## Index

acid sanitizers, 95 acid tolerance, 37 acid-sensitive, S.flexneri mutants, 38 active immobilization, disadvantages, 172 active or artificial immobilization, 172 acyl-homoserine lactone, autoinducer, 5 adsorption phenomenon, 172 alcohol production, 179 alkaline Fit<sup>™</sup> produce wash, 42 animal model, streptomycin-treated mouse, 144 anionic sanitizers, 95 antibiotic production, 183 antimicrobial resistance, 5 atomic force microscopy (AFM), 12 autoaggregation, 112 autoinducer. See also N-acyl-homoserine lactones (AHL) AI-2, 10, 11 in Gram-negative microorganism, 10 synthesis of, 11 Bacillus cerus, ecology of microbes, 21 Bacillus flavothermus, 7. See also disinfectants bacteria-bacteria communication, 160 bacterial growth rate in situ, 144 bacterial populations, in intestinal tract, 133 bacterial strain identification, parameters, 107 beneficial bacterial biofilms, 153-161 biofilm communities, intercellular communication, 115-116 biofilm development role of conjugation, 114-115 use of antibiotics, 120 biofilm ecosystem development, 111-112 biofilm formation, 168 biofilm reactors advantages of, 171-172

applications of, 176 biomass support particles, 174 immobilization, 172 types of, 173 biofilm structure model, 170 biofilm-forming abilities, degrees, 11 biofilms antimicrobial resistance, 5, 6 communication within, 157 control, 120 displacement of, 157 formation of, 157, 168 heterogeneous nature, 6 image of, 12 structure of, 168, 170 biofilms, microbial diversity analysis, 106-111 by Denaturing Gradient Gel Electrophoresis, 108 by DNA sequencing, 106 by fluorescent in situ hybridization, 110 by microarray, 109 by molecular probes, 109 biofilms, microscopic examination, 11 atomic force microscopy (AFM), 12 confocal scanning laser microscopy (CSLM), 12-14 differential interference contrast (DIC), 14 environmental SEM, 12-13 fluorescence microscope, 14 modulation contrast microscopy, 13 scanning electron microscopy (SEM), 12 - 13transmission electron microscopy (TEM), 12 - 13biofouling, 3, 128, 167 Biomass Support Particles (BSPs), 172, 184 BSP-immobilized fungus system, 184

C. perfringens, ecology of microbes on produce, 21 cabbage, S. flexneri levels, 33 Campylobacter, in parsley sample, 20, 35 carrot salad, S. flexneri level, 33 carrots, psychrotrophs, 25 cell immobilization methods, 172 cell-to-cell signaling systems, 11, 115-116 CFR. See Code of Federal Regulations chemical sanitizers effectiveness and inactivation of biofilms, 82-90 chlorine as enterotoxigenic E. coli, 28 concentration in wash water, 26 disinfection of fresh produce, 27-28 cilantro (Coriandrum sativuum) Salmonella population, 36 Salmonella serovar Thompson, 36-37 cleaning and biofilm control, 74 and sanitizing, 25 compounds in, 74-75 cleaning agents effectiveness, 76-78 and concentration, 79 cleaning methods for biofilms removal, 79 Clostridium botulinum, ecology of microbes on produce, 21 Coaggregation between genetically distinct microorganisms, 112 Code of Federal Regulations, 39 coleslaw, S. flexneri levels, 33 commercial Fit<sup>TM</sup> produce wash, efficacy of, 40.42 confocal scanning laser microscopy (CSLM), 12 - 14conjugation, 114, 119, 131 cooperative behavioral patterns, 116 crab salad, S. flexneri level, 33 cucumbers, psychrotroph population, 25 cultured and uncultured representatives, 134 denaturing Gradient Gel Electrophoresis (DGGE), 108 differential interference contrast (DIC), 14 disinfectants, 7 DNA sequencing, 106 DsRed P. agglomerans. See also cilantro, 37 D-values, 98

*E. coli* BJ4, in intestine, 145 efficacy of spray, 29

solubility of, 28 environmental persistence, 117 Environmental Protection Agency (EPA), 39 enzyme production, 184 Erwinia Gram-negative rods, 25 exopolymeric substances (EPS), 5, 7, 9, 10, 15 exopolysaccharides, 9 extracellular polymeric substances (EPS), 50 fatty acid sanitizers, 96 fecal flora coliforms, 21 contamination, 21-22 Fit<sup>TM</sup> treatments, 42 Fixed-bed reactors, 173 Flavobacterium, 7, 61. See also disinfectants Fluorescens, 9. See also food processing surfaces fluorescent in situ hybridization, 110 food environment cell-to-cell communications in, 119-120 mixed culture biofilms, 119-120 food industry impact of biofilms in, 3-5 food processing surfaces, 8 foodborne outbreaks, 21 involving Shigella, 30-32 fresh-processed produce colonization of microorganisms on surface of. 22 consumption, 19 efficacy of sanitizer on microorganisms of, 39 as growing industry, 19 pathogen growth on, 22 produce related outbreaks, 20 spoilage of, 23 Generally recognized as safe (GRAS) status. See also CFR, 39 GFP Salmonella serovar Thompson on cilantro, 37 Gram-negative rods Enterobacter, 24 Erwinia. 24 Pseudomonas, 24-25 Growth-phase-dependent sigma factor $\delta^{38}$ , 38 Gut mucosal biofilms, definition, 128 2-Heptyl-3-hydroxy-4-quinolone (PQS), 10 heterogeneous model. See also biofilms, 170 heterogeneous mosaic model, 170

horizontal gene transfer, 119

## Index

hot water sanitation, 97, 98 human digestive system inactivation of, 73-101 initial attachment of, 49 iodine efficacy, 94 molecular attributes, 58-59 ozone as sanitizer, 93 prediction model for, 99-100 prokaryotic diversity of epithelial mucosal biofilm, 127-145 regulatory pathways, 58-59 sequential treatment with acetic acid and sodium hydroxide, 95 structure of, 50

initiation, in biofilm formation, 49 intestinal tract biofilms, members of underrepresented Phyla, 139 irrigation water, pathogen detection, 21, 22

Klebsiella pneumoniae, mixed species biofilms, 6, 21Knockout mutants, biofilm production, 11

Lactic acid bacteria, ecology of microbs on produce, 24 Lactococcal CluA protein, 115 lasI gene product, 11 lasR-lasI. See also cell-to-cell signaling systems, 11 lettuce bacteria count. 25 E. coli population, 25 microbial quality, 24 psychrotroph populations, 25 shredding temperature, 32 Leuconostocs ecology of microbes on produce, 24 lignin peroxidase, production, 184 liquid shear forces, 168, 169, 174. See also biofilm Listeria monocytogenes adsorption of nisin, 64 biofilm development, 47-67 chlorine dioxide (ClO<sub>2</sub>) sanitizer, 91 effects of halogens, 81 biofilm, prevention and control of, 64-67 effectiveness of chlorine, 66 effectiveness of peracetic acid, 66 electrolyzed (EO) water sanitizer, 92 environmental factors impact, 54 acidity, 57 five-strain cocktail of, 100

nutrients, 55 surface, 55 temperature, 56 EPS formation, 51 food-borne pathogen, 47 inactivation of biofilm, 73, 74 strain variability, 52-54 structural characteristics, 50-52 Listeria Salmonella typhimurium, 28. See also chlorine Listeria Staphylococcus aureus, produce wash. 40 Listeria, food processing environments, 9 Manganese peroxidase (MnP), 184 MexABOprM pump, 118 microarray, 109 microbes on produce, ecology of, 21 microbial biofilms basic units of, 4 cells in, 5-6 definition of, 3 formation of, 4 microbial heat inactivation predictive models, 98 microbial mucolysis, 132 microbiota, of digestive tract, 135 microorganisms, potential sources, 21 minimal processing of vegetables, 23 minimally processed produce deterioration of, 19 features, 19 microflora of, 24 storage temperature of, 22 mixed culture biofilms, 59 public health risks, 117 safety, 117 modeling heat inactivation of biofilms, 98 modified Welshimer's broth (MWB), 54 molecular probes, 109 mucus biofilm niche, 130-131 mucus layer and goblet cell biology, 128 multispecies Biofilms, 6 multispecies biofilms, 6, 7 mushroom or tulip model, 170

N-(3-oxododecanoyl)-L-homoserine lactone, autoinducer. See also cell-to-cell signaling systems; quorum sensing, 10, 11, 113
N-acyl-homoserine lactones (AHL), autoinducer in G (-ve). See also cell-to-cell signaling systems; quorum sensing, 10, 113

ofloxacin resistance, P. aeruginosa biofilms, 118 organic acids production, 180 outbreaks foodborne, 21 produce-related, 20 Pseudomonas aeruginosa biofilms, 6, 10, 40, 59 P. cepacia, produce wash, 40 P. chloroaphis, on Cilantro, 36 P fluorescens, food processing surfaces, 9 P. fluorescens, food processing surfaces, 9 P. fragi, mixed cultured biofilms, 60 Parsley herb, 34 Parsley, S. sonnei population, 34 Passive or natural immobilization, 172 PCS (plastic composite support) biofilm reactors, 175, 176 pectinolytic strains, of Pseudomonas, 24 peroctanoic acid-based sanitizer, 95 peroxygen compounds, 94 produce contamination of, 24 pathogenic microorganisms, 22 washing of, 26 produce sanitizers, efficacy of, 42 produce wash, 39 produce-related outbreaks, 20 pseudo-homogeneous model, 170 quorum sensing, 10, 113. See also cell-to-cell signaling systems 16S rRNA gene, 107-108 ribosomal intergenic spacer analysis (RISA), 108 rpoS-dependent, process in Gram-negative bacteria, 118 Saccharomyces cerevisiae, surface sanitizer, 95 salad vegetables, E. coli O157:H7, 25 Salmonella Typhimurium, surface sanitizer, 95 sanitizing agents and biofilm inactivation, 81 Scallions, consumption, 31. See also Shigella flexneri 6A scanning electron microscopy (SEM), 12-13 Serratia mixed culture biofilms, 25 shear conditions impacts on biofilm formation, 3, 4, 10, 168 Shigella flexneri 6A, multistate outbreak, 31

Shigella sonnei, outbreaks, 30-31 shredded cabbage, S. sonnei survival, 33 signaling processes, 160 single culture L. monocytogenes biofilm, 48 specific genetic predispositions, 141 Staphylococcus, 9, 10, 34. See also Food Processing Surfaces S. aureus, 10, 41. See also cell-cell communication S. boydii, stool culture, 30 S. choleraesuis, produce wash, 40 S. enterica Derby on Cilantro, 37 Enteritidis on Cilantro, 37 Newport on Cilantro, 37 Thompson on Cilantro, 37 S. epidermis, 10 S. flexneri, 6A outbreak, 31-32, 38 and survival on salads, 33 S. Montevideo, on tomato surfaces, 29 S. sciuri biofilm, 61 S. sonnei, outbreaks, 30-32, 34 S. Thompson outbreak, 36 S. typhimurium, on Parsley, 35, 38 S. xylosus biofilms, 62 stationary phase E. coli K-12, 37 stool versus mucosal populations, 141 strain variability, 52 successional colonization of digestive tract, 140 surface type, 80 surfactant sanitizers, 96 survivability on fresh produce, 32 temperature and contact time, 79-80 theory of biofilms, 3 theory of, 3 thermophile sporeforming, 7 thermotolerant coliforms, 21 tomatoes survival of Salmonella Montevideo, 29 uptake of Salmonella, 26 transmission electron microscopy (TEM), 12 - 13vaginal microbiota, 157-158 Vibrio, 10, 11, 116. See also autoinducer virulence genes, transcription, 11 Water in cleaning, role of, 80 Yersinia enterocolitica, chlorine effect, 28,

34