BIOPESTICIDES IN ORGANIC FARMING

RECENT ADVANCES

Edited by
L.P. Awasthi

CRC Press
Taylor & Francis Group

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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

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Foreword

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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.

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Section XVIII

Integrated Pest Management (IPM), a Noble Biopesticidal Approach

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Integrated Pest Management in Major Legume Crops

Jagdish Jaba, Jatin,K, Reddy Ramya Sree, Sathish Kota, and Suraj Prasad Mishra

CONTENTS

44.1 Introduction

Integrated pest management (IPM) is the basic concept in the containment of a pest below economically damaging levels using the combination of feasible control measures with environmental and operational safety. The term was earlier used as "integrated control" by Bartlett (Bartlett, 1956) and was further elucidated by Stern and coworkers (Stern et al., 1959). Various national, international organizations and NGOs support and promote IPM because of its safety for the environment and public health. However, there is no universally agreed definition of IPM. (Alstair, 2003). In principle, IPM may be defined as a principle and holistic approach but in a recent IPM pyramid presented by (Stenberg, 2017) identified the lack of a holistic approach that uses traditional and modern tools. Previous models of IPM mainly focused on ecological and to some extent on the evolutionary aspects of pest management (Peterson et al., 2018).

44.2 Extent of Losses Due to Insect Pests in Grain Legumes

In India, insect pests lead to an approximate economic loss in yield of 15.00% worth $2285.29 million (Dhaliwal et al., 2015). Pod borer, *H. armigera*—the single largest yield shrinking factor in food legumes—causes an estimated loss of $317 million in pigeon pea 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). In general, the estimates of yield losses vary from 50 to 100% in the tropics and 5 to 10% in the temperate regions (van Emden et al., 1988). Another pod borer, *M. vitrata*, causes loss estimated to be $30 million annually (Saxena et al., 2002). In pigeon pea, yield losses due to pod borer 25–70%, pod fly 10–50%, *Maruca* 5–25%, and pod bug 10–30% have been reported (Sharma et al., 2010). Legume flower thrips (LFT), *M. sjostedti* Trybom, and cowpea *V. unguiculata* in tropical Africa causes yield losses ranging from 20 to 100% (Karungi et al., 2000). The avertable losses in grain/food legumes at current production levels of 60.45 mt would be nearly 18.14 mt (at an average loss of 30%), worth nearly $10 billion (Sharma et al., 2008). The loss in legumes due to various pests and pathogens is estimated to be up to 20% on average annually (Dhaliwal et al., 2010). Up to 100% of losses have been observed in various legume crops in Asia and Africa in the circumstances that favor diseases and pests (Vijay et al., 2015). In a survey conducted by ICRISAT, *Helicoverpa armigera* has been reported to cause yield loss varying from 4.2 to 39.7% in 12 major chickpea growing states and in case of pigeon pea *Melanagromyza obtusa* was reported to cause 2.5% yield loss in north India (Krishnamurthy Rao and Murthy 1983) (Table 44.1).

TABLE 44.1

Economically Important Insect Pests in Pulses in Asia and Their Threshold Levels

Common Name	Scientific Name	ETLs	Existing Control Methods
Pigeon Pea			
Pod borer	*Helicoverpa armigera* (Hubner)	5 eggs or 3 small larvae per plant	IPM
Podfly	*Melanagromyza obtusa* (Malloach)	In all endemic locations	Chemical
Leaf webber	*Maruca vitrata* (Geyer)	5 webs per plant	Chemical
Pod sucking bugs	*Clavigralla gibbosa Spinola*	One egg mass per plant	Chemical
Chick Pea			
Pod borer	*Helicoverpa armigera* (Hubner)	3 eggs or 2 small larvae per plant	IPM
Cutworm	*Agrotis ipsilon* (Hufnagel)	5% plant mortality	Chemical
Aphids	*Aphis craccivora* Koch	25.0% of plants infested at seedling stage in dry situations only in rainy season	IPM
Green Gram, Black Gram and Cowpea			
Hairy caterpillar	*Spilosoma obliqua* (Walker)	5 larvae per meter row	Chemical
Leaf miner	*Liriomyza trifoli*	5 infested leaves per plant at 30 days of crop age	IPM
Tobacco caterpillar	*Spodoptera litura* (Fab)	20–25% defoliation at 40 days	IPM
Thrips	*Scirtothrips dorsalis* Hood	5 thrips/terminal at seedling stage	Chemical
Aphids	*Aphis craccivora* Koch	5–10 aphids per terminal at seedling stage in dry spells only in rainy season	IPM
Bruchids	*Callosobruchus chinensis*	Immediately after first observation	Sanitation, Triplelayer bags

44.3 Role of IPM in Organic Farming

Organic farming and sustainable farming systems are the best alternatives to conventional farming (Shetty et al., 2014). The main aim of organic farming is to promote natural enemies (Kristiansen, 2006). The use of botanical pesticides to protect crops from insect pests has assumed greater importance throughout the world in recent years (Hire math, 1994).

44.4 Pest Management Tactics in IPM

The following are common pest management techniques, which can be used at different stages of crop production to prevent, reduce, minimize, or treat pest infestations. Each may provide a certain level of control, but their additive effect may be significant in preventing loss of yield.

44.4.1 Host Plant Resistance

It is described as the best strategy that uses insect resistant and insect tolerant cultivars produced by conventional breeding or genetic engineering (Douglass, 2018). Among various alternatives of IPM, growing genotypes with tolerance to insects would be the most economical way of reducing the yield losses. Painter (1958) classified plant resistance to insects into three categories based on the mechanisms involved: non-preference (for oviposition, food, or shelter), antibiosis (adverse effect of plants on the biology of insects), and tolerance (repair, recover, or ability to withstand infestation). The HPR is the first line of defense in IPM program.

44.4.2 Cultural Control

These maneuvers are location-specific and must be designed to suit local practices and customs (Ranga Rao and Shanower, 1999). A reduced infestation of pod bugs and aphids was recorded in cowpea due to early planting (Karungi et al., 2000) and the pod borer (*Maruca vitrata*), and the pod bug (*Clarigralla tomentosicollis*) in West Africa. A high-density planting system reduced root maggot (Delia spp.) invasions in canola crop of Canada region (Dosdall et al., 1996), and aphid invasions in cowpea in Uganda. Crop rotation with non-host crops or tolerant varieties disrupts the pest life cycles therefore, crop rotation tactic has been widely used in controlling many insect pests all over the world (Mohler and Johnson, 2009). Seed priming in chickpea (soaking overnight) improves the chickpea establishment and reduces losses due to pod borer damage (Musa et al., 1999). Intercropping coriander with chickpea may afford nectar sources for adult parasitoid improving natural control of *Helicoverpa* in chickpea. It was reported that in a sole crop of chickpea, mean parasitism by *Campoletis chlorideae* on the larvae of *H. armigera* was 60.61% and in the chickpea-coriander intercropping ecosystem, it was 76.96% (Jaba et al., 2016).

44.4.3 Biological Control

Insect pests of legume crops have many natural enemies, viz. predatory arthropods (Hajek and Ellenberge 2018) (Figure 44.1).

Predators: Many predators feed on insect pests that attack pigeon pea. For example, >60 species of arthropods have been reported to prey on *H. armigera*. In addition

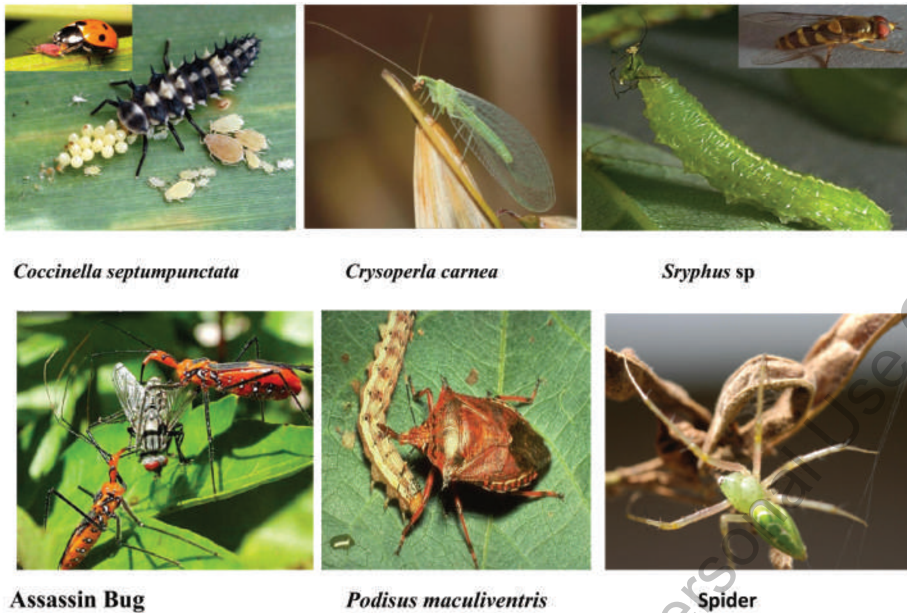

FIGURE 44.1 Generalist predators that are common in pest management.

to predatory insects, several species of spiders, lizards, and birds feed on *H. armigera*.

Parasitoids: Many parasitoids have been reported to feed on pigeon pea pests. For example, more than 75 insect parasitoids (orders: Hymenoptera and Diptera) attack various life stages of *H. armigera*. Some parasitoids can be mass-reared and released into an infested field. In addition, a number of commercial companies are marketing parasitoids, the most common being the egg parasitoid, *Trichogramma* spp., which attack eggs of *H. armigera* and other lepidopterons (Kenis et al., 2017) (Figure 44.2).

44.4.4 Behavioral Control

Pest behavior can be utilized to monitor and regulate the pests through bait, trap, and mating disruption methods. Baits containing poisonous material will attract and kill the pests when scattered in the field or placed in traps. Certain colors, lights, odors of attractants or pheromones draw the attention of the pest by manipulating their behavior. Pheromone lures confuse adult insects and disrupt their mating and thus there will not be any progeny. The techniques used for behavior control were described by Fooster et al., 1997. Various baits mixed with chemicals are used for killing stored grain pests (Figures 44.3 and 44.4).

44.4.5 Physical/Mechanical Methods

It refers to the use of a variety of physical or mechanical techniques for pest exclusion, trapping, removal, and destruction of the pests (Web and Linda, 1992).

44.4.6 Microbial Control

Microbial control refers to the use of disease-causing microorganisms to reduce the population of insect pests below the damaging levels. Using entomopathogenic bacteria, fungi, spore farming unicellular parasites, nematodes, or viruses, and fermentation byproducts of some microbes against arthropod pests, plant-parasitic nematodes, and plant pathogens usually come under microbial control (Mankau, 1981). When controlling lepidopteran pests, the bacteria like *Bacillus thuringiensis*, baculoviruses are successful in IPM. Nucleopolyhedrosis virus (Ha-NPV) is used exclusively for controlling *H. armigera* affecting pigeon pea and chickpea (Figure 44.5).

44.4.7 Chemical Control

Chemical method of pest management usually refers to the use of synthetic chemical pesticides (Pimental, 2009). Although botanical extracts such as azadirachtin and pyrethrins, and microbe-derived toxic metabolites such as avermectin and spinosad are considered as biorationals (Lasota and Dybas, 1991). Chemical pesticides are characterized into different groups based on their mode of action (IRAC, 2018) and switching chemicals pesticides with different modes of action will reduce the risk of resistance development by the targeted pests. (Sparks and Nauen, 2015).

44.5 IPM Modules for Managing Legume Pests

- Seed treatment with fungicide before sowing.
- Deep summer plowing is helpful to eliminate quiescent pupa from the field.
- The use of tolerant/resistant varieties for *Helicoverpa* management.
- Installation of *Helicoverpa* pheromone traps for intensive monitoring and tuning of control strategies.
- Mixing of sorghum/maize seed at 250 g/ha to function as live bird perches. These plants also help in conserving natural enemies.

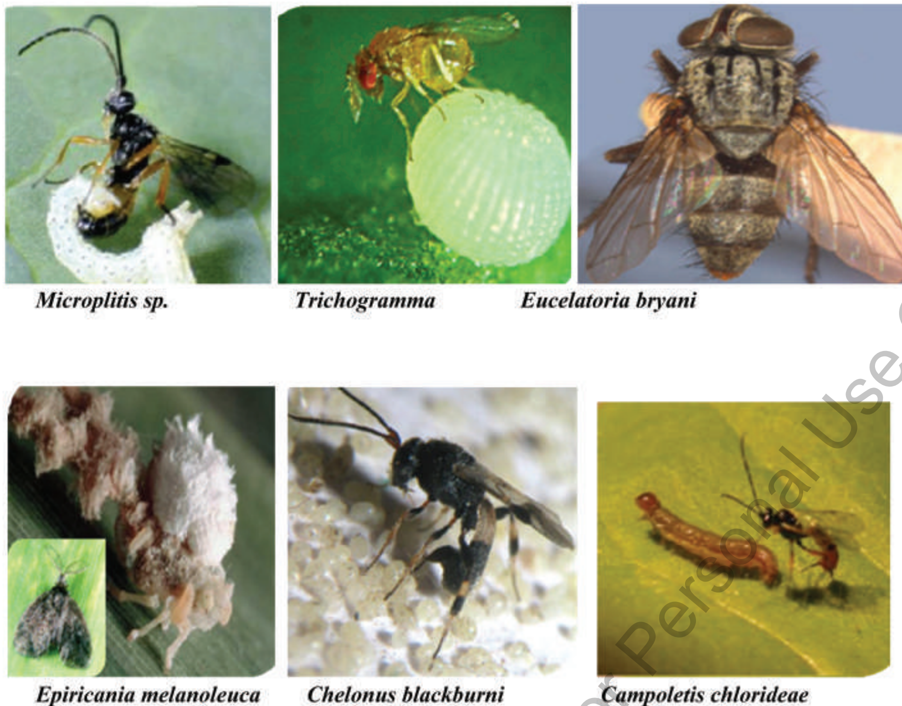

FIGURE 44.2 Generalist parasitoids that are common in pest management.

FIGURE 44.3 Monitoring by pheromone traps.

FIGURE 44.4 Monitoring adult lepidopterans by light traps.

- Intensive weed management in the early stages of the crop.
- Increased monitoring for pod borers at the flower initiation stage.
- Fixing of bird perches after crop establishment.
- Application of 5% neem seed powder extract (NSKE) at flower initiation.
- Early sowing of pigeon pea short duration varieties is helpful against pest attack.
- Polyethylene mulch in peanut reduced thrips damage to 4.6% compared to 24.3% leaflets damaged in an unmulched area. A reduction in injury caused by jassids was recorded as 11% in unmulched ones when compared to mulched ones.
- Pigeon pea varieties ICPL 332 WR, ICPL 84060, ICPL 187-1, and ICP 7203 were promisingly found to be resistant to pod borer *Helicoverpa*, and ICPL 98003 was found to be resistant to *Maruca vitrata* (Sharma et al., 2017).
- Application of HNPV at 500 LE/ha when the egg/larval population reaches ETL.
- The pod borer complex may be managed effectively by applying *Trichogramma chlionis* in the field at weekly intervals at 1.5 lakh/ha/week three to four times.

FIGURE 44.5 *Helicoverpa* larva infected with HaNPV under field conditions.

- Manual shaking of pigeon pea plants to dislodge larvae, and destruction of larvae, in "outbreak" situations.
- Adopt soil application of sulfur at 20 kg/ha (e.g., through SSP, gypsum, or elemental) and zinc as $ZnSO_4$, which will lead to healthy crops and impart general resistance.
- Increased monitoring for pod borers from flower initiation stage.
- Intercrop with linseed/coriander/mustard and "sprinkle" with sunflower to promote bioagent activity. Legumes must be planted before mid-October to save plants from pod borer damage.
- Application of 5% neem seed kernel extract at flower initiation.
- If the infestation by larvae (pod borer or webber or blue butterfly) is causing higher damage spray green label pesticides, e.g., Emamectin benzoate or Chlorantraniliprole (Rynaxypyr) to save the crop. Repeat spray if necessary.
- Cautious application of appropriate chemical pesticides, if the other controls measures recommended above do not contain pest population below ETL's. Appropriate drying, application of inert dusts during storage, conversion of seed into dhal, and fumigation with celphos at 3 g per 40 kg seed against storage pests.
- Spraying of effective molecules like Indoxacarb 14.5 SC% at 300 ml/ha or Emamectin benzoate 5% SG at 11 a.i. gm/ha or spinosad 45 SC at 56–73 a.i. gm/ha is effective against pod borer complex (Sujithra, M, 2013).

44.6 IPM Success Stories

44.6.1 An ICRISAT Success Story

44.6.1.1 Reviving Chickpea through Integrated Pest Management in Nepal

IPM is a new concept in Nepal. Nearly 75% of the population in Nepal has no knowledge about the system while the rest of them have a piece of basic knowledge in pest control through chemical techniques. Chickpea has great potential in Nepal with chickpea occupying a large area of about 390,000 ha. Therefore, an opportunity to arrest and reverse the declining trend in the production of chickpeas by extending the potential benefits of the IPM package to farmers and, indeed with the farmer. The introduction of IPM has revived high demand for the crop. Promotion of IPM was carried out in collaboration with Nepal Agricultural Research Complex and various NGO and farmers self-help groups and ICRISAT. The recommendations suggested by IPM team ICRISAT like, need- and weather-based applications of fungicide for the management of various diseases and insecticide for the management of pod borer, wide spacing, seed treatment with insecticide, installation of pheromone traps, etc were followed. Through IPM, the pod borer incidence was reduced to a six fold increase in grain yield (up to 4 tons per ha was obtained). In the 1998/1999 season, 110 farmers tried IPM with chickpea. The following season there was a five fold increase in IPM adoption. The good news spread, and by the end of 2000/2001 and 2001/2002, 1,100 and 7,000 farmers, respectively, adapted IPM techniques. At the end of 2003, 11,000 farmers have adapted the IPM technology (Icrisat success stories—SS2-Jul 2003).

44.6.2 ICAR Success Story on Implementation of IPM in India

44.6.2.1 Intensive Application of IPM for Increasing Productivity of Pulse Crops

Pigeon pea and chickpea are widely cultivated in the states of Karnataka, Maharashtra, Andhra Pradesh, Uttar Pradesh, Madhya Pradesh and Jharkhand. Farmers in these regions are facing bigger problems with pod borers, plume moths, and cutworms. Farmers were taught new techniques like field scouting, installation of pheromone traps, monitoring population dynamics and pest forecasting through "National Pest Reporting and Alert system e-surveillance" through http://www.ncipm.org.in/A3P/UI/HOME/ Login.aspx. Crop yields have increased and infestation by pod borer decreased after following all the IPM practices recommended by ICAR (Sharma et al., 2016).

44.7 Conclusion and Future Plan

IPM strategies recognize that many environmental factors interact and work together to affect the abundance, distribution, movement, and phenotype of insect pest populations. The IPM system approach draws on an in-depth knowledge of how management practices affect the biology of insects and other trophic interactions. Advances in genomics make it possible to better understand the dynamics of pest populations (e.g., patterns of movement or biotypes that respond differently to host plant resistance traits) that may provide information needed to develop new approaches for insect management. There must be a flow of information between the scientists and users who apply the strategies. Agricultural researchers, instructors, sociologists, economists, professional analysts, managers, growers, pest management professionals, agricultural input manufacturers, retailers, and consumers play a key role in food production. The new IPM model serves as a template for focusing on the different areas of the Paradigm and to encourage collaboration between different disciplines. This new model is expected to develop IPM strategies around the world for implementing sustainable agricultural practices to ensure profitability for farmers, affordability for consumers, and food security for the growing world population.

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