

# INNOVATIVE TECHNOLOGIES FOR FOOD PRESERVATION

Inactivation of Spoilage and  
Pathogenic Microorganisms



Edited by  
Francisco J. Barba , Anderson S. Sant'Ana,  
Vibeke Orlén, and Mohamed Koubaa



# Innovative Technologies for Food Preservation

This page intentionally left blank

# Innovative Technologies for Food Preservation

Inactivation of Spoilage and Pathogenic  
Microorganisms

---

Edited by

**Francisco J. Barba**

University of Valencia, Valencia, Spain

**Anderson S. Sant'Ana**

University of Campinas (UNICAMP), Campinas, SP, Brazil

**Vibeke Orlie**

University of Copenhagen, Frederiksberg C, Denmark

**Mohamed Koubaa**

Ecole Supérieure de Chimie Organique et Minérale, Compiègne, France



**ACADEMIC PRESS**

An imprint of Elsevier

Academic Press is an imprint of Elsevier  
125 London Wall, London EC2Y 5AS, United Kingdom  
525 B Street, Suite 1800, San Diego, CA 92101-4495, United States  
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States  
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom

Copyright © 2018 Elsevier Inc. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: [www.elsevier.com/permissions](http://www.elsevier.com/permissions).

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

#### Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

#### British Library Cataloguing-in-Publication Data

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

#### Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress

ISBN: 978-0-12-811031-7

For Information on all Academic Press publications  
visit our website at <https://www.elsevier.com/books-and-journals>



Working together  
to grow libraries in  
developing countries

[www.elsevier.com](http://www.elsevier.com) • [www.bookaid.org](http://www.bookaid.org)

*Publisher:* Andre Gerharc Wolff

*Acquisition Editor:* Nina Rosa Bandeira

*Editorial Project Manager:* Mariana Kuhl

*Production Project Manager:* Vijayaraj Purushothaman

*Cover Designer:* Victoria Pearson / Mohamed Koubaa

Typeset by MPS Limited, Chennai, India

# Contents

List of Contributors

xi

## Part I Introduction

### 1. Conventional Technologies of Food Preservation

*Pedro E.D. Augusto, Beatriz M.C. Soares and Nanci Castanha*

<b>1.1 Thermal Processing</b>	3
1.1.1 Thermal Processing Main Characteristics	4
1.1.2 Microbial Inactivation Kinetics	7
1.1.3 Process Design	10
<b>1.2 Cooling</b>	11
<b>1.3 Freezing</b>	14
<b>1.4 Water Activity (<math>a_w</math>) Reduction</b>	18
<b>1.5 Hurdle Technology</b>	19
<b>1.6 Conclusions</b>	22
<b>References</b>	22

### 2. Innovative Technologies for Food Preservation

*Francisco J. Barba, Lilia Ahrné, Epameinondas Xanthakis,  
Martin G. Landerslev and Vibeke Orlien*

<b>2.1 Introduction</b>	25
<b>2.2 Physical Technologies</b>	26
2.2.1 High Hydrostatic Pressure Processing	27
2.2.2 High-Pressure Homogenization	31
<b>2.3 Electromagnetic Technologies</b>	34
2.3.1 Pulsed Electric Fields	34
2.3.2 Ohmic Heating	36
2.3.3 Microwaves	36
2.3.4 Radio-Frequency	37
2.3.5 UV-Light (Continuous and Pulsed)	39
<b>2.4 Acoustic Technologies</b>	40
2.4.1 Ultrasound	40
2.4.2 High Hydrodynamic Pressure-Shockwaves	42

2.5	<b>Others</b>	42
2.5.1	Membrane Filtration	42
2.5.2	Dense Phase CO <sub>2</sub>	45
	<b>Acknowledgments</b>	47
	<b>References</b>	47
3.	<b>Main Groups of Microorganisms of Relevance for Food Safety and Stability: General Aspects and Overall Description</b>	
	<i>Jose M. Lorenzo, Paulo E. Munekata, Ruben Dominguez, Mirian Pateiro, Jorge A. Saraiva and Daniel Franco</i>	
3.1	<b>Introduction</b>	53
3.2	<b>Spoilage Nonspore-Forming Bacteria</b>	54
3.2.1	<i>Brochothrix</i> spp.	55
3.2.2	<i>Carnobacterium</i> spp.	56
3.2.3	<i>Lactobacillus</i> spp.	56
3.2.4	<i>Pediococcus</i> spp.	58
3.2.5	<i>Streptococcus</i> spp.	58
3.2.6	<i>Lactococcus</i> spp.	59
3.2.7	<i>Leuconostoc</i> spp.	59
3.2.8	<i>Kurthia</i> spp.	60
3.2.9	<i>Weissella</i> spp.	60
3.3	<b>Spoilage Spore-Forming Bacteria</b>	60
3.3.1	Bacilli	61
3.3.2	Clostridia	63
3.4	<b>Pathogenic Nonspore-Forming Bacteria</b>	65
3.4.1	<i>Brucella</i> spp.	65
3.4.2	<i>Campylobacter</i> spp.	67
3.4.3	<i>Salmonella</i> spp.	68
3.4.4	<i>Yersinia</i> spp.	70
3.4.5	<i>Listeria</i> spp.	71
3.4.6	<i>Escherichia coli</i> spp.	72
3.5	<b>Pathogenic Spore-Forming Bacteria</b>	74
3.5.1	<i>Bacillus</i> spp.	75
3.5.2	<i>Clostridium</i> spp.	76
3.5.3	Sporulation and Germination Process and Morphology	
	Spore	76
3.5.4	Contamination of Bacterial Spores to Food and Inactivation Methods	78
3.6	<b>Yeasts and Molds</b>	80
3.6.1	Yeast	80
3.6.2	Molds	82
3.7	<b>Viruses and Parasites</b>	85
3.7.1	Viruses	85
3.7.2	Parasites	88
3.8	<b>Conclusion</b>	92
	<b>References</b>	92

**Part II****Microbial Inactivation After Innovative Processing of the Main Groups of Microorganism of Relevance for Food Safety and Stability****4. Mechanisms of Microbial Inactivation by Emerging Technologies***Shahin Roohinejad, Mohamed Koubaa, Anderson S. Sant'Ana and Ralf Greiner*

<b>4.1 Introduction</b>	111
<b>4.2 Inactivation Targets and Mode of Action of Emerging Technologies</b>	112
4.2.1 Pulsed Electric Fields	112
4.2.2 Microbial Inactivation by Pulsed Electric Field	113
4.2.3 High Pressure Processing (HPP)	116
4.2.4 Ultrasounds	117
4.2.5 High Intensity Pulsed Light Technology	120
4.2.6 Microwave and Radiofrequency Electromagnetic Radiations	124
<b>4.3 Conclusions</b>	125
<b>Acknowledgment</b>	125
<b>References</b>	126

**5. Effects of Innovative Processing Technologies on Microbial Targets Based on Food Categories: Comparing Traditional and Emerging Technologies for Food Preservation***Mehrdad Niakousari, Hadi H. Gahrue, Maryam Razmjooei, Shahin Roohinejad and Ralf Greiner*

<b>5.1 Introduction</b>	133
<b>5.2 Traditional Methods of Food Preservation</b>	134
<b>5.3 Innovative Processing Technologies of Food Preservation</b>	134
5.3.1 Pulsed Electric Fields	134
5.3.2 High-Pressure Processing	149
5.3.3 Ultrasounds	160
<b>5.4 Conclusions</b>	171
<b>Acknowledgment</b>	172
<b>References</b>	172
<b>Further Reading</b>	185



## 6. Designing, Modeling, and Optimizing Processes to Ensure Microbial Safety and Stability Through Emerging Technologies

*Hassan Masood, Francisco J. Trujillo, Kai Knoerzer and Pablo Juliano*

<b>6.1 Introduction</b>	187
6.1.1 Emerging Food Processing Technologies	187
6.1.2 Modeling and Optimization of Emerging Technologies	188
<b>6.2 Electrical Processing</b>	189
6.2.1 Operational Principles and Control Parameters	190
6.2.2 Microbiological Modeling	192
6.2.3 Multiphysics Models and Numerical Simulations	195
<b>6.3 High-Pressure Processing</b>	203
6.3.1 Operational Principles and Control Parameters	205
6.3.2 Microbiological Modeling	206
6.3.3 Multiphysics Simulations	208
<b>6.4 Ultrasound Processing</b>	213
6.4.1 Operational Principles and Control Parameters	213
6.4.2 Microbiological Modeling	214
6.4.3 Multiphysics Model and Numerical Simulations	215
<b>6.5 Conclusions</b>	219
<b>References</b>	220

## Part III

### **Consumer's, Technological, Environmental and Regulatory Aspects of Application of Emerging Technologies for Food Preservation**

## 7. Consumer Acceptance and Marketing of Foods Processed Through Emerging Technologies

*María Lavilla and Elisa Gayán*

<b>7.1 Introduction</b>	233
<b>7.2 Global Trends of Acceptance and Trade in Foods Processed Through Emerging Technologies</b>	234
<b>7.3 Public Acceptance of Foods Processed Through Emerging Technologies</b>	236
7.3.1 Brief Overview in Trends of Emerging Food Processing Technologies	236
7.3.2 Public Acceptance of Food Processed by High-Pressure Processing	237
7.3.3 Public Acceptance of Food Processed by Microwave Heating	238
7.3.4 Public Acceptance of Food Processed by Pulsed Electric Field	239
7.3.5 Public Acceptance of Food Processed by Ultraviolet Technologies	241

7.4	Market Development and Commercialization of Foods Processed Through Emerging Technologies	244
7.5	Challenges and Opportunities	245
	Acknowledgments	247
	References	247
<b>8.</b>	<b>Environmental Footprint of Emerging Technologies, Regulatory and Legislative Issues</b>	
	<i>Sónia M. Castro, Rita S. Inácio, Elisabete M.C. Alexandre, Liliana G. Fidalgo, Sofia Pereira, Patrícia Quaresma, Paulo Freitas, Paula Teixeira, Manuela Pintado, Ana M. Gomes, Carole Tonello and Jorge A. Saraiva</i>	
8.1	Introduction	255
8.2	Environmental Footprint of Emerging Technologies	256
8.3	Current Status on International Regulations	257
8.3.1	United States of America	258
8.3.2	Canada	262
8.3.3	European Union	264
8.3.4	Japan, Australia, and New Zealand	269
8.4	Concluding Remarks	272
	Acknowledgments	273
	References	273
<b>9.</b>	<b>Technological Hurdles and Research Pathways on Emerging Technologies for Food Preservation</b>	
	<i>Daniela Bermudez-Aguirre</i>	
9.1	Introduction	277
9.2	Emerging Technologies: Technological Limitations	277
9.2.1	Mechanical Processes	280
9.2.2	Electromagnetic Technologies	281
9.2.3	Acoustic Technologies	290
9.2.4	Innovative Chemical Processing Technologies	292
9.2.5	Hurdle Technology	293
9.3	Research Needs	293
9.3.1	High Hydrostatic Pressure	293
9.3.2	Pulsed Electric Fields	294
9.3.3	Ohmic Heating	294
9.3.4	Microwave	295
9.3.5	Cold Plasma	295
9.3.6	Ultraviolet	296
9.4	Challenges and Opportunities	296
9.5	Conclusions	298
	References	298
	Index	305

This page intentionally left blank

# List of Contributors

- Lilia Ahrné** University of Copenhagen, Frederiksberg C, Denmark
- Elisabete M.C. Alexandre** University of Aveiro, Aveiro, Portugal; Universidade Católica Portuguesa, Porto, Portugal
- Pedro E.D. Augusto** University of São Paulo (USP), Piracicaba, SP, Brazil
- Francisco J. Barba** University of Valencia, Valencia, Spain
- Daniela Bermudez-Aguirre** Independent Consultant, Pullman, WA, United States
- Nanci Castanha** University of São Paulo (USP), Piracicaba, SP, Brazil
- Sónia M. Castro** University of Aveiro, Aveiro, Portugal; Universidade Católica Portuguesa, Porto, Portugal
- Ruben Dominguez** Meat Technology Center of Galicia, Ourense, Sapin
- Liliana G. Fidalgo** University of Aveiro, Aveiro, Portugal
- Daniel Franco** Meat Technology Center of Galicia, Ourense, Sapin
- Paulo Freitas** University of Aveiro, Aveiro, Portugal
- Hadi Hashemi Gahruie** Shiraz University, Shiraz, Iran
- Elisa Gayán** KU Leuven, Leuven, Belgium
- Ana M. Gomes** Universidade Católica Portuguesa, Porto, Portugal
- Ralf Greiner** Max Rubner-Institut, Karlsruhe, Germany
- Rita S. Inácio** University of Aveiro, Aveiro, Portugal; Universidade Católica Portuguesa, Porto, Portugal
- Pablo Juliano** CSIRO Agriculture and Food, Melbourne, VIC, Australia
- Kai Knoerzer** CSIRO Agriculture and Food, Melbourne, VIC, Australia
- Mohamed Koubaa** Ecole Supérieure de Chimie Organique et Minérale, Compiègne, France
- Martin G. Landerslev** University of Copenhagen, Frederiksberg C, Denmark
- María Lavilla** AZTI, Derio, Spain
- Jose M. Lorenzo** Meat Technology Center of Galicia, Ourense, Sapin
- Hassan Masood** The University of New South Wales, Sydney, NSW, Australia
- Paulo E. Munekata** University of São Paulo (USP), Pirassununga, SP, Brazil
- Mehrdad Niakousari** Shiraz University, Shiraz, Iran

- Vibeke Orlien** University of Copenhagen, Frederiksberg C, Denmark
- Mirian Pateiro** Meat Technology Center of Galicia, Ourense, Sapin
- Sofia Pereira** University of Aveiro, Aveiro, Portugal; Universidade Católica Portuguesa, Porto, Portugal
- Manuela Pintado** Universidade Católica Portuguesa, Porto, Portugal
- Patrícia Quaresma** University of Aveiro, Aveiro, Portugal
- Maryam Razmjooei** Shiraz University, Shiraz, Iran
- Shahin Roohinejad** Max Rubner-Institut, Karlsruhe, Germany; Shiraz University of Medical Sciences, Shiraz, Iran
- Anderson S. Sant’Ana** University of Campinas (UNICAMP), Campinas, SP, Brazil
- Jorge A. Saraiva** University of Aveiro, Aveiro, Portugal
- Beatriz M.C. Soares** Food Technology Institute (ITAL), Campinas, SP, Brazil
- Paula Teixeira** Universidade Católica Portuguesa, Porto, Portugal
- Carole Tonello** Hiperbaric, Burgos, Spain
- Francisco J. Trujillo** The University of New South Wales, Sydney, NSW, Australia
- Epameinondas Xanthakis** RISE-Research Institutes of Sweden, Gothenburg, Sweden

Part I

# Introduction

This page intentionally left blank