BIOPESTICIDES IN ORGANIC FARMING

RECENT ADVANCES

Edited by
L.P. Awasthi

CRC Press
Taylor & Francis Group

Biopesticides in Organic Farming

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Biopesticides in Organic Farming

Recent Advances

Edited by
L.P. Awasthi

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

First edition published 2021
by CRC Press
6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742

and by CRC Press
2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

Library of Congress Cataloging-in-Publication Data

Names: Awasthi, L.P., editor.
Title: Biopesticides in organic farming : recent advances / L.P. Awasthi.
Description: First edition. | Boca Raton, FL : CRC Press, 2021. | Includes bibliographical references and index.
Identifiers: LCCN 2020041032 | ISBN 9780367460174 (hardback) | ISBN 9781003027690 (ebook)
Subjects: LCSH: Natural pesticides. | Organic farming. | Crops--Diseases and pests--Biological control.
Classification: LCC SB951.145.N37 B567 2021 | DDC 632/.95--dc23
LC record available at https://lccn.loc.gov/2020041032

ISBN: 9780367460174 (hbk)
ISBN: 9781003027690 (ebk)

Typeset in Times
by Deanta Global Publishing Services, Chennai, India

This book is dedicated to my most respected Guru

Professor H.N. Verma

Vice Chancellor

Jaipur National University, Jaipur, Rajasthan, India

Through your smiles and stern looks and subtle remarks to do better, I have sailed through life. When I am tempted to give up, I remember your words, urging me to give it another try. Thank you for making me a stronger person.

Professor L.P. Awasthi

Contents

Section VII Role of Nutrients in the Management of Crop Diseases through Biopesticides

Section VIII Management of Crop Diseases through Bacterial Biopesticides

Section IX Management of Crop Diseases through Fungal Biopesticides

Section X Management of Crop Diseases through Viral Biopesticides

Section XI Management of Crop Diseases through Algal Biopesticides

Section XII Management of the Diseases and Pests of Crops through Protozoan Biopesticides

Section XX Biotechnological Trends in Insect Pest Control Strategy

Section XXI Challenges in the Popularization of Biopesticides in Organic Farming

Section XXII Certification Process and Standards of Organic Farming

Section XXIII Marketing and Export Potential of Organic Products

Foreword

Dr. Richard Alan Humber
USDA-ARS Collection of Entomopathogenic Fungal Cultures (ARSEF)
Emerging Pests and Pathogens Research Unit
Robert W. Holley Center for Agriculture and Health

Virtually all agriculture could have been seen as "organic" until the dawn of using artificial chemical agents to control pests and the rise of industrial-scale agriculture to provide the food and other products required by the exploding human population. As the human population exceeded the planet's presumed carrying capacity, agriculture's capacity to produce an adequate food supply has become deeply stressed. As pesticide and herbicide use burgeoned, the target pests' resistance to chemical control agents became an urgent problem, and the cost of such chemical inputs to agriculture was higher than many growers could easily bear. The current trend to insert pesticidal or herbicidal capacities into the genomes of crop plants has bound those adopting such technologies to buy seed from their corporate providers and to implement complex strategies to delay or to prevent the pests' resistance to these introduced genes. Such issues as the costs of using genetically modified crops (corn, cotton, etc.) met strong resistance from many regulatory agencies and by much of the world's people who neither like nor willingly consume such plants.

The idea of using microbes (at first mostly fungal entomopathogens) as biological control agents emerged in the late 1800s but suffered from many setbacks in the earliest uses against target pests. In addition to the vast number of predatory and parasitic arthropods and parasitoids used to control pests, the range of biological control agents used against insects, mites and other invertebrate pests, plant diseases, and weeds has expanded to include viruses, bacteria, fungi (and organisms once treated as fungi), microsporidia, protozoans, and entomopathogenic nematodes. It is equally important to recognize the contributions of plant extracts for pest control as well as the benefits of co-planting crops with other plants that protect a crop against nematodes, other pests, and soil-borne diseases.

The science supporting the uses of so many organisms is complex and relies on a myriad of technologies from molecular biology and genomics through every imaginable aspect of organismal biology, population biology, and ecology. The screening of global biodiversity for useful microbial biocontrol agents is reasonably well documented even though much of the planet has never been surveyed adequately for such agents. While many entomologists prefer to restrict the term "biological control" to using predatory or parasitic insects and parasitoids against other arthropods, the strategies and principles to use insects against insects apply equally to the uses of microbes, nematodes, and other invertebrate agents.

The rigors of selecting the most virulent microbial agents to bring through efficacy and safety testing are well documented. After an initial focus on basic biological aspects of biopesticide development and efficacy, the emphasis usually switches to the technical problems of scaling up their production and how to formulate and apply these agents, and on the legal hurdles of their regulatory registrations. It is not surprising that, after all of this is done, very few agents become available for practical use—fungi such as *Beauveria bassiana* and *Metarhizium anisopliae*, bacteria such as *Bacillus thuringiensis* and the nematode-borne species of *Photorhabdus* and *Xenorhabdus*, a very small number of viruses, and even fewer microsporidia such as species of *Nosema* and *Vairimorpha*. As the scale of applications of biopesticides and plant-derived pest control agents grows, the full range of skills enabling their adoption needs to be better appreciated; this book surveys on the current state of the art for all of these topics.

Today we have come to the point when the oldest, most traditional approach to agriculture returns to an honored place in many countries. Organic agriculture now presses forward with a new level of biological and agronomic knowledge, and a previously unimaginable array of techniques and technologies. The accelerating adoption of organic agriculture is responding to urgent concerns about the environmental and health costs of continuing use of chemical pesticides. This volume addresses many daunting challenges posed by this push to reduce chemical pest control approaches while embracing integrated pest management (combining biopesticides with limited use of chemical pesticides) or strictly organic practices.

A very diverse set of reviews of the development, application, and environmental and regulatory consequences of implementing biopesticides appear here. Its 24 sections comprise 54 chapters by authorities from around the world. Entomopathogenic viruses, bacteria, fungi, and nematodes are covered in detail, while algae and protozoans that are usually little recognized to have any role in pest management are also covered, and there are three chapters about insect parasitoids as key natural enemies. Other chapters treat the diverse spectrum of plant-derived compounds and insect pheromones that offer positive benefits for managing plant pests and diseases. This compendium will be a key reference for scientific professionals, students, legislators and administrators, the leaders and followers in businesses and in agriculture, farmers, and entrepreneurs wanting to provide safe and healthy food and plant products. Readers should be able to gather new ideas, fresh perspectives, and inspiration to advance their knowledge with the ultimate goal of improving the safety and sustainability of global agriculture.

Biopesticides in Organic Agriculture: Recent Advances, edited by Professor L.P. Awasthi, provides a kaleidoscopic perspective on the adoption, adaption, and expansion of biological and biorational approaches to maintain the agricultural and silvicultural world. If seen from a wholly different perspective, this volume contributes significantly to our increasingly urgent need and responsibility to preserve and, indeed, to cherish the world of plants on which all other forms of life on this planet are so totally dependent.

Preface

Organic agriculture has emerged as an important priority area globally in view of the growing demand for safe and healthy food and concerns about environmental pollution associated with the indiscriminate use of agrochemicals. Organic farming is the pathway that leads to life in harmony with nature. It is key to sound development and sustainable environment, makes use of non-conventional natural resources, and conserves soil fertility through implementation of appropriate conservation practices.

Biopesticides play a significant role in sustainable organic farming, which is a present-day need for better human health. Biopesticides are developed from naturally occurring living organisms such as animals, plants, and microorganisms (e.g., bacteria, fungi, and viruses) that can control serious plant-damaging insect pests by their non-toxic ecofriendly mode of actions, therefore globally demanding and paying attention. Biopesticides and their by-products are mainly utilized for the management of pests that are injurious to plants. As costs of using synthetic chemicals became apparent, there has been a resurgence in academic and industrial research of biopesticides. Biopesticides, including entomopathogenic viruses, bacteria, fungi, nematodes, and plant secondary metabolites, are gaining stature as they are alternatives to chemical pesticides and are a major component of many pest control programs. The virulence of various biopesticides such as nuclear polyhydrosis virus (NPV), bacteria, and plant product were tested very successfully and evaluated under field conditions with major success. Biopesticides are effective, ecofriendly, biodegradable, and do not leave any harmful residue in the environment. Various types of pesticides like bacterial pesticides, viral pesticides, botanicals, pheromones, predators, and parasitoids of biological origin are widely used as biopesticides.

Biopesticides in Organic Farming: Recent Advances describes critically reviewed, key aspects of organic agriculture and provides a unique and timely science-based resource for researchers, teachers, extension workers, students, primary producers, and others around the world. There are different sections in this book. The first section provides an overview of organic farming with special reference to biopesticides, followed by the principles of the applications of biopesticides in organic farming, impact of environmental factors on biopesticides in organic farming, opportunities and challenges in the application of biopesticides in organic farming, strategies for crop protection with biopesticides in organic farming, pesticide exposure impacts on health and need of biopesticides in organic farming, and the role of nutrients in the management of crop diseases through biopesticides. The next section deals with the management of various crop diseases through bacterial, fungal, viral, algal, protozoan, and botanical biopesticides, insect sex hormones, natural enemies, parasitoids biopesticides, microbial biopesticides, integrated pest management, biopesticides weapons against agricultural mite pests, biotechnological trends in insect pests control strategy, challenges in the popularization of biopesticides in organic farming, the certification process, and standards of organic farming and marketing and export potential of organic products. The book gathers together a range of specialists with direct experience over many years of biopesticides in organic farming. This book is intended to be a unique and indispensable resource that offers a diverse range of valuable information and perspectives on biopesticides in organic agriculture at a time when the world community is increasingly aware of the problems of our current agricultural practices with importance of creating sustainable agricultural systems for the long-term health of the biosphere as a whole. This book is designed, considering the requirements of undergraduates, postgraduates, researchers, and university professors, as per the organic agriculture course curriculum of different universities. It has chapters, on each and every aspect related to biopesticides in organic agriculture, compiled by researchers and eminent professors at various universities across the globe. I wish the students and various readers who relish working in the field of organic farming will find the format of the book, its level, and the quantity of information contained in the book to be appropriate for easier learning and understanding. The wide spectrum of information in various chapters with the addition of the terms related to organic agriculture and concept statements is presented in a very concise manner.

I am confident that this publication will be useful to university students, professors, researchers, development department officials, extension workers, policymakers, and all those interested in organic farming.

Professor L.P. Awasthi

Acknowledgments

I would like to express my heartfelt thanks to Prof. H.N. Verma, Vice Chancellor, India, Prof. Ahmad Hadidi, USDA, USA, Prof. Rakesh Yamdagni, Ex Vice chancellor, Prof. S M Ilyas, Ex Vice chancellor, Prof A.N. Mukhopadhyay, Ex Vice chancellor and Prof. Narayan Rishi, Director, Amity University, India, Dr. S.K. Dara and Dr. Matthew Russell Gates, USA for their valuable and fruitful suggestions during the preparation of this book.

I wish to acknowledge and express my sincere thanks to my family members for their untiring support, cooperation and encouragement during the course of the compilation of this book.

Grateful thanks are due to all learned contributors for their cooperation in compiling useful information on different aspects of biopesticides in organic farming. Each of them have endeavored to present an update of their specialized aspect; Drs. M. Prakruthi and M.S. Mahesh, India, Surendra K. Dara, USA, Enespa, Prem Chandra, Rishabh Chitranshi, Sushree Suparna Mahapatra, Sudeepta Pattanayak, Siddhartha Das, L. P. Awasthi, C. R. Patil, and Shekarappa, India, Muhammad Haroon Sarwar, Muhammad Farhan Sarwar, Muhammad Sarwar and Muhammad Taimoor Khalid, Pakistan, Vittal Navi, Santosh G., India, Gabriela Cristina Alles, Diouneia Lisiane Berlitz, Maximiano Cassal and Lidia Mariana Fiuza, Federal Institute of Education, Science and Technology, RS, Brazil, Vilmar Machado, Spain, Subramaniam Gopalakrishnan, Vadlamudi Srinivas, Pratyusha Sambangi, and Sravani Ankati, India, Younes Rezaee Danesh, Iran, Semra Demir, Çağlar Sagun, Solmaz Najafi, Turkey, Jéssica Batista Torres Araújo Oliveira, Cassia Renata Pinheiro and Glacy Jaqueline Da Silva, Brazil, Pradipta Banerjee, Pratibha Sharma, Raja Manokaran and Prashant Prakash Jambhulkar, India, Roohi Aslam, Pakistan, Meenakshi Devi, Suman Devi, Neha Upadhyay, Babli, Upasana Mohapatra, Gayatri Biswal, Deeksha Joshi, Monika Upadhyay, Raghvendra Tiwari and B. Meena, India, ASOGWA Evarestus Uche and Theophilus Chinyere Nkasiobi Ndubuaku, Nigeria, D.K. Kulkarni, R.B. Bhagat, P.V. Patil and S P Taware, India, Naveed Akhter Shad, Riffat Batool and Sidra Sarwar, Pakistan, Desam Nagarjuna Reddy, India, Abdul Jabbar Al-Rajab, Canada, Rajeev Kumar, India, Mara Tabakovic-Tosic, Serbia, Sathish Kota, Jaba Jagdish, Ramya Sree, Reddy, Vinod Kukanur, D. K. Rana and Naveen Arora, India, Simone Mundstock Jahnke and Gisele De Souza Da Silva, Brazil, Hany Mohamad Galal EL-Kawas, Mohamad Mohamad Ahamad Khedr, Egypt, Aparna Shree Singh, India, Fernando Belezini Vinha, Alexandre De Sene Pinto, Kássia Cristina Freire Zilch, Gisele De Souza Da Silva, Cleder Pezzini, Roberta Agostini Rohr, Brazil, Rafaela Cristina dos Santos SP; Brazil, María Alejandra Correa, Massiel Pinto, Oscar Valbuena, Marcelo Molinatti, Domenico Pavone, Venezuela, Jatin. K, and Suraj Prasad Mishra, India., Katherine Girón, Brazil, Matthew Russell Gates, USA, R. Elaini, and R. Bouharroud, Morocco, Noreen Akram and Hafiz Sanaullah Babar, Pakistan, Bugiani Riccardo and Bariselli Massimo, Italy, R. Shekhara Naik, India and Meena Thakur, New Zealand.

I am sure, detailed accounts on different aspects of biopesticides in organic farming will be a great help to students, teachers, researchers and extension workers.

Last but not the least; I would like to extend my thanks to Taylor and Francis Publishers, U.S.A, their publishing team Dr. Renu Upadhyay, Commissioning Editor (Chemical and Life Sciences), CRC Press, Taylor & Francis Group, Dr. Jyotsna Jangra, Editorial Assistant, CRC Press, Taylor and Francis Group, Marsha Hecht, Project Editor, Taylor & Francis Group, LLC and Rennie Alphonsa, Project Manager at Deanta Global along with their team for getting this book published in a presentable form.

Professor L.P. Awasthi

About the Editor

Prof. (Dr.) L.P. Awasthi, Dean School of Agriculture, R N B Global University, Bikaner, India, formerly Research Scientist/Professor, Amity University and Professor and Head, Department of Plant Pathology, N.D. University of Agriculture & Technology, Faizabad (U.P.) India, is a distinguished agriculture scientist with a strong background in molecular plant virology, resistance breeding, IDM, IPM, organic agriculture and mushroom production with proven ability to undertake independent or collaborative scientific studies as demonstrated by successfully completing 28 mega research projects, funded by various International funding organizations. His professional experience includes more than 47 years of teaching and conducting research. He has published more than 350 research papers in foreign and Indian journals of repute, edited/ authored six books, published a number of popular articles, laboratory manuals and contributory chapters for different books, guided 77 M. Sc. (Ag.) and 35 Ph.D. students and has been working as an Editor/ Referee in the editorial boards of many Indian and foreign journals of repute.

Professor Awasthi visited Karl-Marx University, Leipzig, University of Berlin, Institute of Plant Pathology, Ascherslavan, and Haale University, Germany as a visiting professor for higher studies.

He has been member of the Phytosanitary Certificate Issuing Authorities, Ministry of Agriculture, Department of Agriculture and cooperation, Directorate of Plant Protection, Quarantine and Storage, Government of India and is presently a special invited member in the State-level Pest and Disease Surveillance Advisory Unit, Government of Uttar Pradesh. India.

Prof. Awasthi has long been associated with many professional societies, and was conferred Plant Pathology Leadership Award 2012, 2016 and 2019 by Indian Phytopathological Society, India, Outstanding Virologist award (2007) by International Virological Association for outstanding contribution, scientific excellence and distinguished services for the cause of Plant Pathological Research, Education and Technology dissemination, which has impacted science of plant pathology in the country. He has been recognized for disseminating mushroom cultivation technologies to improve the socioeconomic conditions of farmers below poverty line and woman empowerment and also for the popularization of organic farming.

Contributors

Rohr Roberta Agostini
Faculty of Agronomy
Federal Univ of Rio Grande do Sul (UFRGS)
Porto Alegre, Rio Grande do Sul, Brasil

Shad Naveed Akhter
National Institute for Biotechnology & Genetic Engineering (NIBGE)
Faisalabad, Pakistan

Noreen Akram
National Institute for Biotechnology and Genetic Engineering (NIBGE)
Faisalabad, Pakistan

Correa Maria Alejandra
Centro de Biotecnología Aplicada, Departamento de Biología, Facultad de Ciencias y Tecnología
Universidad de Carabobo
Venezuela

Gabriela Cristina Alles
Biotech Biological Defense
RS, Brazil

Abdul Jabbar Al-Rajab
Pesticides & Pest Management
Environmental Pollution & Control
Ottawa, Ontario, Canada

Jéssica Batista Torres Araújo Oliveira
Biological Control/*Bacillus thuringiensis*
Sete Lagoas
Minas Gerais, Brazil

Roohi Aslam
NUTECH School of Applied Sciences and Humanities (NUSASH)
National University of Technology (NUTECH)
Islamabad, Pakistan

L.P. Awasthi
School of Agriculture
RNB Global University, Bikaner
Rajasthan, India

Li Bab
Department of Agronomy
CCS Haryana Agricultural University
Hisar, India

Pradipta Banerjee
Department of Biochemistry & Plant Physiology
Centurion University of Technology and Management
MS Swaminathan School of Agriculture
Odisha, India

Massimo Bariselli
Servizio Fitosanitario – Plant Protection Service
Crop Protection Regione Emilia-Romagna
Bologna, Italy

Diouneia Lisiane Berlitz
Science and Technology
Federal Institute of Education
RS, Brazil

R.B. Bhagat
Anantrao Pawar College
Pirangut, Tal. Mulshi
Pune, Bhor

Gayatri Biswal
Department of Plant Pathology
College of Agriculture
Orissa University of Agriculture and Technology
Bhubaneswar, India

Sagun Çağlar
Soil, Fertilizer and Water Resources
Central Research Institute
Ankara-Turkey

Maximiano Correa Cassal
Universidade do Vale do Rio dos Sinos
RS, Brazil

Prem Chandra
School for Environmental Science
B.B.A. University
Lucknow, India

Rishabh Chitranshi
School for Environmental Science
B.B.A. University
Lucknow, India

Pezzini Cleder
Faculty of Agronomy
Federal Univ of Rio Grande do Sul (UFRGS)
Porto Alegre, Rio Grande do Sul, Brasil

Younes Rezaee Danesh
Urmia University, Iran
Parlakhemundi, India

Surendra K. Dara
Entomology and Biologicals Advisor at University of California Cooperative Extension
San Luis Obispo, California

Siddhartha Das
Department of Plant Pathology
Centurion University of Technology and Management
MS Swaminathan School of Agriculture
Parlakhemundi, India

Nagarjuna Reddy Desam
Anantha Lakshmi Institute of Technology & Sciences, Itikalapalli
Ananthapuramu, Andhra Pradesh, India

Pinto Alexandre De Sene
Department ofAgronomy
Moura Lacerda University
Ribeirão Preto, São Paulo, Brazil

Da Silva Gisele De Souza
Faculty of Agronomy
Federal Univ of Rio Grande do Sul (UFRGS)
Porto Alegre, Rio Grande do Sul, Brasil

Meenakshi Devi
Entomology
PDM University
Bahadurgarh, India

Suman Devi
Department of Agronomy
CCS Haryana Agricultural University
Hisar, India

Rafaela Cristina dos Santos
Entomology, Chemical Ecology and Insect Behavior Laboratory
Entomology and Acarology Department – ESALQ/USP
Piracicaba, Brazil

Hany Mohamad Galal El-Kawas
Institute of Plant Protection Research
Agricultural Research Center
Egypt

Lidia Mariana Fiuza
Department of Microbiology and Agrotoxicology
Riograndense Institute of Rice
RS, Brazil

Zilch Cristina Kassia Freire
Faculty of Agronomy
Federal Univ of Rio Grande do Sul (UFRGS)
Porto Alegre, Rio Grande do Sul, Brasil

Matthew Russell Gates
Cannabis Horticultural Association
San Diego, California

Subramaniam Gopalakrishnan
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru, India

Jagdish Jaba
Department of Entomology
Integrated crop managment
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru, Hyderabad, India

Simone Mundstock Jahnke
Depto. de Fitossanidade
Universidade Federal do Rio Grande do Sul (UFRGS)
Brazil

Da Silva Glacy Jaqueline
Paranaense University, Umuarama
Paraná, Brazil

Deeksha Joshi
Indian Institute of Sugarcane Research
Lucknow, India

D.K. Kulkarni
BAIF Development Research Foundation
Pune, India

Rajeev Kumar
DPPQS, RCIPMC
Lucknow, India

Vilmar Machado
Department of Zoologia y Antropologia Fisica
Universidade de Murcia
Spain

Sushree Suparna Mahapatra
Department of Plant Pathology
Odisha University of Agriculture and Technology
Bhubaneswar, India

M.S. Mahesh
Department of Food Science and Nutrition
Yuvaraja's College (Autonomous)
University of Mysore
Mysuru, India

Raja Manokaran
Department of Plant Pathology
Rani Lakshmi Bai Central Agricultural University
Jhansi, India

Molinatti Marcelo
Centro de Biotecnología Aplicada, Departamento de Biología, Facultad de Ciencias y Tecnología
Universidad de Carabobo
Venezuela

Pinto Massiel
Centro de Biotecnología Aplicada, Departamento de Biología, Facultad de Ciencias y Tecnología
Universidad de Carabobo
Venezuela

B. Meena
Plant Pathology
Regional Research Station
Vriddhachalam, India

Khedr Mohamad Mohamad Ahamad
Plant Protection Research Institute
Agricultural Research Center
Dokki, Giza, Egypt

Upasana Mohapatra
Department of Biotechnology
University of Agricultural Sciences
GKVK
Bengalru, India

Zahid Mukhtar
National Institute for Biotechnology & Genetic Engineering (NIBGE)
Faisalabad, Pakistan

Sarwar Muhammad
National Institute for Biotechnology & Genetic Engineering (NIBGE)
Faisalabad, Pakistan

Shekhara Naik R.
Department of Food Science and Nutrition
Yuvaraja's College
University of Mysore
Mysuru, India

Arora Naveen
Punjab Agricultural University
Ludhiana, Punjab

Vithal Navi
Department of Agricultural Microbiology
University of Agricultural Sciences
Dharwad, India

Theophilus Chinyere Nkasiobi Ndubuaku
Entomology Section
Cocoa Research Institute of Nigeria (CRIN)
Ibadan, Nigeria

Upadhyay Neha
Department of Plant Pathology
G. B. Pant University of Agriculture and Technology
Pantnagar, Uttarakhand, India

Valbuena Oscar
Centro de Biotecnología Aplicada, Departamento de Biología, Facultad de Ciencias y Tecnología
Universidad de Carabobo
Venezuela

C.R. Patil
Department of Agricultural Microbiology
Institute of Organic Farming
University of Agricultural Sciences
Dharwad, India

P.V. Patil
Department of Horticulture
Anantrao Thopte College
Bhor, Maharashtra, India

Sudeepta Pattanayak
Department of Plant Pathology
Centurion University of Technology and Management
MS Swaminathan School of Agriculture
Parlakhemundi, India

Domenico Pavone
Tecnovita
Valencia, Venezuela

Katherine Girón Pérez
Entomóloga Manejo de pragas agrícolas
Resistência de insetos
Milho, Cana e Soja
Paulínia, Brazil

Cassia Renata Pinheiro
São Paulo University, Piracicaba
São Paulo, Brazil

Jambhulkar Prashant Prakash
Department of Plant Pathology
Rani Lakshmi Bai Central Agricultural University
Jhansi, Uttar Pradesh

M. Prakruthi
Central Food Technological Research Institute
Mysuru, India

Mishra Suraj Prasad
International Crops Research Institute for the Semi-Arid Tropics-Patancheru
Telangana, India

Sambangi Pratyusha
ICRISAT
Patancheru, Telangana, India

Elaini Rachid
Omnium Agricole du Souss
Agadir Ida-Outanane Prefecture, Morocco

D.K. Rana
Indira Gandhi Krishi Vishwavidyalaya
Raipur, India

Ramya Sree Reddy
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru, Telangana, India

Bugiani Riccardo
Plant Protection Service
Emilia-Romagna Region
Via A. da Formigine 3, Italy

and

Servizio Fitosanitario – Plant Protection Service
Crop Protection Regione Emilia-Romagna
Bologna, Italy

Batool Riffat
National Institute for Biotechnology & Genetic Engineering (NIBGE)
Faisalabad, Pakistan

Babar Hafiz Sanaullah
Drug Regulatory Authority of Pakistan
Ministry of National Health Services, Regulations and Coordination
Islamabad, Pakistan

G.P. Santosh
Department of Agricultural Microbiology
University of Agricultural Sciences
Dharwad

Muhammad Farhan Sarwar
Allied Health Sciences
University of Sargodha
Sargodha, Pakistan

Muhammad Haroon Sarwar
King Edward Medical University
Lahore, Punjab, Pakistan

Muhammad Sarwar
National Institute for Biotechnology & Genetic Engineerings (NIBGE)
Faisalabad, Pakistan

Sidra Sarwar
Department of Botany, Government Post Graduate College
Faisalabad, Pakistan

Kota Sathish
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru, Telangana, India

Demir Semra
Department of Plant Protection, Faculty of Agriculture
Van Yuzuncu Yil University
Van-Turkey

Pratibha Sharma
Division of Plant Pathology
SKN Agricultural University
Jobner, Jaipur, India

Shekarappa
Department of Agricultural Entomology
Institute of Organic Farming
University of Agricultural Sciences
Dharwad, India

Aparna Shree Singh
Lakshya Society for Social and Environmental Development
New Delhi, India

Enespa Singh
School of Agriculture, SMPDC
University of Lucknow
Lucknow, India

Ranjan Singh
School for Environmental Science
B.B.A. University
Lucknow, India

Najafi Solmaz
Department of Field Crops, Faculty of Agriculture
Van Yuzuncu Yil University
Van-Turkey

Ankati Sravani
ICRISAT
Patancheru, Telangana, India

Vadlamudi Srinivas
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru, India

Mara Tabakovic-Tosic
Department of Forest Protection
Institute of Forestry
Belgrade, Serbia

Khalid Muhammad Taimoor
Allied Health Sciences
University of Sargodha
Sargodha, Pakistan

S.P. Taware
Plant Science Division
Agharkar Research Institute
Pune

Meena Thakur
Biologist R&D
Renovo Technologies Ltd.
New Plymouth, New Zealand

Raghvendra Tiwari
Indian Institute of Sugarcane Research
Lucknow, India

ASOGWA Evarestus Uche
Entomology Section
Cocoa Research Institute of Nigeria (CRIN)
Ibadan, Nigeria

Monika Upadhyay
Indian Institute of Sugarcane Research
Lucknow, India

Fernando Belezini Vinha
Engenheiro Agronômo
Piracicaba, Brazil

Kukanur Vinod
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru, Telangana, India

Mukhtar Zahid
National Institute for Biotechnology & Genetic Engineering (NIBGE)
Faisalabad, Pakistan

33

The Role of Natural Enemies and Biopesticides for Sustainable Management of Major Insect Pests of Legumes

Sathish Kota, Vinod Kukanur, Reddy Ramya Sree, Naveen Arora, Jagdish Jaba, and Rana DK

CONTENTS

33.1 Introduction

Pulses are the important components of a healthy diet and take an important place in the traditional diets throughout the World (Malaguti et al. 2014). pulses are damaged by a large number of insect species, both under field conditions and in storage (Clement et al. 2000).

Among legume insect pests, *Helicoverpa armigera* is the single largest yield shrinking factor in food legumes, causes an estimated loss of US$317 million in pigeonpea and $328 million in chickpea (ICRISAT 1992). Worldwide, it causes an estimated loss of over $2 billion annually, despite over $1 billion value of insecticides used to control *H. armigera* (Sharma 2005). Another pod borer *Maruca vitrata* causes loss to the tune of US$30 million annually (Saxena et al. 2002). Pigeonpea yield losses due to pod borer are 25–70%; Pod fly is second most important pest of pigeonpea in northern and central India, and cause 10 - 50 % yield loss. *Maruca* is reported to cause 5 - 25% yield loss in pigeonpea, pod bug can cause yield loss upto 30%. Soybean aphid, (*Aphis glycines*) can induce up to 58% yield losses in soybean crop (Wang et al. 1994) and annually $2.4 billion estimated losses in yield (Song et al. 2006, Tilmon et al. 2011). Legume flower thrips (LFT), *Mylothris sjostedti* Trybom in cowpea *V. unguiculata* in tropical Africa causes yield losses ranging from 20% to 100% (Karungi et al. 2000).

33.2 Management of Legume Insect Pest through Natural Enemies

33.2.1 *H. armigera* and *H. punctigera*

These are the major insect pests of legume crops; both these pests are managed by natural enemies such as parasitoids, *Trichogramma* and *Telenomus*, which are minute parasitoid wasps (shorter than 1 mm) which parasitize *Helicoverpa* eggs, but their activity levels are too low in chickpea and pigeonpea

FIGURE 33.1 *Campoletis chlorideae* (http://www.nbair.res.in).

because of trichome exudates. There are a numerous number of wasps that parasitize pod borer *Helicoverpa* larvae. Only the species considered to be most significant for pest management are described here. The Ichneumonid, *Campoletis chlorideae* Uchida (Figure 33.1), is most likely the main important larval parasitoid of pod borer, *H. armigera*, on pigeonpea and chickpea in India (Pawar et al. 1986). Late-instar *H. armigera* larvae are parasitized by Tachinids, but result in little reduction in larval density. In India, *Carcelia illota* (Curran), and to a lesser extent, *Goniophthalmus halli* Mesnil, and *Palexorista laxa* (Curran) parasitize up to 22% of *H. armigera* larvae on pigeonpea (Bhatnagar et al. 1983), and up to 54% larvae in chickpea. Prepupal and pupal mortality of *H. armigera* is reliable (Table 33.1).

Netelia producta parasitoid of *H. armigera* (Figure 33.2) is a pupal parasitoid of *Helicoverpa*, some armyworms, and is very active in chickpea crops. A female *Ichneumon promissorius* has a white band in the middle part of the antennae (Figure 33.3), whereas a male *Ichneumon promissorius* has orange and black antennae.

33.2.2 The Spotted Pod Borer, *Maruca vitrata* (Geyer)

There are a numerous number of parasites recorded on larvae/pupae of spotted pod borer, *Maruca vitrata* include Tachinids, Braconids, Chalcidids, Eulophids, Ichneumonids, Pteromalids, and Scelionids (Table 33.2).

33.2.3 Pea Pod Borer and Pea Weevils

Pea pod borer, *Etiella zinckenella* (Treitschke), is attacked by several species of natural enemies, such as the hymenopteran egg parasitoids, *Trichogrammatoidea armigera*. Larval parasitoids are *Bracon hebetor*, *Phanerotoma* sp., *Tetrastichus* sp., and *Phanerotoma planifrons*. Pea weevils (*Bruchus pisorum*) are attacked by several species of natural enemies, such as the hymenopteran egg parasitoids *Uscana senex* Grese (Trichogrammatidae) (Hormazabal & Gerding 1998) and *U. chiliensis* sp. nov (Pintureau et al. 1999).

33.2.4 Cow Pea Aphid

Aphis craccivora Koch and pea aphid, *Acyrthosiphon pisum* Haris (Homoptera: Aphididae), are the major hemipteran insect pest of lentils in America, Europe, Africa, Australia, and Asia. predators such as Syrphid flies, Rove beetle, green lacewing, ladybird beetle, and parasitoids such as *Aphidius* sp. and *Aphelinus* sp. While aphids are attacked by a number of natural enemies, Coccinellids especially prevent their rapid reproduction rate and may reduce infestation levels sufficiently (Table 33.3).

33.2.5 Bean Stem Maggot (*Ophiomyia phaseoli*)

Bean stem maggots, also known as bean flies, are often considered to be the most important field pest of beans in Africa. They account for yield losses ranging from 80% to 100%. The most common species include *O. phaseoli*, *O. spencerella*, and *O. centrosematis*. They attack the crop wherever it is grown. *Ophiomyia phaseoli* is a widely distributed pest of seedling bean.

33.2.6 Red Gram Pod Fly

Melanagromyza obtusa Malloch (Diptera: Agromyzidae) causes serious damage to the pods and seeds of pigeonpea from November to February, resulting in poor germination and making them unfit for human consumption. Until now, more than 25 hymenopteran parasitoids were known to attack this notorious pest (Table 33.4). Among them, *Euderus lividus* and *Ormyrus orientalis* are reported as major biocontrol agents of *M. obtusa* (Yadav et al. 2012).

33.2.7 The Bean Aphids

Aphis fabae is the main aphid pest of common bean in Africa and Asia. Aphids have experienced some adaptation in relation to host plant so that many aphid taxa have a biologically complex life cycle. In some instances, both larvae and adults of predators belonging to the family Coccinellidae (Ladybird beetles) feed on aphids. All species in the braconid subfamily Aphidiinae develop as endoparasitoids (inside) of aphids with one larva completing development in each host.

33.2.8 Tobacco Caterpillar

Spodoptera litura (Fab.) is a serious and regular pest of soybean in India. *Trichogramma chilonis*, *Tetrastichus*, and *Telenomus* are egg parasitoids of *Spodoptera* and *Ichneumon promissorius*, *Carcelia* sp., and *Diglyphus isaea* are larval parasitoids of *Spodoptera*.

33.2.9 Stem Fly

Melanagromyza sojae Zehntner (Diptera: Agromyzidae) has emerged as a major pest in the soybean growing areas of India over the last two decades. Two species of hymenopteran parasitoids from two families, namely Eurytomidae (*Eurytoma melanagromyza* Narendran) and Pteromalidae (*Chlorocytus* sp.)

TABLE 33.1

Parasitoids of Pulse Pod Borer *Helicoverpa armigera*

Order	Family	Stage	Scientific Name
Hymenoptera	Scelionidae	Egg parasitoids	*Telenomus* sp.
	Trichogrammatidae		*Trichogramma* sp., *T. achaeae*, *T. brasiliensis*, *T. chilonis*, *T. chilotraeae*, *Trichogrammatoidea* sp., *Trichogrammatoidea armigera*, *T. bactrae*, *T. fumata*
	Braconidae	Egg larval parasitoids	*Chelonus* sp., *C. heliopae*, *C. narayani*, *Microchelonus curvimaculatus*
Diptera	Sarcophagidae	Larval parasitoids	*Sarcophaga orientoides*
	Tachinidae		*Compsilura concinnata*, *Drino unisetosa*, *Drino imberbis*, *Eucelatoria bryani*, *Exorista fallax*, *Exorista japonica*, *Exorista xanthaspis*, *Somera cinerascens*, *Pales coerulea-nigra*, *Palexorista* sp., *P. laxa*, *P. solennis*, *Sisyropa apicata*, *Spallanzania* sp., *Strobiomyia aegyptia*, *Sturmiopsis inferens*, *Suensonomyia* sp., *Thecocarcelia incedens*, *Voria edentata*, *V. ruralis*, *Winthemia diversoides*
	Chloropidae		*Mepachymerus ensifer*
Hymenoptera	Bethylidae		*Goniozus* sp.
	Braconidae		*Apanteles* sp., *Apanteles* sp. *glomeratus* group, *A. glmeratus*, *A. rujicrus*, *Bracon* sp., *B. brevicornis*, *B. cushmani*, *B. gelechiae*, *B. greeni*, *B. hebetor*, *Microplitis maculipennis*, *Microplitis palidipes*, *Odentepyris* sp., *Paraphylax* sp., *Rogas* sp.
	Eulophidae		*Euplectrus* spp.
	Ichneumonidae		*Agrypon nox*, *Attractodes* sp., *Banchopsis rujicornis*, *Barichneumon* sp., *Campoletis chlorideae*, *C. maculipes*, *Campoletis (Ecphoropsis)* sp., *Disophrys* sp., *Enicospilus* sp., *Enicospilus shinkanus*, *Eriborus argenteopilosus*, *Eriborus pilosellus*, *Eriborus trochanteratus*, *Ichneumon* sp., *Metopius rufus*, *Netelia* sp., *Pristomerus* sp., *Temelucha* sp.
Nematoda	Mermithidae		*Hexamermis* sp., *Ovomermis albicans*
Dlptera	Tachinidae	Larval Pupal parasitoids	*Carcelia* sp., *C. (Stenometopia) illota*, *C. kolkiana*, *C. raoi*, *C. peraequalis*, *Goniophthalmus halli*
Hymenoptera	Ichneumonidae	Pupal parasitioids	*Xanthopimpla stemmator*, *Compoletis chloriedae*
	Chalcididae		*Brachymeria responsator*, *Tetrastichus ayyari*

Source: Manjunath et al. 1999

FIGURE 33.2 *Netelia producta* (http://www.nbair.res.in).

with an average parasitism of 12.50% and 11.14%, respectively, were the most prevalent parasitoid species throughout the season (Gaur et al. 2015).

33.2.10 Lycaenid Pod Borer

Natural enemies of Lycaenid pod borer include parasitoids *Trichogramma* sp., *Tetrastichus* sp., *Telenomus* sp., *Chelonus* sp., *Campoletis* sp., *Bracon* sp., *Carcelia* sp., etc. Predators include

FIGURE 33.3 *Ichneumon promissorius* (http://www.nbair.res.in).

Lacewing, ladybird beetle, spider, red ant, dragonfly, robber fly, reduviid bug, praying mantis, black drongo (King crow), wasp, common mynah, big-eyed bug (*Geocoris* sp), earwig, ground beetle, Pentatomid bug (*Eocanthecona furcellata*), etc.

33.2.11 Field Bean Pod Borer

Natural enemies of field bean pod borer include parasitoids *Trichogramma* sp., *Tetrastichus* sp., *Telenomus* sp., Chelonus sp., *Campoletis* sp., *Bracon* sp., *Carcelia* sp., etc. Predators include Lacewing, ladybird beetle, spider, red ant, dragonfly,

TABLE 33.2

List of Parasitoid Complex of *Maruca vitrata*

Parasitoid	Life Stage Parasitized	Reference
Diptera		
Tachinidae		
Aplomya metallica (Weid.)	Larva	Agyen-Sampong (1978)
Exorista xanthaspis (Wiedemann)	Larva	Barrion et al. (1987)
Palexorista solemnis (Walker)	Larva	Barrion et al. (1987)
Peirbaea orbata (Wiedemann)	Larva	Barrion et al. (1987)
Zygobothria atropivora (Rob.-Desv.)	Larva	Barrion et al. (1987)
Zygobothria ciliata (Wulp)	Larva	Barrion et al. (1987)
Thelairosoma sp.	Larva	Usua and Singh (1977)
Pseudopetichaeta laevis (Vill.)	Larva	Amen-Sampong (1978)
Pseudaporichaeta sp.	Larva	Usua and Singh (1977)
Thecocarcelia incedens (Rond.)	Larva	Agyen-Sampong (1978)
Hymenoptera		
Baraconidae		
Apanteles sp.	Larva	Okeyo-Owuor et al. (1991)
Bracon sp.	Larva	Okeyo-Owuor et al. (1991)
Braunsia sp.	Pupa	Okeyo-Owuor et al. (1991), Agyen-Sampong (1978)
Cardiochiles philippinensis Ashm.	Larva	Barrion et al. (1987)
Chelonus sp.	Larva	Barrion et al. (1987)
Cremnops sp.	Larva-Pupa	Barrion et al. (1987)
Snellenius manitae Ashm.	Larva	Barrion et al. (1987)
Phanertoma handecasisella Cam.	Larva	Subasinghe and Fellows (1978)
Phanertoma sp.	Larva	Usua and Singh (1977)
Chalcididae		
Antrocephalus sp., *nr subelongatus*	-	Subasinghe and Fellows (1978)
Antrocephalus sp.	Pupa	Okeyo-Owuor et al. (1991)
Bmchymetia sp. *A*.	Larva-Pupa	Barrion et al. (1987)
Brachymeria sp. B.	Larva-Pupa	Barrion et al. (1987)
Eulophidae		
Nesolynx thymus (Gir.)		Subasinghe and Fellows (1978)
Tetrastichus sesamiue Risbec	Pupa	Okeyo-Owuor et al. (1991)
Tetrasrichus sp.	Pupa	
Ichneumonidae		
Caenopimpla arealis (Cushman)	Larva	Barrion et al. (1987); Usua and Singh (1977)
Charops nigrita Gupta and Maheswary	Larva	Barrion et al. (1987); Usua and Singh (1977)
Meloboris sinicus (Holmgren)	Larva	Barrion et al. (1987); Usua and Singh (1977)
Metopius rufus hrowni Ashm.	Larva	Barrion et al. (1987); Usua and Singh (1977)
Pteromalidae		
Trichomalopsis sp.	Larva-Pupa	Barrion et al. (1987)
Scelionidae		
Telenomus sp.		Subasinghe and Fellows (1978)

robber fly, reduviid bug, praying mantis, King crow, wasp, common mynah, *Geocoris* sp., earwig, ground beetle, Pentatomid bug (*Eocanthecona furcellata*), etc. The percentages of parasitism of natural enemies on different legume crops are provided in Table 33.5.

33.3 Stored Legumes

Legume seeds are stored in godowns and warehouses in huge and minute quantities and are severely infested by bruchid beetles, *Callosobruchus chinensis* and *C. maculatus* (Tables 33.6 and 33.7).

33.4 Insect Growth Regulators (IGR)

Overlap of insect growth regulator at 5% cyromazine and dipping treatment at 30°C showed a noteworthy decline in the reproductive rate in *C. maculatus*. Moreover, escalating the cyromazine concentration led to a decrease in food burning up and an increase of generation's lifetime (Al-Mekhlafi et al. 2012).

TABLE 33.3

Diversity of Natural Enemy of Cowpea

S. No	Common Name	Scientific Name	Order/Family	Population Status	Host
1	Ladybird beetle	*Micraspis discolor* (Fab.)	Coleoptera: Coccinellidae	High	Egg, nymph, adult of jassid and white fly; Egg larva of Lepidoptera
2	Ladybird beetle	*Coccinella transversilis* (Fab.)	Coleoptera: Coccinellidae	Medium	Egg, nymph, adult of jassid and white fly; Egg larva of Lepidoptera
3	Ladybird beetle	*Brumoides* sp.	Coleoptera: Coccinellidae	Medium	Egg, nymph, adult of jassid and whitefly; Egg larva of Lepidoptera
4	Ladybird beetle	*Menochilus sexmaculatus* (Fab.)	Coleoptera: Coccinellidae	Low	Egg, nymph, adult of jassid and whitefly; Egg larva of Lepidoptera
5	Ladybird beetle	*Coccinella septempunctata* Linn.	Coleoptera: Coccinellidae	Low	Egg, nymph, adult of jassid and whitefly; Egg larva of Lepidoptera
6	Ladybird beetle	*Illeis indica* Timberlake	Coleoptera: Coccinellidae	Low	Egg, nymph, adult of jassid and whitefly; Egg larva of Lepidoptera
7	Rove beetle	*Paedurus* sp.	Coleoptera: Staphylinidae	Medium	Egg, nymph, adult of jassid and whitefly; Egg larva of Lepidoptera
8	Ground beetle	*Ophionea* sp.	Coleoptera: Carabidae	Medium	Egg, nymph, adult of jassid and whitefly; Egg larva of Lepidoptera
9	Yellow hornet	*Vespa* sp.	Hymenoptera: Vespidae	Low	Nymph, adult of jassid
10	Black ant	Unspecified	Hymenoptera: Formicidae	Low	Lepidopteran adults
11	Lynx spider	*Oxyopes* sp.	Araneae: Oxyopidae	High	Nymph, adult of jassid and whitefly; adult of Lepidoptera
12	Long jawed spider	*Tetragnatha* sp.	Araneae: Tetragnathidae	High	Do

Source: Singh and Singh 2014, Niba 2011.

TABLE 33.4

List of Hymenopteran Parasitoids on *M. obtuse*

Species	Super Family	Family	Reference
Euderus sp.	Chalcidoidea	Eulophidae	
Diglyphus funicularis Khan			Khan (1985)
D. mandibularis Khan			Khan (1985)
Tetrastichus atomella			Ipe (1987)
Euderus spp.			Sithantham et al. (1987)
Aprostocetus sp.			Narendran (2005)
O. fredreki			Peter (1992)
Ormyrus sp.			Ketipearachchi (2002)
Eurytoma sp.		Eurytomidae	Ipe (1987)
E. robusta Mayr			Sithanantham et al. (1987)
Plutarchia indefensa (Walker)			Sithanantham et al. (1987)
Microdontomerus (=*Antistrophoplex*) sp.			Sithanantham et al. (1983)
Pseudotorymus (=*Senegalella*) sp.			Singh et al. (1991)
Callitula sp.		Pteromalidae	Makinson et al. (2005)
Eupelmus sp.		Eupelmidae	Thakur and Odak (1982)
Bracon sp.	Ichneumonoidea	Braconidae	Sah and Mehra (1986)
Tricopria sp.	Proctotrupoidea	Diapriidae	Thakur and Odak (1982)
Omytes sp.	Unreported	Unreported	Rao and Babu (2009)

TABLE 33.5

Percentage of Parasitism of Natural Enemies on Different Legume Crops

Crop	Pest	Parasitoid/Predator	Percentage Parasitism	References
Soybean	*Helicoverpa* spp.	Nabidae	50% predation of eggs and larvae	Pfannenstiel et al. (2002)
Pigeonpea	*Helicoverpa armigera*	*T. chilonis*	1.2% to 8.3% on pods and on leaves parasitism varied from 5.0% to 29.0%	(Tandon and Bakthavatsalam, 2005)
Chickpea	*Helicoverpa armigera*	*C. chloridae*	65.0 to 75.0% on larval parasitism	Jagdish Jaba and Agnihotri M (2016)
Pigeonpea	*Maruca vitrata*	Apanteles sp.	Parasitism high as 63% on *M. vitrata* larvae	(Huang et al. 2003)
Pigeonpea	*Maruca vitrata*	Trichogrammatoidea eldanae	< 50% of eggs parasitism	Belmain, S.R. et al. (2013)
S. cannabina	*M. vitrata*	*Apanteles taragamae*	Parasitism reached as high as 63% of *M. vitrata* larvae found attacking	Chi-Chung Huang et al. (2003)
Soybean and pigeonpea	*Etiella zinckenella*	Braconid, *Iconella* (=Apanteles) *etiellae* (Vier.)	3.4%	Alejandro E et al. (1988)
Pigeonpea	*Melanagromyza obtusa*	Three hemenopteran parasitoids *viz*., *Systasis dasyneurae* Mani, *Torymus* sp. Dalman (ectolarval parasitoids) and *Epitranus* sp. Walker (endopupal parasitoid)	The natural parasitism of these parasitoids ranged from 1.69 to 7.32, 5.08 to 29.27 and 2.13 to 4.88%, respectively	Chiranjeevi, B et al. (2017)
Cowpea	*H. armigera*	*Trichogramma* spp.	37.0% level of parasitism	Sithanantham et al. (1983)
Green gram	*H. armigera*	*Trichogramma* spp.	17.4	Pawar et al. (1986)
Pigeonpea	*H. armigera*	*Trichogramma* spp.	0.2	Pawar et al. (1986)
Groundnut	*H. armigera*	*Trichogramma* spp.	32.3	Sithanantham et al. (1983)

TABLE 33.6

Natural Enemies of Pulse Beetles

Natural Enemy	Description
Dinarmus acutus, *D. basalis*, *D. vagabundus* (Pteromalidae: Hymenoptera)	It is a solitary parasitoid that attacks larval, pre-pupal, and pupal stages of *Callosobruchus* sp. (Islam and Kabir 1995)
Pteromalus cerealella, *P. tritici*	It was thought to be a monophagous parasitoid of Angoumois moth (Fulton 1933). Later it was highly successful in killing *Callosobruchus maculates* (F.) as to other storage insects
Anisopteromalus calandrae	It is an ectoparasitoid on the larvae and pupae of pulse beetles *C. maculates* (F.) and this parasitoid preferred younger larvae of the pest
Uscana lariophaga, *U. mukherjii* (Hymenoptera: Trichogrammatidae)	Egg parasitoids: *U. lariophaga* females were able to find hosts up to 75 cm horizontal distance from the host patch, which was the largest distance tested (Stolk et al. 2005)
Eupelmus orientalis, *E. vuilleti*	Parasite larvae/pupae (Anonymous 2014)
Lariophagus distinguendus	Parasite larva (Anonymous 2014)
Heterospilus prospidis	Parasite larva (Anonymous 2014)
Cheyletus eruditus	Predator (Anonymous 2014)
Entomopathogenic fungus	1. *Beauveria bassiana* (Vanmathi et al. 2011); Shaheen et al. 2016) 2. An isolate (CA-2) of *B. brongniartii* (E-9) of *Metarhizium anisopliae* (Rodrigues and Pratissoli 1999)
Entomopathogenic nematodes	1. *Heterorhabditis bacteriophora*, *Steinernema siamkayai*, and *S. pakistanense* were among those nematodes that showed the highest virulence 2. The last larval stage of the pulse beetle seems to be more susceptible than the adult (Shahina and Salma 2009)

33.5 Biopesticides

The term biopesticides defines compounds that are used to manage agricultural pests by means of specific biological effects rather than as broader chemical pesticides. Globally, though biopesticides cover only about 1% of the total plant protection products, their number and the growth rate have been showing an increasing trend in the past two decades (Ranga Rao et al. 2007). In India, they represent only 2.89% of the overall pesticide market and are expected to exhibit an annual growth rate of about 2.3% in the coming years (Mazid et al. 2011).

33.5.1 Baculovirus

Baculovirus is one of the microbial pesticides that have a very narrow host range and generally infests the larvae of crop pests.

TABLE 33.7

Active Ingredients of Plant Extracts of Pulse Beetles

Name of the Plant	Potential Active Ingredients	References
Neem (*Azadirachta indica*)	Tetranortriterpenoids (Azadirachtin, melantriol, salannin, nimbin, nimbidin	Reddy (2010)
Karanj (*Pongammia pinnata*)	Furanoflavonoid (karanjin, pongamol, pongapin, glabrin, karanja chromene, karanjone and pongaglabrone)	Bringi (1987)
Castor (*Ricinus communis*)	Ricin and ricinine	Ramos-López (2010)
Clove (*Syzygium aromaticum*)	Eugenol (4 allyl-2-methoxy phenol; C10H12O2), an organic phenol compound	Shapiro (2012)
Mahua (*Madhuca latifolia*)	Saponin, an alkaloid glucoside (leaves), Sapogenin and other basic acid (seeds)	Sunitha and Sarojini (2013)
Mustard (*Brassica* sp.) Horseradish (*Armoracia rusticana*) Wasabi (*Eutrema japonicum*)	Allyl isothiocyanate (AITC)	Yu et al. (2003)
Soybean (*Glycine max*)	Emulsifiable concentrate formulations of soybean oil	EPA (1993)

FIGURE 33.4 NPV infected pod borer *H. armigera* larva (Source: ICRISAT).

Nuclear polyhedrosis viruses (NPVs) is a nucleic acid (double standard, circular DNA) enclosed in protein matrix, hence it is called polyhedral occlusion body (POB). NPV infects the nucleus of the cell and multiplies within the nucleus. Nuclear polyhedrosis viruses like Ha NPV and Sl NPV are increasingly being used as alternatives to chemicals for the control of polyphagous pests of pulses like gram pod borer (*Helicoverpa armigera*) and tobacco caterpillar (*Spodoptera litura*), respectively (Figure 33.4).

The majority of the commercially formed fungi (*Beauveria*, *Metarhizium*, *Lecanicillium*, and *Verticillium*) have evolved focused mechanisms for the enzymatic deprivation of the integument and for overcoming insect guard compounds; among them *Beauveria* and *Metarhizium* are used for the control of pulse pests like *Helicoverpa armigera*, *Spodoptera litura*, thrips, whiteflies, aphids, and mites (Figure 33.5).

33.5.2 Bacteria

Bacillus thuringiensis (Bt) has been known to be a pool of numerous insecticidal proteins, such as δ-endotoxins, cytolytic proteins, vegetative insecticidal proteins, etc. Among these, δ-endotoxins have been more efficiently utilized for protection of a variety of crops from various insect pests.

33.5.3 Plant-Incorporated Protectants (PIPs)

Limited success of conventional breeding and use of hazardous chemicals have directed to the production of transgenic chickpea plants expressing Bt genes resistance against pod borer, *H. armigera* (Jalu and Panera 2018). A few studies also conclude that *B. thuringiensis* is more effective against pulse beetle, *C. maculatus*, and could be used as one of the potential biocontrol agents in the management of stored product insect pests in the future (Malaikozhundan and Vinodhini 2018).

33.5.4 Biochemicals

Herbal pesticides/biochemicals are concentrates of biologically effective plant items like leaves, stem, roots, and entire plants particularly for the control of soft-bodied insect pests, which feed on the leaves and tender plant parts as flowers and developing grains and so forth. It contains Azadirachtin, a tetranortritarpinoid, a major active ingredient, which is known to disrupt the metamorphosis of insects. Neem Seed Kernel Extract reduces the larval population of *H. armigera* in chickpea and pod damage. Similarly, aqueous leaf extract of *Catharanthus roseus* spray on blakgram also reduced its population (Rajasekaran et al. 1987). Karanja oil (2%) was reported to prolong its larval

FIGURE 33.5 *Helicoverpa armigera* larvae infected with *B. bassiana*. Source: ICRISAT.

development and growth-inhibiting activity (Bajpai and Sehgal 1994). Nicotine sulfate isolated from tobacco leaves was found to be highly toxic to this borer (Patel et al. 1990).

33.6 Pheromones

Sex pheromone-baited traps can be used in the fields to capture males of newly emerged moths and reduce the number of males for mating. Sex pheromone of tobacco caterpillar (*Spodoptera litura*) at 10–12 traps/ha have been recommended for the monitoring of the pests of legumes. Sex pheromone trap for gram pod borer (*Helicoverpa armigera*) at 10–12 traps/ha have been suggested for the monitoring of the pulse crop pests like chickpea, soybean, etc.

33.7 Conclusion and Future Prospects

Grain legumes continue to be important crops not only from a nutritional security perspective, but also for their involvement in the health and fertility of the soil. Cultivation of these crops faces a number of biotic and abiotic stresses, reflected in the form of deteriorated yield and quality. Insecticide misuse has led to increased levels of resistance to insecticides, emergence of secondary pests, loss of biodiversity, and a rise in human health hazards. Integrated pest management (IPM) can help to minimize insecticide use. In recent years, pest management strategies are mostly concentrated on integrating various options such as resistant varieties, biological, mechanical, biopesticides, insect pheromones technology, and chemical control. The role of natural enemies in the management of major insect pests has been underestimated until now. The importance of mixed crops, crop rotations, sowing dates, although very well understood, have not been fully exploited.

REFERENCES

Al-Mekhlafi, F.A.; Ali Mashaly, A.M.; Wadaan, M.A.; Al-Mallah, N.M. Overlap effects of cyromazine concentration, treatment method and rearing temperature on southern cowpea weevil *Callosobruchus maculatus* reared on mung bean. *Pakistan Journal of Zoology*. 2012, 44(1), 285–290.

Alejandro, E.; Segarra, C.; Pedro, B. Notes on the natural enemies of *Etiella zinckenella* in Puerto Rico. *The Journal of Agriculture of the University of Puerto Rico*. 1988, 72(1), 153–159.

Bajpai, N.K.; Sehgal, V.K. Effect of neem products, nicotine and karanj on survival and biology of pod borer, Helicoverpa armigera Hubn. of chickpea. Proc. II AZRA Conf. on Recent Trends in Plant,Animal and Human Pest Management: Impact on Environment. Madras Christian College, Madras, 27–29 Dec,1994 pp:48.

Barrion, A.T.; Bandong, J.P.; De la Cruz, C.G.; Apostol, R.F.; Litsinger, J.A. Natural enemies of the bean pod-borer, *Maruca testulalis* in the Philippines. Tropical Grain Legume Bulletin. 1987, 34, 21–22.

Belmain, S.R.; Haggar, J.; Holt, J.; Stevenson, P.C. *Managing Legume Pests in Sub-Saharan Africa: Challenges and Prospects for Improving Food Security and Nutrition Through Agro-Ecological Intensification*. Chatham Maritime, UK: Natural Resources Institute, University of Greenwich, 2013, 34p.

Bhatnagar, V.S.; Sithanantham, S.; Pawar, C.S.; Jadhav, D.S.; Rao, V.K.; Reed, W. Conservation and augmentation of natural enemies with reference to IPM in chickpea and pigeonpea. In Proceedings of the International Workshop on Integrated Pest Control in Grain Legumes, Goiania, Brazil, 4–9 April 1983, 157–180.

Bringi, N.V. *Non-traditional Oil Seeds and Oils in India*. New Delhi: Oxford and IBH, 1987.

Chiranjeevi, B.; Patange, N.R. New host record of three hymenopteran parasitoids associated with *Melanagromyza obtusa* (Malloch) and their level of natural parasitism. *Journal of Entomology and Zoology Studies*. 2017, 5(4), 277–283.

Clement, S.L.; Wightman, J.A.; Hardie, D.C.; Bailey, P.; Baker, G. McDonald, G. Opportunities for integrated management of insect pests of grain legumes. In: Knight R. (ed.), *Linking Research and Marketing Opportunities for Pulses in the 21st Century*. Dordrecht: Springer, 2000, pp. 467–480.

Environmental Protection Agency, Prevention, Pesticides and Toxic substances (7508W), EPA-738-F-93-027. December, 1993, 1–4.

Fulton, B.B. Notes on *Habrocytes cerealellae*, parasite of the Angoumois grain moth. *Annals of Entomological Society of America*. 1933, 26, 536–553.

Gaur, N.; Sharma, P.; Nautiyal, A. Seasonal incidence of major insect-pests of soybean and their correlation with abiotic factors. *Journal of Hill Agriculture*. 2015, 6, 75–78.

Hormazabal, R.L.; Gerding, P.M. Release density of *Uscana senex* Grese (Hymenoptera: Trichogrammatidae) for control of *Bruchus pisorum* L. (Coleoptera: Bruchidae). *Agro-Ciencia*, 1998, 14, 157–161.

Huang, C-C.; Peng, W-K.; Taleka, N.S. Parasitoids and other natural enemies of *Maruca vitrata* feeding on *Sesbania cannabina* in Taiwan. *BioControl*. 2003, 48(4), 407–416.

International Crops Research Institute for the Semi-Arid Tropics. *The Medium-term Plan*. Patancheru: ICRISAT, 1992.

Ipe, M. Biosystematic studies on Agromyzidae from India. *Proceedings of the* Indian *Academy of Sciences* (*Animal Sciences*). 1987, 96, 573–581.

Islam, W.; Kabir, S.M.H. Biological control potential of *Dinarmus basalis* (Rond.) (Hymenoptera: Pteromalidae) larval-pupal ectoparasitoid of the pulse beetle, *Callosobruchus Chinensis* (L.). *Crop Protection*. 1995, 14(6), 439–443.

Jaba, J.; Agnihotri, M.; Chakravarty, S. Biology and relative parasitization of larval endoparasitoid *Campoletis cholrideae* Uchida on Heliocoverpa armigera Hübner under sole and chickpea-coriander intercropping system. *Journal of Biological Control*. 2016, 30(2), 84–90.

Jalu, R.K.; Panera, A.V. Transgenic Bt. chickpea: India's most required GM pulse crop. *The Pharma Innovation Journal*, 2018, 7(8): 551–552.

Karungi, J.; Adipala, E.; Nampala, P. Pest management in cowpea. Part 3. Quantifying the effect of field pests on grain yields in eastern Uganda. *Crop Protection*. 2000, 19, 343–347.

Ketipearachichi, Y. Hymenoptera parasitoids and hyper parasitoids of crop pests at Aralaganurla in north central province of Sri Lanka. *Annals of the Sri Lanka Department of Agriculture*, 2002, 4, 293–306.

Khan, M.A. Eulophid parasites (Hymenoptera: Eulophidae) of Agromyzidae in India. *Journal of the Bombay Natural History Society*. 1985, 82(1), 149–159.

Makinson, J.; Goolsby, J.; Kirk, A.; Meyerdirk, S. A new record and host association for the pigeon pea podfly, *Melanagromyza obtusa* (Malloch) (Diptera: Agromyzidae) and notes on its parasitoids in the Northern Territory, Australia. *Australian Entomologist*. 2005, 32, 79–82.

Malaikozhundan, B.; Vinodhini, J. Biological control of the Pulse beetle, *Callosobruchus maculatus* in stored grains using the entomopathogenic bacteria, *Bacillus thuringiensis*. *Microbial Pathogenesis*. 2018, 114, 139–146.

Manjunath, T.M.; Bhatnagar, V.S.; Pawar, C.S.; Sithanantham, S. Economic importance of *Heliothis* sp. in India and an assessment of their natural enemies and host plants. In: King E.G.; Jackson R.D. (eds.), Proceedings of the Workshop on Biological Control of *Heliothis*: Increasing the Effectiveness of Natural Enemies. Far Eastern Regional Research Office, United States Department of Agriculture, New Delhi, 1999, pp. 197–228.

Mazid Salma.; Jogen Ch. Kalita.; Ratul Ch. Rajkhowa. A review on the use of biopesticide in the insect pest management. *International Journal of Science and Advanced Technology*. 2011, 1(7), 169–178.

Miller, P.R.; McConkey, B.G.; Clayton, G.W.; Brandt, S.A.; Staricka. J.A.; Johnston, A.M.; Lafond, G.P.; Schatz, B.G.; Baltensperger, D.D.; Neill, K.E. Pulse crop adaptation in the Northern Great Plains, *Agronomy Journal*. 2002, 94, 261–272.

Narendran, T.C. Two new species of *Tetrastichus haliday* (Hymenoptera: Eulophidae) displaying some characters of Aceratoneuromyia Girault. *Bulletin of Pure and Applied Sciences (A)*. 2005, 24(1), 37–42.

Niba, A.S. Arthropod assemblage dynamics on cowpea, *Vigna unguiculata* (L) Walp in subtropical agroecosystem, South Africa. *African Journal of Agricultural Research*. 2011, 6, 1009–1015.

Okeyo-Owuor, J.B.; Oloo, J.B.; Agwaro, P.O. Natural enemies of legume pod-borer, Murucu *testululis* (Geyer) (Lepidoptera: Pyralidae) in small farming systems of western Kenya. *International Journal of Tropical Insect Science*.1991, 12, 35–42.

Patel, H.R.; Patel, D.J.; Patel, C.C.; Thaker, N.A. Affectivity of *Clerodendron inerme* Linn. and Periwinkle, *Catharanthus roseus* (Linn.) G. Don. for management of root-knot nematodes in okra. Presented in National Symposium on Problems and Prospects of Botanical Pesticides. CTRI, Rajahmundry, India, 1990, pp. 40–41.

Pawar, C.S.; Bhatnagar, V.S.; Jadhav. D.R. *Heliothis* species and their natural enemies, with their potential for biological control. *Proceedings: Animal Sciences*. 1986, 95(6), 695–703.

Peter, C. A note on the parasitoid fauna associated with red gram pod fly, *Melanagromyza obtusa* Malloch. *Journal of Insect Science*. 1992, 5, 88.

Pfannenstiel, R.S.; Yeargan, K.V. Identification and diel activity patterns of predators attacking *Helicoverpa zea* (Lepidoptera: Noctuidae) eggs in soybean and sweet corn. *Environmental Entomology*. 2002, 31(2), 232–241.

Pintureau, B.; Gerding, M.; Cisternas, E. Description of three new species of Trichogrammatidae (Hymenoptera) from Chile. *The Canadian Entomologist*. 1999, 131, 53–63.

Rajasekaran, B.; Jayraj, S.; Raghuramman, S.; Narayan swamy, T. Use of neem products for the management of certain rice pests and diseases. In: *Mid Term Appraisal Works on Botanical Pest Control of Rice*, T.N.A.U, Coimbatore, India 1987. p 13.

Ramos-López, M.A.; Pérez, S.; Rodríguez Hernández, G.C.; Guevara Fefer, P.; Zavala Sánchez, M.A. Activity of *Ricinus communis* (Euphorbiaceae) against *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *African Journal of Biotechnology*. 2010, 9(9), 1359–1365.

Ranga Rao, G.V.; Rupela, O.P.; Rameshwar Rao, V.; Reddy, Y.V.R. Role of Biopesticides in crop protection: Present status and future prospects. *Indian Journal of Plant Protection*. 2007, 35(1), 1–9.

Rao, A.G.; Babu, T.R. Biological control of Arthopod pest of pulse crops. In: Upadhyay, R.K.; Mukerji, K.G.; Chandola, B.P.; Dubey, O.P. (eds.), *Integrated Pest and Disease Management*. New Delhi: APH Publishing Corporation, 2009, p. 247.

Reddy DS. Chapter 17: Botanicals. In: *Applied entomology, Pusa Agricultural Book Service*, New Delhi 2010, 109.

Rodrigues, C.; Pratissoli, D. Pathogenicity of *Beauveria brongniartii* (Sacc.) petch and *Metarhizium anisopliae* (Mots.) sorok and their effect on the corn weevil and the bean beetle. *Anais da Sociedade Entomológica do Brasil*. 1999, 19(2), 301–306.

Sah, B.N.; Mehra, B. P. New record of the parasites of *Melanagromyza obtusa* Malloch in Ranchi, India. *Indian Journal of Entomology*. 1986, 348, 359.

Sampong, A. Pests of cowpea and their control in Ghana. In: Singh, S.R.; van Emden, H.F.; Taylor, J.A. (eds.), *Pests of Grain Legumes: Ecology and Control*. London: Academic Press, 1978, pp. 85–92.

Saxena, K.B.; Chandrasena, G.D.S.N.; Hettiarachchi, K.; Iqbal, Y.B.; Fonseka, H.H.D; Jayasekara, S.J.B.A. Evaluation of pigeon pea accessions and selected lines for reaction to Maruca. *Crop Science*. 2002, 42, pp. 615–618.

Shaheen, F.A.; Akram, M.W.; Rashid, M.A.; Nadeem, M.; Saeed, M.; Husain, M.; Khalid, M. Resistance of chickpea (Cicer arietinum L.) cultivars against pulse beetle. Pak. J. Bot. 2006, 38: 1237–1244.

Shahina, F.; Salma, J. Laboratory evaluation of seven Pakistani strains of entomopathogenic nematodes against a stored grain insect pest, Pulse beetle *C. chinensis* (L.). *Journal of Nematology*. 2009, 41, 255.

Shapiro, R. Prevention of vector transmitted diseases with clove oil insect repellent. *Journal of Pediatric Nursing*. 2012, 27(4), 346–349.

Sharma, H.C. Strategies for Heliothis/Helicoverpa management: emerging trends and strategies for future research. New Delhi: Oxford and IBH, 2005.

Sharma, O.P.; Gopali, J.B.; Yelshetty, S. *Pests of Pigeon Pea and Their Management*. New Delhi: National Centre for Integrated Pest Management, IARI Campus, 2010.

Singh, C.; Singh, N.N. Occurrence of insect-pests infesting cowpea (*Vigna unguiculata* walpers) and their natural enemy complex in associations with weather variables. *Legume Research*, 2014, 37(6), 658–664.

Singh, S.; Singh, S.P.; Babu, S.S.; Sebastian, P.C. Bioecology of Hymenoptera parasites of Agromyzidae (Diptera) pests species in India. Memorial School Of Entomology. 1991, 11, 1–238.

Sithanantham, S.; Rao, V.R.; Reed, W. Parasites of the pigeon pea pod fly, *Melanagromyza obtusa* in India. *Journal of Biological Control*. 1987, 1(1), 10–16.

Sithanantham, S.; Rao, V.R.; Reed, W. Survey of pigeon pea pod fly in India. *International Pigeon Pea News Letter*. 1983, 2, 66–68.

Song, F.; Swinton, S.M.; DiFonzo, C. *Profitability Analysis of Soybean Aphid Control Treatments in Three Northcentral States*. Staff Paper 24. Lansing, MI: Department of Agricultural Economics, Michigan State University, 2006.

Stolk, C.; Ghimire, M.N.; Souquie, S.; van der Werf.; van Huis A. Host finding by Uscana lariophaga (Hymenoptera: Trichommatidae) in stored cowpea: the effect of distance, time interval, host patch size and spatial orientation. Bulletin of Entomological Research. 2005, 95(3):231–241.

Subasinghe, S.M.C.; Fellows, R.W. Recent trends in grain legume pest research in Sri Lanka. In Singh, S.R.; van Emden, H.F.; Taylor, J.A. (eds.), *Pests of Grain Legumes: Ecology and Control*. London: Academic Press, 1978, pp. 37–41.

Sunitha, M.; Sarojini, P. *Madhuca Lonigfolia* (Sapotaceae): A review of its traditional uses and nutritional properties. *International Journal of Humanities and Social Science Invention*. 2013, 2(5), 30–36.

Tandon, P.L.; Bakthavatsalam, N. Electrophysiological and olfatometric responses of *Helicoverpa armigera* and *Trichogramma chilonis* Ishii, to volatiles of trap crops *tagetes erecta* L. and *Solanum viarum* Dunal. *Journal of Biological Control*. 2005, 19, 9–16.

Thakur, B.S.; Odak, S.C. New record of the parasites of *Melanagromyza obtusa* Malloch. *Science and Culture*. 1982, 48, 80.

Tilmon, K.J.; Hodgson, E.W.; O'Neal, M.E. Biology of the soybean aphid, Aphis glycines (Hemiptera: Aphididae) in the United States. *Journal of Integrated Pest Management*. 2011, 2(2), 1–7.

Usua, E.J.; Singh, S.R. Parasites and predators of the cowpea podborer, *Maruca testuhlis* (Lepidoptera: Pyralidae). *Nigerian Journal of Entomology*. 1977,1, l00–102.

Vanmathi Shifa, J.; Padma Latha, C.; Ranjit Singh, A.J.A. Impact of entomopathogenic fungus, *Beauveria bassiana* on stored grains pest, *Callosobruchus maculates* (F.) (Coleoptera: Bruchidae). *Journal of Biopesticides*. 2011, 4(2), 194–197.

Wang, X.B.; Fang, Y.H.; Lin, S.Z. A study on the damage and economic threshold of the soybean aphid at the seedling stage. *Plant Protection*. 1994, 20, 12–13.

Yadav, A.K.; Yadav, S.; Singh, M.K. Effect of temperature on the population of parasitoids and their impact on the pest Melanagromyza obtusa (Diptera:Agromyzidae). Journal of Environmental Science. 2012, 1: 45–50.

Yu, J.C.; Jiang, Z.T.; Li, R.; Chan, S.M. Chemical composition of the essential oils of *Brassica juncea* (L.) Coss. grown in different regions, Hebei, Shaanxi and Shandong, of China. *Journal of Food Drug Analysis*. 2003, 11, 22–26.