

Contents

List of Contributors	xiii
Series Preface	xv
Preface	xvii
Part I Introduction	1
1 Agricultural Functions and Action Mechanisms of Plant Biostimulants (PBs): an Introduction	3
<i>Patrick du Jardin, Lin Xu and Danny Geelen</i>	
1.1 The Biostimulant Concept	3
1.2 The Chemistry of Bioactive Ingredients	9
1.2.1 Striving to Identify the Active Ingredient	9
1.2.2 Chemical Characterization of Traditional Biostimulants	10
1.2.3 Novelty by Targeted Modification of Known Bioactive Molecules	11
1.2.4 Approaches to Screen for New Molecules with Biostimulatory Activity	12
1.3 Defining Mode and Mechanism of Action	14
1.3.1 Journey to the Site of Action	14
1.3.2 Multiple Functions of Bioactive Ingredients	15
1.3.3 Tools for a Multilevel Analysis of PBs Action	16
1.4 Focusing on Key Traits Influenced by Biostimulants	17
1.4.1 Nutrient Use Efficiency (NUE)	17
1.4.2 Increasing Tolerance to Abiotic Stress	19
1.4.3 Crop Quality	22
1.5 Perspective	23
1.5.1 Biostimulants: A New Bandwagon to Move Agriculture Forward?	23
1.5.2 Integration of Biostimulants with Precision Agriculture (PA)	24
1.5.3 What Do We Need for the Future?	24

Author Contributions	25
Acknowledgement	25
Further Reading	25
References	25
Part II Examples of Plant Biostimulants	31
2 Plant Biostimulants from Seaweed: An Overview	33
<i>Wendy A. Stirk, Kannan R.R. Rengasamy, Manoj G. Kulkarni and Johannes van Staden</i>	
2.1 Introduction	33
2.2 Global Trends in Seaweed-Derived Plant Biostimulants	34
2.3 Production Technology	35
2.3.1 Methods of Production	35
2.3.2 Seaweed Biomass Variability	35
2.3.3 Shelf-Life	36
2.4 Beneficial Traits of Seaweed Biostimulants: Recent Developments	37
2.4.1 Improved Plant Growth	37
2.4.2 Increased Tolerance to Abiotic and Biotic Stresses	37
2.4.3 Biofortification	38
2.5 Major Biostimulants in Seaweed Extracts	38
2.5.1 Plant Hormones	38
2.5.2 Brassinosteroids	41
2.5.3 Betaines	42
2.5.4 Polyamines	42
2.5.5 Polymers	43
2.6 Concluding Remarks and Future Prospects	48
Acknowledgement	48
Abbreviations	48
References	50
3 Seaweed Carbohydrates	57
<i>Oscar Goñi, Patrick Quille and Shane O'Connell</i>	
3.1 Introduction	57
3.2 Fucoidan from Brown Algae	60
3.2.1 Detailed Description of Chemical Composition and Structure of Fucoidan	60
3.2.2 Experimental Methods for Chemical Characterization of Fucoidan	63
3.2.3 Fucoidan PB Activity and Potential Applications	64
3.3 Alginate from Brown Algae	64
3.3.1 Detailed Description of Chemical Composition and Structure of Alginate	64
3.3.2 Experimental Methods for Chemical Characterization of Alginate	66
3.3.3 Alginate PB Activity and Potential Applications	67

3.4	Carrageenan from Red Algae	69
3.4.1	Detailed Description of Chemical Composition and Structure of Carrageenan	69
3.4.2	Experimental Methods for Chemical Characterization of Carrageenan	71
3.4.3	Carrageenan PB Activities and Potential Applications	71
3.5	Ulvan from Green Algae	74
3.5.1	Detailed Description of Chemical Composition and Structure of Ulvan	74
3.5.2	Experimental Methods for Chemical Characterization of Ulvan	75
3.5.3	Ulvan PB Activities and Potential Applications	75
3.6	Laminarin from Brown Algae	77
3.6.1	Detailed Description of Chemical Composition and Structure of Laminarin	77
3.6.2	Experimental Methods for Chemical Characterization of Laminarin	78
3.6.3	Laminarin PB Activities and Potential Applications	78
3.7	Cellulose and Hemicellulose Derived Oligosaccharides	79
3.7.1	Detailed Description of Chemical Composition and Structure of Cellulose and Hemicellulose Oligosaccharides	79
3.7.2	Experimental Methods for Chemical Characterization of Cellulose and Hemicellulose Oligosaccharides	80
3.7.3	Cellulose and Hemicellulose Oligosaccharides PB Activity and Potential Applications	80
3.8	Conclusions	81
	Abbreviations	81
	References	82
4	Possible Role for Electron Shuttling Capacity in Elicitation of PB Activity of Humic Substances on Plant Growth Enhancement	97
	<i>Richard T. Lamar</i>	
4.1	Introduction	97
4.1.1	Chemical Nature of HS	97
4.1.2	Sources of Commercial HS	98
4.1.3	Formation of Coal-Derived HS and its Effect on HS Chemical Variation	98
4.2	Similar Responses of Plants to HS and Abiotic and Biotic Stresses	99
4.2.1	Stress Elicitation, Plant Stress Sensing and Commonality of Physiological Responses	99
4.2.2	Redox Activity of HS and Possible Role in Elicitation of Biostimulant Response	100
4.2.3	Common Metabolic Events that are Shared by HS and Stress Elicitors	100
4.3	Humic/Fulvic Elicitation Mechanism	111
	References	112

5	Auxin: At the Crossroads Between Chemistry and Biology	123
	<i>Sara Raggi, Siamsa M. Doyle and Stéphanie Robert</i>	
5.1	Introduction: What Is an Auxin?	123
5.1.1	The Importance of Chemical Structure	123
5.1.2	The History of Natural Auxins	125
5.1.3	The Importance of Synthetic Auxins	126
5.1.4	Auxin Gradients and the Regulation of Plant Growth	126
5.2	Taking Advantage of Auxins: Industrial Applications	128
5.2.1	Auxins as Rooting Agents for Plant Propagation	128
5.2.2	Auxins as Herbicides	129
5.3	Understanding Auxin: The Importance of Chemical Tools in Research	130
5.3.1	Inhibitors of Auxin Metabolism as Research Tools	130
5.3.2	Unravelling Auxin Transport with a Plethora of Chemical Tools	134
5.3.3	Chemical Tools Reveal Complicated Auxin Perception and Signalling Pathways	140
5.4	Conclusions	145
	Acknowledgement	146
	References	146
6	Plant Biostimulants in Vermicomposts: Characteristics and Plausible Mechanisms	155
	<i>Wei San Wong, Hong Tao Zhong, Adam Timothy Cross and Jean Wan Hong Yong</i>	
6.1	Introduction	155
6.2	Advantages of Vermicomposting	157
6.3	General Characteristics of Vermicomposts	159
6.3.1	Mineral Nutrient Composition of Vermicomposts	159
6.3.2	Plant Growth Promoting Properties of Vermicompost	161
6.4	Plant Growth Promoting Substances in Vermicomposts	163
6.4.1	Phytohormones and Mass Spectrometric Evidence to Support Their Occurrence and Functions	163
6.4.2	Vermicompost-Derived Phytohormones as Biostimulants for Plant Growth	168
6.5	Benefits of Integrating Vermicomposts into the Current Plant Production Regime	172
6.6	Conclusion	173
	References	173
	Part III Methods to Screen for New Biostimulants	181
7	Exploring Natural Resources for Biostimulants	183
	<i>Giovanni Povero</i>	
7.1	Introduction	183
7.2	Biological Screening Technologies	187
7.2.1	Overview of Most Used Screening Protocols for Bioactives	187

7.2.2	<i>In vitro</i> Bioassays	187
7.2.3	'Acid Growth' Tests	190
7.2.4	Microphenotyping	191
7.2.5	Genomic Investigation	194
7.2.6	Phenomic Studies	197
7.2.7	Other '-Omics'	200
7.3	Conclusions	201
	References	201
Part IV Biostimulants' Mode of Action		205
8	Biostimulant Mode of Action: Impact of Biostimulant on Whole-Plant Level	207
	<i>Elizabeth Wozniak, Adam Blaszcak, Pawel Wiatrak and Michael Canady</i>	
8.1	Introduction	207
8.2	Crop Growth and Development	208
8.2.1	Crop Yield	208
8.2.2	Crop Quality and Post-Harvest Stability	210
8.2.3	Germination	212
8.2.4	Shoot Growth	213
8.2.5	Root Growth	214
8.2.6	Bloom and Fruit Set	215
8.3	Plant Physiology	216
8.3.1	Nutrient Uptake and Distribution	216
8.3.2	Abiotic and Biotic Stress	218
8.4	Conclusion	220
	References	221
9	Biostimulant Mode of Action: Impact of Biostimulant on Cellular Level	229
	<i>Elizabeth Wozniak, Adam Blaszcak, Pawel Wiatrak and Michael Canady</i>	
9.1	Reactive Oxygen Species (ROS) Control	230
9.2	Membrane Stability and Function	232
9.3	Enzyme Activity	233
9.4	Production of Secondary Metabolites	234
9.5	Production of Plant Growth Regulators (PGRs)	235
9.6	Photosynthetic Pigments and Photosynthesis	236
9.6.1	Photosynthetic Pigments	236
9.6.2	Photosynthetic Processes	237
9.7	Conclusions	237
	References	240
10	Biostimulant Mode of Action: Impact of PBs on Molecular Level	245
	<i>Lin Xu, Hoang Khai Trinh and Danny Geelen</i>	
10.1	Molecular Tools to Unravel Small Molecules Mode of Action	246
10.2	Biostimulant Impact on Plants on the Molecular Level	246
10.2.1	Transcriptional Analysis	247

10.2.2	Proteomic Studies	250
10.2.3	Metabolomic Studies	252
10.2.4	Multiple Approaches in Acquiring Omics Data: A Short Introduction	254
10.3	Conclusions	254
	Acknowledgement	256
	References	256
Part V Biostimulants – A Practical Guide		261
11	Use of Plant Metabolites to Mitigate Stress Effects in Crops	263
<i>Nuria De Diego and Lukáš Spíchal</i>		
11.1	Introduction	263
11.2	Plant Metabolites Used for Stress Mitigation in Crops	264
11.2.1	Amino Acids	266
11.2.2	Polyamines	285
11.2.3	Hormones	286
11.2.4	Combined Application of Different Metabolites	287
11.2.5	Common Mode of Action of the Plant Metabolites to Mitigate Stress	287
11.3	Conclusion	289
	Acknowledgement	290
	References	290
Index		301