fornasari, C.H.; Secco, D.; Ferreira Santos, R.; Benetoli da Silva, T.R.; Galant Lenz, N.B.; Kazue Tokura, L.; Lucian Lenz, M.; Melegari de Souza, S.N.; Zanão Junior, L.A.; Gurgacz, F. Efficiency of the use of solvents in vegetable oil extraction at oleaginous crops. Renew. Sust. Energ. Rev. 2017, 80, 121–124.

Fox, P.F. et al. Dairy chemistry and biochemistry. 2nd ed., Springer International Publishing: Switzerland, 2015, p. 584.

Fuertes, S.; Laca, A.; Oulego, P.; Paredes, B.; Rendueles, M.; Díaz, M. Development and characterization of egg yolk and egg yolk fractions edible films. Food Hydrocoll. 2017, 70, 229–239.

Galindez, A.; Daza, L.D.; Homez-Jara, A.; Eim, V.S.; Váquiro, H.A. Characterization of ulluco starch and its potential for use in edible films prepared at low drying temperature. Carbohydr. Polym. 2019, 215, 143–150.

Galindo-Pérez, M.J.; Quintanar-Guerrero, D.; Mercado-Silva, E.; Real-Sandoval, S.A.; Zambrano-Zaragoza, M.L. The effects of tocopherol nanocapsules/xanthan gum coatings on the preservation of fresh-cut apples: evaluation of phenol metabolism. Food Bioprocess Technol. 2015, 8, 8, 1791–1799.

Gallegos-Infante, J.A.; Rocha-Guzmán, N.; González-Laredo, R.; Zuno-Floriano, F.; Vidaña-Martínez, S.A. Caracterización de dos variedades de girasol con potencial para la producción de aceite extraídos con hexano e isopropanol. Grasas y Aceites. 2003, 54, 245–252.

Galus, S.; Lenart, A.; Voilley, A.; Debeaufort, F. Effect of potato oxidized starch on the physyco-chemical properties of soy protein isolate-based edible films. Food Technol. Biotechnol. 2013, 51, 403–409.

García, L.C.; Pereira, L.M.; De Luca Sarantópoulos, C.I.; Hubinger, M.D. Effect of antimicrobial starch coating on shel-life of fresh strawberries. Packag. Technol. Sci. 2012, 25, 413–425.

Gastaldi, E.; Chalier, P.; Guillemin, A.; Gontard, N. Microstructure of protein-coated paper as affected by physico-chemical properties of coating solutions. Colloids Surf. A Physicochem. Eng. Asp. 2007, 301(1–3), 301–310.

Ge, X.L. et al. Development of an aqueous polyethylene glycol-based extraction and recovery method for almond (*Prunus armeniaca L.*) protein. Food Anal. Methods. 2016, 9 (12), 3319–3326.

Gheribi, R.; Puchot, L.; Verge, P.; Jaoued-Grayaa, N.; Mezni, M.; Habibi, Y.; Khwaldia, K. Development of plasticized edible films from Opuntia ficus-indica mucilage: a comparative study of various polyol plasticizers. Carbohydr. Polym. 2018, 190, 204–211.

Gnanasekaran, D. Green Biopolymers and their Nanocomposites. Materials Horizons: From Nature to Nanomaterials. Springer: New York, 2019.

Guillaume, C.; Pinte, J.; Gontard, N.; Gastaldi, E. Wheat gluten-coated papers

for bio-based food packaging: structure, surface and transfer properties. Food Res Int. 2010, 43(5), 1395–1401.

Hadiyanto, H.; Adetya, N.P. Response surface optimization of lipid and protein extractions from Spirulina platensis using ultrasound assisted osmotic shock method. Food Sci. Biotechnol. 2018, 27 (5), 1361–1368.

Hamzah, H.M.; Osman, A.; Tan, C.P.; Ghazali, F.M. Carrageenan as an alternative coating for papaya (Carica papaya L. cv. Eksotika). Postharvest Biol. Technol. 2013, 75, 142–146.

Han, J.H. Edible films and coatings: a review. In Innovations in Food Packaging. Academic Press: Cambridge, MA, 2014; 213–255.

Han, J.H.; Krochta, J.M. Physical properties and oil absorption of Whey-proteincoated paper. J. Food Sci. 2001, 66(2), 294–299.

Han, J.H.; Scanlon, M.C. Mass transfer of gas and solute through packaging materials. In Innovations in Food Packaging. 2 ed. Elsevier: London, 2014; 37–49.

Hashemi, S.M.B.; Khaneghah, A.M.; Ghahfarrokhi, M.G.; Eş, I. Basil-seed gum containing origanum vulgare subsp. viride essential oil as edible coating for fresh cut apricots. Postharvest Biol. Technol. 2017, 125, 26–34.

Hassan, B.; Chatha, S.A.S.; Hussain, A.I.; Zia, K.M.; Akhtar, N. Recent advances on polysaccharides, lipids and protein based edible films and coatings: a review. Int. J. Biol. Macromol. 2018, 109, 1095–1107.

Haward, M. Plastic pollution of the world's seas and oceans as a contemporary challenge in ocean governance. Nat. Commun. 2018, 9, 1, 667.

Hernández, C.; Mieres-Pitre, A. Extracción y purificación del aceite de la almendra del fruto de la palma de corozo (*Acrocomia aculeata*). Rev. Ing. UC. 2005, 12, 68–75.

Hernández-Hernández, E.; Ponce-Alquicira, E.; Jaramillo-Flores, M.E.; Legarreta, I.G. Antioxidant effect rosemary (*Rosmarinus officinalis* L.) and oregano (*Origanum vulgare* L.) extracts on TBARS and colour of model raw pork batters. Meat Sci. 2009, 81, 2, 410–417.

Hernandez-Izquierdo, V.M.; Krochta, J.M. Thermoplastic processing of proteins for film formation—a review. J. Food Sci. 2008, 73, 2, R30–R39.

Hu, H.; Zhou, H.; Li, P. Lacquer wax coating improves the sensory and quality attributes of kiwifruit during ambient storage. Sci. Hortic. (Amsterdam). 2019, 244, 31–41.

Huang, Q.; Qian, X.; Jiang, T.; Zheng, X. Effect of chitosan and guar gum based composite edible coating on quality of mushroom (Lentinus edodes) during postharvest storage. Sci. Hortic. 2019, 253, 382–389.

Isabel Castro-González, M. ÁCIDOS GRASOS OMEGA 3: BENEFICIOS Y FUENTES. Interciencia 2002, 27 (3), 128–136.

Jaimes, W.A.; Rocha, S.; Vesga, J.N.; Kafarov, V. Thermodynamic analysis to a real palm oil extraction process. Prospect 2012, 10, 61–70.

Jiang, R. et al. An Extraction Method Suitable for Two-Dimensional Electrophoresis of Low- abundant Proteins from Ginseng Roots. Lecture Notes in Electrical Engineering, vol. 251, Springer: London, 2014, 3.

Jiménez, A.; Requena, R.; Vargas, M.; Atarés, L.; Chiralt, A. Food hydrocolloids as matrices for edible packaging applications. In Role of Materials Science in Food Bioengineering. Academic Press: London, 2018; 263–299.

Jongjareonrak, A.; Benjakul, S.; Visessaguan, W.; Tanaka, M. Antioxidant activity and properties of fish skin gelatin films incorporated with BHT and α-tocopherol. Food Hydrocoll. 2008, 22, 449–458.

Jornet-Martínez, N.; Campíns-Falcó, P.; Hall, E.A.H. Zein as biodegradable material for effective delivery of alkaline phosphatase and substrates in biokits and biosensors. Biosens. Bioelectron. 2016, 86, 14–19.

Kadzińska, J.; Janowicz, M.; Kalisz, S.; Bryś, J.; Lenart, A. An overview of fruit and vegetable edible packaging materials. Packag. Technol. Sci., 2019, 32, 483–495.

Kaewklin, P.; Siripatrawan, U.; Suwanagul, A.; Lee, Y.S. Active packaging from chitosan-titanium dioxide nanocomposite film for prolonging storage life of tomato fruit. Int. J. Biol. Macromol. 2018, 112, 523–529.

Karbowiak, T.; Debeaufort, F.; Voilley, A.; Trystram, G. From macroscopic to molecular scale investigations of mass transfer of small molecules through edible packaging applied at interfaces of multiphase food products. Innov. Food Sci. Emerg. Technol. 2009, 10, 1, 116–127.

Kim, S.H.; No, H.K.; Prinyawiwatkul, W. Plasticizer types and coating methods affect quality and shelf life of eggs coated with chitosan. J. Food Sci. 2008, 73, 3, S111–S117.

Kinsella, J.E. Functional Properties of Soy Proteins. J. Am. Oil Chem. Soc. 1979, 56, 3, 242–258.

Krishna, M.; Nindo, C.I.; Min, S.C. Development of fish gelatin edible films using extrusion and compression molding. J. Food Eng. 2012, 108, 2, 337–344.

Kumar, R.; Zhang, L. Soy protein films with the hydrophobic surface created through non-covalent interactions. Ind. Crops Prod. 2009, 29, 2/3, 485–494.

Kurek, M.; Galus, S.; Debeaufort, F. Surface, mechanical and barrier properties of bio-based composite films based on chitosan and whey protein. Food. Packag. Shelf Life 2014, 1, 56–67.

Lebreton, L.; Andrady, A. Future scenarios of global plastic waste generation and disposal. Palgrave Commun. 2019, 5, 1, 6.

Lei, Y.; Wu, H.; Jiao, C.; Jiang, Y.; Liu, R.; Xiao, D.; Lu, J.; Zhang, Z.; Shen, G.; Li, S. Investigation of the structural and physical properties, antioxidant and antimicrobial activity of pectin-konjac glucomannan composite edible films incorporated with tea polyphenol. Food Hydrocoll. 2019, 94, 128–135.

Li, C.; Tao, J.; Zhang, H. Peach gum polysaccharides-based edible coatings extend shelf life of cherry tomatoes. 3 Biotech. 2017, 7, 168.

Li, M.; Liu, P.; Zou, W.; Yu, L.; Xie, F.; Pu, H.; Chen, L. Extrusion processing and characterization of edible starch films with different amylose contents. J. Food Eng. 2011, 106, 1, 95–101.

Luque-García, J.L.; Luque de Castro, M.D. Ultrasound-assisted Soxhlet extraction: an expeditive approach for solid sample treatment. application to the extraction of total fat from oleaginous seeds. J. Chromatogr A. 2004, 1034, 237–242.

Ma, Q.; Hu, D.; Wang, H.; Wang, L. Tara gum edible film incorporated with oleic acid. Food Hydrocoll. 2016, 56, 127–133.

Mahalik, N.O.; Nambiar, A.N. (2010). Trends in food packaging and manufacturing systems and technology. Trends Food Sci. Technol. 2010, 21, 117–128.

Malhotra, B.; Keshwani, A.; Kharkwal, H. Antimicrobial food packaging: potential and pitfalls. Front. Microbiol. 2015, 6, 611–611.

Matta, E.; Tavera-Quiroz, M.J.; Bertola, N. Active edible films of methylcellulose with extracts of green apple (Granny Smith) skin. Int. J. Biol. Macromol. 2019, 124, 1292–1298.

McArt, S.H. et al. A modified method for determining tannin-protein precipitation capacity using accelerated solvent extraction (ASE) and microplate gel filtration. J. Chem. Ecol. 2006, 32, 6, 1367–1377.

McEvily, A.; Iyengar, R.; Otwell, S. Inhibition of enzymic browning in foods and beverages. Crit. Rev. Food. Sci. Nutr. 1992, 32, 3, 253–273.

Mihindukulasuriya, S.D.F.; Lim, L.T. Nanotechnology development in food packaging: a review. Trends Food Sci Technol. 2014, 40, 2, 149–167.

Moalemiyan, M.; Ramaswamy, H.S.; Maftoonazad, N. Pectin-based edible

coating for shelf-life extension of Ataulfo mango. J. Food Process Eng. 2012, 35, 572–600.

Mohammadi Nafchi, A.; Olfat, A.; Bagheri, M.; Nouri, L.; Karim, A.A.; Ariffin, F. Preparation and characterization of a novel edible film based on Alyssum homolocarpum seed gum. J. Food Sci. Technol. 2017, 54, 1703–1710.

Montalvo, C.; López Malo, A.; Palou, E. Películas comestibles de proteína: características, propiedades y aplicaciones. Temas Selectos de Ingeniería de Alimentos 2012, 2, 32–46.

Montero-Garcia, M.D.P.; Gómez-Guillén, M.C.; López-Caballero, M.E.; Barbosa-Cánovas, G.V. Edible Films and Coatings: Fundamentals and Applications. CRC Press: Boca Raton, FL, 2016.

Moradi, M.; Tajik, H.; Rohani, S.M.R.; Mahmoudian, A. Antioxidant and antimicrobial effects of zein edible film impregnated with Zataria multiflora Boiss. essential oil and monolaurin. LWT—Food Sci. Technol. 2016, 72, 37–43.

Morales-Hernandez, M., Jr. Evaluación de las propiedades de candelilla y carnauba para su aplicación en emulsiones céreas de uso comercial. Degree Dissertation, Instituto Politécnico Nacional, Mexico City, 2015.

Motamedi, E.; Nasiri, J.; Malidarreh, T.R.; Kalantari, S.; Naghavi, M.R.; Safari, M. Performance of carnauba wax-nanoclay emulsion coatings on postharvest quality of 'Valencia' orange fruit. Sci. Hortic. (Amsterdam). 2018, 240, 170–178.

Mulchandani, K.; Kar, J.R.; Singhal, R.S. Extraction of lipids from chlorella saccharophila using high-pressure homogenization followed by three phase partitioning. Appl. Biochem. Biotechnol. 2015, 176, 6, 1613–1626.

Mulla, M.; Ahmed, J.; Al-Attar, H.; Castro-Aguirre, E.; Arfat, Y.A.; Auras, R. Antimicrobial efficacy of clove essential oil infused into chemically modified LLDPE film for chicken meat packaging. Food Control. 2017, 73, 663–671.

Nawab, A.; Alam, F.; Haq, M.A.; Haider, M.S.; Lutfi, Z.; Kamaluddin, S.; Hasnain, A. Innovative edible packaging from mango kernel starch for the shelf life extension of red chili powder. Int. J. Biol. Macromol. 2018, 114, 626–631.

Ndlela, S.C. et al. Aqueous extraction of oil and protein from soybeans with subcritical wáter. J. Am. Oil Chem' Soc. 2012, 89, 6, 1145–1153.

Oliveira, V.R.L.; Santos, F.K.G.; Leite, R.H.L.; Aroucha, E.M.M.; Silva, K.N.O. Use of biopolymeric coating hydrophobized with beeswax in post-harvest conservation of guavas. Food Chem. 2018, 259, 55–64.

Oregel-Zamudio, E.; Angoa-Pérez, M.V.; Oyoque-Salcedo, G.; Aguilar-González, C.N.; Mena-Violante, H.G. Effect of candelilla wax edible coatings combined with biocontrol bacteria on strawberry quality during the shelf-life. Sci. Hortic. (Amsterdam). 2017, 214, 273–279.

Otoni, C.G.; Avena-Bustillos, R.J.; Azeredo, H.M.; Lorevice, M.V.; Moura, M.R.; Mattoso, L.H.; McHugh, T.H. Recent advances on edible films based on fruits and vegetables—a review. Compr. Rev. Food Sci. Food Saf. 2017, 16, 5, 1151–1169.

Otoni, C.G.; De Moura, M.R.; Aouada, F.A.; Camilloto, G.P.; Cruz, R.S.; Lorevice, M.V.; Mattoso, L.H. Antimicrobial and physical-mechanical properties of pectin/papaya puree/cinnamaldehyde nanoemulsion edible composite films. Food Hydrocolloids. 2014, 41, 188-194.

Palla. C.; Hegel, P.; Pereda, S.; Bottin, S. Extraction of Jojoba oil with liquid CO2+ propane solvent mixtures. J. Supercrit. Fluids 2014, 91, 37–45.

Pastor, C.; Sánchez-González, L.; Cháfer, M.; Chiralt, A.; González-Martínez, C. Physical and antifungal properties of hydroxypropylmethylcellulose based films containing propolis as affected by moisture content. Carbohydr. Polym. 2010, 82, 1174–1183.

Patra, A.; Verma, P.K.; Mitra, R.K. Slow relaxation dynamics of water in hydroxypropyl cellulose-water mixture traces its phase transition pathway: a spectroscopic investigation. J. Phys. Chem. B. 2012, 116 (5), 1508–1516.

Perez Sira, E.; Dufour, D. Native and modified starches as matrix for edible films and covers. Int. J. Nutr. Food Sci. 2017, 3, 3.

Perez-Gago, M.; Rojas, C.; Del Rio, M. Effect of lipid type and amount of edible composite coatings used to protect postharvest quality of mandarins cv. Fortune. Food Chem. Toxicol. 2002, 67, 2903–2910.

Perumalla, A.V.S.; Hettiarachchy, N.S. Green tea and grape seed extracts—potential applications in food safety and quality. Food Res. Int. 2011, 44, 4, 827–839.

Petriccione, M.; Mastrobuoni, F.; Pasquariello, M.; Zampella, L.; Nobis, E.; Capriolo, G.; Scortichini, M. Effect of chitosan coating on the postharvest quality and antioxidant enzyme system response of strawberry fruit during cold storage. Foods 2015, 4, 4, 501–523.

Ponce, A.G.; Roura, S.I.; Del Valle, C.E.; Moreira, M.R. Antimicrobial and antioxidant activities of edible coatings enriched with natural plant extracts: in vitro and in vivo studies. Postharvest Biol. Technol. 2008, 49, 294–300.

Pushkala, R.; Raghuram, P.K.; Srividya, N. Chitosan based powder coating technique to enhance phytochemicals and shelf life quality of radish shreds. Postharvest Biol. Technol. 2013, 86, 402–408.

Ragaert, P.; Devlieghere, F.; Debevere, J. Role of microbiological and physiological spoilage mechanisms during storage of minimally processed vegetables. Postharvest Biol. Technol. 2007, 44, 3, 185–194.

Rai, A.; Mohanty, B.; Bhargava, R. Modeling and response surface analysis of supercritical extraction of watermelon seed oil using carbon dioxide. Sep. Purif. Technol. 2015, 141, 354–365.

Rai, A.; Mohanty, B.; Bhargava, R. Supercritical extraction of sunflower oil: a central composite design for extraction variables. Food Chem. 2016, 192, 647–659.

Ramis-Ramos, G. Antioxidants. Synthetic Antioxidants. Encyclopedia of Food Sciences and Nutrition. In Finglas, P.; Toldra, F.; Caballero, B. Eds.; 2nd ed.; Academic Press: New Jersey, 2003, pp. 265–275.

Ramos-Ramírez, E.G.; Salazar-Montoya, J.A. Procedimiento para la obtención de aceite de coco a partir de pulpa fresca. Mexican Patent 192953, 1995.

Ravber, M.; Knez, Z.; Škerget, M. Simultaneous extraction of oil- and water-soluble phase from sunflower seeds with subcritical water. Food Chem. 2015, 166, 316–323.

Rawles, L.R. Proceedings of the Third International Conference on Jojoba and Its Uses. University of California, Riverside, CA, 1978, 279–283.

Reis, L.C.B.; De Souza, C.O.; Da Silva, J.B.A.; Martins, A.C.; Nunes, I.L.; Druzian, J.I. Active biocomposites of cassava starch: the effect of yerba mate extract and mango pulp as antioxidant additives on the properties and the stability of a packaged product. Food Bioprod. Process. 2015, 94, 382–391.

Reybroeck, W.; Jacobs, F.J.; De Brabander, H.F.; Daeseleire, E. Transfer of sulfamethazine from contaminated beeswax to honey. J. Agric. Food Chem. 2010, 58, 7258–7265.

Rhim, J.W.; Shellhammer, T.H. Lipid-based edible films and coatings. Innovations in Food Packaging. Elsevier Ltd: London, 2005.

Rivera-Hernández, J.R.; Lomelí-Soto, J.M.; Román-Salinas, L.; Vera-Figueroa, F. Extracción de aceite de coco a partir de la copra por medio de disolventes químicos. Conciencia Tecnológica [Online] 2001, 17. http://www.redalyc.org/articulo.oa?id=94401703 (accessed June 12, 2019).

Robles-Sánchez, R.M.; Rojas-Graü, M.A.; Odriozola-Serrano, I.; González-Aguilar, G.; Martin-Belloso, O. Influence of alginate-based edible coating as carrier of antibrowning agents on bioactive compounds and antioxidant activity in fresh-cut Kent mangoes. LWT—Food Sci. Technol. 2013, 50, 1, 240–246.

Rodríguez, O.; Ortuño, C.; Simala, S.; Benedito, J.; Femenia, A.; Rosselló, C. Acoustically assisted supercritical CO2 extraction of cocoa butter: effects on kinetics and quality. J. Supercrit. Fluids. 2014, 94, 30–37.

Rojas, R.; Contreras-Esquivel, J.C.; Orozco-Esquivel, M.; Muñoz, C.; Aguirre-Joya, J.; Aguilar, C.N.; Castro-López, C.; Ventura-Sobrevilla, J.M.; González-Hernández, M.D.; Rojas, R.; Ascacio-Valdés, J.A.; Aguilar, C.N.; Martínez-Ávila, C.G.; De León-Zapata, M.A.; Sáenz-Galindo, A.; Rojas-Molina, R.; Rodríguez-Herrera, R.; Jasso-Cantú, D.; Aguilar, C.N.; Torres-León, C.; Rojas, R.; Contreras-Esquivel, J.C.; Serna-Cock, L.; Belmares-Cerda, R.E.; Aguilar, C.N.; Cázares, R.; Ruiz, R.B.; Fraga, J.C.; Charles, J.C.; Morales, L.E.; Rojas, R.; Flores, A.; Aranda, J.; Martínez-Avíla, C.; García Carmona, J.; Correa López, M. de J.; Rojas Figueroa, R.A.; Martínez Ibarra, R.; Castro-López, C.; Rojas, R.; Sánchez-Alejo, E.J.; Niño-Medina, G.; Martínez-Ávila, C.G.; Sierra-Hernandez, J.M.; Castillo-Guzman, A.; Selvas-Aguilar, R.; Vargas-Rodriguez, E.; Gallegos-Arellano, E.; Guzman-Chavez, D.; Estudillo-Ayala, J.M.; Jaureguí-Vazquez, D.; Rojas-Laguna, R.; Lopez-Contreras, J.J.; Zavala-Garcia, F.; Urias-Orona, V.; Martinez-Avila, C.G.; Rojas, R.; Guillermo, N.-M. Edible candelilla wax coating with fermented extract of tarbush improves the shelf life and quality of apples. Grape Wine Biotechnol. 2015, 57, 1857–1860.

Rojas-Molina, R.; León-Zapata, M.A.; Saucedo-Pompa, S.; Aguilar-González, M.Á.; Aguilar-González, C.N. Chemical and structural characterization of candelilla (Euphorbia antisyphilitica Zucc.). J. Med. Plants Res. 2013, 7, 702–705.

Rouilly, A.; Meriaux, A.; Geneau, C.; Silvestre, F.; Rigal, L. Film extrusion of sunflower protein isolate. Polym. Eng. Sci. 2006, 46(11), 1635–1640.

Ruan, C.; Zhang, Y.; Wang, J.; Sun, Y.; Gao, X.; Xiong, G.; Liang, J. Preparation and antioxidant activity of sodium alginate and carboxymethyl cellulose edible films with epigallocatechin gallate. Int. J. Biol. Macromol. 2019, 134, 1038–1044.

Ruan, C.; Zhang, Y.; Wang, J.; Sun, Y.; Gao, X.; Xiong, G.; Liang, J. Preparation and antioxidant activity of sodium alginate and carboxymethyl cellulose edible films with epigallocatechin gallate. Int. J. Biol. Macromol. 2019, 134, 1038–1044.

Saba, M.K.; Sogvar, O.B. Combination of carboxymethyl cellulose-based coatings with calcium and ascorbic acid impacts in browning and quality of fresh-cut apples. LWT—Food Sci. Technol. 2016, 66, 165–171.

Sabbah, M.; Di Pierro, P.; Cammarota, M.; Dell'Olmo, E.; Arciello, A.; Porta, R. Development and properties of new chitosan-based films plasticized with spermidine and/or glycerol. Food hydrocoll. 2019, 87, 245–252.

Salama, H.E.; Abdel Aziz, M.S.; Sabaa, M.W. Novel biodegradable and antibacterial edible films based on alginate and chitosan biguanidine hydrochloride. Int. J. Biol. Macromol. 2018, 116, 443–450.

Saldaña, M.D.A.; Mohameda, R.S.; Mazzafera, P. Extraction of cocoa butter from Brazilian cocoa beans using supercritical CO2 and ethane. Fluid Phase Equilibria. 2002, 194–197, 885–894.

Salgin, U. Extraction of Jojoba seed oil using supercritical CO2 + ethanol mixture in green and high-tech separation process. J. Supercrit Fluids 2007, 39, 330–337.

Salgin, U.; Çamili, A.; Zühtü-Uysal, B. Supercritical fluid extraction of Jojoba oil. J. Am. Oil Chem. Soc. 2004, 81, 293–296.

Salinas-Roca, B.; Soliva-Fortuny, R.; Welti-Chanes, J.; Martín-Belloso, O. Combined effect of pulsed light, edible coating and malic acid dipping to improve fresh-cut mango safety and quality. Food Control. 2016, 66, 190–197.

Sánchez-González, L.; Pastor, C.; Vargas, M.; Chiralt, A.; González-Martínez, C.; Cháfer, M. Effect of hydroxypropylmethylcellulose and chitosan coatings with and without bergamot essential oil on quality and safety of cold-stored grapes. Postharvest Biol. Technol. 2011, 60, 1, 57–63.

Sanchís, E.; González, S.; Ghidelli, C.; Sheth, C.C.; Mateos, M.; Palou, L.; Pérez-Gago, M.B. Browning inhibition and microbial control in fresh-cut persimmon (Diospyros kaki Thunb. cv. RojoBrillante) by apple pectin-based edible coatings. Postharvest Biol. Technol. 2016, 112, 186–193.

Sandoval-García, A.M.; Altamirano-Cárdenas, J.R.; Aguilar-Ávila, J.; García-Muñiz, J.G. Chemical characterization of oil obtained by homemade methods from three african palm varieties (Elaeis guineensis Jacq.). Rev. Fitotec. Mex. 2016, 39, 317–322.

Saucedo-Pompa, S.; Rojas-Molina, R.; Aguilera-Carbó, A.F.; Saenz-Galindo, A.; De la Garza, H.; Jasso-Cantú, D.; Aguilar, C.N. Edible film based on candelilla wax to improve the shelf life and quality of avocado. Food Res. Int. 2009, 42, 511–515.

Schmid, M.; Müller, K. Whey Protein-Based Packaging Films and Coatings, Whey Proteins. Elsevier Inc: London, 2018.

Schmid, M.; Pröls, S.; Kainz, D.M.; Hammann, F.; Grupa, U. Effect of thermally induced denaturation on molecular interaction-response relationships of whey protein isolate based films and coatings. Prog. Org. Coat. 2017, 104, 161–172.

Sharma, S.; Rao, T.R. Xanthan gum based edible coating enriched with cinnamic acid prevents browning and extends the shelf-life of fresh-cut pears. LWT—Food Sci. Technol. 2015, 62, 1, 791–800.

Shimao, M. Biodegradation of plastics. Environ. Biotechnol. 2001, 12, 242–247.

Silva-Weiss, A.; Ihl, M.; Sobral, P.J.A.; Gómez-Guillén, M.C.; Bifani, V. Natural additives in bioactive edible films and coatings: functionality and applications in foods. Food Eng. Rev. 2013, 5, 4, 200–216.

Singh, P.; Magalhães, S.; Alves, L.; Antunes, F.; Miguel, M.; Lindman, B.; Medronho, B. Cellulose-based edible films for probiotic entrapment. Food Hydrocoll. 2019, 88, 68–74.

Singh, S.; Khemariya, P.; Rai, A.; Rai, A.C.; Koley, T.K.; Singh, B. Carnauba wax-based edible coating enhances shelf-life and retain quality of eggplant (Solanum melongena) fruits. LWT—Food Sci. Technol. 2016, 74, 420–426.

Sirelkhatim, A.; Mahmud, S.; Seeni, A.; Kaus, N.H.M.; Ann, L.C.; Bakhori, S.K.M.; Hasan, H.; Mohamad. D. Review on Zinc Oxide Nanopar, 2015.

Siripatrawan, U.; Noipha, S. Active film from chitosan incorporating green tea extract for shelf life extension of pork sausages. Food hydrocoll. 2012, 27, 1, 102–108.

Soares, N.F.F.; Pires, A.C.S.; Camilloto, G.P.; Santiago-Silva, P.; Espitia, P.J.P.; Silva, W.A. Recent patents on active packaging for food application. Recent Pat. Food Nutr. Agric. 2009, 1, 1, 171–178.

Sogvar, O.B.; Saba, M.K.; Emamifar, A. Aloe vera and ascorbic acid coatings maintain postharvest quality and reduce microbial load of strawberry fruit. Postharvest Biol. Technol. 2016, 114, 29–35.

Soliva-Fortuny, R.C.; Martín-Belloso, O. New advances in extending the shelf-life of fresh-cut fruits: a review. Trends Food Sci. Technol. 2003, 14, 9, 341–353.

Soradech, S.; Nunthanid, J.; Limmatvapirat, S.; Luangtana-anan, M. Utilization of shellac and gelatin composite film for

coating to extend the shelf life of banana. Food Control 2017, 73, 1310–1317.

Spadaro, J.J.; Lambou, M.G. Proceedings of the first international conference on Jojoba and its uses, Tucson, Arizona. Office of Arid Lands Studies College of Earth Sciences, University of Arizona, Tucson, 1972; 47–60.

Spasojević, L.; Katona, J.; Bučko, S.; Savić, S.M.; Petrović, L.; Milinković Budinčić, J.; Tasić, N.; Aidarova, S.; Sharipova, A. Edible water barrier films prepared from aqueous dispersions of zein nanoparticles. LWT—Food Sci. Technol. 2019, 109, 350–358.

Sucheta; Chaturvedi, K.; Sharma, N.; Yadav, S.K. Composite edible coatings from commercial pectin, corn flour and beetroot powder minimize post-harvest decay, reduces ripening and improves sensory liking of tomatoes. Int. J. Biol. Macromol. 2019, 133, 284–293.

Sudo, S. Dielectric properties of the free water in hydroxypropyl cellulose. J. Phys. Chem. B. 2011, 115 (1), 2–6.

Supapvanich, S.; Prathaan, P.; Tepsorn, R. Browning inhibition in fresh-cut rose apple fruit cv. Taaptimjaan using konjac glucomannan coating incorporated with pineapple fruit extract. Postharvest Biol. Technol. 2012, 73, 46–49.

Taboada-Reyes, F. Procedimiento y equipo para extraccion de cera de candelilla con disolventes selectivos. Mexican Patent MX164638, 1992.

Tavassoli-Kafrani, E.; Shekarchizadeh, H.; Masoudpour-Behabadi, M. Development of edible films and coatings from alginates and carrageenans. Carbohydr. Polym. 2015, 137, 360–374.

Tesfay, S.Z.; Magwaza, L.S. Evaluating the efficacy of moringa leaf extract, chitosan and carboxymethyl cellulose as edible coatings for enhancing quality and extending postharvest life of avocado (Persea americana Mill.) fruit. Food Packag. Shelf Life 2017, 11, 40–48.

Thakur, R.; Pristijono, P.; Scarlett, C.J.; Bowyer, M.; Singh, S.P.; Vuong, Q.V. Starch-based films: major factors affecting their properties. Int. J. Biol. Macromol. 2019, 132, 1079–1089.

Tharanathan, R.N. Biodegradable films and composite coatings: Past, present and future. Trends Food Sci. Technol. 2003, 14, 71–78.

Toivonen, P.M.; DeEll, J.R. Physiology of fresh-cut fruits and vegetables. In Fresh-cut fruits and vegetables. CRC Press: Boca Raton, FL, 2002, 99–131.

Toldrá, F.; Nollet, L.M.L. Proteomics in Foods: Principles and Applications. Springer Science & Business Media: London, 2013, 1–590.

Tomadonia, B.; Moreira, M.R.; Pereda, M.; Ponce, A.G. Gellan-based coatings incorporated with natural antimicrobials in fresh-cut strawberries: microbiological and sensory evaluation through refrigerated storage. LWT—Food Sci. Technol. 2018, 97, 384–389.

Torres-León, C.; Vicente, A.A.; Flores-López, M.L.; Rojas, R.; Serna-Cock, L.; Alvarez-Pérez, O.B.; Aguilar, C.N. Edible films and coatings based on mango (var. Ataulfo) by-products to improve gas transfer rate of peach. LWT—Food Sci. Technol. 2018, 97, 624–631.

Treviño-García, J. Method of extracting candelilla wax. U.S. Patent 1,715,194, 1929.

Ullsten, N.H.; Gallstedt, M.; Johansson, E.; Graslund, A.; Hedenqvist, M.S. Enlarged processing window of plasticized wheat gluten using salicylic acid. Biomacromolecules 2006, 7, 3, 771–776.

Valencia-Chamorro, S.A.; Palou, L.; Del Río, M.A.; Pérez-Gago, M.B. Antimicrobial edible films and coatings for fresh and minimally processed fruits and vegetables: a review. Crit. Rev. Food Sci. Nutr. 2011, 51, 872–900.

Valencia-Chamorro, S.A.; Pérez-Gago, M.B.; Del Río, M.Á.; Palou, L. Effect of

antifungal hydroxypropyl methylcellulose (HPMC)-lipid edible composite coatings on postharvest decay development and quality attributes of cold-stored "Valencia" oranges. Postharvest Biol. Technol. 2009, 54, 72–79.

Valero, D.; Díaz-Mula, H.M.; Zapata, P.J.; Guillén, F.; Martínez-Romero, D.; Castillo, S.; Serrano, M. Effects of alginate edible coating on preserving fruit quality in four plum cultivars during postharvest storage. Postharvest Biol. Technol. 2013, 77, 1–6.

Vanderroost, M.; Ragaert, P.; Devlieghere, F.; De Meulenaer, B. Intelligent food packaging: the next generation. Trends Food Sci. Technol. 2014, 39, 47–62.

Vargas, M.; Pastor, C.; Chiralt, A.; McClements, D.J.; González-Martínez, C. Recent advances in edible coatings for fresh and minimally processed fruits. Crit. Rev. Food Sci. Nutr. 2008, 48, 6, 496–511.

Velderrain-Rodríguez, G.R.; Ovando-Martínez, M.; Villegas-Ochoa, M.; Ayala-Zavala, J.F.; Wall-Medrano, A.; Álvarez-Parrilla, E.; González-Aguilar, G.A. Antioxidant capacity and bioaccessibility of synergic mango (cv. Ataulfo) peel phenolic compounds in edible coatings applied to fresh-cut papaya. Food Nutr. Sci. 2015, 6, 3, 365.

Vidhate, G.S.; Singhal, R.S. Extraction of cocoa butter alternative from kokum (Garcinia indica) kernel by three phase partitioning. J. Food Eng. 2013, 117, 464–466.

Vieira, J.M.; Flores-López, M.L.; De Rodríguez, D.J.; Sousa, M.C.; Vicente, A.A.; Martins, J.T. Effect of chitosan–Aloe vera coating on postharvest quality of blueberry (Vaccinium corymbosum) fruit. Postharvest Biol. Technol. 2016, 116, 88–97.

Walstra, P. et al. Dairy Technology-Principles of Milk Properties and Processes. Marcel Dekker Inc.: New York, NY, 2005.

Wambura, P.; Yang, W.; Mwakatage, N.R. Effects of sonication and edible coating containing rosemary and tea extracts on reduction of peanut lipid oxidative rancidity. Food Bioproc. Technol. 2011, 4, 107–115

Wang, D. et al. Combined enzymatic and mechanical cell disruption and lipid extraction of green alga Neochloris oleoabundans. Int. J. Mol. Sci. 2015, 16, 4, 7707–7722.

Wang, Q. Peanut Processing Characteristics and Quality Evaluation. Springer: London, 2017.

Wang, X.; Guo, C.; Hao, W.; Ullah, N.; Chen, L.; Li, Z.; Feng, X. Development and characterization of agar-based edible films reinforced with nano-bacterial cellulose. Int. J. Biol. Macromol. 2018, 118, 722–730.

Wang, X.; Kong, D.; Ma, Z.; Zhao, R. Effect of carrot puree edible films on quality preservation of fresh-cut carrots. Irish J. Agri. Food Res. 2015, 54, 1, 64–71.

Windsor, F.M.; Durance, I.; Horton, A.A.; Thompson, R.C.; Tyler, C.R.; Ormerod, S.J. A catchment-scale perspective of plastic pollution. Global Change Biol. 2019, 25, 4, 1207–1221.

Wu, H.; Lei, Y.; Zhu, R.; Zhao, M.; Lu, J.; Xiao, D.; Li, S. Preparation and characterization of bioactive edible packaging films based on pomelo peel flours incorporating tea polyphenol. Food Hydrocoll. 2019, 90, 41–49.

Wu, S. Extending shelf-life of fresh-cut potato with cactus Opuntia dillenii polysaccharide-based edible coatings. Int. J. Biol. Macromol. 2019, 130, 640–644.

Xiao, C.; Zhu, L.; Luo, W.; Song, X.; Deng, Y. Combined action of pure oxygen pretreatment and chitosan coating incorporated with rosemary extracts on the quality of fresh-cut pears. Food Chem. 2010, 121, 4, 1003–1009.

Xiao, Z.; Luo, Y.; Luo, Y.; Wang, Q. Combined effects of sodium chlorite dip treatment and chitosan coatings on the quality of fresh-cut d'Anjou pears. Postharvest Biol. Technol. 2011, 62, 319–326.

Xing, Y.; Li, X.; Xu, Q.; Yun, J.; Lu, Y.; Tang, Y. Effects of chitosan coating

enriched with cinnamon oil on qualitative properties of sweet pepper (Capsicum annuum L.). Food Chem. 2011, 124, 4, 1443–1450.

Yan, J.; Luo, Z.; Ban, Z.; Lu, H.; Li, D.; Yang, D.; Aghdam, M.S.; Li, L. The effect of the layer-by-layer (LBL) edible coating on strawberry quality and metabolites during storage. Postharvest Biol. Technol. 2019, 147, 29–38.

Yemiş, G.P.; Candoğan, K. Antibacterial activity of soy edible coatings incorporated with thyme and oregano essential oils on beef against pathogenic bacteria. Food Sci. Biotechnol. 2017, 26, 4, 1113–1121.

Yen, M.T.; Yang, J.H.; Mau, J.L. Antioxidant properties of chitosan from crab shells. Carbohydr. Polym. 2008, 74, 4, 840–844.

Yıldırım-Yalçın, M.; Şeker, M.; Sadıkoğlu, H. Development and characterization of edible films based on modified corn starch and grape juice. Food Chem. 2019, 292, 6–13.

Yoruk, R.; Marshall, M.R. Physicochemical properties and function of plant polyphenol oxidase: a review. J. Food Biochem. 2003, 27, 5, 361–422.

Younis, H.G.R.; Zhao, G. Physicochemical properties of the edible films from the blends of high methoxyl apple pectin and chitosan. Int. J. Biol. Macromol. 2019, 131, 1057–1066.

Yousuf, B.; Qadri, O.S.; Srivastava, A.K. Recent developments in shelf-life extension of fresh-cut fruits and vegetables by application of different edible coatings: a review. LWT—Food Sci. Technol. 2018, 89, 198–209.

Yousuf, B.; Srivastava, A.K. A novel approach for quality maintenance and shelf life extension of fresh-cut Kajari melon: effect of treatments with honey and soy protein isolate. LWT—Food Sci. Technol. 2017, 79, 568–578.

Yousuf, B.; Srivastava, A.K. Impact of honey treatments and soy protein isolate-based coating on fresh-cut pineapple during storage at 4°C. Food Packag. Shelf Life. 2019, 21, 100361.

Yuan, G.; Lv, H.; Tang, W.; Zhang, X.; Sun, H. Effect of chitosan coating combined with pomegranate peel extract on the quality of Pacific white shrimp during iced storage. Food Control 2016, 59, 818–823.

Zaher, F.A.; El Kinawy, O.S.; El Haron, D.E. Solvent extraction of jojoba oil from prepressed jojoba meal. Grasas y Aceites. 2004, 55, 129–134.

Zambrano-Zaragoza, M. L.; Mercado-Silva, E.; Del Real, A.; Gutierrez-Cortez, E.; Cornejo-Villegas, M.A.; Quintanar-Guerrero, D. The effect of nano-coatings with α- tocopherol and xanthan gum on shelf-life and browning index of fresh-cut "Red Delicious" apples. Innov. Food Sci. Emerg. Technol. 2014, 22, 188–196.

Zambrano-Zaragoza, M.L.; Quintanar-Guerrero, D.; Real, A.D.; Pinon-Segundo, E.; Zambrano-Zaragoza, J.F. The release kinetics of β-carotene nanocapsules/xanthan gum coating and quality changes in fresh-cut melon (cantaloupe). Carbohydr. Polym. 2017, 157, 1874–1882.

Zárate-Polanco, L.M.; Ramírez-Suárez, L.M.; Otálora-Santamaría, N.A.; Prieto, L.; Garnica-Holguín, A.M.; Cerón-Lasso, M.S.; Argüelles, J.H. 2014. Extracción y caracterización de almidón nativo de clones promisorios de papa criolla (Solanum tuberosum, Grupo Phureja). Revista Latinoamericana de la Papa 18(1), 2–24.

Zeng, K.; Deng, Y.; Ming, J.; Deng, L. Induction of disease resistance and ROS metabolism in navel oranges by chitosan. Sci. Hortic. 2010, 126, 223–228.

Zhang, R.; Wang, W.; Zhang, H.; Dai, Y.; Dong, H.; Hou, H. Effects of hydrophobic agents on the physicochemical properties of edible agar/maltodextrin films. Food Hydrocoll. 2019, 88, 283–290.

Zhao, Y. Edible coatings for extending shelf-life of fresh produce during postharvest

storage. In Encyclopedia of Food Security and Sustainability. Elsevier: Amsterdam, 2019, 506–510.

Zheng, K.; Xiao, S.; Li, W.; Wang, W.; Chen, H.; Yang, F.; Qin, C. Chitosan-acorn starch-eugenol edible film: physico-chemical, barrier, antimicrobial, antioxidant and structural properties. Int. J. Biol. Macromol. 2019, 135, 344–352.

Handbook of Research on Bioenergy and Biomaterials

Consolidated and Green Processes

Providing an understanding of consolidated processing and biorefinery systems for the production of bio-based chemicals and value-added bioproducts from renewable sources, the chapters in this new volume look at a variety of bioenergy technological advances and improvements in the energy and materials sectors that aim to lower our dependence on fossil fuels and consequently reduce greenhouse gas (GHG) emissions. The processes for the production of energy and biomaterials discussed include the Fischer–Tropsch process, gasification, pyrolysis, combustion, fermentation from renewable sources (such as, plants, animals and their byproducts), and others. Applications that are explored include transportation fuels, biodiesel production, wastewater treatment, edible packaging, bioplastics, physical rehabilitation, tissue engineering, biomedical applications, thermal insulation, industrial value compounds, and more.

ABOUT THE EDITORS

Leopoldo Javier Ríos González, PhD, is Professor at the School of Chemistry, Autonomous University of Coahuila, México. He is a biologist chemist specializing in microbiology. He is an expert in the production of liquid and gas biofuels from biomass and is a member of the Bioenergy Thematic Network (REMBIO). Dr. Rios-González has developed research funded by the Secretariat of Agricultural and the National Council of Research and Technology and has handled projects with industry. He has published research papers in international journals and is a member of the National Researchers System in México.

Jośe Antonio Rodríguez-De La Garza, PhD, has been a full-time Professor since 2008 at the School of Chemistry, Autonomous University of Coahuila, Mexico, in the area environmental biotechnology. He currently is head of the biotechnology PhD program at the same institution. Dr. Rodriguez-De la Garza is developing a research project funded by the State Council of Science and Technology of Coahuila He has published research papers in journals and book chapters and has participated and contributed in over 40 scientific meetings.

Miguel Ángel Medina Morales, PhD, is Professor at the School of Chemistry, Autonomous University of Coahuila, Mexico, in the area environmental biotechnology. He is a member of the National Researchers System (SNI). In 2017 he was part of a research team that was honored with the Tritio Award given by the Autonomous University of Coahuila. He has published over 14 papers in scientific journals and several book chapters.

Cristóbal Noé Aguilar, PhD, is Director of Research and Postgraduate Programs at the Universidad Autonoma de Coahuila, Mexico. Dr. Aguilar has published more than 160 papers in journals, more than 40 articles in Mexican journals, and 250 contributions in scientific meetings. He has also published many book chapters, several Mexican books, four editions of international books, and more. He has been awarded several prizes and awards, the most important of which are the National Prize of Research 2010 from the Mexican Academy of Sciences; the prize "Carlos Casas Campillo 2008" from the Mexican Society of Biotechnology and Bioengineering; National Prize AgroBio–2005; and the Mexican Prize in Food Science and Technology.

ISBN: 978-1-77188-955-1
90000
9 781771 889551

APPLE ACADEMIC PRESS

www.appleacademicpress.com