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

 Springer

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Foreword



Crucifers are very important and widespread crops grown worldwide in cool temperate, continental, and subtropical regions. Agriculturally economic crops include *Brassica* oil-yielding crops, *Brassica* vegetable crops, fodder crops, horticultural crops, and several weeds including *Arabidopsis* – a model plant for genomic studies in this modern era. Cruciferous *Brassica* vegetables are a major source of vitamins, fiber, minerals, and proteins in the human diet, while *Brassica* oilseeds are a major source of quality vegetable oil, and cake for animal feed. The demand for *Brassica* vegetables, and oilseeds is increasing annually globally. Crucifers are damaged by several biotic, and abiotic stresses under environmental conditions wherever these crops are grown. Downy mildew in crucifers is the third major biotic stress that causes severe annual yield losses of this crop. This book, *Downy Mildew Disease of Crucifers: Biology, Ecology and Disease Management*, is an important, timely contribution to our knowledge about *Hyaloperonospora parasitica* (Gaum.) Goker, the most destructive pathogens of crucifers globally.

In spite of our access to current information through the Internet, an encyclopaedic book is required where students, researchers, teachers, and industrialists can get well-documented updated information at their desk. This book is arranged into 16 different chapters with proper headings, and subheadings; illustrations such as pho-

tographs, graphs, figures, and tables; and references to stimulate better comprehension on the disease. It provides a much-needed background on the disease, and current information with insight knowledge on future priorities, areas of research, and methodologies, making it a central reference for use by the 'Brassicalogists' across the world regarding investigations on the pathogen, and its host.

I congratulate the authors Drs. G. S. Saharan, Naresh Mehta and P. D. Meena for timely bringing their lifelong professional interest, and expertise into a comprehensive treatise. This book has been designed to be the most useful resource with a wide range of logically organized, and easily accessible information, and is a very important contribution in the series on *Sclerotinia* diseases, white rust disease, and *Alternaria* diseases of crucifers authored by the aforementioned scientists and published by Springer.

New Delhi
11th September, 2017

T. Mohapatra

Preface

Since the first comprehensive treatise publication in the form of a *Monograph on Downy Mildew of Crucifers* (Saharan, Verma, Nashaat, 1997), lots of information have been generated, and published on downy mildew of crucifers in the form of research papers, reviews, book chapters, scientific popular or extension articles, and news for farmers. This book entitled *Downy Mildew Disease of Crucifers: Biology, Ecology, and Disease Management* encompasses all the available published information for the access to researchers, teachers, students, extension experts, and other end users like industrialists, and farmers to comprehend the third most widespread, and devastating disease of crucifers. The disease is known to cause severe yield losses quantitatively and qualitatively in cruciferous crops grown all over the world. The major cruciferous crops challenged by the disease are *Brassica* crops grown for high-quality edible (rapeseed-mustard, canola, and other rape), and industrial (Crambe) oils, forage *Brassicas*, common vegetable crops (cabbage, cauliflower, radish, kohlrabi, broccoli, Brussels sprouts, kales, and other *Brassicas*), ornamental plants (wall flower, stocks), and several weeds including *Arabidopsis*, a model plant for studying genomics, and molecular genetics through *Arabidopsis-Hyaloperonospora* pathosystem. The information has been arranged in 16 chapters with several headings and subheadings in numerical series. Each chapter includes references for original consultation by the readers. The chapter-wise arrangement includes the introduction to the book narrating development in the downy mildew research of crucifers over time comprising of present status of disease, and pathogen; the disease and its distribution, symptomatology, host range, yield losses, and disease assessment; the pathogen and its taxonomy, morphology, phylogeny, variability, sporulation, survival, and perpetuation; spore germination, infection, pathogenesis, seed infection, disease cycle, epidemiology, forecasting, and fine structures; biochemical, histological, genetic, and molecular mechanisms of host resistance, 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, and host resistance methods, and integrated approach; and standardized reproducible techniques. Chapter 15 offers suggestions for future priority areas of research. To track the information given in different

chapters, subject index has been included in Chapter 16. The text has been vividly illustrated with photographs, graphs, figures, histograms, tables, coloured plates, and flowcharts for effective, and stimulating easy comprehension by the readers.

We believe that this book will be immensely useful to the researchers, teachers, extension specialists, students, industrialists, farmers, and all others who are interested to grow healthy, and profitable cruciferous crops all over the world. Any suggestions by the readers are always a source of inspiration for the authors. Any shortcomings, lacunae, and flaws in the book are responsibility of ours.

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B. Journals

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The Canadian Journal of Plant Pathology
The Plant Cell
The Plant Pathology Journal
Transaction of British Mycological Society
Tropical Plant Pathology
Theoretical and Applied Genetics

C. Websites

http://diwww.epfl.ch/wstamatak/index-Dateien/publications/GCB2006_Poster.pdf;
<http://prodes.toulouse.fr/multialign/multialign.html>
<http://brassicadb.org/brad>
<http://www.bio-rad.com>
<http://frodo.wi.mit.edu/primer3>
<http://en.cellfood.com.cn/culture.aspx>
<http://prgdb.cbm.fvg.it>
<http://cals.arizona.edu/PLP/pryorlab/alternaria.html>
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 Wiley Blackwell Publication, Hoboken, New Jersey, USA

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F. Databases

Mycobank, International mycological Association
 Systematic Mycology and Microbiology Laboratory Fungal Database,
 U.S. Department of Agriculture

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Dr. Saharan has more than 250 research publications in journals of national and international repute. He has been editor of books, i.e. 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 Diseases of Oilseed Crops (in Hindi), Sclerotinia Diseases of Crop Plants: Biology, Ecology and Disease Management, White Rust of Crucifers: Biology, Ecology and Management, and Alternaria Diseases 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 Grants 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 the *Journal of Oilseed Brassica* (2012 to date), and president of the Indian Society of Mycology and Plant Pathology (2009) and has played a major role in the organization of global and Asian congress by the leading phytopathological societies of India. He has been a member of QRT, ICAR, New Delhi, for the soybean (2010) and rapeseed-mustard (2015). Dr. Saharan 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 Lifetime Achievement Award (2017) for his outstanding research leadership and expertise in oilseed Brassica research by the Society for Rapeseed-Mustard Research, Bharatpur, India.



Naresh Mehta did his B.Sc. in agriculture (Hons.) in 1978 and M.Sc. in plant pathology in 1980 from Haryana Agricultural University, Hisar. He received his Ph.D. degree in plant pathology in 1993 from CCS HAU, Hisar, under the guidance of Dr. G. S. Saharan. During his study, he attained first position in elective plant protection at bachelor's degree level. Dr. Mehta is the recipient of Excel Industries Ltd. Bombay, India, Award as research fellowship for master's degree programme and 'Senior Research Fellowship' (SRF) Award to pursue Ph.D. programme by the Council of Scientific and Industrial Research (CSIR), New Delhi. He was awarded

Ms. Manju Uterreja Memorial Gold Medal for best Ph.D. thesis (1993–1994).

Dr. Mehta joined as assistant scientist (plant pathology) in 1981, scientist/assoc. professor in 1994, and professor in 2002 at CCS, HAU, Hisar. He was co-principal 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 he is a member of many students' advisory committees. He is the recipient of Best Poster Paper Award for the year 2005 by INSOPP and Indian Phytopathological Soc. (NZ). His students have been awarded P.R. Verma M.Sc. Student Thesis Award for the year 2009 by Indian Soc. 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 a 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 “Diseases of Oilseed Crops” and one of the authors of books *Sclerotinia Diseases of Crop Plants: Biology, Ecology and Disease Management* and *Alternaria Diseases of Crucifers: Biology, Ecology and Disease Management*. He has published more than 100 research papers in the journals of national and international repute. In addition, 10 review articles, 20 book chapters, 10 practical manuals, 25 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 has been admitted as fellow of Indian Phytopathological Society (FPSI), New Delhi, Indian Society of Plant Pathologist (FINSOPP), Ludhiana, and Indian Society of Mycology and Plant Pathology (FISMPP), Udaipur. He has been on the editorial board of Indian Phytopathological Society (2012–2013, 2017–2019), councillor (North Zone) of ISMPP (2005, 2011), a member of editorial board (2012–2014), and editor-in-chief (2014). He is also a member of Editorial Board of Indian Society of Plant Pathologist, Ludhiana, 2017–2018.

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



P.D. Meena is working as Principal Scientist (Plant Pathology) at the Directorate of Rapeseed-Mustard Research (Indian Council of Agricultural Research), Bharatpur-321 303 Rajasthan, India. He started his career in Indian Council of Agricultural Research in 1989 as a senior technical assistant at Central Soil & Water Conservation Research & Training Institute, Dehradun. He obtained his B.Sc. (Ag.) (1987) from the University of Rajasthan, Jaipur, and M.Sc. (Ag.) in 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 white rust resistance genotypes, viz. NRCDR 515, NRCDR-02, NRCHB-506, NRCHB-101, and NRCDR-601 of *Brassica juncea* and NRCYS-05-2 of *B. rapa* ssp. yellow sarson, and developed weather-based forecasting models for rapeseed-mustard diseases. He has published more than 50 research papers, reviews, and book chapters in

international and national reputed refereed journals, and he is editor of the book *Principles of Plant Breeding*. He has been a member of monitoring team for All India Coordinated Research Project on Rapeseed-Mustard in 2004–2010.

He has been honoured with Fellowship of Indian Society of Mycology and Plant Pathology and fellow of Plant Protection Association of India and also awarded with Dr. P.R. Kumar Outstanding Brassica Scientist Award in 2011 by the Society for Rapeseed-Mustard Research. He has served as councillor of Plant Protection Association of India, the founder secretary of the Society for Rapeseed-Mustard Research since 2008, a member of the editorial board (2010–2011), and managing editor (2012–2013) 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).

He is the recipient of the Best Paper Presentation Award (2005), Appreciation Certificate from Rajasthan Jankalyan Van Avum Paryavarn Vikas Sansthan, Jaipur (2006), and K.S. Bilgrami Best Paper Presentation Award (2010).

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

@	At the rate of
<	Less than
>	greater than
μ	Micron
μEm ⁻² S ⁻¹	Micro Einsteins per square metre per second
μg	Microgram
μgml ⁻¹	Microgram per millilitre
μh ⁻¹	Per microhenries
μm	Micrometre
μmol g ⁻¹	Micromole per milligram
°C	Degree Celsius
a.i.	Active ingredient
a.m.	Ante meridiem; before noon
AB	Alternaria blight
Ab	<i>Alternaria brassicae</i>
Ac	<i>Albugo candida</i>
AFLP	Amplified fragment length polymorphism
AICRP-RM	All India Coordinated Research Project on Rapeseed-Mustard
AIP	Aminoindan phosphonic acid
AN	Autogenic necrosis
Å	Angstrom
Ar	<i>Aphanomyces raphani</i>
At	<i>Agrobacterium tumefaciens</i>
AUDPC	Area under the disease progress curve
AY	Aster yellows
B (N)	<i>Belonolaimus</i> (nematode)
BABA	β-Amino-butyric acid
BAC	term
BAC	Bacterial artificial chromosomes
Bc	<i>Botrytis cinerea</i>
BMV(V)	Beet western yellows virus

bp	Base pair
BrS	Bremer decay indices
BS	Black speck
BTH	Benzothiadiazole
C.D.	Critical difference
CAD	Cinnamyl alcohol dehydrogenase
<i>CaM</i>	Calmodulin
CAM (V)	Cauliflower mosaic virus
Cb	<i>Cercospora brassicola</i>
cDNA	Complementary DNA
cDNA-RFLP	cDNA-restriction fragment length polymorphism
CHP	Conserved hypothetical protein
cm	Centimetre
cv.	Cultivar
D (N)	<i>Dolichodoris</i> (nematode)
dai	Days after inoculation
DAS	Days after sowing
DI	Disease index
DM	Downy mildew
dsRNA	Double-stranded RNA
Ec	<i>Erwinia carotovora</i>
Ec	<i>Erysiphe cruciferarum</i>
<i>EDS1</i>	Enhanced disease susceptibility
ER	Endoplasmic reticulum
ER1	Exoribonuclease
F	<i>Fusarium</i>
Fo	<i>Fusarium oxysporum</i>
G	Gummosis
g	Gram
g/kg ⁻¹	Gram per kilogram
GP	Genetic and physiological disorder
h	Hour
Hs (N)	<i>Heterodera schachtii</i> (nematode)
h.p.i.	Hour post inoculation
ha ⁻¹	Per hectare
Hp	<i>Hyaloperonospora parasitica</i>
HP	<i>Hyaloperonospora</i> pathotypes
HR	Hypersensitive cell death response
ICS	Isochorismate synthase
IP	Interaction phenotypes
ITS	Internal transcribed spacer
K	Potash
kb	Kilobyte
KCl	Potassium chloride
lbs	Pound

LIF	Lignification-inducing factor
Lm	<i>Leptosphaeria maculans</i>
LSD	Least significant difference
LSU	Large subunit
M(N)	<i>Meloidogyne</i> (nematode)
Max	Maximum
Mb	<i>Mycosphaerella brassicicola</i>
Mg	Magnesium
min	Minute
Min	Minimum
miRNA	Micro RNA
ML	Maximum likelihood
ml	Millilitre
mm	Millimetre
MM (V)	Mustard mosaic virus
MP	Maximum parsimony
MRC	Major recognition complexes
mRNA	Messenger RNA
N	Nitrogen
NBS-LRR	Nucleotide-binding site-leucine-rich repeat
<i>NDR1</i>	Non-race-specific disease resistance
NiF	term
NIF	Nucleus-inducing factor
No	<i>Nigrospora oryzae</i>
Oa	<i>Orobanchae aegyptiaca</i>
OH-PAS	Hydroxyphenyl-aminosulphinyl acetic acid dimethyl ester
oz/acre	Ounce per acre
PLO	<i>Phytoplasma</i>
P	Phosphorus
P(N)	<i>Paratylenchus</i> (nematode)
p.m.	Post meridiem; after noon
PA(N)	<i>Paratylenchus</i> (nematode)
PAD	Protrusion array devise
PAL	Phenylalanine ammonia-lyase
PAMP	Pathogen-associated molecular pattern
PAZ	Protein domain – Piwi, Argonaute, and Zwillie
Pb	<i>Plasmodiophora brassicae</i>
PBrS	Partitioned Bremer support
Pc	<i>Pseudocercospora capsellae</i>
PCC	Photosynthetic carbon cycle
PCR	Polymerase chain reaction
PDS	Percentage disease severity
PEG	Polyethylene glycol
pH	Potential of hydrogen ion
Pm	<i>Phytophthora megasperma</i>

Pmm	<i>Pseudomonas marginalis</i> pv. <i>marginalis</i>
Po	<i>Phymatotrichum omnivorum</i>
ppm	Parts per million
PR	Pathogenesis related
Psm	<i>Pseudomonas syringae</i> pv. <i>maculicola</i>
PT	<i>Pythium</i>
PTGS	Post-transcriptional gene silencing
Pyb	<i>Pyrenopeziza brassicae</i>
QRT-PCR	Quantitative real-time polymerase chain reaction
QTL	Quantitative trait locus
r	Correlation coefficient
R.H.	Relative humidity
RAPD	Random amplification of polymorphic DNA
rDNA	Ribosomal ribonucleic acid
RdRP	RNA-directed RNA polymerase
RFLP	Restriction fragment length polymorphism
Ribosomal DNA	rDNA
RISC	RNA-induced silencing complex
RITS	RNA-induced transcriptional silencing
RM(V)	Radish mosaic virus
RNA	Ribonucleic acid
ROS	Reactive oxygen species
Rs	<i>Rhizoctonia solani</i>
Rst	<i>Rhizopus stolonifer</i>
SA	Salicylic acid
SAR	Systemic acquired resistance
SCT	Sexual compatibility type
SDW	Sterile distilled water
siRNA	Short interfering RNAs
sq ft	Square feet
Sr	<i>Sclerotium rolfsii</i>
Ss	<i>Sclerotinia sclerotiorum</i>
Sts	<i>Streptomyces scabies</i>
T	Temperature
T.S.	Transverse section
TAS	Trans-acting siRNA
TB(P)	Tip burn
TDFs	Transcript-derived fragments
TEM	Transmission electron microscopy
TGS	Transcriptional gene silencing
TIR	Toll, interleukin-1, resistance
TUM(V)	Turnip mosaic virus
Tu MV	Turnip mosaic virus
USA	United States of America
UK	United Kingdom

v/v	Volume by volume
Va	<i>Verticillium albo-atrum</i>
var	Variety
Vd	<i>Verticillium dahliae</i>
w	Watt
w/v	Weight by volume
WP	Wettable powder
WR	White rust
Xca	<i>Xanthomonas campestris</i> pv. <i>armoraciae</i>
Xcc	<i>Xanthomonas campestris</i> pv. <i>campestris</i>
yr	Year
Ψ	Atmospheric water potentials

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