Nanotechnology in the Agri-Food Sector

Implications for the Future
Contents

List of Contributors  XIII

Introduction  1
Lynn Frewer, Arnout Fischer, Willem Norde, and Frans Kampers

Part 1  Fundamentals  3

1  Intermolecular Interactions  5
Willem Norde
1.1 Introduction  5
1.2 Water  7
1.3 Hydrophobic and Hydrophilic Interactions  9
1.4 Dispersion Interaction  12
1.5 Electrostatic Interactions  13
1.5.1 Atoms and Small Molecules  13
1.5.2 Polymers, Particles, and Surfaces  14
1.6 Steric Interactions Involving Soluble Polymers  17
1.6.1 Depletion Aggregation of Particles by Non-adsorbing Polymers  17
1.6.2 Bridging Aggregation of Particles by Adsorbing Polymers  17
1.6.3 Stabilization of Dispersed Particles by Adsorbing Polymers  19
1.6.4 Polymer Brushes to Prevent Particle Aggregation and Particle Deposition at Surfaces  19
1.7 Epilog  21
Further Reading  22

2  Supramolecular Structures  23
Pieter Stroeve
2.1 Introduction  23
2.2 Self-Assembly  24
2.3 Plant Cells  27
2.4 Organized Self-Assembled Structures 28
2.4.1 Langmuir Layers 28
2.4.2 Lipid Bilayers 30
2.4.3 Solid-Supported Lipid Bilayers 31
2.4.4 Micelles 33
2.4.5 Vesicles 35
2.5 Summary 36
References 36

Part 2 Basic Applications 37

3 Nanotechnology in Food Production 39
Remko M. Boom
3.1 Introduction 39
3.2 Food Production 40
3.2.1 Food and New Ways of Food Production 40
3.2.2 Why Do We Need New Processing and Preparation Methods? 40
3.2.3 More Efficient Fractionation of Crops 41
3.2.4 More Efficient Product Structuring 41
3.2.5 Optimizing Nutritional Value 43
3.2.6 Nanotechnology for Food Production? 43
3.3 Nanotechnology and Food 44
3.3.1 What Is Nanotechnology? 44
3.3.2 Nanotechnology in Food Production 44
3.4 Applications of Nanotechnology in Foods 46
3.4.1 Sensing 46
3.4.2 Packaging 46
3.4.3 Encapsulation 47
3.4.4 Nano-Engineering Food Ingredients to Improve Bioavailability 48
3.4.4.1 Nanocrystalline Food Ingredients 48
3.4.4.2 Nano-Emulsions 49
3.4.4.3 Nano-Engineered Protein Fibrils as Ingredient Building Blocks 49
3.4.5 Preparation of Food Matrices 52
3.5 Concerns about Using Nanotechnology in Food Production 55
3.5.1 Risks of Nanotechnology 55
3.5.2 Rational Argumentation Versus Human Feelings 55
References 56

4 Packaging 59
Frans W.H. Kampers
4.1 Introduction 59
4.2 Reasons to Package Food Products 59
4.3 Physical Properties of Packaging Materials 60
6.7 Conclusions 102
References 103

7 Nanotechnologies for Improving Food Quality, Safety, and Security 107
Douglas K.R. Robinson and Mark Morrison
7.1 Introduction 107
7.2 Improving Quality, Safety, and Security of Agricultural Production 107
7.3 Improving Quality, Safety, and Security in Food Processing 112
7.4 Improving Quality, Safety, and Security in Packaging and Distribution 117
7.5 Wrapping Up 122
References 122

8 Food Functionality and the Physics of Bionanotechnology: Some Examples and Challenges 127
Erik van der Linden
8.1 Introduction: How Are Foods and Bionanotechnology Related? 127
8.2 Physics and Structures in Food Bionanotechnology 129
8.3 Fibrillar Structures 130
8.3.1 Protein-Based Fibrils 131
8.3.2 Extremely Low-Weight Gels Using Fibrils 132
8.3.3 Helix-Based Fibrils in Gelatin Gels 132
8.3.4 Fibrils in Oil 133
8.3.5 Fibril-Enforced Composite Structures 133
8.4 Plate-Like Structures 133
8.5 Spherically Symmetric Structures 135
8.5.1 Protein Fractal Structures in Water 135
8.5.2 Micelles 135
8.5.3 Spherically Symmetric Fractal Structures in Oil 136
8.6 Bicontinuous Structures in Protein-Polysaccharide Systems 136
8.7 Gastronomy and the Nanodomain: Molecular Gastronomy 137
8.7.1 Introduction 137
8.7.2 Recent Developments 140
8.7.2.1 Signatures of Creative Methods at El Bulli 141
8.7.3 A Structured and Scientific Approach to Molecular Gastronomy: Back to Nano 142
8.8 Conclusions 145
References 145

9 Products and Their Commercialization 149
Betty Bugusu, Ursula Vanesa Lay Ma, and John D. Floras
9.1 Introduction 149
9.2 Investment in Nanotechnology Research 150
9.3 Innovations in Food and Agriculture Nanotechnology 152
9.4 Nanotechnology Commercialization 155
9.4.1 The Path to Commercialization 156
9.4.1.1 Ideas and Concepts 156
9.4.1.2 Research and Product Development: Design, Modeling, and Simulation 156
9.4.1.3 Standardization 157
9.4.1.4 Safety Assessment and Regulatory Issues 157
9.4.1.5 Manufacturing—Scale-Up 158
9.4.1.6 Final Product Realization and Marketing 159
9.4.1.7 Intellectual Property 159
9.4.2 Challenges to Commercialization 160
9.4.2.1 Public Acceptance and Societal Implications 161
9.5 Current and Emerging Markets 162
9.5.1 Market Strategies for New Technology Products 165
9.5.1.1 Market Strategies for Evolutionary Technologies 165
9.5.1.2 Market Strategies for Disruptive Technologies 165
9.6 Conclusions 166
References 167

Part 4 Nanotechnology and Society 171

10 Toxicology of Nanomaterials in Food 173
Bernadene A. Magnuson and Hans Bouwmeester
10.1 Introduction 173
10.2 What Makes Nanomaterials Special? 173
10.3 Characterization of Engineered Nanomaterials 174
10.3.1 Unique Issues for Characterization of Engineered Nanomaterials for Food Applications 175
10.4 Safety Assessment of Oral-Exposure Engineered Nanomaterials for Food Application 176
10.4.1 Experimental Design Considerations for Toxicology Studies 176
10.4.2 Toxicokinetics 178
10.4.2.1 Absorption 178
10.4.2.2 Distribution 180
10.4.2.3 Metabolism 180
10.4.2.4 Excretion 181
10.4.3 Toxicodynamics 181
10.4.3.1 In Vivo Toxicity 182
10.4.3.2 In Vitro Toxicity 182
10.4.3.3 Study Reliability 183
10.5 Conclusions 183
References 185
11 Nanomaterials in Food and Food Contact Materials—Potential Implications for Consumer Safety and Regulatory Controls 191
Qasim Chaudhry, Laurence Castle, and Richard Watkins
11.1 Background 191
11.2 Nanomaterials Likely to be Used in Food and Related Applications 192
11.2.1 Inorganic Nanomaterials 192
11.2.2 Surface-Functionalized Nanomaterials 193
11.2.3 Organic Nanomaterials 193
11.3 Potential Consumer Safety Implications 194
11.4 Current and Projected Applications for Food 196
11.4.1 Processed Nanostructures in Foodstuffs 197
11.4.2 Nano-sized Food Additives 198
11.4.3 Applications for Food Packaging 199
11.4.4 Applications in Food Production 201
11.5 Implications for Regulatory Frameworks 202
11.6 Conclusions 204
References 205

12 Environmental Considerations of and Societal Reactions to Nanotechnology in the Food Sector 209
Michael Siegrist, Bernd Nowack, and Hans Kastenholz
12.1 Introduction 209
12.2 Life Cycle of Nanotechnology Food Products 210
12.2.1 Food 211
12.2.2 Packaging 211
12.2.3 Agriculture 212
12.2.4 Non-Food Sector 212
12.3 Occurrence of Engineered Nanoparticles in the Environment 213
12.3.1 Environmental Behavior of Nanoparticles 214
12.3.2 Toxicology of Nanoparticles 215
12.4 How Should Society Deal with Uncertainty? 216
12.4.1 Public Perception of Nanotechnology 217
12.4.2 Scientists and Industrial Perspective 219
12.5 Conclusions 219
References 220

13 Nanotechnology and Food Allergy 225
E.N. Clare Mills, Yuri Aleexev, and Alan R. Mackie
13.1 Introduction 225
13.2 Molecules in Foods Involved in Triggering Allergies 226
13.2.1 Plant Food Allergens 227
13.2.1.1 Prolamin Superfamily 227
13.2.1.2 Cupin Superfamily 228
13.2.1.3 Bet v 1 Family 228
13.2.1.4 Profilins 228
13.2.2 Animal Food Allergens 228
13.2.2.1 Tropomyosins 228
13.2.2.2 Parvalbumins 229
13.2.2.3 Caseins 229
13.3 Food Structure, Processing, and Food Allergy 229
13.3.1 Molecular Effects of Food Processing on Allergenicity 230
13.3.2 Macroscopic Effects of Food Processing on Allergenicity 232
13.3.2.1 Natural Cellular Structures 232
13.3.2.2 Processed Food Structures 233
13.3.3 Molecular and Macroscopic Effects of Processing on Allergenicity of Foods 234
13.4 Impact of Nanoscale Structures on Allergic Potential of Foods 235
13.5 Conclusions 236
Acknowledgments 237
References 237

14 Communication of Risks and Benefits of Nanotechnology: the Issue of Societal Acceptance of Emerging Technologies 243
Lynn J. Frewer, Arnout R.H. Fischer, and J.(Hans)C.M. van Trijp
14.1 Introduction 243
14.2 Science and Society: Lessons for Nanotechnology Applied to Food Production 246
14.3 A Short Introduction to the Psychology of Risk–Benefit Perception 248
14.4 How do People Form Perceptions of New Technologies 250
14.5 Nanotechnology Communication in the Business Context 252
14.6 Conclusion 254
References 255

15 Public Engagement with Emerging Issues in Agri-Food Nanotechnology 257
Lynn J. Frewer, Arnout R.H. Fischer, and Gene Rowe
15.1 Introduction 257
15.2 What Is “Public Engagement“? 258
15.3 Evaluating the Effectiveness of Public and Stakeholder Engagement 260
15.4 Public Engagement Examples 262
15.5 Recommendations for Conducting Public Engagement and Public Consultation Exercises 264
Appendix 266
Glossary 266
References 268