

Bacteria–Plant Interactions

Advanced Research and Future Trends

Edited by

Jesús Murillo

Laboratorio de Patología Vegetal
Departamento de Producción Agraria
Universidad Pública de Navarra
Pamplona
Spain

Robert W. Jackson

School of Biological Sciences
University of Reading
Reading
UK

Boris A. Vinatzer

Department of Plant Pathology,
Physiology, and Weed Science
Virginia Tech
Blacksburg, VA
USA

Dawn L. Arnold

Centre for Research in Biosciences
University of the West of England
Bristol
UK



Copyright © 2015

Caister Academic Press

Norfolk, UK

www.caister.com

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

ISBN (hardback): 978-1-908230-58-4

ISBN (ebook): 978-1-910190-00-5

Description or mention of instrumentation, software, or other products in this book does not imply endorsement by the author or publisher. The author and publisher do not assume responsibility for the validity of any products or procedures mentioned or described in this book or for the consequences of their use.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publisher. No claim to original U.S. Government works.

Cover design adapted from Figure 4.1.

Contents

	Contributors	v
	Preface	ix
1	Functional Diversification of Phytopathogenic Type III Secreted Effector Proteins	1
	Amy Hwei-Yi Lee, Heath O'Brien, Timothy Lo, David S. Guttman and Darrell Desveaux	
2	Systems Biology of <i>Pseudomonas Syringae</i> Type III Secretion Effector Repertoires	31
	Magdalen Lindeberg and Alan Collmer	
3	Towards Understanding Fire Blight: Virulence Mechanisms and their Regulation in <i>Erwinia amylovora</i>	61
	R. Ryan McNally, Youfu Zhao and George W. Sundin	
4	Plant-pathogenic <i>Acidovorax</i> Species	83
	Tally Rosenberg, Noam Eckshtain-Levi and Saul Burdman	
5	The Interactions Between Gram-positive Pathogens and Plant Hosts	101
	Elizabeth A. Savory, Allison L. Creason, Olivier M. Vandeputte, Edward W. Davis II and Jeff H. Chang	
6	The Molecular Interactions Between Human-pathogenic Bacteria and Plants	139
	Nicola J. Holden, Ashleigh Holmes, Yannick Rossez and Robert W. Jackson	
7	Recent Advances in <i>Pseudomonas</i> Biocontrol	167
	Feyisara Eyiwumi Olorunleke, Nam Phuong Kieu and Monica Höfte	

8	The Potential Role of Bacteriophages in Shaping Plant–Bacteria Interactions Britt Koskella and Tiffany B. Taylor	199
	Index	221
	Colour Plate	A1

Preface

With the continuing increase in human population and major changes in climate, our relative food prosperity in the 1980s/1990s has reversed to expose a significant threat to global food security. Add to this the continual battle to control existing plant disease problems, emerging diseases and food contamination with human pathogens, and we realise there are still significant challenges ahead for producing adequate, safe food. However, we are witnessing major advances in technology and scientific exploration as we aim to cope with these issues. The aim of this book is to introduce the reader to advances in the field of bacteria–plant interactions, centred on plant pathogens, human pathogen contamination and potential control strategies. Fundamental to this is the need to build up model systems to help inform other studies – these are exemplified in the *Pseudomonas* and *Erwinia* chapters. Emerging experimental systems examining emerging or neglected diseases have been considered in the chapters on *Acidovorax* and Gram-positive bacterial pathogens. The recent outbreak of food poisoning in Europe was a timely reminder for the need to examine human pathogen colonisation of plants. Finally, with the loss of regulated chemicals, there is a clear need to innovate control methods – two chapters consider biocontrol approaches. Bacteria represent a good opportunity to find antimicrobials against fungi and oomycetes, while phage therapy offers a solution to bacterial infections.

Robert W. Jackson, Jesús Murillo, Boris A. Vinatzer and Dawn L. Arnold

16S rRNA 86, 168, 172

A

Acidovorax 1, 2, 15, 16, 83
A. anthurii 84, 86, 90
A. avenae 83–88, 90–93
A. cattleyae 84–87, 89
A. citrulli 83–88, 90–93
A. konjaci 84–86, 89
A. oryzae 84, 86, 88
A. valerianellae 84, 86, 90
 symptoms 87
 Acetyltransferase 16–18, 20
 Actinobacteria 105–107, 109, 125, 175, 178
 Acylated homoserine lactones (AHLs) 93, 94, 152
 Adherence 92, 139, 143–149, 151, 156
 Adhesin 145, 147–149
Agaricus 184–186, 188
Agrobacterium 67, 185, 188
A. tumefaciens 117, 144, 146–148, 154, 209
 AHL *see* Acylated homoserine lactones
 Alfalfa 18, 102, 144, 146–148, 154
Alternaria 179
 Amphisin 182, 185, 187
 Amylovoran 62, 64, 70, 72, 74, 75
 Antibiosis 168, 176, 178
 Antibiotic 62, 89, 93, 119, 167, 169, 170–172, 174–176, 178, 180, 182–185, 189, 190
 antibiotic resistance 61, 76, 201, 206, 209
 AntiSMASH (Antibiotic and Secondary Metabolite Shell) 174, 190
 Apple 2, 61, 66–71, 75, 76, 142, 144, 145, 173, 186, 212, 213
Arabidopsis 7, 8, 10, 11, 12, 18–20, 33, 34, 36, 38, 43–46, 52, 110, 111, 113, 125, 182
A. thaliana 6, 48, 51, 67, 69, 70, 105, 144, 153, 178
 Arms race *see* Evolutionary arms race
att locus 119–120
 Autoacetylation 17, 18
 Auxin 117, 119, 178

Avirulence 2, 12, 33–35, 37, 38, 64, 68, 69, 75, 76, 91

AvrA 5, 16, 17, 33
 AvrB 5–9, 21, 41, 45, 46, 48, 49
 AvrB1 *see* AvrB
 AvrB2 *see* AvrB
 AvrBsT 16, 17, 19, 20
 AvrE 5, 33, 37–39, 46, 48, 51, 64, 66, 67
 AvrE1 4, 6
 AvrPphE *see* HopX1
 AvrPto 9–11, 19, 20, 33, 34, 38, 39, 41–52
 AvrPtoB 5, 11, 12, 38, 39, 41–51, 69
see also HopAB
 AvrRpt2 5, 6, 35, 38, 41, 46, 47, 50, 64, 67, 68, 73, 75
 AvrRpt2_{EA} *see* AvrRpt2
 AvrRxv 16–20
 AvrXv4 *see* AvrRxv
Azoarcus 144, 146
Azospirillum 144, 148, 178

B

Bacillus 101, 140, 188
 Bacterial black spot (BBS) 84, 86, 90
 Bacterial brown spot (BBS) 89
 Bacterial fruit blotch (BFB) 83, 84, 86, 87
 Bacteriophage 145, 199
 BAK1 10, 12–13, 43, 45, 49
 Banana 188
 Banana blood disease bacterium *see* BDB
 Barley 84, 93, 155, 173, 180
 Basil 144, 148, 149
 BDB 2
 Bean 6, 8, 11, 18, 42, 103, 107, 139, 144, 148, 176, 182, 183, 185, 188
 Biocontrol 167–190, 199, 200, 212, 214
 Biodegradation 83
 Biofilm 70, 71, 92–94, 142–148, 177, 182, 188, 190, 204, 209
 BIO-PCR 89
 Biopesticide 167, 173
 Biosurfactant 182, 183, 190

Botrytis 69, 173, 180–183, 189
Brenneria 1, 2
Brevibacterium 175
 BRI1 10
 Broccoli 144, 148, 186, 189
 Bti9 12–13, 45, 49
Burkholderia 14, 83, 175, 179, 180

C

Cabbage 6, 144, 149, 151
Caenorhabditis 111
 Callose 46, 67, 69, 70, 75, 116
Campylobacter 149
 Canola 185, 188
 Cellulose 114–116, 144, 146, 147
 Cell wall-degrading enzymes 75, 113–114
 CERK1 12–13, 43, 44, 49
 Chaperone 8, 34, 47, 64, 66, 143, 145
 Chicory 182, 183
 Chitin elicitor receptor kinase 1 *see* CERK1
 Chloroplast 41, 45, 46, 48
chp 123–124
Clavibacter 101–102, 105, 107–108, 110, 112, 114–115, 120–124, 180
Clavibacter michiganensis see Clavibacter
C. michiganensis subsp. *michiganensis see Clavibacter*
C. michiganensis subsp. *sepedonicus see Clavibacter*
Clostridium 101, 140
 ClusterMine360 174, 190
 ClustScan 174, 190
Cmm see Clavibacter
Cms see Clavibacter
 Cocoyam 175, 178, 179, 182, 183, 188
 Conserved effector locus (CEL) 4, 37, 40, 46, 51
 Coronatine 52, 116, 117, 155
 CspA 152
 Cucumber 86, 87, 93, 187, 188
 Cucurbits 83–88, 91
 Curli 144, 146, 147, 153
Curtobacterium flaccumfaciens 103, 107
 Cyclic lipopeptide (CLP) 182, 186–190
 Cytokinin 103, 117–119

D

DC3000 *see P. syringae* pv. *tomato* under *Pseudomonas syringae*
 Decoy model 46
 Diacetylphloroglucinol (DAPG) 167, 169, 177–180, 189, 190
Dickeya 1, 2, 6, 75, 147, 181
 Distributed genome hypothesis 123, 125
 DNA–DNA reassociation 86
 DoBISCUIT 174, 190
Drechslera 173, 180
Drosophila 111, 181
 DspE 5, 6, 64, 66–70, 75

E

E3 ubiquitin ligase 13, 42, 44, 45, 47, 116
E. coli see E. coli under *Escherichia*
 Effector 1–21, 31–53, 64, 66–75, 90, 91, 111–114, 149, 152–154
 genes inactivated or lost 41
 inventory 36
 localization 18, 19, 47, 66
 molecular function 48, 49
 repertoire 31–41, 48, 51, 52, 66
 searches 34
see also T3Es and T3SE
 Effector-triggered immunity 2, 32, 91, 112, 153
see also ETI
 EFR 43, 45, 49
 EF-Tu 152
 Endophyte 154, 155
 Endophytic 105, 119, 146, 150–153, 155
Enterobacter 144, 145, 179
 Entolysin 182, 188
 Eop1 5–6, 15, 16, 64, 67, 68, 73, 75
 Eop3 5–6, 73
Erwinia 1–6, 15–16, 61–76, 113, 144, 145, 149, 150, 173, 181, 184–186, 188, 207, 208
E. amylovora 2, 4–6, 15, 61–76, 144, 145, 150, 173, 181, 207
E. carotovora 88, 209, 211
Escherichia 185, 188
E. coli 14, 69, 73, 75, 140–157, 185
 ESX 113
 Ethylene 12–14, 116, 153, 155
 ETI 2, 7, 10–13, 32, 36–41, 44–47, 51–53, 91, 112, 153
 Eukaryotic domain acquisition 41
 Evolution 7, 9, 12, 14, 16, 31, 32, 34, 37, 39–42, 48–52, 101, 105, 109, 112–113, 115, 120–126, 141, 148, 149, 153, 168, 175–189, 199–209, 213
 Evolutionary arms race 39, 112, 113, 120, 123, 152, 202
 Exchangeable effector locus 39

F

fadH 142
fas locus/operon 118–120, 124, 125
 Fen kinase 12, 13, 42, 47, 49
 Fimbriae 143–148
 Fimbrial *see* Fimbriae
fitD 169, 181
 Fitness 19, 93, 94, 141, 176, 199, 200–202, 204–207, 209, 211, 213
 Flagella 40, 63, 65, 92, 93, 109, 144, 148–153, 200, 203
 Flagellin 10, 15, 32, 38, 43, 92, 93, 148, 149, 153
 Flagellin receptor *see* FLS2
 Flagellum *see* Flagella
 FLS2 10, 43–45, 49

Frankia 109, 111
Fusarium 115, 173, 176, 179

G

GacAS 176, 180
Gaeumannomyces 173, 176, 177
Galleria 181
 Galls 103, 109, 117, 120
 Gene Ontology (GO) terms 32, 42–51, 53
 General secretion pathway (*gsp*) 91
 Genome sequence 1, 21, 33, 35, 37, 40, 42, 52, 91, 106, 107, 114, 119–122, 126, 148, 168, 174, 189
 Genomic island 42, 125
 see also Pathogenicity island
 Glycosyl hydrolase 114–115
 GmHID1 20, 46, 50
 GOLD database 174
 Gramineae 88
 Grapevine 108, 182, 183
 Grass 88, 104, 107, 144–146, 155, 173
 Green foxtail 186
 Groundnut 185, 189
 Guard hypothesis 46, 47
 Gumming disease 104, 107

H

Harpins 35, 36, 64, 65, 68–70, 75
 HopAK1 35, 36
 HopP1 35, 36
 HrpN 64–66, 68–70, 75
 HrpW 35, 36, 65–70
 HrpZ1 35, 36
Heliothis 181
 HGT *see* Horizontal gene transfer
 HopAA1 4, 5, 19, 39, 48
 HopAB 4, 5, 11–14, 20, 33, 38, 42
 HopAI 14, 15, 34, 45, 47, 51
 HopF1 6, 42
 HopM1 4, 19, 38–41, 46, 48–52, 66
 HopP1 *see* Harpins
hopQ1-1 5, 37, 38
 HopU1 45, 46, 50
 HopX1 (AvrPphE) 5, 6, 41, 50, 64, 67, 68, 75
 HopZ 5, 15–20, 40, 41, 46, 48–51
 HopZ1 *see* HopZ
 HopZ2 *see* HopZ
 HopZ3 *see* HopZ
 HopZ4 *see* HopZ
 Horizontal gene transfer (HGT) 5, 37–41, 122–125, 126, 167, 176, 179, 190, 199, 206, 211
 Hormone(s) 7, 13, 14, 45, 109, 116, 117, 168
 Host range 2, 38, 68, 75, 86, 122, 146, 201, 202, 208, 209, 212
 Host targets 1, 6, 11, 13, 16, 18–21, 31, 41, 46, 52, 111, 154, 213
 HR *see* Hypersensitive response

Hrp 33
hrp 91
 HrpH 36
 HrpJ 36
hrpL gene 73, 74
 HrpL 73
 see also hrpL gene
 HrpN *see* Harpins
 HrpP 36
hrpS 73, 74
 HrpW *see* Harpins
 HrpW1 *see* HrpW *under* Harpins
 HrpY 91
 HSP90 8
hsv genes 65, 71
 Hydrogen cyanide (HCN) 167, 171, 179, 180, 190
 Hypersensitive response (HR) 2, 6, 7, 18–20, 32, 33, 36, 46, 62, 65–69, 75, 91–94, 153, 154

I

ICE 39, 40, 42, 123–124
 ICEland *see* ICE
 Immunity 1–4, 7, 10–14, 18, 19, 31, 32, 37, 43–46, 67, 91, 93, 109–112, 115–120, 125, 126, 152, 155, 211
 Injectisome 40
 Insect 61, 85, 139
 Insecticidal toxin 167, 169–171, 181, 190
 Integrative conjugative element *see* ICE
In vivo expression technology *see* IVET
 IP6 17, 20
 Iron 63, 71, 72, 167, 168, 177, 180, 190
 IS elements 122–124
 IVET 74, 142

J

JA *see* Jasmonic acid
 Jasmonate *see* Jasmonic acid
 Jasmonic acid (JA) 7, 45, 116–117, 153

K

Kinase 8, 10–13, 16, 17, 20, 42–51, 64, 67, 69, 74, 109
Klebsiella 144, 145, 151, 153, 155
 Konjac 89

L

Leaf blight 84, 88, 213
Leifsonia 102, 105–108, 120–124
Leifsonia xyli subsp. *xyli* *see* *Leifsonia*
Lentinus 188
Leptosphaeria 184, 187
 Lettuce 6, 8, 11, 84, 142–145, 148–152
 Levan 64, 70
 L-Furanomycin 181
 Lipopolysaccharide (LPS) 70, 71, 110, 147, 153, 204, 207, 209

Listeria 89, 101, 140, 141, 144, 148, 149
 LPS *see* Lipopolysaccharide
 LysM 13
 Lysogeny 211
 Lytic phase 200–203, 205, 206, 208, 210–212

M

MAMPs *see* Microbe-associated molecular patterns
 MAMP-triggered immunity *see* PAMP-triggered immunity
Manduca 181
 Mannose 145
 MAPK *see* Mitogen-activated protein kinase
 MAP kinases *see* Mitogen-activated protein kinase
 Massetolide 182, 184, 186
Mcf 181
Medicago 150
 Melon 86, 87, 92, 94, 178
Mesorhizobium 15–16
 Microarray 34, 110, 142
 Microbe-associated molecular patterns (MAMPs) 10, 32, 109–111, 152
 see also Pathogen-associated molecular patterns
 Microtubule network *see* Tubulin
 Mitogen-activated protein kinase (MAPK) 8, 14–17, 20, 44, 47
 MLSA *see* Multilocus sequence analysis
 MLST *see* Multilocus sequence typing
 Mobile genetic elements (MGEs) 39, 40, 42, 122, 123, 211
 Motility 63, 71, 92–94, 105, 145, 148, 151, 182, 188, 203, 204, 207–210
 see also Twitching motility
 Mouse 154
 MPK 8, 15, 44–49, 51, 153
 MPK3 *see* MPK
 MPK4 *see* MPK
 MPK6 *see* MPK
 Multilocus sequence analysis (MLSA) 1, 2, 167, 168, 172, 190
 Multilocus sequence typing (MLST) 37, 52, 53, 157
 Mycolic acids 110
Myxococcus 179

N

NB-LRR 153
nec1 114, 124
 Nematode 154, 181
Nicotiana 68
 N. benthamiana 18–20, 36–39, 43, 47–51, 67, 68, 153, 154
 N. tabacum 48, 68, 69, 70, 112
 see also Tobacco
 NLR proteins 32, 44, 46, 47

Non-ribosomal peptide synthase (NRPS) 116, 172, 174, 178, 190
 NORINE 174, 190
 NRPS *see* Non-ribosomal peptide synthase
 NRPSp website 174

O

Odontotermes 180
 OmpA 144, 147
 Onion 151, 213
 Orchidaceae 89
 Orfamide 174, 182, 185, 188
 OspF 14–15, 20
 Oxygen 176, 177

P

PAI 72, 123–124
 see also Pathogenicity island
 PAMP *see* Pathogen-associated molecular patterns
 PAMP-triggered immunity (PTI) 10, 13, 32, 38, 39, 43, 44–47, 51, 52, 93, 105, 109–112, 116–117, 119–120, 122, 125, 151–153
 Pan-genome 31, 32, 37, 38, 75, 76, 126
Pantoea 1, 2, 5, 6, 117, 145, 175, 213
 P. agglomerans 117, 175, 213
 P. anantiss 145
 P. stewartii 2, 5
 Parsley 146, 151
pat-1 114, 123, 124
 Pathoadaptation 41
 Pathogen-associated molecular patterns (PAMPs) 32, 38, 43–46, 52, 93, 109–111, 142, 148, 151–153
 triggered immunity (PTI) 10, 13, 32, 38, 39, 43, 44–47, 51, 52, 93, 105, 109–112, 116–117, 119–120, 122, 125, 151–153
 see also Microbe-associated molecular patterns
 Pathogenicity island 37, 39, 40, 42, 62, 117, 123, 124, 142, 154, 206
 PPHGI-1 42
 SPI-1 72, 142, 154, 155
 see also PAI
 PCA *see* Phenazine
 pCM1 102, 114, 123
 pCM2 102, 114, 123
 PCN *see* Phenazine
 Peach 141, 173, 212
Pectobacterium 1, 2, 6, 75, 113–114, 141, 175
 Pelle 10–12
 Pepper 6, 11, 147, 182, 183, 187
 Peptidoglycan 13, 32, 110, 152
 Perbergin 120
Peronospora 178
 pFiD188 103, 118–120, 124
 pH 72, 141, 154

- Phenazine 167, 171, 175–177, 182, 183, 188–190
- Phosphothreonine lyase 14–15, 20, 45, 51
- Photorhabdus* 181
- Phyllosphere 105, 186, 200, 202, 204, 207–210, 213
- Phylogeny 2–6, 11, 15, 37, 40, 52, 106, 122, 167, 168, 172, 180
- Phylogroup 1, 2
- Phytoalexins 46, 71
- Phytophthora* 173, 180–187
- Plant and Animal-associated Microbe Gene Ontology Consortium (PAMGO) 43
- Plant-growth promotion 85
- Plant pattern recognition receptors (PRRs) *see* Recognition receptors
- Pleurotus* 185, 188
- Plutella* 181
- Polar flagella 92, 93
see also Flagella
- Polyketide synthase (PKS) 172, 174, 178, 190
- PopP 5, 15–19
- PopP2 *see* PopP
- Potato 102–108, 114–116, 144, 146, 148, 173, 211, 212
- PPHGI-1 42
- Prenylated isoflavanone 112, 120
- Prf 10–12, 46, 47
- Programmable or random *in vivo* assembly shuttle (PRIVAS) system 39
- Promoter 2, 33–35, 72–75, 145
Hrp 2, 33–35, 73, 74
- Promysalin 171, 180
- Prophage 124, 200, 205, 206, 211
see also Temperate phage
- Protease 16, 71, 75, 91, 113–114, 123
cysteine 16–18, 64
serine 102, 114, 123
- Protected core model 51, 52
- PRR 152
- PRR-triggered immunity *see* PAMP-triggered immunity
- Pseudobactin 167
- Pseudogenes 34, 41, 122–123
- Pseudomonas* 1–12, 15, 18–19, 31, 43, 44, 48–53, 66, 68, 75, 85, 89, 90, 111, 116, 144, 145, 148–154, 167–190, 204, 208–210, 213
P. aeruginosa 4, 111, 125, 154, 168–183, 189, 204
species 1, 17, 31, 168, 172, 180
- Pseudomonas*–Plant Interaction website 42
- Pseudomonas syringae* 1–9, 11–12, 15, 18–19, 31–53, 66–71, 91, 116, 117, 144, 148–153, 168–173, 178, 179, 181, 189, 204, 208, 210, 213
pan-genome 31–334, 37, 38
P. syringae pv. *glycinea* 6, 9, 33, 180
P. syringae pv. *phaseolicola* 33–42, 66, 71
P. syringae pv. *syringae* B728a 35, 37, 39, 51
P. syringae pv. *tabaci* 37–39
P. syringae pv. *tomato* 3, 9, 11–15, 32–35, 37–43, 48, 66, 67, 178, 181, 213
P. syringae pv. *tomato* T1 3, 34, 37, 38, 42
- PTI *see* PAMP-triggered immunity
- Pto *see* *Pseudomonas syringae*
- PtoDC3000 *see* *P. syringae* pv. *tomato* under *Pseudomonas syringae*
- Putisolvin 182, 183, 187
- Pyocyanin 171, 175, 207, 209
- Pyoluteorin 171, 178–190
- Pyoverdine 167, 209
- Pyrrrolnitrin 171, 179, 180, 190
- Pythium* 173, 176, 178, 182–188
- ## Q
- Quorum sensing 93, 94, 152, 175, 176, 206, 207
- ## R
- Radish 84, 89, 102, 144, 148
- Ralstonia* 1–2, 5, 12, 15–18, 73, 90, 114, 144, 146, 148, 212, 213
R. solanacearum 2–6, 11, 15–18, 90–92, 144, 146, 148, 212, 213
- RARI 8, 45, 49
- Rathayibacter toxicus* 104, 107, 108
- Reactive oxygen species (ROS) 15, 45, 69, 109, 112, 154, 176
- Receptor-like kinases (RLKs) 10–12, 43, 45, 67
- Recognition receptors (PRRs) 10, 93, 143
- Recombination 40, 41, 123, 124
- Redundant effector groups (REGs) 38, 39
- Resistance 2, 7–12, 18, 31–34, 41, 42, 46, 53, 69, 76, 91–94, 112, 153, 154, 167, 168, 178, 183, 186, 202–213
- Rhamnolipid 176, 182, 183, 209
- Rhizobium* 15–16, 40, 144, 146, 209
- Rhizoctonia* 173, 176, 179, 183, 186–189
- Rhizopus* 180
- Rhizosphere 85, 105, 110, 146, 151, 152, 167, 168, 172, 176–180, 186–189, 200, 207, 208, 213, 214
- Rhizoxin 171, 180
- Rhodococcus* 101, 103, 105, 107–112, 115, 117–126
R. equi 107, 125
R. fascians 103, 107, 109–112, 115–125
R. fascians D188 107, 121–122, 124
R. snyderi 2
Rhodococcus fascians *see* *Rhodococcus*
- Rice 6, 37, 84, 86, 88–91, 93, 118, 144, 147, 177, 180, 186, 208, 212
- RIN4 7–9, 46, 47, 49, 50
- RLK 10–12, 43, 45, 67
- RNASeq 35
- Rocket 144, 148

Root 84, 85, 89, 105, 107–109, 113, 117,
144–146, 148, 150–155, 168, 172, 175, 177,
178, 180, 182, 186, 187, 188, 190, 207

ROS *see* Reactive oxygen species

RPM1 7, 46, 47

RRS1 18–19

Rubus 61, 68, 70

S

SA *see* Salicylic acid

Salicylic acid (SA) 14, 45, 52, 67, 69, 116, 117,
119, 121, 153, 155, 180

Salmonella 14–17, 72, 73, 140–142, 144–155,
157

Scab 69, 102, 103, 107–109, 113–122, 124

Sclerosin 185, 188, 189

Sclerotinia 173, 184, 185, 187, 188

Sclerotium 185, 189

Secondary metabolite 46, 107, 115, 126, 140,
167, 168, 172, 174, 175, 189, 190

Secretin 91

Seedling blight 83

Seedling grow out (SGO) assay 88

Selection 39–43, 109, 112, 123, 148, 152,
203–213

Serratia 179, 181

Siderophore 63, 71, 93, 167, 168

Sigma factor 32, 72–74

Soft rot 2, 113, 141, 211, 212

Soil 1, 83–85, 93, 103, 105, 107, 108, 114, 140,
146, 151, 155, 167, 168, 173, 175, 176, 177, 178,
182, 183, 184, 185, 188, 190, 204, 207–211, 214

Sorbitol 63, 71

Soybean 6, 8–9, 18–20, 33, 46

SPI-1 pathogenicity island 142, 154, 155

Spinach 144–151

Spodoptera 181

Spore 101, 105, 107, 108, 182–188

Staphylococcus aureus 101, 110, 113, 150,
153–155

Stewart's disease 2

Stomata 14, 45, 47, 88, 109, 144, 148–151, 155,
204

Streptomyces 101, 102, 107–110, 113–119,
120–122, 124, 126, 175, 181

Streptomyces acidiscabies *see* *Streptomyces*

Streptomyces scabiei *see* *Streptomyces*

Streptomyces scabies *see* *Streptomyces*

Streptomyces turgidiscabies *see* *Streptomyces*

Streptomycin 62, 213

Stress 11, 45, 70, 71, 108, 116, 125, 141–146,
176, 177, 200, 204, 209

Stunting 102, 107–109, 117

Sugar beet 183–189, 208

Sugarcane 84, 88, 102, 107–108, 186

Symbiont 1, 42–44, 46, 47, 105, 181

Syringomycin 37, 182

Syringopeptin 37, 182, 188

T

T3Es 111
see also Effector

T3SE 1–6, 8–11, 13–15, 18–21, 157
see also Effector

T3SS *see* Type III secretion system

Tat secretion system 113

Tc toxin 181

Temperate phage 200, 201, 203, 205, 210, 211

Temperature 72, 86, 87, 89, 140, 142, 144, 146,
149, 155, 207

Thanamycin 185, 189

Thaxtomin 102–103, 115–116, 118–119

Thielaviopsis 180

Tobacco 10–11, 37, 38, 65–69, 91, 94, 115, 180,
209, 213
see also *N. tabacum* under *Nicotiana*

Tolaasin 182, 185, 188, 189

tomA 114–115, 123–124

Tomato 6, 10–13, 18, 19, 33, 34, 38, 41–43, 45,
47, 91, 102, 105, 110, 114, 115, 123, 141, 142,
144, 147, 150, 173, 178–189, 212, 213

Toxin 2, 37, 52, 65, 67, 70, 71, 91, 101, 107, 110,
115, 116, 167–171, 181, 189, 190, 206

Transposon 33, 35, 39, 62, 92, 125, 146, 154
screens 33, 146

Trichome 109, 150

Tubulin 20, 50

Twitching motility 71, 92, 145, 151, 204
see also Motility

Two-arginine system *see* Tat secretion system

txt genes 116, 120, 124

Type I secretion 63, 65, 71, 111, 113, 144
fimbriae 63, 144, 145

Type II secretion (T2S) 91, 111, 113

Type III 142, 149, 154

Type III secretion system 1–2, 4, 11, 31, 33–41,
46, 47, 62, 65–76, 90, 111, 114, 117, 144,
148–155
effector proteins *see* T3Es
fimbriae 144, 145
secreted effector *see* T3SE

Type IV secretion system 111, 113–114, 144,
146
fimbriae 63, 92, 144–146, 207
pili *see* Fimbriae

Type VII secretion system *see* ESX

U

UV (ultraviolet light) 150, 207, 212, 213

V

Vesicle trafficking 38, 46, 51, 52

Viable but non-culturable (VBNC) 142

vic 115

VirPphA 11, 33
see also AvrPtoB and HopAB

Virulence 1–2, 6–7, 10–14, 20, 33–42, 46, 52,
76, 85, 86, 90–94, 101–126, 142–147, 154, 176,
181, 189, 200, 206, 207, 209

Viscosin 182–189

W

Watermelon 84–93

Web resources 53, 157, 190, 214

Wheat 144, 148, 173, 175, 176, 177, 186

WLIP 182–187

X

Xad 144, 147

Xantholysin 183, 188, 189

Xanthomonas 1–8, 15–20, 73, 75, 90, 91, 144,
147, 148, 154, 183, 185, 187–189, 208, 213

XopAH 5–8

XopAH1 6

XopAL 5–6

Xylella 92, 108, 148

Xylem 61, 70, 92, 101, 105, 107–108, 114, 121,
150

Y

Yag 144

Yersinia 16, 40, 72, 147, 149

YopJ 5, 15–21, 68

Z

ZARI 18, 19, 41