

CONTENTS

Preface to the Second Edition page ix		4.3 4.4	The Fungal Lifestyle: Colony Formation 80 Mycelium Growth Kinetics 81
1	Twenty-First Century Fungal Communities 1	4.5	Colony Growth to Maturity 84
1.1	What and Where Are Fungi? 1	4.6	Morphological Differentiation of Fungal
1.2	Soil, the Essential Terrestrial Habitat 2		Colonies 84
1.3	How Much Soil Is There and Where Is It? 3	4.7	Duplication Cycle in Moulds 85
1.4	The Nature of Soil and Who Made It 3	4.8	Regulation of Nuclear Migration 86
1.5	Soil Biota Are Extremely Varied and Numerous 4	4.9	Growth Kinetics 86
1.6	Microbial Diversity in Soil 5	4.10	Autotropic Reactions 90
1.7	Microbial Diversity in General 6	4.11	Hyphal Branching 91
1.8	Geomycology 7	4.12	Septation 92
1.9	The Origins of Agriculture and Our Dependence	4.13	Ecological Advantage of Mycelial Growth in
1.7	on Fungi 11		Colonising Solid Substrates 93
1.10	References 12	4.14	References 94
1.10	References 12		
2	Evolutionary Origins 15	5	Fungal Cell Biology 97
2.1	Life, the Universe and Everything 15	5.1	Mechanisms of Mycelial Growth 97
2.2	Planet Earth: Your Habitat 16	5.2	The Fungus As a Model Eukaryote 97
2.3	The Goldilocks Planet 17	5.3	The Essentials of Cell Structure 99
2.4	The Tree of Life Has Three Domains 18	5.4	Subcellular Components of Eukaryotic Cells:
2.5	The Kingdom Fungi 24		The Nucleus 101
2.6	The Opisthokonts 26	5.5	The Nucleolus and Nuclear Import and
2.7	Fossil Fungi 26		Export 104
2.8	The Fungal Phylogeny 29	5.6	Mitotic Nuclear Division 105
2.9	References 34	5.7	Meiotic Nuclear Division 107
		5.8	Translation of mRNA and Protein Sorting 108
3	Natural Classification of Fungi 38	5.9	The Endomembrane Systems 110
3.1	The Members of the Kingdom 38	5.10	Cytoskeletal Systems 113
3.2	The Chytrids 39	5.11	Molecular Motors 115
3.3	Neocallimastigomycota 41	5.12	Plasma Membrane and Signalling Pathways 120
3.4	Blastocladiomycota 42	5.13	Fungal Cell Wall 122
3.5	The Traditional Zygomycetes 45	5.14	Cell Biology of the Hyphal Apex 124
3.6	Glomeromycotina 50	5.15	Hyphal Fusions and Mycelial
3.7	Ascomycota 51		Interconnections 127
3.8	Basidiomycota 57	5.16	Cytokinesis and Septation 130
3.9	The Species Concept in Fungi 68	5.17	Yeast-Mycelial Dimorphism 135
3.10	The Untrue Fungi 70	5.18	References 136
3.11	Ecosystem Mycology 72		
3.12	References 74	6	Fungal Genetics: From Gene Segregation
5.12	References 74		to Gene Editing 143
4	Hyphal Cell Biology and Growth on Solid	6.1	Basic Fungal Genetics 143
•	Substrates 79	6.2	Establishing Fungal Genetic Structure 144
1 1		6.3	Introns 146
4.1 4.2	Mycelium: The Hyphal Mode of Growth 79 Spore Germination and Dormancy 80	6.4	Alternative Splicing 148



vi

Contents

6.5	Transposons 148	10	Continuing the Diversity Theme: Cell and Tissue
6.6	Ploidy and Genomic Variation 149		Differentiation 229
6.7	Sequencing Fungal Genomes 150	10.1	What Is Diversity? 229
6.8	Annotating the Genome 153	10.2	Mycelial Differentiation 230
6.9	Fungal Genomes and Their Comparison 158	10.3	Making Spores 232
6.10	Manipulating Genomes: Gene Editing 159	10.4	Aspergillus Conidiophores 235
6.11	References 165	10.5	Conidiation in Neurospora crassa 237
7	State of the state	10.6	Conidiomata 238
7	Structure and Synthesis of Fungal Cell Walls 171	10.7	Linear Structures: Strands, Cords, Rhizomorphs
7.4			and Stipes 240
7.1	The Fungal Wall As a Working Organelle 171	10.8	Globose Structures: Sclerotia, Stromata,
7.2	Fundamentals of Wall Structure and Function 172		Ascomata and Basidiomata 242
7.3	Fundamentals of Wall Architecture 175	10.9	References 245
7.3 7.4	The Chitin Component 175		
7. 4 7.5	The Glucan Component 177	11	Fungi in Ecosystems 249
7.6	The Glycoprotein Component 178	11.1	Contributions of Fungi to Ecosystems 249
7.7	Wall Synthesis and Remodelling 180	11.2	Breakdown of Polysaccharide: Cellulose 250
7.8	On the Far Side 184	11.3	Breakdown of Polysaccharide:
7.9	References 187		Hemicellulose 252
		11.4	Breakdown of Polysaccharide: Pectins 252
8	From the Haploid to the Functional Diploid:	11.5	Breakdown of Polysaccharide: Chitin 253
	Homokaryons, Heterokaryons, Dikaryons	11.6	Breakdown of Polysaccharide: Starch and
	and Compatibility 192		Glycogen 253
8.1	Compatibility and the Individualistic	11.7	Lignin Degradation 255
	Mycelium 192	11.8	Digestion of Protein 258
8.2	Formation of Heterokaryons 194	11.9	Lipases and Esterases 259
8.3	Breakdown of a Heterokaryon 195	11.10	Phosphatases and Sulfatases 260
8.4	The Dikaryon 196	11.11	The Flow of Nutrients: Transport and
8.5	Vegetative Compatibility 197		Translocation 260
8.6 8.7	Biology of Incompatibility Systems 200		Primary (Intermediary) Metabolism 263
0.7	Gene Segregation During the Mitotic Division Cycle 201	11.13	Secondary Metabolites, Including Commercial
8.8	Parasexual Cycle 204		Products Like Statins and Strobilurins 268
8.9	Cytoplasmic Segregations: Mitochondria, Plasmids,	11.14	References 275
	Viruses and Prions 205		
8.10	References 208	12	Exploiting Fungi for Food 279
		12.1	Fungi As Food 279
9	Sexual Reproduction: The Basis of Diversity	12.2	Fungi in Food Webs 279
	and Taxonomy 211	12.3	Wild Harvests: Commercial Mushroom
9.1	The Process of Sexual Reproduction 211	40.4	Picking 284
9.2	Mating in Budding Yeast 214	12.4	Cells and Mycelium As Human Food 286
9.3	Mating Type Switching in Budding Yeast 215	12.5	Fermented Foods 287
9.4	Mating Types of Neurospora 218	12.6	Industrial Cultivation Methods 287
9.5	Mating Types in Basidiomycota 220	12.7	Gardening Insects and Fungi 291
9.6	Biology of Mating Type Factors 226	12.8	Development of a Fungal Sporophore 291
9.7	References 226	12.9.	References 291



Contents (vii

13	Development and Morphogenesis 295	14.13	Monotropoid Endomycorrhizas 360
13.1	Development and Morphogenesis 295	14.14	Orchidaceous Endomycorrhizas 361
13.2	The Formal Terminology of Developmental	14.15	Ectomycorrhizas 363
	Biology 296	14.16	Ectendomycorrhizas 367
13.3	The Observational and Experimental Basis of	14.17	The Effects of Mycorrhizas, Their Commercial
	Fungal Developmental Biology 298		Applications and the Impact of Environmental
13.4	Ten Ways to Make a Mushroom 299		and Climate Changes 367
13.5	Competence and Regional Patterning 301	14.18	Introduction to Lichens 373
13.6	The Coprinopsis Mushroom: Making	14.19	Introduction to Endophytes 376
	Hymenia 303	14.20	Epiphytes 378
13.7	Coprinopsis and Volvariella Making Gills (Not	14.21	References 378
	Forgetting How Polypores Make Tubes) 306		
13.8	The Coprinopsis Mushroom: Making Stems 310	15	Fungi As Symbionts and Predators
13.9	Coordination of Cell Inflation Throughout the		of Animals 388
	Maturing Mushroom 312	15.1	Fungal Cooperative Ventures 388
13.10	Mushroom Mechanics 314	15.2	Ant Agriculture 389
13.11	Metabolic Regulation in Relation to	15.3	Termite Gardeners of Africa 393
	Morphogenesis 314	15.4	Agriculture in Beetles 395
13.12	Developmental Commitment 317	15.5	Anaerobic Fungi and the Rise of the
	Comparisons with Other Tissues and Other		Ruminants 396
	Organisms 319	15.6	Nematode-Trapping Fungi 400
13.14	Genetic Approaches to Study Development:	15.7	References 402
	Through the Classic to Genomic Systems		
	Analysis 320	16	Fungi As Pathogens of Plants 408
13.15	Senescence and Death 330	16.1	Fungal Diseases and Loss of World Agricultural
	Basic Principles of Fungal Developmental		Production 408
	Biology 331	16.2	A Few Examples of Headline Crop
13.17	References 332		Diseases 411
		16.3	The Rice Blast Fungus Magnaporthe oryzae
14	Ecosystem Mycology: Saprotrophs, and		(Ascomycota) 412
	Mutualisms Between Plants and Fungi 341	16.4	Armillaria (Basidiomycota) 412
14.1	Ecosystem Mycology 341	16.5	Pathogens that Produce Haustoria (Ascomycota
14.2	Fungi As Recyclers and Saprotrophs 346		and Basidiomycota) 413
14.3	Make the Earth Move 347	16.6	Cercospora (Ascomycota) 413
14.4	Fungal Toxins: Food Contamination and	16.7	Ophiostoma (Ceratocystis) novo-ulmi
	Deterioration (Including Mention of Statins and		(Ascomycota) 414
	Strobilurins) 348	16.8	Black Stem Rust (<i>Puccinia graminis</i> F. Sp. tritici)
14.5	Decay of Structural Timber in Dwellings 350		Threatens Global Wheat Harvest 415
14.6	Using Fungi to Remediate Toxic and Recalcitrant	16.9	Plant Disease Basics: The Disease Triangle 416
14.0	Wastes 352	16.10	Necrotrophic and Biotrophic Pathogens of
14.7	Release of Chlorohydrocarbons into the		Plants 417
14.7	Atmosphere by Wood-Decay Fungi 354	16.11	The Effects of Pathogens on Their Hosts 418
14.8	Introduction to Mycorrhizas 355		How Pathogens Attack Plants 420
14.9	Types of Mycorrhiza 356	16.13	
14.10	Arbuscular (AM) Endomycorrhizas 357		Openings 421
14.11	Ericoid Endomycorrhizas 359	16.14	
14.12	Arbutoid Endomycorrhizas 360		Enzymatic Penetration of the Host 423
17.12	Albatola Eliaolitycolitiizas 300	10.10	Linging and a character of the Host 420



viii

Contents

16.16	Preformed and Induced Defence Mechanisms in	19	Whole Organism Biotechnology 492
	Plants 426	19.1	Fungal Fermentations in Submerged Liquid
16.17	Genetic Variation in Pathogens and Their Hosts:		Cultures 492
	Coevolution of Disease Systems 427	19.2	Culturing Fungi 493
16.18	References 429	19.3	Oxygen Demand and Supply 496
		19.4	Fermenter Engineering 497
17	Fungi As Pathogens of Animals, Including	19.5	Fungal Growth in Liquid Cultures 499
	Humans 435	19.6	Fermenter Growth Kinetics 501
17.1	Pathogens of Insects 435	19.7	Growth Yield 503
17.2	Microsporidia 436	19.8	Stationary Phase 503
17.3	Trichomycetes 438	19.9	Growth As Pellets 505
17.4	Laboulbeniales 439	19.10	Beyond the Batch Culture 507
17.5	Entomogenous Fungi 440	19.11	Chemostats and Turbidostats 507
17.6	Biological Control of Arthropod Pests 443	19.12	Uses of Submerged Fermentations 510
17.7	Cutaneous Chytridiomycosis: An Emerging	19.13	Alcoholic Fermentations 512
17.7	Infectious Disease of Amphibians 445	19.14	Citric Acid Biotechnology 513
17.8	Aspergillosis Disease of Coral 446	19.15	Penicillin and Other Pharmaceuticals 514
17.9	Snake Fungal Disease 447	19.16	Enzymes for Fabric Conditioning and Processing,
17.70	White-Nose Syndrome of Bats 447		and Food Processing 520
17.10	Mycoses: The Fungus Diseases of Humans 448	19.17	Steroids and Use of Fungi to Make Chemical
17.11	Clinical Groupings for Human Fungal		Transformations 522
17.12	Infections 450	19.18	The Quorn® Fermentation and Evolution in
17.13	Fungi Within the Home and Their Effects on		Fermenters 522
17.13	Health: Allergens and Toxins 455	19.19	Production of Spores and Other Inocula 528
17.14	Comparison of Animal and Plant Pathogens 459	19.20	Natural Digestive Fermentations in
	· · · · · · · · · · · · · · · · · · ·		Herbivores 529
17.15 17.16	Mycoparasitic and Fungicolous Fungi 461 References 466	19.21	Solid-State Fermentations 529
17.10	References 400	19.22	Digestion of Lignocellulosic Residues 532
		19.23	Bread: The Other Side of the Alcoholic
18	Killing Fungi: Antifungals and Fungicides 473		Fermentation Equation 534
18.1	Agents that Target Fungi 473	19.24	Cheese and Salami Manufacture 535
18.2	Antifungal Agents that Target the Fungal	19.25	Soy Sauce, Tempeh and Other Food
	Membrane 474		Products 539
18.3	Antifungal Agents that Target the Fungal	19.26	Fungi As Cell Factories 540
	Wall 481	19.27	References 543
18.4	Agricultural Mycocides for the Twenty-First		
	Century: Strobilurins 482	Apper	ndices 551
18.5	Control of Fungal Diseases for the Twenty-First	Apper	ndix 1 Outline Classification of Fungi 551
	Century: Integrated Pest Management and		ndix 2 Mycelial and Hyphal Differentiation 567
	Combinatorial Therapy 486		-
18.6	References 489	Index	579