
Molecular Aspects of Plant-Pathogen Interaction

Archana Singh • Indrakant K. Singh
Editors

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 Springer

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Preface

Pathogen attack has been one of the chief constraints that reduce crop productivity worldwide. Plants have established sophisticated mechanisms to counter and acclimatize over these invading pathogens at physiological, biochemical as well as molecular levels. Due to severe crop losses by pathogen outbreak, it is mandatory to completely understand the resistance/defense mechanisms against pathogen and develop advanced tactics to improve biotic stress tolerance in crop plants.

We present this book with an objective to realize the plant defense against different pathogens better and to document fundamentals as well as recent findings. This book has an amalgamation of basic information about disease resistance along with current insights into plant-pathogen interaction. The book has 15 chapters to disseminate the most updated information and detailed overviews on the present knowledge on molecular aspects of plant responses and adaptation to biotic stresses. This book is an essential reading for researchers and professionals in plant pathology, cell biology, molecular biology and genetics. This is highly recommended for the ones who are involved in plant disease resistance and crop improvement and to all plant scientists and undergraduates.

Depending on their modes of nutrition, phytopathogens have been categorized as necrotrophs, biotrophs and hemibiotrophs. These pathogens can be bacterial and fungal and cause various diseases in plants. In addition, viruses are another important class of pathogens and are causal agents for many common plant diseases. Plants counter to pathogens by activating a cascade of genes, encoding different receptors, signaling and protective molecules. During biotic stress, first of all effector molecules i.e. pathogen-associated molecular patterns (PAMPs) are perceived by plant recognition receptors (PRRs), after which PRRs interact with additional trans-membrane proteins that act as signaling adapters or amplifiers to achieve full functionality and PAMP triggered immunity (PTI). Defense response by receptor-like protein is a complex strategy, characterized by specific interaction between disease resistance (*R*) genes of plants and corresponding avirulence (*avr*) genes of pathogen that induce effector-triggered immunity (ETI) through hypersensitive response.

The NBS-LRR genes are important class of resistance gene families and their products recognize factors secreted by pathogens, which activates downstream signaling pathways leading to defense. Mitogen-activated protein kinases (MAPKs), which are cell-signaling enzymes that also show vital functions in transmitting extracellular signals to the nucleus during biotic stress. To achieve defense against

pathogen, transcription factors such as WRKY transcription factors bind to plant-specific *cis*-regulatory elements and activate gene expression thereby inducing transcriptional reprogramming and proteomic alterations to coordinate the perception and activation of pathways specific to the type of pathogen in question. Mainly phytohormones, small RNAs and other factors regulate this change at transcript level and protein level. Amongst all the targets, the induction and accumulation of pathogenesis-related (PR) proteins and biosynthesis of secondary metabolites are an integral component of innate immune responses in plants during pathogen attack.

Overall this volume will convey an overview of plant-pathogen interactions and it is a must read to understand this process for the genetic improvement of crops for disease resistance.

We are obliged to the authors of various chapters of this book for writing their chapters methodically and with great responsibility. We are extremely thankful to Dr. Rama, Principal, Hans Raj College, University of Delhi and Dr. Ajay Arora, Principal, Deshbandhu College, University of Delhi for providing overall support for our research and academic pursuits. We would also like to convey our gratitude to Dr. V. K. Kawatra, Mr. P. K. Singh and Dr. Vijay Rani Rajpal for always motivating us. We appreciate the beautiful ambiance created by our little angels Saumya and Kimaya, which allowed us to work tirelessly and gave us all emotional support. We are grateful to our parents for their constant support and blessings. Last but not the least, our sincere thanks to the handling editors and publisher.

We are optimistic that this book will be effective in broadcasting the latest knowledge about the plant-pathogen interaction.

New Delhi, India

Archana Singh
Indrakant K. Singh

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Abbreviations

12-OPDA	12-oxophytodienoic acid
24-EpiBL	24-epibrassinolide
28-HomoBL	28-homobrassinolide
2D-DIGE	Two dimensional differential gel electrophoresis
2D-PAGE	Two dimensional polyacrylamide gel electrophoresis
5-HPT	5-hydroxytryptophan
AABL1	AB15 like1
ABA	Abscisic acid
ABC	ATP binding cassette
ACC	1-aminocyclopropane-1-carboxylic acid
ACMV	African cassava mosaic virus
ACS6	1-aminocyclopropane-1-carboxylic acid synthase
AGO	Argonaute
ALS	Amyotrophic lateral sclerosis
AMV	Alfaalfa mosaic virus
AP2	Apetala2
APAF	Apoptotic protease activating factor
APX	Ascorbate peroxidase
ARID	A/T rich interaction domain
as-1	Activation sequence 1
At	<i>Agrobacterium tumefaciens</i>
AtAGO1	<i>Arabidopsis</i> AGO1
AtEFR	<i>Arabidopsis thaliana</i> EF-TU receptor
AtFSL2	<i>Arabidopsis thaliana</i> flagellin sensing 2
ATRM	<i>Arabidopsis</i> transcriptional regulatory map
ATX1	<i>Arabidopsis</i> homolog of trithorax
Aux	Auxin
Avr	Avirulence
BAK1	BRI1 associated receptor kinase 1
BAW	Beet armyworm
Bc	Botrytis cinerea
BECS	Blumeria effector candidates
BHNs	Broad host range necrotrophs
BIA	β -(Isoxazolin-5-on-2yl)-alanine

BIK1	BRI1 associated kinase
BIN2	Brassinosteroid insensitive 2
BL	Brassinolide
BMAA	β -methylamino-L-alanine
BPH	Brown plant hopper
BRI1	Brassinosteroid insensitive 1
BRs	Brassinosteroids
BWMK1	Blast and wounding activated map KINASE 1
bZIP	Basic domain leucine zipper
CaBD	Calmodulin binding domain
CaM	Calmodulin
CARD	Caspase recruitment domain
Cas	CRISPR associated
CAT	Catalase
CBB	Coomassie brilliant blue
CBD	Chitin binding domain
CC	Coiled coil
CD	C-terminal common docking
cDNA	Complementary DNA
CDPK	Calcium dependent protein kinase
CEBiP	Chitin elicitor binding protein
CED4	Cell death protein 4
CERK1	Chitin elicitor receptor kinase 1
CESA	Cellulose synthase catalytic subunit
CGs	Cytogenic glycosides
ChIP	Chromatin immunoprecipitation
CHS	Chalcone synthase
CKs	Cytokinins
CMV	Cucumber mosaic virus
CNR	Crinkler & necrosis
Col	Columbia
COR	Coronatine
COX5	Cytochrome oxidase subunit v
CP	Coat protein
CRISPR	Clustered regularly interspaced short palindromic repeats
CSEPs	Candidate secreted effector protein
CT	P-coumaroyl tyramine
CWDE	Cell wall degrading enzymes
D	Aspartate
DAMPs	Damage associated molecular patterns
DCL	DICER-like
DGE	Differential gene expression
DHAR	Dehydroascorbate reductase
DMT	DNA methyl transferase
DORN1	Does not respond to nucleotide 1

DRBs	Double stranded RNA binding proteins
DRE	Dehydration responsive element
dsDNA	Double stranded deoxyribonucleic acid
dsRNA	Double stranded Ribonucleic acid
DTI	Danger triggered immunity
eATP	Extracellular ATP
EBL	Epibrassinolide
ECC	<i>Erwinia carotovora</i>
ECM	Extra cellular matrix
ECS	Endocytosis cell signaling
EDS 1	Enhanced disease susceptibility 1
EF	Elongation factor
EFR	EF-Tu receptor
EF-Tu	Elongation factor Tu
EHC	Encasement of the haustorial complex
EHM	Extra haustorial membrane
EIX	Ethylene inducing xylanase
ELISA	Enzyme-linked immunosorbent assay
eLRR	Extra cytoplasmic leucine rich repeat
EPD	Eukaryotic promoter domain
EPSs	Extracellular polysaccharides
ER	Endoplasmic reticulum
ERE	Ethylene responsive elements
EREBP	Ethylene responsive element binding protein
ERF	Ethylene response factor
ESI	Electrospray ionization
ESTs	Expressed sequence tags
ET	Ethylene
ETI	Effector triggered immunity
ETR2	Ethylene resistant 2
ETS	Effector-triggered susceptibility
FISH	Fluorescence in-situ hybridization
FLAK	Phenylalanine, leucine, alanine, lysine
Flg	Flagellin
FLS 2	Flagellin sensing 2
FMs	Functional markers
FT	Feruloyl tyramine
GA	Gibberellic acids
GC-MS	Gas chromatography mass spectrometry
GE	Glucan elicitor
GEBP	GE-binding protein
GM	Genetically modified
GNA	<i>Galanthus nivalis</i> agglutinin
GR	Glutathione reductase
GST	Glutathione s-transferase

HCN	Hydrogen cyanide
HCRSV	Hibiscus chlorotic ringspot carmovirus
hc-siRNAs	Heterochromatic small interfering RNAs
HDA19	Histone deacetylase 19
HeMV	Hempene mosaic virus
HEN1	HUA ENHANCER
HGA	Homogalacturonam
HMGR2	3-hydroxy-3-methylglutaryl CoA reductase 2
HPLC	High performance liquid chromatography
HR	Hypersensitive response
hrc	HR and conserved
hrp	Hypersensitive reaction and pathogenicity
HSN	Host specific necrotroph
HSPs	Heat shock proteins
HSTs	Host specific toxins
HVMK4	<i>Hordeum vulgare</i> signaling protein MAP kinase 4
HYL1	Hyponastic leaves 1
IAA26	Indole-3-acetic acid transcription factor
ICAT	Isotope coded affinity tag
IEF	Isoelectric focusing
IP-ELISA	Immune virus particle-ELISA
IPG	Immobilized pH gradient
IPP	Isopentenyl diphosphate
IPT	Isopentyl transferase
ISR	Induced systemic resistance
ITRAQ	Isobaric tagged for relative and absolute quantitation
JA	Jasmonic acid
JARE	Jasmonic acid responsive element
JS	Justamembrane
LC	Liquid chromatography
LC-MS/MS	Liquid chromatography-tandem mass spectrometry
L-DOPA	L-3,4-dihydroxyphenylalanine
LEA	Late embryogenesis abundant
LecRK	Lectin receptor kinase
Ler	Landsberg erecta
LGD1	Lagging growth development 1
LIR	Localised induced responses
LOS	Lipo-oligosaccharide
LPS	Lipopolysaccharide
LRK	LRR kinase
LRR	Leucine rich repeat
lsiRNAs	Long small interfering RNAs
LTP	Lipid transfer protein
LYK3	LysM receptor like kinase 3
LZNBS-LRR	Leucine zipper nucleotide binding site leucine rich repeat

m/z	Mass to charge ratio
MALDI	Matrix assisted laser desorption/ionisation
MAMPs	Microbe associated molecular patterns
MAPK	Mitogen activated protein kinase
MCPs	Methyl accepting chemotaxis proteins
MDP	Muramyl dipeptide
MeJA	Methyl jasmonate
MIMPs	Microbe induced molecular patterns
miRNA	MicroRNA
MKK	MAP kinase kinase
MKS	MPK4 substrate
MLA 10	Mildew resistance locus A10
MoAGOs	<i>M. oryzae</i> genome encoded AGOs
MoDCL1	<i>M. oryzae</i> genome encoded DCL1
MoDCL2	<i>M. oryzae</i> genome encoded DCL2
MPs	Movement proteins
MPSS	Massively parallel signature sequencing
MS	Mass spectrometry
MSUD	Meiotic silencing of unpaired DNA
MTA	5'-methylthioadenosine
MTI	MAMP triggered immunity
MTI	Microbial associated molecular pattern(MAMP) triggered immunity
MudPIT	Multidimensional protein identification technology
NAG	N-acetylglucosamine
NAM	N-acetyl muramic
NAMP	Nematode associated molecular pattern
NASBA	Nucleic acid sequence based amplification
nat-siRNAs	Natural antisense transcript-derived small interfering RNAs
NBS	Nucleotide binding site
NDPR	Non-pathogen derived resistance
NDR 1	Non race specific disease resistance 1
NEP1	Necrosis and ethylene inducing protein 1
NF	Nodulation factor
NFP	NOD factor perception
NGS	Next generation sequencing
NLPs	Necrosis and ethylene inducing peptide 1 like proteins
NLPs	Nep L like proteins
NLS	Nuclear localization signal
NO	Nitric oxide
NOD	Nucleotide binding oligomerization domain
NPAA	Nonprotein amino acids
NRG1	N-requirement gene
NtMKP1	Tobacco MAP kinase phosphatase 1
nTNL	Non TIR-NBS-LRR
O ₂	Oxygen

OBF	Octopine synthase element binding factor
Obpv	Obuda pepper virus
OG	Oligogalacturonides
ORCAs	Octadecanoid responsive catharanthus APETALA2 domain proteins
Osa	<i>Oryza sativa</i>
osNramp6	osa-miRNA negative regulation of natural resistance associated macrophage protein 6
PAB	Plant associated bacteria
PAD3	Phytoalexin deficient 3
PAL	Phenylalanine ammonia lyase
PAMPs	Pathogen associated molecular pattern
PCD	Programmed cell death
PCR	Polymerase chain reaction
PD	Plasmodesmata
PDR	Pathogen derived resistance
Pel	Pectate lyase
PEN	Penetration genes
PepMV	Pepino mosaic virus
PEST	Pro-Glu-Ser-Thr
PG	Polygalactouronases
PGIP	Polygalactouronase inhibiting protein
PGN	Peptidoglycan
pI	Isoelectric point
PKs	Protein kinases
PLRV	Potato leafroll virus
PMEs	Pectin methyl esterases
PNPs	Plant natriuretic peptides
Pop	<i>Pseudomonas</i> outer protein
PPO	Poly phenol oxidase
PPP	Pentose phosphate pathway
PPV	Plum pox potyvirus
PR	Pathogenesis related
PR1	Pathogenesis related elements
pre-miRNA	Precursor miRNA
pri-miRNA	Primary-miRNA
PRLs	PR like proteins
PRRs	Pathogen recognition receptors
PRRs	Pattern recognition receptors
PRSV	Papaya ring spot virus
PS I	Photosystem I
PS II	Photosystem II
PSE1	Penetration specific effector 1
PstDC3000	Pathovar tomato strain DC3000
PTA-ELISA	Plate trapped antigen-ELISA
PTGS	Post transcriptional gene silencing

PTGS	Post translational gene silencing
PTI	PAMP triggered immunity
PTMs	Post translational modification
PVX	Potato virus X
PVY	Potato virus Y
PX	Peroxiredoxins
QAs	Quinolizidine alkaloids
qPCR	Real time quantitative PCR
QS	Quorum sensing
QTL	Quantitative trait loci
R	Resistance
RALF	Rapid alkalisation factor
ra-siRNAs	Repeat associated small interfering RNAs
RdDM	RNA-directedDNAmethylation
RDR	RNA dependent RNA polymerase
RDV	Rice dwarf virus
REL	Reticuloendotheliosis
REn	Replication enhancer
RenSeq	R gene enrichment and sequencing
RGC2	Resistance gene candidate 2
RIP	Repeat induced point
RISC	RNA induced silencing complex
RLCKs	Receptor like cytoplasmic kinases
RLK	Receptor like kinase
RLP	Receptor like protein
RMs	Random markers
RNAi	RNA interference
RNS	Reactive nitrogen species
ROMT	Resveratrol-o-methyltransferase
ROS	Reactive oxygen species
RP	Reverse phase
RPA	Reverse phase protein microarray
RPW8	Resistance to powdery mildew 8
Rsp1	Repetitive secreted protein 1
RSS	RNA silencing suppressors
RTD	Read through domain
RTP	Read through protein
RT-PCR	Reverse transcriptase-PCR
RUBISCO	Ribulose-1,5-biphosphate carboxylase oxygenase
RYMV	Rice yellow mottle virus
SA	Salicylic acid
SAGE	Serial analysis of gene expression
SAM	S-adenosyl methionine
SAR	Systemic acquired resistance
SARE	Salicylic acid responsive elements

SARE	SA-responsive element
SCF	SKP1-cullin-f-box protein
SCX	Strong cation exchange
SDS-PAGE	SDS- polyacrylamide gel electrophoresis
SE	Sieve element
See1	Seedling efficient effector 1
SEL	Size exclusion limit
SERK3	Somatic embryo receptor kinase 3
SIB1	Sigma factor binding protein 1
SIPK	Salicylic acid protein kinase
SIS	Sex induced silencing
SMV	Soybean mosaic virus
SNARE	Soluble N-Ethylmaleimide-sensitive factor attachment protein receptor
SNPs	Single-nucleotide polymorphisms
SOD	Superoxide dismutase
sRNAs	Small RNAs
ssDNA	Single stranded deoxyribonucleic acid
SSEM	Serologically specific electron microscopy
SSH	Suppression subtractive hybridization
SSITL	<i>Sclerotinia sclerotiorum</i> integrin like
SSPs	Small secretory proteins
SSR	Simple sequence tags
ssRNA	Single stranded ribonucleic acid
SSRs	Simple sequence repeats
STAND	Signal transduction ATPases with numerous domains
STB	Septoria tritici blotch
STS	Stilbone synthase gene
SYMRK	Symbiosis receptor kinase
ta-siRNAs	Trans-acting small interfering RNAs
TBP	TATA-box -binding protein
TCNL	TIR-CC-NBS-LRR
TCV	Turnip crinkle virus
TFs	Transcription factors
TGB	Triple gene block
TGS	Transcriptional gene silencing
THI2.1	Thionin 2.1
TIPK	Trichoderma induced MAPK
TIR	Toll interleukin 1 receptor
TLR 4	Toll like receptor 4
TMV	Tobacco mosaic virus
TNL	TIR-NBS-LRR
TOF-MS	Time of flight mass spectrometry
TrD	Transmembrane domain
tRNA	Transfer RNA

TSWV	Tomato spotted wilt virus
TTSS	Type three secretion system
TuMP	Turnip mosaic virus
TVMV	Tobacco vein molting virus
TYLCD	Tomato yellow leaf curl disease
VIP1	VirE2 interacting protein 1
VOCs	Volatile organic compounds
VRC	Viral replication complex
vRNP	Viral ribonucleoprotein complex
W	Tryptophan
WAK1	Wall associated kinase 1
WIPK	Wound induced protein kinase
Xop	Xanthomonas outer protein