

Contents

Preface	xvii
Part 1: Microbial Bioremediation and Biopolymer Technology	1
1 A Recent Perspective on Bioremediation of Agrochemicals by Microalgae: Aspects and Strategies	3
<i>Prithu Baruah and Neha Chaurasia</i>	
1.1 Introduction	4
1.2 Pollution Due to Pesticides	6
1.2.1 Acute Effects	8
1.2.2 Chronic Effects	9
1.3 Microalgal Species Involved in Bioremediation of Pesticides	9
1.4 Strategies for Phycoremediation of Pesticides	13
1.4.1 Involvement of Enzymes in Phycoremediation of Pesticides	13
1.4.2 Use of Genetically Engineered Microalgae	13
1.5 Molecular Aspects of Pesticide Biodegradation by Microalgae	14
1.6 Factor Affecting Phycoremediation of Pesticides	16
1.6.1 Biological Factor	16
1.6.2 Chemical Factor	16
1.6.3 Environment Factor	17
1.7 Benefit and Shortcomings of Phycoremediation	17
1.7.1 Benefits	17
1.7.2 Shortcomings	17
1.8 Conclusion and Future Prospects	18
References	18

2	Microalgal Bioremediation of Toxic Hexavalent Chromium: A Review	25
	<i>Pritikrishna Majhi, Satyabrata Nayak and Saubhagya Manjari Samantaray</i>	
2.1	Introduction	25
2.1.1	Chromium Cycle	27
2.2	Effects of Hexavalent Chromium Toxicity	27
2.2.1	Toxicity to Microorganisms	27
2.2.2	Toxicity to Plant Body	28
2.2.3	Toxicity to Animals	29
2.3	Chromium Bioremediation by Microalgae	30
2.3.1	Cyanobacteria	30
2.3.2	Green Algae	31
2.3.3	Diatoms	31
2.4	Mechanism Involved in Hexavalent Chromium Reduction in Microalgae	32
2.5	Conclusion	33
	References	34
3	Biodegradation of Heavy Metals Using Biofilm Bacteria	39
	<i>Adyasa Barik, Debasish Biswal, A. Arun and Vellaisamy Balasubramanian</i>	
3.1	Introduction	40
3.2	Source and Toxicity of Heavy Metal Pollution	41
3.2.1	Non-Essential Heavy Metals	42
3.2.1.1	Arsenic	42
3.2.1.2	Cadmium	43
3.2.1.3	Chromium	43
3.2.1.4	Lead	44
3.2.1.5	Mercury	45
3.2.2	Essential Heavy Metals	45
3.2.2.1	Copper	45
3.2.2.2	Zinc	46
3.2.2.3	Nickel	46
3.3	Biofilm Bacteria	47
3.4	Interaction of Metal and Biofilm Bacteria	47
3.5	Biodegradation Mechanisms	48
3.5.1	Biosorption	48
3.5.2	Bioleaching	50
3.5.3	Biovolatilization	52
3.5.4	Bioimmobilization	54

3.6	Conclusion	55
	References	55
4	Microbial-Derived Polymers and Their Degradability Behavior for Future Prospects	63
	<i>Mohammad Asif Ali, Aniruddha Nag and Maninder Singh</i>	
4.1	Introduction	63
4.2	Polyamides	65
4.2.1	Bioavailability and Production	66
4.2.2	Biodegradability of Polyamides	66
4.2.3	Degradation of Nylon 4 Under the Soil	67
4.2.4	Fungal Degradation of Nylon 6 and Nylon 66 (Synthetic Polyamide)	67
4.2.5	Itaconic Acid-Based Heterocyclic Polyamide	68
4.2.6	Summary and Future Development	69
4.3	Polylactic Acid	69
4.3.1	Availability and Production	70
4.3.2	Polymerization Method	71
4.3.3	Biodegradability of Polylactic Acid	73
4.3.4	Copolymerization Method	73
4.3.5	Blending Method	73
4.3.6	Nanocomposite Formation	74
4.3.7	Summary	74
4.4	Polyhydroxyalkanoates	74
4.4.1	Biosynthesis of Polyhydroxyalkanoates	75
4.4.2	Application of PHAs	75
4.4.3	Biodegradability of PHAs	76
4.4.4	Degradability Methods	76
4.4.5	Summary	77
4.5	Conclusion and Future Development	77
	References	78
5	A Review on PHAs: The Future Biopolymer	83
	<i>S. Mohapatra, K. Vishwakarma, N. C. Joshi, S. Maity, R. Kumar, M. Ramchander, S. Pattnaik and D. P. Samantaray</i>	
5.1	Introduction	84
5.2	Green Plastic: Biodegradable Polymer Used as Plastic	85
5.3	Difference Between Biopolymer and Bioplastic	88
5.4	Polyhydroxyalkanoates	88
5.5	Polyhydroxyalkanoates and Its Applications	89
5.6	Microorganisms Producing PHAs	90

5.7	Advantages	96
5.8	Conclusion and Future Prospective	96
	References	96
6	Polyhydroxybutyrate as an Eco-Friendly Alternative of Synthetic Plastics	101
	<i>Shikha Sharma, Priyanka Sharma, Vishal Sharma and Bijender Kumar Bajaj</i>	
6.1	Introduction	102
6.2	Bioplastics	104
6.3	Bioplastics vs. Petroleum-Based Plastics	106
6.4	Classification of Biodegradable Polymers	107
6.5	PHB-Producing Bacteria	109
6.6	Methods for Detecting PHB Granules	113
6.7	Biochemical Pathway for Synthesis of PHB	114
6.8	Production of PHB	116
6.8.1	Process Optimization for PHB Production	117
6.8.2	Optimization of PHB Production by One Variable at a Time Approach	118
6.8.3	Statistical Approaches for PHB Optimization	120
6.9	Production of PHB Using Genetically Modified Organisms	123
6.10	Characterization of PHB	125
6.11	Various Biochemical Techniques Used for PHB Characterization	126
6.11.1	Fourier Transform Infrared Spectroscopy	127
6.11.2	Differential Scanning Calorimetry	127
6.11.3	Thermogravimetric Analysis	128
6.11.4	X-Ray Powder Diffraction (XRD)	128
6.11.5	Nuclear Magnetic Resonance Spectroscopy	128
6.11.6	Microscopic Techniques	129
6.11.7	Elemental Analysis	130
6.11.8	Polarimetry	130
6.11.9	Molecular Size Analysis	130
6.12	Biodegradation of PHB	131
6.13	Application Spectrum of PHB	132
6.14	Conclusion	135
6.15	Future Perspectives	135
	Acknowledgements	136
	References	136
7	Microbial Synthesis of Polyhydroxyalkanoates (PHAs) and Their Applications	151
	<i>N.N.N. Anitha and Rajesh K. Srivastava</i>	

7.1	Introduction	153
7.2	Conventional Plastics and Its Issues in Utility	156
7.2.1	Synthetic Plastic and Its Accumulation or Degradation Impacts	158
7.3	Bioplastics	159
7.3.1	Polyhydroxyalkanoates	160
7.3.1.1	Microorganisms in the Production of PHAs	164
7.4	Fermentation for PHAs Production	171
7.5	Downstream Process for PHAs	173
7.6	Conclusions	175
	References	176
8	Polyhydroxyalkanoates for Sustainable Smart Packaging of Fruits	183
	<i>S. Pati, S. Mohapatra, S. Maity, A. Dash and D. P. Samantaray</i>	
8.1	Introduction	183
8.2	Physiological Changes of Fresh Fruits During Ripening and Minimal Processing	185
8.3	Smart Packaging	186
8.4	Biodegradable Polymers for Fruit Packaging	188
8.5	Legal Aspects of Smart Packaging	189
8.6	Pros and Cons of Smart Packaging Using PHAs	189
8.7	Conclusion	190
	References	191
9	Biosurfactants Production and Their Commercial Importance	197
	<i>Saishree Rath and Rajesh K. Srivastava</i>	
9.1	Introduction	198
9.2	Chemical Surfactant Compounds	200
9.2.1	Biosurfactant Compounds	202
9.3	Properties of Biosurfactant Compound	205
9.3.1	Activities of Surface and Interface Location	205
9.3.2	Temperature and pH Tolerance	205
9.3.3	Biodegradability	206
9.3.4	Low Toxicity	206
9.3.5	Emulsion Forming and Breaking	206
9.4	Production of Biosurfactant by Microbial Fermentation	206
9.4.1	Factors Influencing the Production of Biosurfactants	209
9.4.1.1	Environmental Conditions	209
9.4.1.2	Carbon Substrates	210
9.4.1.3	Estimation of Biosurfactants Activity	211

9.5	Advantages, Microorganisms Involved, and Applications of Biosurfactants	211
9.5.1	Advantages of Using Biosurfactants	211
9.5.1.1	Easy Raw Materials for Biosurfactant Biosynthesis	211
9.5.1.2	Low Toxic Levels for Environment	211
9.5.1.3	Best Operation With Surface and Interface Activity	212
9.5.1.4	Good Biodegradability	212
9.5.1.5	Physical Variables	212
9.5.2	Microbial Sources	212
9.5.3	Production of Biosurfactants	213
9.5.3.1	Production of Rhamnolipids	213
9.5.3.2	Regulation of Rhamnolipids Synthesis	214
9.5.3.3	Commercial Use of Biosurfactants	214
9.6	Conclusions	215
	References	216

Part 2: Microbes in Sustainable Agriculture and Biotechnological Applications 219

10	Functional Soil Microbes: An Approach Toward Sustainable Horticulture	221
	<i>C. Sarathambal, R. Dinesh and V. Srinivasan</i>	
10.1	Introduction	221
10.2	Rhizosphere Microbial Diversity	222
10.3	Plant Growth-Promoting Rhizobacteria	223
10.3.1	Nitrogen Fixation	224
10.3.2	Production of Phytohormones	225
10.3.3	Production of Enzymes That can Transform Crop Growth	225
10.3.4	Microbial Antagonism	226
10.3.5	Solubilization of Minerals	226
10.3.6	Siderophore and Hydrogen Cyanide (HCN) Production	228
10.3.7	Cyanide (HCN) Production	229
10.3.8	Plant Growth-Promoting Rhizobacteria on Growth of Horticultural Crops	229
10.4	Conclusion and Future Perspectives	235
	References	235

11 Rhizosphere Microbiome: The Next-Generation Crop Improvement Strategy	243
<i>M. Anandaraj, S. Manivannan and P. Umadevi</i>	
11.1 Introduction	244
11.2 Rhizosphere Engineering	245
11.3 Omics Tools to Study Rhizosphere Metagenome	246
11.3.1 Metagenomics	246
11.3.2 Metaproteomics	248
11.3.3 Metatranscriptomics	249
11.3.4 Ionomics	250
11.4 As Next-Generation Crop Improvement Strategy	251
11.5 Conclusion	252
References	252
12 Methane Emission and Strategies for Mitigation in Livestock	257
<i>Nibedita Sahoo, Swati Pattnaik, Matrujyoti Pattnaik and Swati Mohapatra</i>	
12.1 Introduction	258
12.2 Contribution of Methane from Livestock	259
12.3 Methanogens	259
12.3.1 Rumen Microbial Community	260
12.3.2 Methanogens Found in Rumen	260
12.3.3 Enrichment of Methanogens from Rumen Liquor	261
12.3.4 Screening for Methane Production	261
12.3.5 Isolation of Methanogens	261
12.3.6 Molecular Characterization	261
12.4 Methanogenesis: Methane Production	262
12.4.1 Pathways of Methanogenesis	262
12.4.2 Pathway of CO ₂ Reduction	262
12.4.3 CO ₂ Reduction to Formyl-Methanofuran	263
12.4.4 Conversion of the Formyl Group from Formyl-Methanofuran to Formyl-Tetrahydromethanopterin	263
12.4.5 Formation of Methenyl-Tetrahydromethanopterin	263
12.4.6 Reduction of Methenyl-Tetrahydromethanopterin to Methyl-Tetrahydromethanopterin	263
12.4.7 Reduction of Methyl-Tetrahydromethanopterin to Methyl-S-Coenzyme M	264
12.4.8 Reduction of Methyl-S-Coenzyme M to CH ₄	264
12.5 Strategies for Mitigation of Methane Emission	264
12.5.1 Dietary Manipulation	264
12.5.1.1 Increasing Dry Matter Intake	264

12.5.1.2	Increasing Ration Concentrate Fraction	265
12.5.1.3	Supplementation of Lipid	265
12.5.1.4	Protozoa Removal	266
12.5.2	Feed Additives	266
12.5.2.1	Ionophore Compounds	266
12.5.2.2	Halogenated Methane Compound	267
12.5.2.3	Organic Acid	267
12.5.3	Microbial Feed Additives	268
12.5.3.1	Vaccination	268
12.5.3.2	Bacteriophages and Bacteriocins	269
12.5.4	Animal Breeding and Selection	270
12.6	Conclusion	270
	References	271
13	Liquid Biofertilizers and Their Applications: An Overview	275
	<i>Avro Dey</i>	
13.1	Introduction	275
13.1.1	Chemical Fertilizer and its Harmful Effect	277
13.2	Biofertilizers "Boon for Mankind"	278
13.3	Carrier-Based Biofertilizers	279
13.3.1	Solid Carrier-Based Biofertilizers	279
13.3.2	Liquid Biofertilizer	279
13.4	Sterilization of the Carrier	282
13.5	Merits of Using Liquid Biofertilizer Over Solid Carrier-Based Biofertilizer	282
13.6	Types of Liquid Biofertilizer	283
13.7	Production of Liquid Biofertilizers	285
13.7.1	Isolation of the Microorganism	285
13.7.2	Preparation of Medium and Growth Condition	285
13.7.3	Culture and Preservation	286
13.7.4	Preparation of Liquid Culture	286
13.7.5	Fermentation and Mass Production	287
13.7.6	Formulation of the Liquid Biofertilizers	287
13.8	Applications of Biofertilizers	288
13.9	Conclusion	290
	References	291
14	Extremozymes: Biocatalysts From Extremophilic Microorganisms and Their Relevance in Current Biotechnology	293
	<i>Khushbu Kumari Singh and Lopamudra Ray</i>	
14.1	Introduction	294
14.2	Extremophiles: The Source of Novel Enzymes	295

14.2.1	Thermophilic Extremozymes	296
14.2.2	Psychrophilic Extremozymes	299
14.2.3	Halophilic Extremozymes	300
14.2.4	Alkaliphilic/Acidiophilic Extremozymes	300
14.2.5	Piezophilic Extremozymes	301
14.3	The Potential Application of Extremozymes in Biotechnology	301
14.4	Conclusion and Future Perspectives	303
	References	304
15	Microbial Chitinases and Their Applications: An Overview	313
	<i>Suraja Kumar Nayak, Swapnarani Nayak, Swaraj Mohanty, Jitendra Kumar Sundaray and Bibhuti Bhusan Mishra</i>	
15.1	Introduction	314
15.2	Chitinases and Its Types	315
15.3	Sources of Microbial Chitinase	317
15.3.1	Bacterial Chitinases	317
15.3.2	Fungal Chitinases	319
15.3.3	Actinobacteria	321
15.3.4	Viruses/Others	322
15.4	Genetics of Microbial Chitinase	322
15.5	Biotechnological Advances in Microbial Chitinase Production	323
15.5.1	Media Components	324
15.5.2	Physical Parameters	325
15.5.3	Modes and Methods of Fermentation	325
15.5.4	Advances Biotechnological Methods	326
15.6	Applications of Microbial Chitinases	327
15.6.1	Agricultural	328
15.6.1.1	Biopesticides	328
15.6.1.2	Biocontrol	328
15.6.2	Biomedical	329
15.6.3	Pharmaceutical	329
15.6.4	Industrial	330
15.6.5	Environmental	330
15.6.5.1	Waste Management	331
15.6.6	Others	331
15.7	Conclusion	332
	References	332
16	Lithobiontic Ecology: Stone Encrusting Microbes and their Environment	341
	<i>Abhik Mojumdar, Himadri Tanaya Behera and Lopamudra Ray</i>	
16.1	Introduction	341

16.2	Diversity of Lithobionts and Its Ecological Niche	342
16.2.1	Epiliths	342
16.2.2	Endoliths	343
16.2.3	Hypoliths	344
16.3	Colonization Strategies of Lithobionts	345
16.3.1	Temperature	346
16.3.2	Water Availability	346
16.3.3	Light Availability	347
16.4	Geography of Lithobiontic Coatings	348
16.4.1	Bacteria	348
16.4.2	Cyanobacteria	349
16.4.3	Fungi	349
16.4.4	Algae	349
16.4.5	Lichens	350
16.5	Impacts of Lithobiontic Coatings	351
16.5.1	On Organic Remains	351
16.5.2	On Rock Weathering	351
16.5.3	On Rock Coatings	352
16.6	Role of Lithobionts in Harsh Environments	352
16.7	Conclusion	353
	Acknowledgement	353
	References	353
17	Microbial Intervention in Sustainable Production of Biofuels and Other Bioenergy Products	361
	<i>Himadri Tanaya Behera, Abhik Mojumdar, Smruti Ranjan Das, Chiranjib Mohapatra and Lopamudra Ray</i>	
17.1	Introduction	362
17.2	Biomass	363
17.3	Biofuel	364
17.3.1	Biodiesel	365
17.3.1.1	Microalgae in Biodiesel Production	365
17.3.1.2	Oleaginous Yeasts in Biodiesel Production	366
17.3.1.3	Oleaginous Fungi in Biodiesel Production	366
17.3.1.4	Bacteria in Biodiesel Production	367
17.3.2	Bioalcohol	367
17.3.2.1	Bioethanol	367
17.3.2.2	Biobutanol	368
17.3.3	Biogas	369

17.3.4	Biohydrogen	369
17.4	Other Bioenergy Products	370
17.4.1	Microbial Fuel Cells	370
17.4.1.1	Microbes Used in MFCs	372
17.4.1.2	Future Aspects of Microbial Fuel Cells	372
17.4.2	Microbial Nanowires in Bioenergy Application	374
17.4.2.1	Pili	375
17.4.2.2	Outer Membranes and Extended Periplasmic Space	375
17.4.2.3	Unknown Type—MNWs Whose Identity to be Confirmed	375
17.4.3	Microbial Nanowires in Bioenergy Production	376
17.5	Conclusion	376
	References	376
18	Role of Microbes and Microbial Consortium in Solid Waste Management	383
	<i>Rachana Jain, Lopa Pattanaik, Susant Kumar Padhi and Satya Narayan Naik</i>	
18.1	Introduction	384
18.2	Types of Solid Waste	384
18.2.1	Domestic Wastes	385
18.2.2	Institutional and Commercial Wastes	385
18.2.3	Wastes From Street Cleansing	385
18.2.4	Industrial Wastes	385
18.2.5	Nuclear Wastes	385
18.2.6	Agricultural Wastes	385
18.3	Waste Management in India	386
18.4	Solid Waste Management	390
18.4.1	Municipal Solid Waste Management	390
18.5	Solid Waste Management Techniques	390
18.5.1	Incineration	392
18.5.2	Pyrolysis and Gasification	392
18.5.3	Landfilling	393
18.5.4	Aerobic Composting	394
18.5.5	Vermicomposting	397
18.5.6	Anaerobic Digestion	401
18.5.6.1	Enzymatic Hydrolysis	402
18.5.6.2	Fermentation	402
18.5.6.3	Acetogenesis	403
18.5.6.4	Methanogenesis	403

xvi CONTENTS

18.5.7	Bioethanol From Various Solid Wastes	404
18.6	Conclusion	413
	References	413
	Index	423