Food-Borne Microbes
SHAPING THE HOST ECOSYSTEM
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Cover photo: Salmonella enterica serovar Typhi can colonize the bile-rich gallbladder, and biofilms on gallstone surfaces in this organ may help establish and maintain a carrier state. A human gallstone was incubated with serovar Typhimurium and 3% bile for 12 days, washed, fixed in glutaraldehyde, and visualized by scanning electron microscopy. The weblike, flocculent material is indicative of desiccated exopolysaccharide from the bacterially initiated extracellular matrix of this mature biofilm. Image assembled by A. M. Prouty and R. W. Crawford in the laboratory of J. S. Gunn.

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CONTENTS

Contributors ix
Preface xiii

I. CIRCULATION AND DYNAMICS AMONG MICROBIAL ECOSYSTEMS / 1

1. The Oral Microbial Ecosystem and Beyond / 3
Howard F. Jenkinson and Richard J. Lamont

2. The Gut Microbiome: Current Understanding and Future Perspectives / 19
Zhongtang Yu and Mark Morrison

3. Natural Microbial Ecosystems and Their Progression in Fresh Foods / 41
James M. Jay

4. Microbial Succession and Gut Health: Probiotics / 63
Gerald W. Tannock

5. Interactions between Environmental Microbial Ecosystems and Humans: the Case of the Water Environment and Antibiotic Resistance / 81
Chuanwu Xi, Kathleen Bush, Karen L. Lachmayr, Yongli Zhang, and Timothy E. Ford

II. INTERACTIONS AND MODIFICATIONS WITHIN MICROBIAL ECOSYSTEMS / 93

6. Biofilms in the Food Environment / 95
Joseph F. Frank
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Quorum Sensing and Signal Transduction in Biofilms: the Impacts of Bacterial Social Behavior on Biofilm Ecology</td>
<td>117</td>
</tr>
<tr>
<td></td>
<td>Yung-Hua Li</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Molecular Mechanisms of Microbial Survival in Foods</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Francisco Diez-Gonzalez and Julie Kuruc</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Using Microbial Succession to the Processor’s Advantage: Food Fermentation and Biocontrol</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>Trevor G. Phister</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>The Interaction of Bile Salts with Pathogenic and Nonpathogenic Intestinal Bacteria</td>
<td>183</td>
</tr>
<tr>
<td></td>
<td>Robert W. Crawford and John S. Gunn</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>The Influence of Helminths on Immunological Diseases</td>
<td>201</td>
</tr>
<tr>
<td></td>
<td>Joel V. Weinstock and David M. Elliott</td>
<td></td>
</tr>
<tr>
<td>III.</td>
<td>ANTIBIOTIC RESISTANCE</td>
<td>211</td>
</tr>
<tr>
<td>12</td>
<td>The Evolution of Antibiotic-Resistant Microbes in Foods and Host Ecosystems</td>
<td>213</td>
</tr>
<tr>
<td></td>
<td>Marilyn C. Roberts</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Antimicrobial Resistance in Food-Borne Pathogens</td>
<td>231</td>
</tr>
<tr>
<td></td>
<td>David G. White and Patrick F. McDermott</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Commensal Bacteria, Microbial Ecosystems, and Horizontal Gene Transmission: Adjusting Our Focus for Strategic Breakthroughs against Antibiotic Resistance</td>
<td>267</td>
</tr>
<tr>
<td></td>
<td>Hua H. Wang</td>
<td></td>
</tr>
<tr>
<td>IV.</td>
<td>MODEL ORGANISMS</td>
<td>283</td>
</tr>
<tr>
<td>15</td>
<td>Antibiotic Resistance and Fitness of Enteric Pathogens</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td>Qijing Zhang and Dan I. Andersson</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Staphylococcus aureus: the “Superbug”</td>
<td>297</td>
</tr>
<tr>
<td></td>
<td>Michael Otto</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Mycobacterium avium subsp. paratuberculosis: an Unconventional Pathogen?</td>
<td>311</td>
</tr>
<tr>
<td></td>
<td>Srinand Sreevatsan, Natalia Cernichiaro, and Radhey Kaushik</td>
<td></td>
</tr>
<tr>
<td>V.</td>
<td>EMERGING TOOLS AND ISSUES</td>
<td>323</td>
</tr>
<tr>
<td>18</td>
<td>Molecular Methods To Study Complex Microbial Communities</td>
<td>325</td>
</tr>
<tr>
<td></td>
<td>Dionysios A. Antonopoulos, Jennifer M. Brulc, Anthony Yannarell, and Bryan A. White</td>
<td></td>
</tr>
</tbody>
</table>
   Jan-Ulrich Kreft

Index / 379
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PREFACE

Food microbiology has historically focused on the study of pathogens or toxin producers causing acute (and sometimes chronic) diseases, spoilage agents affecting food quality, and starter cultures essential for food fermentation or used as probiotics with potential human or animal health benefits. However, it has become increasingly apparent that the same organisms that have been so widely studied actually account for only a small proportion of the microflora associated with foods. In fact, recent evidence from molecular studies shows that microbial populations are more diverse than previously thought, with many microbes actually nonculturable. Furthermore, the interactions between these microbes are complex, multifaceted, and poorly characterized. Clearly, diverse microbial species within the environment, foods, and the host interact with one another in ways that are only beginning to be elucidated.

In recent years, with the assistance of the tools of high-throughput molecular biology and population genetics, the focus of microbiological research has been extended from single cells to complex microbial ecosystems, particularly those associated with the host. It is now recognized that many diseases result from polymicrobial interactions and that the microbial compositions of these ecosystems have direct impacts on the overall health of the host. In addition to the contribution of pathogenic organisms, the contribution of commensal organisms to ecosystem development, disease progression, and the development of resistance to antimicrobial agents is becoming increasingly recognized.

Along the same line, food microbiology research is now evolving to consider complex microbial ecosystems. The study of food-borne pathogens is no longer limited to typing or detection of specific target organisms but now encompasses an understanding of the contributions of various environmental and host factors to the persistence, virulence, and evolution of food-borne bacteria. For instance, recent evidence shows the importance of microbial
interactions in biofilm formation and of the effects of the environment and the host on the stimulation of the microbial stress response and virulence gene expression. This sort of work is at the forefront of microbial ecology, and food microbiologists are part of this movement.

The composition of microbial communities in foods, be they raw, minimally, or highly processed, provides a fertile area for the study of the complexity of environmental ecosystems. It has been understood for decades that many microorganisms are not completely eliminated by using common food processing measures and that injured organisms surviving a process can recover, particularly in the absence of a competitive microflora. Such survivors may harbor stress survival determinants that also facilitate their survival in the presence of host defenses such as low gastrointestinal pH. Furthermore, various food ingredients (such as probiotics, preservatives, antibiotic residues, and homologues of host factors) may also affect, either directly or indirectly, the evolution of host ecosystems by interfering with attachment or integration of microbes to host tissues or detachment of microbes from host tissues or by stimulating host responses. Thus, while an increased understanding of oral and gastrointestinal ecosystems is essential for future disease treatment, understanding of microbial ecosystems within the context of their interactions in foods and with the host ecosystem will be important in food processing and preservation as well as disease prevention.

However, our current understanding of the contributions of food-borne microorganisms to human health and microbial interactions within various microbial ecosystems (the environment, foods, and the host) is quite limited. For example, although it is generally recognized that antibiotic treatments and probiotics can modulate the host ecosystem, there is a lack of knowledge about the overall contribution and significance of food and food-borne microfloras in host ecosystem evolution. Indeed, humans can easily consume $10^{10}$ CFU of microorganisms daily, with up to $10^6$ CFU harboring some sort of antibiotic resistance. The vast majority of these organisms are commensal rather than pathogenic in nature. Clearly, they have ample opportunity to shape the host ecosystem by interacting with other host microfloras by using mechanisms such as signal exchange or horizontal gene transfer or by becoming a part of the host ecosystems. The mechanisms of such interactions are, however, largely unknown.

The purpose of this book is to begin the dialogue between food, environmental, and medical microbiologists as they seek to understand microbial communities and their interactions within and between different environments. In this way, we can better understand the significance of food-borne microbes in the universe of the microbiology. The book is organized into five sections. Section I serves to introduce major microbial ecosystems associated with hosts, foods, and the natural environment and to discuss microbial interactions within the context of each ecosystem. Section II describes various manifestations of and mechanisms for microbial interaction, including biofilm formation, stress response, competitive inhibition, and the unique interactions that occur between the host and the microbial community. In section III, we use antibiotic resistance, a very complicated but hotly debated issue, as an example to illustrate the potential interactions between food, environmental,
and host microbial systems and their potential impact on public health. Section IV focuses on several notable food-borne bacteria as models to demonstrate some of the concepts described in the previous chapters. Section V, the final section, introduces emerging tools which can be used in the further study and characterization of microbial ecosystems.

This book is intended to serve as a comprehensive reference for the general microbiology community, and it may be of particular interest to food and industrial microbiologists and those engaged in microbial ecology research. This includes scientists in industry, university researchers, and those affiliated with regulatory agencies. The book also provides a solid reference for microbiologists without a food microbiology background, providing them a quick primer to understand some of the emerging topics in the field, with particular emphasis on the complexity of microbial ecosystems associated with foods, the environment, and the host and the interactions between these communities. For food microbiologists without a microbial ecology background, this book provides an introduction to key concepts, mechanisms, and tools used in microbial ecology and medical microbiology research, as well as an opportunity to understand the importance of food and food-borne microfloras to public health. We hope that this book will stimulate discussion, brainstorming, and collaboration between food, veterinary, and medical microbiologists and their colleagues. To our knowledge, this is the first comprehensive attempt to emphasize the central position of food and food-borne microbes in host ecosystem development by connecting the complexity of the ecosystems from environment to the host, bridged by the food carrier. We believe that a comprehensive and integrated knowledge of microbial ecology as it relates to food microbiology, the environment, and the host is vital for developing practical approaches for establishing healthy host ecosystems.

Within days of the submission of this book for production, Dr. James Jay, professor emeritus of food microbiology and a senior contributor, passed away. We are humbled by his contributions to the field, and we recognize that his work serves as the foundation upon which many future discoveries in food microbiology and microbial ecology will be based. We dedicate this work to his memory. Jim, you will be missed.

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HUAN H. WANG
LARRY S. SCHLESINGER
<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthamoeba castellanii</td>
<td>316</td>
</tr>
<tr>
<td>Acanthamoeba polyphaga</td>
<td>316</td>
</tr>
<tr>
<td>Accessory gene regulator (agr) of Staphylococcus aureus</td>
<td>125, 304–305</td>
</tr>
<tr>
<td>Acetobacter aceti, fermentation by</td>
<td>162</td>
</tr>
<tr>
<td>Acid resistance (AR)</td>
<td>141–144</td>
</tr>
<tr>
<td>Acid stress</td>
<td>141–144</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>142–143</td>
</tr>
<tr>
<td>Listeria monocytogenes</td>
<td>143</td>
</tr>
<tr>
<td>Salmonella</td>
<td>143–144</td>
</tr>
<tr>
<td>Acid tolerance response (ATR)</td>
<td>141–144</td>
</tr>
<tr>
<td>Acinetobacter</td>
<td>87</td>
</tr>
<tr>
<td>as indicator of antibiotic resistance in water environments</td>
<td>87</td>
</tr>
<tr>
<td>multidrug-resistant</td>
<td>221</td>
</tr>
<tr>
<td>in red meat</td>
<td>49–50</td>
</tr>
<tr>
<td>AcrAB efflux pump</td>
<td>187–188</td>
</tr>
<tr>
<td>Actinomyces naeslundii</td>
<td>5, 7</td>
</tr>
<tr>
<td>biofilm</td>
<td>126</td>
</tr>
<tr>
<td>Actinonin</td>
<td>287, 288</td>
</tr>
<tr>
<td>Adhesins</td>
<td></td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>189</td>
</tr>
<tr>
<td>of oral microbes</td>
<td>5, 6, 13</td>
</tr>
<tr>
<td>Aeromonas hydrophila</td>
<td>223</td>
</tr>
<tr>
<td>Aeromonas salmonicida</td>
<td>224</td>
</tr>
<tr>
<td>AFLP (amplified fragment length polymorphism)</td>
<td>327</td>
</tr>
<tr>
<td>Agar plates, competition of colonies on</td>
<td>361–363</td>
</tr>
<tr>
<td>agr (accessory gene regulator) of Staphylococcus aureus</td>
<td>125, 304–305</td>
</tr>
<tr>
<td>AHL (N-acyl-homoserine lactones)</td>
<td></td>
</tr>
<tr>
<td>as quorum sensing signal</td>
<td>120–121, 123–124, 126, 129</td>
</tr>
<tr>
<td>AIP (autoinducing peptide)</td>
<td>121–122, 125</td>
</tr>
<tr>
<td>Alcoholic fermentation</td>
<td></td>
</tr>
<tr>
<td>beer, 169–171</td>
<td></td>
</tr>
<tr>
<td>wine, 166–169</td>
<td></td>
</tr>
<tr>
<td>Alginate</td>
<td>97</td>
</tr>
<tr>
<td>Allergies</td>
<td></td>
</tr>
<tr>
<td>probiotics and</td>
<td>67–70</td>
</tr>
<tr>
<td>protection against allergic sensitization by helminth infection, 204</td>
<td></td>
</tr>
<tr>
<td>Allochthonous bacteria, in the bowel</td>
<td>66</td>
</tr>
<tr>
<td>Altruism</td>
<td>128, 366–368</td>
</tr>
<tr>
<td>Amplified fragment length polymorphism (AFLP)</td>
<td>327</td>
</tr>
<tr>
<td>Amplified rDNA restriction analysis (ARDRA)</td>
<td>327</td>
</tr>
<tr>
<td>Animal-biofilm relationships</td>
<td>95</td>
</tr>
<tr>
<td>Animals, transmission of antibiotic-resistant bacteria</td>
<td>276</td>
</tr>
<tr>
<td>Antibiotic residues in foods</td>
<td>216</td>
</tr>
<tr>
<td>Antibiotic resistance</td>
<td></td>
</tr>
<tr>
<td>in biofilms</td>
<td>109–110, 118–119, 130</td>
</tr>
<tr>
<td>in Campylobacter</td>
<td>236, 237, 252, 287, 292–293</td>
</tr>
<tr>
<td>control strategies, potential breakthroughs in,</td>
<td>276–277</td>
</tr>
<tr>
<td>destabilization of resistance traits</td>
<td>277</td>
</tr>
<tr>
<td>interruption of spread</td>
<td>276–277</td>
</tr>
<tr>
<td>monitoring system</td>
<td>276</td>
</tr>
<tr>
<td>novel antibiotic delivery strategies</td>
<td>277</td>
</tr>
<tr>
<td>dissemination, key factors in</td>
<td>273–275</td>
</tr>
<tr>
<td>hosts</td>
<td>275</td>
</tr>
<tr>
<td>probiotics</td>
<td>274–275</td>
</tr>
<tr>
<td>type of organism</td>
<td>273–274</td>
</tr>
<tr>
<td>dissemination to humans, pathways of</td>
<td>275–276</td>
</tr>
<tr>
<td>animal contacts</td>
<td>276</td>
</tr>
<tr>
<td>clinical environment</td>
<td>275</td>
</tr>
<tr>
<td>food chain</td>
<td>275</td>
</tr>
<tr>
<td>DNA from antibiotic producers</td>
<td>216–217</td>
</tr>
<tr>
<td>in Enterococcus</td>
<td>214–215, 222–223</td>
</tr>
<tr>
<td>evolution of resistance</td>
<td>213–225</td>
</tr>
</tbody>
</table>
Antibiotic resistance (continued)
evolution to restore fitness, 289–291
compensatory mutations, 290–291
environmental influence, 291
gene amplification, 291
plasmid-host coevolution, 289–290
fitness of enteric pathogens and, 285–293
changes associated with antimicrobial resistance, 286–288
DNA supercoiling alteration, 289
evolution to restore fitness, 289
global regulation change, 288–289
mechanisms associated with fitness changes, 288–289
overview, 285–286
protein synthesis reduction, 288
in food animal bacteria, 214–215
in food-borne pathogens, 231–254
burden of illness associated with, 251–252
Campylobacter, 236, 237, 252
dissemination of resistance, 231–233, 234–238
Escherichia coli, 232, 234, 236–238, 241–246
monitoring resistance in food-borne bacteria, 238–241
risk assessment and management strategies, 253–254
gene stabilization mechanisms, 271–273
chromosomal integration, 272
cross-selection, 272
fitness selection independent of drug usage, 272–273
toxin-antitoxin plasmid “addictive” maintenance, 273
history of, 213–214
horizontal gene transfer and commensal bacteria, 270–271
mechanisms of resistance, 207–209
acquisition of new genes, 219–222
chimeric (mosaic) genes, 217–218, 219
efflux pumps, 219, 236, 288
mobile elements and, 218, 219–222
mutations, 217, 218–219, 287–288
overview, 217–218
transformation, 217–218
methods of acquisition, 286–288
mobile genetic elements and, 219–222, 286–287
integrins, 221–222
plasmids, 219, 220–221, 286–287
transposons, 220, 221, 286–287
of oral microflora, 14
persistence in absence of selection pressure, 277, 292–293
in plant bacteria, 215–216
plasmids, 219, 220–221, 286–287
in probiotic bacteria, 217
in Staphylococcus aureus, 303
transposons, 220, 221, 286–287
in water environment, 86–88, 89
withdrawal of antibiotics, effect of, 287, 291–293
Antibiotics
discovery and early use, 213
growth promoters, 214, 222–223, 233, 292
novel delivery systems for, 277
use in food animals, 214–215, 233–234, 235
use in plants, 215–216
withdrawal, effect on resistance, 287, 291–293
Antimicrobial peptides, Staphylococcus aureus and, 300–301
Antimicrobial resistance. See Antibiotic resistance
aps locus, staphylococcal, 300
Aquaculture
antibiotic use in, 215
tetracycline resistance genes in, 215, 223–224
Aquatic environments, microbial diversity in, 83–84
ARDRA (amplified rDNA restriction analysis), 327
Arginine-dependent system, stress response, 142
ARISA (automated RISA), 327
Atherosclerosis, role of periodontal pathogens in, 11–12
Atopic dermatitis (atopic eczema), probiotic prophylaxis of, 68
Aureobasidium pullulans, 167
Autochthonous bacteria, in the bowel, 66
Autoinducer. See also Quorum sensing
description, 98–99, 119
mathematical modeling of production and diffusion, 372
in oral biofilms, 7
Autoinducer 2 (AI-2), as quorum sensing signal, 120, 122, 126–127
Autoinducing peptide (AIP), 121–122, 125
Autointoxication, 64
Automated RISA (ARISA), 327
Available moisture (a w), effect on microbial growth, 46–47
Avoparcin, 216, 222–223
Bacillus
biofilms, 100
heat stress response, 149
Bacteremias, of oral origin, 11
Bacterial artificial chromosome, 336
Bacteriocins
of Lactobacillus sanfranciscensis, 173
nisin, 271
in oral cavity, 8, 9
quorum sensing and, 124, 125, 128
Bacteriophage, role in microbial succession of sauerkraut fermentation, 174
Bacteroides
B. thetaiotaomicron, 29
colonization of infant GI tract, 21, 23–24
Bap (biofilm-associated protein), 96, 98

Beef

*Escherichia coli* O157:H7 on, 54–55
microbial progression in, 49–50

Beer, 169–171

*bet* regulon, 146

β-lactamases, 219, 286

Bifidobacteria

effect of oligosaccharides on, 23–24
in human milk, 23

*Bifidobacterium*

colonization of infants, 67–68
genome analysis, 29–30
immune system effects, 68
probiotics, 64

Bile, 183–195

coujugation of bile acids, 184
constituents of, 183–184
effect on pathogenic microbes
bile sensing, 185, 187

*Campylobacter*, 189–190

*Escherichia coli*, 188–189

*Helicobacter*, 192–193

*Listeria*, 185, 193–194

*Salmonella*, 185, 187–188

*Shigella*, 189

*Vibrio*, 190–192

viruses, 194–195

efflux pumps

*Campylobacter*, 190

*Escherichia coli*, 188–189

*Salmonella*, 187–188

*Vibrio*, 191

normal flora and, 184–185
storage in gallbladder, 184

Bile salt hydrolases (BSHs), 185, 193

Biofilms, 95–110

advantages to microorganisms, 95
antibiotic resistance, 109–110, 118–119, 130
architectural features, 269

benefits to animal or plant host, 95
bile response

*Salmonella*, 188

*Vibrio*, 191–192
dental, 128

development, 96–99

cell dispersion from biofilm, 99
initiation of formation, 96–97
structure development, 97–99
ecosystem, 100–102
food processing environment, 101–102
microbial interactions, 100–101
on edible plants, 106–107
in fluid handling systems, 107–109
on food processing surfaces, 95–96, 100–102, 107–109
horizontal gene transfer, 269–270

infections, 118–119, 129–130
mathematical models and
diffusion, 363–364
evolution of social behavior, 366–370
extracellular polymeric substances (EPS), 370
individual variability as insurance mechanism, 365
individual-based models (IBMs), 364–366
modeling approaches, diversity of, 364–365
ubiquity, 360

matrix, 99–100
microbial ecosystem development, 268–269
*Mycobacterium avium* subsp. *paratuberculosis* in, 317
quorum sensing, 117–130

AHL-based, 123–124
AI-2-mediated, 126
signal molecule functioning mechanism, 126–127
signal peptide-mediated, 124–125

*Staphylococcus aureus*, 299

strain variation, 102–105
water system, 105–106

Bioluminescence, 119, 122

Bistable growth, 352

*bla* gene in water environments, 87

Bleomycin resistance, 287, 289

*Botox*, 167

Bowel microbial community

blueprint of healthy, 71–73
metabolomics, 73
metagenomics, 72

Bread fermentation, 171–173

Breast-feeding, impact on neonatal intestinal microbiome, 21, 23–24

*Brochothrix* spp., 50

Brownian motion, 363

BSHs (bile salt hydrolases), 185, 193

Butyrate, 33

Cabbage, fermentation of, 173–174

*Campylobacter*

antibiotic resistance, 236, 237, 252, 287, 289, 292–293
bile, response to, 189–190
in biofilms, 101, 102
in retail meats, 239–240

CA-MRSA (community-associated methicillin-resistant *Staphylococcus aureus*), 297

Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS), 238–239

*Candida*

on grapes, 167–168
microbial interference, 55–56
in sourdough fermentations, 172

Canonical correspondence analysis, 335

Capsule, *Staphylococcus aureus*, 299–300
Carbon dioxide
   in beer fermentation, 169
   food packaging, 48
   leavened bread, 171
CARD15 gene, 202–203
Cardiovascular disease, periodontal pathogens as risk factors, 11–12
Carnivores, structure of GI tract, 20
Camobacterium, antibiotic resistance genes, 274, 275
c-di-GMP, 103
Cell dispersion from biofilms, 99
Cell-cell communication. See Quorum sensing
Cellular automata, 361–363
Cephalosporin resistance, in Escherichia coli, 244–245
Cetylpyridinium chloride (CPC), 236
Cheaters, 366, 369–370, 372, 373
Cheese manufacture, biofilm formation, 108
Chemostat
   basic model, 348–349
   competitive exclusion principle, 353–355
   continuous-flow stirred-tank reactors (CSTRs), 360–361
description, 65
dynamics, 352–353
evolution of cross-feeding, 355–357
Freter model, 358–359
growth dependence on substrate concentration, 349
human large bowel as, 65
invention of, 347
kinetic theory of optimal pathway length, 355–357
minimal structured model, 351
mixed-substrate growth, 349, 351–352
Monod curve/function, 349, 350
as nonspatial control, 347–353
plug flow reactors (PFRs), 360–361
schematic drawing, 348
wall growth, 357–360
Chenodeoxycholic acid. See Bile
Chimeric (mosaic) genes, 217–218, 219
Chlamydia suis, antibiotic resistance in, 224
Cholera toxin, 191
Cholesterol, bile synthesis from, 184
Cholic acid. See Bile
Chromosomal integration, of antibiotic resistance genes, 272
CIPARS (Canadian Integrated Program for Antimicrobial Resistance Surveillance), 238–239
Clostridium botulinum, 46, 47, 56
Clumping protein CluA, 269
Clusters of orthologous groups (COGs), 30, 31
CmeABC efflux pump, 190
Cold shock proteins, 151–152
Colitis, protection from by helminth infection, 204, 205
Colonization, by Staphylococcus aureus, 297–299
Colonization resistance, wall growth and, 357–360
Combinatorial model of host-microbe association, 20
ComCDE quorum sensing mechanism, 124–125
Community fingerprinting, 327–331
   amplified fragment length polymorphism (AFLP), 327, 329
   amplified rDNA restriction analysis (ARDRA), 327, 328
   automated RISA (ARISA), 327–328
denaturing gradient gel electrophoresis (DGGE), 327, 330
   random amplified polymorphic DNA (RAPD), 327, 329–330
   ribosomal intergenic spacer analysis (RISA), 327
temperature gradient gel electrophoresis (TGGE), 327, 330
terminal restriction fragment length polymorphism (T-RFLP), 327–328
Community studies, molecular methods for, 325–337
Community-associated methicillin-resistant Staphylococcus aureus (CA-MRSA), 297, 303–304
Companion animals
   antibiotic use in, 234
   transmission of antibiotic-resistant bacteria by, 276
Competence-stimulating peptide (CSP), 124
Competition
   chemostat, 353–355
   colonies on agar plates, 361–363
   competitive exclusion, 52, 353–355
   Complement cascade, inhibition by Staphylococcus aureus, 301–302
Conjugation, role in biofilm formation, 269
Continuous-flow stirred-tank reactors (CSTRs), 360–361
CPC (cetylpyridinium chloride), 236
Crohn’s disease
   environmental factors, 203
   genetic influences, 202–203
   hygiene hypothesis, 203
   Mycobacterium avium subsp. paratuberculosis, 311, 313
probiotics and, 70
response to helminths, 204
Cross-feeding, evolution of, 355–357
Cryptosporidium parvum, oocysts in biofilms, 102
CSP (competence-stimulating peptide), 124
CSTRs (continuous-flow stirred-tank reactors), 360–361
Curli, 96–97, 103
Cyclic di-GMP (c-di-GMP), 98, 99
Cytokines
   effect of oral microbiota on, 9
   helminth infections and, 201, 202, 204–206
Dairy fermentations, 174–176
Danish Integrated Antimicrobial Resistance Monitoring and Research Program (DANMAP), 238, 245, 250–251
Degradative exoenzymes, of *Staphylococcus aureus*, 303
Denaturing gradient gel electrophoresis (DGGE), 21, 327, 330
Dental biofilms, 128
Dental caries, dietary factors and, 8, 10
Dental implants, infection of, 9–10
Deoxycholate. See Bile
Dermicidin, 300
Diauxic growth, 352
Diet, effect on oral microbial communities, 10–11
Diffusion, biofilms and, 363–364
Diffusion sensing, 127
Diversity. See Microbial diversity
DNA, exogenous in biofilms, 100
DNA damage, global stress response to, 136
DNA gyrase genes, mutations in, 218, 287, 289
DNA microarray, 29, 333, 337
DNA supercoiling, alteration with antibiotic resistance, 289
Dot blot hybridization, 333
Drinking water, microbial diversity in, 84–85
Efflux pumps
AcrAB, 187–188
antibiotic resistance, 219, 236, 288
bile tolerance
*Campylobacter*, 190
*Escherichia coli*, 188–189
*Salmonella*, 187–188
*Vibrio*, 191
CmeABC, 190
E$_h$ (oxidation-reduction potential), effect on microbial growth, 47
EHEC (enterohemorrhagic *Escherichia coli*), 241, 242
Embden–Meyerhof-Parnas (EMP) pathway, 162, 163
Endocarditis, infective, 11
Enrofloxacin resistance, 292
*Enterobacter asburiae*, 54
*Enterococcus*
antiobiotic resistance, 214–215, 222–223
bile, response to, 185
in retail meats, 239–240
in root canal microflora, 10
Enterohemorrhagic *Escherichia coli* (EHEC), 241, 242
Enterohepatic circulation, 184
Enteropathogenic *Escherichia coli* (EPEC), 189, 242
Enterotoxins, staphylococcal, 303–305
EPEC (enteropathogenic *Escherichia coli*), 189, 242
EPS (extracellular polymeric substances), in biofilms, 370
*Environia* spp., 57, 215
*Escherichia coli*
bile, response to, 188–189
biofilm formation, 96–97
classes of pathogenic, 242
colonization of infant GI tract, 21
enterohemorrhagic *Escherichia coli* (EHEC), 241, 242
enteropathogenic *Escherichia coli* (EPEC), 189, 242
extraintestinal pathogenic *Escherichia coli* (ExPEC), 242
O157:H7
in biofilms, 103, 106, 109
description, 241–242, 246
microbial interference, 54–55
plasmids, 286–287, 289–290
as probiotic, 70
in retail meats, 239–240, 242–246
serotyping, 241
stress response, 137–139, 142–143, 145–146, 150–154
verocytotoxigenic *Escherichia coli* (VTEC), 242
Essential oils, antimicrobial effects of, 47
Ethanol, production by fermentation, 166–171
Evolution
of antibiotic resistance to restore fitness, 289–291
cross-feeding, 355–357
social behavior in biofilms, 366–370
Exfoliative toxins, *Staphylococcus aureus*, 302
Extracellular polymeric substances (EPS), in biofilms, 370
Extraintestinal pathogenic *Escherichia coli* (ExPEC), 242
FAO (Food and Agriculture Organization), 238
Farnesol, 168
Fatty acids, absorption from bowel, 65
Feces
concentration of bacteria in, 65
microbial genera and species isolated from human, 26–28
Fermentation, 161–177
alcoholic, 166–171
beer, 169–171
wine, 166–169
bread and sourdough, 171–173
dairy, 174–176
Embden–Meyerhof–Parnas (EMP) pathway, 162, 163
general principles, 162–166
history of use, 161
malolactic, 169
phosphoketolase pathway, 164
processors’ tools for controlling, 165
propionic acid pathway, 176
starter culture, 162, 170–171, 175
vegetable, 173–174
Fibronectin
Mycobacterium avium subsp. paratuberculosis, opsonization of, 314–315

Fick’s laws of diffusion, 363

Fingerprinting
community, 327–331
amplified fragment length polymorphism (AFLP), 327, 329
amplified rDNA restriction analysis (ARDRA), 327, 328
automated RISA (ARISA), 327–328
denaturing gradient gel electrophoresis (DGGE), 327, 330
random amplified polymorphic DNA (RAPD), 327, 329–330
ribosomal intergenic spacer analysis (RISA), 327
temperature gradient gel electrophoresis (TGGE), 327, 330
terminal restriction fragment length polymorphism (T-RFLP), 327–328
isolate, 326–327
multilocus sequence typing (MLST), 326, 327
octamer-based genome scanning (OBGS), 326, 327
pulsed-field gel electrophoresis (PFGE), 326
rep-PCR, 326–327

Flagella
bile effects on Campylobacter, 190
biofilm formation and, 96–97
Flavobacterium sp., in biofilms, 101
Fluid handling systems, biofilms in, 107–109
Fluorescence in situ hybridization (FISH), 333–334
Fluorescent oligonucleotide probes, 72
Fluoride ions in oral health, 9
Fluoroquinolone resistance, 272, 287, 289, 292
Food and Agriculture Organization (FAO), 238
Food animals
antibiotic use in, 214–215, 233–234, 235
transmission of antibiotic-resistant bacteria by, 276
Food chain, role in dissemination of antibiotic resistance genes, 275
Food fermentation. See Fermentation
Food processing, biofilms and, 95–110
Foodborne Diseases Active Surveillance Network (FoodNet), 239
FOS (fructo-oligosaccharides), 23
Fruits, microbial growth on, 56
Galerter model, 358–359
Gas presence and concentration, 48
natural coverings, 47–48
nutrient nature and state, 47
oxidation-reduction potential, 47
pH of food, 46
relative humidity of storage environment, 48
temperature of storage, 48
microbial interference, 51–58
competitive exclusion, 52
description, 51–52
Escherichia coli O157:H7, 54–55
lactic antagonism, 52
non-specific, 53–56
pathogens and spoilage microbes, 55–56
replacement therapy, 52
Staphylococcus aureus, 53–54
summary and mechanisms of, 57–58
table of mechanisms, 53
microbial progression, 49–51
poultry, 50–51
red meat, 49–50
vegetables, 51
protective-culture concept, 56–57
Freter model, 358–359
Fusidic acid resistance, 288–289, 290, 291
Fusobacterium, 12
Galacto-oligosaccharides (GOS), 23–24
Gallbladder, 183–184, 186, 188, 192, 193–194, 195
Gallstones, 184, 188, 192
Gastrointestinal tract (GIT)
gut microbiome, 19–34
bowel microbial community, 64–66
colonization and succession in neonates and infants, 20–25
functional analysis by metagenomic analysis, 25, 28–31
future research directions, 31–34
genera and species isolated from human feces, 26–28
mucosa-associated community, 64–65
numerical abundance of major bacterial groups in infants, 22
physioanatomical GI tract variations, 20
microbial colonization and succession in neonates and infants, 20–25
molecular methods to study microbial community, 325–326
physioanatomical variations and host-microbe association, 20

Fresh foods, microorganisms in, 41–58
bacterial genera, 41–44
fungal genera, 45, 46
hurdle technology concept, 57
influences on, 46–49
antimicrobial constituents, naturally occurring, 47
available moisture (a_w), 46–47
competition among members of the microbiota, 48–49
Gene amplification, 291
Genetic competence, quorum sensing and, 124–125
Genomic analysis, of gut microbiomes, 25, 28–31
Genomic diversity among Mycobacterium avium subsp. paratuberculosis strains, 312–313
Geotrichum candidum, 170
Glutamate-dependent (GAD) system, stress response, 143
GOS (galacto-oligosaccharides), 23–24
Gram-negative bacteria, heat stress response, 150–151
Gram-positive bacteria, heat-inducible genes, 149–150
Grape, fermentations and, 166–171
Groundwater, microbial diversity in, 83–84
Group selection theory, 367, 371
Growth promoters, antibiotics as, 214, 222–223, 233, 292
Guillain-Barré syndrome, 190
Gut microbiome, 19–34
bowel microbial community, 64–66
colonization and succession in neonates and infants, 20–25
functional analysis by metagenomic analysis, 25, 28–31
future research directions, 31–34
genera and species isolated from human feces, 26–28
mucosa-associated community, 64–65
numerical abundance of major bacterial groups in infants, 22
physioanatomical GI tract variations, 20
Haemophilus influenzae
ampicillin-resistant, 213
plasmids, 219, 220–221
Halitosis, 9
Halobacterium, 41
Hamilton’s classification of social behavior, 367
Hanseniaspora, 167–168
Heat shock proteins (HSPs), 148–151
Heat shock stress, 148–151
gram-negative bacteria, 150–151
gram-positive bacteria, 149–150
Helicobacter pylori, 64, 192–193
Helminths, 201–207
colonization, 202
deworming, 203
immune system and, 201–207
mechanisms of protection, 204–206
prevention and reversal of immunological disease, 204
Th2 response, 202, 203
nature of, 201–202
negative consequences of colonization, 206–207
Hepatitis B virus (HBV), 194
Hepatitis C virus (HCV), 194
Herbivores, structure of GI tract, 20
Heterofermentative lactic acid bacteria, 162, 164, 171, 172, 173–174
High-pressure processing survival, 152–154
Homoefermenting lactic acid bacteria, 162, 163, 174
Hops, 169–170
Horizontal gene transfer (HGT)
antibiotic resistance and, 218, 219–222
from environmental bacteria into Mycobacterium avium subsp. paratuberculosis, 315
microbial ecosystem development and, 269–270
role in antibiotic resistance dissemination, 271–276
roles of commensal bacteria, 270–271
HSPs (heat shock proteins), 148–151
Human immunodeficiency virus type 1 (HIV-1), 194
Human Microbiome Project, 19
Hurdle technology concept, 57
Hybridization-based technologies, 333–334
DNA microarrays, 333
dot blot hybridization, 333
fluorescence in situ hybridization (FISH), 333–334
suppressive subtractive hybridization (SSH), 333
Hydrogen transactions in the gut, 32–33
Hygiene hypothesis, 68, 203
IBD. See Inflammatory bowel disease (IBD)
IECs (immune evasion clusters), 301
Immune system
hygiene hypothesis, 68, 203
influence of helminths on immunological diseases, 201–207
oral microflora and, 9
rise of immunological diseases, 202–203
staphylococcus interactions with host, 299–303
Immunity genes, 271
Incompatibility groups, plasmid, 220, 221
Individual-based models (IbMs), 364–366
Infants
gut microbial colonization, 67–68
numerical abundance of major bacterial groups in, 22
Inflammatory bowel disease (IBD)
environmental factors, 203
geographic variations in frequency, 203
hygiene hypothesis, 203
probiotics and, 70
response to helminths, 204–206
Innate immunity
effect of helminths on, 201
evaporation by Staphylococcus aureus, 301
Integrons
antibiotic resistance, 221–222
description, 220
Interference. See Microbial interference
Interleukins, 204–206
International Human Microbiome Consortium, 19
Invasion gene regulators, 188
Ionophore antimicrobials, 237
Iron sequestration, *Staphylococcus aureus*, 301
Isolate fingerprinting, 326–327
multilocus sequence typing (MLST), 326, 327
octamer-based genome scanning (OBGS), 326, 327
pulsed-field gel electrophoresis (PFGE), 326
rep-PCR, 326–327
Iterated prisoner’s dilemma, 370–371
Johne’s disease, economic impact of, 311
Kin selection theory, 367
Kinetic theory of optimal pathway length, 355–357
*Klebsiella pneumoniae* biofilms, 100
Koch, Robert, 117
Lactate, 33
Lactic acid bacteria (LAB), in fermentations, 162–164, 170–173, 175
*Lactobacillus*
  antibiotic resistance, 217
  colonization of infant GI tract, 21, 23–24
  genome analysis, 30
  probiotics, 64
  sourdough fermentations, 171–173
*Lactobacillus acidophilus*, antibiotic resistance in, 274
*Lactobacillus curvatus*, in biofilms, 108
*Lactobacillus helveticus*, 174–176
*Lactobacillus johnsonii*, 23
*Lactobacillus plantarum*
  in malting starter culture, 170–171
  in vegetable fermentations, 173, 174
*Lactobacillus reuteri*, 330
*Lactobacillus rhamnosus*, effect on atopic eczema / dermatitis, 68–70
*Lactobacillus sakei*
  biofilms, 102
  on ground beef, 54
*Lactobacillus sanfranciscensis*, 171–173
*Lactococcus lactis*
  in biofilms, 102
  in cheese, 162, 166, 175
  effect on *Listeria* biofilms, 102
  horizontal gene transfer, 269, 270
  nisin production, 271
  Opp gene cluster, 272–273
Lamb carcasses, microbial groups in, 50
las system, in *Pseudomonas*, 123
Lateral gene transfer. See Horizontal gene transfer
Leuconostoc
  on fresh vegetables, 51
  *L. mesenteroides*, 162, 173–174
Leukocidin, 302
LIBSHUFF, 335
Liebig’s law of the minimum, 353
Linear stability analysis, 352
Lipopolysaccharide (LPS)
  cell protection from bile acids, 187
  inflammation and, 205
*Listeria monocytogenes*
  acid stress response, 143
  bile, response to, 185, 193–194
  biofilms, 101–104, 108
  contamination of ready-to-eat foods, 108
  high-pressure stress, 152–154
  inhibition by bacteriocin, 271
  microbial interference, 55, 56–57
  osmotic stress response, 147
  phase variants of, 103
Lithocholate. See Bile
Lotka–Volterra model for competition of species, 351
Low-temperature stress, 151–152
LPS. See Lipopolysaccharide (LPS)
Luciferase, 119
LuxI / LuxR-type quorum sensing, 120
LuxS, 7
Lysine-dependent system, stress response, 142–143
Macrophages, pathogenesis of Johne’s disease and, 313–314
Malolactic fermentation, 169
Malting, 169–170
Manure, *Mycobacterium avium* subsp. *paratuberculosis* in, 317
MAP (modified-atmosphere packaging), 48
Marine water, microbial diversity of, 84
Mathematical models of microbial ecology, 347–373
biofilms
diffusion, 363–364
evolution of social behavior, 366–370
extracellular polymeric substances (EPS), 370
individual variability as insurance mechanism, 365
individual-based models (IbMs), 364–366
modeling approaches, diversity of, 364–365
ubiquity, 360
cellular automata, 361–363
chemostat
basic model, 348–349
competitive exclusion principle, 353–355
dynamics, 352–353
evolution of cross-feeding, 355–357
growth dependence on substrate concentration, 349
kinetic theory of optimal pathway length, 355–357
minimal structured model, 351
mixed-substrate growth, 349, 351–352
Monod curve/function, 349, 350
  as nonspatial control, 347–353
  schematic drawing, 348
  colonization resistance and wall growth, 357–360
  competition of colonies on agar plates, 361–363
  Freter model, 357–360
  mutualism, 370–372
  quorum sensing, 372–373
mazEF system, 273
Mesophiles, 48
Metabolomics, of bowel microbial community, 73
Metagenomics
  bowel community, 72
  of gut microbiomes, 25, 28–31
  libraries, construction of, 336
MetaHIT, 19
Metchnikoff, Elie, 63–64
Methicillin-resistant Staphylococcus aureus (MRSA), 232, 297, 303–304
Metschnikowia, 167–168
Microarrays, DNA, 29, 333, 337
Microbial bowel community
  autochthony and allochthony, 66
  description, 64–66
  human bowel as a chemostat, 65
Microbial diversity
  in aquatic ecosystems, 83–84
  in drinking water and water distribution systems, 84–85
  gut microbiome, 19–34
  oral cavity, 4–5
  in wastewater, 85–86
  in water environments, 83–89
Microbial ecosystem development
  description, 268–269
  horizontal gene transfer, 269–270
Microbial interference, 51–58
  competitive exclusion, 52
  description, 51–52
  Escherichia coli O157:H7, 54–55
  lactic antagonism, 52
  nonspecific, 53–56
  pathogens and spoilage microbes, 55–56
  replacement therapy, 52
  Staphylococcus aureus, 53–54
  summary and mechanisms of, 57–58
  table of mechanisms, 53
Microbial survival in foods, molecular mechanisms of, 135–154
Micropollutants, 85
Milk
  antimicrobial compounds in, 47
  bioactive compounds in humans, 23
  breast-feeding effects on neonatal intestinal microbiome, 21, 23–24
  components of cow’s, 174
  dairy product fermentations, 174–176
MLST (multilocus sequence typing), 326, 327
Mobile elements, antibiotic resistance and, 218, 219–222, 286–287
Modified-atmosphere packaging (MAP), 48
Molds, genera in fresh foods, 45–46
Molecular methods for community studies, 325–337
  community fingerprinting, 327–331
    amplified fragment length polymorphism (AFLP), 327, 329
    amplified rDNA restriction analysis (ARDRA), 327, 328
    automated RISA (ARISA), 327–328
    denaturing gradient gel electrophoresis (DGGE), 327, 330
    random amplified polymorphic DNA (RAPD), 327, 329–330
    ribosomal intergenic spacer analysis (RISA), 327
    temperature gradient gel electrophoresis (TGGE), 327, 330
    terminal restriction fragment length polymorphism (T-RFLP), 327–328
    emerging techniques, 336–337
    hybridization-based technologies, 333–334
    DNA microarrays, 333
    dot blot hybridization, 333
    fluorescence in situ hybridization (FISH), 333–334
    suppressive subtractive hybridization (SSH), 333
    isolate fingerprinting, 326–327
    multilocus sequence typing (MLST), 326, 327
    octamer-based genome scanning (OBGS), 326, 327
    pulsed-field gel electrophoresis (PFGE), 326
    rep-PCR, 326–327
    numerical analysis of molecular data, 334–336
    overview, 325–326
    SSU rRNA gene sequencing, 331–333
Monod curve, 349, 350
Moore neighborhood, 362–363
Mosaic genes, 217–218, 219–222
Mouse, as research model for gut microbiota, 32
MRSA (methicillin-resistant Staphylococcus aureus), 232, 297, 303–304
MSCRAMMs (microbial surface components recognizing adhesive matrix molecules), 298
Multilocus sequence typing (MLST), 326, 327
Multiple sclerosis, Trichinella trichiura and, 204
Mutations, antibiotic resistance and, 217, 218–219, 287–288
Mutualism, 370–372
Mycobacterium avium complex, 311
Mycobacterium avium subsp. paratuberculosis, 311–317
  environment and, 315–316
  genetic diversity, 312–313
  human exposure, potential sources for, 316–317
  Johnne’s disease
**INDEX**

*Mycobacterium avium* subsp. *paratuberculosis* (continued)
- pathogenesis, 313–314
- role of intestinal epithelial cells, 314–315
- microbiology of, 312

*Mycobacterium tuberculosis* complex, 312

*Myxococcus xanthus*, 128

N-acyl-homoserine lactones (AHL), as quorum sensing signal, 120–121, 123–124, 126, 129

National Antimicrobial Resistance Monitoring System (NARMS), 236, 238–241, 243–244, 249–250, 276

Natural coverings of foods, as barrier to bacterial entry, 47–48

*Neisseria*
- *N. gonorrhoeae*
  - penicillin-resistant, 213
  - plasmids, 219, 220
  - transformation in, 217–218, 219

Nematodes, carriage of *Mycobacterium avium* subsp. *paratuberculosis* in, 316–317

Neonates, microbial colonization and succession of the lower GI tract, 20–25

*Nisin*, 271

*Nitrification*, 356

*NOD2* (*CARD15*) gene, 202–203

*NORM-VET*, 238, 243

*Nourseothricin*, resistance to, 234, 236

Octamer-based genome scanning (OBGS), 326, 327

*Oenococcus oeni*, 169

*Ohr* (organic hydroperoxide resistance) proteins, 148

*OIE* (World Organization for Animal Health), 238

Oligopeptide–two-component-type quorum sensing, 120, 121–122, 124–125

Oligosaccharides, in human milk, 23–24

*OmpR/EnvZ* regulatory system, 146

Operational taxonomic unit (OTU), 331–332, 334–335

*Opp* gene cluster, 272–273

Optimal pathway length, 355–357

Oral cavity, 3–14

- antibiotic resistance in oral bacteria, 14
- biofilms
  - accumulation of communities, 5–7
  - healthy biofilms, 8
  - host influences on, 8
  - initial attachment to surfaces, 5
  - interbacterial interactions, 7–8
  - quorum sensing, 7
  - transition from health-associated to disease-associated, 8, 12–13
  - dietary effects on microbial communities, 10–11
  - microbial diversity, 4–5
  - overview, 3–4
  - protective function of oral microbes, 9–10
  - salivary pellicle, 3–5

systemic health and oral microbes, 11–12
- cardiovascular disease, 11–12
- endocarditis, 11
- preterm delivery, 12

*Organic hydroperoxide resistance* (Ohr) proteins, 148

*Orthobiosis*, 64

Osmotic stress, 144–147
  - *Escherichia coli*, 145–146
  - *Listeria monocytogenes*, 146
  - primary responses to, 145
  - *Salmonella*, 145–146
  - signals, 145
  - *Staphylococcus aureus*, 146–147

Oxidation-reduction potential (Eh), effect on microbial growth, 47

Oxidative stress, 147–148

*OxyR* regulon, 148

*Oxidative stress*, 147–148

*OxyR* regulon, 148

*Oxidative stress*, 147–148

*OxyR* regulon, 148

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170

*Pantothenic acid (PA)*, 170
description, 220
first identification of, 219, 220
host range, 220
incompatibility groups, 220, 221
toxin-antidote system, 273
Plug flow reactors (PFRs), 360–361
PolyP, 140–141
Porcine enteric calicivirus (PEC), 194–195
Porphyromonas gingivalis, 6–8, 10
Pouchitis, probiotics and, 70–71
Poultry, progression of microbes on, 50–51
ppGpp, 140, 288
Prebiotics, bifidogenic effects of, 23–24
Pressure, effects on bacteria, 152–154
Preterm delivery of low-birth-weight infants (PDLBW), 11
Prisoner’s dilemma, 370
Probiotics
allergies and, 67–70
 antibiotic resistance and, 217, 274–275
definition, 64
health claims, 67
history of, 63–64
inflammatory bowel diseases and, 70
pouchitis and, 70–71
in self-care market, 66–67
Programmed cell death, toxin-antidote system, 273
Propionibacterium freudenreichii subsp. shermanii, 174–176
Propionic acid pathway, 176
Protective-culture concept, 56
Protein A, 301
Protein synthesis, alteration with antibiotic resistance, 288
Protozoa, Mycobacterium avium subsp. paratuberculosis in, 316
Pseudomonas
biofilms, 105–106
microbial interference, 55, 56
in red meat, 49–50
Pseudomonas aeruginosa
antibiotic resistance, 219
biofilms, 96–97, 99–103, 122–124
quorum sensing, 99, 122–123
Pseudomonas fluorescens, biofilms, 101, 102, 106
PSMs (phenol-soluble modulins), 299, 304
Psychrophiles, 48
PTS (phosphotransferase system) transporters, 30
Pulsed-field gel electrophoresis (PFGE), 326
PVL (Panton-Valentine leukocidin), 302, 304
Pyrolytic toxins, Staphylococcus aureus, 302
Quinolone resistance, 218
Quorum sensing, 117–130
autoinducers, 98–99
bioluminescence, 119, 122
as central mechanism for social activities, 119–120
common themes in, 120–122
connection to biofilms, 117–118
as diffusion sensing, 127
 genetic competence and, 124–125
interference, 129–130
mathematical modeling and, 372–373
in oral biofilms, 7
in regulation of biofilm development, 122–126
AHL-based quorum sensing, 123–124
AI-2-mediated quorum sensing, 126
signal peptide-mediated quorum sensing, 124–125
signal molecule functioning mechanism in biofilms, 126–127
Staphylococcus aureus, 304–305
yeast, 168
Random amplified polymorphic DNA (RAPD), 327
Reactive oxygen species (ROS), 148
Red meat, microbial progression in, 49–50
Redundancy analysis, 335
Relative humidity of food storage environment, 48
rep-PCR, 326–327
Resistant starches, 33
Rhamnolipid, 99
rhl system, in Pseudomonas, 123
RpoS, 137–140, 142, 146, 288–289
Rsb regulon, 143
Ruminococcus bromii, 33
Saccharomyces, in fermentations, 162–163, 166–169, 171–172
Saliva
 antimicrobial compounds in, 3
 density of bacteria in, 3
Salivary pellicle, 3–5
Salmonella
bile, response to, 185, 187–188
biofilms, 106–107, 188
microbial interference, 55
on plants, 106–107
in retail meats, 239–240, 249–251
stress response, 141, 143–144, 145–146
sat-I (streptothricin acetyltransferase gene), 234
Sauerkraut fermentation, 173–174
Schistosomiasis, 206
SCIN (staphylococcal complement inhibition), 301–302
Shewanella oneidensis, 99
Shigella, response to bile, 189
Short-chain fatty acids (SCFA), 23, 33
SigB, 139, 149
α factor, 137–139
α2 regulon, 151
SIGB (continued)

α^p, 149

α^q, 137–139, 143, 146–147, 149, 193

α^K regulon, 150–151

α^K, 137–139, 142–143, 144

Signal peptide-mediated quorum sensing, 124–125, 126–127

Signaling interference, 129–130

Signaling systems, in oral cavity, 7–8

Simpson’s paradox, 367–368, 369, 371

16S rRNA gene studies

bowel communities, 65, 66
gut metagenomics, 25
microarrays, 88
microbial diversity in water environments, 83–85, 87–88

Sludge, microbial diversity in, 85

Small intestine, microbial diversity in, 28

Social behavior, 117–130

in biofilms, 117–130, 366–370
Hamilton’s classification, 367
impacts on ecology and evolution, 128–129
mutualism, 370–372
problems from, 118–119
quorum sensing, 117–130, 372–373

Sortase A, 298

SOS response system, 136–137, 153

Sourdough fermentation, 171–173

Spices, antimicrobial oils in, 47

SSH (suppressive subtractive hybridization), 333

SSU rRNA gene sequencing, 331–333

Stable isotope probing, 72

Staphylococcal complement inhibitor (SCIN), 301–302

Staphylococci, in human milk, 23

Staphylococcus aurous, 297–305

accessory gene regulator (agr), 125, 304–305
attachment to surfaces, 96
colonization, 297–298
community-associated methicillin-resistant (CA-MRSA), 297, 303–304
hospital-associated (nosocomial) infections, 297
immune system interactions with, 299–303
antimicrobial peptides, 300–301
biofilms, 299
capsule, 299–300
complement cascade inhibition, 301–302
degrative exoenzymes, 303
 evasion of host defenses, dedicated mechanisms for, 301
innate host defense, 301
iron sequestration, 301
protein A, 301
staphyloxanthin, 300
toxins, 302–303
lifestyle switches, 304–305
methicillin-resistant, 232, 276, 297, 303–304

microbial interference, 53–54, 57
mobile elements in genome, 218
in oral cavity, 10
osmotic stress response, 146–147
quorum sensing, 124, 125
vancomycin-resistant, 213, 223

Staphylococcus epidermidis

agr gene, 304
antimicrobial peptides, 300
attachment to surfaces, 97
colonization by, 297–298
hospital-associated infections, 297

Staphylococcus sciuri, 101

Staphylokinase, 302

Staphyloxanthin, 300

Starter culture, 162, 170–171, 175

Streptococcus cristaus, 8

Streptococcus gordonii, 5–7

Streptococcus mitis, 5

Streptococcus mutans

biofilms, 124–125, 126
genetic competence, 124–125
in oral health, 6, 8, 11, 12–13
quorum sensing, 124–125, 126, 270

Streptococcus oralis, 5, 7, 126

Streptococcus pneumoniae, quorum sensing and, 125

Streptococcus salivarius, 8, 9, 12–13

Streptococcus sanguinis, 5, 8, 12

Streptococcus spp.
bacteriocin production, 128
transformation in, 217–218, 219

Streptococcus thermophilius, 174–176

Streptomycin resistance, 288, 290, 291

Streptothricin acetyltransferase gene (sat-I), 234

Stress, 135–154

acid stress, 141–144

Escherichia coli, 142–143
Listeria monocytogenes, 143
Salmonella, 143–144
cross-protection, 136
description, 135–136
global stress regulators, 136–141
polyP, 140–141
ppGpp, 140
RpoS, 137–140
SigB, 139
SOS response system, 136–137
stringent response, 140
heat shock stress, 148–151
gram-negative bacteria, 150–151
gram-positive bacteria, 149–150
high-pressure processing survival, 152–154
low-temperature stress, 151–152
osmotic stress, 144–147
Escherichia coli, 145–146
Listeria monocytogenes, 146
primary responses to, 145
Salmonella, 145–146
  signals, 145
Staphylococcus aureus, 146–147
  oxidative stress, 147–148
Stringent response, 140
Substrate affinity, 349
sugE gene, 236–237
Sulfonamide resistance, 292
Suppressive subtractive hybridization (SSH), 333
Surface-bound proteins, staphylococcal, 298
Swiss cheese fermentation, 174–176

Temperature gradient gel electrophoresis (TGGE), 327, 330
Temperature of storage, effect on food microbes, 48
Terminal restriction fragment length polymorphism (T-RFLP), 327–328
tet genes
  in aquaculture environment, 223–224
  integron, 222
  plasmid, 221
  transposon, 221
  in water environments, 87
Tetracycline resistance, persistence in absence of selection pressure, 292–293
TGF-β (transforming growth factor β), 204–206
Th2 response to helminths, 202, 203
Th17 pathway, 204–205
Thermophiles, 48
Tol proteins, 188
Tongue microflora, 9
Toxic shock syndrome (TSS), 297, 302
Toxin-antidote (TA) systems, 273
Toxins, Staphylococcus aureus, 302–303
ToxR regulon, 191
Tragedy of the commons, 368
Transformation, antibiotic resistance acquisition and, 217–218
Transforming growth factor β (TGF-β), 204–206
Transgenic plants, antibiotic resistance in, 216
Transposons
  antibiotic resistance, 221, 286–287
  conjugative, 220, 221
  description, 220, 221
Treeclimber, 335
Treponema denticola, 7
T-RFLP (terminal restriction fragment length polymorphism), 327–328
Trichuris trichiura, multiple sclerosis and, 204
TSS (toxic shock syndrome), 297, 302
Two-component systems, bile sensing by, 185, 187
Type III secretion system (TTSS)
  of Salmonella, 188
  of Shigella, 189
Ulcerative colitis, probiotics and, 70
UNIFRAC, 335
Vacuum packaging, 48
Vancomycin-resistant enterococci, 222–223
Veillonella, 7
Vibrio
  bile, response to, 190–192
  biofilm, 191–192
  V. fischeri, quorum sensing in, 119
  V. harveyi, bioluminescence, 119, 122
  V. parahaemolyticus, rpoS, 140
  V. vulnificus, heat tolerance of, 140
Viruses
  bacteriophage, role in microbial succession of sauerkraut fermentation, 174
  bile, responses to, 194–195
  Volutin granules, 140
  Von Neumann neighborhood, 362
  VSL#3, 71
  VTEC (verocytotoxigenic Escherichia coli), 242
Wastewater, microbial diversity in, 85–86
Water distribution systems, microbial diversity in, 84–85
Water environments
  alterations of ecosystems by humans, 1–3
  antibiotic resistance in water environment, 86–88, 89
  microbial diversity, 83–86, 88–89
  in aquatic ecosystems, 83–84
  in drinking water and water distribution systems, 84–85
  in wastewater, 85–86
  as potential source for human exposure to Mycobacterium avium subsp. paratuberculosis, 316
  routes of human exposure to microbes, 1–2
Water system biofilms, 105–106
Wautersia paucula, 54
WHO (World Health Organization)
  Global Salmonella Surveillance (WHO-GSS), 241
  monitoring antimicrobial resistance, 238, 253–254
  Vine, 166–169
  World Organization for Animal Health (OIE), 238
Yeast. See also specific species
  fermentation, 161–163, 165–173
  genera in fresh foods, 45–46
  microbial interference, 55–56
  quorum sensing, 168