

Contents

Series list	x
Introduction	xx
Acknowledgements	xxiv

Part 1 Understanding and managing resistance

1	How pathogens develop resistance to fungicides: an overview	3
	<i>Richard Oliver, University of Nottingham, UK</i>	
1	Introduction	3
2	Detecting and measuring resistance	4
3	Mechanisms of resistance	7
4	The evolution of resistance	10
5	Conclusion and future trends	14
6	Abbreviations	16
7	Acknowledgements	17
8	Where to look for further information	17
9	References	17
2	Molecular evolution and mechanisms of fungicide resistance in plant pathogenic fungi	21
	<i>Laetitia Chartrain and James K. M. Brown, John Innes Centre, UK</i>	
1	Introduction	21
2	Methyl benzimidazole carbamate: fungicides which target the cytoskeleton	23
3	Azoles: inhibitors of sterol demethylation	27
4	Amines: inhibitors of sterol reductase and sterol isomerase	38
5	Succinate dehydrogenase inhibitors: inhibitors of respiration at Complex II	39
6	Quinone-outside inhibitors: inhibitors of respiration at Complex III	43
7	Conclusion	45
8	Acknowledgements	46
9	References	46

3	Tracking the development of fungicide resistance <i>Francisco J. Lopez-Ruiz, Curtin University, Australia</i>	59
1	Introduction	59
2	Key objectives and requirements in tracking fungicide resistance	60
3	Phenotypic tracking of fungicide resistance	62
4	Developments in genotyping techniques	65
5	Developments in in-field detection and quantification techniques	67
6	Developments in sequencing techniques	70
7	Conclusion and future trends	77
8	Acknowledgements	78
9	References	78
4	Crop disease control efficacy and selection for resistance: two sides of the same coin? <i>Frank van den Bosch, ADAS High Mowthorpe, UK; Stephen Parnell, The University of Warwick Wellesbourne, UK; and Neil Paveley, ADAS High Mowthorpe, UK</i>	89
1	Introduction	89
2	Control versus selection	90
3	Reducing selection while maintaining control: fungicide mixtures	100
4	Two at-risk fungicides	103
5	Generalisation to integrated pest management measures	105
6	Mutual protection	108
7	Conclusion	109
8	Where to look for further information	110
9	References	110
5	Fungicide resistance risk assessment <i>Michael Grimmer, ADAS Boxworth, UK</i>	113
1	Introduction	113
2	Historical development: the risk matrix approach	114
3	Beyond the matrix: a trait-based approach	121
4	Conclusions and future trends	122
5	Where to look for further information	123
6	References	124
6	Good practice in minimising the development of fungicide resistance in crop pathogens <i>Neil Paveley and Frank van den Bosch, ADAS High Mowthorpe, UK</i>	125
1	Introduction	125
2	Resistance management guidance: historical development	126
3	Phases of resistance evolution	128

4	Governing principles of resistance evolution as a foundation of guidance	130
5	Resistance management guidance: future development	131
6	Complementary roles of experiments and modelling to inform resistance management guidance	132
7	Updating resistance management guidance	148
8	Future trends in research	148
9	Where to look for further information	149
10	References	150
7	Fungicide resistance: Evolutionary questions and practical implications <i>Nichola Hawkins, NIAB, UK</i>	155
1	Introduction	155
2	Evolutionary origins	159
3	Adaptive potential and pathogen risks	161
4	Trait complexity and fungicide risk	165
5	Fitness penalties	170
6	Predictability of resistance	173
7	Conclusion and future trends	179
8	Where to look for further information	180
9	References	181
8	The role of Extension in fungicide resistance management <i>Guido Schnabel, Clemson University, USA; and Phillip M. Brannen, University of Georgia, USA</i>	189
1	Introduction	189
2	Case study 1: Establishment of a fungicide resistance management program for gray mold control of strawberry	191
3	Case study 2: The role of Extension in identification and management of resistance in the obligate pathogen <i>Plasmopara viticola</i>	197
4	Case study 3: Development of a novel Extension tool to navigate pesticides and promote fungicide resistance principles	202
5	Conclusion and future trends in research	204
6	References	205
9	Key challenges in developing new fungicides <i>Gregory M. Kemmitt, Corteva Agriscience™, UK</i>	209
1	Introduction	209
2	Past and present fungicide development: a story of success	212
3	Challenges facing fungicide development and registration	218
4	Fungicide resistance: a driver for innovation	223
5	Fungicide development: a look into the future	225
6	Conclusion	229

7	Where to look for further information	229
8	References	230
Part 2 Case studies: resistance in key groups of fungicides		
10	Understanding resistance to sterol biosynthesis inhibitor fungicides <i>Andreas Mehl, Bayer AG, Crop Science Division, Germany</i>	239
1	Introduction	239
2	Sterol biosynthesis inhibitor market and trends	242
3	Short history of demethylation inhibitor fungicides	244
4	Resistance risk and general resistance characteristics of sterol biosynthesis inhibitor fungicides	245
5	Mode of action and mechanisms of resistance	247
6	Examples of resistance	252
7	Recommended uses for resistance management	260
8	Conclusion	262
9	References	263
11	Quinone outside inhibitor fungicide resistance: selection patterns and the current situation <i>Stefano F. F. Torriani and Helge Sierotzki, Syngenta Crop Protection AG, Switzerland</i>	273
1	Introduction	273
2	The history of resistance and resistance mechanisms	276
3	Case study 1: <i>Phakopsora pachyrhizi</i> (soybean - Brazil)	283
4	Case study 2: <i>Cercospora beticola</i> (sugar beet - Europe)	286
5	Case study 3: <i>Plasmopara viticola</i> (grapes - France)	287
6	Current global sensitivity: Qol groups 11, 11A and 45	289
7	Conclusion and future trends	292
8	Where to look for further information	293
9	References	294
12	Understanding resistance to succinate dehydrogenase inhibitor fungicides <i>Wesley Mair, Centre for Crop and Disease Management, Curtin University, Australia</i>	299
1	Introduction	299
2	Mode of action	304
3	Resistance mechanisms	309
4	Fitness cost and resistance risk assessment	316
5	Case study	326
6	Acknowledgements	328
7	References	328

	Contents	ix
13	Understanding resistance to Anilinopyrimidine fungicides <i>Seiya Saito and Chang-Lin Xiao, USDA-Agricultural Research Service, San Joaquin Valley Agricultural Sciences Center, USA</i>	341
	1 Introduction	341
	2 Mode of action	342
	3 Mechanism of resistance	347
	4 Fitness cost	349
	5 Monitoring Anilopyrimidine fungicides resistance	350
	6 Resistance risk management	357
	7 Where to look for further information	359
	8 References	359
14	Understanding resistance to oxysterol binding protein inhibitor fungicides <i>Jean-Luc Genet, Corteva Agriscience, France</i>	367
	1 Introduction	367
	2 Current status of fungicide resistance in oomycetes	369
	3 Mode of action of oxysterol-binding protein inhibitor fungicides	371
	4 Biological activity of oxysterol-binding protein inhibitors	372
	5 Case study: oxysterol-binding protein inhibitor resistance risk assessment	373
	6 Sensitivity monitoring	380
	7 Characterization of resistant mutants	381
	8 Molecular monitoring	382
	9 Use recommendations	382
	10 Conclusion	384
	11 Where to look for further information	385
	12 References	385
	Index	391