

Plant Abiotic Stress

Edited by

MATTHEW A. JENKS

*Center for Plant Environmental Stress Physiology
Purdue University
Indiana, USA*

and

PAUL M. HASEGAWA

*Center for Plant Environmental Stress Physiology
Purdue University
Indiana, USA*



**Blackwell
Publishing**

Contents

Contributors	xi
Preface	xvi
1 Eco-physiological adaptations to limited water environments	1
ANDREW J. WOOD	
1.1 Introduction	1
1.2 Limited water environments	2
1.2.1 Arid and semiarid regions of the world	2
1.2.2 Plant strategies for water economy	4
1.2.3 Ability to survive in water-limited environments	5
1.2.4 Surviving water-deficit (drought) and severe water-deficit (desiccation)	6
1.3 Adaptation to limited water environments	7
1.3.1 Evolution of land plants	7
1.3.2 Tolerance to desiccation	10
1.4 Refresher of the world – how to create more drought-tolerant crops	10
	☉
2 Plant cuticle function as a barrier to water loss	14
S. MARK GOODWIN and MATTHEW A. JENKS	
2.1 Introduction	14
2.2 Cuticle structure and composition	14
2.3 Cuticle function as a barrier to plant water loss	18
2.4 Genetics of cuticle permeability	24
2.5 Conclusions	31
3 Plant adaptive responses to salinity stress	37
MIGUEL A. BOTELLA, ABEL ROSADO, RAY A. BRESSAN and PAUL M. HASEGAWA	
3.1 Salt stress effects on plant survival, growth and development	37
3.1.1 NaCl causes both ionic and osmotic stresses	38
3.1.2 Secondary effects of salt stress	38

3.2	Plant genetic models for dissection of salt tolerance mechanisms and determinant function	39
3.2.1	<i>Arabidopsis thaliana</i> as a model for glycophyte responses to salt stress	40
3.2.2	<i>Thellungiella halophila</i> (salt cress) – a halophyte molecular genetic model	40
3.3	Plant adaptations to NaCl stress	41
3.3.1	Intracellular ion homeostatic processes	41
3.3.1.1	Na ⁺ influx and efflux across the plasma membrane	42
3.3.1.2	Na ⁺ and Cl ⁻ compartmentalization into the vacuole	42
3.3.1.3	K ⁺ /Na ⁺ selective accumulation	44
3.3.2	Regulation of Na ⁺ homeostasis in roots and shoots	44
3.3.3	Sensing and regulatory pathways that control ion homeostasis	45
3.3.4	Osmotic homeostasis: compatible osmolytes	46
3.3.5	Damage response and antioxidant protection	46
3.4	Plant salt tolerance determinants identified by functional genetic approaches	47
3.4.1	Effector genes	52
3.4.1.1	Na ⁺ homeostasis	52
3.4.1.2	Genes involved in osmotic homeostasis: synthesis of compatible solutes	54
3.4.1.3	Genes involved in ROS scavenging	54
3.4.1.4	Genes involved in protection of cell integrity	56
3.4.2	Regulatory genes	56
3.4.2.1	Kinases	56
3.4.2.2	Transcription factors	57
3.4.2.3	Other salt tolerance determinants	58
3.5	Global analysis of transcriptional activation of salt-responsive genes	58
4	The CBF cold-response pathway SARAH FOWLER, DANIEL COOK and MICHAEL F. THOMASHOW	71
4.1	Introduction	71
4.2	<i>Arabidopsis</i> CBF cold-response pathway	72
4.2.1	Discovery and overview	72
4.2.2	CBF proteins	75
4.2.2.1	General properties	75
4.2.2.2	Mechanism of action	76

4.2.3	Function of the CBF cold-response pathway	78
4.2.3.1	Cryoprotective proteins	79
4.2.3.2	Regulatory proteins	81
4.2.3.3	Biosynthetic proteins	82
4.2.4	Regulation of CBF gene expression in response to low temperature	83
4.2.4.1	DNA regulatory elements controlling CBF expression	84
4.2.4.2	Proteins with positive roles in CBF expression	84
4.2.4.3	Proteins with negative roles in CBF expression	85
4.2.4.4	Other potential CBF regulatory proteins	87
4.2.4.5	Light and circadian rhythms	87
4.2.4.6	Role of calcium	88
4.2.4.7	Role of ABA	89
4.3	Conservation of the CBF cold-response pathway	89
4.3.1	<i>Brassica napus</i>	89
4.3.2	Tomato	90
4.3.3	Rice	92
4.4	Concluding remarks	93
5	Plant responses to high temperature	100
	JANE LARKINDALE, MICHAEL MISHKIND and ELIZABETH VIERLING	
5.1	Introduction	100
5.2	Physiological responses to high temperature	101
5.2.1	High temperature limits to optimal plant performance	101
5.2.2	Heat sensitivity of photosynthesis	102
5.2.3	Heat sensitivity of reproduction	104
5.3	Cellular acquired thermotolerance	104
5.4	Heat shock proteins/molecular chaperones	105
5.4.1	<i>Hsp100/ClpB</i>	106
5.4.2	<i>Hsp90</i>	110
5.4.3	<i>Hsp70/DnaK</i>	111
5.4.4	<i>Hsp60/GroE</i>	111
5.4.5	The <i>sHSP</i> family of proteins	112
5.5	Other components of the response to heat	114
5.5.1	Antioxidant production	115
5.5.2	Other heat-stress regulated genes	118
5.5.3	Other heat-protective responses	120
5.5.4	Mutants defective in heat tolerance	121
5.5.5	Transgenic plants with altered heat tolerance	122

5.6	Signaling pathways involved in response to heat	125
5.6.1	Heat shock transcription factors	125
5.6.2	Other signaling pathways	126
5.6.3	Abscisic acid	126
5.6.4	Salicylic acid	127
5.6.5	Calcium	127
5.6.6	Active oxygen species	128
5.6.7	Ethylene	128
5.6.8	Signaling lipids	129
5.6.9	Kinases and phosphatases	129
5.7	Genetic variation in heat tolerance	131
5.7.1	Agricultural/horticultural plants	131
5.7.2	Natural variation in heat tolerance	132
5.8	Summary	132
6	Adaptive responses in plants to nonoptimal soil pH	145
	V. RAMÍREZ-RODRÍGUEZ, J. LÓPEZ-BUCIO and L. HERRERA-ESTRELLA	
6.1	Introduction	145
6.2	Soil pH	146
6.3	Soil acidification	146
6.4	Acid soils	147
6.5	Calcareous soils	148
6.6	Plant responses to soil stress	149
6.7	Plant responses to heavy metals	150
6.8	Aluminum tolerance by exclusion○	150
6.9	Aluminum tolerance by internal accumulation	152
6.10	Metal hyperaccumulators	153
6.11	Plant responses to mineral deficiency	155
6.11.1	Phosphorus deficiency	155
6.11.2	Improving P efficiency in transgenic plants	156
6.11.3	Plant responses to iron deficiency	158
6.12	Morphological responses to mineral deficiency	161
6.12.1	Effects of iron availability on transfer cell formation	161
6.12.2	Effects of nutrient availability on root hair formation	162
6.12.3	Effects of nutrient availability on root branching	162
6.13	Functional genomics for the discovery of genes involved in mineral nutrition	163
6.14	Application of functional genomics to iron and phosphorus nutrition	164

7	Plant response to herbicides	171
	WILLIAM E. DYER and STEPHEN C. WELLER	
7.1	Introduction	171
7.2	Photosynthetic inhibitors	174
7.2.1	Resistance	176
7.3	Biosynthetic inhibitors	177
7.3.1	Branched-chain amino acid synthesis inhibitors	177
7.3.1.1	Resistance	179
7.3.2	Aromatic amino acid synthesis inhibitors	181
7.3.2.1	Resistance	184
7.3.3	Fatty acid synthesis and elongation inhibitors	186
7.3.3.1	Resistance	189
7.3.4	Cellulose synthesis inhibitors	190
7.3.4.1	Resistance	190
7.3.5	Folic acid synthesis inhibitors	190
7.3.5.1	Resistance	191
7.3.6	Nitrogen metabolism inhibitors	191
7.3.6.1	Resistance	191
7.3.7	Quinone synthesis inhibitors	192
7.3.7.1	Resistance	193
7.3.8	Carotenoid biosynthesis inhibitors	193
7.3.8.1	Resistance	194
7.4	Induction of herbicide metabolism	194
7.4.1	Resistance	196
7.5	Protoporphyrinogen oxidase inhibitors	196
7.5.1	Resistance	197
7.6	Mitotic disruptors	197
7.6.1	Resistance	198
7.7	Hormone disruptors	198
7.7.1	Resistance	199
7.8	Genome effects	201
7.9	Summary and future prospects	202
8	Integration of abiotic stress signaling pathways	215
	MANU AGARWAL and JIAN-KANG ZHU	
8.1	Introduction	215
8.1.1	Sensors	216
8.1.2	ROS	218
8.1.3	Calcium	220
8.1.4	Phospholipids	221

8.1.5	SOS pathway	224
8.1.6	SOS3-like Ca^{2+} -binding proteins and SOS2-like protein kinases	227
8.1.7	CDPKs	228
8.1.8	MAPKs	229
8.1.9	ICE1 pathway for cold regulation	230
8.2	Regulation of gene expression by ABA	234
8.3	Conclusions and perspectives	237
8.4	Summary	237
9	Genomic Analysis of Stress Response	248
	MOTOAKI SEKI, JUNKO ISHIDA, MAIKO NAKAJIMA, AKIKO ENJU, KEI IIDA, MASAKAZU SATOU, MIKI FUJITA, YOSHIHIRO NARUSAKA, MARI NARUSAKA, TETSUYA SAKURAI, KENJI AKIYAMA, YOUKO OONO, AYAKO KAMEI, TAISHI UMEZAWA, SAHO MIZUKADO, KYONOSHIN MARUYAMA, KAZUKO YAMAGUCHI-SHINOZAKI and KAZUO SHINOZAKI	
9.1	Introduction	248
9.2	Expression profiling under stress conditions by cDNA microarray analysis	248
9.3	DNA Microarrays are an excellent tool for identifying genes regulated by various stresses	249
9.4	DNA microarrays are a useful tool for identifying the target genes of the stress-related transcription factors	250
9.5	Expression profiling in various stress-related mutants	253
9.6	Rehydration- or proline-inducible genes and functions of their gene products identified by RAFL cDNA microarray	254
9.7	Abiotic stress-inducible genes identified using microarrays in monocots	255
9.8	Many stress- or hormone-inducible transcription factor genes have been identified by the transcriptome analysis	256
9.8.1	7K RAFL cDNA microarray analysis	256
9.8.2	GeneChip analysis	257
9.9	Application of full-length cDNAs to structural and functional analysis of plant proteins	258
9.10	Conclusions and perspectives	259
9.11	Summary	260
	Index	266