Contents

Preface to second edition xiv
Preface to first edition xvi

1 Foodborne infections and intoxications 1

1.1 Origins of safe food production 1
1.2 Foodborne illness 2
1.3 Causes of foodborne illness 7
1.4 Public perception of safe food 8
1.5 Host-related issues 15
1.6 Hygiene hypothesis 17
1.7 The size of the foodborne illness problem 17
1.8 Chronic sequelae following foodborne illness 19
1.9 Changes in antibiotic resistance 21
1.10 The cost of foodborne diseases 22
1.11 Control of foodborne pathogens 26
  1.11.1 Example 1 – the control of Salmonella serovars in poultry 26
  1.11.2 Example 2 – control of E. coli and Salmonella in fresh produce 28
1.12 Surveillance programmes 29
  1.12.1 International Food Safety Authorities Network (INFOSAN) 30
  1.12.2 FoodNet in the United States 31
  1.12.3 PulseNet: US E. coli O157:H7, Salmonella and Shigella detection network 32
  1.12.4 European Centre for Disease Prevention and Control (ECDC) and Enter-Net; European surveillance network for salmonellosis and shigatoxic E. coli (STEC) 32
  1.12.5 Foodborne viruses in Europe network 33
  1.12.6 Rapid Alert System for Food and Feed (RASFF) 34
  1.12.7 Global Salm-Surv (GSS) 34
  1.12.8 Surveillance of ready-to-eat foods in the United Kingdom 34
1.13 Outbreak investigations 36
  1.13.1 Preliminary outbreak investigation 37
  1.13.2 Case definition and data collection 40
  1.13.3 Data collation and interpretation 41
1.14 Food terrorism and biocrimes 47
1.15 Food safety following natural disasters, and conflict 50
vi Contents

2 Basic aspects 52

2.1 The microbial world 52

2.2 Bacterial cell structure 55

2.2.1 Morphology 55

2.2.2 Cell membrane structure and the Gram stain 55

2.2.3 Lipopolysaccharide, O antigen 57

2.2.4 Flagella (H antigen) 57

2.2.5 Capsule (Vi antigen) 58

2.3 Bacterial toxins and other virulence determinants 58

2.3.1 Bacterial toxins 58

2.3.2 Pathogenicity islands 63

2.3.3 Bacterial toxins encoded in bacteriophages 64

2.4 Microbial growth cycle 65

2.5 Death kinetics 66

2.5.1 Expressions 66

2.5.2 Decimal reduction times ($D$ values) and $Z$ values 66

2.6 Factors affecting microbial growth 71

2.6.1 Intrinsic and extrinsic factors affecting microbial growth 71

2.6.2 Water activity 72

2.6.3 pH 73

2.6.4 Temperature 73

2.6.5 Interplay of factors affecting microbial growth in foods 75

2.7 Microbial response to stress 75

2.7.1 General stress response (GSR) 77

2.7.2 pH stress 78

2.7.3 Heat shock 78

2.7.4 Cold shock 79

2.7.5 Osmotic shock 80

2.8 Predictive modelling 80

2.8.1 Predicting modelling development 81

2.8.2 Primary models and the Gompertz and Baranyi equations 81

2.8.3 Secondary models 84

2.8.4 Tertiary models 84

2.8.5 Application of predictive microbial modelling 85

2.9 Bioinformatic studies 87

2.9.1 Bioinformatics and genomes 87

2.9.2 16S rRNA gene sequence and denaturing gradient gel electrophoresis (DGGE) 90

2.9.3 Campylobacter jejuni and Campylobacter coli genome sequence 91

2.9.4 Salmonella evolution and PAIs 92

2.9.5 E. coli O157:H7 genome sequence 93

2.9.6 The diversity of the lactic acid bacteria and bifidobacteria 95

2.9.7 Listeria species genome sequence analysis 98

2.9.8 Staphylococcus aureus enterotoxin phylogenetic analysis 100
Contents

3 The microbial flora of food and its preservation 101

3.1 Spoilage micro-organisms 101
3.1.1 Spoilage micro-organisms 103
3.1.2 Spoilage of dairy products 105
3.1.3 Spoilage of meat and poultry products 105
3.1.4 Fish spoilage 106
3.1.5 Egg spoilage 106

3.2 Shelf-life indicators 106

3.3 Methods of preservation and shelf-life extension 109

3.4 The hurdle concept 110

3.5 Preservatives 110
3.5.1 Organic acids 110
3.5.2 Hydrogen peroxide and lactoperoxidase system 111
3.5.3 Chelators 113
3.5.4 Natural antimicrobials 113
3.5.5 Non-acidic preservatives 113
3.5.6 Preservation due to weak acids and low pH 115

3.6 Physical methods of preservation 116
3.6.1 Preservation by heat treatment 116
3.6.2 High-pressure treatment 117
3.6.3 Ohmic heating and radio frequency 118
3.6.4 Pulsed electric fields 119
3.6.5 Ultrasound 119
3.6.6 Intense light pulse 119
3.6.7 Food irradiation 119
3.6.8 Reduced oxygen packaging, modified atmosphere packaging and active packaging 123

3.7 Fermented foods 125
3.7.1 Lactic acid bacteria and their metabolism 126
3.7.2 Fermented milk products 130
3.7.3 Fermented meat products 133
3.7.4 Fermented vegetables 134
3.7.5 Fermented protein foods; shoyu and miso 134
3.7.6 Future use of the lactic acid bacteria 134

3.8 Functional foods; prebiotics, probiotics and synbiotics 136
3.8.1 Functional foods 136
3.8.2 Claims of probiotics 137
3.8.3 Probiotic studies 138

3.9 Nanotechnology and food preservation 139

4 Foodborne pathogens 141

4.1 Introduction 141
4.1.1 The human intestinal tract 141
4.1.2 Host resistance to foodborne infections 144
4.1.3 The normal human intestinal flora 147

4.2 Indicator organisms 151
Contents

4.2.1 Coliforms 152
4.2.2 *Enterobacteriaceae* 152
4.2.3 Enterococci 152
4.2.4 Bacteriophage 153

4.3 Foodborne pathogens, bacteria 153
4.3.1 *C. jejuni*, *Campylobacter coli* and *Campylobacter lari* 153
4.3.2 *Salmonella* species 157
4.3.3 Pathogenic *E. coli* 163
4.3.4 *Sh. dysenteriae* and *Sh. sonnei* 174
4.3.5 *Listeria monocytogenes* 176
4.3.6 *Y. enterocolitica* 180
4.3.7 *St. aureus* 182
4.3.8 *Cl. perfringens* 184
4.3.9 *Cl. botulinum* 186
4.3.10 *B. cereus* 187
4.3.11 *Vibrio cholerae*, *V. parahaemolyticus* and *V. vulnificus* 190
4.3.12 *Brucella melitensis*, *Br. abortus* and *Br. suis* 192
4.3.13 *Aeromonas hydrophila*, *A. caviae* and *A. sobria* 193
4.3.14 *Plesiomonas shigelloides* 194
4.3.15 *Streptococcus* and *Enterococcus* species 195

4.4 Foodborne pathogens, viruses 197
4.4.1 Norovirus (formerly known as Norwalk-like viruses and small round structured viruses) 199
4.4.2 Hepatitis A 202
4.4.3 Hepatitis E 204
4.4.4 Rotaviruses 204
4.4.5 Small round viruses, astroviruses, SLVs, adenoviruses and parvoviruses 205
4.4.6 Human enteroviruses 206

4.5 Seafood and shellfish poisoning 207
4.5.1 Ciguatera poisoning 208
4.5.2 Scombroid poisoning 208
4.5.3 Paralytic shellfish poisoning 209
4.5.4 Diarrhoeic shellfish poisoning 209
4.5.5 Neurotoxic shellfish poisoning 210
4.5.6 Amnesic shellfish poisoning 210

4.6 Foodborne pathogens: eucaryotes 210
4.6.1 *Cyclospora cayetanensis* 211
4.6.2 *Cryptosporidium parvum* 211
4.6.3 *Anisakis simplex* 211
4.6.4 *Taenia saginata* and *Taenia solium* 212
4.6.5 *Toxoplasma gondii* 213
4.6.6 *Trichinella spiralis* 214

4.7 Mycotoxins 214
4.7.1 Aflatoxins 216
4.7.2 Ochratoxins 217
4.7.3 Fumonisins 217
4.7.4 Zearalenone 217
4.7.5 Trichotheccenes 218
4.8 Emerging and uncommon foodborne pathogens 218
4.8.1 Prions 219
4.8.2 Cronobacter spp. 220
4.8.3 Mycobacterium paratuberculosis and pasteurised milk, an emerging pathogen? 222
4.8.4 Arcobacter genus 222
4.8.5 Nanobacteria 223

5 Methods of detection and characterisation 224
5.1 Prologue 224
5.2 Conventional methods 229
5.2.1 Culture media 230
5.2.2 Sublethally injured cells 232
5.2.3 Viable but non-culturable bacteria (VNC) 233
5.3 Rapid methods 234
5.3.1 Sample preparation 234
5.3.2 Separation and concentration of target 234
5.4 Rapid end-detection methods 238
5.4.1 ELISA and antibody-based detection systems 238
5.4.2 Reversed passive latex agglutination (RPLA) 239
5.4.3 Impedance (conductance) microbiology 239
5.4.4 ATP bioluminescence techniques and hygiene monitoring 240
5.4.5 Protein detection 241
5.4.6 Flow cytometry 242
5.4.7 Nucleic acid probes and the polymerase chain reaction (PCR) 243
5.4.8 Microarrays 245
5.4.9 Biosensors 246
5.5 Molecular typing methods 248
5.5.1 Pulsed-field gel electrophoresis (PFGE) 248
5.5.2 Restriction fragment length polymorphism (RFLP) 249
5.5.3 Multiple-locus variable-number tandem-repeats (MLVA) 249
5.5.4 Multilocus sequence typing (MLST) 249
5.6 Specific detection procedures 250
5.6.1 Aerobic plate count (APC) 250
5.6.2 Salmonella serovars 250
5.6.3 Campylobacter 252
5.6.4 Enterobacteriaceae and E. coli 253
5.6.5 Pathogenic E. coli, including E. coli O157:H7 255
5.6.6 Shigella spp. 255
5.6.7 Cronobacter spp. 256
5.6.8 L. monocytogenes 258
5.6.9 St. aureus 260
5.6.10 Clostridium perfringens 261
5.6.11 Bacillus cereus, B. subtilis and B. licheniformis 262


Contents

5.6.12 Mycotoxins 263
5.6.13 Viruses 263
5.7 Accreditation schemes 265

6 Microbiological criteria 266
6.1 Background to microbiological criteria and end-product testing 266
6.2 International Commission on Microbiological Specifications for Foods (ICMSF) 266
6.3 Codex Alimentarius principles for the establishment and application of microbiological criteria 267
6.4 Sampling plans 269
6.5 Variables plans 271
6.6 Attributes sampling plan 274
   6.6.1 Two-class plan 274
   6.6.2 Three-class plan 275
6.7 Principles 275
   6.7.1 Defining a ‘lot’ of food 275
   6.7.2 Sample unit number 275
   6.7.3 Operating characteristic curve 276
   6.7.4 Producer risk and consumer risk 279
   6.7.5 Stringency of two- and three-class plans, setting \( n \) and \( c \) 279
   6.7.6 Setting the values for \( m \) and \( M \) 281
6.8 Microbiological limits 281
   6.8.1 Definitions 281
   6.8.2 Limitations of microbiological testing 282
6.9 Examples of sampling plans 282
   6.9.1 Egg products 282
   6.9.2 Milk and milk products 282
   6.9.3 Processed meats 283
   6.9.4 Cereals and cereal products 284
   6.9.5 Cook-chill and cook-freeze products 284
   6.9.6 Seafoods 284
6.10 Implemented microbiological criteria 286
   6.10.1 Microbiological criteria in the European Union 286
   6.10.2 EU directives specifying microbiological standards for foods 288
6.11 UK guidelines for ready-to-eat foods 288

7 Hygienic production practices 289
7.1 Contribution of food handlers to foodborne illness 289
7.2 Personal hygiene and training 289
7.3 Cleaning 292
7.4 Detergents and disinfectants 294
7.5 Microbial biofilms 295
7.6 Assessment of cleaning and disinfection efficiency 299

8 Food safety management tools 301
8.1 The manufacture of hygienic food 301
8.2 Microbiological safety of food in world trade 307
Contents

8.3 Consumer pressure effect on food processing 308
8.4 The management of hazards in food which is in international trade 309
8.5 HACCP 309
8.6 Prerequisite programme 310
8.7 Outline of HACCP 312
  8.7.1 Food hazards 312
  8.7.2 Preparation for HACCP 312
  8.7.3 Principle 1: hazard analysis 313
  8.7.4 Principle 2: critical control points 314
  8.7.5 Principle 3: critical limits 316
  8.7.6 Principle 4: CCP monitoring 316
  8.7.7 Principle 5: corrective actions 316
  8.7.8 Principle 6: verification 316
  8.7.9 Principle 7: record keeping 317
8.8 Microbiological criteria and HACCP 317
8.9 Microbiological hazards and their control 319
  8.9.1 Sources of microbiological hazards 319
  8.9.2 Temperature control of microbiological hazards 320
  8.9.3 Non-temperature control of microbiological hazards 321
8.10 HACCP plans 321
  8.10.1 Production of pasteurised milk 321
  8.10.2 Swine slaughter in the abattoir 322
  8.10.3 Chilled food manufacture 322
  8.10.4 Generic models 323
8.11 GMP and GHP 327
8.12 Quality systems 336
8.13 TQM 336
9 Microbiological risk assessment 338
  9.1 Risk analysis and microbiological risk assessment 338
  9.2 Origin of microbiological risk assessment 339
  9.3 Microbiological risk assessment – an overview 342
  9.4 Microbiological risk assessment – structure 344
    9.4.1 Risk assessment 346
    9.4.2 Risk management 347
    9.4.3 Risk communication 348
  9.5 Risk assessment 348
    9.5.1 Statement of purpose 349
    9.5.2 Hazard identification 349
    9.5.3 Exposure assessment 350
    9.5.4 Hazard characterisation 354
    9.5.5 Dose–response assessment 356
    9.5.6 Dose–response models 358
    9.5.7 Dose and infection 362
    9.5.8 Risk characterisation 365
    9.5.9 Production of a formal report 367
    9.5.10 Triangular distributions and Monte Carlo simulation 367
## Contents

9.6 Risk management 368  
9.6.1 Risk assessment policy 372  
9.6.2 Risk profiling 372  
9.7 Food safety objectives 373  
9.8 Risk communication 374  
9.9 Future developments in microbiological risk assessment 376  
9.9.1 International methodology and guidelines 376  
9.9.2 Data 376  
9.9.3 Training courses and use of resources 377

10 Application of microbiological risk assessment 378
10.1 *Salmonella* risk assessments 378  
10.1.1 *S. Enteritidis* in shell eggs and egg products 378  
10.1.2 Hazard identification and hazard characterisation of *Salmonella* in broilers and eggs 381  
10.1.3 Exposure assessment of *Salmonella* spp. in broilers 384  
10.1.4 *Salmonella* spp. in cooked chicken 385  
10.1.5 *Salmonella* spp. in cooked patty 386  
10.1.6 Poultry FARM 387  
10.1.7 Domestic and sporadic human salmonellosis 388  
10.2 *Campylobacter* risk assessments 388  
10.2.1 *C. jejuni* risk from fresh chicken 388  
10.2.2 Risk profile for pathogenic species of *Campylobacter* in Denmark 390  
10.2.3 Risk assessment of *C. jejuni* in broilers 391  
10.2.4 *Campylobacter* fluoroquinolone resistance 392  
10.3 *L. monocytogenes* risk assessment 394  
10.3.1 *L. monocytogenes* hazard identification and hazard characterisation in ready-to-eat foods 394  
10.3.2 *L. monocytogenes* exposure assessment in RTE foods 396  
10.3.3 Relative risk of *L. monocytogenes* in selected RTE foods 398  
10.3.4 *L. monocytogenes* in EU trade 400  
10.3.5 *L. monocytogenes* in meat balls 401  
10.3.6 Listeriosis from RTE meat products 402  
10.4 *E. coli* O157 risk assessment 403  
10.4.1 *E. coli* O157:H7 in ground beef 403  
10.5 *Bacillus cereus* risk assessment 406  
10.5.1 *B. cereus* risk assessment 406  
10.6 *Vibrio parahaemolyticus* risk assessment 407  
10.6.1 Public health impact of *V. parahaemolyticus* in raw molluscan shellfish 407  
10.7 *Cronobacter* spp. (*Enterobacter sakazakii*) and *Salmonella* in powdered infant formula 409  
10.8 Viral risk assessments 410  
10.8.1 Viral contamination of shellfish and coastal waters 410
Contents

11 International control of microbiological hazards in foods: regulations and authorities 412

11.1 World Health Organisation, global food security from accidental and deliberation contamination 412
11.2 The foodborne disease burden epidemiology reference group (FERG) 415
11.3 Regulations in international trade of food 416
11.4 Codex Alimentarius Commission 417
11.5 Sanitary and phytosanitary measures (SPS), technical barriers to trade (TBT) and WHO 417
11.6 European Union legislation 419
   11.6.1 Food hygiene directive (93/43/EEC) 420
11.7 Food safety agencies 420
   11.7.1 Food authorities in the United States 421

Glossary of terms 423
List of abbreviations 428
Food safety resources on the world wide web 429
References 435
Index 461

A colour plate section is found facing page 222

See the supporting companion website for this book:
http://www.wiley.com/go/forsythe