Govind Singh Saharan · Naresh K. Mehta
Prabhu Dayal Meena

Powdery Mildew Disease of Crucifers: Biology, Ecology and Disease Management

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ISBN 978-981-13-9852-0 ISBN 978-981-13-9853-7 (eBook)
https://doi.org/10.1007/978-981-13-9853-7

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

Crucifers are crops grown all over the world in temperate, cool temperate, continental, and sub-tropical regions. Economically important crucifers include oil yielding, vegetable, fodder, and horticultural *Brassica* crops. Several weeds also belong to family Cruciferae. The crucifer *Brassica* vegetables constitute major source of vitamins, fiber, minerals, and proteins in human diet, while *Brassica* oilseeds are major source of quality vegetable oil and cake for animal feed. The demand for *Brassica* vegetables and oil is consistently increasing every year all over the globe. Crucifer crops are threatened by several biotic and abiotic stresses under variable and changing climatic conditions wherever these are cultivated. Out of biotic stresses, powdery mildew (belonging to Erysiphales) is the most widespread and devastating disease causing yield losses both quantitatively and qualitatively. It has been reported that it is capable of causing up to 90 percent loss in oil quality and up to 7 percent in quantity. Powdery mildew being a favorable host-pathogen system has been largely exploited as model for basic research on host-parasite interactions, developmental morphology, cytology, and molecular biology to detect effective proteins/genes governing different biological functions. *Arabidopsis thaliana* has been

widely used as a tool for molecular and genetic studies. This book *Powdery Mildew Disease of Crucifers: Biology, Ecology and Disease Management* is a comprehensive treatise on important disease of crucifers encompassing most of the published information. The information in this book has been arranged in 11 different chapters with appropriate headings and subheadings. Photographs, graphs, figures, tables, and references stimulate interest and better comprehension of the description on the disease. This book provides much needed background and current information projecting future priorities, areas of research, and methodologies. It ensures its place as a central document necessary for the Brassicalogists of the world for further investigations on this host parasite system.

The book has been crafted as the most useful document with a wide range of logically organized and easily accessible information. The authors have already contributed books on Sclerotinia diseases, White rust disease, *Alternaria* diseases, and downy mildew diseases of crucifers published by Springer. I congratulate Drs. G. S. Saharan, Naresh Mehta, and P. D. Meena for bringing out this publication which is an addition to the series and outcome of their lifelong professional interest and expertise. I am sure it will be useful for researchers, teachers, students, extension experts, industrialists, and farmers.

Honorary Professor
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S. S. Chahal

Former Vice-Chancellor MPUA&T
Udaipur, Rajasthan, India

Preface

Powdery mildews are one of the world's most frequently encountered pathogenic fungi causing quantitative and qualitative yield losses in all kinds of annual and perennial, horticultural and ornamental, cash, and industrial crops, forest trees, shrubs, grasses, and all kinds of vegetation in tropical, sub-tropical, and temperate regions of the world. It is fourth most widespread and devastating disease on cruciferous crops causing yield losses up to 90 percent with loss in oil quality and up to 7 percent in rapeseed-mustard quantity. Powdery mildews are often very conspicuous owing to their profuse production of conidia on the host surface in the form of white granular coating giving them their common name. Powdery mildews are also favorable host-pathogen system as model for basic research on host-parasite interactions, developmental morphology, cytology, and molecular biology to dissect effector proteins/genes governing different biological functions. This book *Powdery Mildew Disease of Crucifers: Biology, Ecology and Disease Management* is a comprehensive treatise on the fourth most important disease of crucifers encompassing all the published information which will be useful for researchers, teachers, students, extension experts, industrialists, and farmers. The information has been arranged in 11 chapters with appropriate headings and subheadings, illustrations, photographs, graphs, figures, tables, histogram, colored plates of micrographs, electron micrographs, and flow charts for effective and stimulating comprehension by the readers. The different chapters of the book include detailed information on the status of disease and pathogen; the disease, its distribution, symptomatology, host range, yield losses, and disease assessment; pathogen, its taxonomy, morphology, phylogeny, variability, sporulation, survival, and perpetuation; spore germination, infection, pathogenesis, disease cycle, epidemiology, forecasting, and fine structures; mechanisms of host resistance, biochemical, histological, genetic, and molecular including cloning and mapping of R genes; sources of resistance, disease resistance breeding strategies, and genetics of host-parasite interactions; disease management through cultural, chemical, biological, host resistance, and integrated approach; and standardized reproducible techniques. Although we have taken every

care to seek permission from the authors/publishers to include their valuable contributions in this book, nevertheless inadvertently for any error, we humbly request to excuse us. All sources have been duly acknowledged. We owe the responsibility for any error or omission and are open to include your suggestions in the revised editions.

Hisar, Haryana, India — Govind Singh Saharan
Hisar, Haryana, India — Naresh K. Mehta
Bharatpur, Rajasthan, India — Prabhu Dayal Meena

Acknowledgments

Authors are very grateful to the following persons/scientists/publishers/societies/journals/institutes/websites and all others whose valuable materials such as photographs (macroscopic, microscopic, electron micrographs, scanning electron micrographs), drawings, figures, histograms, graphs, tables, flow charts, etc. have been used through reproduction in the present document. The details of the author(s)/source(s) from where the material was adopted can be obtained from the reference section of the book.

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B. **Journals**

Agricultural Science and *Technology*
Botanica Helvetica
CBS Biodiversity Series
Cellular Microbiology
Crop Protection
Current Opinion in Plant Biology
Frontiers in Plant Science
International Journal of Advanced Research
International Journal of Plant Protection
Journal of Experimental Botany
Journal of Oilseed Brassica
Journal of Plant Diseases and Protection
Mausam
Molecular Plant-Microbe Interactions
Molecular Plant Pathology
Mycological Research
Mycological Society of America
Mycopathologia

New Phytologist
Nova Hedwigia
Plant Breeding
The Plant Cell
Plant Disease Research
Plant Methods
Plant Pathology
Plant Pathology Journal
PLOS One
Proceedings of the National Academy of Sciences of the United States of America
Scientific Reports
The Arabidopsis Book
The Plant Journal
Trends in Biosciences Journal
World Applied Sciences Journal

Websites

http://www.ncbi.nl.nih.gov/
www.genevestigator.com
https://www.genevestigator.ethz.ch/andATGenExpress (http://www.arabidopsis.org/info/ expression/ATGenExpress.jsp)

Publishers

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Institutions

Agriculture and Agri-Food Canada, Saskatoon Research and Development Centre, Saskatoon, Canada
Canadian Phytopathological Society
CCS Haryana Agricultural University, Hisar, India
Global Council for Innovation in Rapeseed and Canola (GCIRC)
ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, India
Indian Council of Agricultural Research, India
Indian Phytopathological Society
Indian Society of Mycology and Plant Pathology
International Development Research Centre, Ottawa, Ontario, Canada

Mycological Society of America
University of Arizona, School of Plant Sciences, USA
Society for Rapeseed-Mustard Research
The American Phytopathological Society
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The British Society for Plant Pathology
The Korean Society of Plant Pathology

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MycoBank, International Mycological Association
Systematic Mycology and Microbiology Laboratory Fungal Database, US Department of Agriculture

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About the Authors

Prof. (Dr.) Govind Singh Saharan, former Professor and Head, Department of Plant Pathology, retired from the active service in 2002. He did his B.Sc. Agriculture (1965) and M.Sc. Agriculture (1967) from SKN College of Agriculture, Jobner, University of Udaipur, and Ph.D. (1977) from Himachal Pradesh University, Palampur, India. He served as Lecturer (1967–1976) and Assistant Professor (1976–1980) at HPKV, Palampur, and as Associate Professor (1980–1988), Professor (1988–2002), and Professor and Head (2002) at the Department of Plant Pathology, CCS Haryana Agricultural University, Hisar. He has been a Visiting Professor at the Department of Plant Sciences, University of Alberta, Edmonton, Canada (1991 and 1994); Agriculture and Agri-Food Canada, Saskatoon Research and Development Centre, Saskatoon, Canada (1991, 1994, 1997); and Rothamsted Research, IACR, Harpenden, UK (1994 and 1997).

Dr. Saharan has more than 250 research publications in journals of national and international repute. He has been Editor of books, such as *Diseases of Oilseed Crops*, *Annual Review of Plant Pathology*, *Phytopathological Techniques*, *Plant Pathology at a Glance*, and *Plant Pathological Research Problems and Progress*, and Author of books such as *Diseases of Oilseed Crops* (in Hindi); *Sclerotinia Diseases of Crop Plants: Biology, Ecology and Disease Management*; *White Rust of Crucifers: Biology, Ecology and Management*; *Alternaria Diseases of Crucifers: Biology, Ecology and Disease Management*; and *Downy Mildew Disease of Crucifers: Biology, Ecology*

and Disease Management. He has authored monographs on white rust, *Alternaria* blight, and downy mildew diseases of rapeseed-mustard, including 5 bibliographies and 40 review articles in books. He is on the Panel of Experts of State Agricultural Universities, Indian Council of Agricultural Research, Central Scientific and Industrial Research, University Grant Commission, and Department of Biotechnology in India. He has contributed immensely in the preparation and release of Crop Protection Compendium (2002), CAB International, UK. He has guided three M.Sc. and eight Ph.D. students who are well-established scientists at different universities and research organizations in India and abroad.

Dr. Saharan has conducted research in diverse fields of plant pathology including standardization of artificial inoculation techniques, identification of sources of resistance, determination of pathogenic variability, genetics of host-parasite interaction, epidemiology, and management of several diseases. He has been President (North Zone) of the Indian Phytopathological Society (2001), Editor-in-Chief of the *Journal of Mycology and Plant Pathology* (1999–2000) and *Journal of Oilseed Brassica* (2012 to date), and President of the Indian Society of Mycology and Plant Pathology (2009). He has also played a major role in the organization of the global and Asian congress by the leading Phytopathological Societies of India. He has been Member of QRT, ICAR, New Delhi, for the Soybean (2010) and Rapeseed-Mustard (2015). He has been awarded with Y. L. Nene Outstanding Plant Pathology Teacher Award (2015) by the Indian Society of Mycology and Plant Pathology, Udaipur, India. He has been bestowed with Life Time Achievement Award (2017) for his outstanding research leadership and expertise in Oilseed Brassica Research by the Society for Rapeseed-Mustard Research, Bharatpur, India.

Prof. (Dr.) Naresh Kumar Mehta completed his B.Sc. Agriculture (Hons.) in 1978 and M.Sc. Plant Pathology in 1980 from Haryana Agricultural University, Hisar. He obtained his Ph.D. degree in 1993 in Plant Pathology from CCS HAU, Hisar, under the guidance of Dr. G. S. Saharan. During his study, he attained his first position in elective Plant Protection at Bachelor's degree level. He is the recipient of Excel Industries Ltd., Bombay, India, Award as Research Fellowship for Master's degree program and "Senior Research Fellowship" (SRF) Award to pursue his Ph.D. program by the Council of Scientific and Industrial Research (CSIR), New Delhi. He was awarded Ms. Manju Utereja Memorial Gold Medal for best Ph.D. thesis (1993–1994).

Dr. Mehta joined as Assistant Scientist (Plant Pathology) in 1981, Scientist/Associate Professor in 1994, and Professor in 2002 at CCS, HAU, Hisar. He was Co-Principle Investigator in the scheme "Pathogenic variability and epidemiology of Alternaria Brassicae" funded by ICAR, New Delhi.

He has been teaching Plant Pathology courses to undergraduate and postgraduate students. He has guided five M.Sc. (Plant Pathology) and two Ph.D. students and was Member of many students' advisory committees. He is the Recipient of Best Poster Paper Award for the year 2005 by the INSOPP and Indian Phytopathological Society (NZ). His students have been awarded P.R. Verma M. Sc. Student Thesis Award for the year 2009 by the Indian Society of Mycology and Plant Pathology and M.J. Narasimhan Academic Awards (NZ) by Indian Phytopathological Society, New Delhi, for the year 2010.

He has conducted research in diverse fields of plant pathology covering pathogenic variability, genetics of host-pathogen interaction, epidemiological studies, identification of resistant sources, biochemical/genetic basis for resistance, residual analysis of fungicides, and disease management.

Dr. Mehta was Member of Expert Committee, UGC, New Delhi, for 12 B status for The Gandhigram Rural Institute-Deemed University, Gandhigram, Tamil Nadu.

Dr. Mehta is one of the editors of the book entitled *Diseases of Oilseed Crops* published by Indus

Publishing Co., New Delhi, and one of the authors of three books, i.e., *Sclerotinia Diseases of Crop Plants: Biology, Ecology and Disease Management*, *Alternaria Diseases of Crucifers: Biology, Ecology and Disease Management*, and *Downy Mildew Disease of Crucifers: Biology, Ecology and Disease Management* published by Springer. He has published more than 100 research papers in the journals of national and international repute. In addition, 11 review articles, 20 book chapters, 10 practical manuals, 26 lead lectures in the conferences, 91 research paper presentations in the conferences, 35 popular articles, and 13 radio/TV talks are to his credit.

Dr. Mehta is Fellow of the Indian Phytopathological Society (FPSI), New Delhi; the Indian Society of Plant Pathologist (FINSOPP), Ludhiana; and the Indian Society of Mycology and Plant Pathology (FISMPP), Udaipur. He has been on the editorial board of the Indian Phytopathological Society (2012–2013; 2017–2019), Councilor (North Zone) of ISMPP (2005, 2011), Member of the editorial board (2012–2014), and Editor-in-Chief during 2014. He is also Member of the editorial board of the Indian Society of Plant Pathologist, Ludhiana (2017–2018).

Dr. Mehta has been a Visiting Scientist at the University of Alberta, Edmonton, Canada, in 1999 and as a FAO Fellow and presented a research paper in 8th International Congress of Plant Pathology at Christchurch, New Zealand, in 2002. He was invited to deliver lectures in the 9th International Congress of Plant Pathology at Torino, Italy, in 2008, and in the 5th International Conference on Plant Pathology "Plant Pathology in the Globalized Era," New Delhi, in 2009. He has delivered lead lecture in the 3rd Global Conference "Plant Pathology for Food Security" during 2012 with several lead lectures in the national conferences held from time to time.

Dr. Prabhu Dayal Meena is working as Principal Scientist (Plant Pathology) at the ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, Rajasthan, India. He started his carrier in the Indian Council of Agricultural Research in 1989 as a Senior Technical Assistant at Central Soil and Water Conservation Research and Training Institute, Dehradun. He obtained his B.Sc. Agriculture (1987) from the University of Rajasthan, Jaipur; M.Sc. Agriculture and Plant Pathology (1997) from Rajasthan Agricultural University, Bikaner; and Ph.D. in Botany (2005) from the University of Rajasthan, Jaipur. He has developed garlic bulb aqueous extract (2 % w/v) as botanical product for control of *Sclerotinia* rot and *Alternaria* blight diseases of mustard. He has identified, namely, white rust resistance genotypes NRCDR 515, DRMR 2019, DRMR 2035 and involved in the development of NRCDR-02, NRCHB-506, NRCHB-101, NRCDR-601 cultivars of *Brassica juncea*, and NRCYS-05-2 of *B. rapa* ssp. yellow sarson.He developed weather-based forecasting models for rapeseed-mustard diseases. He has also developed screening methods for different diseases of oilseed Brassica. Dr. Meena published more than 85 research papers, 5 reviews, and 13 book chapters in international and national reputed refereed journals and is also one of the authors of the 6 books entitled *Principles of Plant Breeding, White rust of crucifers: Biology, Ecology and Management; Alternaria blight of crucifers: Biology, Ecology and Management; Downy Mildew Disease of Crucifers: Biology, Ecology and Disease Management; Brassica Oilseeds Breeding and Management; and Climate Change and Sustainable Agriculture*. He has been a Member of Monitoring Team for All India Coordinated Research Project on Rapeseed Mustard during 2004–2019.

Dr. Meena honored as a Fellow of the Indian Society of Mycology and Plant Pathology and Fellow of the Plant Protection Association of India and has also been awarded with Dr. P.R. Kumar Outstanding Brassica Scientist Award in 2011, Brassica Gold Medal 2019 by the Society for Rapeseed-Mustard Research. He has served as Councilor of the Plant Protection Association of India, the Founder Secretary of the Society for

Rapeseed-Mustard Research since 2008, and Managing Editor (2012–2019) for the *Journal of Oilseed Brassica*.

Dr. Meena has been a Principal Investigator (PI) and Co-PI for ICAR-Outreach Programme on Diagnosis and Management of Leaf Spot Diseases in Field and Horticultural Crops (2009–2013), ICAR-Network Project on Transgenics in Crops (Functional Genomics Component for *Alternaria* and Drought), and National Network for Management of *Alternaria* blight in *Brassica juncea* and Vegetable Crops (2004–2008), All India Coordinated Research Project on Rapeseed-Mustard (2017 to continue).

He undertook 3 months of research attachment training (2007) at the Rothamsted Research, Harpenden, UK, under Indo-UK Collaborative Research on Oilseed Brassica crops. He has supervised nine M.Sc. students and co-supervised one Ph.D. student.

Abbreviations

%	Percent
/	Per
@	At the rate of
~	Tilde
<	Less than
=	Is equal to
>	More than
≥	Greater than or equal to
µl	Microliter
µm	Micrometer
µmol	Micromoles
4M13G	4-methoxy-indol-3-ylmethyl-glucosinolate
a.i.	Active ingredient
AAA- ATpase	ATpase associated with diverse cellular activities
ABA	Abscisic acid
ABC	ATP-binding cassette
ADFs	Actin depolymerizing factors
AICRPRM	All India Coordinated Research Project on Rapeseed and Mustard
ALD	Aminotransferase AGD2-like defense response protein
AM fungi	Arbuscular mycorrhizal fungi
ANN	Artificial neural network
ARF-GAP	ARF-GTPase-activating protein
ARF-GEF	ADP ribosylation factor-GTP exchange factor
At	*Arabidopsis thaliana*
At STP	*Arabidopsis* sugar transport protein
ATAF	*Arabidopsis thaliana* activating factor
ATG	Autophagy-related gene
ATL	*Arabidopsis* toxicos en levadura
AUDPC	Area under the disease progress curve
Avp. E	Evaporation evening

Avp. M	Evaporation morning
Avr	Avirulence
BC	Backcross
BC/Ratio	Benefit-cost ratio
BDM	2,3-butanedione monoxime
BEC	Bgh effector candidate
Bgh	*Blumeria graminis* f. sp. *hordei*
bHLH	Basic helix-loop-helix
BI-1	Bax inhibitor -1-(endoplasmic reticulum-resident cell death suppressor)
BjNPR	*Brassica juncea* NPR
CA	Constitutively activated
CAM	Calmodulin
CAPS	Cleaved amplified polymorphic sequence
CCaMKs	Calcium/calmodulin-dependent protein kinases
CD	Critical difference
CDC	Cell division control protein
cDNA	Complementary DNA
CDPK	Calcium-dependent protein kinase
CEP	Constitutive expression of protein
CEP	Cysteine endopeptidase
CERK	Chitin elicitor receptor kinase gene
CESA	Cellulose synthase
CEV	Constitutive expression of VSP
CF	Culture filtrate
CFU	Colony-forming unit
CH_4	Methane
CHI	Chitinase
CHIP	Chromatin immunoprecipitation
cm	Centimeter
CML	Calmodulin-like
CO_2	Carbon dioxide
COI	Coronation-insensitive protein
Conc.	Concentration
CPR	Constitutive expression of PR genes
CV	Coefficient of variation
cv.	Cultivar
cvs.	Cultivars
CWAs	Cell wall apposition
CY	Cytochrome
Cys EPs	Cysteine endopeptidases
DA	Ubiquitin receptor (DA is Chinese for large)
dai	Days after inoculation
DAMPs	Damage-associated molecular patterns
DAPG	2-4-Diacetyl-phloroglucinol

DAR	DA-related
Dec.	December
DEL1	Loss of function mutation of DP-E2F-like 1
diam	Diameter
dpi	Days post-inoculation
DR	Disease reaction
DSI	Disease severity index
e.g.	For example
EC	Emulsifiable concentrate
EDR	Enhanced disease resistance
eds	Enhanced disease susceptibility
EHM	Extra-haustorial membrane
EIN	Ethylene-insensitive
ER	Endoplasmic reticulum
ERF	Ethylene response factor
ET	Ethylene
et al	*et* alia
ETI	Effector-triggered immunity
ETL	*Economic threshold level*
ETR	Encoding a transmembrane protein kinase with a LRR domain
f. sp.	Fungal forma specialis
F1 GHs	Family-1 glycoside hydrolases
FLS	Flagellin-triggered signaling
FS	Foliar spray
FYM	Farmyard manure
GAAP	Golgi anti-apoptotic protein
GAPDH	Glyceraldehyde 3-phosphate dehydrogenase
GBP	Glutamate-binding protein
Gc	*Golovinomyces* (Syn. *Erysiphe*) *cichoracearum*
GFP	Green fluorescent protein
GHGs	Greenhouse gases
gm	Gram
Go	*Golovinomyces* (Syn. *Erysiphe*) *orontii*
GRX/ROX	TGA-interacting glutaredoxin
GSL	Glucosinolate
GSL	Glucan synthase-like
GSNOR	S-nitrosoglutathione reductase
Gy	Gyro
ha	Hectare
hpi	Hours post-inoculation
hr	Hours
HR	Hypersensitive response
HS	Highly susceptible
i.e.	That is
IAA	Indole-3-acetic acid

IAN	Indole-3-acetonitrile
IAOx	Indole-3-acetaldoxime
ICM	Integrated crop management
ICN	International Code of Nomenclature for algae, fungi, and plants
ICS	Isochorismate synthase
IDM	Integrated disease management
INR	Indian Rupees
IPM	Integrated pest management
IR	Induced resistance
ISR	Induced systemic resistance
ITS	Internal transcribed spacer
JA	Jasmonic acid
JAZ	Jasmonate ZIM-domain protein
kb	Kilobyte
KDEL-CysEPs	C-terminal KDL endoplasmic reticulum retention signal with cysteine endopeptidases from Castor bean
KEG	Keep on going
km	Kilometer
L.s.d.	Least significant difference
LFG	Life guard proteins
LIN	Lesion initiation
LM	Light microscopy
LYK	Lysine motif receptor-like kinase
LysM RLK	Receptor-like kinase gene
M	Mutant
MAPKK	Mitogen-activated protein kinase kinase
MAMPs	Microbe-associated molecular patterns
MAPE	Mean absolute percentage error
MAPK	Mitogen-activated protein kinase
MAPs	Microtubule-associated proteins
Max.	Maximum
Mbp	Genome size megabase pair
MGH	Massachusetts General Hospital isolate of powdery mildew
min	Minute
Min.	Minimum
ml	Milliliter
MLO	Mildew resistance locus
MLOs	Mycoplasma-like organisms
MLP	Multilayer perception
mm	Millimeter
MR	Moderately resistant
MS	Moderately susceptible
MT	Microtubule
MYB	Myeloblastosis
N/A	Not available

N_2O	Nitrous oxide
NB-LRRs	Nucleotide binding site-leucine-rich repeats
NDR	Non-race-specific disease resistance
NEM	*N*-ethylmaleimide
ng	*Nanogram*
NHR	Nonhost resistance
NNM	Neural network models
Nov.	November
NPR	Non-expression of PR genes
NS	Nonsignificant
^{O}C	Degree Celsius
Oct.	October
OECs	Go effector candidates
ORA	Octadecanoid-responsive *Arabidopsis*
OXLP	Oxalate oxidase-like protein
PAD	Phytoalexin-deficient
PAMPs	Pathogen-associated molecular patterns
PAPP	Phytochrome-associated protein phosphatase
PCD	Programmed cell death
PCR	Polymerase chain reaction
PDF	Plant defensin factor
PDI	Per cent disease intensity
PDI	Percentage disease incidence
PDR	Pleiotropic drug resistance
PEN	Penetration gene
PLT	Pyoluteorin
PM	Powdery mildew
PMR	Powdery mildew-resistant
PR	Pathogenesis-related
PR proteins	*Pathogenesis-related* (*PR*) *proteins*
PRRs	Pattern recognition receptors
PTI	Pattern-triggered immunity
PUB	Peptide-N-glycanase/UBA- or UBX-containing protein
PUX	Plant UBX domain-containing protein
Pv.	Pathovar
q	Quintal
qPCR	Quantitative PCR
R	Resistant
R^2	Coefficient of determination
Rab	Ras-related to brain
RAPD	Random amplification of polymorphic DNA
RAR	Encoding a protein with two zinc finger-like domains required for accumulation of many proteins
RBF	Radial basis function
rDNA	Ribosomal DNA