P. Parvatha Reddy

Biointensive Integrated Pest Management in Horticultural Ecosystems

Springer

Biointensive Integrated Pest Management in Horticultural Ecosystems

P. Parvatha Reddy

Biointensive Integrated Pest Management in Horticultural Ecosystems

Springer

Dr. P. Parvatha Reddy
Former Director
Indian Institute of Horticultural Research
Bangalore
Karnataka
India

ISBN 978-81-322-1843-2 ISBN 978-81-322-1844-9 (eBook)
DOI 10.1007/978-81-322-1844-9
Springer New Delhi Dordrecht Heidelberg London New York

Library of Congress Control Number: 2014933684

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Through 'Green Revolution' in late 1960s, India achieved self-sufficiency in food production, which was hailed as a breakthrough on the farm front by international agricultural experts. But still the country has not achieved self-sufficiency in production of horticultural crops. Most of the growth in food production during the green revolution period is attributed to the use of improved crop varieties and higher levels of inputs of fertilizers and pesticides. The modern agricultural techniques such as use of synthetic fertilizers and pesticides are continuing to destroy stable traditional ecosystems and the use of high yielding varieties of crops has resulted in the elimination of thousands of traditional varieties with the concurrent loss of genetic resources. The introduction of high yielding varieties changed the agricultural environment leading to numerous pest problems of economic importance. In the process of intensive farming, the environment has been treated in an unfriendly manner.

Prof. Swaminathan (2000) emphasized the need for 'Ever Green Revolution' keeping in view the increase in population. The increase in population and diminishing per capita availability of land demands rise in productivity per unit area. In India, annual crop losses due to pests, diseases, and weeds have been estimated to be about ₹ 600,000 million in 2005. Increasing yields from existing land requires effective crop protection to prevent losses before and after harvest. The challenge before the crop protection scientist is to do this without harming the environment and resource base. This can be achieved by adopting eco-friendly Biointensive Integrated Pest Management (BIPM) strategy.

BIPM is defined as "A systems approach to pest management based on an understanding of pest ecology. It begins with steps to accurately diagnose the nature and source of pest problems, and then relies on a range of preventive tactics and biological controls to keep pest populations within acceptable limits. Reduced-risk pesticides are used if other tactics have not been adequately effective, as a last resort, and with care to minimize risks" (Benbrook 1996).

BIPM incorporates ecological and economic factors into agricultural system design and decision making, and addresses public concerns about environmental quality and food safety. The benefits of implementing BIPM can include reduced chemical input costs, reduced on-farm and off-farm environmental impacts, and more effective and sustainable pest management.

An ecology-based Integrated Pest Management (IPM) has the potential of decreasing inputs of fuel, machinery, and synthetic chemicals-all of which are energy intensive and increasingly costly in terms of financial and environmental impact. Such reductions will benefit the grower and society.

The information on biointensive integrated pest management (insect, mite and nematode pests, and diseases caused by bacteria, fungi, virus/mycoplasma) in horticultural ecosystems (fruits, vegetables, ornamentals, medicinal, aromatic, tuber, plantation, and spice crops) is very much scattered. There is no book at present which comprehensively and exclusively deals with the above aspects. The present book deals with the most recent biointensive integrated approaches utilizing components such as bioagents [predators, parasitoids, and pathogens (bacteria, fungi, viruses)], botanicals (biofumigation, oil cakes, FYM, compost, crop residues, green manuring, and other organic amendments), endomycorrhizae, physical methods (hot water treatment of planting material, soil solarization), cultural methods (crop rotation, summer ploughing, fallowing, intercropping, pruning, mulching, spacing, planting date, trap cropping, etc.), biorational chemicals (pheromones) and resistant cultivars. The book is illustrated with excellent quality photographs enhancing the quality of publication. The book is written in lucid style, easy to understand language along with adoptable recommendations for pest management.

This book can serve as a useful reference to policy makers, research, and extension workers, practicing farmers and students. The material can also be used for teaching post-graduate courses. Suggestions to improve the contents of the book are most welcome (E-mail: reddy_parvatha@yahoo.com). The publisher, Springer, deserves commendation for their professional contribution.

Bangalore, India
5 Mar 2014

Dr. P. Parvatha Reddy
Indian Institute of Horticultural Research

Contents

About the Author

Dr. P. Parvatha Reddy obtained his MSc (Agri.) degree from Karnataka University, Dharwad, and PhD degree jointly from the University of Florida, USA and the University of Agricultural Sciences, Bangalore.

Dr. Reddy served as the Director of the prestigious Indian Institute of Horticultural Research (IIHR) at Bangalore from 1999 to 2002 during which period the Institute was honoured with *ICAR Best Institution Award*. He also served as the Head, Division of Entomology and Nematology at IIHR and gave tremendous impetus and direction to research, extension and education in developing bio-intensive integrated pest management strategies in horticultural crops. These technologies are being practiced widely by the farmers across the country since they are effective, economical, eco-friendly and residue-free. Dr. Reddy has about 34 years of experience working with horticultural crops and involved in developing an F1 tomato hybrid *Arka Varadan* resistant to root-knot nematodes. He has also developed bio-intensive integrated pest management strategies in horticultural crops using eco-friendly components such as bio-control agents, botanicals and arbuscular mycorrhizal fungi.

Dr. Reddy has over 237 scientific publications to his credit, which also include 25 books. He has also guided two PhD students at the University of Agricultural Sciences, Bangalore.

Dr. Reddy has been awarded with the prestigious *Association for Advancement Pest Management in Horticultural Ecosystems Award, Dr. G.I. D'souza Memorial Lecture Award, Prof. H.M. Shah Memorial Award* and *Hexamar Agricultural Research and Development Foundation Award* for his unstinted efforts in developing sustainable, bio-intensive and eco-friendly integrated pest management strategies in horticultural crops.

Dr. Reddy served as a member of the Research Advisory Committee of the National Centre for Integrated Pest Management, New Delhi; the National Research Centre for Citrus, Nagpur and the Project Directorate of Biological Control, Bangalore. He also served as a Member of the ICAR Scientific Panel for Nematology, Member, QRT to review the progress of AICRP on Nematodes and AINRP on Betelvine. He is the *Honorary Fellow* of the Society for Plant Protection Sciences, New Delhi, *Fellow* of the Indian Phytopathological Society, New Delhi and *Founder President* of the Association for Advancement of Pest Management in Horticultural Ecosystems (AAPMHE), Bangalore.

Dr. Reddy has organized *Fourth International Workshop on Biological Control and Management of Chromolaena odorata, National Seminar on Hitech Horticulture, First National Symposium on Pest Management in Horticultural Crops: Environmental Implications and Thrusts* and *Second National Symposium on Pest Management in Horticultural Crops: New Molecules and Biopesticides.*

Part I
Introduction

Introduction

1

Through 'Green Revolution' in late 1960s, India achieved self-sufficiency in food production, which was hailed as a breakthrough on the farm front by international agricultural experts. But still the country has not achieved self-sufficiency in production of horticultural crops. Most of the growth in food production during the green revolution period is attributed to the use of improved crop varieties and higher levels of inputs of fertilizers and pesticides. The modern agricultural techniques such as use of synthetic fertilizers and pesticides are continuing to destroy stable traditional ecosystems and the use of high yielding varieties of crops has resulted in the elimination of thousands of traditional varieties with the concurrent loss of genetic resources. The introduction of high yielding varieties changed the agricultural environment leading to numerous pest problems of economic importance. In the process of intensive farming, the environment has been treated in an unfriendly manner.

Prof. Swaminathan (2000) emphasized the need for 'Ever green revolution' keeping in view the increase in population. The increase in population and diminishing per capita availability of land demands rise in productivity per unit area. In India, annual crop losses due to pests, diseases and weeds have been estimated to be about ₹ 600,000 million in 2005. Increasing yields from existing land requires effective crop protection to prevent losses before and after harvest. The challenge before the crop protection scientist is to do this without harming the environment and resource base. This can be achieved in horticultural ecosystems by adopting eco-friendly biointensive integrated pest management (BIPM) strategy.

1.1 Integrated Pest Management

Integrated pest management (IPM) is an important principle on which sustainable crop protection can be based. IPM allows farmers to manage pests in a cost effective, environmentally sound, and socially acceptable way. According to Food and Agriculture Organization (FAO), IPM is defined as 'A pest management system that in the context of the associated environment and the population dynamics of the pest species utilizes all suitable techniques and methods, in a compatible manner as possible and maintains the pest populations at levels below those causing economic injury'.

1.2 Biointensive Integrated Pest Management (BIPM)

BIPM incorporates ecological and economic factors into agricultural system design and decision making, and addresses public concerns about environmental quality and food safety. The benefits of implementing BIPM can include reduced chemical input costs, reduced on-farm and off-farm environmental impacts, and more effective

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_1, © Springer India 2014

and sustainable pest management. An ecology-based IPM has the potential of decreasing inputs of fuel, machinery, and synthetic chemicals—all of which are energy intensive and increasingly costly in terms of financial and environmental impact. Such reductions will benefit the grower and society.

Over-reliance on the use of synthetic pesticides in crop protection programmes around the world has resulted in disturbances to the environment, pest resurgence, pest resistance to pesticides, and lethal and sublethal effects on non-target organisms, including humans. These side effects have raised public concern about the routine use and safety of pesticides. At the same time, population increases are placing ever-greater demands upon the 'ecological services', i.e., provision of clean air, water, and wildlife habitat for a landscape dominated by farms. Although some pending legislation has recognized the costs to farmers of providing these ecological services, it is clear that farmers will be required to manage their land with greater attention to direct and indirect off-farm impacts of various farming practices on water, soil, and wildlife resources. With this likely future in mind, reducing dependence on chemical pesticides in favour of ecosystem manipulations is a good strategy for farmers.

BIPM is defined as 'A systems approach to pest management based on an understanding of pest ecology. It begins with steps to accurately diagnose the nature and source of pest problems, and then relies on a range of preventive tactics and biological controls to keep pest populations within acceptable limits. Reduced-risk pesticides are used if other tactics have not been adequately effective, as a last resort, and with care to minimize risks' (Benbrook 1996).

The primary goal of BIPM is to provide guidelines and options for the effective management of pests and beneficial organisms in an ecological context. The flexibility and environmental compatibility of a BIPM strategy make it useful in all types of cropping systems. BIPM would likely decrease chemical use and costs even further.

1.2.1 Components of BIPM

An important difference between conventional IPM and BIPM is that the emphasis of the latter is on proactive measures to redesign the agricultural ecosystem to the disadvantage of a pest and to the advantage of its parasite and predator complex. At the same time, BIPM shares many of the same components as conventional IPM, including monitoring, use of economic thresholds, record keeping, and planning.

1.2.1.1 Planning

Good planning must precede implementation of any IPM programme, but is particularly important in a biointensive programme. Planning should be done before planting because many pest strategies require steps or inputs, such as beneficial organism habitat management, that must be considered well in advance. Attempting to jump-start an IPM programme in the beginning or middle of a cropping season generally does not work.

When planning a BIPM programme, some considerations include:

- Options for design changes in the agricultural system (beneficial organism habitat, crop rotations).
- Choice of pest-resistant cultivars.
- Technical information needs.
- Monitoring options, record keeping, equipment, etc.

When making a decision about crop rotation, consider the following questions: Is there an economically sustainable crop that can be rotated into the cropping system? Is it compatible? Important considerations when developing a crop rotation are:

- How might the cropping system be altered to make life more difficult for the pest and easier for its natural controls? What two (or three or several) crops can provide an economic return when considered together as a biological and economic system that includes considerations of sustainable soil management?
- What are the impacts of this season's cropping practices on subsequent crops?

- What specialized equipment is necessary for the crops?
- What markets are available for the rotation crops?

Management factors should also be considered. For example, one crop may provide a lower direct return per hectare than the alternate crop, but may also lower management costs for the alternate crop, with a net increase in profit.

1.2.1.2 Pest Identification

A crucial step in any IPM programme is to identify the pest. The effectiveness of both proactive and reactive pest management measures depends on correct identification. Misidentification of the pest may be worse than useless; it may actually be harmful and cost time and money. Help with positive identification of pests may be obtained from university personnel, private consultants, the Cooperative Extension Service (CES), and books and web sites.

After a pest is identified, appropriate and effective management depends on knowing answers to a number of questions. These may include:

- What plants are hosts and non-hosts of this pest?
- When does the pest emerge or first appear?
- Where does it lay its eggs?
- For plant pathogens, where is the source(s) of inoculum?
- Where, how, and in what form does the pest overwinter?

Monitoring (field scouting) and economic injury and action levels are used to help answer these and additional questions.

1.2.1.3 Monitoring

Monitoring involves systematically checking crop fields for pests and beneficials, at regular intervals and at critical times, to gather information about the crop, pests, and natural enemies. Sweep nets, sticky traps, and pheromone traps can be used to collect insects for both identification and population density information. Leaf counts are one method for recording plant growth stages. Records of rainfall and temperature are sometimes used to predict the likelihood of disease infections.

The more often a crop is monitored, the more information the grower has about what is happening in the fields. Monitoring activity should be balanced against its costs. Frequency may vary with temperature, crop, growth phase of the crop, and pest populations. If a pest population is approaching economically damaging levels, the grower will want to monitor more frequently.

1.2.1.4 Economic Injury and Action Levels

The economic injury level (EIL) is the pest population that inflicts crop damage greater than the cost of control measures. Because growers will generally want to act before a population reaches EIL, IPM programmes use the concept of an economic threshold level (ETL or ET), also known as an action threshold. The ETL is closely related to the EIL and is the point at which suppression tactics should be applied in order to prevent pest populations from increasing to injurious levels.

ETLs are intimately related to the value of the crop and the part of the crop being attacked. For example, a pest that attacks the fruit or vegetable will have a much lower ETL (i.e., the pest must be controlled at lower populations) than a pest that attacks a non-saleable part of the plant. The exception to this rule is an insect or nematode pest that is also a disease vector. Depending on the severity of the disease, the grower may face a situation where the ETL for a particular pest is zero, i.e., the crop cannot tolerate the presence of a single pest of that particular species because the disease it transmits is so destructive.

1.2.2 BIPM Options

BIPM options may be considered as proactive or reactive.

1.2.2.1 Proactive Options

Proactive options, such as crop rotations and creation of habitat for beneficial organisms, permanently lower the carrying capacity of the farm for

the pest. The carrying capacity is determined by the factors like food, shelter, natural enemy complex, and weather, which affect the reproduction and survival of a pest species. Cultural control practices are generally considered to be proactive strategies. Proactive practices include crop rotation, resistant crop cultivars including transgenic plants, disease-free seed and plants, crop sanitation, spacing of plants, altering planting dates, mulches, etc.

The proactive strategies (cultural controls) include:

- Healthy, biologically active soils (increasing below-ground diversity).
- Habitat for beneficial organisms (increasing above-ground diversity).
- Appropriate plant cultivars.

(i) Intercropping Intercropping is the practice of growing two or more crops in the same, alternate, or paired rows in the same area. This technique is particularly appropriate in vegetable production. The advantage of intercropping is that the increased diversity helps 'disguise' crops from insect pests and, if done well, may allow for more efficient utilization of limited soil and water resources.

(ii) Strip Cropping Strip cropping is the practice of growing two or more crops in different strips across a field wide enough for independent cultivation. It is commonly practiced to help reduce soil erosion in hilly areas. Like intercropping, strip cropping increases the diversity of a cropping area, which in turn may help 'disguise' the crops from pests. Another advantage to this system is that one of the crops may act as a reservoir and/or food source for beneficial organisms.

The options described above can be integrated with no-till cultivation schemes and all its variations (strip till, ridge till, etc.) as well as with hedgerows and intercrops designed for beneficial organism habitat. With all the cropping and tillage options available, it is possible, with creative and informed management, to evolve a biologically diverse, pest-suppressive farming system appropriate to the unique environment of each farm.

(iii) Disease-free Seed and Plants These are available from most commercial sources and are certified as such. The use of disease-free seed and nursery stock is important in preventing the introduction of disease.

(iv) Resistant Varieties These are continually being bred by researchers. Growers can also do their own plant breeding simply by collecting non-hybrid seeds from healthy plants in the field. The plants from these seeds will have a good chance of being better suited to the local environment and of being more resistant to insects and diseases. Since natural systems are dynamic rather than static, breeding for resistance must be an ongoing process, especially in the case of plant disease, as the pathogens themselves continue to evolve and become resistant to control measures.

Perhaps the greatest single technological achievement is the advance in breeding crops for resistance to pests. Cultivation of resistant varieties is the cheapest and best method of controlling pests. One of the important components of IPM is the use of resistant cultivars to key pests. Under All India Co-ordinated Research Projects of Indian Council of Agricultural Research, a large number of highly/moderately resistant varieties are released to the farmers (Table 1.1).

(v) Biotech Crops Gene transfer technology is being used by several companies to develop cultivars resistant to insects, diseases, and nematodes. An example is the incorporation of genetic material from *Bacillus thuringiensis* (*Bt*), a naturally occurring bacterium, into brinjal and potatoes, to make the plant tissues toxic to shoot and fruit borer and potato beetle larvae, respectively.

Whether or not this technology should be adopted is the subject of much debate. Opponents are concerned that by introducing *Bt* genes into plants, selection pressure for resistance to the *Bt* toxin will intensify and a valuable biological control tool will be lost. There are also concerns about possible impacts of genetically modified (GM) plant products (i.e., root exudates) on nontarget organisms as well as fears of altered genes being transferred to weed relatives of crop plants. Whether there is a market for gene-altered crops

Table 1.1 Horticultural crop varieties resistant to pests/diseases

Horticultural crop	Pest/disease	Resistant varieties
Banana	*Radopholus similis*	Kadali, Pedalimoongil, Ayiramkapoovan, Peykunnan, Kunnan, Pisang Seribu, Tongat, Vennettu Kunnan, Anaikomban
	Panama wilt (*Fusarium oxysporum* f. sp. *cubense*)	Robusta, Dwarf Cavendish
Citrus	*Tylenchulus semipenetrans*	Trifoliate Orange, Swingle Citrumelo
	Gummosis, leaf fall, fruit rot (*Phytophthora* spp.)	Cleopatra mandarin, Rangpur lime, Trifoliate orange rootstocks
Grapevine	Root-knot nematode, *Meloidogyne incognita*	Black Champa, Dogridge, 1613, Salt Creek, Cardinal, Banquabad
Papaya	Ring spot virus	Rainbow, Sun Up
Passion fruit	Root-knot nematode, *M. incognita*	Yellow, Kaveri
Potato	Late blight	Kufri Sutlej, Kufri Badshah, Kufri Jawahar (in plains), Kufri Jyothi, Kufri Giriraj, Kufri Kanchan, Kufri Meghad (in hills)
Tomato	Bacterial wilt	Arka Abha, Arka Alok, Arka Shreshta, Arka Abhijit, Megha, Shakthi, Sun 7610, Sun 7611
	PM	Arka Asish
	Fusarium and *Verticillium* wilt	Vaishali, Rupali, Rashmi
	Leaf curl virus	Avinash-2, Hisar Anmol
	Root-knot nematode	Hisar Lalit, Pusa Hybrid-2, Arka Vardaan
Brinjal	Bacterial wilt	Arka Nidhi, Arka Keshav, Arka Neelkant, Arka Anand, Swarna Shree, Swarna Shyamali, Surya, Ujjwala
	Phomopsis blight	Pusa Bhairav
	Little leaf	Pusa Purple Long, Pusa Purple Cluster (Field resistant)
Chilli	TMV, CMV, leaf curl	Pusa Sada Bahar, Punjab Lal, Pusa Jwala
	Thrips	NP 46 (T)
	PM	Arka Suphala (T)
	Dieback and PM	Musalwadi (T)
	Mosaic, leaf curl	Pant C-1
	Leaf curl and fruit rot	Jawahar 218 (T)
	Viruses	Arka Harita, Arka Meghana
French bean	Angular leaf spot, mosaic	Pant Anupama
	Rust, bacterial blight	Arka Anoop
	Rust	Arka Bold, Swarna Priya, Swarna Latha, Arka Anoop
	Rust, *Alternaria* leaf spot	Arka Bold
Pea	PM	Pusa Pragati, Jawahar Matar 5, Jawahar Peas 83
	PM, rust	Arka Ajit, Arka Karthik, Arka Sampoorna
	Fusarium wilt	JP Batri Brown 3, JP Batri Brown 4
Cowpea	Bacterial blight	Pusa Komal
Pigeon pea	*Fusarium* wilt	Maruti
Field bean	Viral diseases, jassid, aphid, pod borer	Pusa Sem-2, Pusa Sem-3
Cluster bean	PM, *Alternaria* leaf spot	Gomah Manjari
Okra	YVMV	Pusa Sawani, Arka Abhay, Arka Anamika, Hisar Unnat, DVR-1, DVR-2, IIVR-10, Varsha Upkar, P-7, Pusa A-4, Parbhani Kranti (T), Punjab Kesari, Punjab Padmini, Sun-40, Makhmali
	YVMV and fruit borer	Pusa A-4

Table 1.1 (continued)

Horticultural crop	Pest/disease	Resistant varieties
Cucumber	PM	Swarna Poorna
	PM, DM, angular leaf spot, anthracnose	Poinsette
Cabbage	Black rot	Pusa Mukta
	Black leg	Pusa Drum Head
Cauliflower	Black rot	Pusa Snowball K-1
	Black rot and curd blight	Pusa Shubhra
	Curd blight	Pusa Synthetic
	DM	Pusa Hybrid-2
Onion	Purple blotch, basal rot, thrips	Arka Pitamber, Arka Kirtiman, Arka Lalima
	Purple blotch, *Alternaria porri*	Arka Kalyan
Garlic	Purple blotch, *Stemphylium* disease	Agri-found White
Muskmelon	PM	Arka Rajhans, Pusa Madhuras (MR)
	PM, DM	Punjab Rasila
	Fusarium wilt	Pusa Madhuras, Durgapura Madhu, Arka Jeet, Punjab Sunehari (MR), Harela
Watermelon	PM, DM, anthracnose	Arka Manik
Pumpkin	Fruit fly	Arka Suryamukhi
Ridge gourd	PM, DM	Swarna Uphaar
Bottle gourd	Blossom end rot	Arka Bahar (T)
	CMV	Punjab Komal
Carrot	PM, root-knot nematode	Arka Suraj
Amaranth	White rust	Arka Arunima, Arka Suguna (MR)
Palak	*Cercospora* leaf spot	Arka Anupama
China aster	Root-knot nematode, *M. incognita*	Shashank, Poornima (MR)
Tuberose	Root-knot nematode, *M. incognita*	Sringar, Suvasini (T)
Mentha	Root-knot nematode, *M. incognita*	Kukrail, Arka Neera
Black pepper	Root-knot nematode, *M. incognita*	IISR Pournami (T)
	Foot rot, *Phytophthora capsici*	IISR Shakthi
Cardamom	Mosaic	IISR Vijetha
	Rhizome rot	IISR Avinash
Ginger	Root-knot nematodes	IISR Mahima
	Soft rot	Maran
Cumin	*Fusarium* wilt	GC-4

CMV cucumber mosaic virus, *DM* downy mildew, *MR* moderately resistant, *PM* powdery mildew, *T* tolerant, *TMV* tobacco mosaic virus, *YVMV* yellow vein mosaic virus

is also a consideration for farmers and processors. Proponents of this technology argue that use of such crops decreases the need to use toxic chemical pesticides.

Transgenic crop varieties in horticultural crops (tomato, potato, brinjal, beans, cabbage, cauliflower, musk melon, banana, coffee) have been developed by cloning *Bt* endotoxin genes which are cultivated in large areas. In 2011, India is the fourth largest GM crops growing country (10.6 million ha) in the world only next to USA (69 million ha), Brazil (30.3 million ha), and Argentina (23.7 million ha) (Clive James 2011). Combining a host gene for resistance with pathogen-derived genes or with genes coding for antimicrobial compounds provides for a broad

Table 1.2 Development of transgenics in vegetable crops in India

Vegetable crop	Target pathogen	Transgene(s)	Institute
Potato	Tuber moth	*Bt* Cry 1Ab	CPRI, Shimla
	Potato virus Y	Coat protein	CPRI, Shimla
Tomato	Leaf curl virus	Leaf curl virus sequence	IIHR, Bangalore IAHS, Bangalore
		Replicase gene	IARI, New Delhi
	Fungal diseases	Chitinase and glucanase	IIHR, Bangalore
		Alfalfa glucanase	IAHS, Bangalore
		Oxalate decarboxylase (OXDC)	JNU, New Delhi
	Lepidopteran pests	*Bt* Cry 1Ab	IARI, New Delhi Proagro PG-S (India) Ltd.
Brinjal	Fungal diseases	Chitinase, glucanase, and thaumatin encoding genes	
	Lepidopteran pests	*Bt* Cry 1Ab	IARI, New Delhi Proagro PG-S (India) Ltd.
Cabbage	Lepidopteran pests	*Bt* Cry 1Ab	IARI, New Delhi Proagro PG-S (India) Ltd.
		Cry 1H/Cry 9C	Proagro PG-S (India) Ltd.
Cauliflower	Lepidopteran pests	*Bt* Cry 1Ab	IARI, New Delhi Proagro PG-S (India) Ltd.
		Cry 1H/Cry 9C	Proagro PG-S (India) Ltd.

and effective resistance in many host–pathogen combinations (Table 1.2).

(vi) Sanitation It involves removing and destroying the overwintering or breeding sites of the pest as well as preventing a new pest from establishing on the farm (e.g., not allowing off-farm soil from farm equipment to spread nematodes or plant pathogens to your land). This strategy has been particularly useful in horticultural and tree-fruit crop situations involving twig and branch pests. If, however, sanitation involves removal of crop residues from the soil surface, the soil is left exposed to erosion by wind and water. As with so many decisions in farming, both the short- and long-term benefits of each action should be considered when tradeoffs like this are involved.

(vii) Spacing of Plants It heavily influences the development of plant diseases. The distance between plants and rows, the shape of beds, and the height of plants influence air flow across the crop, which in turn determines how long the leaves remain damp from rain and morning dew. Generally speaking, better air flow will decrease the incidence of plant disease. However, increased air flow through wider spacing will also allow more sunlight to the ground. This is another instance in which detailed knowledge of the crop ecology is necessary to determine the best pest-management strategies. How will the crop react to increased spacing between rows and between plants? Will yields drop because of reduced crop density? Can this be offset by reduced pest management costs or fewer losses from disease?

(viii) Altered Planting Dates This can at times be used to avoid specific insects or diseases. For example, squash bug infestations on cucurbits can be decreased by the delayed planting strategy, i.e., waiting to establish the cucurbit crop until overwintering adult squash bugs have died. To assist with disease management decisions, the CES will often issue warnings of 'infection periods' for certain diseases, based upon the weather.

In some cases, the CES also keeps track of 'degree days' needed for certain important insect pests to develop. Insects, being cold-blooded,

will not develop below or above certain threshold temperatures. Calculating accumulated degree days, i.e., the number of days above the threshold development temperature for an insect pest, makes the prediction of certain events, such as egg hatch, possible. *University of California* has an excellent web site that uses weather station data from around the state to help California growers predict pest emergence.

Some growers gauge the emergence of insect pests by the flowering of certain non-crop plant species native to the farm. This method uses the 'natural degree days' accumulated by plants. For example, a grower might time cabbage planting for 3 weeks after the *Amelanchier* species (also known as saskatoon, shad bush, or service berry) on their farm are in bloom. This will enable the grower to avoid peak egg-laying time of the cabbage maggot fly, as the egg hatch occurs about the time *Amelanchier* species are flowering (Couch 1994). Using this information, cabbage maggot management efforts could be concentrated during a known time frame when the early instars (the most easily managed stage) are active.

(ix) Optimum Growing Conditions Plants that grow quickly and are healthy can compete with and resist pests better than slow-growing, weak plants. Too often, plants grown outside their natural ecosystem range must rely on pesticides to overcome conditions and pests to which they are not adapted.

(x) Mulches Living or non-living mulches are useful for suppression of insect pests and some plant diseases. Hay and straw, for example, provide habitat for spiders. Research in Tennessee showed a 70 % reduction in damage to vegetables by insect pests when hay or straw was used as mulch. The difference was due to spiders, which find mulch more habitable than bare ground (Reichert and Leslie 1989). Other researchers have found that living mulches of various clovers reduce insect pest damage to vegetables and orchard crops. Again, this reduction is due to natural predators and parasites provided habitat by the clovers.

Mulching helps in minimizing the spread of soil-borne plant pathogens by preventing their spread through soil splash. Winged aphids are repelled by silver- or aluminium-coloured mulches. Recent springtime field tests at the Agricultural Research Service in Florence, South Carolina, have indicated that red plastic mulch suppresses root-knot nematode damage in tomatoes by diverting resources away from the roots (and nematodes) and into foliage and fruit (Adams 1997).

1.2.2.2 Reactive Options

The reactive options mean that the grower responds to a situation, such as an economically damaging population of pests, with some type of short-term suppressive action. Reactive methods generally include inundative releases of biological control agents, mechanical and physical controls, botanical pesticides, and chemical controls.

(i) Biological Controls

Biological control is the use of living organisms—parasites, predators, or pathogens—to maintain pest populations below economically damaging levels, and may be either natural or applied. A first step in setting up a BIPM programme is to assess the populations of beneficials and their interactions within the local ecosystem. This will help to determine the potential role of natural enemies in the managed horticultural ecosystem. It should be noted that some groups of beneficials (e.g., spiders, ground beetles, bats) may be absent or scarce on some farms because of lack of habitat. These organisms might make significant contributions to pest management if provided with adequate habitat.

(a) Natural Biological Control It results when naturally occurring enemies maintain pests at a lower level than would occur without them, and is generally characteristic of biodiversity systems. Mammals, birds, bats, insects, fungi, bacteria, and viruses all have a role to play as predators, parasites, and pathogens in a horticultural system. By their very nature, pesticides decrease the biodiversity of a system, creating the potential for instability and future problems. Pesticides,

whether synthetically or botanically derived, are powerful tools and should be used with caution.

Creation of habitat to enhance the chances for survival and reproduction of beneficial organisms is a concept included in the definition of natural biocontrol. *Farmscaping* is a term coined to describe such efforts on farms. Habitat enhancement for beneficial insects, for example, focuses on the establishment of flowering annual or perennial plants that provide pollen and nectar needed during certain parts of the insect life cycle. Other habitat features provided by farmscaping include water, alternative prey, perching sites, overwintering sites, and wind protection. Beneficial insects and other beneficial organisms should be viewed as mini-livestock, with specific habitat and food needs to be included in farm planning.

The success of such efforts depends on knowledge of the pests and beneficial organisms within the cropping system. Where do the pests and beneficials overwinter? What plants are hosts and non-hosts? When this kind of knowledge informs planning, the ecological balance can be manipulated in favour of beneficials and against the pests.

It should be kept in mind that ecosystem manipulation is a two-edged sword. Some plant pests (such as the tarnished plant bug and lygus bug) are attracted to the same plants that attract beneficials. The development of beneficial habitats with a mix of plants that flower throughout the year can help prevent such pests from migrating en masse from farmscaped plants to crop plants.

(b) Applied Biological Control It is also known as augmentative biocontrol, involves supplementation of beneficial organism populations, for example, through periodic releases of parasites, predators, or pathogens. This can be effective in many situations—well-timed inundative releases of *Trichogramma* egg wasps for codling moth control, for instance.

Most of the beneficial organisms used in applied biological control today are insect parasites and predators. They control a wide range of pests from caterpillars to mites. Some species of biocontrol organisms, such as *Eretmocerus californicus*, a parasitic wasp, are specific to one host—in this case the sweet potato whitefly. Others, such as green lacewings, are generalists and will attack many species of aphids and whiteflies.

Information about rates and timing of release is available from suppliers of beneficial organisms. It is important to remember that released insects are mobile; they are likely to leave a site if the habitat is not conducive to their survival. Food, nectar, and pollen sources can be 'farmscaped' to provide suitable habitat.

The quality of commercially available applied biocontrols is another important consideration. For example, if the organisms are not properly labelled on the outside packaging, they may be mishandled during transport, resulting in the death of the organisms. A recent study by Rutgers University noted that only two of six suppliers of beneficial nematodes sent the expected numbers of organisms, and only one supplier out of the six provided information on how to assess product viability.

While augmentative biocontrols can be applied with relative ease on small farms and in gardens, applying some types of biocontrols evenly over large farms has been problematic. New mechanized methods that may improve the economics and practicality of large-scale augmentative biocontrol include ground application with 'biosprayers' and aerial delivery using small-scale (radio-controlled) or conventional aircraft.

Inundative releases of beneficials into greenhouses can be particularly effective. In the controlled environment of a greenhouse, pest infestations can be devastating; there are no natural controls in place to suppress pest populations once an infestation begins. For this reason, monitoring is very important. If an infestation occurs, it can spread quickly if not detected early and managed. Once introduced, biological control agents cannot escape from a greenhouse and are forced to concentrate predation/parasitism on the pest(s) at hand.

An increasing number of commercially available biocontrol products are made up of

Table 1.3 Biological control of fruit crop pests

Fruit crop	Pest	Biocontrol agent/dosage
Apple	Woolly aphid, *Eriosoma lanigerum*	*Aphelinus mali*—1,000 adults or mummies/infested tree
	San Jose scale, *Quadraspidiotus perniciosus*	*Encarsia perniciosi*—2,000 adults/infested tree
	Codling moth, *Cydia pomonella*	*Chilocorus infernalis*—20 adults or 50 grubs/tree; *Trichogramma embryophagum*—2,000 adults/tree; *Steinernema carpocapse*
Citrus	Cottony cushion scale, *Icerya purchasi*	*Rodolia cardinalis*—10 beetles/infested plant
	Mealy bug, *P. citri*	*C. montrouzieri*—10 beetles/infested plant; *L. dactylopii* 3,000 adults/ha
	Red scale, *Aonidiella aurantii*	*Chilocorus nigrita*—15 adults/infested tree
	Scale insect, *Coccus viridis*	*Verticillium lecanii*—16×10^4 spores/mL + 0.05 % Teepol
	Leaf miner, *Phyllocnistis citrella*	*S. carpocapse*
Grapevine	Mealy bug, *Maconellicoccus hirsutus*	*C. montrouzieri*—2,500–3,000 beetles/ha or 10 beetles/vine
Guava	Green shield scale, *Chloropulvinaria psidii*	*C. montrouzieri*—10–20 beetles/infested plant
	Aphid, *Aphis gossypii*	*V. lecanii*—10^9 spores/mL + 0.1 % Teepol

microorganisms, including fungi, bacteria, nematodes, and viruses.

Of late, biological suppression of pests has become an intensive area of research because of environmental concerns. About 60 % of the natural control of insect pests is by the natural enemies of pests such as parasitoids, predators, and pathogens. The Australian lady bird beetle, *Cryptolaemus montrouzieri* has been found very effective against mealy bugs infesting grapes, guava, citrus, mango, pomegranate, ber, and custard apple. The encyrtid parasite, *Leptomastix dactylopii*, is effective against mealy bug, *Planococcus citri* on guava, citrus, pomegranate, ber, and custard apple (Mani 2001). *Bt* is effective against tomato fruit borer, okra fruit borer, and diamondback moth on cabbage and cauliflower.

Several methods of enrichment and conservation of natural enemies include providing nesting boxes for wasps and predatory birds; retaining pollen- and nectar-bearing flowering plants like Euphorbia, wild clover on bunds to provide supplementary food for natural enemies; and placing bundles of paddy straw in fields for attracting predatory spiders. In addition, erecting perching sites, water pans, retaining bushes (Acalypha, Hibiscus, Crotons) help in retention of predatory birds.

The last decade has witnessed a tremendous breakthrough in biological control of diseases and nematodes like *Rhizoctonia, Pythium, Fusarium, Macrophomina, Ralstonia,* and *Meloidogyne* in banana, tomato, egg plant, pea, grapes, cucumber, black pepper, cardamom, ginger, and turmeric, especially by using species of *Trichoderma, Pochonia, Pseudomonas,* and *Bacillus* (Tables 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 1.10, 1.11, 1.12).

(c) Avermectins The avermectins are a new class of macrocyclic lactones derived from mycelia of the soil actinomycete, *Streptomyces avermitilis* (soil inhabiting which is ubiquitous in nature). These compounds were reported to be possessing insecticidal, acaricidal, and nematicidal properties (Putter et al. 1981). They are commonly distributed in most of the cultivated soils and are in widespread use, especially as agents affecting plant parasitic nematodes, mites, and insect pests. The water solubility of avermectin B1 is approximately 6–8 ppb and its leaching potential through many types of soil is extremely low. These physical properties also confer many advantages upon the use of avermectins as pesticides. Their rapid degradation in soil and poor leaching potential suggest that field applications would not result

Table 1.4 Biological control of fruit crop diseases

Fruit crop	Disease(s)/Pathogen(s)	Potential biocontrol agent(s)
Banana	Panama wilt, *F. oxysporum* f. sp. *cubense*	*Trichoderma viride, Aspergillus niger, Pseudomonas fluorescens, T. viride* + *P. fluorescens*—sucker treatment
Citrus	Root rot, *Phytophthora* spp.	*T. viride/Trichoderma harzianum* at 100 kg/ha; *Penicillium funiculosum*, *Pythium nunn*—soil treatment
	Canker, *Xanthomonas campestris* pv. *citri*	*A. niger* AN 27
Strawberry	Grey mold, *Botrytis cinerea*	*T. harzianum*
Mulberry	Leaf spot, *Cercospora moricola*	*T. viride, T. harzianum, P. fluorescens*
	Cutting rot, *Fusarium solani*	*Trichoderma virens, T. harzianum, Trichoderma pseudokoningii*
Grapevine	Powdery mildew, *Uncinula necator*	*Ampelomyces quisqualis*—dispersal from wick cultures at 15 cm of shoot growth and bloom
	Downy mildew, *Plasmopara viticola*	*Fusarium proliferatum* weekly spray starting from 15 cm of shoot growth—10^6 spores/mL
Guava	Anthracnose, *Pestalotia psidii, Colletotrichum gloeosporioides*	*T. harzianum*
	Wilt, *Gliocladium roseum* and *F. solani*	*Penicillium citrinum, A. niger* AN 27, *T. harzianum*
Mango	Anthracnose, *Colletotrichum gloeosporioides*	*T. harzianum, Streptosporangium pseudovulgare*
	Powdery mildew, *Oidium mangiferae*	*S. pseudovulgare*
	Bacterial canker, *X. campestris* pv. *mangiferaeindicae*	*Bacillus coagulans*
Apple	Scab, *Venturia inaequalis*	*Chaetomium globosum, Aureobasidium pullulans, Microsphaeropsis* sp., *Cladosporium* spp., *Trichothecium roseum*—Foliar spray
	Collar rot, *Phytophthora cactorum*	*Enterobacter aerogenes, Bacillus subtilis*—Soil treatment; *T. virens*—soil treatment
	White root rot, *Dematophora necatrix*	*T. viride, T. harzianum, T. virens*—soil treatment
Pear	Blue mold, *Penicillium expansum*; Grey mold, *B. cinerea*	*Cryptococcus infirmo-miniatus* YY6, *Cryptococcus laurentii* RR87–108, *Rhodotorula glutinis* HRB6—fruit spray 3 week or 1 day prior to harvest—10^8 cfu/mL; *Pantoea agglomerans* CPA-2—post-harvest fruit dipping in 8×10^8 cfu/mL
	Fire blight, *Erwinia amylovora*	*P. fluorescens*—foliar spray
Peach	Brown rot, *Monilinia fructicola*	*B. subtilis* (B-3)—post-harvest fruit line spray at 5×10^8 cfu/g); *Pseudomonas syringae*-post-harvest fruit dipping in 10^7 cfu/mL
	Twig blight, *Monilinia laxa*	*Penicillium frequentans*—spray shoots in early growing season—$10^{8–9}$ spores/mL
	Crown gall, *Agrobacterium tumefaciens*	*Agrobacterium radiobacter* K84, K1026—root dip treatment
Strawberry	Grey mold, *B. cinerea*	*Trichoderma* products (BINAB TF and BINAB T), *Bacillus pumilus, Pseudomonas fluorescens, G. roseum*—spray flowers and fruits—white flower bud to pink fruit—10^6 spores/mL; *G. roseum*—bee vectoring of flowers—10^9 cfu/g of powder
Passion fruit	Collar rot, *Rhizoctonia solani*	*T. harzianum, Trichoderma* sp
Amla	Bark splitting, *R. solani*	*A. niger* AN 27

Table 1.5 Biological control of vegetable crop pests

Vegetable crop	Pest	Biocontrol agent/dosage
Beans	Mite, *Tetranychus* spp.	*Phytoseiulus persimilis*—10 adults/plant or release 1–6 leaves with predatory mites.
Pigeon pea	Pod borer, *Helicoverpa armigera*	*Ha* NPV-250 LE/ha
Potato	Cut worm, *Agrotis ipsilon, Agrotis segetum*	*S. carpocapse, Steinernema bicornutum, Heterorhabditis indica*
Tomato	Fruit borer, *H. armigera*	*Trichogramma brasiliensis/Trichogramma chilonis/T. pretiosum*—50,000/ha; *Ha* NPV-250 LE/ha
Brinjal	Fruit and shoot borer, *Leucinodes orbonalis*	*S. carpocapse, H. indica*
Chilli	Fruit borer, *H. armigera*	*Ha* NPV—250 LE/ha
Cabbage	Diamondback moth, *Plutella xylostella*	*S. carpocapse, Steinernema glaseri, Steinernema feltiae, S. bicornutum, Heterorhabditis bacteriophora*
Mushroom	*Lycoriella auripila, Lycoriella mali, Lycoriella solani, Megaselia halterata*	*S. feltiae*

in persistent residues or contamination of ground water.

Avermectins offer an outstanding alternative to any of the available synthetic pesticides. Their novel mode of action, high potency, and specific physico-chemical properties make the avermectins excellent candidates for further insecticidal, acaricidal, and nematicidal studies.

Scientists at the Indian Institute of Horticultural Research, Bangalore, for the first time in India, have isolated six strains of *S. avermitilis* and showed their effectiveness for the management of root-knot nematodes infecting tomato, egg plant, chilli, carnation, and gerbera; and red spider mite on carnation and gerbera (Reddy and Nagesh 2002; Table 1.13). Avermectins are also effective against other insect pests (potato leaf miner, *Liriomyza huidobrensis*; chilli thrips, *Scirtothrips dorsalis*; cabbage diamondback moth, *Plutella xylostella*; bean leaf miner, *Liriomyza huidobrensis*; rose thrips, *Rhipiphorothrips cruentatus, Scirtothrips dorsalis*; poinsettia whitefly, *Trialeurodes vaporariorum*), mite pests (chilli yellow mite, *Polyphagotarsonemus latus*; bean spider mite, *Tetranychus urticae*; rose red spider mite, *Tetranychus urticae*), and nematode pests (banana nematodes, *Meleidogyne javanica, Radopholus similis*; citrus nematode, *Tylenchulus semipenetrans*; tomato reniform nematode, *Rotylenchulus reniformis;* cucumber root-knot nematode, *M. incognita*; garlic stem and bulb nematode, *Ditylenchus dipsaci*).

(ii) Mechanical and Physical Controls

Methods included in this category utilize some physical components of the environment, such as temperature, humidity, or light, to the detriment of the pest. Common examples are tillage, flaming, flooding, soil solarization, and plastic mulches to kill pests.

Heat or steam sterilization of soil is commonly used in greenhouse operations for control of soil-borne pests. Floating row covers over vegetable crops exclude flea beetles, cucumber beetles, and adults of the onion, carrot, cabbage, and seed corn root maggots. Insect screens are used in greenhouses to prevent aphids, thrips, mites, and other pests from entering ventilation ducts. Large, multi-row vacuum machines have been used for pest management in strawberries and vegetable crops. Cold storage reduces post-harvest disease problems on produce.

Although generally used in small or localized situations, some methods of mechanical/physical control are finding wider acceptance because they are generally more friendly to the environment.

Table 1.6 Biological control of vegetable crop diseases

Crop	Disease(s)/pathogen(s)	Biocontrol agent/mode of application
French bean	Dry root rot, *Macrophomina phaseolina*	*Pseudomonas cepacia* UPR5C—seed treatment
	Wilt, *F. oxysporum* f. sp. *phaseoli*	*Streptomyces* spp.—seed treatment
Pea	Root rot, *Aphanomyces euteiches*	*Pseudomonas cepacia, P. fluorescens* PRA25, AMMD-seed treatment
	Damping-off, *Pythium ultimum*	*P. cepacia* AMMD, *Pseudomonas putida* NIR—seed treatment
	Wilt, *F. oxysporum* f. sp. *udum*	*T. viride, T. harzianum, Trichoderma koningii*—seed treatment, *A. niger* AN 27
Cluster bean	Bacterial blight, *Xanthomonas axonopodis* pv. *cyamopsidis*	*A. niger* AN 27
Cabbage	Damping-off, *R. solani*	*T. viride, T. harzianum, T. koningii*—seed treatment
Cauliflower	Blight, *Alternaria brassicola*	*Streptomyces griseoviridis*—seed treatment
Okra	*R. solani*	*Bradyrhizobium japonicum, Rhizobium* spp.—seed treatment
Tomato	Damping-off, *Pythium aphanidermatum*	*T. viride, T. harzianum, Pseudomonas aeruginosa* 7NSK2
	Wilt, *F. oxysporum* f. sp. *lycopersici*	*T. viride, T. harzianum, A. niger,* non-pathogenic *F. oxysporum, F. oxysporum* f. sp. *dianthi, P. fluorescens* strains Pf1, *P. putida*, *Penicillium oxalicum, Pythium oligandrum, B. subtilis* strain FZB-G, *Streptomyces* spp.—seed treatment, seed and soil treatment
Potato	Black scurf, *R. solani*	*T. harzianum, T. viride*—tuber treatment, *A. niger* AN 27, *Verticillium biguttatum*—soil treatment, *Laetisaria arvalis*—tuber treatment, Binucleate *Rhizoctonia*
	Wilt, *Ralstonia solanacearum*	*Bacillus cereus, B. subtilis*
Bell pepper	*P. capsici*	*T. viride, T. harzianum*—fruit treatment
	Damping-off, *P. aphanidermatum*	*S. griseoviridis*—seed and soil treatment
Brinjal	Damping-off, Wilt, *Phytophthora* sp., *P. aphanidermatum, F. solani*	*T. viride, T. harzianum, T. koningii*—seed and soil treatment
	Collar rot, *Sclerotinia sclerotiorum*	*T. viride, T. virens, B. subtilis*—soil treatment
Carrot	Soft rot, *S. sclerotiorum*	*Coniothyrium minitans*—soil treatment
	Root rot, *R. solani*	*T. virens* GL-21
Radish	Wilt, *F. oxysporum* f.sp. *raphani*	*P. fluorescens* strains WCS374, WCS417r—soil treatment
	Root rot, *R. solani*	*Laetisaria rosiepellis, Pythium acanthicum*—soil treatment
Beet root	Damping-off, *Pythium debaryanum, P. ultimum*	*Penicillium* spp + *P. fluorescens*-seed treatment, *P. oligandrum*
Cucumber	Wilt, *F. oxysporum* f. sp. *cucumerinum, R. solani*	*Colletotrichum orbiculare, F. oxysporum* f. sp. *niveum, P. putida* 89B-27, *Serratia marcescens,* tobacco necrosis virus
	Powdery mildew	*A. quisqualis*—foliar spray
	Cucumber mosaic virus	*P. fluorescens* strain 89B-27
Water melon	Wilt, *F. oxysporum* f. sp. *solani, F. o.* f. sp. *niveum*	*T. viride, A. niger*—seed and soil treatment, *Penicillium janczewskii*
Musk melon	Wilt, *F. oxysporum, F. solani, R. solani*	*T. harzianum, A. niger*—seed treatment
Onion	Soft rot, *Sclerotium cepivorum*	*C. globosum, Trichoderma* sp. C62—soil treatment

Table 1.7 Biological control of ornamental crop diseases

Crop	Disease(s)/pathogen(s)	Biocontrol agent/mode of application
Rose	Grey mold, *B. cinerea*	*T. viride, T. harzianum*—cutting treatment
Gladiolus	Yellows and corm rot, *F. oxysporum* f. sp. *gladioli*	*T. virens, T. harzianum*—corm and soil treatment
Chrysanthemum	Wilt, *F. oxysporum*	*T. harzianum* at 160 kg/ha—soil application
	R. solani	*A. niger* AN 27
Carnation	Wilt, *F. oxysporum* f. sp. *dianthi*	*P. fluorescens* strain WCS 417r—soil appln; *P. putida* WCS 358r—root dip treatment; *Alcaligenes* sp., *Bacillus* sp.; *Arthrobacter* sp., *Hafnia* sp.; *Serratia liquefaciens*
Gerbera	*Phytophthora cryptogea*	*Trichoderma* spp.—soil treatment
Narcissus	Wilt, *F. oxysporum* f. sp. *narcissi*	*S. griseoviridis, Minimedusa polyspora*—bulb treatment
Zinnia	*R. solani*	*T. virens* GL-21, *T. virens* GL-20
Marigold	*P. ultimum*	*Glomus intraradices, Glomus mosseae*—soil treatment

Table 1.8 Biological control of medicinal and aromatic crop diseases

Medicinal/aromatic crop	Disease(s)/Pathogen(s)	Biocontrol agent
Opium poppy	Sclerotinia rot and blight, *S. sclerotiorum*	*T. harzianum, T. viride, T. koningii, T. virens*—soil treatment
	Downy mildew, *Peronospora arborescens*	*Trichoderma* spp.—seed treatment
Periwinkle	*Phytophthora parasitica*	*P. parasitica* var. *nicotianae*—soil treatment
Jasmine	Root rot, *M. phaseolina*	*T. viride, T. harzianum*—cutting treatment
Chinese rose	Wilt, *F. oxysporum*	*A. niger*—soil treatment
Menthol mint	Stolon decay, *S. sclerotiorum*	*T. harzianum, T. virens*—sucker treatment
	Verticillium dahliae	*Verticillium nigrescens*

Table 1.9 Biological control of tuber crop diseases

Tuber crop	Disease(s)/Pathogen(s)	Biocontrol agent
Yam	*Botrytis theobromae*	*T. viride*
Cassava	*Phytophthora drechsleri*	*T. viride*
Elephant foot yam	*Sclerotium rolfsii*	*T. harzianum, T. pseudokoningii*

Table 1.10 Biological control of plantation crop pests

Plantation crop	Pest	Biocontrol agent/dosage
Coconut	Black headed caterpillar, *Opisinia arenosella*	*Goniozus nephantidis*—3,000 adults/ha
	Rhinoceros beetle, *Oryctes rhinoceros*	Baculovirus—10 infected beetles/tree
Areca nut	*Ischnaspis longirostris*	*C. nigrita*—20 to 50 adults/plant
Coffee	Mealy bugs, *Planococcus* and *Pseudococcus* spp.	*C. montrouzieri*—2–10 beetles/infested plant

(iii) Chemical Controls (Reduced-Risk Pesticides)

Included in this category are both synthetic pesticides and botanical pesticides.

(a) Synthetic Pesticides They comprise a wide range of man-made chemicals used to control insects, mites, nematodes, plant diseases, and vertebrate and invertebrate pests. These powerful chemicals are fast acting and relatively inexpensive to purchase.

Pesticides are the option of last resort in BIPM programmes because of their potential negative impacts on the environment, which result from the manufacturing process as well as from their application on the farm. Pesticides should be used only when other measures, such as biological or

Table 1.11 Biological control of plantation crop diseases

Crop	Disease/causal agent	Biocontrol agents reported
Coconut	Stem bleeding, *Thielaviopsis paradoxa (Ceratostomella paradoxa)*	*T. virens, T. Harzianum*, phosphobacteria
	Basal stem rot, *Ganoderma lucidum*	*T. virens, T. harzianum*
Areca nut	Bud rot, *Phytophthora* spp.	*Trichoderma* spp.
	Fruit rot, *Phytophthora arecae, Colletotrichum capsici*	*Trichoderma* spp., *P. fluorescens*
	Foot rot/anabe, *G. lucidum*	*T. harzianum*
Tea	Red root rot, *Poria hypolateritia*	*T. harzianum*
	Brown root, *Fomes noxius*	*T. virens, T. harzianum*
	Black root rot, *Rosellinia arcuata*	*T. virens, T. harzianum*
Coffee	Black root, *Pellicularia koleroga*	*T. virens, T. harzianum*
	Brown root, *F. noxius*	*T. virens, T. harzianum*
	Santhaveri wilt, *F. oxysporum* f. sp. *coffeae*	*T. virens, T. harzianum*
Rubber	Brown rot, *Phellinus noxius*	*T. viride, T. harzianum, T. hamatum*
Betel vine	Foot and root rot, *P. parasitica* pv. *piperina*	*T. viride, T. harzianum*—soil treatment
	Collar rot, *S. rolfsii*	*T. harzianum, T. viride, T. koningii, T. virens*—soil treatment

Table 1.12 Biological control of spice crop diseases

Spice crop	Disease/causal organism	Effective biocontrol agents/mode of application
Black pepper	Foot rot, *P. capsici*	*T. harzianum, T. virens, Glomus fasciculatum*—soil treatment; *P. fluorescens, Bacillus* sp.—foliar spray
	Anthracnose, *Colletotrichum gloeosporioides*	*P. fluorescens*—foliar spray
	Slow decline, *R. similis, M. incognita, P. capsici*	*T. harzianum, T. virens, Paecilomyces lilacinus, Pochonia chlamydosporia*—soil treatment
Cardamom	Damping off, *Pythium vexans*	*T. harzianum, T. viride*—soil treatment in solarized nursery beds
	Clump rot/rhizome rot, *P. vexans, R. solani, M. incognita*	*T. harzianum*—soil treatment
	Capsule rot, *Phytophthora meadii, P. nicotianae* var. *nicotianae*	*T. harzianum, T. viride, T. virens, T. hamatum*—soil treatment
Ginger	Rhizome rot, *P. aphanidermatum, P. myriotylum*	*T. harzianum, T. virens*—soil solarization + soil treatment; *T. viride, P. fluorescens*—seed treatment; *A. niger* AN 27—soil treatment
	Yellows, *F. oxysporum* f. sp. *zingiberi, M. incognita*	*T. harzianum, T. virens, T. hamatum*—soil solarization + soil treatment, Rhizome treatment
	Bacterial wilt, *R. solanacearum*	Avirulent *R. solanacearum, P. fluorescens*, endophytic bacteria—soil treatment
Turmeric	Rhizome rot, *Fusarium* sp., *Pythium graminicolum, P. aphanidermatum, R. similis, M. incognita*	*T. harzianum, T. viride, T. virens*—soil treatment
Fenugreek	Root rot, *R. solani*	*T. viride, P. fluorescens*—seed treatment
Coriander	Root rot/wilt, *F. oxysporum* f. sp. *corianderii*	*T. viride, T. harzianum, Streptomyces* sp.—seed treatment
Cumin	Wilt, *F. oxysporum* f. sp. *cumini*	*Trichoderma* spp., *T. virens*—soil treatment
Vanilla	Root rot, *P. meadii, F. oxysporum* f. sp. *vanillae*	*T. harzianum, P. fluorescens*—soil treatment
Mustard	Damping-off, *P. aphanidermatum*	*T. viride, T. harzianum*—seed and soil treatment

Table 1.13 Management of horticultural crop nematodes using avermectins

Horticultural crop	Nematode	Avermectin/dose
Tomato, egg plant, chilli	*M. incognita*	Aqueous solution of avermectins (250 mL of 0.001 %/m^2 nursery bed); charcoal formulations of *S. avermitilis* at 100 g/m^2
Carnation and gerbera (commercial polyhouses)	*M. incognita*	Post-plant treatment at 250 mL/m^2 at two intervals (6 and 12 months after planting)
	Tetranychus urticae	Avermectins at 0.001 % achieved 92 % mortality

Table 1.14 Insect pests on which soaps were found effective

Crop	Insect pests
Cabbage and cauliflower	DBM, leaf webber, aphids, young *Spodoptera* larva
Tomato	Whitefly, red spider mites, fruit borer (egg-laying stage), leaf miner
Okra	Leaf hopper, whitefly, aphids
Cucurbits	Fruitfly, leaf miner
Mango	Leaf hopper
Ornamental crops	Mites, whitefly

DBM diamondback moth

cultural controls, have failed to keep pest populations from approaching economically damaging levels.

If chemical pesticides must be used, it is to the grower's advantage to choose the least-toxic pesticide that will control the pest but not harm non-target organisms such as birds, fish, and mammals. Pesticides that are short-lived or act on one or a few specific organisms are in this class. Examples include insecticidal soaps, horticultural oils, copper compounds (e.g., Bordeaux mixture), sulphur, boric acid, and sugar esters.

(b) Biorational Pesticides Biorational pesticides are generally considered to be derived from naturally occurring compounds or are formulations of microorganisms. Biorationals have a narrow target range and are environmentally benign. Formulations of *Bt* are perhaps the best-known biorational pesticide. Other examples include silica aero gels, insect growth regulators, and particle film barriers.

A relatively new technology, particle film barriers are currently available under the trade name Surround WP Crop Protectant. The active ingredient is kaolin clay, an edible mineral long used as an anti-caking agent in processed foods, and in such products as toothpaste and kaopectate. There appears to be no mammalian toxicity or any danger to the environment posed by the use of kaolin in pest control. The kaolin in Surround is processed to a specific particle size range, and combined with a sticker-spreader. Non-processed kaolin clay may be phytotoxic. Surround is sprayed on as a liquid, which evaporates, leaving a protective powdery film on the surface of leaves, stems, and fruits. Conventional spray equipment can be used and full coverage is important. The film works to deter insects in several ways. Tiny particles of the clay attach to the insects when they contact the plant, agitating and repelling them. Even if particles do not attach to their bodies, the insects may find the coated plant or fruit unsuitable for feeding and egg-laying. In addition, the highly reflective white coating makes the plant less recognizable as a host.

(c) Sugar Esters Sugar esters have performed as well as or better than conventional insecticides against mites and aphids in apple orchards; psylla in pear orchards; and whiteflies, thrips, and mites on vegetables. However, sugar esters are not effective against insect eggs. Insecticidal properties of sugar esters were first investigated a decade ago when a scientist noticed that tobacco leaf hairs exuded sugar esters for defence against some soft-bodied insect pests. Similar to insecticidal soap in their action, these chemicals act

as contact insecticides and degrade into environmentally benign sugars and fatty acids after application.

(d) Inorganic Chemicals Spray application of K_2HPO_4 or KH_2PO_4 at 3.5 g/L of water has been reported to control powdery mildew in rose and carnation. Similarly, the above treatment was also found effective for the management of powdery mildew on mango, grapes, and cucurbits.

(e) Strobilurin Fungicides Strobilurin fungicides are also called Qo inhibitors as they act on cytochrome Qo of the fungi. The Basidiomycetous fungus, *Strobilurus tenacellus* produces antibiotics to ward off competition from other fungi. Based on this principle, several fungicides have been developed namely Azoxystrobin, Kresoxy methyl, Metominostrobin, Trifloxystrobin, Picoxystrobin, Pyraclostrobin, Famoxadone, and Fenomidone during 1996–2001. Within 4 years, sale of these fungicides reached $ 620 million, accounting for 10 % of total fungicide market in the world. This success is unparalleled in the history of fungicides.

Strobilurin fungicides are naturally occurring compounds and hence eco-friendly, highly systemic, have unique mode of unisite action, hence development of resistance is common. They have broad spectrum of activity on all groups of fungi and registered in 72 countries on 84 crops representing over 400 crop/disease systems.

(f) Botanical Pesticides They can be as simple as pureed plant leaves, extracts of plant parts, or chemicals purified from plants. Pyrethrum, neem formulations, and rotenone are examples of botanicals. Some botanicals are broad-spectrum pesticides. Others, like ryania, are very specific. Botanicals are generally less harmful to the environment than synthetic pesticides because they degrade quickly, but they can be just as deadly to beneficials as synthetic pesticides. However, they are less hazardous to transport and in some cases can be formulated on-farm. The manufacture of botanicals generally results in fewer toxic by-products.

Neem products such as cake, oil, neem seed kernel extract (NSKE), neem seed powder extract (NSPE), pulverized NSPE, and soaps are being used extensively to manage horticultural crop pests (bean fly, *Ophiomyia phaseoli*; serpentine leaf miner, *Liriomyza trifolii* on several crops; cucurbit fruit fly, *Bactrocera cucurbitae*; tomato fruit borer, *Helicoverpa armigera*; brinjal fruit and shoot borer, *L. orbonalis*; water melon and chilli thrips, *Thrips* spp.; chilli yellow mite, *Polypha-gotarsonemus latus*; and okra leaf hopper, *Amrasca biguttulla biguttulla*; Krishna Moorthy and Krishna Kumar 2002).

The soap sprays were highly effective on leaf hoppers, aphids, red spider mites, and white flies in many vegetables, but moderately effective on thrips in water melon and chillies (Table 1.14).

(g) Compost Teas They are most commonly used for foliar disease control and applied as foliar nutrient sprays. The idea underlying the use of compost teas is that a solution of beneficial microbes and some nutrients is created and then applied to plants to increase the diversity of organisms on leaf surfaces. This diversity competes with pathogenic organisms, making it more difficult for them to become established and infect the plant.

An important consideration when using compost teas is that high-quality, well-aged compost be used, to avoid contamination of plant parts by animal pathogens found in manures that may be a component of the compost. There are different techniques for creating compost tea. The compost can be immersed in the water, or the water can be circulated through the compost. An effort should be made to maintain an aerobic environment in the compost–water mixture.

References

Adams, S. (1997). Seein' red: Colored mulch starves nematodes. *Agricultural Research, October,* 18.

Benbrook, C. M. (1996). *Pest management at the crossroads* (272 pages). Consumers Union, Yonkers.

Cilve James. (2011). Global Status of Commercialized Biotech/GM Crops: 2011. ISAAA Briefs No. 43, ISAAA, Ithaca, New York.

Couch, G. J. (1994). The use of growing degree days and plant phenology in scheduling pest management activities. *Yankee Nursery Quarterly, Fall,* 12–17.

Krishna Moorthy, P. N., & Krishna Kumar, P. N. (2002). Advances in the use of botanicals for the IPM of major vegetable pests. *Proceedings of the international conference on vegetables*, Bangalore. Dr. Prem Nath Agricultural Science Foundation, Bangalore, pp. 262–272.

Mani, M. (2001). Biological control of fruit crop pests. In P. P. Reddy, A. Verghese, & N. K. Krishna Kumar (Eds.), *Integrated pest management in horticultural ecosystems* (pp. 93–107). Capital Publishing Co., New Delhi.

Reddy, P. P., Rao, M. S., & Nagesh, M. (2002). Integrated management of burrowing nematode (*Radopholus similis*) using endomycorrhiza (*Glomus mosseae*) and oil cakes. In H. P. Singh & K. L. Chadha (Eds.), *Banana* (pp. 344–348). AIPUB, Trichy.

Putter, J. G., Mac Connell, F. A., Preiser, F. A., Haidri, A. A., Rishich, S. S., & Dybas, R. A. (1981). Avermectins: Novel class of insecticides, acaricides and nematicides from a soil microorganism. *Experientia, 37,* 963–964.

Reichert, S. E., & Leslie, B. (1989). Prey control by an assemblage of generalist predators: Spiders in garden test systems. *Ecology*. *Fall,* 1441–1450.

Swaminathan, M. S. (2000). For an evergreen revolution. *The Hindu Survey of Indian Agriculture, 2000,* 9–15.

Part II

Biointensive Integrated Pest Management in Fruit Crops

Tropical Fruit Crops

2

2.1 Banana, *Musa* spp.

2.1.1 Diseases

2.1.1.1 Panama Wilt, *Fusarium oxysporum* f. sp. *cubense*

Panama wilt is one of the most devastating diseases of banana in the world. The disease is prevalent in Australia, Costa Rica, Hawaii, India, Jamaica, Panama, South America, Surinam and West Africa. In India, it became widespread in Tamil Nadu, Kerala, Karnataka, Bihar and Assam. The disease is also prevalent in West Bengal, Maharashtra and Andhra Pradesh, especially where cultivars. Rasabale, Amritpani, Malbhog and Martban are grown belonging to Rasthali group.

(i) Symptoms: The entry of the fungus is facilitated by root damage caused by the nematodes (*Radopholus similis, Meloidogyne incognita*, etc.). The fungus blocks the vascular system and causes wilting (Fig. 2.1). The infected plants show characteristic yellowing of leaf blades developing as a band along the margin and spreading towards midrib. The leaf wilts and the petiole buckles. The leaf hangs between the pseudo stem while the middle of lamina is still green. All leaves eventually collapse, whereas the petioles join the pseudo stem and die. Often the emerging heart leaf gets affected. After 4–6 weeks after the appearance of first symptoms, only the pseudo stem with dead leaves hanging around it remains. Young and old plants show dwarfing or stunting. When an affected rhizome is cut transversely, the disease is seen localized in the vascular strands (Fig. 2.1). Individual strand appears yellow. Red or brown dots or streaks are also seen. The cut stem smells like rotten fish. The suckers growing out of diseased corms wilt and eventually the whole mat dies.

(ii) Epidemiology: Light textured loam and sandy loam soils, which are acidic, favour the disease development. Such soils are referred as conducive soils for fusarial infection. Soil infestation by nematodes (*R. similis, M. incognita*, etc.) predisposes the plant to infection. The pathogen is soil-borne and survives for long periods in soil as chlamydospores (even up to 20 years in the absence of its host). Ramakrishnan and Damodaran (1956) found that liming of soil reduced the survival period to 2 months. The primary spread of the disease is through infected rhizomes and secondary spread is through irrigation water. Continuous cultivation of banana in the same field results in abundant build up of inoculum in the soil.

(iii) Integrated Management

(a) Cultural, Bioagents and Botanicals: Fallowing for 21 days before planting, soil application of bioagents such as *Trichoderma viride* and *Pseudomonas fluorescens* and incorporation of cassava residue at 10 MT/ha plus rice bran was found to check the occurrence of the disease effectively.

(b) Bioagents and Botanicals: Combination of *T. viride* isolate 6 and neem cake/pongamia cake had inhibitory effect against panama wilt pathogen and increased plant growth parameters (leaf num-

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_2, © Springer India 2014

Fig. 2.1 Panama wilt symptoms on banana

ber, leaf area, pseudo stem girth and root weight). Red soil with pH between 7 and 8 maintained at 60% moisture holding capacity was found to favour the survival of the antagonist (Satish 1996).

2.1.2 Nematodes

2.1.2.1 Burrowing Nematode, *Radopholus similis*

This nematode in India was first reported on banana from the Palghat district of Kerala by Nair et al. (1966). *R. similis* causes 'rhizome rot' or 'toppling' or 'black head' disease of banana and is becoming a serious problem.

(i) Economic Importance and Losses: The burrowing nematode is responsible for 30.76 to 41% yield loss in banana (Rajagopalan and Naganathan 1977b; Nair 1979; Reddy et al. 1996d; Vadivelu et al. 1987). Root population of *R. similis* is indirectly correlated with the yield (Charles et al. 1985).

(ii) Symptoms: It causes retarded growth and extensive root and rhizome necrosis. Wounding of banana roots by the burrowing nematode usually induces reddish-brown cortical lesions, which are diagnostic of the disease (Fig. 2.2). These lesions are clearly seen when an affected root is split longitudinally and examined immediately. Root and rhizome necrosis is manifested

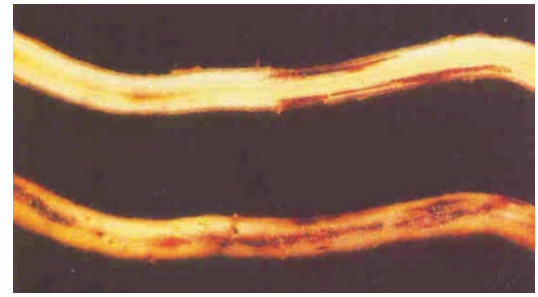


Fig. 2.2 Banana roots infected with *Radopholus similis*. *Upper*—longitudinally cut root, *lower*—complete root. (Courtesy: Union Carbide Agril. Products Co. Inc. 1986)

by varying degrees of retarded growth, leaf yellowing and falling of mature plants.

With the increase in nematode population, feeding roots are invaded and destroyed as fast as they are formed. The resulting setback in the uptake of plant nutrients leads to debility of the plant and production of smaller fruits. The lesioning of the primary roots together with the girdling and death of these anchor roots makes the plant prone to 'tip over' by wind action (Fig. 2.3).

(iii) Integrated Management

(a) Botanicals and Arbuscular Mycorrhizal Fungi (AMF): Integration of neem cake at 200 g/plant with *Glomus mosseae* at 100 g/plant (containing 25–30 chlamydospores/g of inoculum) was most effective in reducing the *R. similis* population both in soil and roots, while

Fig. 2.3 Premature fall of banana plants due to infection of *Radopholus similis*. *Front*—toppled plants from non-treated plots, *back*—treated plants. (Courtesy: Union Carbide Agril. Products Co. Inc. 1986)

karanj cake with *G. mosseae* gave maximum increase in fruit yield of banana. Mycorrhizal root colonization and number of chlamydospores of *G. mosseae* were maximum in neem cake amended soil (Table 2.1; Reddy et al. 2002).

(b) Cultural and Chemical: Double paring of banana suckers along with dipping in 0.5% monocrotophos for 45 min gave maximum yield (63.283 MT/ha) and recorded higher benefit-cost ratio (2.92) (Patil et al. 1999; Table 2.2).

Integration of paring of banana suckers, dipping in 0.5% monocrotophos solution for 45 min along with intercropping with marigold or sunn hemp gave higher fruit yield (62.838 and 61.816 MT/ha, respectively) and benefit-cost ratio (1.70 and 1.28, respectively) (Patil et al. 1999; Table 2.3).

(c) Bioagents and Botanicals: Integration of neem cake at 400 g per plant with *Pasteuria penetrans* at 100 g soil (300 spores/g)/*Trichoderma harzianum*/*T. viride* at 250 g/plant while planting was found effective in reducing nematode population both in soil and roots of banana by more than 50% and increased plant growth parameters. The treatment should be repeated 4 months after planting. The burrowing nematodes on banana were effectively managed by integration of neem cake at 500 g and farmyard manure (FYM) enriched with *T. harzianum* at 2 kg/plant. The above treatment increased the fruit yield to 45 kg/plant and bunches came to harvest 65 to 75 days earlier (Fig. 2.4).

Soil application of FYM enriched with *Paecilomyces lilacinus* (10^6 cfu/g) and *P. fluorescens* (10^9 cfu/g) at 2 kg/plant at the time of planting and subsequent application for four times at an interval of 6 months reduced the root population of *R. similis* by 64.5% and increased the fruit yield by 21%. Benefit-cost ratio (calculated for marginal cost of biopesticides and returns accrued by application of biopesticides) was 3.6.

Soil application of 2 kg FYM with *P. fluorescens* (with 1×10^9 spores/g) and *Pochonia chlamydosporia* (with 1×10^6 spores/g) per plant at the time of planting and at an interval of 4 months significantly reduced the burrowing nematode by 64% compared to control.

(d) Botanicals, Chemicals, Bioagents and AMF: Integration of neem cake at 400 g/plant, carbofuran at 20 g/plant, *Glomus fasciculatum* at 50 g/plant and *P. penetrans* at 100 g soil/plant was most effective in reducing the population of *R. similis* in banana (Channabasappa et al. 1995).

Integration of neemark, carbofuran, *P. penetrans* and *G. fasciculatum* was found effective in enhancing the plant growth and yield of banana besides raising the benefit-cost ratio (2.65) and reducing the *R. similis* population both in soil and roots (Vidya and Reddy 1998).

2.1.2.2 Spiral Nematode, *Helicotylenchus multicinctus*

(i) Economic Importance: The spiral nematode causes serious decline of banana yield to the tune of 34 to 56% with delayed flowering. It is responsible for 33.83% loss in yield, 55.88% loss in number of fruits per bunch and delayed fruiting by 134 days (Vadivelu et al. 1987).

(ii) Symptoms: The spiral nematode incites discrete, relatively shallow, necrotic lesions on banana roots. *H. multicinctus* causes extensive root necrosis, die-back and dysfunction leading eventually to debility of the entire plant.

(iii) Integrated Management

(a) Bioagents/AMF and Botanicals: Significant reduction in population of *H. multicinctus* was observed in banana plants treated with *P. fluorescens* at 2 g/*G. mosseae* at 25 g along with press mud at 3 kg/plant. These treatments also enhanced the plant height, pseudo stem girth, number of

Table 2.1 Effect of *Glomus mosseae* and oil cakes on population of *Radopholus similis* and yield of banana

Treatment	Dose (g)/plant	Population of *R. similis*		Yield (kg)/plant
		Roots (10 g)	Soil (250 mL)	
G. mosseae	200	112	122	8.64
Castor cake	400	146	132	8.18
Karanj cake	400	118	128	10.34
Neem cake	400	118	112	8.91
G. mosseae + Castor cake	100 + 200	90	108	12.68
G. mosseae + Karanj cake	100 + 200	76	80	16.61
G. mosseae + Neem cake	100 + 200	48	62	14.80
Control	–	218	184	5.45
Critical Difference (*CD*) *(P = 0.05)*		*11.97*	*8.31*	*0.84*

Table 2.2 Effect of paring of suckers and dipping in insecticide solution on nematode population and yield of banana

Treatment	Nematode population in 200 mL soil	Nematode population in 5 g roots	Yield (MT/ha)	Benefit-cost ratio
Unpared sucker	365	27	57	–
Paring + drying for 72 h	209	23	59	1.17
Double paring + drying for 72 h	187	21	59	1.72
Paring + dipping in 0.5% monocrotophos for 45 min	109	18	61	2.01
Paring + dipping in 0.75% monocrotophos for 45 min	89	16	60	0.30
Double paring + dipping in 0.5% monocrotophos for 45 min	85	15	63	2.92
Double paring + dipping in 0.75% monocrotophos for 45 min	76	12	63	2.22
Paring + pralinage with carbofuran at 40 g/sucker	76	12	63	0.15

Table 2.3 Effect of paring of suckers, dipping in insecticide solution and intercropping on nematode population and yield of banana

Treatment	Nematode population in 200 mL soil	Nematode population in 5 g roots	Yield (MT/ha)	Benefit-cost ratio
Untreated control	454	29	58.439	–
Paring + dipping in 0.5% monocrotophos	283	18	60.927	1.20
Paring + dipping in 0.5% monocrotophos + incorporation of sunn hemp at 10 g/m^2	252	14	61.816	1.28
Paring + dipping in 0.5% monocrotophos + incorporation of cowpea at 10 g/m^2	274	17	60.483	1.04
Paring + dipping in 0.5% monocrotophos + incorporation of marigold at 2 g/m^2	239	15	62.838	1.70
Carbofuran at 1.25 g a.i./plant	240	14	61.860	1.58

Fig. 2.4 Application of farmyard manure enriched with bioagent to banana plant

leaves, leaf area and bunch weight (Jonathan and Cannayane 2002).

2.1.2.3 Root-knot Nematode, *Meloidogyne incognita*

The root-knot nematodes, *M. incognita* and *Meloidogyne javanica* attack bananas and may interact with other nematodes or soil pests. *M. incognita* caused 30.90% loss in fruit yield of banana (Jonathan and Rajendran 2000).

(i) Symptoms: The infected plants were stunted, having small chlorotic leaves and galled roots (Fig. 2.5). Galling of the plant roots is most commonly found in areas previously planted with sugarcane. The galls vary in size and occur at the tips as well as in other areas along the root. Roots with galled tips cease to grow and sometimes develop secondary roots above the gall. Swollen female nematodes were found inside the galled and sometimes non-galled roots.

(ii) Survival and Spread: Root-knot nematodes survive on dicotyledonous plants, which are usually present in most soils in which bananas are growing. Survival and spread also occurs with the planting material on infected roots and corms.

(iii) Integrated Management

(a) Bioagents and Botanicals: Soil application of 2 kg FYM with *P. fluorescens* (with 1×10^9 spores/g) and *P. chlamydosporia* (with 1×10^6 spores/g) per plant at the time of planting and at an interval of 4 months significantly reduced the root-knot nematode by 76% compared to control.

Application of *T. harzianum* along with FYM has reduced the root-knot nematode population in soil (from 175/100 mL soil in control plot to 42/100 mL soil in treated plot) and roots (from 17/g root in control plot to 4/g root treated plot). Further, application of the bioagent also reduced *Fusarium* wilt incidence and increased the yield by 4.53 MT/ha over control.

Jonathan and Rajendran (2000) reported that application of *P. lilacinus* multiplied on neem cake at 15–20 g/plant significantly reduced root gall index, egg masses, eggs, females and soil population of *M. incognita* in banana.

2.1.2.4 Burrowing, Spiral and Root-knot Nematode Complex

R. similis, H. multicinctus and *M. incognita* cause nematode complex in banana.

(i) Integrated Management

(a) Physical, Cultural, Chemical and Botanical: Integration of paring and hot water treatment (at 55°C for 20 min) of banana suckers along with application of carbofuran 3G (at 16.6 g/plant) and neem cake (at 1 kg/plant) at the time of planting reduced the soil and root population of nematodes besides increasing growth, development and yield of banana (Table 2.4).

2.1.2.5 Burrowing Nematode, *R. similis* and Panama Wilt, *F. oxysporum* f. sp. *cubense* Disease Complex

Incidence and losses due to Panama wilt caused by *F. oxysporum* f. sp. *cubense* is enhanced in association with the burrowing nematode, *R. similis* under high nematode population. This clearly indicates the existence of synergistic interaction between the burrowing nematode and *Fusarium* wilt pathogen in banana.

(i) Symptoms: Newhall (1958) showed that the incidence of Panama wilt in banana caused by *F. oxysporum* f. sp. *cubense* (Fig. 2.6) was doubled in the presence of *R. similis* during the experimental period of 3 months. When Gros Michel

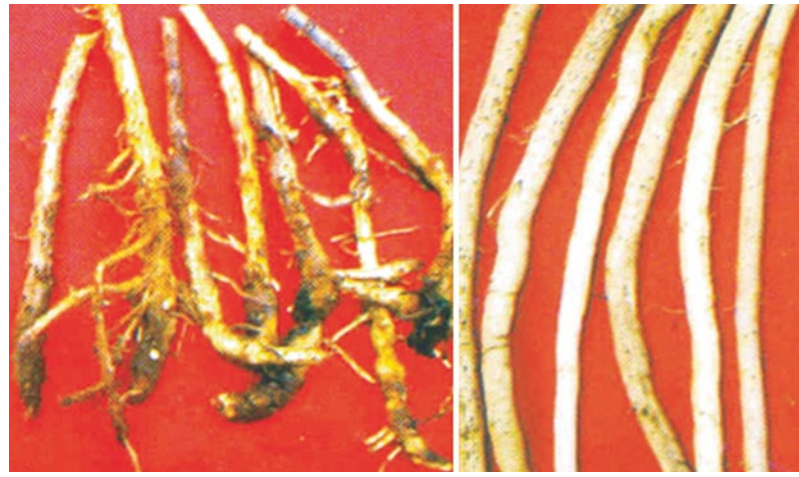


Fig. 2.5 Root-knot nematode on banana roots. *Left*—infected, *right*—healthy

Table 2.4 Management of nematode complex in banana

Treatment[a]	Fruit yield/ plant (kg)	Cost: benefit ratio	Nematode population/200 ml soil			Nematode population/5 g roots		
			Rs	*Hm*	*Mi*	*Rs*	*Hm*	*Mi*
Untreated check	4.2	1:1.49	213	150	133	62	51	3
Paring + hot water treatment + carbofuran	5.8	1:2.01	97	78	40	30	19	21
Paring + hot water treatment + carbofuran + neem cake	7.6	1:2.12	74	53	48	20	11	10
Critical Difference (CD) (P = 0.05)	*0.6*	–	*10.6*	*10.6*	*13.9*	*3.0*	*3.5*	*3.3*

Hm Helicotylenchus multicinctus; Mi Meloidogyne incognita; Rs Radopholus similis

[a] Hot water treatment at 55°C for 20 min, Carbofuran 3G at 16.6 g/plant, Neem cake at 1 kg/plant

Fig.2.6 Burrowing nematode and Panama wilt disease complex in banana

Fig. 2.7 Leaf miner infestation on leaves of citrus, adult

bananas infected with *R. similis* were inoculated with *F. oxysporum* f. sp. *cubense*, the period between inoculation and the onset of wilt was also considerably shortened (Loos 1959).

Lesions formed after inoculation with both *R. similis* and *F. oxysporum* f. sp. *cubense* were more extensively necrotic and increased in size more rapidly than when *R. similis* alone was used (Blake 1966). *F. oxysporum* f. sp. *cubense* readily establishes itself in the feeder roots of banana when they are invaded by the nematode *R. similis*, but the fungus has seldom been recovered from nematode-free roots (Blake 1966).

Rishbeth (1960) suggested that nematodes breakdown resistance to Panama wilt in Lacatan bananas.

(ii) Integrated Management

(a) Bioagents, Botanicals and Chemicals: Soil application of neem cake + *T. viride* + carbendazim was found effective in reducing the burrowing nematode (*R. similis*) and wilt (*F. oxysporum* f sp. *cubense*) disease complex and in increasing the banana fruit yield (15.147 MT/ha as compared to 9.887 MT/ha in control). This treatment also gave minimum lesion index (1.1) and root-knot index (1.0) as compared to control (4.0) with benefit-cost ratio of 2.72 (Ravi et al. 2001).

2.2 Citrus, *Citrus* spp.

2.2.1 Insect Pests

2.2.1.1 Leaf Miner, *Phyllocnists citrella*

(i) Damage: It is a serious pest of nursery and young plants but even attacks the grown up citrus trees all over India. The larvae feed on the epidermis of tender leaves making serpentine mines, which are silvery in colour (Fig. 2.7). The affected leaves become distorted and crumpled. The larvae may also mine the epidermis of tender shoots. Severe infestation may cause defoliation. Since new flush is attacked, the growth is severely hampered. In case of twig attack in young plants, 'die-back' also occurs. Ventral surface is preferred by the pest, but due to high population pressure, dorsal infestation is also seen. Citrus leaf miner helps in spreading mealy bug infestation and also acts as foci of citrus canker.

Of the total damage caused by the pest complex in citrus, 30% is claimed by the leaf miner alone. Moderate infestation of one to two larvae of leaf miners per leaf on 7-year-old trees was sufficient to reduce leaves and lower yields by 30–40% in the following year. A reduction in yield up to 50% and fruit weight from 120 to 70 g was observed.

(ii) Integrated Management

(a) Two Bioagents: Combined release of *Mallada boninensis* (30 larvae/tree) and *Tamarixia radiata* (40 adults/tree) resulted in 23–26% reduction in leaf miner population.

2.2.1.2 Black Fly, *Aleurocanthus woglumi*

This is a regional endemic pest in parts of Maharashtra and Karnataka. The epidemic proportion of the pest during late 70s and 80s brought havoc on the citrus industry in Central India. The monitory loss was estimated to the tune of Rs. 25 to 50 million annually.

Fig. 2.8 Black fly on citrus

(i) Damage: Both nymphs and adults suck cell sap and secrete voluminous honeydew on which sooty mold grows wildly that leads to fungal manifestation (*Capnodium* sp.) covering entire plant due to which photosynthesis is affected. The adults lay eggs in spiral fashion on new leaves. The nymphs, which are black in colour, suck sap from leaves and devitalize the plants (Fig. 2.8). In severe cases, fruit bearing capacity of the tree is also affected. Fruits are rendered insipid in taste and blackened due to sooty mold. Such fruits fetch low price in the market.

For successful fruit set, a minimum of 2.2% organic nitrogen in leaf is must. Five to ten black flies/cm^2 area or 50 to 100 nymphs/leaf are sufficient to reduce leaf nitrogen level below 2.2%.

(ii) Pre-disposing Factors for Citrus Black Fly Incidence: Grown up orchards on heavy clay soils had evergreen canopies intermingling with each other thus creating a microniche underneath. Further, poor drainage in such soils adds to the dampness which together helps in pest buildup. The tall evergreen border shrubs aggravate the pest problem further by sheltering pest population and in a way provide alternative to main host citrus plants.

(iii) Integrated Management

(a) Two Bioagents: Combined release of *M. boninensis* (30 larvae/tree) and *T. radiata* (40 adults/tree) resulted in 28–30% population, respectively.

2.2.1.3 Green Scale, *Coccus viridis*

The green scale is a serious pest of citrus and coffee in Kodagu (Karnataka) and Palani and Shevroy hills of Tamil Nadu.

(i) Damage: The females breed parthenogenetically producing 500 nymphs or crawlers. The nymphs settle on all parts of the leaves preferring to settle on the under surface of the leaves along the midribs. The nymphs suck sap and excrete honeydew. The vigour of the infested plant is reduced and the black sooty mold fungus develops on the honeydew excreted. The insect passes through 3–4 generations. In cases of severe attack, the fruits also get smudged with black sooty mold and the market value of such fruits is lost.

(ii) Integrated Management

(a) Bioagents and Chemicals: In mixed planted orchards (citrus + coffee) with more shade and less light interception (900–1,400 lx), spray of *Verticillium lecanii* at 10×10^6 spores/ml +0.005% quinalphos +0.05% teepol just before the onset of rainy season was highly effective against green scale (*C. viridis*) both in citrus and coffee. In pure citrus orchards, the combination was only effective during the rainy season (Singh 1995).

2.2.1.4 Brown Scale, *Saissetia coffeae*

The brown scale is present in citrus and coffee plantations throughout the year. Its outbreaks are recorded which cause more concern than even *Coccus viridis*.

(i) Damage: By and large *S. coffeae* behaves similar to *C. viridis*. The eggs hatch inside the body of the female and the nymphs or crawlers start emerging from the underside of the hemispherical shell. Nymphs settle on the leaves and the damaging cycle begins.

(ii) Integrated Management

(a) Bioagents and Chemicals: In mixed planted orchards (citrus + coffee) with more shade and less light interception (900–1,400 lx), spray of *Verticillium lecanii* at 10×10^6 spores/ml + 0.005 % quinalphos + 0.05 % teepol just before the onset of rainy season was highly effective against brown scale both in citrus and coffee. In pure citrus orchards, the combination was only effective during the rainy season. *V. lecanii* at 3×10^8 spores/mL is found effective in reducing the population of brown scale in humid areas.

2.2.2 Diseases

2.2.2.1 Damping-Off, *Phytophthora nicotianae, P. citrophthora, P. palmivora, Rhizoctonia solani, Pythium* spp.

Damping-off of seedlings in nursery bed is widespread problem in citrus industry. The disease frequently occurs in field nurseries where maintenance of sanitary measures is difficult. More than 20 % seedling mortality has been observed in Central India due to this disease (Naqvi 2001).

(i) Symptoms: Necrosis of tissue and typical damping-off of seedlings occur due to fungal infection just above the soil level. The seeds/soil infested with the pathogen results in pre-emergence rot of seeds and post-emergence damping-off of seedlings. In infested seed beds, the mortality of seedlings occurs in patches. The seedling mortality increases where excessive soil moisture accompanies the favourable temperature for the pathogen. Pathogens survive in soil either through saprophytic growth (*R. solani*) or production of resistant structures such as chlamydospores or oospores (*Phytophthora* spp.). Seedlings become tolerant to *R. solani* infection on maturity of first true leaf. Flood irrigation in flat bed system spreads the pathogen from one bed to other. However, infection of seedlings with *Phytophthora* spp. in primary nursery beds perpetuates and causes further losses to seedlings in secondary nursery beds. The budded plants show stunted, chlorotic growth with development of poor feeder roots.

(ii) Integrated Management

(a) Bioagents and Botanicals: Mixing 1 kg of *T. viride* in 40 kg of FYM and incubating the mixture for 24 h and application at 250 g mixture/m^2 is effective.

2.2.2.2 Foot Rot, Root Rot, Crown Rot, Gummosis, Leaf Fall and Fruit Rot, *Phytophthora palmivora, P. nicotianae* var. *parasitica*

The disease seems to occur especially in the high rainfall areas. Its prevalence has been reported in south India, Maharashtra, Gujarat, Punjab and Assam states. *P. nicotianae* var. *parasitica* is widespread in Assam, while *P. palmivora* is prevalent throughout India.

(i) Symptoms: Profuse gumming on the surface of the attacked bark is the main ymptom. When gumming occurs on the stem, droplets of gum trickle down the stem (Fig. 2.9). The bark gradually turns brown to dark brown and develops longitudinal cracks. A thin layer of wood tissue is also affected. When gumming starts close to the soil, the disease spreads to the main roots and then around the base of the trunk. As a result of severe gumming, the bark becomes completely rotten and the tree dies owing to girdling effect. The trees usually blossom heavily and die after the fruits mature. In such cases, the disease is called as foot rot or collar rot. The pathogen produces symptoms of decline through rotting of the rootlets, girdling of the trunk and dropping of the blighted leaves. The fruits lying on the ground are liable to invasion by the pathogen and develop brown rot.

Leaf fall and fruit rot phase of the disease is severe on mandarin oranges in heavy rainfall areas of south India. Quick shedding of leaves is

Fig. 2.9 Gummosis on main stem, foot rot and decline of Nagpur mandarin tree

the earliest symptom. The infection starts as water-soaked lesions at the leaf base. By the time the lesions extend to the whole leaf, the leaf drop off. The infection may spread to young twigs and fruits of all stages. The affected fruits show water-soaked patches on rind and subsequently drop off and rot.

(ii) Epidemiology: Severe occurrence of the disease is noticed in sweet oranges, acid lime and lemon. Heavy soil, high water table, high soil moisture, soil pH of 5.4–7.5 and temperature of 25°–28°C are conducive for disease development. Low grafting, deep planting and nearness of bud union to ground level increase the chances for soil-borne infection. The fungi survive on fallen fruits, twigs, leaves and in cracks of the tree and spread by irrigation water, rain splashes, wind and insects to stems, leaves and fruits.

(iii) Integrated Management

(a) Bioagents and Botanicals: Soil application of *Trichoderma* spp. along with organic matter in the ratio of 1:40 at 2 kg/plant or FYM enriched with *Trichoderma* spp. at 2 kg/plant is effective against the pathogen.

T. harzianum has been advocated to have a potent antagonistic action against *Phytophthora* root rot of Coorg mandarin when applied along with coffee waste, poultry manure and FYM (Sawant and Sawant 1989).

2.2.2.3 Penicillium Rot, *Pencillium digitatum, Pencillium italicum*

Green mold (*P. digitatum*) and blue mold (*P. italicum*) decays are important post-harvest diseases which occur in all citrus growing areas and often constitute the predominant type of decay (Gardner et al. 1986). Post-harvest losses of citrus fruits caused by these pathogens can account for more than 90% of all post-harvest losses in semi-arid production areas of the world (Eckert and Eaks 1989).

(i) Symptoms: A soft water-soaked area is developed at the infection site in both the diseases. Coloured spore mass is developed at the centre of the lesion surrounded by broad band of white mycelial growth in green mold infection, whereas white mycelial growth around the spore mass of blue mold is usually not more than 2 mm wide. Both the pathogens occur frequently, but green mold grows faster at moderate temperature and contaminates the fruit. The spores of green mold are unable to infect healthy uninjured adjacent fruits while the blue mold develops nesting onto uninjured healthy fruits and may cause serious damage (Fig. 2.10).

(ii) Integrated Management

(a) Bioagent and Chemical: Combining 0.2% glycolchitosan (antimicrobial substance) with the antagonist *Candida saitoana* was more effective in controlling green mold of oranges and lemons than either treatment alone.

2.2.2.4 Canker, *Xanthomonas campestris* pv. *citri*

Citrus canker was first reported from UK and the USA in 1933 on herbarium specimens of *Citrus medica* collected at Dehradun during 1827–1831.

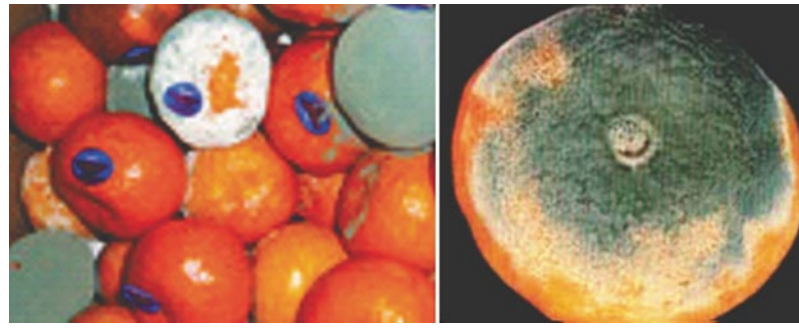


Fig. 2.10 Citrus green mold, *Pencillium digitatum*

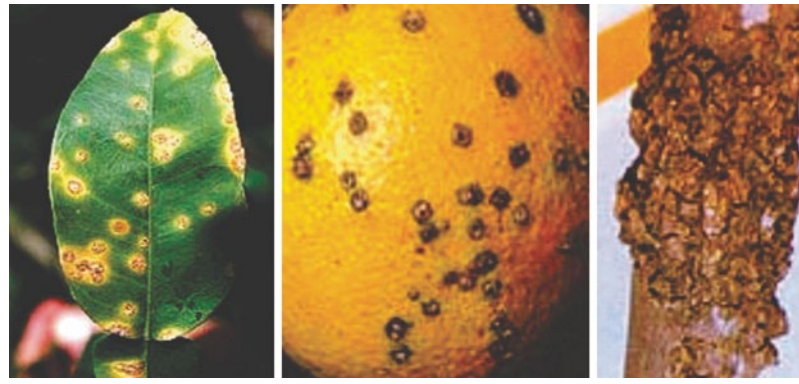


Fig. 2.11 Bacterial canker on acid lime leaf, fruit and bark. (Courtesy: K. Srinivasan, TAFE, Chennai; V.K. Das, NRCC, Nagpur)

The disease is known to occur in almost all citrus growing areas. The disease is very severe on acid lime, lemon and grapefruit.

(i) Symptoms: The disease affects leaves, twigs, older branches, thorns and fruits (Fig. 2.11). Lesions first appear as small, round, watery, translucent spots on lower surface of the leaves and then on the upper surface. As the disease progresses, spots become white or greyish and give a rough corky crater appearance. The lesions are surrounded by yellowish halo. Elongated lesions are formed on twigs. On larger branches, the cankers are irregular, rough and more prominent. Cankers on fruits are similar to those on leaves except that the yellow halo is absent and crater-like depressions in the centre are more pronounced. The lesions on fruits remain confined to the rind, but sometimes, it causes cracks and fissures on the skin.

(ii) Epidemiology: The disease is carried from one season to another in the cankerous leaves, twigs and branches, which form the main source of inoculum. The pathogen survives up to 5 months in the infected leaves (Rao and Hingorani 1963). Chakravarti et al. (1966) reported that the bacterium can survive up to 76 months in infected twigs. The pathogen enters the host through stomata, lenticels and wounds. Temperatures between 20 and 30°C with evenly distributed rains are most suitable for the disease development. Presence of free moisture on the host surface for 20 min is essential for successful infection (Ramakrishnan 1954). The pathogen from cankers is disseminated mainly by wind splashed rains. Dissemination through leaf miner (*P. citrella*) is reported by Nirvan (1961). The long distance dissemination takes place through infected planting material.

(iii) Integrated Management

(a) Cultural and Chemical: Pruning of infected twigs before monsoon and spraying three times with 500 ppm streptomycin sulphate +0.2% copper oxychloride at 20 days interval was found

Fig. 2.12 Sweet orange plants (9-month-old) infected with *Tylenchulus semipenetrans*. *Left*—healthy, *right*—infected

effective to manage the disease (Ravi Kumar et al. 2001).

2.2.3 Nematodes

2.2.3.1 Citrus Nematode, *Tylenchulus semipenetrans*

Siddiqi (1961) reported the citrus nematode for the first time from India and observed that about 80% of the citrus trees at Aligarh, Uttar Pradesh, were infested with this nematode. The nematode causes 'slow decline' and is considered to be one of the factors responsible for die-back of citrus trees. The disease is known to occur in almost all citrus growing areas. The disease is very severe on acid lime, lemon and grapefruit.

(i) Economic Importance and Losses: Yield increases of 40–200% have been obtained following the control of the nematode over a range of growing conditions (Swarup and Seshadri 1974). *T. semipenetrans* was responsible for 69, 29 and 19% loss in fruit yield of sweet orange (Baghel and Bhatti 1983a), lemon (Mukhopadhyaya and Suryanarayana 1969) and sweet lime (Mukhopadhyaya and Dalal 1971), respectively.

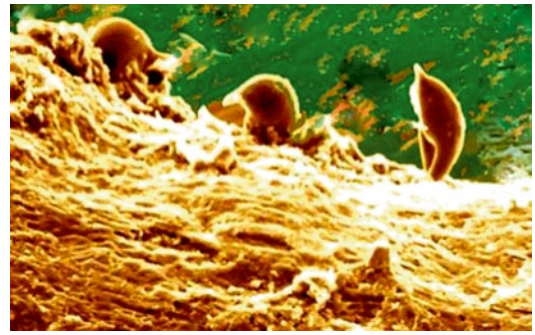


Fig. 2.13 Citrus root infected with *Tylenchulus semipenetrans*

(ii) Symptoms: 'Slow decline' of citrus is a diseased condition of trees with symptoms similar to those caused by drought and malnutrition. Affected trees exhibit reduced vigour (Fig. 2.12), chlorosis and falling of leaves, twig dieback and consequently, reduced fruit production (Prasad and Chawla 1965). This decline of the tree is gradual and persists until the crop is so small that tree maintenance may become uneconomical.

As the nematode feeds on roots (Fig. 2.13) and reproduces, a large proportion of the feeder roots of citrus trees, particularly in the upper soil layers, is inactivated or destroyed, the uptake of water and minerals from the soil is reduced and the symptoms appear on the above ground tree parts. Heavily infested roots are darker in colour with branch rootlets shortened, swollen and irregular in appearance than in normal ones (Chona et al. 1965).

Soil particles usually cling tightly, even after washing, to the gelatinous egg masses which cover the protruding part of the nematode body (Fig. 2.14). In heavily infested roots, the cortex separates readily from the vesicular stele.

(iii) Integrated Management

(a) Bioagents and Botanicals: Management of the citrus nematode based on the application of neem cake and castor cake both at 10 kg per plant along with a parasitic fungus, *P. lilacinus* at 250 g (grown on paddy seeds) per plant three times in

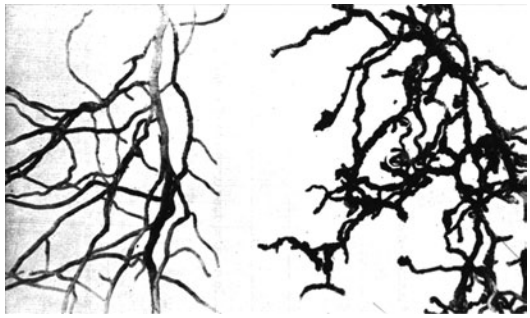


Fig. 2.14 Citrus root infected with *Tylenchulus semipenetrans*. *Left*—healthy, *right*—infected

a year at 15 cm depth and 50 cm away from the trunk was found to be extremely effective in reducing the citrus nematode population with a consequent increase in the growth of acid lime trees. The above treatment also gave highest parasitization of egg masses and eggs of *T. semipenetrans* and increased spore density of *P. lilacinus* in soil (Reddy et al. 1991, 1993; Table 2.5).

T. harzianum in combination with neem oil cake was effective in increasing the growth of acid lime trees and reducing the citrus nematode population both in soil and roots. The parasitization of citrus nematode females with *T. harzianum* increased in the presence of oil cakes (Reddy et al. 1996b; Table 2.6).

Incorporation *V. lecanii* with neem cake facilitated the effective management of *T. semipenetrans* on acid lime (Reddy et al. 1996a).

Integration of neem cake with *P. fluorescens* gave maximum reduction in citrus nematode population both in soil and roots and increased plant growth of acid lime (Reddy et al. 2000; Table 2.7).

(b) AMF and Botanicals: Inoculation of endomycorrhiza, *G. fasciculatum* in the soils amended with neem cake was found effective for the management of *T. semipenetrans* on acid lime. This strategy can help in combating the menace of citrus nematode at nursery stage and also provide highly mycorrhizal seedlings of acid lime for transplanting in the main field for the management of *T. semipenetrans* under field conditions (Reddy et al. 1995).

(c) Bioagents and AMF: Integration of *P. lilacinus* (4 g/kg soil), *T. harzianum* (4 g/kg soil) and *G. fasciculatum* (500 spores/kg soil) was effective in increasing plant growth parameters and in reducing the citrus nematode population both in soil and roots of Rough lemon (Walode et al. 2008).

(d) Two Bioagents: Application of bacterial bioagent, *Pasteuria penetrans* (at 2×10^9 spores/plant) and fungal bioagent, *P. lilacinus* (at 50 g/plant with 4×10^7 spores/g) was effective in reducing the *T. semipenetrans* population and in increasing the parasitization of larvae by *P. penetrans* and eggs by *P. lilacinus* (Reddy and Nagesh 2000; Table 2.8).

(e) Bioagents and Chemicals: Integration of *P. lilacinus* (at 4 g/plant) with carbofuran (at 30 mg a.i./plant) was found effective in increasing the plant growth parameters of acid lime and in reducing the citrus nematode population both in soil and roots (Reddy et al. 1996c; Table 2.9).

(f) Botanicals and Chemicals: Neem cake at 1 kg/plant combined with carbofuran at 2 kg/ha reduced 47.1 % nematode population and increased the yield by 41.1 % (Baghel 1995).

2.2.3.2 Root-knot Nematodes, *Meloidogyne javanica*, *Meloidogyne indica*

In India, Thirumala Rao (1956) reported that *Meloidogyne* sp. caused considerable damage to citrus in Andhra Pradesh when a susceptible crop like tobacco or okra is grown as an intercrop. This is the first report of nematode damage to citrus in India.

Mani (1986) reported that *M. javanica* caused severe crop loss to acid lime in Andhra Pradesh and was pathogenic to acid lime and sweet orange. It is confined to only coastal Andhra Pradesh.

Chitwood and Toung (1960) observed the root-knot nematode resembling *M. incognita* infecting *Citrus sinensis* from Delhi and proved its pathogenicity to citrus.

Whitehead (1968) reported *M. indica* on citrus from India (Fig. 2.15).

(i) Symptoms: *M. javanica* infected trees are poor in vigour, unthrifty in appearance and show severe stunted growth. They fail to flower and produce fruits even after several years of planting.

Table 2.5 Effect of oil cakes and *Paecilomyces lilacinus* on *Tylenchulus semipenetrans* on acid lime

Treatment	Dose (g/plant)	Nematode population/plant		% egg masses parasitized	% eggs infected	Spore density (cfu/g soil)
		Soil	Root			
Castor cake	20	3,980	2,342	–	–	–
Karanj cake	20	5,040	2,932	–	–	–
Neem cake	20	3,840	2,320	–	–	–
P. lilacinus	8	4,680	2,074	52.8	56.3	5,556
Castor cake + *P. lilacinus*	20+4	2,500	1,606	58.0	65.0	6,471
Karanj cake + *P. lilacinus*	20+4	4,240	1,650	57.0	59.0	5,997
Neem cake + *P. lilacinus*	20+4	2,120	1,330	67.5	72.4	7,123
Control	–	16,080	4,498	–	–	–
Critical Difference (CD) (P = 0.05)	–	*995.3*	*449.5*	*5.58*	*5.5*	*576*

Table 2.6 Effect of *Trichoderma harzianum* and oil cakes on plant growth and population of *Tylenchulus semipenetrans* on acid lime.

Treatment	Dose (g)/plant	Dry shoot wt. (g)	Nematode population		Parasitization of females (%)
			Roots (10 g)	Soil (200 mL)	
T. harzianum	4	4.7	228	184	22
Castor cake	40	5.5	246	170	–
Karanj cake	40	5.3	274	180	–
Neem cake	40	5.8	196	166	–
T. harzianum + Castor cake	2+20	6.8	140	132	34
T. harzianum + Karanj cake	2+20	6.5	184	142	30
T. harzianum + Neem cake	2+20	8.0	128	108	42
Control	–	3.5	1,520	1,180	–
Critical Difference (CD) (P = 0.05)	–	*0.88*	*56.3*	*53.8*	*2.3*

Table 2.7 Effect of integrated use of *Pseudomonas fluorescens* and oil cakes on plant growth and population of *Tylenchulus semipenetrans* on acid lime

Treatment	Dose (g)/plant	Plant wt. (g)	CFU/g root	Nematode population	
				Soil (100 mL)	Root (10 g)
P. fluorescens	4×10^9 spores	21.14	2.0×10^7	9,116	2,418
Castor cake	50 g	23.00	–	9,012	2,264
Karanj cake	50 g	22.09	–	9,228	2,426
Neem cake	50 g	23.40	–	8,804	2,310
P. fluorescens + Castor cake	½ dose each	25.97	12.4×10^7	6,398	1,218
P. fluorescens + Karanj cake	½ dose each	24.42	10.2×10^7	6,548	1,298
P. fluorescens + Neem cake	½ dose each	28.97	18.6×10^7	6,034	1,010
Control	–	17.60	–	13,456	6,142
Critical Difference (CD) (P = 0.05)	–	*1.76*	–	*234.64*	*212.34*

Table 2.8 Effect of integration of *Pasteuria penetrans* and *Paecilomyces lilacinus* on population of *Tylenchulus semipenetrans* and parasitization by bioagents on acid lime

Treatment	Dose/plant	Nematode population		Spores (cfu)		% parasitization	
		Root (5 g)	Soil (250 mL)	*Pp* (100 mL soil	*Pl* (5 g roots)	*Pp* (Female)	*Pl* (Egg masses)
Pp_1	2×10^6 spores	1,668	460	64.6	–	16	–
Pl_1	2×10^6 spores	2,298	588	–	1,698	–	24
$Pp_1 + Pl_1$	½ dose each	1,268	386	62.6	1,726	15	22
$Pp_1 + Pl_2$	½ dose each	994	228	59.9	1,122	28	24
$Pp_2 + Pl_1$	½ dose each	1,694	612	36.2	1,456	10	22
$Pp_2 + Pl_2$	½ dose each	1,832	644	39.4	1,232	12	20
Control	–	2,724	698	–	–	–	–
Critical Difference (CD) (P = 0.05)	–	*22.2*	*12.4*	*3.6*	*99.8*	*2.8*	*1.2*

Pp Pasteuria penetrans; Pl Paecilomyces lilacinus

Table 2.9 Effect of *Paecilomyces lilacinus* and pesticides on plant growth and population of *Tylenchulus semipenetrans* on acid lime

Treatment	Dose/plant	Plant weight (g)	Nematode population	
			Soil	Root
P. lilacinus	8 g	19.98	6,888	1,811
Carbofuran	60 mg a.i.	26.60	9,794	1,948
Phorate	60 mg a.i.	15.86	3,391	853
P. lilacinus + Carbofuran	4 g + 30 mg a.i.	27.20	2,813	643
P. lilacinus + Phorate	4 g + 30 mg a.i.	16.87	3,176	676
Control	–	13.86	15,057	4,440
Critical Difference (CD) (P = 0.05)	–	*3.14*	*431.8*	*221.4*

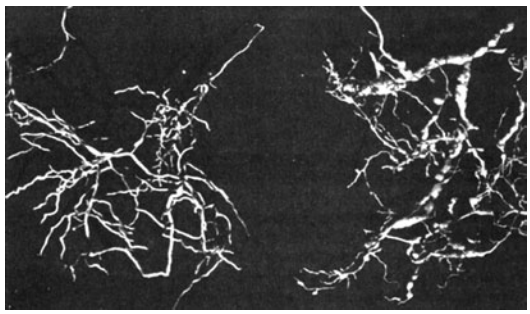


Fig. 2.15 Acid lime roots infected with *Meloidogyne indica*. *Left*—healthy roots, *right*—infected roots

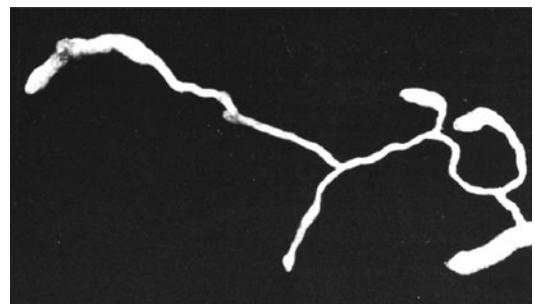


Fig. 2.16 Citrus roots infected with *Meloidogyne javanica*

The roots have conspicuous galls on pioneer and fibrous roots (Fig. 2.16). In advanced stage, large cavities can be observed in place of galls. Egg masses can be seen as thin films spread over the root surface. Nematode infestation gets aggravated if vegetables like okra, brinjal, cucurbits, tomato and tobacco are grown as intercrops in orchards or as rotational crops in nurseries (Mani 1986).

Table 2.10 Effect of integration of bioagents for the management of *Meloidogyne javanica* infecting acid lime

Treatment/dose/kg soil	Root-knot index	% egg parasitization		Root colonization (cfu/g)		Spore density (cfu/g soil)	
		Pl	*Pc*	*Pl*	*Pc*	*Pl*	*Pc*
P. lilacinus—5 g	5.5	43.9	–	31,678	–	27,975	–
P. lilacinus—10 g	5.1	57.4	–	34,578	–	29,874	–
P. chlamydosporia—5 g	6.2	–	51.9	–	28,765	–	25,439
P. chlamydosporia—10 g	5.9	–	58.9	–	32,674	–	27,896
P. lilacinus—5 g + *P. chlamydosporia*—5 g	3.2	40.7	40.8	30,785	27,347	28,753	25,873
P. lilacinus—10 g + *P. chlamydosporia*—10 g	3.8	56.9	30.8	35,687	23,879	28,796	21,784
Control (Untreated)	7.9	–	–	–	–	–	–
Critical Difference (CD) (P = 0.05)	*1.34*	*9.6*	*7.6*	*2,598.4*	*2,145.9*	*2,566.6*	*1,987.5*

Pl Paecilomyces lilacinus; Pc Pochonia chlamydosporia

(ii) Integrated Management

(a) Two Bioagents: The combined use of *P. lilacinus* and *P. chlamydosporia* each at 5 g/kg soil significantly reduced root galling, nematode population (*M. javanica*) both in soil and roots of acid lime, number of eggs per egg mass, and increased egg parasitization, root colonization and spore density of bioagents in soil (Rao 2005; Table 2.10).

(b) Bioagents and Botanicals: Combined application of *Aspergillus niger* and *P. lilacinus* at transplantation, 10 days prior to which mustard cake was introduced, significantly increased the plant vigour and reduced the root-knot nematode population.

2.3 Sapota, *Manilkara achras*

2.3.1 Diseases

2.3.1.1 Dry Root Rot/Wilt, *Fusarium solani*

(i) Symptoms: Infected plants initially show yellowing of leaves. When the disease is severe, the infected stems produce brown-to-black colour lesions along with disintegration of tissues at soil level resulting in death of affected plants.

(ii) Integrated Management

(a) Bioagents and Chemicals: Soil drenching with 0.1% carbendazim plus 0.3% copper oxychloride followed by soil application of *T. harzianum* helps in managing the disease.

2.4 Papaya, *Carica Papaya*

2.4.1 Diseases

2.4.1.1 Damping-off, *Pythium aphanidermatum, Phytophthora parasitica*

(i) Symptoms: The typical symptoms caused are the pre- and post-emergence damping-off. The post-emergence damping-off is characterized by dull green to pale seedlings showing water-soaked lesions on the cotyledons which become weak and the seedlings collapse. There is also rotting of roots where *P. parasitica* is involved.

(ii) Integrated Management

(a) Bioagents and Botanicals: Soil treatment with neem cake + *T. harzianum* gave good germination and seedling stands by controlling damping-off disease.

(b) AMF and Botanicals: Plant mortality was least in *G. fasciculatum* + vermicompost (25%) followed by *G. fasciculatum* (31.35%). The least disease incidence was recorded in *G. fasciculatum* + vermicompost (7.01%) which was at par with *Sclerocystis dussii* (7.74%) and *S. dussii* + vermicompost (8.27%).

Fig. 2.17 Papaya plant infected with *Meloidogyne incognita*

2.4.2 Nematodes

2.4.2.1 Root-knot Nematodes, *Meloidogyne* spp.

M. incognita and *M. javanica* have been reported to be the major nematode pests of papaya in India.

(i) Economic Importance: Ponte (1980) and Taylor et al. (1982) reported 10 to 20 % reduction in papaya fruit yield due to root-knot nematodes.

(ii) Symptoms: Papaya orchards infected with *Meloidogyne* spp. show patches of poor growth with many plants missing in the rows. General symptoms visible in field include poor growth, yellowing of foliage, dropping of leaves, reduction in leaf production, weak vigour and premature dropping of fruits. Roots exhibit typical below-ground symptoms *i.e.* galls of varying sizes (Fig. 2.17). The lateral branching of roots is limited. In heavily infected old roots, adjacent galls join together and form large galls. In mild infestation, root tips become swollen and root growth inhibition is distinctly seen.

(iii) Integrated Management

(a) Two Bioagents: Nursery bed treatment with *T. harzianum* and *P. lilacinus* each at 5 or 10 g/kg soil resulted in production of highly vigorous papaya seedlings whose roots were colonized with both the bioagents. There was significant reduction in root galling in the combination treatments (2.9–3.2) compared to control (8.9) (Rao and Naik 2003; Table 2.11).

Seed treatment with *P. fluorescens* (10^8 spores/g) combined with soil application of *T. harzianum* (10^6 spores/g) and *P. fluorescens* (10^8 spores/g) at 5 g/kg soil gave significant reduction in *M. incognita* population both in soil and roots, number of eggs per egg mass and hatching of eggs and increased root colonization by both the bioagents in papaya under nursery conditions (Table 2.12; Rao 2007a).

Simultaneous application of *P. lilacinus* and *T. harzianum* both at 1 g per plant gave maximum increase in plant growth parameters and highest reduction in reproduction factor and root galling in papaya (Khan 1991).

Integrated management strategy for root-knot nematodes (*M. incognita*) infecting papaya was standardized by nursery bed treatment with neem-based formulation of *P. lilacinus* (1×10^6 cfu/g) + *T. harzianum* (1×10^9 cfu/g) (each at 5 or 10 g/kg soil) and application of 35 g each of *P. lilacinus* + *T. harzianum*/pit while transplanting. The above treatment increased plant height, plant weight and reduced root galling, number of egg masses/plant and number of eggs/egg mass in nursery (Table 2.13). The integration of both the bioagents also increased root colonization of bioagents, propagule density in soil and parasitization of egg masses under field conditions (Table 2.14).

(b) Bioagents and Botanicals: Application of 2 kg FYM enriched with *P. fluorescens* (10^9 spores/g) and *P. lilacinus* (1×10^6 cfu/g) per plant at the time of planting and at an interval of 6 months significantly reduced reniform and root-knot nematodes on roots by 66 % and 70 %, respectively. Significant increase in fruit yield (28 %) was also observed. Benefit-cost ratio (calculated for marginal cost of biopesticides and returns accrued by application of biopesticides) was 3.2 (Anon 2012).

2.4.2.2 Root-knot, *M. incognita* and Wilt, *F. solani* Disease Complex

(i) Symptoms: Increasing inoculum of *M. incognita*, whether present alone or together with *F. solani*, decreased seedling emergence of papaya. The combination of highest inoculum of both pathogens (3,000 nematodes and 3 g culture of fungus) caused maximum inhibition of seedling emergence and also increased post-emergence damping-off of papaya seedlings (Khan and Hussain 1990).

Significant reduction was observed in plant height, root length, shoot and root weight in plants inoculated with nematode and fungus simultaneously, and prior inoculation of nematode followed by fungus 12 days later. Root galling was highest in case of nematode alone followed by nematode inoculation 12 days prior to fungus, and simultaneous inoculation of nematode and fungus (Table 2.15; Kishore et al. 2005).

Table 2.11 Effect of integration of bioagents for the management of *Meloidogyne incognita* infecting papaya

Treatment[a]	Root-knot index	Root colonization (cfu/g)		Propagule density (cfu/g soil)		% egg masses parasitized by *Th* and/or *Pl*
		Th	*Pl*	*Th*	*Pl*	
T1	5.6	–	26,434	–	22,097	59.36
T2	5.2	–	29,157	–	23,134	57.44
T3	6.4	35,765	–	29,347	–	58.42
T4	5.2	37,464	–	30,956	–	62.46
T5	3.0	35,124	23,301	27,437	17,104	80.62
T6	2.8	35,624	24,211	30,147	16,122	73.84
T7	8.5	–	–	–	–	–
Critical Difference (CD) (P = 0.05)	*0.65*	*2,613.46*	*1,905.27*	*2,116.82*	*1,817.43*	*8.75*

Th Trichoderma harzianum; Pl Paecilomyces lilacinus

[a] T1—Nursery soil mixed with *P. lilacinus* (5 g/kg), T2—Nursery soil mixed with *P. lilacinus* (10 g/kg), T3—Nursery soil mixed with *T. harzianum* (5 g/kg), T4—Nursery soil mixed with *T. harzianum* (10 g/kg), T5—T1 + T3, T6—T2 + T4, T7—Control

Table 2.12 Effect of integration of bioagents for the management of *Meloidogyne incognita* infecting papaya

Treatment[a]	No. of nematodes/10 g roots	No. of J_2/100 mL soil	No. of eggs/egg mass	% egg hatch suppression	Root colonization (cfu/g)	
					T. harzianum	*P. fluorescens*
T1	47	78	389	32	–	8,769
T2	42	70	364	45	–	18,457
T3	50	65	375	43	22,649	–
T4	35	52	358	65	21,895	18,249
T5	38	56	326	55	–	24,531
T6	45	63	347	54	22,412	8,566
T7	31	45	310	67	20,874	24,124
T8	68	126	412	–	–	–
Critical Difference (CD) at 5%	*6.6*	*8.5*	*33.2*	*7.4*	*2,365.7*	*2,487.2*

[a] T1—Seed treatment with *P. fluorescens*, T2—Nursery soil mixed with *P. fluorescens* (5 g/kg), T3—Nursery soil mixed with *T. harzianum* (5 g/kg), T4—Nursery soil mixed with *T. harzianum* (5 g/kg) + *P. fluorescens* (5 g/kg), T5—Seed treatment with *P. fluorescens* + Nursery soil mixed with *P. fluorescens* (5 g/kg), T6—Seed treatment with *P. fluorescens* + Nursery soil mixed with *T. harzianum* (5 g/kg), T7—Seed treatment with *P. fluorescens* + Nursery soil mixed with *T. harzianum* (5 g/kg) and *P. fluorescens* (5 g/kg), T8—Control

(ii) Integrated Management

(a) Two Bioagents: Khan et al. (1997) have reported that *P. lilacinus* gave better overall protection of papaya plants against *M. incognita–F. solani* disease complex than *T. harzianum*. They reported that application of both the biocontrol agents further limited the damage caused by *M. incognita* and *F. solani* and gave a 35% increase in plant growth compared to individual applications.

2.5 Jackfruit, *Artocarpus Heterophyllus*

2.5.1 Diseases

2.5.1.1 Die-back, *Botryodiplodia theobromae*

(i) Symptoms: This is the most destructive disease of the jackfruit. The onset of die-back symptoms becomes evident by discolouration and darkening of the bark at some distance from the

Table 2.13 Effect of neem-based formulations of bioagents on plant growth and management of *Meloidogyne incognita* infecting papaya in nursery

Treatment/Dose	Plant height (cm)	Plant weight (g)	Root-knot index (1–10 scale)	No. of egg masses/seedling	No. of eggs/egg mass
P. lilacinus—5 g/kg soil	25.35	5.58	5.8	15.45	356
P. lilacinus—10 g/kg soil	28.87	6.21	5.2	12.86	325
T. harzianum—5 g/kg soil	23.69	5.76	6.5	17.89	421
T. harzianum—10 g/kg soil	29.72	6.89	5.4	14.59	398
P. lilacinus—5 g/kg soil + T. harzianum—5 g/kg soil	32.89	7.99	3.1	10.33	270
P. lilacinus—10 g/kg soil + *T. harzianum*—10 g/kg soil	33.72	8.65	2.8	9.65	262
Control	18.64	4.12	8.7	26.27	412
Critical Difference (*CD*) *(P = 0.05)*	*3.67*	*1.25*	*0.65*	*2.38*	*34.87*

Table 2.14 Effect of neem-based formulations of bioagents on plant growth and management of *Meloidogyne incognita* infecting papaya in main field.

Treatment/Dose	Root colonization (cfu/g)		Propagule density in soil (cfu/g)		Parasitization of egg masses (%)	
	Th	*Pl*	*Th*	*Pl*	*Th*	*Pl*
P. lilacinus—5 g/kg soil	–	25,876	–	21,765	–	55.89
P. lilacinus—10 g/kg soil	–	28,231	–	23,867	–	61.98
T. harzianum—5 g/kg soil	34,789	–	28,765	–	56.76	–
T. harzianum—10 g/kg soil	37,895	–	31,194	–	66.89	–
P. lilacinus—5 g/kg soi + T. harzianum—5 g/kg soil	34,853	24,129	26,986	17,459	41.68	35.98
P. lilacinus—10 g/kg soil + *T. harzianum*—10 g/kg soil	36,432	23,679	29,457	16,934	40.21	32.49
Control	–	–	–	–	–	–
Critical Difference (*CD*) *(P = 0.05)*	*2,655*	*2,106*	*2,317*	*1,567*	*7.89*	*7.95*

Th Trichoderma harzianum; Pl Paecilomyces lilacinus

Table 2.15 Effect of *Meloidogne incognita* and *Fusarium solani* on disease complex in papaya

Treatment	Root rot (%)	Plant height (cm)	Shoot weight (g)	Root weight (g)	Galls/g roots
M. incognita	12	98.7	58.2	10.8	74
F. solani	48	106.3	63.3	13.3	0
M. incognita + *F. solani* (simultaneously)	64	65.3	53.6	9.2	43
M. incognita (prior) + *F. solani* (later)	94	73.2	60.3	9.7	65
F. solani (prior) + *M. incognita* (later)	52	83.7	76.6	15.6	35
Uninoculated Control	0	125.7	85.8	70.6	0
Critical Difference (*CD*) *(P = 0.05)*	*7.15*	*12.66*	*5.12*	*2.37*	–

tip. The dark area spreads and young green twigs start withering first at the base and then extending outwards along the veins of leaf edges. The affected leaves turn brown and their margins roll upwards. At this stage, the twig or branch dies, shrivels and drops. There may be exudation of gum from affected branches. Such branches have also been found to be affected by shoot borers.

Table 2.16 Effect of fungicide alone and in combination with mulch on incidence of fruit rot and yield of strawberry

Treatment	Disease incidence (%)	Fruit rot control (%)	Fruit yield (kg/plot)	% increase in fruit yield
Polythene mulch	18.43	54.36	1.600	71.99
Ridomil MZ	24.67	38.92	1.258	35.23
Paddy straw mulch	28.02	30.63	1.056	13.51
Polythene mulch + Ridomil MZ	10.31	74.47	1.838	97.57
Paddy straw mulch + Ridomil MZ	14.17	64.92	1.768	90.04
Control	40.39	–	0.930	–
Critical Difference (CD) (P = 0.05)	*5.025*	*14.263*	–	–

Infected twigs show internal discolouration. In early stages, epidermal and sub-epidermal cells of twigs appear slightly shrivelled.

(ii) Integrated Management

(a) Cultural and Chemical: Pruning of infected twigs followed by spraying of 0.1 % carbendazim or Topsin M or 0.2 % chlorothalanil has been recommended for the management of the disease.

2.6 Strawberry, *Fragaria* spp.

2.6.1 Diseases

2.6.1.1 Fruit Rot, *Phytophthora cactorum*

(i) Integrated Management

(a) Physical, Cultural and Chemical: Maximum disease control was achieved in plots that were mulched with polythene and sprayed with ridomil MZ (74.47 %) followed by paddy straw mulch and ridomil MZ sprays (64.92 %). The fruit yield of strawberry also increased significantly in combined treatment of polythene mulch and ridomil MZ (97.57 %) followed by paddy straw mulch and ridomil MZ (90.04 %) (Table 2.16; Bharadwaj and Sharma 2000).

(b) Physical and Bioagents: The combination of soil solarization and application of *Trichoderma* spp. reduced *P. cactorum* soil population to the maximum extent (88.9 % in January 2001, 97.6 % in 2002 and 99.0 % in 2003). The very promising effect of *Trichoderma* spp. and solarization against *P. cactorum* indicates that there may be future alternatives to traditional chemicals for disease control (Porras et al. 2007).

2.6.1.2 Root Rot, *Phytophthora cinnamoni*

(i) Symptoms: Infected roots turn dark and lose their feeder roots (Fig. 2.18). Black root rot causes poor plant vigour. This problem is associated with soils of high clay content, excessive irrigation and soil compaction. Avoid these soils and provide adequate soil aeration for vigorous root growth.

(ii) Integrated Management

(a) Biofumigation and Solarization: Soil solarization and biofumigation with *Brassica carinata* (B + S) increased plant growth (foliar surface), fruit weight and strawberry yield the most each year. Plant growth differences were observed relative to soil solarization (S) and untreated control (C), with foliar surface (cm^2) of B + S, S and C of 502, 414 and 351, and 435, 346 and 228 in January 2006 and 2007, respectively. Furthermore, S increased plant growth and strawberry yield relative to C. Fruit weight (g/fruit) of B + S, S and C was 25, 22 and 17, and 23, 20 and 17 in 2006 and 2007, respectively. In addition, both treatments reduced *Phytophthora* soil population relative to C. The current work contributes to the development and optimization of biofumigation with *Brassica* and soil solarization as alternatives to the traditional use of chemicals in strawberry production (Porras et al. 2009).

2.6.1.3 Fusarium Wilt

(i) Symptoms: Symptoms consisted of wilting of foliage, drying and withering of older leaves, stunting of plants and reduced fruit production. Plants eventually collapsed and died. Internal vascular

Fig. 2.18 Root rot symptoms on strawberry

and cortical tissues of plant crowns showed a brown to orange brown discolouration (Fig. 2.19).

(ii) Integrated Management

(a) Botanicals and AMF: Combined use of AMF *Gigaspora margarita* and 3–15 % charcoal compost (which contained antagonistic microorganisms such as *Bacillus subtilis, Thermomonospora* sp. and *Thermoactinomyces* sp.) drastically reduced *Fusarium* wilt in strawberry. Moreover, AMF and charcoal compost stimulated rooting and increased the root volume, and hence plant growth (Kabayashi 1989a).

2.6.2 Nematodes

2.6.2.1 Lesion Nematode, *P. penetrans* and Wilt, *Verticillium dahliae* Disease Complex

(i) Symptoms: Infested plants are stunted, pale green, have reduced yields and eventually die. Root symptoms appear as distinct brown lesions in early or light infestation. The entire root system eventually becomes black and necrotic as populations increase and secondary organisms invade (Fig. 2.20).

(ii) Integrated Management

(a) Crop Rotation and Biofumigation: Nematode population densities were significantly lower after biofumigation [canola was ploughed under at late bloom (end of July) followed by white mustard which was ploughed at full bloom (October)] along with crop rotation with both pearl millet cultivars (CFPM 101 and Tifleaf) than after corn and oats. In 2006, both pearl millets and biofumigation significantly reduced by an average of 21 % of the incidence of Verticillium wilt and allowed a 54 % average increase in the development of strawberry plants cv. Jewel.

(b) Biofumigation and Solarization: Plastic mulch significantly improved biofumigation (by incorporating poultry manure at 15 t/ha at canola-crop ploughing time) with a 95 % reduction in the number of *P. penetrans* densities when compared to canola ploughed with poultry manure but no plastic mulch (Bélair and Coulombe 2008).

2.6.2.2 Root-Knot Nematodes, *Meloidogyne* spp.

(i) Symptoms: Symptoms associated with root-knot nematodes include: stunting, yellowing of leaves, reduced berry yields, reduced production of runner plants, wilting and general loss of vigour.

This nematode causes tiny galls (about 3 mm in diameter) on feeder roots. Several short branch roots stick out from each tiny swelling or gall (Fig. 2.21). Injured plants appear stunted, take on an 'off' colour and produce little fruit. Weakened plants are more subject to drought damage and make fewer runners.

(ii) Integrated Management

(a) Botanicals and Chemicals: Application of neem cake in combination with carbofuran at the time of planting increased the yield by 35.2 % over control (Laqman Khan 2001).

Fig. 2.19 *Fusarium* wilt affected crown with brown discolouration of water conducting tissues

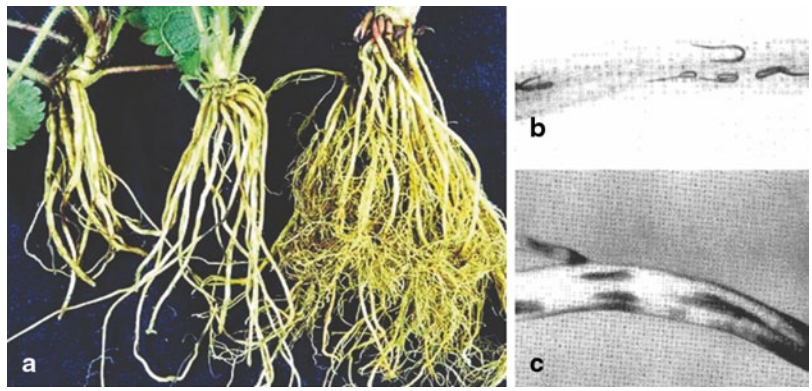


Fig. 2.20 The lesion nematode (*Pratylenchus penetrans*) on strawberry. **a** *Left* 2 plants, infected, *right*, healthy. **b** *Top*, lesion nematodes inside the root. **c** *Bottom*, lesions on the root

(b) Solarization and Chemicals: Solarization + MB/Telopic or MB, were effective in controlling root-knot nematodes compared to solarization and biofumigation (Table 2.17)

2.7 Mulberry, *Morus* spp.

2.7.1 Diseases

2.7.1.1 Nursery Diseases: Stem Canker and Dieback, *Botryodiplodia theobromae;* Cutting Rot, *F. solani;* Collar Rot, *Phoma mororum, Phoma sorghina*

(i) Symptoms: These diseases cause more than 30% mortality of mulberry stem cuttings and death of saplings. Initial establishment of mulberry is greatly affected resulting in poor plant survivability, growth and leaf yield.

(ii) Integrated Management

(a) Bioagents, Botanicals and Chemicals: Integration of 'Nursery-Guard' (*Trichoderma pseudokoningii*) applied to soil as pre-planting treatment after mixing with FYM (1:60 ratio) with soaking of stem cuttings in 0.1% mancozeb resulted in reducing the severity of nursery diseases by 82% and increasing the plant stand by 40%. The integration helps to improve the overall establishment and growth of mulberry plantation, and thus provides better yield (Gupta 2000, 2001; Gupta et al. 1998, 1999).

2.7.1.2 Root Rot, *Fusarium oxysporum, F. solani*

(i) Symptoms: The disease symptoms include decaying of roots resulting in sudden withering of leaves followed by defoliation and death of plants (Fig. 2.22; Gupta 2001) . Occurrence is mostly seen in summer. In initial stage, leaf blade

Fig. 2.21 *L*—Strawberry plants infested with nematodes appear stunted (left rows) and produce fewer berries than healthy plants not infested with nematodes (right rows). *R*—Root swelling or knot symptoms on strawberry roots caused by root-knot nematodes

Table 2.17 Effect of different soil fumigation methods for the management of root-knot nematodes

Treatment	Location: Cartaya[a]			Location: Moguer[a]		
	Incidence[b]	Severity[c]	♀/g[d]	Incidence[b]	Severity[c]	♀/g[d]
Control	54.2 a[e]	2.01 a	13.5 a	15.0 a	0.99 a	13.1 a
Solarization	36.7 a	1.48 ab	5.8 ab	8.3 ab	1.20 a	10.3 a
Biofumigation	32.5 ab	1.10 bc	5.0 ab	0.8 b	0.25 b	0.2 a
Solarization + Metham sodium	26.7 b	0.63 bcd	3.6 bc	0.0 b	0.00 b	0.0 a
Solarization + MB/Telopic	12.5 b	0.72 cd	1.7 bc	0.0 b	0.00 b	0.0 a
Methyl Bromide	0.8 c	0.08 d	0.0 c	0.0 b	0.00 b	0.0 a

[a] Mean of 10 plants/plot, 3 blocks/year and 4 years
[b] Percentage of disease plants
[c] Severity (0 = no symptoms; 4 = more than 90 % of roots affected)
[d] Number of females/g of roots
[e] Means followed by the same letter are not different under an Multidimensional scaling (MDS) test ($P < 0.05$)

turns to wilt and then spreads to entire plant. At later stage, black fungus appears on branches and stem. The disease spread through soil and water.

(ii) Integrated Management

(a) Bioagents, Botanicals and Chemicals: Soil application of enriched FYM with *T. harzianum* (commercial product 'Raksha' 10 g + 500 g FYM) at 500 g/pit before replanting in infested area and *T. harzianum* integrated with mancozeb (dressing of stem cutting or roots of sapling before planting) gave about 80 % control of root rot disease in mulberry (Philip et al. 1996; Gupta 2001).

Fig. 2.22 Root rot symptoms on mulberry

2.7.2 Nematodes

2.7.2.1 Root-knot Nematodes, *Meloidogyne* spp.

Govindaiah et al. (1991) reported 11.8 % loss in herbage yield of mulberry due to *M. incognita*.

(i) Symptoms: Above-ground symptoms include stunted growth, poor and delayed sprouting, reduced leaf size and yield, chlorosis and marginal necrosis of leaves, yellowing and wilting of leaves in spite of adequate soil moisture availability, and death of plants in severe cases.

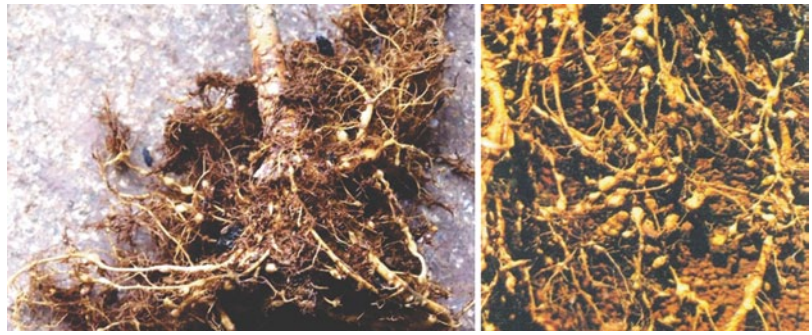


Fig. 2.23 Root-knot galls on mulberry roots

These symptoms first appear as isolated patches, slowly spreading over the entire garden.

Below-ground symptoms include formation of galls or knots on roots (Fig. 2.23), reduced and stubby root system, and necrotic lesions on the root surfaces and death of roots.

(ii) Integrated Management

(a) Bioagents and AMF: Combined inoculation of AMF and *P. fluorescens* had positive effect on root-knot nematode control on mulberry (Kumutha 2001).

(b) Cultural and Botanicals: Intercropping of mulberry with marigold at wider spacing of 30–45 cm controlled *M. incognita*, increased leaf moisture and leaf yield of mulberry (Govindaiah et al. 1990).

(c) Two Bioagents: Combined soil application of *P. fluorescens* and *T. viride* each at 10 g/plant was effective to check the nematode population and improve growth of mulberry with increased leaf yield (Muthulakshmi et al. 2010).

References

Anon. (1993). Biennial report (1991–93) of AICRP on plant parasitic nematodes with integrated approach for their control, Department of Nematology, Haryana Agriculture University, Hisar, pp. 80.

Baghel, P. P. S. (1995). Nematode problems in citrus. In G. Swarup, D. R. Dasgupta, & J. S. Gill (Eds.), *Nematode pest management-an appraisal of eco-friendly approach* (pp. 203–210). New Delhi: Nematology Society of India.

Baghel, P. P. S., & Bhatti, D. S. (1983a). Evaluation of pesticides for the control of phytonematodes on citrus. Third nematology symposium, Y.S. Parmar University of Horticulture & Forestry, Solan, India, pp. 38–39.

Bélair, G., & Coulombe, J. (2008). Green manure and biofumigation for root lesion nematode and Verticillium wilt management in strawberry production. Third international biofumigation symposium, Canberra, Australia.

Bharadwaj, L. N., & Sharma, S. K. (2000). Y.S. Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh. In S. R. Sarma (Ed.), *Progress report for the period Sept. 1997–Aug. 2000 of national network project on phytophthora diseases of horticultural crops* (pp. 26–40). Calicut: Indian Institute of Spices Research.

Blake, C. D. (1966). The histological changes in banana roots caused by *Radopholus similis* and *Helicotylenchus multicinctus*. *Nematologica, 12,* 129–132.

Chakravarti, B. P., Porwal, S., & Rangarajan, M. (1966). Studies on citrus canker in Rajasthan I. Disease incidence and survival of the pathogen. *Labdev Journal of Science and Technology, 4,* 262–265.

Channabasappa, B. S., Krishnappa, K., & Reddy, B. M. R. (1995). Utilization of ecofriendly biological agents and biocomponents in the integrated management of *Radopholus similis* on banana. National symposium on nematode problems of India—an appraisal of the nematode management with ecofriendly approaches and biocomponents, Indian Agriculture Research Institute, New Delhi.

Charles, J. S. K., Venkitesan, T. S., Thomas, Y., & Varkey, P. A. (1985). Correlation of plant growth components to bunch weight in banana infested with burrowing nematode, *Radopholus similis* (Cobb). *Indian Journal of Nematology, 15,* 186–190.

Chitwood, B. G., & Toung, M. C. (1960). Host parasite interactions of the Asiatic pyroid citrus nematode. *Plant Disease Reporter, 48,* 848–854.

Chona, B. L., Sethi, C. L., Swarup, G., & Gill, J. S. (1965). Citrus nematode (*Tylenchulus semipenetrans* Cobb, 1913) associated with die-back disease of citrus. *Indian Journal of Hortticulture, 22,* 370–373.

Eckert, J. W., & Eaks, I. L. (1989). Post-harvest disorders and diseases of citrus fruits. In W. Reuther, E. C. Calavan, & G. E. Carman (Eds.), *The citrus industry* (Vol. 5, pp. 179–250). Oakland: University of California Press.

Gardner, P. D., Eckert, J. W., Baritelle, J. L., & Bancroft, M. N. (1986). Management strategies for control of

Pencillium decay in lemon packing houses: Economic benefits. *Crop Protection, 5,* 26–32.

Govindaiah, Dandin, S. B., & Sharma, D. D. (1991). Pathogenicity and avoidable leaf yield loss due to *Meloidogyne incognita* in mulberry (*Morus alba* L.). *Indian Journal of Nematology, 21,* 52–57.

Govindaiah, Dandin, S. B., Philip, T., & Datia, R. K. (1990). Effect of marigold (*Tagetes patula*) intercropping against *Meloidogyne incognita* infecting mulberry. *Indian Journal of Nematology, 20,* 96–99.

Gupta, V. P. (2000). Biological control of mulberry diseases—The current status. In M. K. Dasgupta (Ed.), *Diseases of plantation crops, spices, betelvine and mulberry* (pp. 145–148). Srineketan: Visva-Bharati Publications.

Gupta, V. P. (2001). Diseases of mulberry and their management. In P. C. Trivedi (Ed.), *Plant pathology* (pp. 130–164). Jaipur: Pointer Publishers.

Gupta, V. P., Mishra, R. K., & Sarkar, A. (1998). Management of nursery diseases of mulberry through integrated approach. 7th International Congress of Plant Pathology, Edinburgh, Scotland, U.K., Vol. 3, Abstr. 3.7.80.

Gupta, V. P., Sharma, D. D., Rekha, M., & Chandrasekar, D. S. (1999). Integration of *Trichoderma pseudokoningii* with agrochemicals for disease management and plant development in mulberry. *Archiv fur Phytopasthologie und Pflanzenschutz, 32,* 521–529.

Jonathan, E. I., & Cannayane, I. (2002). Field application of biocontrol agents for management of spiral nematode, *Helicotylenchus multicinctus* in banana (Abstr.). Global conference on banana and plantain, Bangalore, p. 193.

Jonathan, E. I., & Rajendran, G. (2000). Assessment of avoidable yield loss in banana due to root-knot nematode, *Meloidogyne incognita. Indian Journal of Nematology, 30,* 162–164.

Kabayashi, N. (1989a). Charcoal compost fixed antagonistic microorganisms and its effect to soil-borne diseases (Abstr.). *Annals of the Phytopathological Society of Japan, 55*.

Khan, T. A. (1991). Studies on a disease complex of papaya caused by *Meloidogyne incognita* and *Fusarium solani*. Final technical report, DST Project, Aligarh Muslim University, Aligarh, 47 pages.

Khan, T. A., & Hussain, S. I. (1990). Effect of interaction of various inoculum levels of *Meloidogyne incognita* and *Fusarium solani* on seedling emergence and post-emergence damping-off of papaya seedlings. *New Agriculturist, 1,* 17–20.

Khan, T. A., Khan, S.T., Fazal, M., & Siddiqui, Z. A. (1997). Biological control of *Meloidogyne incognita* and *Fusarium solani* disease complex in papaya using *Paecilomyces lilacinus* and *Trichoderma harzianum. Indian Journal of Nematology, 7,* 127–132.

Kishore, R., Kamalwanshi, R. S., & Pandey, M. (2005). Effect of root-knot nematode with *Fusarium solani* on damping-off of papaya. *Indian Journal of Nematology, 35,* 96–97.

Kumutha, K. (2001). Symbiotic influence of AM fungi and Rhizobacteria on biochemical and nutritional changes in mulberry (*Morus alba*). Ph.D. thesis, Tamil Nadu Agriculture. University, Coimbatore.

Laqman Khan, M. (2001). Dr. Y.S. Paramar University of Horticulture and Forestry, Solan, Himachal Pradesh. In S. C. Dhawan et al. (Eds.), *Indian nematology-progress and prospectives* (pp. 153–158). New Delhi: Division of Nematology, Indian Agricultural Research Institute.

Loos, C. A. (1959). Symptom expression of *Fusarium* wilt disease of the Gros Michel banana in the presence of *Radopholus similis* (Cobb, 1893) Thorne, 1949 and *Meloidogyne incognita acrita* Chitwood, 1949. *Proceedings of the Helminthological Society of Washington, 26,* 103–111.

Mani, A. (1986). Occurrence of *Meloidogyne javanica* on citrus in Andhra Pradesh (India). *International Nematology Network Newsletter, 3*(2), 9–10.

Mukhopadhyaya, M. C., & Dalal, M. R. (1971). Effect of two nematicides on *Tylenchulus semipenetrans* and on sweet lime yield. *Indian Journal of Nematology, 1,* 95–97.

Mukhopadhyaya, M. C., & Suryanarayana, D. (1969). Citrus decline in Haryana : Role of *Tylenchulus semipenetrans* and its control. *Indian Phytopathology, 22,* 495–497.

Muthulakshmi, M., Devarajan, K., & Jonathan, E. I. (2010). Biocontrol of root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood in mulberry (*Morus alba* L.). *Journal of Pesticides, 3,* 479–482.

Nair, K. K. R. (1979). Studies on the chemical control of banana nematodes. *Agricultural Research Journal of Kerala, 17,* 232–235.

Nair, M. R. G. K., Das, N. M., & Menon, M. R. (1966). On the occurrence of the burrowing nematode *Radopholus similis* (Cobb, 1893) Thorne, 1949 on banana in Kerala. *Indian Journal of Entomology, 28,* 553–554.

Naqvi, S. A. M. H. (2001). Diagnosis and management of fungal diseases of citrus. In S. Singh & S. A. M. H. Naqvi (Eds.), *Citrus* (pp. 375–391). Lucknow: International Book Distributing Company.

Newhall, A. G. (1958). The incidence of Panama disease of banana in the presence of the root-knot and the burrowing nematodes (*Meloidogyne incognita* and *Radopholus similis). Plant Disease Reporter, 42,* 853–856.

Nirvan, R. S. (1961). Citrus canker and its control. *Horticultural Advances, 5*, 124–125.

Patil, N. M., Dharne, P. K., & Deshmukh, S. S. (1999). Sucker dip treatment in monocrotophos with intercrops for the management of plant parasitic nematodes in banana. Seminar on technological advancement in banana production, handling and processing management, Jalgaon, Maharashtra, pp. 126–128.

Philip, T., Sharma, D. D., & Govindaiah (1996). Biological control of mulberry root-rot disease. *Indian Silk, 34,* 6–8.

Ponte, J. J. D. A. (1980). *Meloidogyne*—importanica and control no nordeste. *Sociedade Brasileira Nematologia, 4,* 1–14.

Porras, M., Barrau, C., Arroyo, F. T., Santos, B., Blanco, C., & Romero, F. (2007). Reduction of *Phytophthora*

cactorum in strawberry fields by *Trichoderma* spp. and soil solarization. *Plant Disease, 91,* 142–146.

Porras, M., Barrau, C., Romero, E., Zurera, C., & Romero, F. (2009). Effect of biofumigation with *brassica carinata* and soil solarization on *phytophthora* spp. and strawberry yield. *Acta Horticulture, 842,* 969–972.

Prasad, S. K., & Chawla, M. L. (1965). Observations on the population fluctuations of citrus nematode, *Tylenchulus semipenetrans* Cobb, 1913. *Indian Journal of Entomology, 27,* 450–455.

Rajagopalan, P., & Naganathan, T. G. (1977b). Studies on nematode parasites of banana. *Tamil Nadu Agricultural University Annual Report, 6,* 131.

Ramakrishnan, T. S. (1954). *Common diseases of citrus in Madras*. Madras: Government of Madras Publication.

Ramakrishnan, T. S., & Damodaran, S. (1956). Observations on the wilt disease of the banana. *Proceedings of the Indian Academy of Science, 43,* 213–222.

Rao, M. S. (2005). Management of *Meloidogyne javanica* on acid lime nursery seedlings by using formulations of *Pochonia chlamydosporia* and *Paecilomyces lilacinus. Nematologia Mediterranea, 33,* 145–148.

Rao, M. S. (2007a). Papaya seedlings colonized by the bio-agents *Trichoderma harzianum* and *Pseudomonas fluorescens* to control root-knot nematodes. *Nematologia Mediterranea, 35,* 199–203.

Rao, M. S., & Naik, D. (2003). Effect of *Trichoderma harzianum* and *Paecilomyces lilacinus* on *Meloidogyne incognita* on papaya (*Carica papaya* L.) nursery seedlings. *Pest Managment in Horticultural Ecosystems, 9,* 155–160.

Rao, Y. P., & Hingorani, M. K. (1963). Survival of *Xanthomonas citri* (Hasse) Dowson in leaves and soil. *Indian Phytopatholgy, 16,* 362–364.

Ravi Kumar, M. R., Somasekhara, Y. M., Jahagirdar, S., & Ryagi, Y. H. (2001). Field evaluation of antibiotics against citrus canker caused by *Xanthomonas axonopodis* pv. *citri. Agricultural Science Digest, 21,* 253–255.

Ravi, K., Nanje Gowda, D. N., & Reddy, P. P. (2001). Integrated management of disease complex in banana involving borrowing nematode and Panama wilt—an ecofriendly approach. In A. Verghese & P. P. Reddy (Eds.), *IPM in horticultural crops: Emerging trends in the new millennium* (p. 154). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Reddy, P. P., & Nagesh, M. (2000). Integrated management of the citrus nematode using bacterial (*Pasteuria penetrans)* and fungal (*Paecilomyces lilacinus)* biocontrol agents. Proceedings of international symptoms on citriculture, Nagpur, pp. 825–829.

Reddy, P. P., Khan, R. M., & Rao, M. S. (1991). Integrated management of the citrus nematode, *Tylenchulus semipenetrans* using oil cakes and *Paecilomyces lilacinus. Afro-Asian Journal of Nematolology, 1,* 221–222.

Reddy, P. P., Khan, R. M., & Rao, M.S. (1993). Integrated management of the citrus nematode, *Tylenchulus semipenetrans* using neem cake and the parasitic fungus, *Paecilomyces lilacinus. Proceedings of the world neem conference*, Bangalore, pp. 647–650.

Reddy, P. P., Rao, M. S., Mohandas, S., & Nagesh, M. (1995). Integrated management of the citrus nematode, *Tylenchulus semipenetrans* Cobb using VA mycorrhiza, *Glomus fasciculatum* (Thaxt.) Gerd & Trappe and oil cakes. *Pest Management in Horticultural Ecosystems, 1,* 37–41.

Reddy, P. P., Rao, M.S., & Nagesh, M. (1996a). Management of the citrus nematode, *Tylenchulus semipenetrans* by integration of *Trichoderma harzianum* with oil cakes. *Nematolologia Mediterranea,* 24*,* 265–267.

Reddy, P. P., Rao, M. S., & Nagesh, M. (1996b). Management of the citrus nematode on acid lime by integration of parasitic fungi and oil cakes. *Pest Management in Horticultural Ecosystems 2*, 15–18.

Reddy, P. P., Rao, M. S., & Nagesh, M. (1996c). Integrated management of the citrus nematode, *Tylenchulus semipenetrans* using pesticides and parasitic fungus, *Paecilomyces lilacinus. Pest Management in Horticultural Ecosystems, 2,* 61–63.

Reddy, P. P., Rao, M. S., & Nagesh, M. (1996d). Crop loss estimation in banana due to the burrowing nematode, *Radopholus similis. Pest Management in Horticultural Ecosystems, 2*, 85–86.

Reddy, P. P., Nagesh, M., Rao, M. S., & Rama, N. (2000). Management of *Tylenchulus semipenetrans* by integration of *Pseudomonas fluorescens* with oil cakes. Proceedings of the international symposium on citriculture, Nagpur, pp. 830–833.

Reddy, P. P., Rao, M. S., & Nagesh, M. (2002). Integrated management of burrowing nematode (*Radopholus similis*) using endomycorrhiza (*Glomus mosseae*) and oil cakes. In H. P. Singh & K. L. Chadha (Eds.), *Banana* (pp. 344–348). Trichy: Association of the Improvement in Production and Utilisation of Banana.

Rishbeth, J. (1960). Factors affecting the incidence of banana wilt ('Panama disease'). *Empire Journal of Experimental Agriculture, 28,* 109–113.

Satish. (1996). Management of Panama disease of banana caused by *Fusarium oxysporum* f. sp. *cubense* by using microorganisms. M.Sc. thesis, University of Agricultural Science, Bangalore, 98 pages.

Sawant, I. S., & Sawant, S. D. (1989). Coffee fruit skin and cherry husk as substrates for mass multiplication of *Trichoderma harzianum* an antagonist of citrus *Phytophthora Indian Phytopathology, 42,* 336.

Siddiqi, M. R. (1961). Occurrence of the citrus nematode, *Tylenchulus semipenetrans* Cobb. 1913 and the reniform nematode, *Rotylenchulus reniformis* in India. *Proceedings of 48th of Indian Science Congress, 3,* 504.

Singh, S. P. (1995). *Technology for production of natural enemies*, (221 pages). Technical Bulletin No. 4, Project Directotate of Biological Control, Bangalore.

Swarup, G., & Seshadri, A. R. (1974). Nematology in India—problems and progress. In S. P. Raychaudhuri & J. P. Verma (Eds.), *Current trends in plant pathol-*

ogy (pp. 303–311). Lucknow: Department of Botany, University of Lucknow.

Taylor, A. L., Sasser, J. N., & Nelson, L. A. (1982). *Relationship of climate and soil characteristics to geographical distribution of meloidogyne species in agricultural soil*. Raleigh: Co-operative Publication, Department of Plant Pathology, North Carolina State University & U. S. Agency for International Development, 65 pages.

Thirumala Rao, V. (1956). Stray notes on some pest outbreaks of South India. *Indian Journal Entomology, 18*, 123–126.

Vadivelu, R. S., Rajendran, G., Naganathan, T. G., & Jayaraj, S. (1987). Studies on the nematode pests of banana and their management—A review. Third group discussion on the nematological problems of plantation crops, Sugarcane Breeding Institute, Coimbatore, pp. 32–33.

Vidya, K., & Reddy, B. M. R. (1998). Integrated management of *Radopholus similis* infecting banana using plant product, nematicide and biocontrol agents. *Mysore Journal of Agricultural Science, 32,* 186–190.

Walode, N. B., Sinha, A. K., & Neog, P. P. (2008). Biological control of citrus nematode, *Tylenchulus semipenetrans* on *Citrus jambhiri. Indian Journal of Nematology, 38,* 244–245.

Whitehead, A. G. (1968). Taxonomy of *Meloidogyne* (Nematodea: Heteroderidae) with descriptions of four new species. *Transactions of the Zoology Society of London, 31,* 263–401.

Subtropical Fruit Crops

3

3.1 Mango, *Mangifera indica*

3.1.1 Insect Pests

3.1.1.1 Fruit Fly, *Dacus dorsalis*

This is one of the most serious pests of mango in India, which has created problem in the export of fresh fruits. Its infestation is more in southern states than in northern states. The pest is active throughout the year in south India, whereas in northern part it hibernates during winter (November to March) in pupal stage (Kapoor 1993).

(i) Damage: The female punctures the outer wall of the mature fruits with the help of its pointed ovipositor and inserts eggs just below the fruit epidermis (1–4 mm deep) in small clusters inside the mesocarp. After hatching the maggots feed on pulp of these fruits (Fig. 3.1) and the infested fruits start rotting and fall down. As a result the brown patch appears around the place of oviposition and the infested fruits start rotting. The maggots come out of affected fruits to pupate in the soil. The flies breed on fruits that are mature and population increases rapidly during summer (May to July). The population declines slowly from August to September. In methyl eugenol traps, it was found that peak trap catch was between 16 and 17 h (Jayanthi and Verghese 1998).

High temperature coupled with high humidity prevailing during May–July months are the favourable environmental factors for the development and reproduction of fruit fly.

(ii) Integrated Management

(a) Cultural, Chemical and Physical: The following pre- and post-harvest Integrated Pest Management (IPM) combining sanitation + intercultural ploughing + three insecticidal sprays at 15 days interval prior to harvest + hot water treatment of fruits gives 95–100 % control (Verghese et al. 2000).

Pre-Harvest Management

1. 45 days before harvest the following precautions need to be taken:
   a. Destroy all fallen fruits at weekly intervals.
   b. Install at least 10 methyl eugenol bottle traps (0.1 %) per ha.
   c. Plough/rake the soil at the tree basin at frequent intervals (one or two times between flowering and harvest) to expose pupae to sun.
   d. Avoid delay in harvesting.
2. Three weeks before the harvest, spray decamethrin 2.8 EC at 0.5 mL/L + azadirachtin (0.3 %) at 2 mL/L and take up timely harvest.

Post-Harvest Management Within 24 h after harvest, hot water treatment of fruits at 48 °C maintained by thermostat for 1 h, gave 100 % fruit fly infestation-free fruits in cultivars. Banganapalli and Totapuri. Hot water treatment in 5 % salt solution at 55 °C for 30 min without thermostat gave 100 % control in cultivars. Banganapalli, Totapuri and Alphanso.

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_3, © Springer India 2014

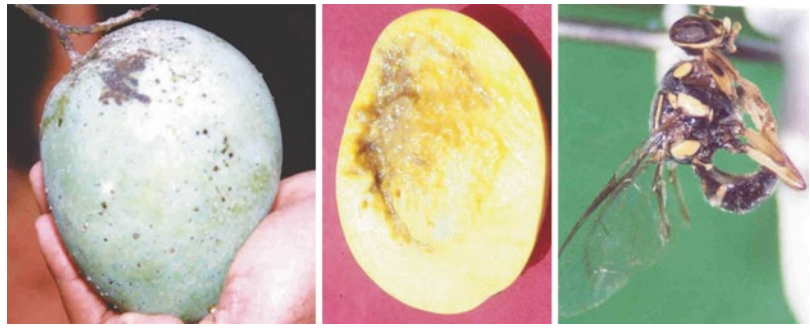


Fig. 3.1 Mango fruit fly and its damage to the fruit. (Courtesy: A. Verghese, IIHR, Bangalore)

Table 3.1 Economics of Integrated Pest Management (IPM) in mango

Parameters	IPM plots	Non-IPM plots	% increase
Yield MT/ha	6.0–9.0	3.5–7.0	28.57–71.43
Net profit (Rs/ha)	30,000–55,000	17,000–35,000	57.14–76.47

3.1.2 Validation of Mango Integrated Pest Management (Uttarakhand)

- Spraying of 0.3% copper oxychloride for control of die-back, anthracnose and red rust diseases wherever they appeared during September–October.
- Ploughing of orchard in November–December to expose pupae of fruit flies, midges, leaf hoppers and eggs of mealy bugs to natural enemies.
- Polythene banding of tree trunk in December–January and application of 5% neem seed kernel extract and *Beauveria bassiana* in January.
- Spraying of 0.2% sulfex for the control of powdery mildew disease.
- Spraying of *Verticillium lecanii* in orchards for control of hoppers.
- Fixing methyl eugenol traps (wooden blocks impregnated with methyl eugenol) to control fruit flies from April to August.
- Mechanical removal of mango leaf webber larvae and webs by leaf web removing device (developed by the Central Institute of Subtropical Horticulture, Lucknow) from April to September–October.

The Integrated Pest Management (IPM) package was successfully validated in 16.8 ha of mango orchards in Gulabkhera, Habibpur, Budhadia, Pathakganj, Rehmankhera and Kanar villages in Malihabad and Kakori belt of mango near Lucknow on Dashehari variety during 2000–2004. As a result of adoption of Integrated Pest Management (IPM), yield of mango increased from 6.0 to 9.0 MT/ha as it was 3.5–7.0 MT/ha earlier in non-IPM orchards. By adopting Integrated Pest Management (IPM), the mango growers in that area earned a net profit of ₹ 30,000/- to ₹ 55,000/- while the farmers who did not adopt Integrated Pest Management (IPM), earned a net profit of ₹ 17,000/- to 35,000/- per ha only (Table 3.1) (Trivedi et al. 2004a).

3.2 Grapevine, *Vitis vinifera*

3.2.1 Insect Pests

3.2.1.1 Lepidopterous Caterpillars, *Helicoverpa armigera*, *Spodoptera litura*

(i) Damage: These polyphagous caterpillar pests cause severe damage to the leaves and berries of grapes.

(ii) Integrated Management

(a) Bioagents, Cultural and Chemicals: A combination of pheromone traps (2/acre) + Nuclear Polyhedrosis Virus (NPV) at 250 LE/acre + sprays of endosulfan 35 EC at 2 mL/L or cypermethrin 25 EC at 0.5 mL/L (depending on severity) + hand picking and destroying was found effective.

Fig. 3.2 Grey mold rot of grapevine

3.2.2 Diseases

3.2.2.1 Grey Mold Rot, *Botrytis cinerea*

The disease occurs in the entire grape growing regions of the world. It is one of the principal causes of post-harvest spoilage in storage. The pathogen is capable of growing at low temperatures.

(i) Symptoms: In early stage, tissue just beneath the surface of fruit is infected loosening the skin from the flesh. The affected area turns light brown. The fungal infection advances into the inner flesh resulting in a soft watery mass of decayed tissue. Under moist atmosphere, the fungus sporulates on the surface of the fruit and the typical powdery grey mold stage becomes evident (Fig. 3.2). Infected fruits shrivel and turn dark brown. The disease starts in mid-season and continues to develop until harvest in the absence of rain. The fungus infects stigma and style and becomes latent in the necrotic stigma and style tissues at the stylar end of the berry. In a compact infected bunch, fruits inside may split during growth. Infection of such fruits results in bunch rot. Even a single field infected berry may cause 'nest rot' in transit and storage.

(ii) Integrated Management

(a) Bioagents and Chemicals: Application of *Trichoderma harzianum* 1293-22 at bloom and early fruit development, followed by a tank-mix application of the antagonist and half rates of iprodione, suppressed the *Botrytis* bunch rot by 98 % (Harman et al. 1989).

3.2.3 Nematodes

3.2.3.1 Root-Knot Nematodes, *Meloidogyne* spp.

Two species of root-knot nematodes, *Meloidogyne javanica* and *Meloidogyne incognita* are recognized as the major pests of grapes causing economic damage. In India, *M. javanica* is most prevalent in northern part of the country (Baghel et al. 1980) and *M. incognita* in southern part (Darekar and Patil 1985). *M. incognita* is also reported from some parts of Haryana. *M. incognita* was responsible for 55 % loss in fruit yield of grapes (Rajagopalan and Naganathan 1977), while *M. javanica* caused 53 % loss in yield (Baghel and Bhatti 1983).

(i) Symptoms: The root-knot nematode infestation is not manifested by any typical aboveground symptoms. Patches of poorly branched vines with scant foliage, pale and small leaves and poor bearing are the indications of root-knot nematode damage (Fig. 3.3). In young plants, premature decline, weak vegetative growth are commonly associated with nematode attack. The visibly unthrifty growth is generally attributed to moisture stress, low fertility, nutritional deficiency and other adverse conditions. However, the confirmation of nematode attack is possible by assaying soil and root samples. The root system shows typical localized swellings particularly on feeder roots and young secondary roots (Fig. 3.3) and females may be found on internodal

Fig.3.3. Root-knot nematodes on grapevine

Table 3.2 Field evaluation of biocontrol potential of *Pseudomonas fluorescens* against *Meloidogyne incognita* infecting grapevine

Treatment	No. of galls/5 g roots	No. of egg masses/5 g roots	Root colonization (10^8 cfu/g)	Yield (MT/ha)
P. fluorescens—1 g/vine	428c	94c	24	12.07b
P. fluorescens—2 g/vine	390b	85b	36	15.41c
P. fluorescens—4 g/vine	326a	72a	58	22.07d
Carbofuran 3G—60 g/vine	300a	67a	–	31.65e
Control (Untreated)	535d	180d	–	8.33a

Figures with different letters are significantly different from each other at 5% level by analysis of variance test

trunk just below the ground level. *Meloidogyne incognita* has been reported to stimulate the production of many new fine rootlets above the site of nematode infection resulting in 'hairy root' condition. Depending upon the variety of grape, *M. javanica* forms galls of varying size and shape and distorts the normal appearance of roots.

(ii) Integrated Management

(a) Cultural and Bioagents: Pruning (during July) and soil application of 4 g talc formulation of *Pseudomonas fluorescens* (containing 15×10^8 cfu/g)/vine around root-knot infested grapevine at 15 cm depth in the basin significantly reduced root galling due to *M. incognita* (39%), number of egg masses (250%) and increased fruit yield (166%) (Shanthi et al. 1998) (Table 3.2).

(b) Two Bioagents: The combined application of two bioagents *Paecilomyces lilacinus* and Parteuria *penetrans* was most effective in increasing the fruit yield of grapevine besides checking *M. incognita* with benefit to cost ratio of 3.3 (Sivakumar and Vadivelu 1999).

(c) Botanicals and Chemicals: Application of neem cake (200 g/plant) + carbofuran (10 g/plant) reduced the nematode populations in the soil and roots. Combination of garlic and carbofuran at 0.1 g a.i./m^2 reduced nematode population (44.2–47.6%) and increased yield (88.3–105.6%) over control with benefit to cost ratio of 4–5 (Anon 1993).

(d) Bioagents and Botanicals: Application of neem cake at 200 g and *P. lilacinus* at 50 g/vine helps in improving vine growth and yield. Application of FYM enriched with *T. harzianum* and *P. lilacinus* to the field at the rate of 2 kg per plant for five to six times at an interval of 2 months reduced the nematode problems significantly and improved the yield levels of grapes (1 kg of neem based formulation of *T. harzianum* and *P. lilacinus* was applied to 1 t of farm yard manure (FYM). One hundred kg of neem cake was applied to the FYM to enhance the rate of enrichment by bio-agents. The FYM was kept

moist for 15 days under shade with thorough mixing of FYM at 5 days' interval).

(e) Botanical, Cultural and Chemicals: Combined application of neem cake and nematicide at reduced doses, along with intercropping with onion and garlic is highly profitable.

3.2.3.2 Root-Knot Nematode, *M. incognita* and Wilt, *Fusarium moniliforme* Disease Complex

(i) Integrated Management

a) Bioagents and Botanicals: Soil application of *P. fluorescens* at 100 g and FYM at 20 kg/vine gave effective management of disease complex and improved the plant stand by reducing the final soil nematode population (56.9%), root gall index (1.8) and per cent disease incidence (15.67%). This treatment also increased the number and weight of fruit bunches (17.83 and 155.40%, respectively) and fruit quality (more total soluble solids (TSS)–13.53 Brix, TSS to acid ratio–14.87, lower acidity–0.91%). The bunch weight of grapevine increased by 155.4% compared to untreated control (Kumar and Rajendran 2004).

References

Anon. (1993). Biennial report (1991–1993) of AICRP on plant parasitic nematodes with integrated approach for their control, Deparment of Nematology, Haryana Agricultural University, Hisar, 80 pp.

Baghel, P. P. S., & Bhatti, D. S. (1983). Relative efficacy of nematicides for control of phytonematodes on grapevine varieties. Third Nematology Symposium, Y.S. Parmar University of Horticulture & Forestry, Solan, p. 39.

Baghel, P. P. S., Bhatti, D. S., & Chauhan, K. S. (1980). Haryana. *The Journal of Horticultural Science, 9,* 136–137.

Darekar, K. S., & Patil, N. G. (1985). Screening of grapevine varieties to root-knot nematode. *Journal of Maharashtra Agricultural Universities, 10,* 104.

Harman, G. E., Taylor, A. G., & Stasz, T. E. (1989). Combining effective strains of Trichoderma harzianum and solid matrix priming to improve biological seed treatments. *Plant Disease, 73,* 631–637.

Jayanthi, P. D. K., & Verghese, A. (1998). Hourly trap catch of the mamngo fruit fly (Bactrocera dorsalis Hendel) using methyl eugenol bottle trap. *Insect Environment, 4*(2), 60.

Kapoor, V. C. (Ed.). (1993). *Indian fruit flies (Insecta: Diptera: Tephritidae)* (228 pp), New Delhi: Oxford & IBH Publishing Co. Pvt. Ltd.

Kumar, S. T., & Rajendran, G. (2004). Biocontrol agents for the management of disease complex involving root-knot nematode, Meloidogyne incognita and Fusarium moniliforme on grapevine (Vitis vinefera). *Indian Journal of Nematology, 34,* 49–51.

Rajagopalan, P., & Naganathan, T. G. (1977). Studies on nematode parasites of grape-vine. Tamil Nadu Agri. *University Annual Report, 6,* 129.

Shanthi, A., Rajeswari, S., & Sivakumar, C. V. (1998). Soil application of Pseudomonas fluorescens (Migula) for the control of root-knot nematode (Meloidogyne incognita) on grapevine (Vitis vinefera Linn.). In U. K. Mehta (Ed.), *Nematology—Challenges and Opportunities in 21st Century* (pp. 203–206). Coimbatore: Sugarcane Breeding Institute.

Sivakumar, M., & Vadivelu, S. (1999). Management of Meloidogyne incognita on grapevine using biocontrol agents, botanicals and biofertilizers. *Pest Management in Horticultural Ecosystem, 5,* 127–131.

Trivedi, T. P., Sardana, H. R., Shukla, R. P., & Misra, A. K. (2004a). Validated Integrated Pest Management (IPM) technologies: Mango. In A. Singh, H. R. Sardana, & N. Sabir (Eds.), *Validated Integrated Pest Management (IPM) Technologies for Selected Crops* (pp. 149–162). New Delhi: National Centre for Integrated Pest Management (ICAR).

Trivedi, T. P., Sardana, H. R., & Thakur, V. S. (2004b). Validated Integrated Pest Management (IPM) technologies: Apple. In A. Singh, H. R. Sardana, & N. Sabir (Eds.), *Validated Integrated Pest Management (IPM) Technologies for Selected Crops* (pp. 163–177). New Delhi: National Centre for Integrated Pest Management (ICAR).

Verghese, A., Jayanthi, P. D. K., & Sudha Devi, K. (2000). Developing an Integrated Pest Management (IPM) based export protocol and forewarning model for mango fruit fly, Bactrocera dorsalis Hendel. National Seminar on Hitech Horticulture, Bangalore.

Temperate Fruit Crops

4

4.1 Apple, *Pyrus malus*

4.1.1 Insect Pests

4.1.1.1 Codling Moth, *Cydia pomonella*

The codling moth is a serious pest of apple and other fruits in Leh and Kargil districts of Ladakh region (Khaltse, Nurla, Nemo, Sapol, Basgo, Leh, Saboo, Kargil, etc.) of Jammu and Kashmir.

(i) Damage: About 30–70 % of the apple fruits are rendered unmarketable by this pest. The females lay eggs on fruit or leaves and the black-headed yellow larvae attack the fruit immediately upon hatching. Each larva burrows into the fruit, eats for around 3 weeks (Fig. 4.1) and then leaves the fruit to overwinter and pupate elsewhere. Most nourishment is obtained by feeding on the proteinaceous seeds.

(ii) Integrated Management

(a) Bioagents and Chemicals: Synchronizing the release of egg parasitoid *Trichogramma embryophagum* at 2,000 adults/tree with the first appearance of the moth, along with use of pheromone traps (E, E-10, 12-dodecadien-1-01) increased the efficiency of controlling codling moth.

4.1.2 Diseases

4.1.2.1 Scab, *Venturia inequalis*

Scab is the most destructive disease of apple and present in all the countries of the world where apples are grown. The disease is particularly severe in high rainfall and humid areas. In India, it is present in all the apple growing areas of Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, Sikkim, Arunachal Pradesh and Nilgiris. Losses from scab result from mid-season defoliation of trees, reduction in fruit production, devaluation in fruit grade, weakening of the trees, failure of fruit bud formation and increased expenses on spray operations. The first epidemic of scab in Kashmir valley in 1973 completely ruined the apple crop worth US$ 540,000. During 1983, it rendered 10 % apple crop (30,000 MT) unfit for consumption in Himachal Pradesh which has to be destroyed and as a result the state suffered a loss of ₹1.5 crores (Gupta 1985).

(i) Symptoms: Scab may appear on leaves, fruits, petioles and green twigs. The most striking symptoms of scab are commonly observed on leaves and fruits. Fruits may show small, rough, black, circular lesions on their skin (Fig. 4.2) while on the tree or after keeping in cold storage. Fruits picked from infected trees appear apparently

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_4, © Springer India 2014

Fig. 4.1 Codling moth damage on apple and adult

Fig. 4.2 Apple leaf and fruits infected with scab

healthy but are too sticky to keep even in cold storage. Such fruits soon develop scab symptoms even at low temperature and may not last long in storage. The affected fruits rot due to secondary infection of the lesions. Secondary infections on leaves are so numerous that the entire leaf surface appears covered with scab, commonly referred as sheet scab. Lesions on young fruits resemble those on leaves but turn dark brown to black and become corky or scab-like with time. Infections are often limited to one or two spots per fruit. Secondary infections are clumped together.

(ii) Integrated Management (a) Bioagents and Chemicals: Integrated control of apple scab by modifying the nutrient status of overwintering leaves is well established. Treatment of senescent apple leaves on trees shortly before leaf fall or of fallen leaves on the orchard floor with a solution of 2% urea greatly reduced ascospore production in the spring. Urea treatment of fallen apple leaves greatly increased the bacterial populations found on decaying leaves. Fluorescent pseudomonads increased greatly in number on urea treated leaves. Pseudothecial development may be reduced directly by antibiotics produced by fluorescent pseudomonads on decaying leaves, or indirectly by degeneration of leaf structure due to enhanced degradation of leaf material in the presence of higher bacterial populations induced by treatment with a good nitrogen source (Burchill and Cook 1971).

4.1.2.2 White Root Rot, *Dematophora necatrix*

(i) Symptoms: This is a soil-borne disease, which is most important as the fungus can cause death of plants. The disease appears on underground plant parts and causes complete rotting of the roots. The fine roots are attacked first that are completely devoured and infection spreads to main root through secondary root system. Lateral roots turn dark brown and become infected with white flocculent fungus during monsoon months. Bronzing of leaves, stunted growth and size are

Fig. 4.3 The tree with the bronzed leaves is in the process of being killed by the disease

important above-ground symptoms (Fig. 4.3). Root rot affected trees are usually associated with a heavy blossom and fruiting next year. However, in succeeding years, few leaves emerge and much of the immature fruits fail to reach maturity. Infected trees often persist for 2–3 years depending upon infestation of fungus.

(ii) Epidemiology: Small black sclerotia may be formed over the dead bark of wood. Infection of new roots is brought about by the mycelial growth in the soil or contact of plant with old dead roots left in the soil from previous infected plants. The disease incidence is severe when soil moisture is excessive during June to September and 100–140 cm rainfall. Soil type and soil pH between 6.0 and 6.5 are more favourable for survival of the pathogen. High textured soil is more favourable for development of the disease.

(iii) Integrated Management

(a) Physical and Bioagents: Use of antagonists like *Trichoderma viride*, *Trichoderma harzianum, Enterobacter aerogenes* and *Bacillus subtilis* along with soil solarization have been found to protect the plants from root rot infection.

(b) Bioagents and Chemicals: Application of *E. aerogenes*+carbendazim (0.1 or 0.05%) showed more than 92% disease control when applied as pre-inoculation to the pathogen. In simultaneous inoculation, 0.1% carbendazim in combination with *E. aerogenes*, completely prevented the appearance of the disease, however, 0.05% in combination with *E. aerogenes, T. viride* and *Gliocladium virens* gave 90.4, 86.9 and 81.0% disease control, respectively (Gupta and Sharma 2004).

(c) Physical, Botanicals and Bioagents: Soil solarization in combination with organic amendments and biocontrol agents in general gave good control of the disease in nursery. However, cent per cent control of the disease was achieved in plots where *T. viride* or *T. harzianum* or *Bacillus* sp. was incorporated in combination with organic amendments (deodar needles, neem cake) (Table 4.1).

4.1.2.3 Collar/Crown Rot, *Phytophthora cactorum*

The disease, also known as crown rot and trunk canker, is universally present in all the apple growing regions of the world including USA, UK, Canada, New Zealand, The Netherlands, Germany, Australia and India. On susceptible varieties, it causes extensive losses even resulting in death of apple trees within a few years.

(i) Symptoms: The above-ground symptoms are often confused with white root rot. The infection starts from the collar region and spreads to the underground parts. Bark at the soil level becomes slimy and rots resulting in cankered areas (Fig. 4.4). The infected trees are recognized by chlorotic foliage with red colouration of veins and margins.

Table 4.1 Effect of soil solarization, organic amendments and biocontrol agents against soil-borne diseases in apple nursery

Treatment	White root rot (%)	Collar rot (%)	Hairy root (%)	Crown gall (%)
SS	1.15	0.00	2.25	4.00
SS + NC	0.00	0.00	4.15	1.50
SS + DN	3.75	0.00	2.00	0.50
SS + Tv	0.00	0.00	0.00	2.50
SS + Th	0.00	0.00	0.00	0.00
SS + Ba	0.00	0.00	0.00	0.00
SS + NC + Tv	0.00	0.00	0.00	0.00
SS + NC + Th	0.00	0.00	0.00	0.00
SS + DN + Tv	2.38	0.00	1.75	0.00
SS + DN + Th	0.00	0.00	0.00	0.00
SS + NC + DN + Tv	0.00	0.00	0.00	0.00
SS + NC + DN + Th	0.00	0.00	0.00	0.00
US = US) + NC	4.50	1.00	7.00	3.00
US + DN	7.75	0.75	9.45	6.55
US+ Tv	1.50	0.00	6.75	3.95
US+ Th	1.43	0.00	5.85	4.15
US + Ba	2.01	0.00	3.15	5.25
US + NC + Tv	0.00	0.00	0.50	0.00
US + NC + Th	0.00	0.00	0.00	1.50
US + DN + Tv	2.36	0.00	3.75	1.75
US + DN + Th	2.27	0.00	4.25	2.15
US + NC + DN + Tv	0.00	0.00	2.05	0.05
US + NC + DN + Th	0.00	0.00	1.00	0.00
US	22.82	2.05	16.00	8.00

SS soil solarization, *NC* neem cake, *DN* deodar needles, *Tv Trichoderma viride*, *Th Trichoderma harzianum*, *Ba Bacillus* sp., *US* Unsterilized soil

Fig. 4.4 Crown rot on apple

Fig. 4.5 Hairy root symptoms on apple

(ii) Epidemiology: The fungus is known to survive in most of the orchard soils but a soil temperature of 12–20 °C associated with pH 5–6 is found to be the best for its survival. Majority of infections in apple occur through mycelial penetration of stems near the ground line but zoospore infection may occur since these are liberated in the soil. Pieces of bark containing the oospores may also serve as the source of infection, which usually occurs during damp and cool weather in the spring. Temperature of 20–25 °C along with high soil moisture is favourable for sporangial production but oospores are produced at low moisture level at the same temperature.

(iii) Integrated Management

(a) Soil Solarization and Bioagents: Use of antagonists like *T. viride*, *T. harzianum, E. aerogenes* and *B. subtilis* along with soil solarization have been found to protect the plants from collar rot infection.

(b) Soil Solarization, Organic Amendments and Bioagents: Soil solarization in combination with organic amendments and biocontrol agents in general gave good control of collar rot disease in nursery. However, cent per cent control of the disease was achieved in plots where *T. viride* or *T. harzianum* or *Bacillus* sp. was incorporated in combination with organic amendments (deodar needles, neem cake). Collar rot pathogen was highly sensitive to the biocontrol agents and organic amendments both in solarized and unsolarized soil.

4.1.2.4 Hairy Root, *Agrobacterium rhizogenes*

(i) Symptoms: At the union between scion and root piece, an enlargement somewhat resembling a newly formed crown gall appears. From this arise numerous roots, fleshy or fibrous in texture, with many containing numerous branches (Fig. 4.5). The surface of these enlargements bears numerous convolutions with fissures extending deep into the interior of the enlargements.

(ii) Integrated Management

(a) Soil Solarization, Organic Amendments and Bioagents: Soil solarization in combination with organic amendments and biocontrol agents in general gave good control of hairy root disease in nursery. However, cent per cent control of the disease was achieved in plots where *T. viride* or *T. harzianum* or *Bacillus* sp. was incorporated in combination with organic amendments (deodar needles, neem cake).

4.1.2.5 Crown Gall, *Agrobacterium tumefaciens*

(i) Symptoms: Crown gall bacterium enters the plant through wounds in roots or stems and stimulates the plant tissues to grow in a disorganized way, producing swollen galls. Galls are present all year. Crown gall is identified by overgrowths appearing as galls on roots and at the base or "crown" of apple (Fig. 4.6).

(ii) Integrated Management

(a) Physical, Botanicals and Bioagents: Soil solarization in combination with organic amendments and biocontrol agents in general gave good

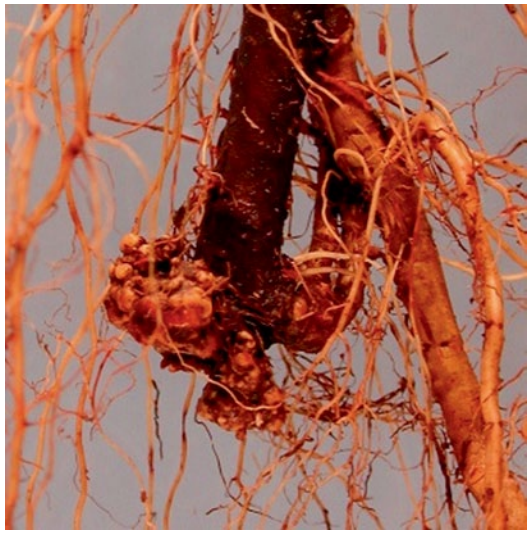
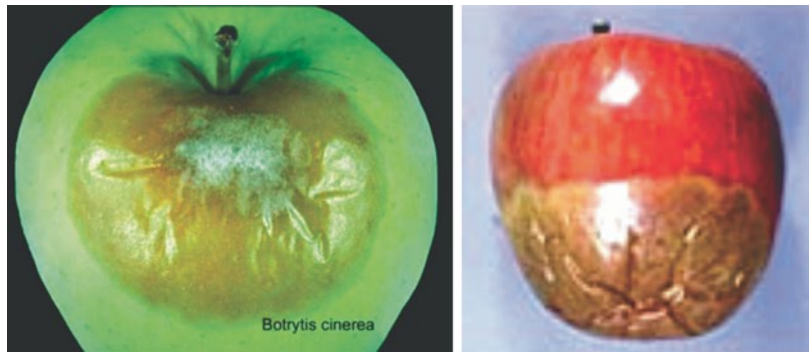


Fig. 4.6 *Agrobacterium tumefaciens* induced galls on apple roots (crown gall)

Fig. 4.7 Blue mold on apple fruit

Fig. 4.8 Gray mold on apple fruits



control of crown gall disease in nursery. However, cent per cent control of the disease was achieved in plots where *T. viride* or *T. harzianum* or *Bacillus* sp. was incorporated in combination with organic amendments (deodar needles, neem cake).

4.1.2.6 Fruit Rot, Blue Mold, *Pencillium expansum*; Gray Mold, *Botrytis cinerea*

(i) Symptoms: When apples are infected by blue mold, the rotted areas on the fruit are soft, watery and light brown in colour. Bluish-green spores cover the surface of older lesions (Fig. 4.7). Fortunately, this fungus will not move from an infected fruit to an adjacent fruit unless the fruit is bruised or punctured in some way.

When apples are infected by gray mold, the texture of the decay on the fruit is firm and the skin is tight and tough. The lesions are pale tan to brown and the surfaces of older lesions are covered with greyish mycelium and dark brown spores (Fig. 4.8). Unfortunately, gray mold can move from fruit to fruit and whole bins or boxes of fruit can become infected.

(ii) Integrated Management

(a) Two Bioagents: Combined application of *Pseudomonas* sp. and *Acremonium breve* gave

Fig. 4.9 Fire blight of apple

complete control of *P. expansum* and *B. cinerea* on apple (Janisiewicz 1988).

A co-application involving the bacterial antagonist *Pseudomonas syringae* and the yeast *Sporobolomyces roseus* applied in equal biomass provided control of blue mold that was superior to that obtained by treatment with the individual agents applied separately (Janisiewicz and Bors 1995).

Preharvest combined application of two strains of *Aureobasidium pullulans* and an isolate of *Rhodotorula glutinis* was superior to any of the strains applied individually in controlling decay caused by *P. expansum, Pezicula malicorticis* and *B. cinerea* (Leibinger et al. 1997).

Mixtures of *R. glutinis* SL1 with *Candida albidus* SL43 and *R. glutinis* SL30 with *C. albidus* SL43 showed synergistic effect against *P. expansum*, but not against *B. cinerea* (Calvo et al. 2003).

(b) Bioagents and Chemicals: Combining 0.2% glycolchitosan (antimicrobial substance) with the antagonist *Candida saitoana* was more effective in controlling gray and blue molds of apples than either treatment alone (El-Ghaouth et al. 2000).

Chand-Goyal and Spotts (1996a, b) showed that the control of apple blue mold by *Candida laurentii* HRA5 was increased by combining it with tiabendazole (TBZ) fungicide. Combination of *P. syringae* MA-4 at 1–3×10^7 cfu/mL with cyprodinil at 5 to 10 µg/mL controlled both blue and gray mold by more than 90% on apple, demonstrating that the integration could not only improve disease control efficacy but also extended the degree of control to more than one important disease (Zhou et al. 2002).

McLaughlin et al. (1990) showed that addition of 2% $CaCl_2$ to a cell suspension of yeast *Candida guilliermondii* significantly increased its efficacy in control of apple post-harvest diseases, compared with either yeast or calcium used alone. In another report (Wisniewski et al. 1995), addition of 90 or 180 mM $CaCl_2$ enhanced biocontrol activity of *Candida oleophila* isolate 182 against *B. cinerea* and *P. expansum*.

Aspire, when combined with 2% sodium bicarbonate, showed enhanced efficacy in the control of *B. cinerea* and *P. expansum* rot in apple, compared with that used alone (Droby et al. 2003).

4.1.2.7 Fire Blight, *Erwinia amylovora*

(i) Symptoms: The intensity of blossom infection with consequent loss of crop and the possible loss of some branches as a result of cankering would be very serious (Fig. 4.9). Primary infection frequently occurs as a result of transfer of the bacteria by pollinating insects to open blossom. At that time (April) in North India, temperature above 24 °C and plentiful rains occur which favours infection and rapid spread of the disease. Presence of naturally occurring hosts (pear) in the vicinity of apple orchards constitute a permanent reservoir of infection.

(ii) Integrated Management

(a) Bioagents and Chemicals: Studies conducted with *Pseudomonas fluorescens* A 506 in combination with antibiotic (streptomycin/oxytetracycline) applications (7 days after application of the antagonist) suggest that the control

achieved is likely to be additive in nature (Lindow et al. 1996).

4.1.3 Validation of Apple Integrated Pest Management (Himachal Pradesh)

4.1.3.1 Winter Module (October–November)

- Use of 5% urea at leaf shedding stage for early decomposition of the infested leaves and to encourage the population of antagonists in the plant rhizosphere.
- Use of Bordeaux paint during autumn on the naked plant stem to overcome the direct effect of UV rays on the plant skin to reduce sun burn and canker disease complex.
- Overwinter spray of Bordeaux mixture as eradicative action to pathogens and total disinfection of plant surface.

4.1.3.2 Spring Module (April–June)

- Use of Neemarin at pink bud stage i.e. pre-bloom stage to manage blossom thrips population.

4.1.3.3 Summer Module (July–September)

- Use of *Bacillus thuringiensis* at fruit development stage for the management of fruit scrapper insect pests.
- Use of *T. viride* (Bioderma) for the control of root rot fungus.
- Use of Bordeaux mixture for the control of root and collar rots.

During the period 2001–2004, Integrated Pest Management (IPM) for apple crop was validated and promoted in 30 ha of orchards in Kotkhai, Jhubbal, Theneder and Rohroo villages of Himachal Pradesh. By adopting Integrated Pest Management (IPM) package, farmers were able to harvest 580 boxes (4.99 MT/ha) of apple in Integrated Pest Management (IPM) plots as compared to 380 boxes (4.12 MT/ha) in case of non-IPM farmers. Apple growers who adopted Integrated Pest Management (IPM) earned a profit of ₹145,733/- while the farmers who did not adopt Integrated Pest Management (IPM) earned a profit of ₹110,889/-. Average benefit cost ratio of Integrated Pest Management (IPM) to non-IPM was 4.07:3.01 (Table 4.2) (Trivedi et al. 2004b).

Table 4.2 Economics of apple IPM

Parameters	IPM plots	Non-IPM plots	% increase
Yield (MT/ha)	4.99	4.12	21.11
Net profit (₹/ha)	145,733	110,889	31.42
Benefit cost ratio	4.07	3.01	35.21

4.2 Peach, *Prunus persica* and Plum, *Prunus salicina*

4.2.1 Diseases

4.2.1.1 Brown Rot of Fruits, *Monilinia fructicola, Monilinia fructigena, Monilinia laxa, Monilinia laxa* f. sp. *mali*

Among the fruit rots, brown rot is the most important in stone fruits including peach.

(i) Symptoms: Symptoms of the disease are blighting of blossom and leaves, canker production on woody tissues and rotting of fruits (Fig. 4.10). Blossom blight is the first symptom during spring and attacked parts turn grey to dark brown. The fungus spreads through peduncle and reaches branches causing twig blight. Stem cankers usually develop from blighted twigs or fruit spurs. Fruit rot is the most destructive phase of the disease. Rotted fruits either fall down or hang as firm mummies. Conidia and ascospores produced on the mummified fruits and canker spots serve as a source of primary infection.

(ii) Integrated Management

(a) Bioagents and Chemicals: Biocontrol agents can be used in combination with fungicides. Such an approach was successful in controlling rots on peach, in cases where *B. subtilis* (B3), effective against brown rot (incited by *M. fructicola*), was combined with dicloran used for the control of *Rhizopus* rot (Pusey et al. 1986).

Fig. 4.10 Brown rot on peach and plum fruits

Fig. 4.11 Peach tree short life symptoms

Zhou et al. (1999) reported that addition of 0.5% calcium to cell suspension of *P. syringae* MA-4 resulted in a greater reduction of peach brown rot incidence when sprayed on peaches naturally infected with *M. fructicola*. Pre-harvest application of *P. syringae* MA-4 with a foliar calcium fertilizer also significantly increased biocontrol efficacy against peach brown rot (Zhou and Schneider 1998).

Aspire, when combined with 2% sodium bicarbonate, showed enhanced efficacy in the control of *Monilinia* and *Rhizopus* rot in peach, compared with that used alone (Droby et al. 2003).

4.2.2 Nematodes

4.2.2.1 Peach-Tree Short-Life, *Mesocriconema xenoplax*

(i) Symptoms: It causes pruning and necrosis of fine feeder roots, especially on young plants, but also feeds on older parts of the root. It predisposes some *Prunus* spp. and *Malus* spp. to infection by *P. syringae* pv *syringae,* resulting in tree mortality due to bacterial canker (BC) and to winter frost damage. The combined effect of the nematode, bacterium and cold injury result in enhanced tree mortality (Fig. 4.11).

(ii) Integrated Management

(a) Biofumigation and Solarization: Four months (January 1999) after establishing the sorghum biofumigant and methyl bromide plots and prior to planting peach trees, ring nematode (*M. xenoplax*) populations were greatest ($P<0.05$) in the unfumigated soil than in sorghum + plastic, sorghum without plastic, and methyl bromide fumigated plots. In September 1999 (12 months after incorporating the sorghum as a green manure), no differences in nematode populations were detected among the unfumigated and two sorghum treatment plots.

However, nematode populations were still suppressed ($P<0.05$) in the methyl bromide

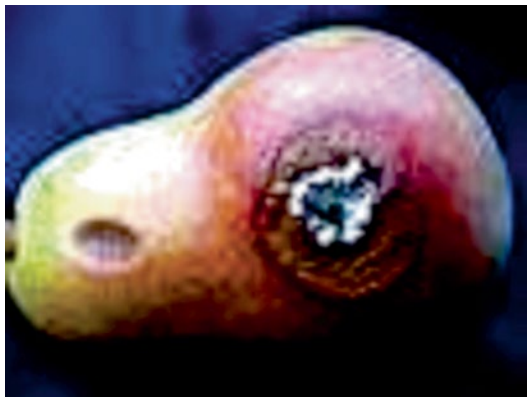


Fig. 4.12 Gray mold on pear fruit

plots. At 24 months after methyl bromide application (September 2000), the nematode population density in fumigated soil did not differ from the other treatment plots. Ring nematode populations continued to increase in subsequent sampling dates. Peach trees developed typical peach-tree short-life (PTSL) symptoms and died during this experiment. In 2001 and 2002, percentage of PTSL tree death was greater in unfumigated without plastic (29 and 54%) followed by sorghum + plastic (12 and 46%), sorghum without plastic (8 and 50%), unfumigated soil + plastic (4 and 29%), and methyl bromide (4 and 29%), respectively. No differences in trunk diameter were detected among any of the treatments. Sorghum as a green manure with and without plastic did suppress the population of *M. xenoplax* in the early stages of this experiment, but suppression did not last as long as preplant methyl bromide fumigation (i.e., 12 vs 24 months, respectively) (Nyczepir and Rodriguez-Kabana 2004).

4.3 Pear, *Pyrus communis*

4.3.1 Diseases

4.3.1.1 Gray Mold, *Botrytis cinerea*

(i) Symptoms: Gray mold and its many strains cause death of flower parts, leaves, buds, shoots, seedlings and fruits (Fig. 4.12). The disease needs moisture as one of its criteria for infection. The wetter the plant is, the more likely the gray mold will show up on plants. Not only are the numbers of infected areas increased but also so are the numbers of plants attacked as well as the severity of the infections (quicker growth of the disease and death of tissue).

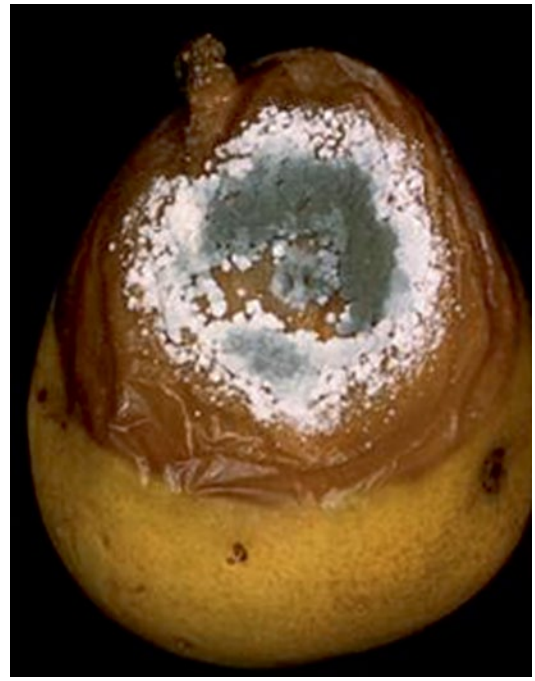


Fig. 4.13 Blue mold rot on pear fruit

(ii) Integrated Management

(a) Bioagents and Chemicals: In a packing house trial, combination of Bio-Save 110 or Aspire with TBZ at 100 µg/mL (about 17.6% of the label rate) provided control of blue mold and gray mold of pears, similar to that of TBZ alone used at the label rate (569 µg/mL) (Sugar and Spotts 1999).

4.3.1.2 Blue Mold, *Penicillium expansum*

(i) Symptoms: The rotted areas are soft, watery and light brown in colour. The surface of older lesions may be covered by bluish-green spores that initially are nearly snow white in colour (Fig. 4.13). The lesions are of varying shades of brown, being lighter on the yellow or green varieties. Two characteristics are of importance in the recognition of *P. expansum*, the most common species, namely the musty odor and the formation of conidial tufts or coremia on the surface of well developed lesions.

Fig. 4.14 Fire blight infection on tree and fruit

(ii) Integrated Management (a) Bioagents and Chemicals: In a packing house trial, combination of Bio-Save 110 or Aspire with TBZ at 100 µg/mL (about 17.6% of the label rate) provided control of blue mold and gray mold of pears, similar to that of TBZ alone used at the label rate (569 µg/mL) (Sugar and Spotts 1999).

4.3.1.3 Fire Blight, *Erwinia amylovora*

(i) Symptoms: The term "fire blight" describes the appearance of the disease, which can make affected areas appear blackened, shrunken and cracked, as though scorched by fire (Fig. 4.14). Observe blighted limbs and shoots for removal during the normal pruning operation.

(ii) Integrated Management

(a) Bioagents and Chemicals: Lindow et al. (1996) reported that use of *P. fluorescens* strain A 506 in combination with streptomycin and oxytetracycline could reduce pear fire blight by 40 to 50%.

References

Burchill, R. T., & Cook, R. T. A. (1971). The interaction of urea and microorganisms in suppressing development of perithecia of Venturia inequalis (Cke.) Wint. In T. F. Preace & C. H. Dickensen (Eds.), *Ecology of leaf surface microorganisms* (pp. 471–483). New York: Academic Press.

Calvo, J., Calvente, V., De Orellano, M. E., Benuzzi, D., & De Tosetti, M. I. S. (2003). Improvement in the biocontrol of post-harvest diseases of apples with the use of yeast mixtures. *BioControl, 48,* 579–593.

Chand-Goyal, T., & Spotts, R. A. (1996a). Post-harvest biological control of blue mold of apple and brown rot of sweet cherry by natural saprophytic yeasts alone or in combination with low doses of fungicides. *Biological Control, 6,* 252–259.

Chand-Goyal, T., & Spotts, R. A. (1996b). Biological control of postharvest diseases of apple and pear under semi-commercial and commercial conditions using three saprophytic yeasts. *Biological Control, 10,* 199–206.

Droby, S., Wisniewski, M., El-Ghaouth, A., & Wilson, C. (2003). Influence of food additives on the control of post-harvest rots of apple and peach and efficacy of the yeast-based biocontrol product Aspire. *Postharvest Biology and Technology, 27,* 127–135.

El-Ghaouth, A., Smilanick, J. L., Brown, G. E., Ippolito, A., Wisniewski, M., & Wilson, C. L. (2000). Application of Candida saitoana and glycolchitosan for the control of postharvest diseases of apple and citrus fruits under semi-commercial conditions. *Plant Disease, 84,* 243–248.

Gupta, G. K. (1985). Apple Scab (Venturia inaequalis). R. Merck (India) Ltd., Bombay, 36 pp.

Gupta, V. K., & Sharma, K. (2004). Integration of chemicals and biocontrol agents for managing white root rot of apple. *Acta Horticulturae, 635,* 141–149.

Janisiewicz, W. J. (1988). Biocontrol of postharvest diseases of apples with antagonist mixtures. *Phytopathology, 78,* 194–198.

Janisiewicz, W. J., & Bors, B. (1995). Development of a microbial community of bacterial and yeast antagonists to control wound-invading postharvest pathogens of fruits. *Applied and Environmental Microbiology, 61,* 3261–3267.

Leibinger, W., Breuker, B., Hahn, M., & Mendgen, K. (1997). Control of post-harvest pathogens and colonization of the apple surface by antagonistic microorganisms in the field. *Phytopathology, 87,* 1103–1110.

Lindow, S. E., McGourty, G., & Elkins, R. (1996). Interactions of antibiotics with Pseudomonas fluorescens strain A506 in the control of fire blight and frost injury to pear. *Phytopathology, 86,* 841–848.

McLaughlin, R. J., Wisniewski, J. I., Wilson, C. L., & Chalutz, E. (1990). Effect of inoculum concentration and salt solutions on the biological control of post-harvest diseases of apples with Candida sp. *Phytopathology, 80,* 456–461.

Nyczepir, A. P., & Rodriguez-Kabana, R. (2004). Effectiveness of biofumigation for ring nematode control in a young peach orchard. First International Biofumigation Symposium, Florence, Italy.

Pusey, P. L., Wilson, C. L., Hotchkiss, M. W., & Franklin, J. D. (1986). Compatibility of Bacillus subtilis for postharvest control of peach brown rot with commercial fruit waxes, dicloran, and cold-storage conditions. *Plant Disease, 70,* 587–590.

Sugar, D., & Spotts, R. A. (1999). Control of postharvest decay in pear by four laboratory- grown yeasts and two registered biocontrol products. *Plant Disease, 83,* 155–158.

Trivedi, T. P., Sardana, H. R., & Thakur, V. S. (2004a). Validated Integrated Pest Management (IPM) technologies: Apple. In A. Singh, H. R. Sardana, & N. Sabir (Eds.), *Validated Integrated Pest Management (IPM) technologies for selected crops* (pp. 163–177). New Delhi: National Centre for Integrated Pest Management (ICAR).

Trivedi, T. P., Sardana, H. R., Shukla, R. P., & Misra, A. K. (2004b). Validated Integrated Pest Management (IPM) technologies: Mango. In A. Singh, H. R. Sardana, & N. Sabir (Eds.), *Validated Integrated Pest Management (IPM) technologies for selected crops* (pp. 149–162). New Delhi: National Centre for Integrated Pest Management (ICAR).

Wisniewski, M., Droby, S., Chalutz, E., & Eilam, Y. (1995). Effect of Ca2+ and Mg2+ on Botrytis cineria and Pencillium expansum in vitro and on the biocontrol activity of Candida oleophila. *Plant Pathology, 44,* 1016–1024.

Zhou, T., & Schneider, K. (1998). Control of peach brown rot by preharvest applications of an isolate of Pseudomonas syringae (Abstr.). *7th International Congress of Plant Pathology, 3,* 20.

Zhou, T., Northover, J., & Schneider, K. (1999). Biological control of postharvest diseases of peach with phyllosphere isolates of Pseudomonas syringae. *Canadian Journal of Plant Pathology, 21,* 375–381.

Zhou, T., Northover, J., Schneider, K., & Lu, X. (2002). Interaction between Pseudomonas syringae MA-4 and cyprodinil in the control of blue mold and gray mold of apple. *Canadian Journal of Plant Pathology, 24,* 154–161.

Semiarid Fruit Crops

5

5.1 Pomegranate, *Punica granatum*

5.1.1 Insect Pests

5.1.1.1 Anar Butterfly, *Deudorix isocrates, Deudorix epijarbas*

(i) Damage The larvae bore into the fruits of pomegranate and can destroy up to 50 % of fruits (Fig. 5.1). The female butterfly lays eggs singly on calyx of flowers or small fruits. On hatching, the caterpillars bore inside the developing fruits and feed on pulp and seeds. This will allow the entry of fungi and bacteria causing fruit rot. The conspicuous symptoms of damage are offensive smell and excreta of caterpillars coming out of the entry holes. The affected fruits rot, get dried and ultimately fall down. Besides pomegranate, the pest also damages guava, amla, annona, apple, ber, citrus, litchi, loquat, sapota, mulberry, peach, pear, plum etc.

(ii) Integrated Management

(a) Botanical, Bioagent and Chemical: An Integrated Pest Management (IPM) technology has been developed against the fruit borer with the following components:

- Spraying 3 % neem oil at the time of butterfly activity.
- One week later, release of *Trichogramma chilonis* at 2.5 lakhs/ha.
- Five days later, spraying of 0.05 % monocrotophos as an ovicide.
- Spraying of 0.07 % endosulfan twice, first 15 days after ovicide spray and the second 15 days thereafter reduced the incidence of the pest to a greater extent.

5.1.2 Diseases

5.1.2.1 Bacterial Blight, *Xanthomonas axonopodis* pv. *punicae*

(i) Symptoms Small irregular, water-soaked spots 2–5 mm in diameter with necrotic centre of pinhead size appear on the leaves. Spots are translucent, which later turn to light brown to dark brown, and are surrounded by prominent water-soaked margins (Fig. 5.2). Spots coalesce to form larger patches. Severely infected leaves fall off. The bacterium attacks stems, branches and fruits also. On the stem, the disease starts as brown to black spots around the nodes resulting in girdling and cracking of nodes. Finally, the branches break down. Brown to black spots appears on the pericarp with L- or Y-shaped cracks. The spots on fruits are raised and oily in appearance. In severe cases, there will be extensive cracking of fruits (Fig. 5.2).

(ii) Epidemiology High temperature and low humidity favour the disease. The bacterium survives on the tree. It can survive for 120 days on fallen leaves during off-season. The primary infection is through infected cuttings. The disease spreads through wind-splashed rains.

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_5, © Springer India 2014

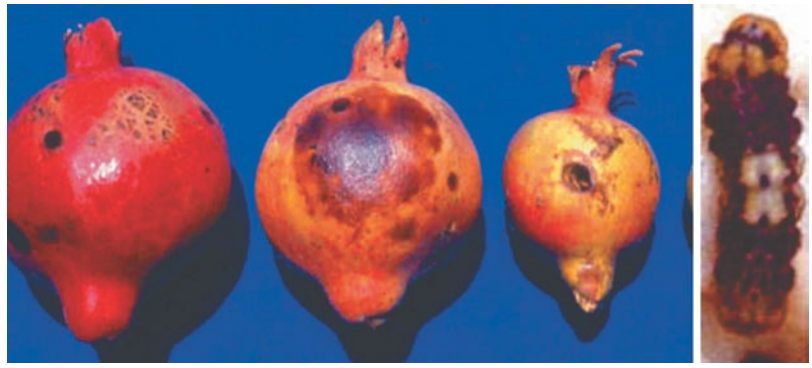


Fig. 5.1 Anar butterfly damage on pomegranate fruit

Fig. 5.2 Bacterial blight on leaf and fruits of pomegranate

(iii) Integrated Management
(a) Cultural and Chemicals

Before Planting

- Use disease-free seedlings for planting.
- Application of farm yard manure/compost/vermicompost helps in building up resistance in plants to bacterial blight.

After Planting

- Practice field sanitation (collection and burning of diseased leaves, stem and fruits) to prevent the spread of the disease.
- Before pruning, spray 1% Bordeaux mixture on diseased leaves. Then spray with ethrel solution (2.0–2.5 ml/l) to defoliate the diseased leaves. Collect and destroy the fallen leaves.
- Dust the tree basins with bleaching powder at 20–25 kg/ha to kill the bacteria on leftover leaves.
- After pruning, paste the diseased stems with bromopal (Bacterinashak or Bitertanol) at 0.5 g/l or copper oxychloride (3 g/l) mixed with red sandy loam soil.
- At the beginning of disease incidence stage, give five to six sprays with bromopal (0.5 g/l) or copper oxychloride (2 g/l) at 10 days interval.
- After each spraying of bactericides, give mineral spray (1 g each of $CuSO_4$, $MgSO_4$, $CaSO_4$ and boron in 1 l of water) to reduce the disease severity in plants.

Part III

Biointensive Integrated Pest Management in Vegetable Crops

Solanaceous Vegetable Crops

6

6.1 Potato, *Solanum tuberosum*

6.1.1 Diseases

6.1.1.1 Black Scurf, *Rhizoctonia solani*

(i) Symptoms Lesions characteristic of *Rhizoctonia* on stems and stolons are brown to black and sunken. These cankers can continue to expand and are capable of girdling stems and stolons of young developing plants (Fig. 6.1). *Rhizoctonia* infection of older plants very seldom leads to girdled stems that die. However, the health of these plants can be severely compromised and they can frequently become more susceptible to other diseases, particularly early blight.

Perhaps the most readily apparent phase of *Rhizoctonia* disease is the black scurf or sclerotia present on tuber surfaces. These sclerotia can vary in size from very small, flat, superficial black specks to large, raised, irregularly shaped masses that can cover a major portion of the tuber (Fig. 6.1). While black scurf can, under extreme conditions, affect the marketability of table stock/fresh pack potatoes, it is an extremely important seed-borne phase of the pathogen that deserves attention by all potato producers.

Potato plants are most severely affected in the spring when underground sprouts can be killed prior to emergence. The secondary sprouts that develop are generally less vigorous and emerge much later causing irregular, uneven stands. Sprouts of severely affected plants that do not die are frequently stunted and remain so for the rest of the growing season. Infections of stolons that occur early in the growing season frequently result in pruning to tuber formation or abortion of tubers early in their development.

Mid-season *Rhizoctonia* infections of potato plants will result in deep, sunken cankers on the main stem. The above ground portion of the plant will appear yellow with some purpling and upward curling of the foliage.

(ii) Epidemiology *R. solani* can be either a soil-borne or a seed-borne pathogen. The fungus survives in soil as mycelium in decomposing plant tissues. It also survives as sclerotia on tuber surfaces (seed-borne) or in the soil for extended periods. Populations of *R. solani* decline in the absence of a susceptible host although the rate of decline is affected by soil type, rotational crops and possibly the amount of organic matter present in the soil.

Disease development on emerging sprouts is favoured by cold, wet soil conditions. Although these conditions may not increase disease incidence, disease severity is generally much greater. These conditions slow sprout development but favour germination of sclerotia and infection causing cankers to develop on young, underdeveloped tissues. Tuber-borne inoculum is very important in this phase of the disease while soil-borne inoculum is believed to be generally more important in stem and stolon infections. Cool, moist conditions, with moisture being the most critical factor, also favour disease development

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_6, © Springer India 2014

Fig. 6.1 Black scurf on collar region of potato

Table 6.1 Effect of biofumigation and solarization on black scurf and yield of potato

Treatment	Soil solarization	Yield (kg/m^2)	Black scurf (%)
Millet	Ecotex	2.208	4.4
	None	1.943	21.5
Cabbage	Ecotex	2.187	15.1
	None	2.101	15.9
Mustard	Ecotex	2.279	2.0
	None	2.090	22.0
Corn	Ecotex	2.401	13.1
	None	2.067	17.2
Control	Ecotex	2.135	14.3
	None	1.996	35.1

on stems and stolons. Disease development is optimum at around 65°F and decreases as soil temperatures increase.

(iii) Integrated Management

(a) Physical/Chemical and Bioagents: Although solar heating or methyl bromide fumigation significantly reduced the disease, the combination of either solar heating or methyl bromide soil fumigation followed by *Trichoderma harzianum* application improved control over solarization or fumigation alone and additionally controlled *Verticillium dahliae* and *Sclerotium rolfsii* (Elad et al. 1980).

(b) Physical and Bioagents: Combination of soil solarization of black scurf-infested fields and seed treatment with *Trichoderma viride* further improved the disease control.

(c) Biofumigation and Solarization: Application of mustard chopped green manure in combination with plastic coat (with an appropriate polymer formulation that forms continuous plastic coats) gave maximum reduction in black scurf followed by millet chopped green manure in combination with plastic coat. The maximum yield was obtained in corn-chopped green manure in combination with plastic coat followed by mustard chopped green manure in combination with plastic coat (Table 6.1).

6.1.1.2 *Verticillium* Wilt, *Verticillium dahliae, Verticillium alboatrum*

(i) Symptoms Foliar symptoms first appear as chlorosis and necrosis beginning in the lower leaves. On warm, sunny days, leaves may appear limp and flaccid. Sometimes symptoms occur on only one side of the leaf or the plant (Fig. 6.2). In severely diseased plants, medium-tan discolouration of the vascular tissue is evident (Fig. 6.2), and the plants may be stunted. Tubers of some cultivars may develop a light brown discoloura-

Fig. 6.2 *Verticillium* wilt affected potato plant

tion of the vascular ring, although other factors may cause this symptom. Tuber yield is reduced because of the decreased rate of photosynthesis and premature death of foliage. The optimum temperature range for potato growth is 18–20 °C. When the temperature rises above 20 °C, plant stress increases and symptoms of *Verticillium* wilt are more severe.

(ii) Integrated Management

(a) Physical/Chemical and Bioagents: Although solar heating or methyl bromide fumigation significantly reduced the disease, the combination of either solar heating or methyl bromide soil fumigation followed by *T. harzianum* application improved control over solarization or fumigation alone and additionally controlled *R. solani* and *S. rolfsii* (Elad et al. 1980).

(b) Bioagents and Chemicals: Ordentlich et al. (1990) integrated *T. harzianum* with captan to protect potato tubers against *V. dahliae* in order to reduce the disease incidence and to increase potato yield by 15.7 % under field conditions.

6.1.2 Nematodes

6.1.2.1 Root-Knot Nematode, *Meloidogyne incognita*

The root-knot nematodes are by far the most important nematode pests of potatoes in India. Severe infestation of root-knot nematodes leading to crop failure has been noticed in Mahasu district of Himachal Pradesh and Hassan in Karnataka where farmers did not even get what they planted. An initial level of two root-knot larvae per gram of soil resulted in 100 % tuber infection with an overall yield reduction of 42.5 % (Prasad 1989).

(i) Symptoms Plants affected by root-knot nematodes are generally stunted, slightly yellow and may wilt during hot weather. The diagnostic symptoms of a *Meloidogyne* attack on potatoes are the galls found on both roots and tubers. Tuber surface becomes uneven and warty because of numerous blister-like galls (Fig. 6.3). When an infested tuber is transversely cut, the white glistening swollen females of the size of pin head can be easily seen embedded in the potato tissue (Fig. 6.3). Such tubers are invariably small, unfit for marketing, rot quickly and cause considerable yield losses. Galling on tubers may render them unsalable.

(ii) Integrated Management

(a) Bioagents and Botanicals: Application of neem cake/farmyard manure (FYM)/compost enriched with *T. harzianum/Paecilomyces lilacinus* gave effective control of root-knot nematodes.

(b) Physical and Cultural: Following 2 years' crop rotational sequence of maize–wheat–potato–wheat coupled with summer fallow after two or three deep ploughings in North Western Plains reduced root-knot damage significantly.

(c) Bioagents, Cultural and Chemical: Aldicarb at 2.5 kg a.i./ha and aldicarb + *P. lilacinus* combined with crop rotation with maize

Fig. 6.3 Potato tubers with blisters incited by *Meloidogyne incognita*

Table 6.2 Effect of integration of physical, chemical and organic amendment on yield of potato tubers

Treatment	Potato yield (kg/m^2)	Relative yield
Soil solarization + Methyl bromide	2.80a	125
Soil solarization + Telopic	2.53ab	113
Soil solarization + fresh chicken manure	2.45ab	109
Soil solarization alone	2.40ab	107
Methyl bromide	2.24bc	100
Control (no disinfestation)	1.81c	81

Figures with different letters are significantly different from each other at 5% level by Analysis of Variance Test

reduced root-knot nematodes and increased tuber quality in *P. lilacinus* and *P. lilacinus* + aldicarb plots. Yield of maize, a rotation crop, in *P. lilacinus* and *P. lilacinus* + aldicarb-treated plots was double than that in control plots. Yield of potato in *P. lilacinus* treated plots was higher than in the plots treated with only aldicarb (Jatala 1985).

(d) Physical, Botanical and Chemical: Several chemical and non-chemical alternatives to standardized cold or hot diffusion of Methyl bromide (MB) (50 g/m^2) are able to maintain adequate sanitary (against *M. incognita*) and productivity levels on potato cultivation (Table 6.2).

6.1.2.2 Columbia Root-Knot Nematode, *Meloidogyne chitwoodi*

(i) Symptoms Pimple-like galls are produced which appear as small, raised lumps above the developing nematodes, giving the skin a rough appearance (Fig. 6.4). Galls may be grouped in a single area or scattered near the tuber eyes. Infestations are difficult to detect in freshly harvested tubers, but after a few months the egg sacs turn from translucent to brown and can be seen as brown spots in the cortex of cut tubers. Brown spots only become evident when the females begin egg production. Internally, brown spots are usually within 5–6 mm of the tuber surface. There are no symptoms on potato roots and above ground symptoms are generally lacking.

(ii) Integrated Management

(a) Biofumigation and Chemicals: Riga et al. (2006) reported a strategy in which a *Brassica* crop arugula (*Eruca sativa* var. Nemat) cover crop was combined with lower rates of a synthetic nematicide to manage nematodes and reducing pest management costs by 50 %. Results are promising, with nematodes reduced up to 80 %. The current recommendation is the use of rapeseed or mustard cover crop plus the application of nematicide (MOCAP). This regimen costs about the same as fumigation (2006 prices).

Arugula in combination with half the recommended rate of Telone/Temik reduced root-knot nematode populations, *M. chitwoodi*. In addition, Arugula did not reduce the beneficial free-living nematode populations and the non-pathogenic *Pseudomonas*. The cost of growing and incorporating Arugula and combining it with half rate of

Fig. 6.4 Columbia root-knot nematode infestation on potato

Fig. 6.5 Potato plants and roots infected with *Globodera rostochiensis*

Telone and one fungicide was approximately half of the present commercial cost of Telone and fungicide applications.

6.1.2.3 Cyst Nematode, *Globodera rostochiensis*

The potato cyst nematode is established as one of the major crop protection problems of the world. The ability of this nematode to build up to damageable levels in a short span of 5–6 years, substantial yield reductions in the crop, lack of inexpensive nematicides for soil treatment capable of providing adequate level of control under field conditions, the relative ease with which the cysts are dispersed with soil adhering to the seed tubers and the long persistence of eggs within the cyst in the absence of the host makes this nematode as probably the most important pest problem on potatoes.

The avoidable yield loss in susceptible potato due to cyst nematodes was 99.5–99.8 % in summer and autumn crops. Total failure of the crop has been reported under severe infestation conditions. An average loss of about 9 % of global potato is accounted to the cyst nematodes amounting to about 45 million tons (Prasad 1989).

(i) Symptoms The infested plants exhibit typical symptoms of patchy growth of weak and stunted plants. The patches increase in time with continuous potato cropping. Under conditions of severe infestation, the plant growth is stunted and wilting occurs during hot part of the day. Plants show tufting of leaves at the top as the outer leaves turn yellow and die. Root system is infected with adults and cysts (Fig. 6.5). Root system is smothered, secondary roots are induced at the collar region and the plants can be easily pulled out. Tubers formed are less in number and reduced in size. In extreme cases, tuber formation is arrested. The total photosynthesis per plant is also significantly reduced as a result of reduced leaf area and this is reflected in reduced potato yield.

Table 6.3 Integrated management of the potato cyst nematode

Sl. No.	Management method(s)	Resulting killed population (% initial population)	Kill (%)	Population after growing and harvesting a susceptible cv., calculated at two assumed nematode multiplication rates (% initial population)	
				30×	70×
1	4 years without potato	3	97	90	<100
2	1 year with resistant potato	20	80	>100	>100
3	Nematicide treatment (fumigant)	25	75	>100	>100
4	1 and 2	0.6	99.4	18	42
5	1 and 3	0.75	99.25	22.5	52.5
6	2 and 3	5	95	>100	>100
7	All 3 methods	0.15	99.85	4.5	10.5

(ii) Integrated Management

(a) Bioagents and Botanicals: Soil application of neem cake at 5 t/ha along with *T. viride* at 0.5 kg/ha recorded maximum tuber yield (23.14 t/ha) and reduction in potato cyst nematode multiplication (reproduction factor—1.09).

(b) Cultural, Chemical and Host Resistance: The combination of disease escape (by planting early maturing varieties) and the use of nematicides gave good control of the potato cyst nematode. Hygiene in the form of seed certification, combined with crop rotation in seed growing areas is effective. Use of a resistant variety followed by a nematicide would kill 99% of the nematode population. The potato cyst nematode problem in Nilgiris is being managed by chemical treatments, crop rotations and utilizing the available sources of resistance (cv. Kufri Swarna).

The most effective management combines crop rotation, use of nematicides and resistant varieties to keep the nematode at an economically acceptable level (Jones 1969) (Table 6.3).

A well-known integration of methods can control *G. rostochiensis* in potato in a 4-year rotation combining soil fumigation (causes 30% reduction in nematode population), cultivation of non-host (50% reduction), cultivation of resistant potato variety (30% reduction), cultivation of non-host (50% reduction) and then cultivation of susceptible variety of potato (Oostenbrink 1972).

(c) Solarization, Organic Amendments and Bioagents: Better control of *G. rostochiensis* by *Pasteuria penetrans* was possible with soil solarization combined with application of FYM or karanj cake, which resulted in greater kill of nematodes (Sitaramaiah and Naidu 2003).

6.1.2.4 Potato Rot Nematode, *Ditylenchus destructor*

D. destructor is the most important pest of potato tubers and is responsible for dry rot of tubers. High yield losses occur in the areas where climatological conditions favour establishment of the potato rot nematode. The effect of nematodes will manifest itself at harvest or storage when infected tubers will rot.

(i) Symptoms *D. destructor* enters potato tubers through lenticels and initially causes small white mealy spots just below the surface that are only visible if the skin is removed. Infested areas enlarge and coalesce and light brown lesions, consisting of dry granular tissue, may be visible beneath the skin. As the infestation progresses, the tissues dry and shrink and the skin becomes cracked and papery (Fig. 6.6). Internal tissues gradually darken and there are often secondary invasions of fungi, bacteria, mites, etc. If stored in moist conditions, a general rot may ensue and spread to neighbouring tubers.

(ii) Survival and Spread *D. destructor* has a wide host range, can survive on weeds and on a wide range of soil-inhabiting fungi. It can also survive on infected tubers left in the field. Spread occurs by introduction of infected tubers and in

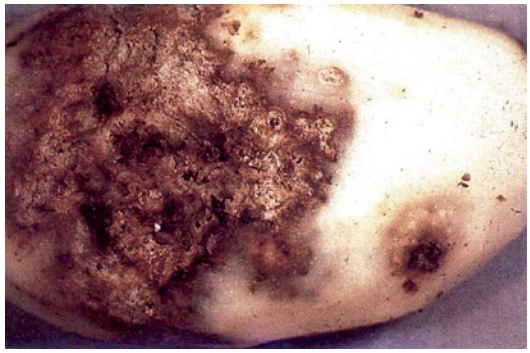


Fig. 6.6 Dry rot of potato tuber incited by *Ditylenchus destructor*

soil adhering to seed pieces. Irrigation water and cultivation by infested farm tools and machinery are other sources of inoculum dissemination.

(iii) Integrated Management The control of potato rot nematode was achieved by the combination of disease escape, hygiene, in the form of seed certification and crop rotation as follows (Winslow and Willis 1972):

- Healthy seed, planted late, harvested early and stored as cool and dry as possible
- Proper rotation of potatoes with non-host crops and growing of potatoes not more frequently than once in 3 or 4 years
- Field hygiene in the form of removal of old infested tubers and weed control

6.1.2.5 Early Dying/Lesion Nematode, *Pratylenchus penetrans* and Wilt, *V. dahliae* Disease Complex

(i) Symptoms The potato early dying disease results in premature vine senescence (Fig. 6.7) and can limit potato tuber yield by as much as 30–50%. Early dying is primarily caused by *V. dahliae*, a fungal vascular wilt pathogen, but co-infection of potato by both *V. dahliae* and the lesion nematode, *Pratylenchus penetrans*, can greatly increase the severity of disease.

(ii) Integrated Management

(a) Physical/Chemical and Bioagents: Although solar heating or methyl bromide fumigation significantly reduced the disease, the combination of either solar heating or methyl bromide soil fumigation followed by *T. harzianum* application improved control over solarization or fumigation alone and additionally controlled *R. solani* and *S. rolfsii* (Elad et al. 1980).

Fig. 6.7 Early dying of potato plant

6.2 Tomato, *Lycopersicon esculentum*

6.2.1 Insect Pests

6.2.1.1 Fruit Borer, *Helicoverpa armigera*

Tomato fruit borer is a polyphagous pest infesting tomato, reducing marketable yield and market value of the crop. This pest has already developed resistance to a number of insecticides in different crops, and is thus difficult to manage. Losses up to 50% in Tamil Nadu (Srinivasan 1958); 65% in Punjab (Singh and Singh 1975) and 22–38% in Karnataka (Tewari and Krishna Murthy 1984) have been reported due to this pest attack.

Fig. 6.8 Fruit borer damage on tomato

(i) Damage The first instar larvae initially feed on the leaves and later migrate to the developing green fruits. Later the larvae bore into the fruits with the posterior end outside the hole (Fig. 6.8). Pupation takes place in the soil. Eight or more eggs for every 30 trifoliate leaves below the top most flower cluster were observed to cause economic loss.

(ii) Integrated Management

(a) Bioagents/Botanicals and Cultural: Use of African marigold (*Tagetes erecta*) as a trap crop for the management of fruit borer on tomato involves planting one row of 45-day-old marigold seedlings after every 16 rows of 25-day-old tomato seedlings and spraying of *H. armigera* nuclear polyhedrosis virus (*Ha*NPV) at 250 LE/ha or 4% neem seed kernel extract (NSKE) or 4% pulverized neem seed powder extract (NSPE), 28 and 45 days after planting (DAP) coinciding with peak flowering (Srinivasan et al. 1994) (Fig. 6.9).

(b) Two Bioagents: For effective control of *H. armigera*, the egg parasitoid, *Trichogramma pretiosum* and *Ha*NPV could be integrated to tackle different stages of the pest. *T. pretiosum* was released at 2.5 lakh/ha and *Ha*NPV was sprayed two times (28 and 35 DAP) at 250 LE/ha for effective control of the pest (4.18% fruit borer damage as compared to 21.79% fruit borer damage in control). The increase in yield was 65.5% over control and the reduction in fruit borer damage was 80.8% over control (Krishnamoorthy et al. 1999).

Three releases of *T. pretiosum* + three sprays of *Bacillus thuringiensis* at 1 kg/ha was found highly effective against fruit borer in Himachal Pradesh (Gupta and Rajaram Mohan Babu 1998).

(c) Bioagents and Chemicals: An endosulfan tolerant strain of *Trichogramma chilonis* has been developed at the Project Directorate of Biological Control at Bangalore, and transferred to the private industry, which is now marketed under the trade name of 'Endogram'. This strain has been further developed for multiple tolerance to monocrotophos and fenvalerate. This strain of parasitoid can be utilized in places where both the releases of egg parasitoid *T. chilonis* and spraying of endosulfan/monocrotophos/fenvalerate for the control of other pests are warranted (Singh 2000).

*Ha*NPV with endosulfan, both at reduced doses, is recommended for minimizing the borer damage effectively (Ganguli et al. 1997). The reduction in larval population of *H. armigera* was maximum (69.3%) in the treatments where the three components (*Bt* + *Ha*NPV + endosulfan-half dose) were applied 55 and 75 DAP. This was followed by *Ha*NPV + endosulfan (55.28%) and *Bt* + endosulfan (52.68%) (Mahalingam and Saminathan 2003). The observations on the fruit damage revealed that combination of *Bt* + *Ha*NPV + endosulfan-half dose recorded minimum fruit damage (7.82%).

(d) Cultural, Bioagents and Botanicals: Use of nylon nets (40 gauge) to avoid insect vectors, spraying of *Ha*NPV twice at 28 and 35 DAP, spraying of pongamia soap at 1% given at 40 DAP was found effective for the management of fruit borer and leaf miner. The bored fruits were removed mechanically once at 40 DAP. The fruit borer and leaf miner incidence were 2% and 0.7–2.7 mines/leaf, respectively.

Fig. 6.9 Integrated management of tomato fruit borer using African marigold as a trap crop

6.2.2 Diseases

6.2.2.1 Damping-off, *Pythium aphanidermatum, Pythium ultimum*

(i) Symptoms In the pre-emergence phase of the disease, the young seedlings are killed even before they emerge out of the soil surface. However, this disease mostly occurs at post-emergence stage which is characterized by the toppling over of the infected seedlings anytime after they emerge from the soil (Fig. 6.10) until the stem has hardened sufficiently to resist invasion by the pathogen. Infestation usually occurs at ground level or through roots. The infected tissue appears soft and water-soaked. As the disease advances, the stem becomes constricted at the base of the plants that collapse later. Seedlings that are healthy looking one day may have collapsed the next morning.

Fig. 6.10 Damping-off of tomato seedlings

(ii) Integrated Management

(a) Bioagents and Botanicals: Seed treatment with *T. viride* and *Pseudomonas fluorescens* and addition of neem cake to the nursery beds enhanced seed germination and seedling stand.

Seed treatment with *T. viride* + soil application of FYM enriched with *T. viride* gave effective control of damping-off (Table 6.4; Rahman et al. 2002).

(b) Bioagents and Chemicals: Dey and Mukhopadhyay (1994) reported effective control of damping-off of tomato by integration of *Trichoderma virens* with thiram/apron.

(c) Physical and Bioagents: Combination of the seed/root application of *T. harzianum* or *P. fluorescens* with soil solarization was very effective in management of damping-off of tomato in nursery at farmers' field.

(d) Physical and Botanicals: Composted chicken manure applied to solarized soil reduced numbers of *P. ultimum* (Table 6.5). Fungal numbers and galling index generally decreased with increasing fertilizer dosage. Soil solarization reduced colony-forming units (cfu) of *P. ultimum* in all cases.

6.2.2.2 Wilt, *Fusarium oxysporum* f. sp. *lycopersici*

(i) Symptoms The disease is characterized by yellowing and wilting of leaves and finally the entire plant wilts and dies prematurely (Fig. 6.11). Stem tissue often is discoloured throughout the plant. Vascular browning takes place in the root

Table 6.4 Comparative efficacy of bioagents and organic amendments against damping-off of tomato

Treatment	% disease index
Seed treatment with *Trichoderma viride* at 4 g/kg + soil application of 50 kg FYM enriched with 500 g of *T. viride*	5.70 (13.71)
Seed treatment with *Pseudomonas fluorescens at* 10 g/kg + soil application of 50 kg FYM enriched with 2.5 kg of *P. fluorescens*	7.93 (16.06)
Seed treatment with *Trichoderma harzianum* at 4 g/kg + soil application of 50 kg FYM enriched with 500 g of *T. harzianum*	7.83 (16.03)
Seed treatment with *Azotobacter croococcum* at 16 g/kg + soil application of 50 kg FYM enriched with 500 g of *A. croococcum*	8.46 (16.68)
Control (check)	30.64 (33.55)
Critical Difference (CD) at 5%	*(3.23)*

Figures in parentheses indicate the arc sin transformed values
FYM farmyard manure

Table 6.5 In vitro effect of amending soil with composted chicken manure[1] and/or soil heating[2] on numbers (cfu) of *Pythium* sp.

Treatment manure dosage	*Pythium* sp. (cfu/g soil)
Control	14.4a[3]
Solarization only	12.0b
Chicken manure at 2,690 kg/ha	9.6b
Chicken manure at 5,381 kg/ha	1.1c
Chicken manure at 2,690 kg/ha + solarization	1.8c
Chicken manure at 5,381 kg/ha + solarization	0.0c

[a] Containing 3,280 mg NH_4-N/kg
[b] Three-day incubation. Diurnal healing regime: 42 °C high, 18 °C low
[c] Values within columns followed by different letters are different at $P < 0.05$ according to Duncan's multiple range test

(Fig. 6.11). The fungus can persist in the soil for many years and is virulent at moderate temperature (26–28 °C).

(ii) Integrated Management

(a) Two Bioagents: Mao et al. (1998) found that combined inoculation of *T. virens* and *Burkholderia cepacia* resulted in increased plant stand and greater yield than those obtained with either biocontrol agent alone.

6.2.2.3 Southern Blight, *Sclerotium rolfsii*

(i) Symptoms The first symptom of the disease is observed as soft tissue necrosis of bark of the stem near soil line. White growth of cottony mycelium is clearly visible on the affected portion just below the soil surface (Fig. 6.12). Later, dense silvery fungus growth along with white to light brown mustard-like sclerotia is observed on the same portion. Progressive drooping, yellowing or wilting of the entire plant is observed (Fig. 6.12). Sometimes the plant is collapsed soon after infection. The disease is soil-borne where the pathogen survives in the form of sclerotia.

(ii) Integrated Management

(a) Solarization and Bioagents: Studies by Elad et al. (1980) have demonstrated that 2–4-week soil solarization during the summer was able to reduce sclerotial numbers and limit disease. Additionally, combining solar heating with applications of *T. harzianum* was more effective than either treatment alone. The growth of the biological control agent *T. harzianum* is enhanced with solar heating (Jenkins and Averre 1986).

Studies in North Carolina showed that soil solarization combined with *T. virens* reduced the disease incidence by 49 % during the first season after solarization and 60 % during the second season (Ristaino et al. 1991).

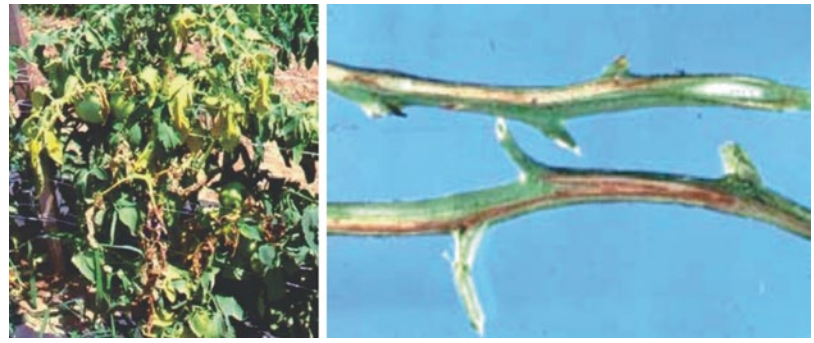


Fig. 6.11 Tomato plant infected by *Fusarium* wilt

Fig. 6.12 Southern blight symptoms on tomato

(b) Biofumigation, Solarization and Chemicals: Pre-plant soil treatments utilizing composted amendments, biofumigation, solarization, and low dosage dazomet (Basamid) produced higher yields and resulted in a lower incidence of the soil-borne disease, southern blight, than did controls (Fig. 6.13). The compost-amended plots produced yields 59 % higher than controls. Methyl-isothiocyante (MITC) and biofumigation plots had 39 and 40 % higher yields than controls. However, the combined MITC + compost plots produced the highest yields—82 % above control. These results suggest that the most effective treatments for prevention of tomato diseases and enhanced yields may be those that integrate two or more control mechanisms while also favouring the growth of beneficial soil organisms.

6.2.2.4 Wilt, *Verticillium dahliae*

(i) Symptoms Verticillium wilt is a soil-borne fungal disease that results in the yellowing, and eventual browning and death of foliage, particularly in branches closest to the soil (Fig. 6.14). The wilt starts as yellow, V-shaped areas that narrow at the leaf margins. These yellow areas grow over time, turn brown, and then the leaf dies. Often, entire branches are infected.

(ii) Integrated Management

(a) Physical and Chemical: In Morocco, solar heating of the soil proved to be efficient in controlling *V. dahliae* on tomato (Besri and Drame 1982). The mean maximum temperature at 15 cm depth in the solarized plot was 42 °C (9 °C higher than non-covered control soil), and the mean minimum was 34 °C (7 °C higher than the control).

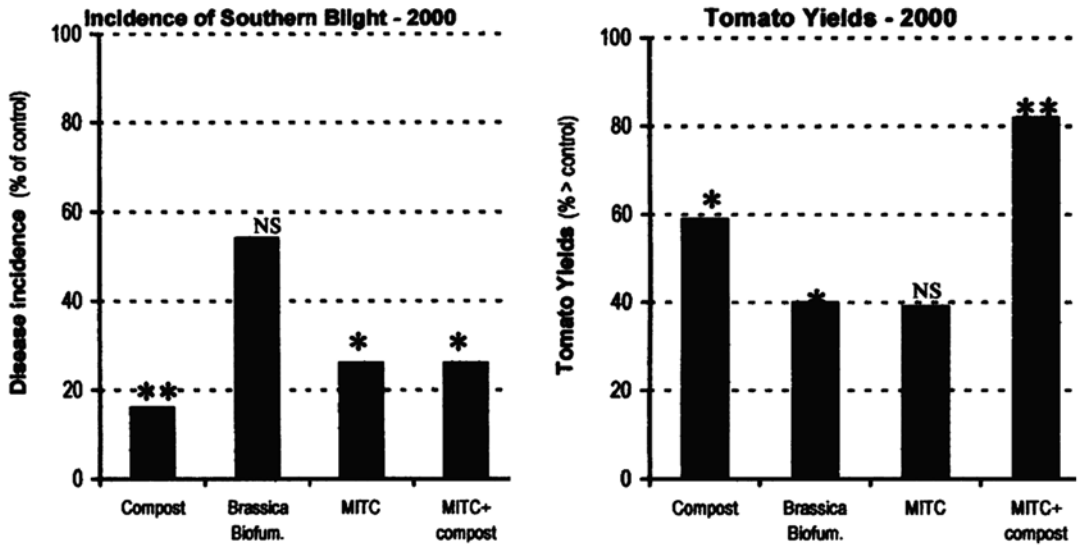


Fig. 6.13 Incidence of southern blight and tomato yields in different treatments

Fig. 6.14 *Verticillium* wilt of tomato

Maximum temperatures at 15 cm depth in the fine sandy loam plot were 44 °C and 36 °C in solarized and control plots, respectively.

Factorial Analysis of Variance (ANOVA) revealed significant activity of fertilizers against *V. dahliae* in the loam soil, but not in the fine sandy loam (Table 6.6). Fungicidal activity of solarization was highly significant in both soils. A highly significant fertilizer–solarization interaction was found against *V. dahliae* in the loam soil.

There were no differences in number of surviving plants in either soil, and no symptoms of *Verticillium* wilt were observed. Factorial Analysis of Variance (ANOVA) showed both fertilizers and solarization to be highly significant in increasing all growth parameters in the loam soil; however, no fertilizer–solarization interactions were found (Table 6.7). No significant differences in tomato growth due to fertilizers were found in the sandy loam plot. Solarization, however, was highly significant in increasing numbers of fruit and fruit fresh weight.

6.2.2.5 Corky Root, *Pyrenochaeta lycopersici*

(i) Symptoms A key diagnostic symptom seen in problem fields is the presence of brown, corky bands on the roots that may develop into dark, rotted roots (Fig. 6.15); and loss of small feeder roots. Other symptoms include stunting, slow growth and premature defoliation. On severely affected roots, the outer layer (cortex) can be easily pulled off the root core (stele).

(ii) Integrated Management

(a) Biofumigation and Solarization: Soil solarization alone or in combination with *Brassica* green manures resulted in a significant ($P<0.05$) decrease of corky root severity of tomato in all three years of trial (1999–2002). *Brassica oleracea* ('Senshi') green manure treatment significantly reduced ($P<0.05$) the disease in 2 years

Table 6.6 Populations of *Verticillium dahliae* in soil treated with ammonia-based fertilizers and/or solarization[a]

Treatment	Colony-forming units[b]	
	Loam soil	Fine sandy loam soil
Aqua ammonia	5.5	17.4
Aqua ammonia + solarization	0.1	5.2
Urea	1.6	23.0
Urea + solarization	0	5.7
Ammonium sulphate	3.0	0.5
Ammonium sulphate + solarization	0	0
Ammonium phosphate	8.9	14.0
Ammonium phosphate + solarization	0	0.4
Non-treated control	9.5	19.2
Solarization	0.1	0
LSD	3.6	13.1
Factorial analysis for variance		
Fertilizers	$P<0.01$	NS
Solarization	$P<0.01$	$P<0.01$
Fertilizers[c] × solarization[d]	$P<0.01$	NS

cfu colony-forming units, *NS* no significant differences, *LSD* least significant difference
[a] Fertilizers were applied at 305 kg N/ha
[b] Populations are cfu/g of oven-dried soil at 0.15 cm soil depth
[c] $P<0.05$ or 0.01
[d] Interaction of treatments

Table 6.7 Fresh market tomato ('Early Pak 7') growth in soil treated with ammonia-based fertilizers and/or solarization

Soil treatment[a]	Loam soil			Fine sandy loam soil		
	No. of fruits[b]	Fruit fresh wt. (g)	Vegetative fresh wt. (g)	Number of fruits	Fruit fresh wt. (g)	Vegetative fresh wt. (g)
Aqua ammonia	5.9	90.8	604	22.7	398.3	1,386
Aqua ammonia + solarization	14.0	210.4	1,102	30.5	493.6	1,384
Urea	8.7	151.8	538	26.0	490.6	1,130
Urea + solarization	14.5	206.4	1,080	30.7	605.0	1,246
Ammonium sulphate	12.3	175.1	690	22.6	404.8	1,160
Ammonium sulphate + solarization	21.4	382.6	1,582	32.3	552.0	1,660
Ammonium phosphate	18.5	321.5	1,162	27.9	359.7	1,754
Ammonium phosphate + solarization	26.1	502.7	1,668	28.3	533.0	1,766
Non-treated control	11.7	132.1	638	22.4	360.3	1,180
Solarization	15.0	215.7	1,078	33.5	574.4	1,448
LSD	8.0	171.9	437	11.9	247.6	670
Factorial analysis of variance						
Fertilizers	$P<0.01$	$P<0.01$	$P<0.01$	NS	NS	NS
Solarization	$P<0.01$	$P<0.01$	$P<0.01$	$P<0.01$	$P<0.01$	NS
Fertilizers[c] × solarization[d]	NS	NS	NS	NS	NS	NS

NS no significant differences
[a] All fertilizers were applied at 305 kg N/ha
[b] All values are given on a per-plant basis
[c] $P=0.05$ or 0.01
[d] Interaction of treatments

Fig. 6.15 Corky root symptoms on tomato

Fig. 6.16 Bacterial wilt affected tomato plant

out of 3. *Brassica rapa* local ecotype caused a significant ($P<0.05$) reduction of corky root, and tomato yield increased in 1 year of testing out of 3. Soil manuring with *B. oleracea* ('Senshi') resulted in a significant ($P<0.05$) increase of tomato yield in 2 years out of 3.

Immediately after its application, soil-solarization alone or in combination with green manures significantly ($P<0.05$) reduced fluorescent *Pseudomonas* sp. population. However, *Pseudomonas* population increased at the end of tomato cropping in most cases. At the end of tomato cultivation, *Bacillus* sp. population was higher in solarized plots than in non-solarized ones. Corky root severity was negatively correlated with *Bacillus* sp. population density in all trials (Amenduni et al. 2004).

6.2.2.6 Bacterial Wilt, *Ralstonia solanacearum*

(i) Symptoms This is the most serious bacterial disease of solanaceous crops. Characteristic symptoms of the disease are: wilting without leaf yellowing and collapse of the entire plant (Fig. 6.16). The vascular system shows browning. If a segment of the stem is cut and squeezed, bacterial ooze is visible (Fig. 6.16). It causes sudden wilt and ultimately, the plant is killed resulting in total loss.

(ii) Integrated Management

(a) Bioagents, Arbuscular Mycorrhizal Fungi (AMF) and Botanicals: Even though soil application of *T. viride* at 5 kg/ha mixed in FYM and *Glomus mosseae* at 500 g/m^2 gave maximum fruit yield (142.1% and 141.1% increase over

Table 6.8 Effect of bioagents, plant extracts, oil cakes and chemicals on bacterial wilt and yield of tomato cv. *Pusa Ruby*

Treatment	% reduction of initial inoculum	% decrease over control	% increase in yield over control
Glomus mosseae	41.4	39.41	141.1
Trichoderma viride	29.0	27.52	142.1
Azotobacter + phosphobacteria	37.3	27.62	89.9
Asafoetida + turmeric extract	39.3	44.01	71.2
Onion extract	32.7	38.09	71.2
Garlic extract	24.4	9.80	64.4
Karanj cake + bleaching powder	32.5	34.87	123.4
Bleaching powder + lime	36.2	37.37	107.5
Urea + lime	30.8	22.72	52.6
Control	33.6	–	–

Table 6.9 Effect of copper-sensitive strain (PT12) and copper-resistant strains (PT23.200 and PT23.201) of *Pseudomonas syringae* pv. *tomato* with and without Kocide on the incidence of bacterial speck on tomato

Pseudomonas syringae pv. *tomato* strain	Preinoculation treatment with Kocide 101	Lesions/leaflet
PT12 (2×10^7/mL)	–	47.9a
	+	5.6c
PT12 (2×10^7) + PT23.200 (5×10^8/mL)	–	16.3b
	+	5.6c
PT12 (2×10^7) + PT23.201 (5×10^8/mL)	–	7.9c
	+	2.2d

Figures with different letters are significantly different from each other at 5% level by Analysis of Variance Test

control), karanj cake along with bleaching powder was more effective in reducing the apparent bacterial growth rate at flowering stage, which is the most critical stage of bacterial wilt, in which 132.2% more yield was obtained which was at par with that of *T. viride* and *G. mosseae* (Table 6.8).

(b) Botanicals and Bioagents: Integration of growing and incorporation of sunn hemp (green manure crop) into the soil and seed treatment with *P. fluorescens* (10^{10} cfu/mL) was highly effective in reducing the bacterial wilt incidence to 6.75% and significantly increasing the fruit yield to 25.5 t/ha as compared to high wilt incidence (55.6%) and low yield (7.8 t/ha) in control. Thus, the efficacy of *P. fluorescens* is increased under green manure incorporated soil against bacterial wilt of tomato (Gopalakrishnan and Ajit Kumar 2006).

6.2.2.7 Bacterial Speck, *Pseudomonas syringae* pv. *tomato*

(i) Symptoms The disease starts as small, round, water-soaked spots, which gradually become yellowish brown and finally blackish brown with sunken ashy centre and pale yellowish green halo. Later on, spots become irregular to circular, measuring 1 mm in diameter, distributed over the entire leaf lamina and in severe cases forming large blotches. Spots on petioles are more or less oval.

(ii) Integrated Management

(a) Bioagents and Chemicals: Application of copper fungicide (Kocide), preceding application of the non-pathogenic, copper-resistant mutant of *P. syringae* pv. *tomato*, resulted in greater reduction in disease than either treatment alone (Cooksey 1988) (Table 6.9).

6.2.3 Nematodes

6.2.3.1 Root-knot Nematodes, *Meloidogyne* spp.

(i) Economic Importance *M. incognita* was responsible for 30.57–46.92% loss in fruit yield of tomato (Bhatti and Jain 1977; Reddy 1985; Darekar and Mahse 1988), while *Meloidogyne*

Fig. 6.17 Heavy galling of tomato roots with *Meloidogyne incognita*

javanica caused 77.5% loss in yield (Anon 1993).

(ii) Symptoms Above ground symptoms are stunting, yellowing, wilting, reduced yield and premature death of plants. Below ground symptoms are swollen or knotted roots (root galls) or a stubby root system (Fig. 6.17). Root galls vary in size and shape depending on the nematode population levels, and species of root-knot nematode present in the soil.

(iii) Integrated Management

(a) Botanicals and Bioagents: Application of *Aspergillus niger* and *P. lilacinus* along with mustard cake gave maximum reduction in nematode population both in root and soil with enhanced plant vigour. *A. niger* being toxic agent, kills the second stage juveniles present in the rhizosphere; while *P. lilacinus* being the egg parasite, invade the eggs of *M. incognita* which escaped from the toxicity of *A. niger*. As a result, there is an overall reduction in root and soil population. Further, addition of mustard cake also helps to maintain the general plant health in addition to possessing nematicidal properties (Goswami et al. 1998) (Table 6.10).

Combined application of *P. penetrans* + *T. viride* + neem/castor cake each at one-third dose was significantly superior compared with their individual applications in terms of increased tomato plant growth and reduced root galling, egg mass production and final populations of *M. incognita*. Similarly, total parasitization by bioagents was higher in plants treated with these bioagents in terms of number of juveniles encumbered and adult females infected with *P. penetrans* and egg masses parasitized by *T. viride*, compared to their individual applications (Rangaswamy et al. 1999).

The integration of castor leaves with *P. lilacinus* increased the efficiency of nematode control (*M. javanica*) in tomato. The residual effect on the second crop of tomato revealed the reduction in root-knot index (29.6–356.8%) and J_2 population in soil (26.4–57.9%) (Zaki 1998). *P. lilacinus* in combination with castor leaves reduced the nematode population up to 89% and increased plant growth and yield in tomato (Zaki and Bhatti 1991).

In nursery, integration of *P. penetrans* (at 28×10^4 spores/m^2), *P. lilacinus* (at 10 g/m^2 with 19×10^9 spores/g) and neem cake (at 0.5 kg/m^2) gave maximum increase in plant growth and number of seedlings per bed. Parasitization of *M. incognita* females was highest when neem cake was integrated with *P. penetrans*, while parasitization of eggs was highest when neem cake was integrated with *P. lilacinus*. In field, planting of tomato seedlings (raised in nursery beds amended with neem cake + *P. penetrans*) in pits incorporated with *P. lilacinus* (at 0.5 g/plant) gave least root galling and nematode multiplication rate and increased fruit weight and yield of tomato (Table 6.11; Parvatha Reddy et al. 1997).

Soil drenching with 5% Wellgro solution (at 200 mL/seed pan) along with *P. lilacinus* (at 2×10^4 spores/mL) gave maximum increase in seedling weight and highest reduction in root galling. Roots of tomato seedlings raised in the above treatment dipped in 5% Wellgro solution mixed with *P. lilacinus* spores (at 2×10^4 spores/mL) for 20 min when transplanted in pots gave maximum increase in plant growth, root colonization and parasitization of egg masses of *M. incognita* by

Table 6.10 Effect of *Aspergillus niger, Paecilomyces lilacinus* and mustard cake on biomass and multiplication of *Meloidogyne incognita* infecting tomato

Treatment	Biomass	No. of galls/plant	No. of egg masses/plant	No. of eggs/egg mass	Nematode population/500 g soil
Aspergillus niger	9.8	34	18	272	470
Paecilomyces lilacinus	10.2	42	23	262	580
A. niger + *P. lilacinus*	12.2	26	16	264	270
A. niger + *P. lilacinus* + mustard cake	12.6	22	10	255	290
Control	9.0	98	72	320	2,880
Critical Difference (CD) at 5%	*2.33*	*7.24*	*3.24*	*27.18*	*162.80*

Table 6.11 Effect of neem cake, *Pasteuria penetrans* and *Paecilomyces lilacinus* on root galling and yield of tomato

Treatment		Root-knot index	Yield (kg)/6 m^2
Nursery (m^2)	Main field (per plant)		
Neem cake—1 kg	*P. lilacinus*—0.5 g	3.4	9.168
Neem cake—1 kg	*P. penetrans* (28×10^4 spores)	3.2	9.312
P. lilacinus—20 g	*P. penetrans* (28×10^4 spores)	3.0	9.504
P. penetrans (28×10^7 spores)	*P. lilacinus*—0.5 g	2.9	9.624
Neem cake—0.5 kg + *P. lilacinus*—10 g	*P. penetrans* (28×10^4 spores)	2.5	9.672
Neem cake—0.5 kg + *P. penetrans* (28×10^4 spores)	*P. lilacinus*—0.5 g	2.0	9.984
Neem cake—0.5 kg + *P. lilacinus*—10 g + *P. penetrans* (28×10^4 spores)	–	2.6	9.600
Control	–	4.6	8.352
Critical Difference (CD) (P = 0.05)		*0.14*	*0.100*

the bioagent and highest reduction in root galling and final nematode population both in soil and roots (Rao and Parvatha Reddy 1993a).

Bare root-dip treatment of tomato seedlings in 10% castor leaf extract mixed with *P. lilacinus* spores (at 1.5×10^8 spores/mL) for 20 min significantly increased the plant growth and reduced root galling and final nematode population. The above treatment also gave significant increase in parasitization of eggs and egg masses and propagule density of *P. lilacinus* in roots (Rao et al. 1999). Similarly, root-dip treatment of tomato seedlings in 5 and 10% neem leaf extract mixed with *P. lilacinus* spores (at 6×10^4 spores/mL) for 30 min gave significant reduction in root galling and final nematode population. Significant increases in root colonization, parasitization of eggs and egg masses and propagule density of the bioagent in soil were also noticed in the above treatment (Parvatha Reddy et al. 1998).

Application of *Pochonia chlamydosporia* (100 mL/seed pan containing 4×10^5 spores/mL) with neem leaves (150 g/seed pan) increased seedling weight and colonization of roots with the bioagent. Tomato seedlings raised in the above treatment transplanted in pots resulted in maximum increase in plant growth, least root galling, nematode population both in soil and roots and highest parasitization of eggs, egg masses and propagule density of *P. chlamydosporia* in roots (Parvatha Reddy et al. 1999).

Incorporation of neem cake (20 g/pot) along with *P. chlamydosporia* (10 mL/pot containing 4×10^5 spores/mL) gave maximum increase in plant growth and significant reduction in root galling and nematode population both in soil and roots. The above treatment also gave highest parasitization of eggs and egg masses of *M. incognita* and maximum propagule density of the bioagent in soil and roots (Rao et al. 1998b).

Integration of neem cake (40 g/plant) with *T. harzianum* (at 5 g/plant with 4×10^8 spores/g) was effective in increasing the plant growth and reducing root galling and final population of *M.*

Table 6.12 Effect of integration of *Glomus mosseae* with oil cakes on root galling and yield of tomato infected with *Meloidogyne incognita*

Treatment	Dose/plant	Root gall index	Yield (kg/plant)
Control	–	4.4	1.44
Castor cake	50 g	3.9	2.00
Karanj cake	50 g	4.1	2.06
Neem cake	50 g	3.6	2.23
G. mosseae	500 cm^3 soil	3.4	2.19
Castor cake + *G. mosseae*	50 g + 500 cm^3 soil/m^3	3.4	2.53
Karanj cake + *G. mosseae*	50 g + 500 cm^3 soil/m^3	3.0	2.69
Neem cake + *G. mosseae*	50 g + 500 cm^3 soil/m^3	2.8	2.98
Carbofuran	0.1 g	3.0	2.33
Critical Difference (CD) (P = 0.05)	–	*0.27*	*0.43*

incognita infecting tomato. The above treatment also gave maximum reduction in number of eggs/egg mass and increased root colonization, spore density in soil and parasitization of adult females with *T. harzianum* (Rao et al. 1997c).

Nursery bed treatment with *P. fluorescens* (with 1×10^9 spores/g) and *P. chlamydosporia* (10 mL/pot containing 4×10^6 spores/mL) each at 20 g/m^2 and field application of 5 t of FYM enriched with the above bioagents each at 5 kg, significantly reduced root-knot nematodes in tomato by 76% over untreated check. The yield increase was up to 21.7% with benefit to cost ratio of 4.9.

Integration of *P. lilacinus* and *T. viride* with mustard cake gave significant reduction in root galling, egg mass production, fecundity, reproduction factor and nematode population both in soil and roots coupled with increase in plant growth parameters (Tripathi and Singh 2006).

(b) Botanicals and AMF: Application of calotropis leaves at 400 g/m^2 along with *Glomus fasciculatum* (250 g/m^2 containing 25–30 chlamydospores/g) in nursery beds gave significant reduction in root galling and fecundity of *M. incognita*. The above treatment also gave maximum increase in plant growth and root colonization with *G. fasciculatum* (Rao et al. 1996). Organic amendments (oil cakes, calotropis leaves) in combination with AMF enhance the colonization of AMF on tomato roots, which further increased plant growth and reduced gall index.

Inoculation of *G. mosseae* or *G. fasciculatum* in the nursery beds amended with neem cake/castor cake/neem leaf/calotropis leaf reduced the infestation of root-knot and reniform nematodes to the maximum extent on tomato. Amendment of botanicals in the nursery beds increased the multiplication of endomycorrhizae and colonization of tomato root which in turn could protect the crop from these nematodes in the main field resulting in increased yields (Rao et al. 1996, 1997a).

In nursery, integration of neem cake (at 500 g/m^2) with *G. mosseae* (at 250 g/m^2 containing 16 chlamydospores/g) significantly reduced *M. incognita* population in soil, root galling, egg mass production, fecundity and produced vigorous tomato seedlings with increased root colonization with *G. mosseae*. The seedlings raised in the above treatment when planted in the main field significantly reduced root galling and increased fruit yield, root colonization with *G. mosseae* and chlamydospore population in soil (Parvatha Reddy et al. 1998; Rao et al. 1995; Table 6.12).

(c) Bioagents and AMF: Interestingly, integration of bioagent (*P. lilacinus*) and endomycorrhizae (*G. mosseae/G. fasciculatum*) has culminated in the successful management of *M. incognita* infecting tomato. This phenomenon facilitated standardization of a strategy wherein inoculation of mycorrhizae and bioagent in the nursery beds protected the seedlings of tomato from the attack of *M. incognita*. Further, these mycorrhizal seedlings (colonized either with *G. mosseae* or *G. fasciculatum*) can be given a root-dip treatment with spore suspension of *P. lilacinus* for 5–10 min for the effective management

Table 6.13 Effect of integration of neem cake with *Trichoderma harzianum/Glomus fasciculatum* on root galling and yield of tomato infected with *Meloidogyne incognita*

Treatment	Dose/m^2	Root-knot index	Yield (kg/plant)
Neem cake	1 kg	3.1	1.57
T. harzianum	100 g	3.2	1.43
G. fasciculatum	6,000 spores	2.6	1.72
Neem cake + *T. harzianum*	500 g + 50 g	2.4	2.22
Neem cake + *G. fasciculatum*	500 g + 3,000 spores	2.0	2.64
Control	–	4.2	1.10
Critical Difference (CD) (P = 0.05)	–	*0.21*	*0.38*

of nematodes in the main field after transplanting (Rao et al. 1993a).

Integration of *Glomus deserticola* with *P. chlamydosporia* gave effective management of *M. incognita* in tomato, increased seedling weight, root colonization with *G. deserticola* and *P. chlamydosporia* and parasitization of eggs of *M. incognita* with *P. chlamydosporia* and reduced root galling, egg mass production and fecundity of root-knot nematodes (Rao et al. 1997a).

(d) Bioagents, AMF and Botanicals: Inoculation of *G. mosseae* in neem leaf/neem cake-amended nursery beds followed by the root-dip treatment of mycorrhizal seedlings of tomato in spore suspension of *P. lilacinus* gave effective management of *M. incognita* under field conditions (Rao et al. 1995).

In nursery, integration of neem cake (at 500 g/m^2) with *G. fasciculatum* (200 g/m^2 containing 15 spores/g) gave maximum increase in plant growth and highest root colonization with *G. fasciculatum* and least root galling. Integration of neem cake (at 500 g/m^2) with *T. harzianum* (at 100 g/m^2 with 4×10^8 spores/g) gave maximum parasitization of eggs with *T. harzianum*. In field, planting of tomato seedlings raised in nursery beds treated with neem cake + *G. fasciculatum* in pits incorporated with *T. harzianum* (at 0.5 g/plant with 4×10^8 spores/g) was effective in increasing tomato fruit yield, root colonization with *G. fasciculatum* and egg parasitization with *T. harzianum* and significant reduction in root galling and multiplication rate of *M. incognita* (Parvatha Reddy et al. 1998; Table 6.13).

(e) Bioagents and Chemicals: Maheswari et al. (1987) reported that application of *P. penetrans* in combination with carbofuran, aldicarb, miral, sebufos and phorate significantly improved plant growth of tomato by greatly reducing galling due to *M. javanica*.

Integration of *P. chlamydosopria* with carbofuran recorded maximum plant growth parameters and minimum gall index and nematode population. The above treatment also recorded maximum number of fruits/plant and yield/plant. Maximum parasitization of *M. incognita* with *P. chlamydosopria* was also noticed when the bioagent and the chemical were integrated (Gopinatha et al. 2002).

(f) Two Bioagents: Integration of two bioagents, *P. lilacinus* and *P. chlamydosopria* resulted in combined and complimentary effects for the successful management of *M. incognita* infecting tomato (Rao and Parvatha Reddy 1992).

Tomato seedlings raised in nursery beds treated with *P. chlamydosopria* and *P. penetrans* when transplanted in the main field had significantly lower root-knot index, number of eggs per egg mass and nematode population in roots and soil. The above treatment also increased root colonization and egg parasitization with *P. chlamydosporia,* infection of *M. incognita* females with *P. penetrans* and increased tomato fruit yield. This method of integrated nematode management resulted in significant reduction in the amount of inoculum of the bioagents required for the treatment of soil only in the nursery beds (Rao et al. 1998a; Table 6.14).

Maheswari and Mani (1988) also observed that population of *M. incognita* and *M. javanica* were suppressed effectively and yields of tomato were greater when *P. penetrans* and *P. lilacinus* were applied together.

Table 6.14 Effect of integration of *Pochonia chlamydosopria* with *Pasteuria penetrans* on root galling, fruit yield and egg parasitization by *P. chlamydosopria* on tomato infected with *Meloidogyne incognita*

Treatment	Root-knot index	Yield (kg)/6 m^2	% eggs parasitized by *P. chlamydosopria*
P. chlamydosopria	5.8	7.4	43
P. penetrans	6.6	6.3	–
P. chlamydosopria + *P. penetrans*	4.7	8.2	57
Control	8.0	5.1	–
Critical Difference (CD) (P = 0.05)	*0.78*	*0.88*	*4.72*

Combined soil application of *P. lilacinus* and *A. niger* at the time of transplanting tomato is very effective in reducing root-knot nematodes.

The combination treatment with *T. harzianum* + *T. viride* each at 50 g (4×10^8 cfu/g) considerably increased the plant growth, yield and reduced the root galls and soil nematode population (Hassan and Sobita Devi 2004).

Consortial formulation of biocontrol agents *viz*., *P. fluorescens* Pf 128 and *Bacillus subtilis* Bbv 57 recorded the highest defense enzymatic activity (peroxidase, polyphenol oxidase and phenylalanine ammonia lyase) and lowest nematode population in tomato roots compared to other strains either alone or in combination (Sankarimeena et al. 2012).

(g) Cultural and Chemical Methods: Treatment combination of three deep summer ploughings at 10 days' interval (20 cm deep) during June (atmospheric temperature between 42–47 °C) (92.3 % reduction in *M. javanica* population) + aldicarb-treated nursery (0.4 g a.i./m^2) + spot application of aldicarb at 1 kg a.i./ha at transplanting of healthy tomato seedlings of 8-weeks-old gave maximum yield (7.8 kg/plot compared with 3.8 kg/plot in check) (102.6 % higher yield over control) with minimum root-knot index (1.3) and final nematode population (85.5 %–93.7 % reduction in nematode population; see Jain and Bhatti (1985).

(h) Solarization and Biofumigation: Tsror et al. (2006) reported much improved control of *Meloidogyne* spp. on tomato by combining solarization with biofumigation compared to solarization alone.

Integration of soil solarization of nursery beds (with linear low-density polyethylene (LLDPE) transparent film of 25 μ for 15 days) with soil incorporation of calotropis leaves at 4 kg/1.44 m^2 resulted in increased plant height (29.9 cm compared with 20 cm in control), fresh shoot weight (176.49 g compared with 100 g in control), transplantable seedlings (546/m^2 compared with 297 in control) with minimum root-knot index (1.83 compared with 3.85 in control); see Patel et al. (2006). Soil solarization with clear LLDPE film (25 μ) for 15 days in hot summer in combination with poultry manure at 2 t/ha proved effective in the management of nematodes and higher production of transplants in tomato nursery with benefit to cost ratio of 3.10.

(i) Botanicals and Cultural: In commercial greenhouse trials in Spain an integrated management system was developed, including biofumigation with sheep manure and mushroom residue and the cultivation of short-cycle vegetables acting as trap crops. Using this strategy, initial very high levels of *M. incognita* were reduced to near zero in the main susceptible tomato crop (Bello 1998).

(j) Chemicals, Cultural and Physical: Significant nematode control (75–88 %) was observed when soil solarization was introduced to the cropping system (a resistant crop preceding tomato), ranging from 40 to 51 %. Per cent nematode control increased when the soil was chemically treated, and particularly when solarization was included in the system (Table 6.15; Heald and Robinson 1987).

(k) Botanicals and Chemicals: Integration of chopped castor leaves (40–60 g/kg soil) 1 or 2 weeks before transplanting with application of aldicarb or carbofuran each at 2 kg a.i./ha at transplanting, significantly reduced number of galls due to *M. javanica* and enhanced the growth of tomato (Dutt and Bhatti 1986).

Table 6.15 The effect of short-term soil solarization and cropping system on the integrated control of *Meloidogyne* spp. under laizemeter conditions

Cropping system	Egg masses/5 g roots (% of control)	Females/5 g roots (% of control)	Nematode control (%)
S-T	100	100	0
M-T	41	35	62
R-T	0	0	100
Z-S-T	64	55	40
Z-M-T	29	26	73
Z-R-T	0	0	100
S-Z-T	60	55	43
M-Z-T	23	21	78
R-Z-T	0	0	100
Z-S-Z-T	50	48	51
Z-M-Z-T	18	17	83
Z-R-Z-T	0	0	100
S-Tr	20	30	75
M-Tr	9	17	87
R-Tr	0	0	100
Z-S-Tr	11	21	84
Z-M-Tr	4	6	95
Z-R-Tr	0	0	100
S-Z-Tr	15	25	80
M-Z-Tr	1	10	95
R-Z-Tr	0	0	100
Z-S-Z-Tr	10	15	88
Z-M-Z-Tr	3	6	96
Z-R-Z-Tr	0	0	100

S susceptible host, *M* moderately susceptible host, *R* resistant host, *Z* solarization, *T* tomato, *Tr* tomato + chemical treatment

In tomato, application of aldicarb and carbofuran each at 1 kg a.i./ha in combination with neem cake and urea each at 10 kg N/ha at transplanting, produced maximum yield with lowest gall index (2.5) and nematode population, 90 DAP (Routaray and Sahoo 1985).

Integration of soil application of castor leaves with inorganic fertilizer (75 kg N/ha) enhanced plant growth of tomato and reduced *M. javanica* infestation (95 and 78% reduction in root galls and egg mass production, respectively; Zaki and Bhatti 1989).

Application of carbofuran at 1 kg a.i./ha in the nursery beds followed by neem cake at 400 kg/ha in the main field increased yield and reduced the gall index (Singh and Gill 1998; Table 6.16).

(l) Physical and Chemical: Addition of ammonium phosphate fertilizer to loam soil significantly reduced galling of tomato roots by *M. incognita*. Galling index generally decreased with increasing fertilizer dosage. Soil solarization along with ammonium phosphate fertilizer further reduced nematode galling in all cases (Table 6.17).

Factorial Analysis of Variance (ANOVA) showed both fertilizers and solarization to be highly significant in increasing all growth parameters in the loam soil; however, no fertilizer–solarization interactions were found (Tables 6.17).

The mean maximum temperature at 15 cm depth in the solarized plot was 42 °C (9 °C higher than non-covered control soil) and the mean minimum was 34 °C (7 °C higher than the control). Maximum temperatures al 15 cm depth in the fine sandy loam plot were 44 °C and 36 °C in solarized and control plots, respectively.

6.2.3.2 Reniform Nematode, *Rotylenchulus reniformis*

R. reniformis was responsible for 42.25–49.02% loss in fruit yield of tomato (Subramanyam et al. 1990).

(i) Symptoms General symptoms include reduced root systems, leaf chlorosis, overall stunting of host plants, and reduced yields and plant longevity. Female nematodes and their eggs are often visible when plant roots are viewed under a dissecting microscope (Fig. 6.18).

(ii) Integrated Management

(a) Botanicals and Chemicals: Application of neem cake in the nursery at 100 g/m^2 followed by carbofuran at 1 kg a.i./ha in the main field significantly reduced the soil population of *R. reniformis* and enhanced the fruit yield of tomato by 67% (Anitha and Subramanian 1998).

(b) Bioagents and Chemicals: Integration of a bioagent, *P. lilacinus* with carbofuran at 1 kg a.i./ha was found effective in the management of reniform nematode, *R. reniformis* infecting tomato (Parvatha Reddy and Khan 1988; Table 6.18).

(c) Bioagents and Botanicals: Nursery bed treatment with *P. fluorescens* (with 1×10^9

Table 6.16 Integrated management of root-knot nematodes in tomato using botanicals and chemicals

Treatment/dose	% reduction in root galling	% increase in yield
Carbofuran (1 kg a.i./ha) + neem cake at 400 kg/ha	77.00	61.50
Carbofuran (1 kg a.i./ha) + urea (23.8 kg/ha) + neem cake at 200 kg/ha	67.90	49.20
Phenamiphos (1 kg a.i./ha) + neem cake at 400 kg/ha	74.90	39.70
Phenamiphos (1 kg a.i./ha) + urea (23.8 kg/ha) + neem cake at 200 kg/ha	67.90	31.43

Table 6.17 Effect of ammonium phosphate fertilization and soil solarization on galling of tomato roots by *Meloidogyne incognita*

Treatment and dosage	Root galling[a]	Number of fruits[b]	Fruit fresh wt. (g)	Vegetative fresh wt. (g)
Ammonium phosphate—100 mg, 1	2.0	5.9	90.8	604
Ammonium phosphate—100 mg, 1 + soil solarization	0.8	14.0	210.4	1,102
Ammonium phosphate—200 mg, 1	1.0	8.7	151.8	538
Ammonium phosphate—200 mg, 1 + soil solarization	0.3	14.5	206.4	1,080
Ammonium phosphate—300 mg, 1	0.9	12.3	175.1	690
Ammonium phosphate—300 mg, 1 + soil solarization	0.2	21.4	382.6	1,582
Ammonium phosphate—400 mg, 1	0.7	18.5	321.5	1,162
Ammonium phosphate—400 mg, 1 + soil solarization	0.0	26.1	502.7	1,668
Control	3.5	11.7	132.1	638
Soil solarization only	1.8	15.0	215.7	1,078
LSD	0.7	8.0	171.9	437
Factorial Analysis of Variance (ANOVA) fertilizer	0.01[b]	0.01[c]	0.01	0.01
Soil solarization	0.01	0.01	0.01	0.01
Fertilizer × soil solarization	NS	NS	NS	NS

NS no significant difference
[a] Based upon 0–4 rating scale
[b] Significance level
[c] Significance level

Fig. 6.18 Tomato root infected with *Rotylenchulus reniformis*

spores/g) and *P. chlamydosporia* (with 1×10^6 spores/g) each at 20 g/m^2 and field application of 5 t of enriched FYM with the above bioagents each at 5 kg significantly reduced reniform nematodes in tomato by 72% over control. The yield increase was up to 21.7% with benefit to cost ratio of 4.9.

6.2.3.3 Root-knot Nematode, *M. incognita* and Wilt, *F. oxysporum* f. sp. *lycopersici* Disease Complex

(i) Symptoms The effect of the nematode in combination with the fungus enhanced the suppression of plant growth than that of the fungus alone. Inoculation of the nematode and fungus exhibited a synergistic effect on growth retardation of plants. Maximum reduction in plant height (33.08 cm) was observed when nematode and fungus were inoculated simultaneously.

Jenkins and Coursen (1957) induced wilting in *Fusarium* wilt-resistant tomato variety 'Chesapeake' only when root-knot nematodes were

Table 6.18 Effect of *Paecilomyces lilacinus* and carbofuran on *Rotylenchulus reniformis* infecting tomato

Treatment	Dose	Mature females in root/plant	Total nematode population/plant	Reproduction factor	% males
P. lilacinus	0.5 g/plant	29	3,893	3.8	45.2
P. lilacinus	1.0 g/plant	9	3,257	3.3	53.1
P. lilacinus	2.0 g/plant	14	2,232	2.2	49.2
P. lilacinus + carbofuran	2.0 g/plant + 2 kg a.i./ha	9	1,537	1.5	56.1
Carbofuran	2 kg a.i./ha	8	1,160	1.2	65.3
Control	–	57	6,669	6.7	42.8
Critical Difference (CD) (P = 0.05)	–	*5.8*	*2,011*	–	*15.9*

Fig. 6.19 The simultaneous occurrence of both root-knot nematode (*Meloidogyne* spp.) and *Fusarium* wilt causing enhanced disease development and tomato yield loss

present along with fungal inoculum. Furthermore, when *Meloidogyne hapla* was combined with the fungus, only 60% of the plants wilted, whereas *M. incognita acrita* promoted wilt in 100% of the plants (Fig. 6.19).

(ii) Integrated Management

(a) Bioagents and Botanicals: Tomato roots that received *P. lilacinus* along with *T. harzianum* and neem cake were free from root-knot nematodes (*M. incognita*) and did not wilt due to *F. oxysporum* f. sp. *lycopersici* till harvest. The roots were also free from *Fusarium* infection. The above treatment also reduced the percentage of wilt (10% compared with 90% in control), root-knot index (1.8 compared with 4.4 in control) and increased root colonization with bioagents (74% compared to 0% in control), parasitization of egg masses (56% compared with 0% in control) and eggs/egg mass (44% compared with 0% in control) (Nagesh et al. 2006; Table 6.19).

(b) Bioagents, Cultural and Host Resistance: Deep ploughing and exposing soil to hot sun in summer, removal and burning of crop debris, soil application of *T. viride* and *P. lilacinus*, use of wilt resistant varieties like Utkal Pallavi, Utkal Deepti, Utkal Kumari, Utkal Urbasi, etc. help in controlling the disease complex.

(c) AMF and Botanicals: Bhagawati et al. (2000) demonstrated that although the mustard cake and AMF, *Glomus etunicatum* were effective in reducing the damage caused by *M. incognita* and *F. oxysporum* f. sp. *lycopersici* on tomato, the performance of concomitant application of both (bioagent and botanical) was much better than the individual application.

Table 6.19 Effect of integration neem cake and bioagents on the management of *Meloidogyne incognita* infecting tomato

Treatment	Healthy plants (%)	Root-knot index	Colonization by bioagents		
			Root colonization (%)	Colonization of egg masses/eggs (%)	
				Egg masses	Eggs
Control	10	4.4	–	–	–
P. lilacinus	30	3.6	48	48	46
T. harzianum	40	4.0	50	44	32
Neem cake	10	4.2	–	–	–
P. lilacinus + neem cake	60	2.8	62	62	58
T. harzianum + neem cake	70	3.8	68	36	32
P. lilacinus + *T. harzianum* + neem cake	90	1.8	74	56	44
Critical Difference (CD) (P = 0.05)	*8.87*	*1.78*	*3.66*	*4.11*	*3.22*

Table 6.20 Effect of *Meloidogyne incognita* and *Rhizoctonia solani* on plant growth and fruit yield of tomato cv. K-25

Treatment	Fruit yield (kg/plant)	Plant height (cm)	Root-knot index	% root infection by *R. solani*
Untreated uninoculated	2.530	67.5	–	–
M. incognita (4,000 J_2/4 kg soil)	1.280	50.8	3.50	–
R. solani (10 g mycelial mat/4 kg soil)	1.440	53.7	–	30.0
M. incognita + *R. solani* simultaneously	0.487	26.7	2.00	63.5
M. incognita 7 days prior to *R. solani*	0.658	31.8	2.50	55.0
R. solani 7 days prior to *M. incognita*	0.821	40.0	1.35	48.5
Critical Difference (CD) (P = 0.05)	–	*2.41*	*0.13*	*2.65*

6.2.3.4 Root-Knot Nematode, *Meloidogyne* spp. and Root Rot, *R. solani* Disease Complex

(i) Symptoms Abu-Elamayem et al. (1978) observed that damping-off of tomato was more severe in soil infested with both *M. javanica* and *R. solani* than with the fungus alone. *M. javanica* increased the extent of damage by pre- and post-emergence phases of damping off caused initially by *R. solani* in tomato.

M. incognita and *R. solani* are also frequently associated with tomato causing considerably greater damage to this crop (Haseeb 2003). Highest reduction in fruit yield and plant height was observed in plants inoculated with nematode-fungus simultaneously followed by nematode 7 days prior to fungus. The highest root-knot index (3.5) was observed in plants inoculated with nematode alone followed by nematode inoculation 7 days prior to the fungus (Table 6.20). The highest root infection by the fungus was observed in simultaneous inoculation followed by nematode inoculation 7 days prior to the fungus (Kumar and Haseeb 2009). The fact that prior inoculation of nematode caused more damage indicates that the roots are predisposed by *M. incognita* for subsequent damage by *R. solani*.

(ii) Integrated Management

(a) Two Bioagents: Combined application of *Pseudomonas aeruginosa* and *P. lilacinus* significantly suppressed soil-borne root-infecting fungi such as *Macrophomina phaseolina, F. oxysporum, Fusarium solani, R. solani* and *M. javanica. P. lilacinus* parasitized eggs and female of *M. javanica* and this parasitism was not significantly influenced in the presence of *P. aeruginosa* (Siddiqui et al. 2000).

P. aeruginosa–B. subtilis treatment was the most effective in the suppression of root-rot disease complex with enhancement of plant growth (Siddiqui and Ehteshamul-Haque 2001).

Fig. 6.20 Root-knot nematode and bacterial wilt disease complex

6.2.3.5 Root-knot Nematode, *M. incognita* and Bacterial Wilt, *R. solanacearum* Disease Complex

Pani and Das (1972) have reported the association of root-knot nematode with bacterial wilt of tomato.

(i) Symptoms Haider et al. (1987) reported the significant reduction in the root-knot index and larval development of *M. incognita* in soil where *R. solanacearum* was present. *R. solanacearum* and *M. incognita* alone as well as in different combinations reduced plant growth and yield significantly with the nematode followed by the bacterium combination showing the maximum reduction in growth.

Napiere (1980) and Napiere and Quinio (1980) found that wilt disease development occurred earlier and with a higher mortality rate in both wilt-resistant and susceptible tomato cultivars grown in *R. solanacearum* and *M. incognita*-infested soil (Fig. 6.20).

(ii) Integrated Management

(a) Bioagents and Botanicals: Treatment of nursery bed with *P. fluorescens* (10^9 cfu/g) and *T. harzianum* (10^6 cfu/g) each at the rate of 20 g/m^2 and subsequent application of 5 t of farm yard manure enriched with 5 kg each of *P. fluorescens* (10^9 cfu/g) and *P. lilacinus* (10^6 cfu/g) per hectare, significantly reduced *R. reniformis* and *M. incognita* in tomato roots by 74 and 70%, respectively; reduced the incidence of bacterial wilt; and increased the yield by 24.2%. Benefit to cost ratio (calculated for the additional cost of the biopesticides and additional returns accrued by the application of the bio-pesticide) was 4.4 (Rao et al. 2009).

6.2.4 Validated IPM Technology for Tomato

6.2.4.1 Bangalore, Karnataka

Nursery

- Prepare raised seed bed of 15 cm height.
- Solarize soil for 3 weeks using transparent polythene sheet of 45 µm thickness.
- Grow leaf curl resistant hybrid/varieties like Avinash-2.
- Treat seed with *T. viride* at 4 g/kg of seed.
- Use nylon nets to prevent entry of white fly, etc.

Main field

- Apply neem cake at 250 kg/ha while planting or 20 DAP.
- Give wide spacing of 90 × 60 cm.
- Dip seedling roots in imidacloprid at 0.5 mL/L for 15 min before transplanting.
- Transplant 1 row of African marigold as trap crop for *H. armigera* after every 14 rows of tomato.
- Spray imidacloprid/thiomethoxam at 0.5 mL/L at 15 DAP for white fly.
- Spray 5% NSKE at 15 DAP against leaf miner.
- Install pheromone traps at 5/ha 20 DAP for monitoring of *H. armigera*.
- Monitor top three leaves for *H. armigera* eggs at flowering.

Table 6.21 Yield and economics of IPM in tomato at different locations

Centre	Yield (t/ha)	Net returns (₹)	Benefit-to-cost ratio
Bangalore			
IPM	74.03	249,721	4.82
Non-IPM	45.05	69,704	0.61
Varanasi			
IPM	14.25	39,917	3.30
Non-IPM	13.00	38,167	2.02
Ranchi			
IPM	22.29	56,705	1.87
Non-IPM	18.77	41,776	1.32

- Release of *T. pretiosum* at 1 lakh/ha six times after appearance of adults.
- Spray *Ha*NPV at 250 LE/ha or neem soap three times at 28, 35 and 42 DAP.
- Regularly collect and destroy damaged fruits.
- Spray endosulfan at 650 g a.i./ha against *H. armigera*.
- Destroy leaf curl and wilt-affected plants.
- Spray mancozeb/captan at 0.2% for the control of early and late blight.

6.2.4.2 Varanasi, Uttaranchal

Nursery

- Prepare raised seed bed of 15 cm height.
- Solarize soil for 3 weeks using transparent polythene sheet of 45 µm thickness.
- Treat seed with *T. viride* at 4 g/kg of seed.
- Spray 0.2% copper oxychloride.

Main field

- Spray imidacloprid at 0.5 mL/L at 15 DAT.
- Install pheromone traps at 5/ha, for monitoring of *H. armigera*.
- Spray *Ha*NPV at 250 LE/ha.
- Release of *Trichogramma bactrae* at 1 lakh/ha six times.
- Regularly collect and destroy damaged fruits.
- Apply pesticides like thiomethoxam and mancozeb at 0.2% based on needs.

6.2.4.3 Ranchi, Jarkhand

Nursery

- Prepare raised seed bed of 15 cm height.
- Solarize soil for 3 weeks using transparent polythene sheet of 45 µm thickness.
- Grow leaf curl resistant hybrid/varieties like Avinash-2.
- Treat soil with FYM enriched with *T. viride* at 1 kg/t.

Main field

- Spray imidacloprid at 0.5 mL/L at 15 DAT.
- Install pheromone traps at 5/ha, for monitoring of *H. armigera*.
- Monitor top three leaves for *H. armigera* eggs at flowering.
- Release of *T. chilonis* at 1 lakh/ha six times after appearance of adults.
- Spray *Sl*NPV at 250 LE/ha twice at 15 days' interval or *Ha*NPV for *H. armigera*.
- Regularly collect and destruct damaged fruits from time to time.
- Apply pesticides like endosulfan at 0.07% based on needs.

During the period 2001–2004, IPM technology in tomato was validated and promoted in more than 40 ha area in 42 villages covering 88 families located 40 km from Bangalore. Similarly, near Varanasi IPM technology has been validated in 8 villages in about 40 ha area covering 100 families. Near Ranchi, IPM technology has been validated and promoted in 20 villages with the support of 100 farming families covering an area of 40 ha together. In IPM validation studies conducted at three locations (Bangalore, Varanasi and Ranchi), IPM fields recorded higher tomato fruit yields of 74.038, 14.250 and 22.293 t/ha as compared to 45.056, 13.000 and 18.772 t/ha in non-IPM fields, respectively (Sardana et al. 2004; Table 6.21). The cost of production of tomato by IPM was ₹ 0.95/kg as against ₹ 2.30 in non-IPM plots.

Khaderkhan et al. (1998) observed that the farmers who adopted the IPM technology sprayed eight times and spent ₹ 6,628/ha, where as the non-adopters applied 17 sprays and spent ₹ 11,362/ha. Thus, on an average non-adopters spent ₹ 4,734/ha extra money. Net returns in the farmers practice was ₹ 47,359/ha with a benefit to cost ratio of 1.08 as compared with ₹ 60,168/ha net profit and 1.53 benefit to cost ratio by IPM followers (Table 6.22)

Table 6.22 Economic analysis of IPM practice in tomato

Practice	Yield (t/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Benefit-to-cost ratio
Farmers practice (non-IPM adopters)	49.400	91,375	47,359	1.08
IPM practice (IPM adopters)	62.280	99,450	60,168	1.53

Fig. 6.21 Shoot and fruit borer damage on brinjal

6.3 Brinjal, *Solanum melongena*

6.3.1 Insect Pests

6.3.1.1 Shoot and Fruit Borer, *Leucinodes orbonalis*

This is the most important pest on brinjal not only in India, but also in all the South Asian countries. This pest has developed resistance against all groups of insecticides and management is very difficult. Often the extent of damage due to this pest reaches up to 70–80%. Damage is very severe during rainy season and early winter.

(i) Damage Caterpillars feed inside the tender shoots before flowering and cause wilting of the affected shoots (Fig. 6.21). Later, the larvae bore into flowers, flower buds and the grown up larvae migrate and bore fruits contaminating them with excreta (Fig. 6.21). When the incidence is high, unopened flower buds swell and harbour the borer. Just before pupation, the grown up larvae come out of the fruits and flower buds to pupate in silky cocoons on plant parts or debris.

(ii) Integrated Management

(a) Botanicals and Cultural: Combination of clipping of shoots affected by the borer at weekly interval followed by neem cake application (250 kg/ha) at 30 DAP and 4% pulverized NSPE/1% neem soap/1% pongamia soap sprays at 60, 75, 90 and 105 DAP was most effective with 22% borer damage as compared with 46% in control (Krishnamoorthy and Krishna Kumar 2002) (Table 6.23).

(b) Bioagents and Chemicals: Minimum brinjal fruit infestation by *L. orbonalis* (3.74%) and maximum fruit yield (16.410 t/ha) was recorded in treatment of *B. thuringiensis* var. *kurstaki* (*Btk*) + methomyl (1.0 mL + 0.8 g/L of water) as against 12.34% fruit damage and 9.977 t/ha fruit yield in untreated control. Treatment of *Btk* + endosulfan (1.0 mL + 0.75 mL/L of water) was on par with the above treatment (Quereshi et al. 1998) (Table 6.24).

B. thuringiensis (Dipel) in combination with carbaryl (Baskaran and Kumar 1980) was found to be more effective in reducing borer damage in brinjal fields and giving maximum fruit yield.

Setting of pheromone traps integrated with release of egg parasitoid *T. chilonis* at 5.0 lakh/ha from flower initiation, and spraying of *B.*

Table 6.23 Incidence of shoot and fruit borer of brinjal under different treatments

Treatments	Cumulative % of borer infestation	Yield (kg/plot)
Soil application of neem cake at 250 kg/ha at 30, 60 and 90 DAP	30.05	5.96
Shoot clipping at weekly interval + neem cake at 30 DAP + 4% NSKE spray at 60, 75, 90 and 105 DAP	22.04	6.72
Barrier crop of maize sown 10 days before brinjal planting (2 rows at 30 cm from brinjal and maize at 5 cm form plant to plant) + shoot clipping at weekly interval + 4% NSKE spray at 45, 60, 75 and 90 DAP	23.51	6.53
Barrier crop as above + shoot clipping + endosulfan 700 g a.i./ha alternated with cypermethrin at 50 g a.i./ha at 45, 60, 75 and 90 DAP	29.44	9.01
Cypermethrin at 50 g a.i./ha at 45, 60, 75 and 90 DAP	36.62	9.59
4% NSKE spray at 45, 60, 75 and 90 DAP	28.54	14.33
Control	45.90	5.33
Critical Difference (CD) (P = 0.05)	*2.71*	*3.40*

DAP days after planting, *NSKE* neem seed kernel extract

Table 6.24 Bioefficacy of *Btk* and insecticides for the management of *Leucinodes orbonalis* on brinjal

Treatment	Dose/L of water	Fruit damage (%)	Fruit yield (t/ha)
Btk (Dipel 8 L)	1.5 mL	10.33	10.549
Btk (Dipel 8 L)	2.0 mL	8.78	12.073
Btk + Endosulfan 35 EC	1.0 mL + 0.75 mL	4.74	15.666
Btk + Methomyl 40 SP	1.0 mL + 0.8 g	3.74	16.410
Endosulfan 35 EC	1.5 mL	6.10	12.939
Methomyl 40 SP	1.6 g	5.60	14.983
Control (untreated check)	–	12.34	9.977
Critical Difference (CD) (P = 0.05)	–	*3.07*	*2.000*

Btk Bacillus thuringiensis var. *kurstaki, EC* emulsifiable concentrate

thuringiensis var. *krustaki* at 2.0 mL/L once in 10 days' interval (a total of five sprays were given) recorded a mean infestation of 2.5%, followed by 3.1% fruit damages in treatment involving setting of pheromone trap integrated with weekly releases of egg parasitoid *T. chilonis*. A mean of 27.4% fruit damage was recorded when pheromone alone was erected (Ganga Visalakshy and Krishnamoorthy 2009).

(c) Botanicals and Chemicals: Neem oil at 4% recorded the minimum infestation of brinjal shoot and fruit borer (9.07%) which was on par with endosulfan 0.07% + neem oil 2% (9.49%), endosulfan 0.07% (9.56%), endosulfan 0.07% + NSKE 5% (9.98%) and NSKE 5% (10.89%). The maximum fruit yield was obtained in neem oil 4% (24.48 t/ha) which was on par with endosulfan 0.07% + neem oil 2% (23.53 t/ha), carbaryl 0.05% (23.15 t/ha) and endosulfan 0.07% (23.13 t/ha); see Raja et al. 1998 and Table 6.25.

(d) Two Bioagents: Spraying *B. thuringiensis* formulation (1%) at weekly interval followed by release of *T. chilonis* at 250,000/ha (50,000/release—five times at weekly intervals, starting from flowering) was found to reduce the borer incidence.

6.3.1.2 Epilachna Beetle, *Henosepilachna vigintioctopunctata*

(i) Damage Both grubs and adult beetles scrape the leaves in semi-circular or half moon-shaped fashion (Fig. 6.22). Heavy infestation results in leaf skeletonization. Pupation takes place on the plant itself.

(ii) Integrated Management

(a) Botanicals and Chemicals: Neem oil 2% + endosulfan 0.035% reduced the epilachna grub population by 57.3% and was comparable with endosulfan 0.07% alone (53.9%). The maximum

Table 6.25 Effect of neem products and insecticides on the shoot and fruit borer infestation and yield of brinjal

Treatment	Fruit borer damage (%)	% decrease over control	Marketable yield (t/ha)	% increase over control
Endosulfan 0.035%	16.6	61.38	20.15	54.28
Endosulfan 0.07%	9.56	77.76	23.13	77.11
Carbaryl 0.05%	10.89	74.66	23.15	77.26
Neem oil 2%	14.18	67.01	21.60	65.39
Neem oil 4%	9.07	78.90	24.48	87.44
NSKE 5%	10.89	74.66	21.85	67.30
Endosulfan 0.07% + neem oil 2%	9.49	77.92	23.53	80.17
Endosulfan 0.07% + NSKE 5%	9.98	76.78	21.86	67.38
Trichogramma chilonis release at fortnightly interval	16.18	62.35	20.30	55.44
Control	42.98	–	13.06	–
Critical Difference (CD) (P = 0.05)	*2.83*	–	*1.61*	–

Fig. 6.22 Epilachna beetle and grub damage on brinjal leaf

fruit yield was obtained in endosulfan 0.07% alone (5.99 t/ha), which was on par with endosulfan 0.07% + neem oil 2% (5.64 t/ha); see Rajendran 1998 and Table 6.26.

6.3.2 Diseases

6.3.2.1 Damping-off, *Pythium aphanidermatum*

(i) Symptoms The pathogen causes pre- and post-emergence damping off in the nursery beds. In pre-emergence phase of disease, the young seedlings are killed before they emerge through the soil surface. In fact, the seeds may rot or the seedlings may be killed before the hypocotyl has broken the seed coat. The radical and the plumule, when they come out of the seed, undergo complete rotting. Since this happens under the soil surface, the disease is often not recognized by the farmer, who attributes the failure of emergence to poor quality of the seed.

The post-emergence mortality of seedlings is generally very conspicuous. This phase of the disease is characterized by the toppling over of infected seedlings any time after they emerge from the soil (Fig. 6.23) until the stem has hardened sufficiently to resist invasion. Infection usually occurs through the roots or at the ground level. The infected tissue appears soft, stained and water soaked. As the disease advances, the stem becomes constricted at the base and the plant collapses. Seedlings that are apparently healthy one day may have collapsed by the following morning. Generally, the cotyledons and leaves wilt slightly before the seedlings are prostrated, although sometimes they remain green and turgid until collapse occurs. In fields and nurseries, the disease usually radiates from initial infection points, causing large spots or areas in which nearly all the seedlings are killed.

(ii) Integrated Management

(a) Physical and Bioagents: Combination of the seed/root application of *T. harzianum* or *P. fluorescens* with soil solarization was very effective

Table 6.26 Effect of neem oil and endosulfan on epilachna beetle on brinjal

Treatment	*Epilachna* grubs/5 plants	% reduction over control	Fruit yield (t/ha)
Neem oil 1%	8.75	20.2	4.12
Neem oil 2%	7.90	27.3	4.56
Neem oil 3%	6.29	41.1	4.98
Neem oil 4%	5.30	49.2	5.49
Neem oil 2% + Endosulfan 0.035%	4.60	57.3	5.64
Endosulfan 0.035%	4.70	53.9	5.99
Teepol	10.30	13.8	4.41
Control	11.30	11.3	4.24
Critical Difference (CD) (P = 0.05)	*0.48*	–	*0.62*

Fig. 6.23 Damping-off symptoms on brinjal seedlings

for the management of damping-off in brinjal nursery at farmers' field.

(b) Physical, Chemical and Bioagents: Soil solarization gave least damping-off followed by seed treatment with captan + soil drenching with captan which was on par with seed treatment with *T. viride* + soil application of FYM enriched with *T. viride* (Table 6.27; Rahman et al. 2002).

6.3.2.2 *Fusarium* Wilt/Root Rot, *F. oxysporum, F. solani*

(i) Symptoms Affected plants show yellowing of leaves that progressively wilt and die from bottom upwards (Fig. 6.24). Woody stem and root tissue of diseased plants turn brown.

(ii) Integrated Management

(a) Physical and Chemical/Botanical/Bioagent: The effect of solarization, and its combinations with dazomet (400 kg/ha), chicken manure (10t/ha) or *Trichoderma*, on soil-borne diseases (*Fusarium* spp.) were detected in eggplant. Solarization with dazomet and solarization and manure gave better disease control compared to other treatments (Table 6.28).

6.3.2.3 Collar Rot, *Sclerotinia sclerotiorum*

(i) Symptoms Infection takes place on leaves, twigs, flowers and fruits (Fig. 6.25). Water-soaked lesions develop and the infected tissue is macerated by the pathogen. White mass of mycelium grow on the surface and later embedded sclerotia are formed (Fig. 6.25). These sclerotia become black after drying. The pathogen is soil-borne. The disease affects plant population, yield and quality of the fruits.

(ii) Integrated Management

(a) Physical and Chemical/Botanical/Bioagent: The effect of solarization, and its combinations with dazomet (400 kg/ha), chicken manure

Table 6.27 Comparative efficacy of soil solarization, bioagents and fungicide against damping-off of brinjal

Treatment	% disease index
Soil solarization with transparent polythene sheets for 30 days	1.50 (6.93)
Seed treatment with *Trichoderma viride* at 4 g/kg + soil application of 50 kg FYM enriched with 500 g of *T. viride*	4.74 (12.40)
Seed treatment with *Pseudomonas fluorescens* at 10 g/kg + soil application of 50 kg FYM enriched with 2.5 kg of *P. fluorescens*	7.20 (15.37)
Seed treatment with *Trichoderma harzianum* at 4 g/kg + soil application of 50 kg FYM enriched with 500 g of *T. harzianum*	6.31 (14.40)
Seed treatment with *Azotobacter croococcum* at 16 g/kg + soil application of 50 kg FYM enriched with 500 g of *A. croococcum*	10.88 (19.17)
Seed treatment with captan at 2.5 g/kg + soil drenching with captan at 0.25 % at 6 L/m^2	4.38 (11.55)
Control (check)	42.82 (29.74)
Critical Difference (CD) at 5 %	*(3.13)*

Figures in parentheses indicate the arc sin transformed values

Fig. 6.24 *Fusarium* wilt on brinjal

(10 t/ha) or *Trichoderma*, on soil borne diseases (*S. sclerotiorum*) was observed in the field. Solarization + *Trichoderma* controlled diseases better than solarization + dazomet or solarization + manure (Table 6.29).

(b) Physical and Bioagents: Summer ploughing and seedling dip treatment with *T. viride* effectively controlled the disease incidence at all the growth stages up to the maturity of crop (185 to 205 DAT) (Jadon 2009).

Table 6.28 Effect of integration of soil solarizaton, chemical, organic amendment and bioagent on disease incidence in eggplant

Treatment	% disease
Soil solarization + dazomet	20
Soil solarization + chicken manure	20
Soil solarization + *Trichoderma*	31.2
Check	57.5

6.3.2.4 Root Rot, *Rhizoctonia solani*

(i) Symptoms Generally early transplanted brinjal crop is much affected during the months of August–September. Lesions start on stem near collar region at or below the soil level and expand downward into the roots. Initially the bark becomes wet, soft with macerated tissue. Later on, drooping and wilting of the plant is observed. The disease is more common in poorly drained soil and the fields having prolonged excessive moisture.

(ii) Integrated Management

(a) Bioagents and Chemicals: Combined treatments of the fungicide Pentachloronitrobenzene (PCNB) and *T. harzianum* decreased the inoculum potential of *R. solani* and increased the disease control in comparison to separate treatments for the control of damping-off of eggplant (Hadar et al. 1979).

Fig. 6.25 Collar rot symptoms on brinjal

Table 6.29 Effect of integration of soil solarizaton, chemical, organic amendment and bioagent on disease incidence in eggplant

Treatment	% disease
Soil solarization + dazomet	10.5
Soil solarization + chicken manure	11.2
Soil solarization + *Trichoderma*	9.1

6.3.3 Nematodes

6.3.3.1 Root-knot Nematode, *Meloidogyne* spp.

M. incognita was responsible for 27.30–48.55% loss in fruit yield of brinjal (Bhatti and Jain 1977; Parvatha Reddy and Singh 1981; Darekar and Mahse 1988).

(i) Symptoms Affected plants are normally stunted and eventually wilt and die. The most characteristic symptom is formation of root galls (knots) and these can be seen with the naked eye (Fig. 6.26). The infested roots eventually rot and affected plants die.

(ii) Integrated Management

(a) Bioagents and Botanicals: Integration of *P. chlamydosporia* (at 100 mL/ seed pan containing 1.2×10^4 spores/mL) in castor cake (at 40 g/ seed pan)-amended soil was effective in increasing the seedling weight and colonization of roots with the bioagent.

Brinjal seedlings raised in the above treatment transplanted in pots gave maximum increase in plant growth, root colonization and parasitization of eggs of *M. incognita* by *P. chlamydosporia*. The above treatment also gave least root galling and final nematode population both in soil and roots (Rao and Reddy 1993b; Table 6.30).

Borkakaty (1993) observed that inoculation of *P. lilacinus* at 4 g/kg of soil in combination with mustard oil cake at 0.5 and 1.0 t/ha increased plant growth with corresponding decrease in number of galls, egg masses and eggs/egg mass of *M. incognita* on brinjal.

Application of 10% neem cake extract (at 20 mL/pot) mixed with spores of *P. lilacinus* (at 1×10^6 spores/mL) was effective in increasing plant growth and reducing root galling and final nematode population both in soil and roots. The above treatment also gave maximum parasitization of egg masses of *M. incognita* and spore density of *P. lilacinus* in soil (Rao and Parvatha Reddy 1994).

Dipping of eggplant seedling (30 days' old seedlings raised in sterilized soil) roots in 5% and 10% neem leaf suspensions mixed with *P. lilacinus* at 4×10^5 spores/mL for 30 min before transplanting gave significant reduction in root galling and final population of *M. incognita*. Further, significant increases were observed on the colonization of *P. lilacinus* on the roots of eggplant and parasitization of eggs of *M. incognita*, indicating the complementary interaction between these two components for the effective management of root-knot nematodes on eggplant (Rao et al. 1997b; Table 6.31).

Root-dip treatment of brinjal seedlings in neem cake extract-based formulation of *P. lilacinus* (at 5×10^6 spores/mL) for 20 min and planted in pots gave significant increase in plant growth,

Fig. 6.26 Root-knot nematode on brinjal

Table 6.30 Effect of integration of castor cake and *Pochonia chlamydosporia* on root galling, final nematode population, root colonization and egg parasitization in eggplant infected with *Meloidogyne incognita*

Treatment	Rot-knot index	Final nematode population (soil + roots)	*P. chlamydosporia* root colonization (cfu/g)	% parasitization of egg masses by *P. chlamydosporia*
Castor cake	3.2	3,474	–	–
P. chlamydosporia	2.7	2,863	3,578	53
Castor cake + *P. chlamydosporia*	2.0	1,746	5,102	71
Control	4.3	6,497	–	–
Critical Difference (CD) (P = 0.05)	*0.25*	*349.75*	*415.35*	*5.32*

cfu colony-forming units

Table 6.31 Effect of root dip treatment with *Paecilomyces lilacinus* and neem leaf suspension on root galling, root colonization, spore density in soil and parasitization of eggs of *Meloidogyne incognita* infecting brinjal

Treatment	Root-knot index	Final nematode population (soil + roots)	*P. lilacinus* root colonization (cfu/g)	*P. lilacinus* spore density in soil (cfu/g)	Parasitization of eggs by *P. lilacinus* (%)
P. lilacinus	2.8	3,832	32,540	20,560	53
NLS—5 %[a]	3.1	5,346	–	–	–
NLS—10 %[a]	2.7	4,056	–	–	–
P. lilacinus + NLS—5 %	2.4	2,964	36,680	25,640	59
P. lilacinus + NLS—10 %	2.1	2,356	39,460	27,690	64
Control	4.2	8,258	–	–	–
Critical Difference (CD) (P = 0.05)	*0.46*	*785.32*	*3,050.76*	*2,850.78*	*4.59*

NLS neem leaf suspension

root colonization, propagule density in soil and parasitization of eggs of *M. incognita* by *P. lilacinus* and drastic reduction in root galling, fecundity and final nematode population in soil and roots (Rao et al. 1998d).

Application of castor cake extract-based formulation of *T. harzianum* (at 500 mL/m^2 containing 9.9×10^3 spores/mL) to nursery beds of brinjal was effective in producing vigorous seedlings (with maximum seedling weight) with least root galling. The above treatment also increased root colonization and parasitization of *M. incognita* females by *T. harzianum* (Rao et al. 1998c; Table 6.32).

Integration of neem seed powder/neem cake with *P. lilacinus* gave effective control of root-knot and reniform nematodes infecting brinjal (Table 6.33).

Soil application of poultry manure at 10 t/ha a week prior to transplanting + *P. lilacinus* (10^9/

Table 6.32 Effect of oil cake-based *Trichoderma harzianum* on root galling, root colonization, and egg parasitization of egg plant infected with *Meloidogyne incognita*

Treatment	No. of galls/100 seedlings	*T. harzianum* root colonization (cfu/g)	% parasitization of eggs by *T. harzianum*
NCE—10%	62	–	–
CCE—10%	58	–	–
PCE—10%	64	–	–
10% NCE-based *T. harzianum*	60	13,746	43
10% CCE-based *T. harzianum*	57	15,625	51
10% PCE-based *T. harzianum*	61	12,242	42
T. harzianum (grown on paddy seeds)	69	9,648	30
Control	93	–	–
Critical Difference (CD) (P = 0.05)	*8.56*	*94.75*	*4.26*

NCE neem cake extract, *CCE* castor cake extract, *PCE Pongamia* cake extract

Table 6.33 Integrated management of *Meloidogyne incognita* and *Rotylenchulus reniformis* in brinjal using botanicals and biocontrol agents

Treatment	No. of galls/plant	Nematode population in soil (100 mL)	
		M. incognita	*R. reniformis*
NSP	25	125	200
NC	27	125	250
Paecilomyces lilacinus	31	150	258
Pochonia chlamydosporia	32	167	242
NSP + *Paecilomyces lilacinus*	10	100	167
NSP + *Pochonia chlamydosporia*	13	108	208
NC + *Paecilomyces lilacinus*	14	108	192
NC + *Pochonia chlamydosporia*	18	117	208
Control	41	200	375

NSP neem seed powder, *NC* neem cake

conidia/g) at 25 kg spore dust with carrier/ha at the time of transplanting; or neem cake at 2 t/ha a week prior to transplanting + *P. lilacinus* (10^9/conidia/g) at 25 kg spore dust with carrier/ha at the time of transplanting; or carbofuran at 2 kg/ha in two equal splits (one at the time of transplanting and the other after 75 days) + *P. lilacinus* (10^9/conidia/g) at 25 kg spore dust with carrier/ha at the time of transplanting considerably reduced root galling and also gave higher brinjal fruit yield over control (Vyas et al. 2009; Table 6.34).

(b) AMF and Botanicals: Brinjal seedlings raised in nursery treated with *G. fasciculatum* (at 250 g/m^2 containing 16 chlamydospores/g) planted in pots amended with castor cake (applied at 10 g/kg soil 15 days before transplanting) resulted in maximum plant growth, root colonization with *G. fasciculatum* and chlamydospore density in soil and least root galling, fecundity and final nematode population in soil and roots (Rao et al. 1998f; Table 6.35).

Integration of *G. fasciculatum* and neem cake at 0.5 t/ha was found to be effective in increasing plant growth parameters and yield (30 t/ha compared with 17 t/ha in control) and in reducing the root-knot index (2.6 compared with 4.8 in control) and final nematode population (173.3/250 mL soil compared with 510.8/250 mL soil in control) (Borah and Phukan 2000).

(c) Bioagents and AMF: Brinjal seedlings raised in seed pans treated with *G. mosseae* (at 100 g/seed pan containing 28–32 chlamydo spores/g) dipped in *P. lilacinus* spore suspension (containing 4×10^5 spores/mL) for 5 min and transplanted in pots gave maximum increase in plant growth, root colonization, propagule densi-

Table 6.34 Effect of different organic amendments, bioagent and nematicide for the management of *Meloidogyne incognita* infecting brinjal

Treatment	Gall index (0–5 scale)	Yield (t/ha)	ICBR
P. lilacinus at 25 kg/ha + poultry manure at 10 t/ha	2.0	42.088	1:18.5
P. lilacinus at 25 kg/ha + mustard cake at 2 t/ha	2.0	44.801	1:7.7
P. lilacinus at 25 kg/ha + neem cake at 2 t/ha	1.8	41.745	1:5.8
P. lilacinus at 25 kg/ha + carbofuran at 2 kg a.i./ha	1.9	41.498	1:13.6
P. lilacinus at 25 kg/ha	2.5	39.941	1:77.6
Poultry manure at 10 t/ha	2.3	40.000	1:18.5
Mustard cake at 2 t/ha	1.9	41.810	1:6.7
Neem cake at 2 t/ha	1.9	39.954	1:5.2
Carbofuran at 2 kg a.i./ha	2.0	40.530	1:14.9
Control	3.9	28.107	–

ICBR incremental cost–effectiveness ratio

Table 6.35 Effect of integration of castor cake and *Glomus fasciculatum* on root galling, final nematode population, root colonization and egg parasitization in eggplant infected with *Meloidogyne incognita*

Treatment	Root-knot index	Final nematode population (soil + roots)	No. of eggs/egg mass	% root colonization by *G. fasciculatum*	*G. fasciculatum* chlamydospore density in 10 g soil
G. fasciculatum	6.2	5,349	356	61	53
Castor cake—5 g	5.7	4,756	426	–	–
Castor cake—10 g	5.1	3,431	458	–	–
G. fasciculatum + Castor cake—5 g	4.4	2,934	295	73	72
G. fasciculatum + Castor cake—10 g	4.1	2,346	263	78	80
Control	8.3	9,398	584	–	–
Critical Difference (CD) (P = 0.05)	*1.25*	*814.36*	*27.52*	*9.95*	*10.32*

Table 6.36 Effect of integration of *Glomus mosseae* and *Paecilomyces lilacinus* on root galling, final nematode population, root colonization and egg parasitization in eggplant infected with *Meloidogyne incognita*

Treatment	Root-knot index	Final nematode population	*P. lilacinus* root colonization (cfu/g)	% root colonization by *G. mosseae*	Parasitization of eggs by *P. lilacinus* (%)
G. mosseae	3.0	4,876	–	62	–
P. lilacinus	2.7	3,252	35,240	–	52
G. mosseae + *P. lilacinus*	2.3	2,564	37,270	64	65
Control	4.3	7,746	–	–	–
Critical Difference (CD) (P = 0.05)	*0.32*	*541*	*875*	*NS*	*5*

ty in soil of both *G. mosseae* and *P. lilacinus* and parasitization of eggs of *M. incognita*. The above treatment also gave least root galling, fecundity and final nematode population in soil and roots (Rao et al. 1998; Table 6.36).

(d) Bioagents, AMF and Botanicals: Inoculation of *G. fasciculatum* in the castor cake-amended nursery beds followed by the root-dip treatment of mycorrhizal seedlings of brinjal in spore suspension of *P. lilacinus* was found effective for the management of *M. incognita* (Rao et al. 1993b).

In nursery, soil application of neem cake at 400 g/m^2 along with *G. mosseae* (at 500 g/m^2 containing 26–32 chlamydospores/g) and *P. lilacinus* (at 2 L/m^2 containing 6×10^5 spores/mL)

Table 6.37 Effect of integration of *Glomus mosseae, Paecilomyces lilacinus* and neem cake on root galling, root colonization, egg parasitization and yield of egg plant infected with *Meloidogyne incognita*

Treatment	Rot-knot index	Yield (kg)/6 m^2	*P. lilacinus* root colonization (cfu/g)	% root colonization by *G. mosseae*	Parasitization of eggs by *P. lilacinus* (%)
G. mosseae	7.2	6.2	–	47	–
Neem cake	6.6	5.6	–	–	–
P. lilacinus	7.0	5.3	41,660	–	31
Neem cake + *G. mosseae*	5.9	7.3	–	58	–
Neem cake + *P. lilacinus*	5.7	6.9	59,600	–	36
G. mosseae + *P. lilacinus*	5.4	6.5	44,760	56	40
Neem cake + *G. mosseae* + *P. lilacinus*	4.8	7.8	51,382	50	51
Control	8.7	5.3	–	–	–
Critical Difference (CD) (P = 0.05)	*0.49*	*0.89*	*1,377.21*	*6.49*	*4.52*

resulted in production of healthy and vigorous brinjal seedlings colonized with *G. mosseae* and *P. lilacinus* and with least root galling. In field, transplanting of brinjal seedlings raised in the above treatment gave maximum reduction in root galling, egg mass production, fecundity and final nematode population in soil and roots. The above treatment also gave highest fruit yield, root colonization with *G. mosseae* and *P. lilacinus* and egg parasitization with *P. lilacinus* (Rao and Parvatha Reddy 2001; Table 6.37).

(e) Two Bioagents: Integration of highly toxic fungus, *A. niger* (kills most of the infective second stage juveniles) and an egg parasite, *Cladosporium oxysporum* (invades and kills the eggs in egg sac) both at half the dosages significantly reduced *M. incognita* population and exhibited better plant growth than when either of the fungal bioagents in brinjal (Goswami and Singh 2002).

In eggplant, the nursery seedling stand index was good with seed treatment with *P. fluorescens* (50 g/kg) + soil application of *P. fluorescens* (10 g/m^2 seed bed) followed by soil application of neem-based *T. harzianum* + *P. fluorescens* and neem-based *P. fluorescens*, where the crop stand index was 4.6 and 4.0, respectively.

Combined soil application of *P. lilacinus* and *A. niger* at the time of transplanting brinjal is very effective in reducing root-knot nematodes.

(f) Bioagents and Chemicals: Split application of *T. harzianum* at 50 kg/ha (10^8 cfu/g) (before transplanting and 45 days after transplanting) + carbofuran 3G at 16.5 kg/ha was effective in increasing the brinjal fruit yield (Haseeb et al. 2004).

(g) AMF/Bioagents and Chemicals: Integration of AMF *G. fasciculatum* at 25 g/m^2 (600 spores) with carbofuran at 0.5 kg a.i./ha gave significant increase in plant growth characters and yield with corresponding decrease in root galling and egg mass production, followed by *T. harzianum* at 2 g/kg soil + carbofuran at 0.5 kg a.i./ha (Saikia and Borah 2008; Table 6.38).

(h) Cultural and Chemicals: The planting of marigold combined with application of carbofuran at 1 kg a.i./ha controls *M. javanica* infestation on brinjal (Singh 1991).

Nursery treatment with carbofuran at 0.3 g a.i./m^2 along with main field treatment with ploughing + exposing the field and ploughing + covering with polythene sheets for 15 days improved the plant growth and yield of brinjal by 20–32 % (Sheela et al. 2002).

(i) Botanicals and Chemicals: Application of aldicarb at 1.0 kg a.i./ha in the nursery beds along with neem cake at 400 kg/ha increased yield and reduced root galling (Singh and Gill 1998; Table 6.39).

(j) Cultural and Physical: Integrating summer ploughing with soil solarization with polythene mulching effectively reduced *M. javanica* population in brinjal (Table 6.40; Jain and Gupta 1991).

(k) Physical and Botanicals: Soil solarization of nursery beds (using 100 gauge low-density polyethylene (LDPE) clear film for 15 days)

Table 6.38 Effect of integration of AMF/bioagents and carbofuran for the management of *Meloidogyne incognita* infecting brinjal

Treatment	% increase in yield	No. of galls/plant	No. of egg masses/plant	Nematode population/200 mL soil	Nematode population in roots
G. fasciculatum—25 g/m^2	70.12	51.73	29.30	265	2,486
P. penetrans—1 g/kg soil	56.49	77.86	61.93	324	3,372
T. harzianum—2 g/kg soil	55.84	138.93	116.86	310	3,078
Carbofuran—2 kg a.i./ha	43.50	40.76	33.83	147	1,608
G. fasciculatum—25 g/m^2 + carbofuran—0.5 kg a.i./ha	108.44	20.63	12.30	170	1,727
P. penetrans—1 g/kg soil + carbofuran—0.5 kg a.i./ha	68.83	33.63	22.43	214	2,320
T. harzianum—2 g/kg soil + carbofuran—0.5 kg a.i./ha	80.51	24.06	16.43	176	2,187
Control	–	366.10	211.30	527	5,558
Critical Difference (CD) (P = 0.05)	–	*4.944*	*17.33*	*16.6*	*18.55*

AMF arbuscular mycorrhizal fungus

Table 6.39 Integrated management of root-knot nematodes in brinjal with neem cake and nematicides

Treatment	% reduction in gall index	% increase in yield
Aldicarb (1.0 kg a.i./ha) + neem cake (400 kg/ha)	92.90	58.70
Carbofuran (1.0 kg a.i./ha) + neem cake (400 kg/ha)	68.10	68.10

Table 6.40 Integrated management of root-knot nematodes by summer ploughing/fallowing and soil solarization in brinjal

Treatment	Reduction in nematode population (%)		Yield in kg/m^2	
	Hisar	Vellayani	Hisar	Vellayani
Ploughing + fallowing for 15 days	87.00	66.20	28.98	–
Ploughing + covering with polythene sheet for 15 days	94.90	77.00	18.84	78.00
No ploughing + no covering	77.60	–	–	–

and application of neem cake at 200 g/m^2 proved most effective in reducing root-knot nematode infestation and increasing yield in brinjal. Solarization of nursery beds for 15 days in summer and application of poultry manure at 200 kg/ha gave maximum yield (Jain and Gupta 1991).

6.3.3.2 Reniform Nematode, *Rotylenchulus reniformis*

(i) Symptoms General symptoms include reduced root systems, leaf chlorosis, overall stunting of host plants, and reduced yields and plant longevity. Female nematodes and their eggs are often visible when plant roots are viewed under a dissecting microscope.

(ii) Integrated Management

(a) Bioagents and Chemicals: Integration of a bioagent, *P. lilacinus* with carbofuran at 1 kg a.i./ha was found effective in the management of reniform nematode, *R. reniformis* infecting brinjal (Parvatha Reddy and Khan 1989; Table 6.41).

(b) Botanicals, Bioagents and AMF: Inoculation of *G. fasciculatum* in the castor cake-amended nursery beds followed by the root-dip treatment of mycorrhizal seedlings of brinjal in spore suspension of *P. lilacinus* is effective for the management of *R. reniformis* (Rao et al. 1993b).

Table 6.41 Effect of *Paecilomyces lilacinus* and carbofuran on *Rotylenchulus reniformis* infecting brinjal

Treatment	Dose	Mature females in root/plant	Total nematode population/plant	Reproduction factor	% males
P. lilacinus	1 g/plant	12.00	1,086	1.09	27.00
P. lilacinus	2 g/plant	7.33	834	0.83	48.79
P. lilacinus	4 g/plant	5.33	315	0.31	60.00
P. lilacinus + Carbofuran	2.0 g/plant + 0.5 kg a.i./ha	6.67	704	0.70	55.02
P. lilacinus + Carbofuran	2.0 g/plant + 1.0 kg a.i./ha	4.67	389	0.39	34.81
Carbofuran	0.5 kg a.i./ha	8.67	961	0.96	33.33
Carbofuran	1.0 kg a.i./ha	10.00	551	0.55	30.77
Control	–	25.50	2,550	–	28.54
Critical Difference (CD) (P = 0.05)	–	*7.80*	*95.00*	–	–

Fig. 6.27 Root-knot nematode and bacterial wilt disease complex in brinjal

6.3.3.3 Root-knot Nematode, *M. incognita* and Bacterial Wilt, *R. solanacearum* Disease Complex

(i) Symptoms Eggplant is prone to many soil-borne diseases among which the bacterial wilt in combination with root-knot nematode takes heavy toll every year all over the world (Naik 2004; Fig. 6.27). Association of pathogenic and above pathogenic levels of inoculum of both *M. incognita* and *R. solanacearum* increased the severity of wilt on brinjal crops.

The combined pathogenic effects of *M. incognita* and *R. solanacearum* on a resistant brinjal cultivar (Pusa purple cluster) provided synergistic effect towards the development of wilt symptoms and negatively influenced different plant growth parameters such as shoot length, shoot weight, root length and root weight.

(ii) Integrated Management

(a) Two Bioagents: Combined formulation of *T. harzianum* and *P. chlamydosporia* performed very well on disease complex. The yield was 2.024 kg/3 m^2 followed by combination of *P. fluorescens* + *P. chlamydosporia* (1.782 kg) and *T. harzianum* + *P. fluorescens* (1.680 kg). Root gall index (RGI) and wilt disease incidence (WDI) due to *R. solanacearum* was minimum in combination treatment of *T. harzianum* + *P. chlamydosporia* followed by *P. fluorescens* + *P. chlamydosporia* and *T. harzianum* + *P. fluorescens* where the RGI was 1.8, 1.81 and 1.93, respectively, and that of WDI was 22.18 %, 25.13 % and 27.28 %, respectively (Naik 2004).

(b) Cultural, Chemicals, Botanicals and Bioagents: Integration of two summer ploughing during May–June, half recommended dose each of carbofuran (0.75 kg a.i./ha), neem cake (7.5 g/spot), streptocycline (250 ppm at 30 mL/spot) and full dose of *T. harzianum* (150 g/spot) improved plant growth parameters and fruit yield with corresponding decrease in the nematode reproduction rate (*M. incognita*), bacterial population in the soil and bacterial wilt incidence (*R. solanacearum*) in brinjal (Hussain and Bora 2008) (Table 6.42).

6.3.3.4 Root-knot Nematode, *M. incognita* and Wilt, *Fusarium* spp. Disease Complex

Brinjal was not susceptible to *F. oxysporum* unless *M. incognita* was also present (Smits and Noguera 1982; Fig. 6.28).

Table 6.42 Effect of integration of different practices for the management of disease complex in brinjal

Treatment	No. of galls/ root system	No. of egg masses/ root system	% wilt incidence	Yield (kg/4 m^2)
Two summer ploughings + full dose of carbofuran (1.5 kg a.i./ha)	65	59	27.77	3.21
Two summer ploughings + full dose of neem cake (15 g/spot)	71	69	27.77	3.10
Two summer ploughings + full dose of streptocycline (500 ppm at 30 mL/spot)	128	112	38.88	2.43
Two summer ploughings + full dose of *T. harzianum* (150 g/spot)	67	63	27.77	3.10
Two summer ploughings + half dose carbofuran + full dose *T. harzianum*	35	26	5.53	3.90
Two summer ploughings + half dose neem cake + full dose *T. harzianum*	57	47	11.10	3.30
Two summer ploughings + half dose streptocycline + full dose *T. harzianum*	59	55	24.99	3.20
Two summer ploughings + half dose carbofuran + half dose neem cake + half dose streptocycline	28	20	5.53	4.20
Two summer ploughings + half dose carbofuran + half dose neem cake + half dose streptocycline + full dose *T. harzianum*	24	17	5.53	4.90
Control	362	207	66.66	1.6
Critical Difference (CD) (P = 0.05)	*6.69*	*6.75*	*11.15*	*0.83*

Fig. 6.28 Root-knot *Fusarium* wilt complex in brinjal

(i) Integrated Methods

(a) Bioagents and Chemicals: Treatment of nursery beds with carbofuran at 1 kg a.i./ha + *T. harzianum* at 50 kg/ha (having 10^8 cfu/g) was found highly effective in increasing the number and fresh weight of brinjal seedlings and maximum reduction in root-knot index due to *M. incognita*. However, minimum per cent root infection by *F. solani* was observed in carbofuran at 1 kg a.i./ha + bavistin at 1 kg a.i./ha treated seedlings (Kumar et al. 2009a).

6.3.4 Validated IPM Technology for Brinjal Pests and Diseases at Ghaziabad

Nursery

- Raised seed bed of 10–15 cm height to avoid flooding of bed.
- Soil solarization for 3 weeks during June using polythene sheets of 45 µm thickness.
- Soil treatment with *T. viride* at 100 g/kg FYM. Enrichment of *T. viride* for 3 weeks before mixing in soil.

Table 6.43 Yield and economics of IPM in brinjal

Parameter	IPM	Non-IPM	% increase
Yield (t/ha)	61.30	50.90	20.43
Net returns (₹/ha)	62,700	28,043	20.01
Benefit to cost ratio	2.27	1.02	122.55

IPM integrated pest management

Main field

- Erection of bird perches at 25/ha to facilitate predation of insects.
- Soil application of neem cake at 250 kg/ha.
- Installation of delta traps and yellow sticky traps at 5/ha for hopper and white fly.
- Pheromone traps installed at 12/ha for mass trapping as well as monitoring of *L. orbonalis*.
- Soil application of neem cake at 250 kg/ha along the plant rows 30 DAP.
- Three sprays of 5% NSKE against leaf hoppers, aphids, mites depending upon the appearance of the pests.
- Six releases of egg parasitoid, *T. chilonis* at 1 lakh/ha at weekly interval for shoot and fruit borer.
- Collection and destruction of egg masses, larvae and adults of hadda beetle.
- Clipping of borer damaged shoots and collection and destruction of damaged fruits.
- Rouging out of little leaf affected plants at monthly interval.
- One spray each of imidacloprid at 0.5 mL/L and cypermethrin at 1 mL/L in the season.

In brinjal crop, IPM technology has been validated in about 3 ha area in Raispur village near Ghaziabad during 2003–2004. IPM fields gave higher yields of 61.3 t/ha as compared to 50.9 t/ha in non-IPM fields (Sardana et al. 2004; Table 6.43).

6.4 Chilli and Bell Pepper, *Capsicum* spp.

6.4.1 Insect Pests

6.4.1.1 Fruit Borer, *Helicoverpa armigera*

Tomato fruit borer, *H. armigera* is also a serious pest in chilli and capsicum. It affects the marketable value of the chilli crop to a great extent, if proper care is not taken.

(i) Damage Young larvae feed on flower buds and young pod by making a circular hole. Later, the larvae feed on seeds usually with its head inside the pod and rest of the body outside. A circular hole is noticed at the base of the pedicel. Premature dropping of flower and pods is also noticed (Fig. 6.29).

(ii) Integrated Management

(a) Cultural and Bioagents: Planting of one row of African marigold after every 18 rows of chilli and spraying with *Ha*NPV was very efficient in controlling the larval population of *H. armigera* on chilli. There was a significant reduction in mean larval population of *H. armigera* (1.10 larvae/plant). The percentage fruit damage of 8.88% was lowest and the fruit yield was highest (2.822 t/ha of dry chillies) in this treatment.

(b) Bioagents, Botanicals and Chemicals: IPM comprising of three releases of *Trichogramma japonicum* followed by sequential application of *Ha*NPV at 250 LE/ha, 3% neem oil- and need-based application of 0.07% endosulfan gave effective control of fruit borer and increased the fruit yield (22.4 t/ha) as compared to non-IPM fields (18.2 t/ha).

6.4.1.2 Thrips, *Scirtothrips dorsalis*

(i) Damage Both adults and nymphs suck the sap from young leaves. Affected leaves curl upwards along the margin, and get crinkled and reduced in size (Fig. 6.30). When the incidence is severe, leaves drop and cause heavy reduction in yield. The pest is serious during dry monsoon periods and summer months.

(ii) Integrated Management

(a) Botanicals and Chemicals: Pongamia oil at 2 mL when mixed with 0.5 g acephate + 2 mL of sticker gave excellent control of thrips in chillies, even during summer (Krishnamoorthy and Krishna Kumar 2002). The thrips damage rating was reduced to 20.67 in the above treatment as compared to 45.67 in control. Similarly, the yield was also increased in treated plots over control (Table 6.44).

Fig. 6.29 Pod borer, *Helicoverpa armigera* damage on chilli fruits

Fig. 6.30 Thrips on leaves of chilli

Table 6.44 Thrips damage and yield under different management programmes in chilli. The experiment was conducted during Summer Season of year 2002.

Treatments	Doses	Rating of thrips damage/5 leaves	Yield (kg/plot)
Acepahte + pongamia oil	0.5 g + 2 mL	20.67	1.69
Dimethoate + neem oil	2 mL + 2 mL	30.00	1.26
Pongamia oil	20 mL	45.67	1.05
Neem oil	20 mL	40.67	3.50
Dimethoate	2 mL	25.00	0.90
Neem seed powder	4%	40.00	0.05
Acephate	0.75 g	10.67	1.35
Control	–	45.67	0.02
Critical Difference (CD) (P = 0.05)	–	*7.33*	*0.10*

6.4.2 Diseases

6.4.2.1 Damping-off, *Pythium aphanidermatum*

(i) Symptoms The shrinking of the cortical tissue of the hypocotyl and toppling over of the infected seedlings takes place. It affects germination and stand of seedlings in nursery beds due to pre-emergence damping-off. The pathogen is responsible for death of seedlings in nursery beds (Fig. 6.31).

(ii) Integrated Management

(a) Physical, Botanicals and Bioagents: Integration of soil solarization, application of neem cake and *T. viride* gave effective control of the disease.

Fig. 6.31 Damping-off in chilli nursery

Table 6.45 Comparative efficacy of soil solarization, bioagents and fungicide against damping-off of chilli

Treatment	% disease index
Soil solarization with transparent polythene sheets for 30 days	1.28 (6.45)
Seed treatment with *Trichoderma viride* at 4 g/kg + soil application of 50 kg FYM enriched with 500 g of *T. viride*	4.70 (12.26)
Seed treatment with *Pseudomonas fluorescens* at 10 g/kg + soil application of 50 kg FYM enriched with 2.5 kg of *P. fluorescens*	6.75 (14.82)
Seed treatment with *Trichoderma harzianum* at 4 g/kg + soil application of 50 kg FYM enriched with 500 g of *T. harzianum*	6.03 (13.97)
Seed treatment with Azotobacter croococcum at 16 g/kg + soil application of 50 kg FYM enriched with 500 g of A. croococcum	6.68 (14.80)
Seed treatment with captan at 2.5 g/kg + soil drenching with captan at 0.25 % at 6 L/m^2	4.75 (12.29)
Control (check)	20.13 (26.22)
Critical Difference (CD) at 5 %	*(3.09)*

Figures in parentheses indicate the arc sin transformed values

(b) Physical, Chemical and Bioagents: Soil solarization gave least damping-off followed by seed treatment with *T. viride* + soil application of FYM enriched with *T. viride* (Table 6.45; Rahman et al. 2002).

(c) Physical and Bioagents: Combination of the seed/root application of *T. harzianum* or *P. fluorescens* with soil solarization was very effective in management of damping-off of capsicum in nursery at farmers' field.

Fig. 6.32 Fusarium wilt of chilli

6.4.2.2 Wilt, *Fusarium oxysporum* f. sp. *capsici, F. solani*

(i) Symptoms Symptoms include leaf chlorosis, vascular discolouration and wilting of chilli pepper plants (Fig. 6.32). High temperature and high moisture are conducive to symptom development.

(ii) Integrated Management

(a) Two Bioagents: Combined seedling root-dip treatment and soil application of non-pathogenic *Fusarium* (Fo 52) and *P. fluorescens* gave maximum inhibition of wilt (Singh et al. 2002).

6.4.2.3 Root Rot, Fruit Rot and Leaf Blight, *Phytophthora capsici*

(i) Symptoms This is a disease of rainy season, characterized by small, water-soaked spots appearing on fruits leading to complete rot of fruits. On leaves, water-soaked bleached spots appear, resulting in blighting. It causes damage to plants and affect fruit yield. Infection of the root and lower portion of the stem leads to plant wilting (Fig. 6.33), which is the most conspicuous symptom of the disease. In furrow-irrigated fields, there is a row-delimited pattern of wilted plants (Fig. 6.33). Over time, wilting is displayed over the entire field. *P. capsici* produces specialized swimming cells, known as zoospores, which enable spread of the pathogen from plant to plant.

Fig. 6.33 Wilting of chilli plant and a field severely affected by *Phytophthora* root rot. (Courtesy: D. Lindsey)

Table 6.46 Effect of solarization and biofumigation on *Phytophthora* root rot in plastic greenhouses (Season 1998–1999)

Treatments	Plants height (cm)	Commercial yield (kg m^{-2})	% plants with *Phytophthora*
MB 60 g/m^2	163.8a	9.7a	0.4a
Biofumigation and solarization (4 weeks)	135.3b	8.7b	9.4b
Untreated	122.4c	4.3c	37.9c

No significant differences between values with the same letter ($P > 0.05$)

(ii) Integrated Management

(a) Bioagents and Chemicals: Seed treatment with carbendazim (0.2%) + seedling dip in *P. fluorescens* (10 g/L) + two sprays of *P. fluorescens* at 45 and 60 days after transplanting + two sprays of hexaconazole at 75 and 90 days after transplanting recorded the least disease incidence of fruit rot (16.0 Percent Disease Index (PDI)) and powdery mildew (26.7 PDI). This treatment also gave highest yield (8.5 q/ha) and highest net returns (₹ 25,940/ha) (Mesta et al. 2009).

(b) Physical and Botanicals: Solarization and biofumigation with fresh sheep manure (if it is done from July to October) shown promise to be efficient disinfectants which increased plant growth, yield and decreased disease incidence (Table 6.46; Bello et al. 1997a). The best results were obtained when biofumigation with solarization was applied at the end of August or the beginning of September. Sweet pepper yield using fresh sheep manure with soybean flour, or fresh sheep manure with chicken manure treatments, was similar to sweet pepper yield when Methyl bromide (MB) was used. The reiteration of biofumigation with solarization over two or more years led to an improvement in pathogen and weed control, higher plants, an increase in yield and improvements in the soil physical properties, with a higher level of macro- and micronutrients as well as electrical conductivity.

Fig. 6.34 Southern blight symptoms on capsicum

6.4.2.4 Southern Blight, *Sclerotium rolfsii*

(i) Symptoms Early symptoms consisted of water-soaked lesions on crown and lower stem tissue in contact with the soil. Plant foliage became pale green and wilted, followed by a complete collapse of the plant. A dense white mycelial mat formed on the lower stem and crown with 1- to 2-mm-diameter, spherical, tan-to-dark brown sclerotia (Fig. 6.34).

(ii) Integrated Management

(a) Physical and Bioagents: Solarization of fallow soil in raised beds for 6 weeks and application of a bran prill formulation of *T. virens* significantly reduced the southern blight disease incidence in bell pepper and survival of sclerotia of *S. rolfsii* to depths of 30 cm (Ristaino et al. 1996).

Fig. 6.35 Powdery mildew on chilli leaf

(b) Bioagents and AMF: Sreenivasa (1997) reported significant reduction in sclerotial bodies produced by *S. rolfsii* when chilli crop was co-inoculated with AMF and *T. harzianum*.

(c) Bioagents and Chemicals: Effective control of *S. rolfsii* on bell pepper with a combination of *T. harzianum* and ridomil has been reported.

6.4.2.5 Powdery Mildew, *Leveillula taurica*

(i) Symptoms Pepper powdery mildew grows unseen under the surface of leaves (Fig. 6.35), within the leaf tissue for a latency period of up to 21 days. Disease monitoring, early detection and prevention of pepper powdery mildew is critical. By the time pepper powdery mildew is detected in a greenhouse many more leaves are already infected but do not show any disease symptoms. In addition, pepper plants can become defoliated and do not recover as quickly. Pepper powdery mildew does not infect the fruit or stems but can quickly destroy unprotected leaves and eventually the entire pepper crop.

(ii) Integrated Management

(a) Bioagents and Chemicals: Seed treatment with carbendazim (0.2%) + seedling dip in *P. fluorescens* (10 g/L) + two sprays of *P. fluorescens* at 45 and 60 days after transplanting + 2 sprays of hexaconazole at 75 and 90 days after transplanting recorded the least disease incidence of fruit rot (16.0 Percent Disease Index (PDI)) and powdery mildew (26.7 PDI). This treatment also gave highest dry chilli yield (0.85 t/ha) and highest net returns (₹ 25,940/ha); see Mesta et al. (2009).

Fig. 6.36 *Alternaria* fruit rot on capsicum

6.4.2.6 Alternaria Rot, *Alternaria alternata*

(i) Symptoms

- The fungus is reported to enter wounds (sunscald or punctures).
- Dusty black spores on fruit spots are characteristic.
- In most instances this disease follows blossom-end rot, but it also follows injuries, chilling and other decays.
- On the fruit, large greenish-brown-to-brown lesions covered with grayish-brown mold are produced (Fig. 6.36).

Fig. 6.37 Chilli leaf curl Gemini virus

- Similar lesions on the lower-part of the fruit are characteristic of *Alternaria* rot following blossom-end rot.
- The larger lesions may show alternating light and dark-brown concentric zones.
- Shipping peppers under standard refrigeration will check the development of this rot, but when the fruit is removed from refrigeration the decay will advance rapidly at moderate-to-warm temperatures.

(ii) Integrated Management

(a) Physical and Chemical: MITC at 0.56 mg/mL in combination with LDPE film solarization reduced the fungal infection (*A. alternata*) in the bell pepper fruit better than a commercial fungicide (Captan) without any detrimental effects on fruit quality (Troncoso-Rojas et al. 2008).

6.4.2.7 Leaf Curl Virus

(i) Symptoms The Gemini virus causes enation leaf curl symptom. Reduction in size of leaves, shortening of veins, puckering, sometimes mottling and stunting of plants are common symptoms of the disease (Fig. 6.37). Veins are prominently visible on the lower side of the leaves. The infected plants remain stunted and bear no fruits.

(ii) Integrated Management (of insect-borne viruses)

(a) Cultural, Chemicals and Botanicals: At Coimbatore, soil application of carbofuran at 1 kg a.i./ha + covering the nursery bed with nylon net of 400 mesh followed by two sprays of 2% neem oil at 15 and 35 DAP recorded lesser virus incidence and highest yield with benefit to cost ratio of 3.3.

(b) Cultural and Chemicals: At Sabour, use of nylon net and soil application of carbofuran at 1 kg a.i./ha in seed bed and application of carbofuran at 1.5 kg a.i./ha in the main field a week after transplanting + three sprays of nuvacron at 1 mL/L was most effective in managing the disease with benefit to cost ratio of 5.64.

Use of nylon net cover in nursery beds, soil application of carbofuran at 1 kg a.i./ha in combination with foliar application of 0.1% imidacloprid at 10 days' interval effectively reduced the vector population as well as the disease incidence.

6.4.3 Nematodes

6.4.3.1 Root-knot Nematodes, *Meloidogyne* spp.

(i) Symptoms Nematode infestations damage the plant roots, and therefore symptoms reflect poorly functioning root systems. Aboveground symptoms of severe root-knot infestations include patches of chlorotic, stunted, necrotic or wilted plants. Nematode-infested plants are more susceptible to moisture or temperature stress and exhibit stress symptoms earlier than other plants. Furthermore, root systems that have been damaged by nematodes are often more susceptible to infection by soil-inhabiting fungi such as *Fusarium* and *Verticillium* species. Feeding by root-knot nematodes results in characteristic galls on roots. Severely galled roots may appear malformed and the root system shortened and thickened (Fig. 6.38). Root galls caused by root-knot nematodes on sweet pepper are frequently small.

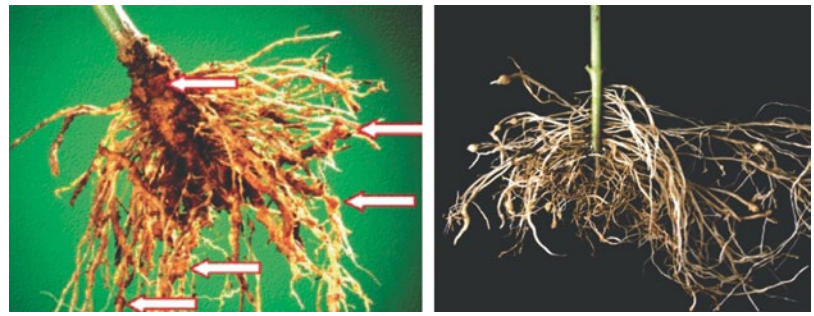


Fig. 6.38 Root-knot nematode on bell pepper

Table 6.47 Effect of integration of bioagents for the management of *Meloidogyne incognita* and fruit yield of capsicum

Treatment	Dose/m^2	Root-knot index (1–10 scale)	Yield in kg/2 m^2
P. chlamydosporia	50 g (10^6 cfu/g)	6.20	2.58
T. harzianum	50 g (10^6 cfu/g)	7.20	2.36
P. lilacinus	50 g (10^6 cfu/g)	6.70	2.61
P. chlamydosporia + *P. lilacinus*	25 g+25 g	4.35	3.28
T. harzianum + *P. lilacinus*	25 g+25 g	4.75	2.86
P. chlamydosporia + *T. harzianum*	25 g+25 g	5.35	2.07
P. chlamydosporia + *T. harzianum* + *P. lilacinus*	17 g+17 g+17 g	5.10	2.05
Carbofuran	25 g	7.80	2.30
Control	–	8.75	2.04
Critical Difference (CD) (P = 0.05)	–	*0.44*	*0.77*

(ii) Integrated Management

(a) Two Bioagents: Integration of *P. lilacinus* with *P. chlamydosporia* in nursery was found most effective in increasing the plant growth of capsicum seedlings and reducing the nematode population both in soil and roots by 59 and 72%, respectively. When capsicum seedlings raised in nursery treated with *P. lilacinus* + *P. chlamydosporia* were transplanted in the main field, there was reduction in RGI by 51% and increase in fruit yield by 44% compared to control (Naik 2004; Table 6.47).

Integrated management of *M. incognita* infecting capsicum was achieved by seed treatment with *P. fluorescens* at 50 g/kg combined with nursery bed treatment with *P. chlamydosporia* at 50 g/m^2. The above treatment was significantly effective in increasing the seedling growth and root colonization with bioagents and in reducing root galling (Table 6.48). These seedlings when transplanted in field significantly reduced nematode population both in soil and roots, root galling and increased root colonization by bioagents, propagule density in soil, parasitization of eggs and fruit yield. The main purpose of these studies was to raise capsicum seedlings that are colonized by *P. chlamydosporia* before transplanting so that they could carry the bioagent to the field. During this process the field soil would be enriched with the propagules of the bioagent for two or three seasons (Rao et al. 2004; Table 6.49).

(b) Biofumigation and Solarization: The best results were obtained when biofumigation with solarization was done at the end of August or the beginning of September. Sweet pepper yield using fresh sheep manure with soybean flour, or fresh sheep manure with chicken manure treatments, was similar to sweet pepper yield when Methyl bromide (MB) was used. The reiteration of biofumigation with solarization over two or more years led to an improvement in pathogen and weed control, higher plants, an increase in yield and improvements to the soil physical properties, with a higher level of macro- and micronutrients as well as electrical conductivity (Bello et al. 2004).

Table 6.48 Effect of integration of bioagents on plant growth and management of *Meloidogyne incognita* infecting capsicum in nursery

Treatment/dose	Seedling weight (g)	No. of galls/10 seedlings	Root colonization of *P. chlamydosporia* (cfu/g)	Root colonization of *P. fluorescens* (cfu/g)
P. chlamydosporia—nursery treatment (25 g/m^2)	3.6	62	15,896	–
P. chlamydosporia—nursery treatment (50 g/m^2)	3.8	59	17,459	–
P. fluorescens—seed treatment (50 g/kg)	4.0	55	–	12,563
P. fluorescens—seed treatment (50 g/kg) + *P. chlamydosporia*—nursery treatment (25 g/m^2)	4.5	51	16,256	12,249
P. fluorescens—seed treatment (50 g/kg) + *P. chlamydosporia*—nursery treatment (50 g/m^2)	4.4	53	16,789	11,897
Control	3.2	82	–	–
Critical Difference (CD) (P = 0.05)	*0.34*	*7.96*	*959.72*	*729.65*

Table 6.49 Effect of integration of bioagents on plant growth and management of *Meloidogyne incognita* infecting capsicum under field conditions

Treatment	Root-knot index (1–10 scale)	Yield (kg/6 m^2)	% eggs parasitized by *P. chlamydosporia*	Root colonization (cfu/g)		Propagule density (cfu/g soil)	
				Pochonia chlamydosporia	*Pseudomonas fluorescens*	*Pochonia chlamydosporia*	*Pseudomonas fluorescens*
T_1	6.3	4.4	41.00	22,456	–	19,569	–
T_2	5.6	4.7	45.00	25,789	–	22,845	–
T_3	6.0	5.1	–	–	22,568	–	15,987
T_4	4.8	5.3	40.00	21,679	21,789	19,234	16,843
T_5	4.4	5.5	42.67	24,587	21,567	23,221	15,359
Control	8.1	4.0	–	–	–	–	–
CD 5%	*0.45*	*0.28*	*3.78*	*1,246.76*	*1,089.86*	*1,178.32*	*873.65*

T_1—*P. chlamydosporia*—nursery treatment (25 g/m^2), T_2—*P. chlamydosporia*—nursery treatment (50 g/m^2), T_3—*P. fluorescens*—seed treatment (50 g/kg), T_4—*P. fluorescens*—seed treatment (50 g/kg) + *P. chlamydosporia*—nursery treatment (25 g/m^2), T_5—*P. fluorescens*—seed treatment (50 g/kg) + *P. chlamydosporia*—nursery treatment (50 g/m^2)

(c) Physical and Chemicals: Experiments in Sicily (Cartia and Greco 1987; Cartia et al. 1988, 1989), aimed at the control of soil-borne pathogens of pepper in greenhouse culture, yield and fruit size from solarized soil averaged 12.2 and 2.3 times, respectively, over those in controls. Higher yield was obtained with soil solarization, alone or in combination with reduced dosages of methyl bromide, and with methyl bromide alone (six times over control) than with DD (5.4 times the control).

(d) Botanicals and Bioagents/Chemicals: Soil application of poultry manure at 10 t/ha a week prior to transplanting + *P. lilacinus* (10^9/ conidia/g) at 25 kg/ha spore dust with carrier at the time of transplanting; or neem cake at 2 t/ha a week prior to transplanting + *P. lilacinus* (10^9 conidia/g) at 25 kg/ha spore dust with carrier at the time of transplanting; or carbofuran at 2 kg/ha in two equal splits (one at the time of transplanting and the other after 75 days) + *P. lilacinus* (10^9 conidia/g) at 25 kg/ha spore dust with carrier at the time of transplanting considerably reduced root galling and also gave higher capsicum fruit yield over control (Vyas et al. 2009; Table 6.50).

(e) Physical and Botanicals/Bioagents/Chemicals: The effect of solarization, and its combinations with dazomet (400 kg/ha), chicken manure (10t/ha) or straw (500 kg/ha), on soil-borne nematodes and crop were demonstrated at various sites. Combinations of solarization with basamid (400 kg/ha), chicken manure (10t/ha)

Table 6.50 Effect of different organic amendments, bioagent and nematicide for the management of *Meloidogyne incognita* infecting capsicum

Treatment	Gall index (0–5 scale)	Yield (t/ha)	ICBR
P. lilacinus at 25 kg/ha + poultry manure at 10 t/ha	2.0	42.088	1:18.5
P. lilacinus at 25 kg/ha + mustard cake at 2 t/ha	2.0	44.801	1:7.7
P. lilacinus at 25 kg/ha + neem cake at 2 t/ha	1.8	41.745	1:5.8
P. lilacinus at 25 kg/ha + carbofuran at 2 kg a.i./ha	1.9	41.498	1:13.6
P. lilacinus at 25 kg/ha	2.5	39.941	1:77.6
Poultry manure at 10 t/ha	2.3	40.000	1:18.5
Mustard cake at 2 t/ha	1.9	41.810	1:6.7
Neem cake at 2 t/ha	1.9	39.954	1:5.2
Carbofuran at 2 kg a.i./ha	2.0	40.530	1:14.9
Control	3.9	28.107	–

ICBR incremental cost–effectiveness ratio

Table 6.51 Effects of treatments on the nematode population as percentage of non-treated check during the growing season of pepper

Date	Treatments and control rates (%)				
	Solarization + basamid	Solarization + *Trichoderma*	Solarization + manure	Solarization + straw	Methyl bromide
03-10-2000	100.0	100.0	100.0	100.0	100.0
19-10-2000	98.8	100.0	100.0	100.0	100.0
07-11-2000	100.0	100.0	100.0	100.0	100.0
28-11-2000	89.9	100.0	80.0	100.0	97.8
19-12-2000	100.0	100.0	100.0	100.0	100.0
09-01-2001	96.3	99.2	79.9	99.3	100.0
30-01-2001	99.7	100.0	100.0	100.0	99.3
20-02-2001	100.0	100.0	100.0	100.0	97.0
13-03-2001	100.0	99.3	99.9	98.1	97.9
03-04-2001	79.7	98.7	96.2	94.3	91.6
25-04-2001	99.5	95.5	99.8	70.9	90.4
16-05-2001	72.9	88.8	94.4	93.2	87.4
06-06-2001	74.6	91.4	95.8	99.6	59.4
23-07-2001	40.8	59.3	84.9	0.0	0.0

100 shows complete control and 0 shows no control

or *Trichoderma* were the most effective applications for the management of root-knot nematodes infecting bell pepper. Methyl bromide (MB) and solarization + straw (500 kg/ha) were partially effective. However, it can be said that all treatments effectively controlled nematodes (Table 6.51). Galling index overall averages of six pepper plastic houses were 0.10, 0.89, 0.98, 1.92, 2.04 and 5.95 for solarization + *Trichoderma*, solarization + manure, solarization + dazomet, MB, solarization + straw and check, respectively.

6.4.3.2 Root-knot Nematode, *M. incognita* and Bacterial Wilt, *R. solanacearum* Disease Complex

(i) Symptoms Capsicum is prone to many soil-borne diseases among which the bacterial wilt (*R. solanacearum*) in combination with root-knot nematode (*M. incognita*) takes heavy toll every year all over the world (Fig. 6.39) (Naik et al. 2003). The disease ratings of bacterial wilt in treated plants (inoculated with *M. incognita* 1 month later with *R. solanacearum*; inoculated

Fig. 6.39 *Meloidogyne incognita* and *Ralstonia solanacearum* disease complex in capsicum

Table 6.52 Effect of integration of bioagents on nursery stand of capsicum seedlings

Treatment	Nursery stand of seedlings[a]
Seed treatment with talc-based *P. fluorescens*	3.4
Nursery bed treatment with neem-based *P. fluorescens*	3.2
Seed treatment with talc-based *P. fluorescens* + nursery bed treatment with neem-based *P. fluorescens*	4.2
Nursery bed treatment with *T. harzianum* + *P. fluorescens*	4.4
Control	3.0

[a] 3—poor, 4—good, 5—very good

with *R. solanacearum* and 2 weeks later with the nematodes; or inoculated with nematodes and *R. solanacearum* simultaneously) were higher than ratings in plants inoculated with bacteria only. It is concluded that a complex infection of root-knot nematodes and *R. solanacearum* increased disease severity and reduced the resistance of bacterial wilt-resistant chilli plants.

(ii) Integrated Management

(a) Two Bioagents: The seedling stand was good when the nursery beds were combinedly treated with neem-based formulations of *T. harzianum* + *P. fluorescens* followed by seed treatment with talc-based *P. fluorescens* + nursery bed treatment with neem-based *P. fluorescens* (Naik et al. 2003) (Table 6.52).

Combined application of neem-based formulations of *P. fluorescens* and *P. chlamydosporia/T. harzianum* at 40 g/m^{2}in nursery beds and transplanting these seedlings in the main field resulted in significant reduction in disease index and root-knot index in capsicum to the tune of 70% and increased the crop yield by 37% (Rao et al. 2002a; Table 6.53). Combinations of the bioagents did not affect the colonization of the individual bioagents on the roots and hence the transplants carried the bioagents to the main field. This has resulted in the effective management of the pathogens involved in the disease complex.

Integration of seed treatment with *P. fluorescens* and nursery bed treatment with *P. chlamydosporia* at 25 or 50 g/m^2 increased plant height, weight of seedlings and root colonization with bioagents; and reduced root galling in capsicum (Table 6.54; Naik et al. 2003). The seedlings were highly vigorous which were colonized by the bioagents and reached the main field when transplanted.

The seedlings raised in nursery beds treated with *P. chlamydosporia* at 25 or 50 g/m^2 + seed treatment with *P. fluorescens* when transplanted in the main field gave least root galling and increased fruit yield, colonization of roots with the bioagents and parasitization of eggs by *P. chlamydosporia* (Table 6.55; Naik et al. 2003).

Naik (2004) reported that combination of *T. harzianum* along with *P. fluorescens* increased the yield (3.320 kg/3 m^2 plot) followed by combination of *T. harzianum* and *P. chlamydosporia* (2.960 kg/3 m^2). The least gall index was present where the combination of *T. harzianum* and *P. fluorescens* was used (1.5) followed by *T. harzianum* + *P. chlamydosporia* (1.7) and *P. fluorescens* + *P. chlamydosporia* (1.7). But among combination treatment of bioagents, all the treatments were on par (*P. fluorescens* + *T. harzianum, P. fluorescens* + *P. chlamydosporia, T. harzianum* + *P. chlamydosporia*). Results related to the percent bacterial wilt disease (*R. solanacearum*) incidence also showed similar trend in which *T. harzianum* + *P. fluorescens* performed very well and the percent incidence was 16.90 followed by *T. harzianum* + *P. chlamydosporia* (17.20); see Table 6.56.

Table 6.53 Effect of integration of neem-based bioagents on plant growth and management of root-knot and bacterial wilt disease complex and yield of capsicum

Treatment	Seedling weight (g)	Root-knot index (1–10)	Disease index (1–9)	Yield in kg/4 m^2
Seed treatment with *P. fluorescens*	421	5.6	6.4	4.3
Seed treatment with neem-based *P. fluorescens*	428	5.2	6.7	4.7
Nursery treatment with *P. fluorescens*	435	4.6	5.4	4.8
Nursery treatment with *P. chlamydosporia*	364	4.4	7.3	3.2
Nursery treatment with *T. harzianum*	374	4.8	7.0	3.4
Nursery treatment with *P. fluorescens* + *P. chlamydosporia*	463	4.1	5.2	4.0
Nursery treatment with *P. fluorescens* + *T. harzianum*	493	3.8	3.5	5.1
Control	340	8.7	8.2	2.6
Critical Difference (CD) (P = 0.05)	*27.20*	*0.49*	*0.38*	*0.25*

Table 6.54 Effect of integration of bioagents on plant growth, root galling and root colonization by bioagents in capsicum under nursery conditions

Treatment	Plant height (cm)	Seedling weight (g)	No. of galls/10 seedlings	*P. chlamydosporia* root colonization (cfu/g)	*P. fluorescens* root colonization (cfu/g)
T_1	12.58	3.6	62	15,896	–
T_2	14.63	3.8	59	17,459	–
T_3	15.87	4.0	55	–	12,563
T_4	18.54	4.5	51	16,256	12,349
T_5	17.42	4.4	53	16,789	11,897
T_6	11.23	3.2	82	–	–
Critical Difference (CD) (P = 0.05)	*1.67*	*0.34*	*7.96*	*959.72*	*729.65*

T_1—nursery bed treatment *P. chlamydosporia* at 25 g/m^2 , T_2—nursery bed treatment *P. chlamydosporia* at 50 g/m^2, T_3—seed treatment with *P. fluorescens*, T_4—$T_1 + T_3$, T_5— $T_2 + T_3$, T_6—control

Table 6.55 Effect of integration of bioagents on fruit yield, root galling and root colonization by bioagents in capsicum under field conditions

Treatment	Root-knot index	Fruit yield (kg/6 m^2)	*P. chlamydosporia* root colonization (cfu/g)	*P. fluorescens* root colonization (cfu/g)	% eggs parasitized by *P. chlamydosporia*
T_1	6.3	4.4	22,456	–	41.00
T_2	5.6	4.7	25,789	–	45.00
T_3	6.0	5.1	–	22,568	–
T_4	4.8	5.3	21,679	21,789	40.00
T_5	4.4	5.5	24,587	21,567	42.67
T_6	8.1	4.0	–	–	–
Critical Difference (CD) (P = 0.05)	*0.45*	*0.28*	*1,246.76*	*1,089.86*	*3.78*

T_1—nursery bed treatment *P. chlamydosporia* at 25 g/m^2 , T_2—nursery bed treatment *P. chlamydosporia* at 50 g/m^2, T_3—seed treatment with *P. fluorescens*, T_4—$T_1 + T_3$, T_5— $T_2 + T_3$, T_6—control

Naik et al. (2003) reported that soil application of organically developed *P. lilacinus* (50 g/m^2 of formulated product containing 10^6 spores/g) along with pure culture of *Bacillus pumilis* (10^8 cfu/mL) to the nursery beds of bell pepper increased plant growth, root galling and root colonization by the bioagents. The above seedlings when transplanted in field significantly reduced root galling and wilt incidence, and increased root colonization, propagule density in soil, egg parasitization and fruit yield in the main field (Tables 6.57 and 6.58).

Table 6.56 Effect of integration of bioagents on root galling, wilt disease incidence and fruit yield of capsicum

Treatment	No. of fruits/ plant	Fruit yield (kg/3 m^2)	Root-knot index	Wilt disease incidence (%)
Neem + wheat bran formulation (8:2) of *T. harzianum*	31.2	2.30	1.90	23.8 (29.20)
Liquid broth formulation of *P. fluorescens*	34.2	2.40	1.75	21.4 (27.56)
Neem + Pongamia + wheat bran formulation (4:4:2) of *P. chlamydosporia*	32.8	2.04	1.92	26.7 (31.11)
T. harzianum + *P. fluorescens*	46.2	3.32	1.50	16.9 (24.20)
T. harzianum + *P. chlamydosporia*	40.6	2.96	1.70	17.2 (24.50)
P. fluorescens + *P. chlamydosporia*	40.0	2.48	1.70	17.8 (24.95)
Neem + wheat bran	27.2	1.93	2.25	30.5 (33.52)
Neem + Pongamia + wheat bran	29.8	2.00	2.00	36.4 (37.11)
Control	26.2	1.78	3.80	96.0 (78.46)
Critical Difference (CD) (P = 0.05)	*7.38*	*0.41*	*0.32*	*3.28*

Table 6.57 Effect of integration of bioagents on plant growth and management of disease complex in bell pepper in nursery beds

Treatment	Seedling length (cm)	Seedling weight (g)	No. of galls/10 plants	Root colonization (cfu/g)	
				P. lilacinus	*B. pumilis*
T_1	12.63	3.8	52	13,342	–
T_2	15.53	4.0	50	16,539	–
T_3	15.17	4.2	55	–	14,431
T_4	18.43	4.4	44	12,984	13,964
T_5	19.25	4.6	40	16,839	14,291
T_6	10.53	3.3	76	–	–
Critical Difference (CD) (P = 0.05)	*1.29*	*0.37*	*6.28*	*1087.95*	*976.75*

T_1—nursery bed treatment with *P. lilacinus* (25 g/m^2), T_2—nursery bed treatment with *P. lilacinus* (50 g/m^2), T_3—nursery bed treatment with *B. pumilis*, T_4—$T_1 + T_3$, T_5—$T_2 + T_3$, T_6—control

Table 6.58 Effect of integration of bioagents on root galling, wilt incidence, root colonization, propagule density and yield of bell pepper under field conditions

Treatment	Root-knot index	Mortality %	Yield kg/6 m^2	Root colonization (cfu/g)		Propagule density (cfu/g soil)	
				P. lilacinus	*B. pumilis*	*P. lilacinus*	*B. pumilis*
T_1	6.5	68.90	4.8	30,653	–	21,346	–
T_2	5.3	52.45	5.4	34,289	–	23,467	–
T_3	7.0	34.62	7.5	–	25,875	–	17,321
T_4	4.3	25.86	8.2	31,764	21,459	20,457	15,347
T_5	4.1	17.69	8.5	34,762	20,764	22,689	14,569
T_6	8.4	91.45	0.5	–	–	–	–
Critical Difference (CD) (P = 0.05)	*0.58*	*8.94*	*0.35*	*1,176.52*	*1,087.54*	*1,234.87*	*897.34*

T_1—nursery bed treatment with *P. lilacinus* (25 g/m^2), T_2—nursery bed treatment with *P. lilacinus* (50 g/m^2), T_3—nursery bed treatment with *B. pumilis*, T_4—$T_1 + T_3$, T_5—$T_2 + T_3$, T_6—control

Fig. 6.40 Root-knot and *Fusarium* wilt complex in chilli. *Front*—infected, *back*—healthy

6.4.3.3 Root-knot Nematode, *M. javanica* and Wilt, *F. oxysporum* Disease Complex

(i) Symptoms The disease complex involving *M. javanica* and *F. oxysporum/F. solani* inflict severe losses to chilli crop (Haseeb 2003). The simultaneous occurrence of both root-knot nematode and *Fusarium* wilt disease caused enhanced disease development and chilli yield loss (Fig. 6.40).

(ii) Integrated Management

(a) Bioagents and Botanicals: Integration of *T. harzianum* at 50 kg/ha with neem seed powder at 250 kg/ha in nursery beds was found to be highly effective in increasing the number of germinated seedlings (87/0.5 m^2 compared to 39/0.5 m^2 in control) and fresh weight of seedlings (146.9 g compared to 61 g in control). The above treatment was also effective in reducing root galling due to *M. incognita* (0.7 Root-knot Index (RKI) compared to 3.5 Root-knot Index (RKI) in control) and percent root infection by *F. solani* (5% compared with 41.5% in control) in nursery beds (Table 6.59; Kumar et al. 2009b).

(b) Two Bioagents: *P. aeruginosa* and *P. lilacinus* when used together significantly reduced infection of the disease complex on chilli (Perveen et al. 1998). Use of *P. aeruginosa* and *P. lilacinus* significantly ($P<0.05$) increased plant height of chilli. *P. aeruginosa* and *P. lilacinus* used alone or together significantly ($P<0.05$) reduced infection of *M. javanica* and root infecting fungi viz., *M. phaseolina, R. solani, F. solani* and *F. oxysporum* on chilli. *P. aeruginosa* was more effective than *P. lilacinus* in reducing the *M. javanica* infection (Table 6.60).

Bare root-dip treatment with *P. aeruginosa* along with or without *T. harzianum, T. koningii* and *T. hamatum* significantly controlled infection of roots by *F. solani* and *M. javanica* on chilli. Combined use of *T. harzianum* along with *P. aeruginosa* caused the greatest reduction in root galling by *M. javanica* (Siddiqui et al. 1999).

6.4.3.4 Root-knot Nematode, *M. incognita* and Damping-off, *P. aphanidermatum* Disease Complex

(i) Symptoms *P. aphanidermatum* and *R. solani* were both found to interact with *M. incognita* on chilli, causing some loss of nematode resistance in two cultivars tested (Hasan 1985a, b). The interaction of *P. debaryanum* with this nematode appeared to be due to physiological response of the plants to nematode infection, making the roots more susceptible to invasion by the fungus.

(ii) Integrated Management

(a) Bioagents and Botanicals: Biological control of *P. aphanidermatum–M. incognita* disease complex in chilli with organic amendments (FYM and neem cake), antagonistic organisms *T. viride* and *T. harzianum* (against *P. aphanidermatum*) and *P. lilacinus* (against *M. incognita*) was reported by Karthikeyan et al. (1999).

Table 6.59 Effect of biocontrol agents and organic amendments against *Meloidogyne incognita–Fusarium solani* disease complex in chilli

Treatment	No. of seedlings emerged/bed	Fresh total wt. of seedlings/bed (g)	Root-knot index	% root infection
Untreated control	39	61.0	3.5	41.5
Trichoderma harzianum	67	110.3	1.5	15.0
Aspergillus niger	62	100.0	2.3	21.5
Paecilomyces lilacinus	60	97.5	1.5	15.0
Pseudomonas fluorescens	65	105.7	1.9	17.3
NSP	64	105.0	1.3	15.5
FYM	45	71.9	3.3	35.5
T. harzianum + NSP	87	146.9	0.7	5.0
A. niger + NSP	77	128.7	1.0	13.0
P. lilacinus + NSP	74	123.0	0.9	13.5
P. fluorescens + NSP	81	136.7	0.7	5.5
T. harzianum + FYM	80	134.5	1.2	7.7
A. niger + FYM	71	115.3	2.0	15.5
P. lilacinus + FYM	70	113.0	1.3	23.5
P. fluorescens + FYM	75	124.9	1.5	13.0
Carbofuran	72	117.0	0.6	25.5
Critical Difference (CD) (P = 0.05)	*3.53*	*7.91*	*0.06*	*0.65*

NSP neem seed powder, *FYM* farmyard manure

Table 6.60 Effect of *Pseudomonas aeruginosa* and *Paecilomyces lilacinus* on plant height and control of root-rot disease complex in chilli

Treatment	Plant height (cm)	Root-knot index	Infection (%)			
			M. phaseolina	*R. solani*	*F. solani*	*F. oxysporum*
Control	10.5	3.3	31	19	75	37
P. lilacinus	14.5	2.9	19	0	56	44
P. aeruginora	16.5	2.5	12	6	75	21
P. lilacinus + *P. aeruginora*	14.7	2.1	12	25	69	12
Critical Difference (CD) (P = 0.05)	*2.2*	*0.34*	*6.1*	*6.1*	*6.1*	*6.1*

References

Abu-Elamayem, M. M., Shehata, M. R. A., Tantaway, G. A., Ibrahim, I. K., & Schuman, M. A. (1978). Effect of CGA 12223 and benomyl against *Meloidogyne javanica* and *Rhizoctonia solani*. *Phytopathologische Zeitschrift, 92,* 289–293.

Amenduni, M., D'Amico, M., Colella, C., & Cirulli, M. (2004). Effect of Brassicaceae green manures and soil-solarization on corky root of tomato. *First International Biofumigation Symposium*, Florence, Italy.

Anitha, B., & Subramanian, S. (1998). Management of the reniform nematode *Rotylen-chulus reniformis* in tomato. In U. K. Mehta (Ed.), *Nematology—challenges & opportunities in 21st century* (pp. 249–250). Coimbatore: Sugarcane Breeding Institute.

Anon. (1993). Biennial Report (1991–1993) of AICRP on Plant Parasitic Nematodes with Integrated Approach for their Control, Dept. of Nematology, Haryana Agriculture University, Hisar, 80 pp.

Baskaran, P., & Kumar, A. (1980). Further studies on Dipel-insecticide combinations against the insect pests of brinjal. *Pesticides, 14,* 9–11.

Bello, A., Escuer, M., Sanz, R., López-Pérez, J. A., & Guirao, P. (1997). Biofumigación, nematodos y bromuro de metilo en el cultivo de pimiento. In A. López & J. A. Mora (Eds.), *Posibilidad de Alternativas Viables al Bromuro de Metilo en Pimiento de Invernadero* (pp. 67–108). Spain: Consejería de Medio Ambiente, Agricultura y Agua de Murcia

Bello, A. (1998). Biofumigation and integrated crop management. In A. Bello, J. A. Gonzalez, M. Arias, & R. Rodriguez-Kabana (Eds.), *Alternatives to methyl bromide for the southern European countries* (pp. 99–126). Valencia: Phytoma-Espania, DG XI EU, CSIC.

Bello, A., Escuer, M., Sanz, R., López-Pérez, J. A., & Guirao, P. (1997). In A. López & J. A. Mora (Eds.),

Posibilidad de Alternativas Viables al Bromuro de Metilo en Pimiento de Invernadero (pp. 67–108). Spain: Consejería de Medio Ambiente, Agricultura y Agua de Murcia.

Bello, A., López-Pérez, J. A., Garcia-Alvarez, A., Sanz, R., & Lacasa, A. (2004). *Biofumigation and nematode control in the Mediterranean region*. In R. C. Cook & D. J. Hunt (Eds.), Proceedings of the Fourth International Congress of Nematology (Vol. 2, pp. 133–149). Nematology Monographs and Perspectives, Brill, Leiden and Boston.

Besri, M., & Drame, A. (1982). Control of *Fusarium oxysporum* f. sp. *lycopersici* and *Verticillium dahliae* by soil solarization. Proceedings of the First Meeting of the Arab Society for Plant Protection, Amman, p. 113.

Bhagawati, B., Goswami, B. K., & Singh, C. S. (2000). Management of disease complex of tomato caused by *M. incognita* and *Fusarium oxysporum* f. sp. *lycopersici* through bioagents. *Indian Journal of Nematology, 30,* 16–22.

Bhatti, D. S., & Jain, R. K. (1977). Estimation of loss in okra, tomato and brinjal yield due to *Meloidogyne incognita. Indian Journal of Nematology, 7,* 37–41.

Borah, A., & Phukan, P. N. (2000). Effect of VAM fungus, *Glomus fasciculatum* and root-knot nematode, *Meloidogyne incognita* on brinjal. *Journal of the Agricultural Science Society of North-East India, 13,* 212–214.

Borkakaty, D. (1993). Management of root-knot nematode, meloidogyne incognita (Kofoid and White, 1919) Chitwood, 1949 on Brinjal by Integrated Approach. M. Sc. (Agri.) Thesis, Assam Agricultural University, Jorhat.

Cartia, G., & Greco, N. (1987). Effetti della solarizzazione del suolo su una coltura di peperone in serra. *Colture Protette, 16*(5), 61–65.

Cartia, G., Greco, N., & Cirvilleri, G. (1988). *Solarizzazione e bromuro di metile nella difesa dai parassiti del pomodoro in ambiente protetto*. Proceedings Giornate Fitopatologiche, Lecce, Italy, 1, 437–488.

Cartia, G., Greco, N., & Cipriano, T. (1989). Effect of soil solarization and fumigants on soil-borne pathogens of pepper in greenhouse. *Acta Horticulturae, 255***,** 111–116.

Cooksey, D. A. (1988). Reduction in infection by *Pseudomonas syringae* pv. *tomato* on tomato using a non-pathogenic, copper-resistant strain combined with a copper bactericide. *Phytopathology, 78,* 601–603.

Dey, R. K., & Muhkopadhyay, A. N. (1994). Biological control of tomato damping-off by *Gliocladium virens. Journal of Biological Control, 8,* 34–40.

Darekar, K. S., & Mahse, N. L. (1988). Assessment of yield losses due to root-knot nematode, *Meloidogyne incognita* Race 3 in tomato, brinjal and bitter gourd. *International Nematology Network Newsletter, 5*(4), 7–9.

Darekar, K. S., & Patil, N. G. (1985). Screening of grapevine varieties to root-knot nematode. *Journal of Maharashtra Agricultural Universities, 10,* 104.

Dutt, R., & Bhatti, D. S. (1986). Determination of effective doses and time of application of nematicides and castor leaves for controlling *Meloidogyne javanica* in tomato. *Indian Journal of Nematology, 16,* 8–11.

Elad, Y., Katan, J., & Chet, I. (1980). Physical, biological, and chemical control integrated for soil borne diseases in potatoes. *Phytopathology, 70,* 418–422.

Ganga Visalakshy, P. N., & Krishnamoorthy, A. (2009). Development of bio-intensive integrated management for brinjal shoot and fruit borer, *Leucinodes orbonalis* Guene. *International Conference on Horticulture*, Bangalore.

Ganguli, R. N., Singh, V. V., Dixit, S. A., & Kowshik, U. K. (1997). Efficacy of NPV (nuclear polyhedrosis virus) and endosulfan against tomato fruit borer, *Heliothis armigera. Current Research, 26,* 210–212.

Gopalakrishnan, C., & Ajith Kumar, K. (2006). Increasing the field efficacy of *Pseudo-monas fluorescens* in the management of bacterial wilt in tomato, *Lycopersicon esculentum* Mill. *National Symposium on Improving Input Use Efficiency in Horticulture*, Indian Institute of Horticultural Research, Bangalore, pp. 197–198.

Gopinatha, K. V., Nanje Gowda, D. N., & Nagesh, M. (2002). Management of root-knot nematode *Meloidogyne incognita* on tomato using bioagent *Verticillium chlamydo-sporium*, neem cake, marigold and carbofuran. *Indian Journal of Nematology, 32,* 179–181.

Goswami, B. K., & Singh, S. (2002). Effect of *Aspergillus niger* and *Cladosporium oxys-porum* on plant vigour and root-knot nematode, *Meloidogyne incognita* multiplication on egg plant. *Indian Journal of Nematology, 32,* 94–96.

Goswami, B. K., Rao, U., & Singh, S. (1998). *Potentiality of some fungal bioagents against root-knot nematode, Meloidogyne incognita infecting tomato*. Proceedings of First National Symposium on Pest Management in Horticultural Crops. Bangalore, pp. 304–307.

Gupta, P. R., & Raja Ram Mohan Babu, B. (1998). Management of *Helicoverpa armigera* on tomato with *Trichogramma pretiosum* and *Bacillus thuringiensis* var. *kurstaki*. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds.), *Advances in pest management of horticultural crops* (pp. 75–80). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Hadar, Y., Chet, I., & Henis, Y. (1979). Biological control of *Rhizoctonia solani* damping -off with wheat bran culture of *Trichoderma harzianum. Phytopathology, 69,* 64–68.

Haider, M. G., Nath, R. P., Thakur, S. C., & Ojha, K. L. (1987). Interaction of *Meloidogyne incognita* and *Pseudomonas solanacearum* on tomato plants. *Indian Journal of Nematology, 17,* 174–176.

Heald, C. M., & Robinson, A. F. (1987). Effect of soil solarization on *Rotylenchulus reniformis* in the lower Rio Grande Valley of Texas. *Journal of Nematology, 19,* 93–103.

Hasan, A. (1985a). Synergistic interaction between *Pythium aphanidermatum* and *Rhizoctonia solani* with *Meloidogyne incognita* on chilli. *Nematologica, 31,* 210–217.

Hasan, A. (1985b). Breaking resistance in chilli to root-knot nematode by fungal pathogens. *Nematologica, 31,* 210–217.

Hassan, M. G. & Sobita Devi (2004). *Efficacy of bioagents against root-knot nematode, (Meloidogyne incognita) of tomato*. National Symposium on Paradigms in Nematology Research for Biodynamic Farming, University of Agricultural Science, Bangalore, p. 88.

Haseeb, A. (2003). Management of root-knot nematode and wilt complex and their interaction in vegetable crops using organic amendments and biocontrol agents. Report of the UPCAR Sponsored Project, Lucknow, 52 pp.

Haseeb, A., Shukla, P. K., Kumar, V., & Khan, R. U. (2004). *Comparative efficacy of bio- control agents, neem seed powder and pesticides against Meloidogyne incognita and Fusarium oxysporum on brinjal*. National Symposium on Paradigms in Nematological Research for Biodynamic Farming, University of Agricultural Science, Bangalore, p. 80.

Hussain, Z., & Bora, B. C. (2008). Integrated management of *Meloidogyne incognita* and *Ralstonia solanacearum* complex in brinjal. *Indian Journal of Nematology, 38,* 159–164.

Jadon, K. S. (2009). Eco-friendly management of brinjal collar rot caused by *Sclerotium rolfsii* Sacc. Indian Phytopathology*, 62,* 345–347.

Jain, R. K., & Bhatti, D. S. (1985). Effect of summer ploughing alone and in combination with some other effective practices on the incidence of root-knot nematode (*Meloidogyne javanica*) on tomato (Cultivar HS 101). *Indian Journal of Nematology, 15,* 262.

Jain, R. K., & Gupta, D. C. (1991). Integrated management of root-knot nematode, *Meloidogyne javanica* infecting *Solanum melongena. Afro–Asian Journal of Nematology, 1,* 156–160.

Jatala, P. (1985). Biological control of nematodes. In J. N. Sasser & C. C. Carter (Eds.), *Advanced treatise on meloidogyne, biology and control* (Vol. 1, pp. 303–308). Raleigh: North Carolina State University Graphics.

Jenkins, S. F., & Averre, C. W. (1986). Problems and progress in integrated control of southern blight of vegetables. *Plant Disease, 70,* 614–619.

Jenkins, W. R., & Coursen, B. W. (1957). The effect of root-knot nematodes, *Meloidogyne incognita acrita* and *M. hapla*, on *Fusarium* wilt of tomato. *Plant Disease Reporter, 41,* 182–186.

Jones, F. C. E. (1969). Integrated control of the potato cyst nematode. *Proceedings of Fifth British Insecticide Fungicide Conference, 3,* 646–656.

Karthikeyan, G., Duraisamy, S., Sivakumar, C. V., & Duraisamy, S. (1999). Biological control of *Pythium aphanidermatum, Meloidogyne incognita* disease complex in chilli with organic amendments. *Madras Agricultural Journal, 86,* 320–323.

Khaderkhan, H., Nataraju, M. S., & Nagaraja, G. N. (1998). Economics of IPM in tomato. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds), *Advances in IPM for horticultural crops* (pp 151–152). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Krishna Moorthy, P. N., & Krishna Kumar, P. N. (2002). *Advances in the use of botanicals for the IPM of major vegetable pests*. Proceedings of the International Conference on Vegetables, Bangalore. Dr. Prem Nath Agricultural Science Foundation, Bangalore, pp. 262–272.

Krishnamoorthy, A., Gopalakrishnan, C., & Mani, M. (1999). *Integration of egg parasitoid and HaNPV for the control of Helicoverpa armigera Hubn on tomato*. International Seminar on IPM, Indian Institute of Chemical Technology, Hyderabad.

Kumar, V., & Haseeb, A. (2009). Interactive effect of *Meloidogyne incognita* and *Rhizoctonia solani* on the growth and yield of tomato. *Indian Journal of Nematology, 39,* 178–181.

Kumar, V., Haseeb, A., & Sharma, A. (2009a). Integrated management of *Meloidogyne incognita-Fusarium solani* disease complex of brinjal cv. Pusa Kranti. *Annals of Plant Protection Sciences, 17,* 192–194.

Kumar, V., Haseeb, A., & Sharma, A. (2009b). Integrated management of *Meloidogyne incognita* and *Fusarium solani* disease complex of chilli. *Indian Phytopathology, 62,* 324–327.

Mahalingam, C. A., & Saminathan, V. R. (2003). Efficacy of *Bt, Ha*NPV and endosulfan individually and in combination for the management of the tomato fruit borer, *Helicoverpa armigera* (Hubner) (Noctuidae: Lepidoptera). In S. Ignacimuthu & S. Jayaraj (Eds.), *Biological control of insect pests* (pp. 88–91). New Delhi: Phoenix Publishing House Pvt. Ltd.

Maheswari, T. U., & Mani, A. (1988). Combined efficacy of *Pasteuria penetrans* and *Paecilomyces lilacinus* on the biocontrol of *Meloidogyne javanica* on tomato. *International Nematology Network Newsletter, 5*(3), 10–11.

Maheswari, T. U., Mani, A., & Rao, P. K. (1987). Combined efficacy of the bacterial spore parasite *Pasteuria penetrans* (Thorne, 1940) and nematicides in the control of *Meloidogyne javanica* on tomato. *Journal of Biological Control, 1,* 53–57.

Mao, W., Lewis, J. A., Lumsden, R. D., & Hebber, K. P. (1998). Biocontrol of selected soilborne disease of tomato and pepper plants. *Crop Protection, 17,* 535–542.

Mesta, R. K., Mohankumar, H. D., Shivaprasad, M., Tatagar, M. H., & Rao, M. S. L. (2009). *Management of fruit rot and powdery mildew of chilli through Pseudomonas fluorescens.* International Conference on Horticulture, Bangalore.

Naik, D. (2004). biotechnological approaches for the management of wilt disease complex in capsicum (*Capsicum annum* L.) and egg plant (*Solanum melongena*) with special emphasis on biological control. Ph.D. thesis, Kuvempu University, Shimoga.

Naik, D., Rao, M. S., Shylaja, M., Reddy, M. S., & Rahiman, B. A. (2003). Management of wilt disease complex in capsicum using *Bacillus pumilus* and *Paecilomyces lilacinus. Proceedings of International Plant Growth Promoting Rhizobacteria Workshop*, Calicut, India, pp. 276–281.

Nagesh, M., Hussaini, S. S., Ramanujam, B., & Chidanandaswamy, B. S. (2006). Management of *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *lycopersici*

wilt complex using antagonistic fungi in tomato. *Nematology Mediterranea, 34,* 63–68.

Napiere, C. M. (1980). Varying inoculum levels of bacteria, nematodes and the severity of tomato bacterial wilt. *Annals of Tropical Research, 2,* 129–134.

Napiere, C. M., & Quinio, A. J. (1980). Influence of root-knot nematode on bacterial wilt severity in tomato. *Annals of Tropical Research, 2,* 29–39.

Oostenbrink, M. (1972). Evaluation and integration of nematode control methods. In J. M. Webster (Ed.), *Economic nematology* (pp. 497–514). New York: Academic Press.

Ordentlich, A., Nachmias, A., & Chet, I. (1990). Integrated control of *Verticillium dahliae* in potato by *Trichoderma harzianum* and captan. *Crop Protection, 9,* 363–366.

Pani, A. K., & Das, S. N. (1972). Studies on etiological complexes in plant disease. I. Association of root-knot nematodes in bacterial wilt of tomato. *J Res Orissa Univ Agri Technol, 2,* 54–59.

Parvatha Reddy, P., & Khan, R. M. (1988). Evaluation of *Paecilomyces lilacinus* for the biological control of *Rotylenchulus reniformis* infecting tomato as compared with carbofuran. *Nematology Mediterranea, 16,* 113–116.

Parvatha Reddy, P., & Khan, R. M. (1989). Evaluation of biocontrol agent *Paecilomyces lilacinus* and carbofuran for the management of *Rotylenchulus renfiromis* infecting brinjal. *Pakistan Journal of Nematology, 7,* 55–59.

Parvatha Reddy, P., & Singh, D. B. (1981). Assessment of avoidable yield loss in okra, brinjal, French bean and cowpea due to root-knot nematodes. *Third International Symposium on Plant Pathology*, New Delhi, pp. 93–94.

Parvatha Reddy, P., Nagesh, M., & Devappa, V. (1997). Effect of integration of *Pasteuria penetrans, Paecilomyces lilacinus* and neem cake for the management of root-knot nematode infecting tomato. *Pest Management Horticultural Ecosystems, 3,* 100–104.

Parvatha Reddy, P., Rao, M. S., & Nagesh, M. (1998). Effect of bare-root dip treatment of tomato seedlings in plant leaf extracts mixed with *Paecilomyces lilacinus* spores for the management of *Meloidogyne incognita*. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds.), *Advances in IPM for horticultural crops* (pp. 334–338). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Parvatha Reddy, P., Rao, M. S., & Nagesh, M. (1999). Eco-friendly management of *Meloidogyne incognita* on tomato by integration of *Verticillium chlamydosporium* with neem and calotropis leaves. *Journal of Plant Disease Protection, 106,* 530–533.

Patel, S. K., Patel, H. V., & Patel, A. D. (2006). Integrated management of root-knot nematode in tomato nursery through botanical plant materials. *Indian Journal of Nematology, 36,* 307–308.

Perveen, S., Ehteshamul-Haque, S., & Ghaffar, A. (1998). Efficacy of *Pseudomonas aeruginosa* and *Paecilomyces lilacinus* in the control of root rot-root knot disease complex on some vegetables. *Nematology Mediterranea, 26,* 209–212.

Prasad, K. S. K. (1989). Nematological problems and progress of research on potato in India. *Fourth Group Meeting on Nematology. Problems of Plantation Crops*, University of Agricultural Science, Bangalore.

Quereshi, Q. G., Mathur, N. M., & Srivastava, R. C. (1998). Management of brinjal shoot and fruit borer *Leucinodes orbonalis* Guenee using *Bacillus thuringiensis* var *kurstaki*. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds.), *Advances in pest management of horticultural crops* (pp. 81–83). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Rahman, M. A., Vijaya, M., Chiranjeevi, C. H., Sai Reddy, C., & Reddy, I. P. (2002). *Disease management of Solanaceous vegetable crops at nursery stage with biocontrol agents*. Proceedings of the International Conference on Vegetables, Bangalore, India, pp. 352–355. Dr. Prem Nath Agricultural Science Foundation, Bangalore.

Raja, J., Rajendran, B., & Papaiah, C. M. (1998). Management of egg plant shoot and fruit borer, *Leucinodes orbonalis* Guen. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds.), *Advances in pest management of horticultural crops* (pp. 84–86). Bangalore: Association for Advancement of Pest Management in Hortilcultural Ecosystems.

Rajendran, B. (1998). Effect of neem oil and insecticide on the population and parasitization of eggplant spotted beetle, *Henosepilachna vignitioctopunctata* F. (Cocinellidae: Coleoptera). In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds.), *Advaces in IPM for horticultural crops* (pp. 102–105). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Rangaswamy, S. D., Parvatha Reddy, P., Nagesh, M., & Nanje Gowda, D. N. (1999). Integrated management of *Meloidogyne incognita* using *Pasteuria penetrans, Tricho-derma viride* and oil cakes in tomato. *Pest Management in Horticulture Ecosystems, 5,* 122–126.

Rao, M. S., & Parvatha Reddy, P. (1992). *Innovative approaches of utilization of biocontrol agents-Paecilomyces lilacinus and Verticillium chlamydosporium against root-knot nematode on tomato* (Abstract). First Afro-Asian nematology symposium, Aligarh Muslim University, Aligarh, pp. 25–26.

Rao, M. S., & Parvatha Reddy, P. (1993a). Effective use of 'Welgro' and 'RD-9 Repelin' for the management of root-knot nematode on tomato. In R. P. Singh, M. S. Chari, A. K. Raheja, & W. Kraus (Eds.), *Neem and environment* (Vol. 2, pp. 651–656). New Delhi: Oxford & IBH Publishing Co. Pvt. Ltd.

Rao, M. S., & Parvatha Reddy, P. (1993b). Interactive effect of *Verticillium chlamydosporium* and castor cake on the control of root-knot nematode on eggplant. In D. Rajagopal, R. D. Kale, & K. Bano (Eds.). *Soil organisms and sustainability* (pp. 114–118). Bangalore: Indian Society of Soil Biology and Ecology, University of Agricultural Science.

Rao, M. S., & Parvatha Reddy, P. (1994). A method for conveying *Paecilomyces lilacinus* to soil for the man-

agement of root-knot nematodes on eggplant. *Nematologia Mediterranean, 22,* 265–267.

Rao, M. S., & Parvatha Reddy, P. (2001). Control of *Meloidogyne incognita* on eggplant using *Glomus mosseae* integrated with *Paecilomyces lilacinus* and neem cake. *Nematologia Mediterranean, 29,* 153–157.

Rao, M. S., Mohandas, S., Parvatha Reddy, P., & Khan, R. M. (1993a). Synergistic effect of endomycorrhizal fungus (*Glomus fasciculatum*) and biocontrol fungus (*Paecilomyces lilacinus*) in the management of root-knot nematode infecting tomato. In D. Rajagopal, R. D. Kale, & K. Bano (Eds.), *Soil Organisms and Sustainability* (pp. 119–123). Bangalore: Indian Society of Soil Biology and Ecology, University of Agricultural Science.

Rao, M. S., Mohan Das, S., Parvatha Reddy, P., & Khan, R. M. (1993b). Management of reniform nematode on egg plant by integrating a botanical (castor cake), mycorrhiza (*Glomus fasciculatum*) and bio-agent (*Paecilomyces lilacinus*). *Golden jubilee symposium on horticulture research—changing scenario* (pp. 259–260), Bangalore.

Rao, M. S., Parvatha Reddy, P., & Mohandas, S. (1995). *Studies on development of a biorational management strategy against root-knot nematode attacking tomato*. In G. Swarup, D. R. Dasgupta, & J. S. Gill (Eds.), National symposium on nematode problems of India—an appraisal of the nematode management with eco-friendly approaches, Nematol. Soc. of India, New Delhi, p. 14.

Rao, M. S., Parvatha Reddy, P., & Mohandas, S. (1996). Effect of integration of *Calotropis procera* leaf and *Glomus fasciculatum* on the management of *Meloidogyne incognita* infesting tomato. *Nematologia Mediterranean, 24,* 59–61.

Rao, M. S., Parvatha Reddy, P., Somasekhar, N., & Nagesh, M. (1997a). Management of root-knot nematodes, *Meloidogyne incognita* in tomato nursery by integration of endomycorrhiza, *Glomus fasciculatum* with castor cake. *Pest Management in Horticulture Ecosystems, 3,* 31–35.

Rao, M. S., Parvatha Reddy, P., & Nagesh, M. (1997b). Integration of *Paecilomyces lilacinus* with neem leaf suspension for the management of root-knot nematodes on eggplant. *Nematologia Mediterranean, 25,* 249–252.

Rao, M. S., Parvatha Reddy, P., & Nagesh, M. (1997c). Management of root-knot nematode, *Meloidogyne incognita* on tomato by integration of *Trichoderma harzianum* with neem cake. *Journal of Plant Diseases and Protection, 104,* 423–425.

Rao, M. S., Parvatha Reddy, P., & Nagesh, M. (1998a). Integrated management of *Meloi-dogyne incognita* on tomato using *Verticillium chlamydosporium* and *Pasteuria penetrans. Pest Management in Horticulture Ecosystems, 4,* 32–35.

Rao, M. S., Parvatha Reddy, P., & Nagesh, M. (1998b). Integrated management of *Meloi-dogyne incognita* on tomato using oil cakes and a bioagent, *Verticillium chlamydos-porium*. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds.), *Advances in IPM for horticultural crops* (pp. 345–348). Bangalore: Association for Advancement of Pest Management in Hortilcultural Ecosystems.

Rao, M. S., Parvatha Reddy, P., & Nagesh, M. (1998c). Evaluation of plant based formulations of *Trichoderma harzianum* for the management of *Meloidogyne incognita* on eggplant. *Nematologia Mediterranean, 26,* 59–62.

Rao, M. S., Parvatha Reddy, P., & Nagesh, M. (1998d). Evaluation of *Paecilomyces lilacinus* cultured on neem cake extract for the management of root-knot nematodes on eggplant. *Pest Management in Horticulture Ecosystems, 4,* 116–119.

Rao, M. S., Parvatha Reddy, P., & Sukhada, M. (1998e). Biointensive management of *Meloidogyne incognita* on eggplant by integrating *Paeciloymces lilacinus* and *Glomus mosseae. Nematologia Mediterranean, 26,* 213–216.

Rao, M. S., Parvatha Reddy, P., Sukhada, M., Nagesh, M., & Pankaj (1998f). Management of root-knot nematodes on eggplant by integrating endomycorrhiza (*Glomus fasciculatum*) and castor (*Ricinus communis*) cake. *Nematologia Mediterranean, 26,* 217–219.

Rao, M. S., Parvatha Reddy, P., & Nagesh, M. (1999). Bare root-dip treatment of tomato seedlings in calotropis or castor leaf extracts mixed with *Paecilomyces lilacinus* spores for the management of *Meloidogyne incognita. Nematologia Mediterranean, 27,* 323–326.

Rao, M. S., Naik, D., Shylaja, M., & Parvatha Reddy, P. (2002a). Prospects for the management of nematode disease complex in capsicum using biological control agents. Proceeding of international conference on vegetables, Bangalore, pp. 347–351.

Rao, M. S., Naik, D., & Shylaja, M. (2004). Bio-intensive management of root-knot nematodes on bell pepper using *Pochonia chlamydosporia* and *Pseudomonas fluorescens. Nematology Mediterranea, 32,* 159–163.

Rao, M. S., Ramachandran, N., Sowmya, D. S., Ratnamma, K., Chaya, M. K., & Manoj Kumar, R. (2009). Biological control of nematode induced disease complex in certain vegetable crops. International conference on horticulture, Bangalore.

Reddy, D. D. R. (1985). Analysis of crop losses in tomato due to *Meloidogyne incognita*. *Indian Journal of Nematology, 15,* 55–59.

Riga, E., Pierce, F., & Collins, H. (2006). *The use of arugula on its own and in combination with systemic nematicides against plant parasitic nematodes of potatoes* (Abstracts). Second international biofumigation symposium, Idaho, USA, p. 42.

Ristaino, J. B., Perry, K. B., & Lumsden, R. D. (1991). Effect of solarization and *Gliocladium virens* on sclerotia of *Sclerotium rolfsii*, soil microflora, and the incidence of southern blight of tomato. *Phytopathology, 91,* 1117–1124.

Ristaino, J. B., Perry, K. B., & Lumsden, R. D. (1996). Soil solarization and *Gliocladium virens* reduce the incidence of southern blight (*Sclerotium rolfsii*) in bell pepper in the field. *Biocontrol Science and Technology, 6,* 583–593.

Routaray, B. N., & Sahoo, H. (1985). Integrated control of root-knot nematode, *Meloidogyne incognita* with

neem cake and granular nematicides on tomato. *Indian Journal of Nematology, 15,* 261.

Saikia, M. K., & Borah, A. (2008). Comparative efficacy of fungal and bacterial bioagents with nematicides against *Meloidogyne incognita* on brinjal. *Indian Journal of Nematology, 38,* 159–164.

Sankarimeena, K., Jonathan, E. I., Devarajan, K., & Raghuchander, T. (2012). *Pseudomonas fluorescens* induced systemic resistance in tomato against *Meloidogyne incognita. Indian Journal of Nematology, 42,* 5–10.

Sardana, H. R., Trivedi, T. P., Bambawale, O. M., Sabir, N., Singh, R. V., Arora, S., Krishna Moorthy, P. N., Pandey, P. K., Pandey, K. K., & Sengupta, A. (2004). Validated IPM technologies: Vegetable crops. In A. Singh, H. R. Sardana, & N. Sabir (Eds.), *Validated IPM technologies for selected crops* (pp. 119–148). New Delhi: National Centre for Integrated Pest Management (ICAR).

Sheela, M. S., Jiji, T., & Nisha, M. S. (2002). *Evaluation of different control strategies for the management of nematodes associated with vegetables (brinjal)* (Abstracts). International conference on Vegetables, Bangalore, p. 268.

Siddiqui, I. A., & Ehteshamul-Haque, S. (2001). Suppression of the root rot-root knot disease complex by *Pseudomonas aeruginosa* in tomato: The influence of inoculum density, nematode populations, moisture and other plant-associated bacteria. *Plant and Soil, 237,* 81–89. http://www.springerlink.com/content/100326/?p=3da034a628b945dcbc3418bb3e615468&pi=0.

Siddiqui, I. A., Ehteshamul-Haque, S., & Ghaffar, A. (1999). Root-dip treatment with *Pseudomonas aeruginosa* and *Trichoderma* spp. in the control of root rot-root knot disease complex in chilli (*Capsicum annuum* L.). *Pakistan Journal of Nematology, 17,* 67–75.

Siddiqui, I. A., Qureshi, S. A., Sultana, V., Ehteshamul-Haque, S., & Ghaffar, A. (2000). Biological control of root rot-root knot disease complex of tomato. *Plant and Soil, 227,* 163–169.

Singh, D. (1991). *Studies on the Effect of Tagetes Species on Meloidogyne javanica* Infectivity in Brinjal (*Solanum melongena*). Ph. D. thesis, Haryana Agricultural University, Hisar, p. 83.

Singh, S. P. (2000). Application of biotechnology in bio-intensive integrated pest management. In K. L. Chadha, P. N. Raveendran, & L. Sahijram (Eds.), *Biotechnology in horticultural and plantation crops* (p. 836). New Delhi: Malhotra Publishing House.

Singh, R. V., & Gill, J. S. (1998). Important nematode problems on vegetables and their management. In S. M. Paul Khurana (Ed.), *Pathological problems of economic crop plants and their management* (pp. 557–570). Jodhpur: Scientific Publishers.

Singh, H., & Singh, G. (1975). Biological studies on *Heliothis armigera* (Hubner) in Punjab. *Indian Journal of Entomology, 37,* 154–164.

Singh, R. S., Singh, P. P., & Bedi, J. S. (2002). Final report of DBT scheme on biocontrol of seed and soil-borne diseases of vegetables. Punjab Agricultural University, Ludhiana, p. 90.

Sitaramaiah, K., & Naidu, H. (2003). Plant parasitic nematodes-management opportunities and challenges. In P. C. Trivedi (Ed.), *Nematode management in plants* (pp. 57–80). Jodhpur: Scientific Publishers.

Smits, B. G., & Noguera, R. (1982). Effect of *Meloidogyne incognita* on the pathogenicity of different isolates of *Fusarium oxysporum* on brinjal (*Solanum melongena* L.). *Agronomia Tropical, 32,* 284–290.

Sreenivasa, M. N. (1997). Influence of VAM and *Trichoderma harzianum* on *Sclerotium* in three varieties of chilli. *Environment Ecology, 15,* 343–345.

Srinivasan, P. M. (1958). Control of fruit borer, *Heliothis armigera* (Hub) on tomato. *Indian Journal of Horticulture, 16,* 187–188.

Srinivasan, K., Krishna Moorthy, P. N., & Raviprasad, T. N. (1994). African marigold as a trap crop for the management of the fruit borer *Helicoverpa armigera* on tomato. *International Journal of Pest Mangement, 40,* 56–63.

Subramanyam, S., Rajendran, G., & Vadivelu, S. (1990). Estimation of loss in tomato due to *Meloidogyne incognita* and *Rotylenchulus reniformis*. *Indian Journal of Nematology, 20,* 239–240.

Tewari, G. C., & Krishna Murthy, P. N. (1984). Yield loss in tomato caused by fruit borer. *Indian Journal of Agricultural Science, 54,* 341–343.

Tripathi, P. K., & Singh, C. S. (2006). Effect of some compatible biocontrol agents along with mustard cake and furadan on *Meloidogyne incognita* infecting tomato plant. *Indian Journal of Nematology, 36,* 309–311.

Troncoso-Rojas, R., Espinoza, C., Sánchez-Estrada, A., Sergio-García, H., Pryor, B., Baez-Flores, M. E., & Tiznado-Hernández, M. E. (2008). *Evaluation of isothiocy-anates to control postharvest fruit and vegetable losses by fungal infections in Mexico*. Third international biofumigation symposium, Canberra, Australia.

Tsror, L., Lebiush, S., Meshulam, M., Matan, E., & Lazzeri, L. (2006). *Biofumigation for controlling soil-borne diseases of tomato, potato and olive*. Second international biofumi-gation symposium, Idaho, USA, p. 46.

Vyas, R. V., Patel, B. A., Patel, B. N., & Patel, J. G. (2009). Integrated management of root-knot nematode in brinjal under field conditions. *Indian Journal of Nematology, 39,* 35–37.

Winslow, R. D., & Willis, R. J. (1972). Nematode diseases of potato. In J. M. Webster (Ed.), *Economic Nematology* (pp. 17–48). London: Academic Press.

Zaki, F. A. (1998). Biological control of *Meloidogyne javanica* in tomato by *Paecilomyces lilacinus* and castor leaves. *Indian Journal of Nematology, 28,* 132–139.

Zaki, F. A., & Bhatti, D. S. (1989). Effect of castor (*Ricinus communis*) leaves in combination with different fertilizer doses on *Meloidogyne javanica* infecting tomato. *Indian Journal of Nematology, 19,* 171–176.

Zaki, F. A., & Bhatti, D. S. (1991). Effect of castor *Ricinus communis* and the biocontrol fungus, *Paecilomyces lilacinus* on. *Meloidogyne javanica. Nematologica, 36,* 114–122.

Bulbous Vegetable Crops

7

7.1 Onion, *Allium cepa* and Garlic, *Allium sativum*

7.1.1 Diseases

7.1.1.1 Damping-Off, *Pythium* sp., *Rhizoctonia solani, Fusarium* sp.

(i) Symptoms: Cold, wet soils often encourage the development of damping-off symptoms very early in the seedling's growth. Seedlings may fall over and die as a result of breakdown of plant tissues at the soil line (Fig. 7.1). Sometimes damping-off occurs before the seedling even emerges. The disease is usually caused by *Pythium, Rhizoctonia* or *Fusarium* fungi, either alone or in combination. Damping-off can occur in the field or in the nursery if conditions are too wet.

(ii) Integrated Management:
(a) Physical and Bioagents: Seed treatment with *Trichoderma harzianum* at 5 g/kg and sowing in solarized soil helps in reducing the disease incidence.

7.1.1.2 Basal Rot, *Fusarium oxysporum* f. sp. *cepae*

(i) Symptoms: The early symptoms in the field are yellowing of leaves and tip dieback. As the disease progresses, the whole plant may collapse and, if the plant is pulled, it often comes out without any roots attached since they have decayed. The basal plate of the onion becomes pinkish-brown and secondary bacterial rots may develop in the affected area (Fig. 7.2). If infection occurs late in the season, the symptoms may not show up until the onions are in storage. Basal rot generally occurs when soil temperatures are very warm (optimum 29 °C).

(ii) Integrated Management
(a) Bioagents and Botanicals: *Trichoderma viride* at 1,250 g + 50 kg farm yard manure (FYM) if applied to soil before planting gives good control of basal rot in seed crop.

7.1.1.3 White Rot, *Sclerotium cepivorum*

White rot is a very destructive disease that begins in the field and can carry over into storage.

(i) Symptoms: The first above-ground symptoms are yellowing and dieback of the leaf tips, followed by a collapse of the affected leaves. When the bulbs and roots are examined, a white, fluffy mold and soft rot will be observed. Masses of tiny black sclerotia can also be seen within this mold (Fig. 7.3). These sclerotia remain in the soil for many years. Infected bulbs can rot in storage boxes and stain other bulbs. White rot typically develops in patches in the field and is less of a problem when soils are warm (higher than 24 °C) and dry.

(ii) Integrated Management
(a) Bioagents and Chemicals: Seed treatment with captan (for control of damping-off) along with *Trichoderma atroviride* and application of procymidone (for control of onion white rot) during later stages is very effective (McLean et al. 2001).

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_7, © Springer India 2014

Fig. 7.1 Damping-off of onion seedlings

Fig. 7.2 Basal rot on onion bulbs

Fig. 7.3 White rot of onion

Fig. 7.4 Root-knot nematode on onion

(b) Bioagents and Botanicals: Integration of *T. atroviride* (pellet formulation) with organic amendments including poultry manure, spent mushroom compost and certified green compost gave effective control of onion white rot disease.

(c) Physical and Bioagents: Application of *Bacillus subtilis, T. harzianum, T. viride*, and *Trichoderma virens* to the solarized soil effectively controlled the disease. Incorporation of *T. harzianum* in soil after soil solarization effectively controlled *S. cepivorum* in soil and increased the control from 79 % to 98 %. A significant population growth of antagonist occurred attaining 108 cfu/g of soil (Pereira et al. 1996).

Table 7.1 Effect of neem cake and bioagents on the bulb yield of onion

Treatments	Yield (t/Ac)
NC	12.972
PL	14.022
PF	13.746
NC+PL	17.347
NC+PF	16.842
PL+PF	14.749
Control	12.476

NC neem cake, *PL Paecilomyces lilacinus, PF Pseudomonas fluorescens*

7.1.2 Nematodes

7.1.2.1 Root-Knot Nematodes, *Meloidogyne* spp.

(i) Symptoms: Above-ground symptoms on onions heavily infected with *Meloidogyne hapla* are those of general stunting, uneven growth; thicker necks and smaller bulbs; and also delayed maturity. The diagnostic symptoms are found on roots as galls or root thickenings of various sizes and shapes with protruding egg masses (Fig. 7.4). On onions, galls are usually small and barely noticeable, often no more than slight swellings. Bulb weight of onions was reduced by as much as 70 % in heavily infested sections of commercial fields. In field micro plots, bulb weight of the onion cultivars Norstar and Paragon were reduced by about 50 % at an infestation level of 20 eggs/cc soil.

(ii) Integrated Management

(a) Bioagents and Botanicals: Root dip treatment of onion seedlings in neem cake suspension + *Paecilomyces lilacinus* for 1 h before transplanting proved effective.

Seed treatment with *Pseudomonas fluorescens* (10^9 cfu/g) at 10 g/kg and subsequent soil application of 5 t of FYM enriched with 5 kg each of *P. fluorescens* (10^9 cfu/g) and *Pochonia chlamydosporia* (10^6 cfu/g) per ha significantly reduced *Meloidogyne incognita* population in roots by 69 % and increased bulb yield by 21 % (Anon 2012).

Integration of neem cake with *P. lilacinus* was found effective and increased bulb yield (Table 7.1).

References

Anon. (2012). Annual Report (2011–12). Indian Institute of Horticultural Research, Bangalore, pp. 23–24.

McLean, K. L., Hunt, J., & Stewart, A. (2001). Compatibility of the biocontrol agent *Trichoderma harzianum* (C52) with fungicides. *New Zealand Plant Protection, 54,* 84–88.

Pereira, C. M. F., Chaves, G. M., Zambolim, L., Matsuoka, K., Acuna, R. S., & DoVale, F. X. R. (1996). Control of *Sclerotium cepivorum* by the use of vermicompost, solarization, *Trichoderma harzianum* and *Bacillus subtilis*. *Summa Phytopathologica, 22,* 228–234.

Cruciferous Vegetable Crops

8

8.1 Cabbage, *Brassica oleracea* var. *capitata* and Cauliflower, *Brassica oleracea* var. *botrytis*

8.1.1 Insect Pests

8.1.1.1 Diamondback Moth, *Plutella xylostella*

This is a major pest of cruciferous crops, particularly cabbage and cauliflower during January–June months and also during drought periods in monsoon.

(i) Damage: The first instar larvae mine the epidermal surface of the leaves. Second instar onwards the larvae feed externally by making holes in the leaves (Fig. 8.1).

(ii) Integrated Management

(a) Cultural and Bioagents: Integrated pest management (IPM) using Indian mustard as a trap crop involves planting of paired rows of mustard after every 25 rows of cabbage/cauliflower (Fig. 8.2), and spraying of 4% NSKE at primordial formation. Two more sprays of 4% NSKE may be given at 10–15 day interval after the first spray. The IPM gave 60% more yield and 152% more returns than pure cabbage crop (Table 8.1; Khaderkhan et al. 1998). IPM controls diamondback moth (DBM) (*P. xylostella*); leaf webber (*Crocidolomia binotalis*); stem borer (*Hellula undalis*); aphids (*Brevicorne brassicae, Hyadaphis erysimi*) and bug (*Bagrada cruciferarum*; Srinivasan and Krishna Moorthy 1991).

In another study, the benefit-to-cost ratio in IPM and non-IPM plots was 2.42 and 0.83, respectively (Table 8.2; Krishna Moorthy et al. 2003).

(b) Bioagents and Chemicals: Maximum mortality of DBM larvae was achieved (98.03%) on treatment with emamectin benzoate + *Beauveria bassiana* at 3.0 + 0.75 g/L of water along with 15.536 t/ha yield potential followed by emamectin benzoate + *B. bassiana* at 2.5 + 0.50 g/L of water with 96.54% morality over the control (Vishwakarma et al. 2009).

Integration of gibberellic acid at 1,000 ppm + *Pseudomonas fluorescens* at 5 kg/ha + *Bacillus thuringiensis* (*Bt*) var. *kurstaki* at 1 kg/ha in alternation with *P. xylostella* granulosis virus at 1.5×10^{13} OB/ha recorded significantly lower incidence of *P. xylostella* (4.33 and 5.67 larvae/10 plants as compared to 43.00 in control), and increased curd yield of cauliflower (32.33 t/ha and 35.33 t/ha as compared to 21.33 t/ha in control; Mohanasundaram and Dhandapani 2009).

(c) Bioagents and Botanicals: The number of DBM larvae was lowest in cabbage treated with four alternate sprays of 3% NSKE and 0.1% *Bt* alternately at 25 days interval.

8.1.1.2 Tobacco Caterpillar, *Spodoptera litura*

(i) Damage: It is a polyphagous pest. The young larvae up to third instar feed gregariously and skeletonize the leaves (Fig. 8.3). Grown up larvae completely devour the leaves and other plant

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems*,
DOI 10.1007/978-81-322-1844-9_8, © Springer India 2014

Fig. 8.1 Diamond-back moth damage on cabbage

Fig. 8.2 IPM in cabbage and cauliflower using Indian mustard as a trap crop

Table 8.1 Economics of cabbage IPM

Practice	Yield (MT/ha)	% increase	Net returns (₹)	% increase
Farmers' practice	20	–	19,817	–
IPM practice	32	60	49,251	152

Table 8.2 Economics of cabbage IPM

Treatment	Yield (MT/ha)	Net returns (₹/ha)	Benefit-to-cost ratio
IPM plots	55	30,085	2.42
Non-IPM plots (farmers' practice)	35	5,090	0.83

Fig. 8.3 Cabbage head damaged by *Spodoptera litura*

Fig. 8.4 Damping-off of crucifer seedlings

parts in case of severe incidence. When the incidence is high they attain cut worm status, hide during daytime, and come out during night and devastate the crop. During severe infestation, the entire crop may be defoliated overnight.

(ii) Integrated Management

(a) Bioagents and Chemicals: Under field conditions, half the dosage of *S. litura* nuclear polyhedrosis virus (*Sl*NPV) (2.6×10^6 POB/mL) + 50 ppm endosulfan was very effective in reducing the leaf damage caused by *S. litura* on cauliflower (Chaudhari and Ramakrishnan 1980).

8.1.2 Diseases

8.1.2.1 Damping-Off, *Pythium aphanidermatum*

(i) Symptoms: The fungus attacks in the seedling stage causing damping-off disease (Fig. 8.4).

(ii) Integrated Management (a) Bioagents and Chemicals: Mukherjee et al. (1989) reported effective control of *P. aphanidermatum* on cauliflower with a combination of *Trichoderma harzianum* and ridomil.

8.1.2.2 Brown Rot, *Rhizoctonia solani*

(i) Symptoms: A dark, water-soaked lesion initially appears on the stem. Later, stems become wiry and slender at the point of the lesion. Diseased crucifer plants transplanted to the field grow poorly, are stunted, and may eventually die, especially if there is inadequate moisture shortly after transplanting. If infected plants remain alive, the stem becomes tough and woody (Fig. 8.5). Plants that survive usually mature late and fail to produce a marketable head.

(ii) Integrated Management

(a) Physical, Botanicals, Bioagents and Chemicals: The seed treatment with carbendazim at 2 g/kg seed, raising seedling in solarized beds, crop raising in green manure field + neem cake 25 kg/ha with soil treatment by *Trichoderma viride* at 2 kg/ha gave the lowest disease intensity of 11.50 with maximum curd yield of 29.958 t/ha and highest per cent disease control (51.00) over control treatment (Dabbas et al. 2009).

8.1.2.3 Alternaria Black Spot, *Alternaria brassicola*

(i) Symptoms: On leaves, several small, dark brown zonate spots are produced expanding rapidly to form circular lesions up to 1 cm in diameter. The enlargement of lesions may lead to formation of concentric circles which coalesce in the centre (Fig. 8.6). In humid weather, the fungus may cause bluish growth in the centre of the spots which hampers the photosynthetic activity of the plant thereby hampering the overall productive potential of the plants. Sometimes cauliflower heads are also infected by the pathogen. The heads show browning, starting at the margin of the individual flowers or flower clusters.

(ii) Integrated Management

(a) Bioagents and Botanicals: Seed treatment with *T. viride* and *P. fluorescens* and soil treatment of nursery beds with neem cake enhanced seed germination and seedling stand.

8.1.3 Nematodes

8.1.3.1 Root-Knot Nematode and Club Root Disease Complex

(i) Integrated Management (a) Two Bioagents: PGPR strains (*P. fluorescens* and *Bacillus subtilis*) combined with fungal biocontrol agents

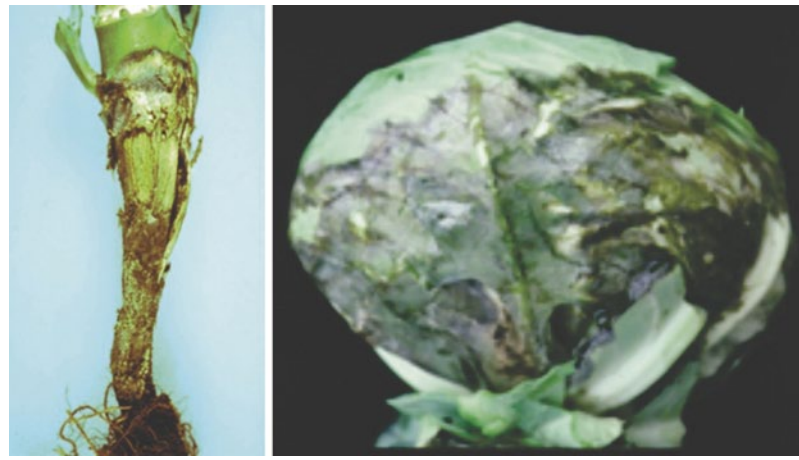


Fig. 8.5 Wire stem symptoms on lower stem and head rot

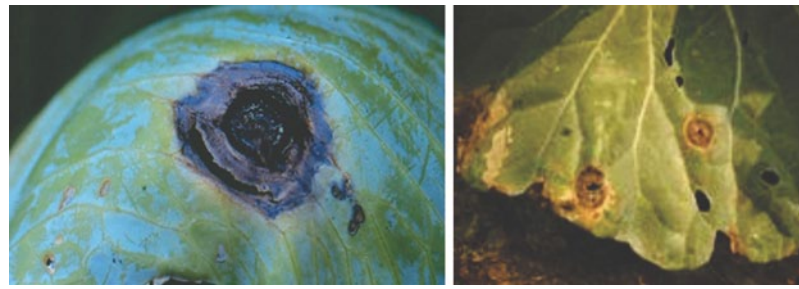


Fig. 8.6 *Alternaria* leaf spot on cabbage

(*T. viride* and *T. harzianum*) were found to be effective in reducing the nematode-fungal disease complex in cabbage (Loganathan et al. 2001). The bioformulation mixture of *P. fluorescens, T. viride* and chitin effectively reduced the disease complex in cabbage and cauliflower both under greenhouse and field conditions (Samiyappan 2003; Table 8.3).

8.1.4 Validated IPM Technology for Cabbage

8.1.4.1 Bangalore, Karnataka

Nursery

- Preparation of raised seed beds up to 15 cm height.
- Soil drenching with 0.2% copper oxychloride.
- Seed treatment with *T. harzianum* at 4 g/kg.
- Use of nylon net to avoid entry of sucking pests.
- Spray *Bt* at 0.5 mL/L 1 day before planting.
- Spray Dithane M-45/Ridomil at 0.2% against downy mildew.

Main Field

- Growing of two rows of mustard after every 25 rows of cabbage as trap crop at the time of planting.
- Wider spacing of 60 × 45 cm.
- Installation of light traps at 5/ha for trapping adult DBM.
- Spray *Bt* at 1 g/L if DBM is noticed early or spray 5% NSKE/1% neem soap/pongamia soap at primordial stage. Repeat 3–4 sprays.
- Removal of disease affected basal leaves from time to time.
- Need-based sprays of chlorothalonil/mancozeb at 0.2% for *Alternaria* and blitox + streptocycline for black rot.

Table 8.3 Efficacy of bioformulation mixtures against root-knot nematode—club root disease complex in cabbage under greenhouse conditions

Treatment	Club root index	Nematode incidence	
		Population	Root-knot index
T. viride	25.99 (30.65)	129	2.66
P. fluorescens	28.20 (32.07)	112	2.33
T. viride + *P. fluorescens*	25.33 (30.22)	114	2.33
T. viride + Chitin	25.44 (30.29)	108	2.33
P. fluorescens + Chitin	25.66 (30.43)	111	2.00
T. viride + *P. fluorescens* + Chitin	22.22 (28.12)	108	2.00
Chitin alone	31.70 (34.26)	139	3.00
Carbendazim	19.90 (26.49)	264	4.66
Carbofuran	39.90 (39.17)	106	1.66
Carbendazim + Carbofuran	15.00 (22.79)	103	1.66
Plasmodiophora brassicae alone	48.90 (44.37)	0.033	0.133
Meloidogyne incognita alone	0.03 (0.60)	280	5.00

Table 8.4 Yield and economics of IPM in cabbage at different locations

Centre	Yield (MT/ha)	Net returns (₹)	Benefit-to-cost ratio
Bangalore—IPM	62.01	80,934	3.04
Bangalore—Non IPM	58.01	40,661	0.61
Varanasi—IPM	24.08	37,500	3.70
Varanasi—Non IPM	21.17	33,333	1.89
Ranchi—IPM	34.75	231,386	2.80
Ranchi—Non IPM	28.76	156,900	1.84

8.1.4.2 Varanasi, Uttaranchal

Nursery

- Preparation of raised seed beds up to 15 cm height.
- Soil solarization for 3 weeks with 45 µm polythene sheet.
- Seed treatment with *T. harzianum* at 4 g/kg.
- Use of nylon net to avoid entry of sucking pests.

Main Field

- Spray *Bt* at 1 g/L if one DBM is noticed per plant.
- Spray 5% NSKE at primordial stage i.e. 15–20 DAP. Repeat 3–4 sprays.
- Release of *T. bactrae* at 0.75 lakh/ha at weekly interval.
- Removal of disease affected heads and bottom leaves from time to time.
- Need-based application of pesticides like mancozeb at 0.2%.

8.1.4.3 Ranchi, Jharkhand

Nursery

- Preparation of raised seed beds up to 15 cm height.
- Soil solarization for 3 weeks with 45 µm polythene sheet.
- Soil treatment with farm yard manure (FYM) enriched with *T. harzianum* at 1 kg/MT.

Main Field

- Spray Neemarin at 5% when DBM appeared early.
- Spray *Bt* at 1 g/L if one DBM is noticed per plant.
- Spray 1% pongamia soap at 15–20 DAP.
- Installation of pheromone traps at 5/ha for *S. litura* monitoring.
- Need-based application of fungicides like chlorothalonil at 0.2% for *Alternaria*.
- Spray of insecticides like endosulfan at 0.07% or triazophos at 0.05%.

During the period 2001–2004, IPM technology in cabbage was validated and promoted in more than 40 ha area in 42 villages covering 88 families located 40 km from Bangalore. Similarly, near Varanasi also IPM technology has been validated in eight villages in about 40 ha area covering 100 families. Near Ranchi, IPM technology in cabbage has been validated and promoted in 20 villages with the support of 100 farming families covering an area of 40 ha. In IPM validation studies conducted at three locations (Bangalore, Varanasi and Ranchi), IPM fields recorded higher yields of 62.013, 24.080 and 34.750 MT/ha as compared to 58.013, 21.170 and 28.760 MT/ha, respectively, in non-IPM fields (Sardana et al. 2004; Table 8.4).

References

Chaudhari, S., & Ramakrishnan, N. (1980). Field efficacy of baculovirus and its combination with sub-lethal dose of DDT and endosulfan on cauliflower against tobacco caterpillar *Spodoptera litura* (Fabricus). *Indian Journal of Entomology, 42,* 592–596.

Dabbas, M. R., Singh, D. P., Yadav, J. R., & Katiyar, R. P. (2009). Management of rhizoctonia root rot of cauliflower through IDM practice. International Conference on Horticulture, Bangalore.

Khaderkhan, H., Nataraju, M. S., & Nagaraja, G. N. (1998). Economics of IPM in tomato. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese, (Eds.), *Advances in IPM for horticultural crops,* (pp. 151–152). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Krishna Moorthy, P. N., Krishna Kumar, N. K., Girija, G., Varalakshmi, B., Prabhakar, M. (2003). *Integrated Pest Management in Cabbage Cultivation*. Extn Bull No 1, Indian Institute of Horticultural Research, Bangalore, 10 p.

Loganathan, M., Swarnakumari, N., Sivakumar, M., Prakasam, V., Mohan, L., Ramraj, B., & Samiyappan, R. (2001). Biological suppression of fungal nematode complex diseases of major cruciferous vegetables. *South Indian Horticulture, 49* (Special issue), 296–300.

Mohanasundaram, A., & Dhandapani, N. (2009). Gibberellic acid (GA_3) and *Pseudomonas fluorescens* as components of biointensive pest management strategy against *Plutella xylostella* in cauliflower. *Pest Management In Horticultural Ecosystems, 15,* 1–8.

Mukherjee, P. K., Upadhyay, J. P., & Mukhopadhyay, A. N. (1989). Biological control of *Pythium* damping-off of cauliflower by *Trichoderma harzianum*. *Journal of Biological Control, 3,* 119–124.

Samiyappan, R. (2003). Biological control of fungal and nematode complex diseases by plant growth promoting rhizobacteria (PGPR). *Winter School on Biological Control of Plant Parasitic Nematodes*, Tamil Nadu Agriculture University, Coimbatore, pp. 69–77.

Sardana, H. R., Trivedi, T. P., Bambawale, O. M., Naved Sabir, Singh, R. V., Arora, S., Krishna Moorthy, P. N., Pandey, P. K., Pandey, K. K., & Sengupta, A. (2004). Validated IPM technologies: Vegetable crops. In A. Singh, H. R. Sardana, & N. Sabir (Eds.), *Validated IPM technologies for selected crops* (pp. 119–148). New Delhi: National Centre for Integrated Pest Management (ICAR).

Srinivasan, K., & Krishna Moorthy, P. N. (1991). Indian mustard as a trap crop for management of major lepidopterous pests on cabbage. *Tropical Pest Management, 37,* 26–32.

Vishwakarma, R., Prasad, P. H., & Ghatak, S. S. (2009). Bio-efficacy of botanicals and bio-pesticide against diamondback moth (*Plutella xylostella* Linn.) infesting red cab-bage (*Brassica oleracea* L. var. *capitata* f. *rubra* L.). International Conference on Horticulture, Bangalore.

Malvaceous Vegetable Crops

9

9.1 Okra, *Abelmoschus esculentus*

9.1.1 Insect Pests

9.1.1.1 Fruit Borer, *Earias vitella*

Earias vittella, commonly called as spotted bollworm, is very destructive to okra. It is active throughout the year reaching peaks during March–May and August–October. The pest has about 8–12 overlapping generations in a year. *Earias insulana* is found in drier regions.

(i) Damage Female lays green coloured eggs with longitudinal ridges on buds, flowers and fruits. When the crop is young—larvae bore into tender shoots and tunnel downwards—which wither, drop down and growing points are killed (Fig. 9.1). With the formation of fruits, the caterpillars bore inside these and feed on inner tissues which become deformed in shape with no market value (Fig. 9.1). Like brinjal shoot and fruit borer, the infestation is seen on shoots before flowering, and after flowering they feed exclusively on fruits.

(ii) Integrated Management

(a) Botanicals and Chemicals: The fruit damage was reduced to a minimum of 7.22 % in endosulfan 0.07 %+NSKE 5 % which was on par with neem oil 4 % (7.53 %) and endosulfan 0.07 %+neem oil 2 % (9.29 %). The marketable fruit yield was maximum in neem oil 4 % (13.77 t/ha) which was on par with endosulfan 0.07 % (13.40 t/ha), endosulfan 0.07 %+NSKE 5 % (13.17 t/ha), NSKE 5 % (13.08 t/ha) and neem oil 2 % (12.98 t/ha); see Raja et al. 1998 and Table 9.1.

(b) Bioagents, Botanicals and Chemicals: Module II (first spray of monocrotophos at flowering followed by two subsequent sprays of a combination of *Bacillus thuringiensis* var. *kurstaki* and methomyl at fortnightly intervals) recorded minimum fruit borer infestation (4.21 %) and maximum fruit yield (4.067 t/ha) as against 41.59 % fruit borer damage and 1.658 t/ha fruit yield in the untreated control. However, statistically comparable results (fruit borer damage—5.30 % and yield—4.009 t/ha) were obtained when the second spray of *Btk*—methomyl (module II) was replaced by nimbecidine (module III); see Mathur et al. 1998 and Table 9.2.

Soil application of neem cake (with 8 % oil) at 250 kg/ha when combined with sprays of 1 % neem soap (NS), 4 % neem seed powder extract (NSPE), 1 % *Bacillus thuringiensis* (*Bt*) reduced the okra fruit borer (*Earias vitella*) and leaf hopper (*Amrasca biguttula biguttula*) significantly and increased marketable okra fruit yield in all the three seasons as compared to spray treatments of NS, NSPE, *Bt* and indoxacarb alone (Table 9.3).

9.1.1.2 Aphids, *Aphis gossypii*

(i) Damage This is a polyphagous pest, feeding in colonies and completely covers the shoot tips, buds and lower surface of leaves (Fig. 9.2). Aphids multiply parthenogenetically in large numbers in a very short period. Both nymphs and adults suck the sap due to which plants lose their vitality. Leaves curl downwards and there is

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems*,
DOI 10.1007/978-81-322-1844-9_9, © Springer India 2014

Fig. 9.1 Shoot and fruit borer damage on okra

Table 9.1 Effect of neem products and endosulfan on fruit borer and yield of okra

Treatment	Fruit borer infestation (%)	Reduction over control (%)	Marketable fruit yield (t/ha)
Endosulfan 0.07%	10.55	61.48	13.40
Endosulfan 0.07% + neem oil 2%	9.29	66.08	13.28
Neem oil 2%	10.95	60.02	12.98
Neem oil 4%	7.53	72.51	13.77
NSKE 5%	10.64	61.15	13.08
Endosulfan 0.07% + NSKE 5%	7.22	73.64	13.17
Trichogramma chilonis release at fortnightly interval	13.91	49.22	12.20
Control	28.39	–	10.67
Critical Difference (CD) ($P=0.05$)	2.68	–	1.12

Table 9.2 Bioefficacy of different IPM modules for management of *Earias vitella* and yield of okra

Module	Treatment	Dose/ha (l)	Fruit damage (%)	Fruit yield (t/ha)
I	(i) Monocrotophos 36 SL (ii) *Btk* (Dipel −8 L) + Endosulfan 35 EC (iii) *Btk* (Dipel-8 L) + Endosulfan 35 EC	1.0 1.0 + 0.625 1.0 + 0.625	8.80	3.410
II	(i) Monocrotophos 36 SL (ii) *Btk* (Dipel-8 L) + Methomyl 40 SP (iii) *Btk* (Dipel-8 L) + Methomyl 40 SP	1.0 1.0 + 0.625 1.0 + 0.625	4.21	4.067
III	(i) Monocrotophos 36 SL (ii) Nimbecidine (Azadirachtin-300 pm) (iii) *Btk* (Dipel-8 L) + Methomyl 40 SP	1.0 1.5 1.0 + 0.625	5.30	4.009
IV	(i) Monocrotophos 36 SL (ii) Endosulfan 35 EC (iii) Endosulfan 35 EC	1.0 1.25 1.25	12.42	2.583
V	(i) Nimbecidine (Azadirachtin-300 pm) (ii) *Beauveria bassiana* (Dispel) (iii) *Btk* (Dipel-8 L)	1.5 1.5 1.5	16.73	2.100
VI	Control (untreated check)			
	Critical Difference (CD) ($P=0.05$)	–	2.24	0.424

Table 9.3 Effect of neem products and *Bacillus thuringiensis* on fruit borer, leaf hopper and yield of okra

Treatment	Fruit borer incidence	Plant hopper incidence	Marketable yield (t/ha)
Neem cake—250 kg/ha	15.09	26.92	9.37
Neem cake—250 kg/ha + Neem seed powder extract 4 %	9.19	19.83	9.81
Neem cake—250 kg/ha + Neem soap 1 %	9.77	19.50	9.89
Neem cake–250 kg/ha + *Bacillus thuringiensis* 1 %	8.74	17.50	11.06
Neem cake—250 kg/ha + Indoxacarb	9.23	26.33	10.54
Neem seed powder extract 4 %	16.97	35.75	9.58
Neem soap 1 %	16.49	38.92	9.84
Bacillus thuringiensis 1 %	22.85	42.58	10.97
Indoxacarb	15.00	39.17	10.73
Control	26.61	58.92	7.20
Critical Difference (CD) (P = 0.05)	*4.28*	*1.36*	*2.66*

Fig. 9.2 Aphid infestation on okra leaves

retardation of growing shoots. They also excrete honeydew on which sooty mould develops which hampers the photosynthetic activity of the plant.

(ii) Integrated Management

(a) Bioagents and Chemicals: Spraying of *Verticillium lecanii* spores at 10×10^6/ml + 0.005 % quinalphos + 0.05 % Teepol before the onset of rainy season is effective against aphids.

9.1.1.3 Pod Borer, *Helicoverpa armigera*

(i) Damage This pest is occasionally serious during monsoon season on okra (Fig. 9.3). Damage is restricted to the apical end only. Since okra fruits are harvested once in 2–3 days, damage by *H. armigera* is not very high.

(ii) Integrated Management

(a) Two Bioagents: The release/application of biocontrol agents viz., *Trichogramma chilonis* (45 and 60 DAS), *Chrysoperla carnea* (45 and 60 DAS), *Bacillus thuringiensis* var. *kurstaki* (45 and 75 DAS), and *Ha*NPV (60 DAS) were superior in reducing the larval population and fruit damage by *H. armigera* (Praveen and Dhandapani 2001).

9.1.2 Diseases

9.1.2.1 Yellow Vein Mosaic Virus (YVMV)

This is the most important and devastating virus disease of okra. Sastry and Singh (1974) estimated that if the plants are infected within 20 days

Fig. 9.3 *Helicoverpa armigera* infestation on okra fruit

Fig. 9.4 YVMV infection on okra leaves

after germination, the loss in yield was recorded up to 98%. The plants that infected at 35 and 50 days after germination, the loss in yield was estimated to be 83 and 49%, respectively.

(i) Symptoms YVMV is caused by Gemini virus and transmitted by whitefly, *Bemisia tabaci*. Characteristic symptoms appear as yellow vein and veinlets leaving green tissue in interveinal area (Fig. 9.4). Severely infected leaves sometimes become completely yellow. Fruits also change in colour to yellow and become hard in early stage of development. The infected plants are stunted and bear very few yellow coloured fruits.

(ii) Epidemiology Vector population and virus incidence were more during March–June when the atmospheric temperature remained high and humidity is less, which is favourable for whitefly multiplication and spread of the disease.

(iii) Integrated Management

(a) Cultural and Chemical: Sowing of 4–5 rows of sorghum or pearl millet or maize all round the okra field at least 60 days before sowing okra has been found beneficial for the management of YVMV. Border cropping along with 3–4 foliar sprays of either dimethoate or monocrotophos both at 0.1% at 10 days interval has been found more effective (Singh 1990).

Table 9.4 Incidence of various insect pests and diseases in okra at Raispur village during 2003–2004

Pest/disease incidence	IPM	Non-IPM
Leaf hopper/three top leaves	3.20	16.22
Fruit borer (%)	1.15	8.02
Blister beetle/plot	7.77	7.00
Yellow vein mosaic virus (%)	3.11	32.06

9.1.3 Validation of okra IPM at Ghaziabad, Uttar Pradesh

- Planting of yellow vein mosaic virus resistant (YVMV) hybrids viz., Sun-40 and Makhmali
- Sowing of sorghum/maize as border crop
- Installation of yellow sticky polythene traps smeared with castor oil, and delta traps set up for whitefly and other small sucking pests
- Erection of bird perches at 25/ha for facilitating predation of borer larvae
- Installation of pheromone traps at 5/ha for monitoring *E vitella*
- Three sprays of 5% NSKE for hopper, whitefly and mites starting at 28 DAS
- Five releases of *Trichogramma chilonis* at 1 lakh/ha starting from 42 DAS at weekly interval
- Rouging out YVMV affected plants from time to time

In okra crop, IPM technology has been validated in about 3 ha area in Raispur village near Ghaziabad during 2003–2004. The incidence of various insect pests and diseases recorded was invariably high in non-IPM fields during 2003–2004 (Table 9.4).

IPM fields gave higher yields of 10.305 t/ha as compared to 7.246 t/ha in non-IPM fields (Sardana et al. 2004; Table 9.5).

Table 9.5 Yield and economics of IPM in okra

Parameter	IPM	Non IPM	% increase
Yield (t/ha)	10.30	7.24	42
Net returns (Rs/ha)	64797	34678	86
Benefit: cost ratio	1.28	0.72	77

9.1.4 Nematodes

9.1.4.1 Root-knot Nematodes, *Meloidogyne* spp.

Meloidogyne incognita was responsible for 28.08–90.90% loss in fruit yield of okra (Bhatti and Jain 1977; Parvatha Reddy and Singh 1981), while *Meloidogyne javanica* caused 20.20–41.20% loss in yield (Jain et al. 1986).

(i) Symptoms Diseased plants are stunted, yellow and have a tendency to wilt in hot weather. Diseased plants appear in patches in the field. The root system of diseased plants is heavily galled and devoid of lateral roots in the final stage (Fig. 9.5). Plant growth and yield are negatively affected.

(ii) Integrated Management

(a) Bioagents and Botanicals: Soaking of okra seeds in 10% castor cake suspension mixed with spores of *Paecilomyces lilacinus* (1.5×10^6 spores/ml) for 30 min, and sowing in soil drenched with 10% castor cake suspension at 20 l/6 m^2 was effective in reducing root galling, final nematode population of *M. incognita* and increasing the fruit yield, root colonization, propagule density in soil and parasitization of eggs by *P. lilacinus* (Rao et al. 1997; Table 9.6).

Integration of *Paecilomyces lilacinus* with neem cake gave effective control of *M. incognita* on okra.

Application of 5% inoculum of *Arthrobotrys conoides* to the pot soil amended with FYM, effectively reduced the larval penetration of *M. incognita* and root galling was reduced by 30–40% in okra (Srivastava and Swarup 1986).

(b) Botanicals and Chemicals: An integrated management of *M. incognita* infecting okra using neem or karanj oil cake at 0.5 t/ha along with carbofuran at 1 kg a.i./ha gave maximum reduction in root galling with consequent increase in okra fruit yield (Parvatha Reddy and Khan 1991).

Application of subabool (*Leucaena leucophila*) leaves at 40 g/kg soil which were allowed to decompose for 4 weeks before sowing + carbofuran at 1 kg a.i./ha, while sowing of okra seeds resulted

Fig. 9.5 Okra roots damaged by root-knot nematodes. Note gall or root-knots (*left*) and healthy roots (*right*)

Table 9.6 Effect of integration of bioagents and botanicals for the management of *Meloidogyne incognita* infecting okra

Treatment	Root-knot index	Yield (kg/6 m^2)	% egg parasitization
Seed treatment with *Paecilomyces lilacinus*	7.6	5.2	43
Seed treatment with castor cake suspension	7.2	5.0	–
Soil drenching with castor cake suspension	7.5	5.4	–
Seed treatment with *Paecilomyces lilacinus* + castor cake suspension	5.5	5.7	46
Seed treatment with *Paecilomyces lilacinus* and castor cake suspension + soil drenching with castor cake suspension	4.7	6.8	53
Seed treatment with castor cake suspension + soil drenching with castor cake suspension	5.9	6.3	–
Castor cake—1 t/ha	5.6	6.5	–
Castor cake—2 t/ha	4.6	7.0	–
Carbofuran—1 kg a.i./ha	5.2	6.4	–
Carbofuran—2 kg a.i./ha	4.5	6.7	–
Control	9.2	4.7	–
Critical Difference (CD) ($P = 0.05$)	0.87	0.72	2.24

in minimum galling (35.4 galls/plant) in comparison to control (64 galls/plant) and better plant growth parameters in okra (Paruthi et al. 1987).

(c) Bioagents, Chemicals and Botanicals: The combined treatment with *P. lilacinus* at 4 g/kg soil + carbosulfan 25 EC at 0.2 % + poultry manure at 2.5 t/ha + FYM at 2.5 t/ha gave maximum increase in plant growth parameters and yielded 9.2 t/ha compared to 2.0 t/ha in control, and decrease in number of galls (83.5 compared to 183.6 in control), egg masses per root system (23.6 compared to 70.5 in control) and final nematode population in soil (200 compared to 585 in control); see Das and Sinha 2005.

(d) Physical, Cultural, Botanical and Chemical: Summer ploughing + seed treatment with carbofuran at 3 % a.i. w/w + main field treatment with aldicarb at 1 kg a.i./ha led to 76–79 % decrease in nematode population and 35.1 % higher yield over untreated check. Further, Summer ploughing + mulching transparent polythene sheet + seed treatment with carbosulfon at

3 % a.i. w/w led to 32.5 % higher yield. Summer solarization + treated seeds + use of neem cake at 400 kg/ha was most effective treatment and gave 50 % higher okra yield.

(e) Physical and Botanicals: Integration of soil solarization for 15 days in summer and application of neem cake at 200 kg/ha is effective in the management of root-knot nematodes and in getting higher yields.

(f) Physical and Chemicals: Soil solarization with single layer of polyethylene mulch for 20 days during June and application of carbofuran at 0.5 kg a.i./ha gave least root galling (42/plant compared to 245/plant in control) (Sharma et al. 2005).

9.1.4.2 Reniform Nematode, *Rotylenchulus reniformis*

(i) Integrated Management

(a) Botanicals and Chemicals: Application of aldicarb at 1 kg a.i./ha + neem cake at 0.5 t/ha followed by carbofuran at 1 kg a.i./ha + neem cake at 0.5 t/ha proved most effective in reducing the *R. reniformis* population and in increasing the growth of okra plants (Krishna Rao et al. 1987).

(b) Cultural and Chemicals: Deep ploughing (20 cm) followed by fallowing for 1 month after weeding, integration of aldicarb application at 0.8 kg a.i. per ha at sowing after either of the cultural practices or deep ploughing (20 cm) together with carbofuran or aldicarb seed treatment resulted in the control of the reniform nematode and better yield of okra (Lakshmanan and Sivakumar 1981).

9.1.4.3 Root-knot Nematode, *M. incognita* and Wilt, *Fusarium oxysporum* f. sp. *vasinfectum* Disease Complex

Meloidogyne-Fusarium disease complex has been considered important on many crops including okra leading to reduction in its productivity.

(i) Integrated Management

(a) Bioagents and Botanicals: Soil application of 25 g/m^2 of *Pseudomonas fluorescens* (2×10^6 cfu/g) or *Pochonia chlamydosporia* (2×10^6 cfu/g) enriched deoiled neem cake has proved to be an effective treatment in combating the damage caused by *M. incognita* and *F. oxysporum* f. sp. *vasinfectum* to the tune of 68 and 57 %, respectively. This treatment also increased the yield of okra fruits by 24 % under field conditions (Chaaya et al. 2010).

9.1.4.4 Root-knot Nematode, *M. incognita* and Root Rot, *Rhizoctonia solani* Disease Complex

(i) Symptoms Plants in untreated field soil or in sterilized soil inoculated with both organisms, developed a root rot in about 42 days. If the nematode preceded the fungus by 3 weeks, the root rot was more severe and appeared within 14–21 days. The fungus penetrated either directly or through ruptures in the root created by the mature female nematode. *R. solani* colonized nematode giant cells and root xylem cells. Vascular discolouration occurred both in roots and stem, however no fungus was isolated from stems.

M. incognita predisposed roots to *R. solani*, which resulted in severe root rot and subsequent plant death. Okra plants inoculated with either *R. solani* or *M. incognita* alone were free of root decay for the entire period of 6-week study. Three weeks after nematode and fungus inoculation, black sclerotia of *R. solani* were visible on nematode-induced galls, while on non-galled portions on the same root system were free of sclerotia. Prior to root rot development, *R. solani* demonstrated marked preference for root galls on nematode infected roots. It is hypothesized that the leakage of nutrients from the root was responsible for attracting the fungus to the galls and for initiating sclerotial formation.

Five weeks after inoculation, distinct brown lesions were observed only on the galls of plants inoculated with both *M. incognita* and *R. solani*. Lower leaves of plants were chlorotic and suffered premature leaf drop.

M. incognita and *Rhizoctonia bataticola* when inoculated simultaneously in soil, reduce the germination of seeds in okra (Chhabra and Sharma 1981). Combined attack of both these pathogens cause significantly greater damage to the crop

Table 9.7 Effect of bioagents and chemicals for the management of disease complex caused by *Meloidogyne incognita* and *Rhizoctonia solani*

Treatment[a]	Pre-emergence damping-off (%)	Post-emergence damping-off (%)	Plant height (cm)	Number of galls/ root system	Number of egg masses/root system
T_1	32.98	34.34	27.30	236.00	138.25
T_2	11.05	13.99	36.40	70.50	44.68
T_3	10.86	12.52	36.82	74.75	46.25
T_4	6.26	7.73	44.26	54.25	26.25
T_5	20.45	24.95	31.85	102.25	58.75
T_6	18.69	25.14	32.76	107.50	60.25
T_7	18.88	23.38	36.10	72.50	42.50
T_8	20.26	24.94	32.58	76.00	40.26
T_9	18.78	24.76	31.40	146.00	62.30
T_{10}	5.01	7.73	43.60	51.75	30.75
T_{11}	0.00	0.00	45.94	0.00	0.00
Critical Difference (CD) ($P=0.05$)	3.94	4.25	3.26	0.71	0.67

[a] T_1—*M. incognita* + *R. solani* (inoculated and untreated control), T_2—*M. incognita* + *R. solani* + *T. harzianum* (seed treatment), T_3—*M. incognita* + *R. solani* + *P. fluorescens* (seed treatment), T_4—*M. incognita* + *R. solani* + *T. harzianum* + *P. fluorescens* (seed treatment), T_5—*M. incognita* + *R. solani* + *T. harzianum* (soil application), T_6—*M. incognita* + *R. solani* + *P.* fluorescens (soil application), T_7—*M. incognita* + *R. solani* + *T. harzianum* + *P. fluorescens* (soil application), T_8—*M. incognita* + *R. solani* + carbosulfan (seed treatment), T_9—*M. incognita* + *R. solani* + carbendazim (seed treatment), T_{10}—*M. incognita* + *R. solani* + carbosulfan + carbendazim 50 (seed treatment), T_{11}—Uninoculated and untreated control

than that of the damage caused by either pathogen alone (Bhagawati et al. 2007).

(ii) Integrated Management

(a) Bioagents and Botanicals: Chaitali et al. (2003) observed that *Trichoderma viride* combined with neem cake controlled the disease complex better than *T. viride* combined with groundnut cake in okra.

(b) Two Bioagents: The lowest pre-emergence (5.01%) and post-emergence (7.73%) damping-off were observed in the treatment, where both carbosulfan 25 SD and carbendazim 50 WP were applied together as seed treatment (T_{10}) which was at par with the treatment with dual application of *Trichoderma harzianum* (6.26%) and *P. fluorescens* (7.73%) as seed treatment (T_4). As evidenced from the results, the seed treatment was found to be significantly superior to soil application of bioagents (Bhagawati et al. 2009; Table 9.7).

The maximum plant height was recorded in the uninoculated and untreated control (T_{11}) followed by the treatment receiving *T. harzianum* and *P. fluorescens* as seed treatment (T_4) which were at par with the treatment receiving carbosulfan 25 SD and carbendazim 50 WP as seed treatment (T_{10}) (Bhagawati et al. 2009; Table 9.6).

The minimum number of galls and egg masses in roots were recorded in the treatment receiving carbosulfan 25 SD and carbendazim 50 WP as seed treatment (T_{10}) which was on par with the treatment receiving *T. harzianum* and *P. fluorescens* as seed treatment (T_4). Further, the treatment with *T. harzianum* and *P. fluorescens* as seed treatment was found to be significantly better in reducing the host infection and nematode multiplication than soil application of both these bioagents (Bhagawati et al. 2009; Table 9.6).

References

Bhagawati, B., Das, B. C., & Sinha, A. K. (2007). Interaction of *Meloidogyne incognita* and *Rhizoctonia solani* on okra. *Annals of Plant Protection Sciences, 15,* 533–535.

Bhagawati, B., Choudhury, B. N., & Sinha, A. K. (2009). Management of *Meloidogyne incognita-Rhizoctonia*

solani complex on okra through bioagents. *Indian Journal of Nematology, 39,* 156–161.

Bhatti, D. S., & Jain, R. K. (1977). Estimation of loss in okra, tomato and brinjal yield due to *Meloidogyne incognita. Indian Journal of Nematology, 7,* 37–41.

Chaaya, M. K., Rao, M. S., & Ramachandran, N. (2010). Biomanagement of disease complex in okra (*Abelmoschus esculentus* L. Moench) using microbial antagonists. *National Conf. on Innovations in Nematological Research for Agricultural. Sustainability-Challenges and a Roadmap Ahead* (pp. 96–97). Coimbatore: Tamil Nadu Agricultural University.

Chaitali, L., Singh, S., & Goswami, B. K. (2003). Effect of cakes with *Trichoderma viride* for the management of disease complex caused by *Rhizoctonia bataticola* and *Meloidogyne incognita* on okra. *Annals of Plant Protection Sciences, 11,* 178–180.

Chhabra, H. K., & Sharma, J. K. (1981). Combined effect of *Meloidogyne incognita* and *Rhizoctonia bataticola* on pre-emergence damping-off of okra and brinjal. *Science and Culture, 47*(7), 256–257.

Das, N., & Sinha, A. K. (2005). Integrated management of root-knot nematode (*Meloidogyne incognita*) on okra (*Abelmoschus esculentus* (L.) Moench). *Indian Journal of Nematology, 35*(2), 175–182.

Jain, R. K., Paruthi, I. J., Gupta, D. C., & Dhankar, B. S. (1986). Appraisal of losses due to root-knot nematode, *Meloidogyne javanica* on okra under field conditions. *Tropical Pest Management, 32*(4), 341–342.

Krishna Rao, A. B. V., Padhi, N. N., & Acharya, A. (1987). Effect of different nematicides, oilcakes and urea in the control of *Rotylenchulus* in okra. *Indian Journal of Nematology, 17*(2), 171–173.

Lakshmanan, P. L., & Sivakumar, C. V. (1981). *Control of Rotylenchulus reniformis in Bhendi by integrated method*. Second Nematology Symposium, Tamil Nadu Agricultural University, Coimbatore, p. 54.

Mathur, N. M., Sharma, G. K., & Qureshi, Q. G. (1998). Fruit borer (*Earias* spp.) management on okra in semi-arid region of Rajasthan. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds.), *Advances in IPM for horticultural crops*, pp. 121–123. Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Paruthi, L. J., Jain, R. K., & Gupta, D. C. (1987). Effect of different periods of degradation of subabool leaves alone and in combination with nematicides in okra. *Indian Journal of Nematology, 17*, 30–32.

Parvatha Reddy, P., & Singh, D. B. (1981). *Assessment of avoidable yield loss in okra, brinjal, French bean and cowpea due to root-knot nematodes*. Third International Symposium Pl Path, New Delhi, pp. 93–94

Parvatha Reddy, P., & Khan, R. M. (1991). Integrated management of root-knot nematodes infecting okra. *Current Nematology, 2*(2), 115–116.

Praveen, P. M., & Dhandapani, N. (2001). Development of biocontrol based pest management in okra (*Abelmoschus esculentus* Moench). In A. Verghese & P. Parvatha Reddy (Eds.), *IPM in horticultural crops: Emerging trends in the new millennium* (pp. 192–193). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Raja, J., Rajendran, B., & Papaiah, C. M. (1998). Management of bhendi fruit borer, *Earias vitella* F. In P. Parvatha Reddy, N. K. Krishna Kumar, & A. Verghese (Eds.), *Advances in pest management of horticultural crops* (pp. 118–120). Bangalore: Association for Advancement of Pest Management in Horticultural Ecosystems.

Rao, M. S., Parvatha Reddy, P., & Nagesh, M. (1997). Integrated management of *Meloidogyne incognita* on okra by castor cake suspension and *Paecilomyces lilacinus. Nematologia Mediterranea, 25*(1), 17–19.

Sardana, H. R., Trivedi, T. P., Bambawale, O. M., Sabir, N., Singh, R. V., Arora, S., Krishna Moorthy, P. N., Pandey, P. K., Pandey, K. K., & Sengupta, A. (2004). Vegetable crops. In A. Singh, H. R. Sardana, & N. Sabir (Eds.), *Validated IPM technologies for selected crops* (pp. 119–148). New Delhi: National Centre for Integrated Pest Management (ICAR).

Sastry, K. S. M., & Singh, S. J. (1974). Effect of yellow vein mosaic virus infection on growth and yield of okra crop. *Indian Phytopathology, 27,* 316–317.

Sharma, H. K., Pankaj, & Mishra, S. D. (2005). Polyethylene mulching in the management of plant parasitic nematodes. *Indian Journal of Nematology, 35*(1), 82–85.

Singh, S. J. (1990). Etiology and epidemiology of white-fly-transmitted virus diseases of okra in India. *Plant Disease Research, 5*(1), 64–70.

Srivastava, S. S., & Swarup, G. (1986). Biomanagement of root-knot nematode (*Meloidogyne incognita*) through the predatory fungus, *Arthrobotrys conoides*. National conference on plant parasitic nematodes of India-problems and progress, Indian Council of Agricultural Research Institute, New Delhi, p. 85.

Root Vegetable Crops

10

10.1 Carrot, *Dacus carota*

10.1.1 Diseases

10.1.1.1 Soft Rot, Erwinia carotovora s. sp. carotovora

(i) Symptoms The disease causes a soft, watery, slimy rot. Water soaked irregular lesions appear on tubers (Fig. 10.1). The rotted tissues are grey to brown and may have a foul odour. It decays the core of the root. Also prolonged wet weather favours disease development. It is a serious transit and storage problem if the affected carrots are not discarded. In the field, tops of rotted carrots turn yellow and wilt as the roots break down. Mostly, the disease occurs after the harvest.

(ii) Integrated Management

(a) Bioagents and Botanicals: Seed treatment with *Pseudomonas putida* (10^9 cfu/g) at 10 g/kg and subsequent application of 5 t of farm yard manure (FYM) enriched with 5 kg each of *P. putida* (10^9 cfu/g) and *Trichoderma harzianum* (10^6 cfu/g) per hectare significantly reduced soft rot to 4.4% compared to 24% in control. Significant increase in yield (24%) was also observed. Benefit-to-cost ratio calculated for marginal cost of biopesticides and returns accrued by application of biopesticides was 5.3 (Anon 2012).

10.1.2 Nematodes

10.1.2.1 Root-Knot Nematode, *Meloidogyne incognita*

(i) Symptoms Devi (1993) reported that *M. incognita* was responsible for 56.64% loss in yield of carrots. The nematode larvae feed on roots, causing the swellings or knots that are characteristic of root-knot infection. Roots are often stunted and deformed. Root-knot nematodes develop characteristic forking of the roots in carrots (Fig. 10.2).

(ii) Integrated Management

(a) Bioagents and Botanicals: Soil application of *Paecilomyces lilacinus* (2×10^6 cfu/g) at 2.5 kg + FYM at 2.5 t/ha gave minimum number of galls and final nematode population (120 and 12.5, respectively) compared to control (440 and 235, respectively). The highest yield was also recorded in the above treatment (9.34 t/ha) over control (6.54 t/ha).

Integration of neem cake with *P. lilacinus* and *T. harzianum* was found effective and increased carrot yield (Table 10.1).

Seed treatment with *P. putida* (10^9 cfu/g) at 10 g/kg and subsequent application of 5 t of FYM enriched with 5 kg each of *P. putida* (10^9 cfu/g) and *T. harzianum* (10^6 cfu/g) per hectare significantly reduced reniform and root-knot nematode population in roots by 70% and 77%, respectively. Significant increase in yield (24%) was

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems*,
DOI 10.1007/978-81-322-1844-9_10, © Springer India 2014

Fig. 10.1 Soft rot on carrot

also observed. Benefit-to-cost ratio calculated for marginal cost of biopesticides and returns accrued by application of biopesticides was 5.3 (Anon 2012).

Seed treatment with *T. harzianum* at 10 g (with 1×10^6 cfu/g)/kg and *P. fluorescens* at 10 g (with 1×10^9 cfu/g)/kg and subsequent field application of 5 t of enriched FYM with *T. harzianum* (with 1×10^6 cfu/g) and *P. fluorescens* (with 1×10^9 cfu/g) per hectare significantly reduced root-knot and reniform nematodes in carrot roots by 79% and 75%, respectively. The yield increase was to the tune of 29.8% with a benefit-to-cost ratio of 13.6.

A significantly lower number of second stage juveniles (J2s) was recovered from the soil incorporated with broccoli leftover materials and *Trichoderma* inoculant. Galls and egg masses in secondary roots were highest in unamended inoculated soil, which was significantly different from broccoli-amended soil with solarization and *Trichoderma* inoculant. The yield was significantly higher in broccoli-amended soil with solarization and *Trichoderma* inoculant. In general, the treatments with broccoli residues and *Trichoderma* inoculant were able to decrease root-knot nematode population and significantly increase the yield relative to untreated soil (Pedroche et al. 2009).

(b) Cultural and Chemical: A soil fumigant at the beginning of two consecutive carrot crops, followed by 2-year onion production and at last a cover crop Sudax in the course of 5-year rotation can control *Meloidogyne hapla* problem (Bird 1981).

10.1.2.2 Root-Knot Nematode, *M. incognita* and Wilt, *E. carotovora* s. sp. *carotovora* Disease Complex

(i) Integrated Management

(a) Bioagents and Botanicals: The neem cake enriched with *P. fluorescens* and *P. lilacinus* applied at 10 g/m^2 increased the root colonization of both the bioagents and reduced the incidence of *M. incognita* and *E. carotovora* s. sp. *carotovora* by 68% and 56%, respectively. There was also a significant increase in the yield of carrot to the tune of 23% (Sowmya et al. 2010).

10.2 Radish, *Raphanus sativus*

10.2.1 Diseases

10.2.1.1 Damping-Off, *Rhizoctonia solani*

(i) Integrated Management

(a) Bioagents and Botanicals: When applied to soil at rates of 0.04–0.15 g/kg (dry weight basis), wheat-bran cultures of *T. harzianum* protected radish seedlings from damping-off induced by *R. solani* and also increased radish germination in non-infested soils. Protection lasted for five successive weekly plantings (Henis et al. 1978).

(b) Bioagents and Chemicals: Combined treatments of the fungicide Pentachloronitrobenzene (PCNB) at 4 µg/g and *T. harzianum* decreased the inoculum potential of *R. solani* and increased the disease control in comparison to separate treatments for control of damping-off of radish (Henis et al. 1978).

Integration of banodanil and *T. harzianum* were found to be effective for the control of *Rhizoctonia* pre-emergence damping-off of radish (Lifshitz et al. 1985).

Fig. 10.2 Forking of carrots incited by root-knot nematodes

Table 10.1 Effect of neem cake and bioagents on yield of carrot

Treatment	Yield (t/acre)
NC	20.120
NC+TH	22.830
NC+PL	23.347
NC+PL+TH	26.742
Control	18.245

NC neem cake, *TH Trichoderma harzianum*, *PL Paecilomyces lilacinus*

(c) Two Bioagents: BINAB, a mixture of *T. harzianum* and *Trichoderma polysporum,* has been registered for the control of *Rhizoctonia* damping-off complex (Utkhede and Gupta 1996).

10.3 Beet Root, *Beta vulgaris*

10.3.1 Diseases

10.3.1.1 Storage Rot, *Sclerotium rolfsii*

(i) Symptoms Sclerotium root rot or southern root rot can be a very destructive disease of beet root in some areas. Symptoms appear as poor top growth with wilting occurring as the tap root is decayed by the fungus. Under high temperatures, plants will eventually wilt permanently. The pathogen is characterized by cottony mycelial growth on the surface of the tap root with small (1–3 mm) spherical sclerotia that are tan to dark tan when mature (Fig. 10.3).

(ii) Integrated Management (a) Two Bioagents: The conidial mixture of two bioagents *Trichoderma pseudokoningii* (effective in reducing the mycelial growth) and *Trichoderma virens* (good colonizer of sclerotia) was effective in reducing the incidence of storage rot.

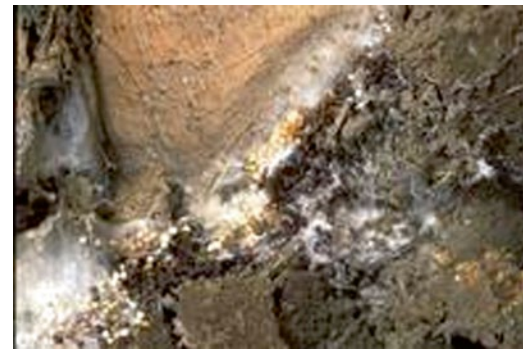


Fig. 10.3 Storage rot symptoms on beet root

References

Anon. (2012). Annual Report (2011–12), Indian Institute of Horticultural Research, Bangalore, pp. 23–24.

Bird, G. W. (1981). Integrated nematode management for plant protection. In B. M. Zuckerman & R. A. Rohde (Eds.), *Plant parasitic nematodes* (Vol. 3, pp. 355–375). New York: Academic.

Devi, G. (1993). Pathogenicity, crop loss assessment and management of *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 on carrot (*Dacus carota* L.)., M. Sc. (Agri.) thesis, Assam Agri. Univ., Jorhat.

Henis, Y., Ghaffar, A., & Barker, R. (1978). Integrated control of *Rhizoctonia solani* of radish: Effect of successive plantings, Pentachloronitrobenzene (PCNB), and *Trichoderma harzianum* on pathogen and disease. *Phytopathology, 68,* 900–907.

Lifshitz, R., Lifshitz, F., & Baker, R. (1985). Decrease in incidence of *Rhizoctonia* pre-emergence damping-off

by use of integrated chemical and biological control. *Plant Disease, 60,* 431–434.

Pedroche, N. B., Villanueva, L. M., & De Waele, D. (2009). Management of root-knot nematode, *Meloidogyne incognita* in carrot. *Communications in Agricultural and Applied Biological Sciences, 74,* 605–615.

Sowmya, D. S., Rao, M. S., Gopalakrishnan, C., & Ramachandran, N. (2010). *Biomanagement of Meloidogyne incognita and Erwinia carotovora s. sp. carotovora infecting carrot (Dacus carota L.)*. Paper presented at National Conference on Innovations in Nematological Research for Agricultural Sustainability—Challenges and A Roadmap Ahead (p. 97), Tamil Nadu Agri. Univ., Coimbatore.

Utkhede, R. S., & Gupta, V. K. (1996). *Management of soil borne diseases* (pp. 100–122). New Delhi: Kalyani.

Leguminous Vegetable Crops 11

11.1 PEA, *Pisum sativum*

11.1.1 Diseases

11.1.1.1 Damping-Off, *Pythium ultimum*

(i) Symptoms: *P. ultimum* commonly cause seed rot as well as pre- and post-emergence damping-off of pea. Root rot of older plants also occurs, and often results in root-pruning that significantly reduces root length. Infected roots are typically brown in colour and soft and watery to the touch. Infected plants are frequently stunted and pale green to yellow in colour.

(ii) Integrated Management (a) Bioagents and Chemicals: Integration of soil application of wheat bran-based formulation of *Trichoderma harzianum* and giving two sprays of 0.05 % carbendazim starting from flowering stage at 15 days' interval was found effective (Kapoor and Sharma 2000).

(b) Bioagents, Botanicals and Chemicals: Soil amendment with *Lantana camara* (10 MT/ha), application of Trichoguard (*Trichoderma viride*) at 2.5 kg in 10 kg farm yard manure (FYM)/ha (Kapil and Kapoor 2002) followed by one to two sprays of 0.05 % carbendazim was found effective in reducing damping-off disease of pea.

11.1.1.2 Powdery Mildew, *Erysiphe polygonum*

(i) Symptoms: Mealy white patches appear on both sides of leaves, stems, branches, pods and tendrils (Fig. 11.1). These patches originate as minute discoloured specks from which a powdery mass radiates on all sides and covers a large area of aerial parts. It causes considerable damage and may result in 20–30% losses in pod number and quality. If it attacks early, plants fail to bear fruit or the pods get chaffy.

(ii) Integrated Management (a) Bioagents and Botanicals: In organically grown pea, biopriming of pea seeds with *T. harzianum* + *Pseudomonas fluorescens* was most effective in improving the seedling stand. Foliar application of bioagents significantly reduced the incidence of powdery mildew disease and increased the yield of pea (Table 11.1).

11.1.1.3 White Rot, *Sclerotium rolfsii*

(i) Symptoms: It is a ubiquitous fungus with a broad host range. Initially wet rotting of bark is observed. Entire bark of the plant near collar region rots. The characteristic symptoms include white, cottony fungus growth observed on affected portion as well as on parts in contact with soil. Gradually this hyphal mat is converted into small, mustard-like sclerotia that survive in the soil.

(ii) Integrated Management (a) Bioagents and Botanicals: Soil application of *Trichoderma* spp. supplemented with organic matter and green manuring is beneficial.

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_11, © Springer India 2014

Fig. 11.1 Powdery mildew on pea leaves and pod

Table 11.1 Effect of different biocontrol agents applied through seed, FYM and/or foliar application on powdery mildew disease and yield of pea

Treatment	Seedling stand/m^2	Powdery mildew incidence (%)	Yield (kg/ha)
Seed biopriming with *Trichoderma harzianum* + sprays with *Pseudomonas fluorescens*	56	13	355
FYM colonized with *T. harzianum* + sprays with *P. fluorescens*	63	16	352
Seed biopriming with *T. harzianum* + FYM colonized with *T. harzianum* + sprays with *T. harzianum*	69	12	388
Control	52	36	301
CD (*P=0.05*)	*6*	*10*	*53*

FYM farm yard manure

Fig. 11.2 *Fusarium* wilt of pea

11.1.1.4 White Mold, *Sclerotinia sclerotiorum*

(i) Symptoms: The disease is commonly found on pea that is responsible for complete killing of plants. Symptoms observed include wet and soft rotting of the tissues. White fungus growth is observed on the rotted portion. Embedded sclerotia covered with white mycelium are formed on the infected portion as well as on inner portion of the pith and fruits.

(ii) Integrated Management

(a) Botanicals and Bioagents: Addition of *Eupatorium/Ageratum conyzoides* plant material with wheat bran-based formulation of *T. harzianum* at the time of sowing was found effective in managing root rot/wilt complex of pea (Kaur 1999).

11.1.1.5 Wilt, *Fusarium oxysporum* f. sp. *pisi*

(i) Symptoms: Infection leads to drooping and wilting of plants at early stage of plant growth (Fig. 11.2). Vascular discolouration of stem and reddish appearance in the pith extends towards roots. The roots turn black and rot (Fig. 11.2). Plant growth is checked, foliage turns yellow and downward curling of stipules and leaflets takes place. The entire plant wilts and the stem

Fig. 11.3 *Rhizoctonia* patches in green pea (*left*), pea roots rotted by *Rhizoctonia solani* (*right*)

Fig. 11.4 Stem fly damage on stem of French bean

shrivels. Epinasty of affected plants is a characteristic symptom.

(ii) Integrated Management (a) Bioagents and Botanicals: Soil amendment with green manure and application of *T. harzianum* is most beneficial.

11.1.1.6 *Rhizoctonia* Root Rot

(i) Symptoms: It primarily rots seeds and causes pre- and post-emergence damping-off. Roots of older plants can be rotted and stems can be infected to cause death of plants (Fig. 11.3). Mild lesions and root rot can result in stunted and stressed plants. A firm, dry, brown to reddish-brown decay or sunken lesion appears on the root and stem below or near the soil line. Plants may be stunted and may wilt or break off.

(ii) Integrated Management (a) Bioagents and Chemicals: By itself, *Bacillus subtilis* provided more disease protection than the fungicide Anchor, but Anchor combined with *B. subtilis* was even more effective.

11.2 French Bean, *Phaseolus vulgaris*

11.2.1 Insect Pests

11.2.1.1 Bean Fly, *Ophiomyia phaseoli;* Leaf Hopper, *Empoasca kerri;* Leaf Miner, *Liriomyza trifolii*

(i) Damage: The bean fly larvae mine the leaf lamina, veins, midrib, petiole and enter the stem. Larval feeding in stem results in mortality or reduction of the plant growth (Fig. 11.4).

The greenish yellow nymphs and adults of leaf hopper suck the sap. During September–October months after the onset of North East monsoon, the pest becomes very serious causing withering of the foliage and plants.

Leaf miner mines the leaves below epidermis in zigzag manner generally in basal leaves and feed on chlorophyll (Fig. 11.5).

(ii) Integrated Management (a) Botanicals and Chemicals: Spraying 4% neem seed kernel extract (NSKE)/1% neem or pongamia soap 10 DAS combined with spraying of endosulfon at 15 DAS during rainy season is effective against bean pests.

Fig. 11.5 Serpentine leaf miner damage on bean

11.2.2 Diseases

11.2.2.1 Web Blight, *Rhizoetonia solani*

(i) Symptoms: At emergence, the infection on hypocotyl and stem results in damping-off symptoms, but afterwards, elongated, sunken, reddish brown lesions are produced on the stem at ground level. On the foliage, circular to irregular brown spots having distinct borders appear. Leaf scald symptoms are common. In rainy season, the disease assumes serious proportions. Extensive damage results under continuous wet weather along with high temperature.

(ii) Integrated Management

(a) Bioagents and Arbuscular **M**ycorrhizal **F**ungi **(AMF):** Integration of *Glomus mosseae* with *T. viride* gave total protection against *R. solani* infection in French bean (Ganeshan 1999).

11.2.2.2 Collar Rot, *sclerotinia sclerotiorum*

(i) Symptoms: The pathogen causes *Sclerotinia* wilt or white mold and also stem rot under certain conditions. The disease frequently occurs after a period of warm, humid weather. It can be recognized by the white fungus growth and large (2–5 mm) black bodies (sclerotia) in the pith of the stem.

(ii) Integrated Management Bioagents and Chemicals: *Coniothyrium minitans* in combination with other control measures such as fungicide applications late in the growing season has been suggested (Trutmann et al. 1982).

Fig. 11.6 Heavy galling of cowpea roots infected with *Meloidogyne incognita*. (Courtesy: F.E. Caveness)

11.3 Cowpea, *Vigna unguiculata*

11.3.1 Nematodes

11.3.1.1 Root-Knot Nematode, *Meloidogyne incognita*

Reddy and Singh (1981) reported that *M. incognita* was responsible for 28.60 % loss in pod yield of cowpea.

(i) Symptoms: Symptoms of damage induced by root-knot nematode include patches of stunted and yellowed plants. Severe damage can lead to reduced number of leaves and buds. At high densities severe root galling occurs (Fig. 11.6). Visual symptoms of damage first occurred at 1,000 and 10,000 juveniles/500 g of soil.

(ii) Integrated Management

(a) Botanicals and Bioagents: Hasan and Jain (1992) reported that soil application of *Paecilomyces lilacinus* cultured on sorghum seeds together with certain organic matter effectively reduced the incidence of *M. incognita* and increased the crop yield of cowpea.

(b) Cultural and Chemical: Summer ploughing along with seed treatment with carbosulfon 3 % w/w or seed soaking in monocrotophos at 0.1 % for 6 h gave effective control of root-knot nematodes and increased the cowpea yield.

Fig. 11.7 Pod borer damage on pigeon pea

(c) AMF and Botanicals: Combined application of *Glomus fasciculatum* and Achook, a neem product was very effective in reducing root-knot nematode population in cowpea (Jain and Hasan 1995).

Integration of chopped leaves of *Prosopis juliflora* with *G. fasciculatum* to cowpea increased the spore production and root colonization of *G. fasciculatum* that resulted in reduced *M. incognita* population.

11.3.1.2 Reniform Nematode, *Rotylenchulus reniformis*

(i) Symptoms: The reniform nematode *R. reniformis* is known to attack and cause growth reduction of cowpea. This nematode is most likely to cause or contribute to yield losses on cultivated cowpea.

(ii) Integrated Management (a) Physical and Chemical: Summer ploughing along with seed treatment with carbosulfan 3 % w/w or seed soaking in monocrotophos at 0.1 % for 6 h gave effective control of reniform nematodes and increased the cowpea yield.

11.3.1.3 Root-Knot Nematode, *M. incognita* and Root Rot, *Macrophomina phaseolina* Disease Complex

(ii) Integrated Management (a) Botanicals and AMF: Devi and Goswami (1992) demonstrated that *G. fasciculatum* together with mustard cake helped in reducing the disease severity caused by *M. incognita* and *M. phaseolina* in cowpea. They observed that the pre-establishment of AMF checked the entry of *M. incognita* larvae as also colonization of pathogenic fungus.

11.3.1.4 Root-Knot Nematode, *M. incognita* and Wilt, *F. oxysporum* Disease Complex

The wilt fungus, *F. oxysporum* and root-knot nematode, *M. incognita* co-infect cowpea. Histopathological studies revealed that in nematode + fungus inoculated cowpea roots, conidia of *F. oxysporum* could be observed in the cortex as well as in xylem vessels adjacent to the giant cells but not inside the giant cells induced by *M. incognita* (Singh et al. 2007).

(i) Integrated Methods (a) Chemicals and Botanicals: The minimum gall diameter index was reported in reduced dose of both neem cake and carbofuran (Singh et al. 2007).

11.4 Pigeon Pea, *Cajanus cajan*

11.4.1 Insect Pests

11.4.1.1 Pod Borer, *Helicoverpa armigera*

(i) Damage: The larvae feed for short time on the tender leaflets, flower buds and tender roots. Slowly it enters and feed on the seeds inside the pods. The half portion of larva remains inside while feeding on the developing seeds (Fig. 11.7).

(ii) Integrated Methods (a) Two Bioagents: The least population of *H. armigera* was observed in virus [*H. armigera* nuclear polyhedrosis virus (*Ha*NPV) at 2×10^6 polyhedral inclusion bodies (PIBs)/mL] + nematode [DD-136 (*Steinernema feltiae*) at 3×10^3 infective juveniles/mL] treated plots (0.2) when compared to control (12.6). The percentage of pod damage was significantly lower in virus + nematode (1.07) when compared to control (40.31). Significant increase in pod yield was obtained in virus + nematode-treated plots (10.7 kg) when compared to control (3.2 kg) (Narayanan and Gopalakrishnan 1988).

Fig. 11.8 Dead plant due to *Fusarium* wilt (*left*), blackening of the xylem (*right*)

Table 11.2 Field performance of bacterial antagonists against *Fusarium* wilt of pigeon pea

Treatment	Formulation used and cfu/g	Disease control (%)	Increase in yield (%)
Seed treatment with *Pseudomonas fluorescens* at 10 g/kg + soil application at 2.5 kg/ha mixed with FYM	Talc 10^7–10^8	22	6
Seed treatment with *Pseudomonas putida* at 10 g/kg + soil application at 2.5 kg/ha mixed with FYM	Talc 10^6–10^7	28	12
Seed treatment with *Bacillus subtilis* at 10 g/kg + soil application at 2.5 kg/ha mixed with FYM	Talc 10^6–10^7	26	14

11.4.2 Diseases

11.4.2.1 Wilt, *Fusarium udum*

(i) Symptoms: The disease is characterized by slow wilting of the plant. The symptoms can be observed after a month of sowing or at the flowering or pod formation stage. The affected plants become yellow in colour followed by drooping and finally the whole plant dries up (Fig. 11.8). The symptoms resemble as if the plant is suffering from the drought. The disease can be diagnosed whenever the affected stem is cut and opened where the browning of the xylem vessels could be clearly seen (Fig. 11.8). It has been recorded that wilting can be partial or total. However, it has been observed that partial wilting is mainly associated with lateral root infection, whereas tap root infection may cause complete wilting.

(ii) Integrated Management

(a) Bioagents and Chemicals: Wilt of pigeon pea was successfully managed by integration of *T. harzianum* and *Trichoderma virens* with carboxin (Mukhopadhyay 1994).

Upadhyay and Roy (1997) reported effective management of *Fusarium* wilt by integration of *T. virens* with Fytolan.

(b) Bioagents and AMF: Application of *B. subtilis, Bradyrhizobium japonicum* and *G. fasciculatum* used either alone or in combination increased shoot dry weight, number of nodules, phosphorus content and reduced nematode multiplication and wilting index in pigeon pea (Siddiqui and Mahmood 1995).

(c) Bioagents and Botanicals: Pigeon pea seed treatment with bacterial antagonists (*Pseudomonas putida, B. subtilis*) at 10 g/kg seed + soil application at 2.5 kg/ha of above bioagents mixed with FYM gave 22–28% *Fusarium* wilt control and increased the yield by 12–14% (Ramanujam et al. 2003) (Table 11.2).

11.4.3 Nematodes

11.4.3.1 Cyst Nematode, *Heterodera cajani*

The cyst nematode has been found associated with pigeon pea in a number of regions of India.

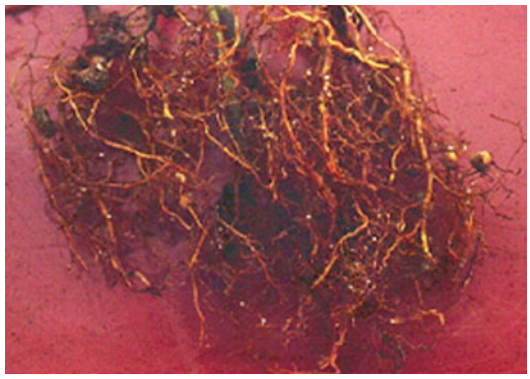


Fig. 11.9 Root damage symptoms of pearly root caused by *Heterodera cajani* in pigeon pea

Table 11.3 Effect of bioagents on plant growth and management of *Heterodera cajani* infecting pigeon pea

Treatment	Seedling mortality	Yield (kg/plant)	Eggs/cyst
T. harzianum—5 kg/ha	13.21	0.529	36.8
P. chlamydosporia—2 kg/ha	13.67	0.545	30.1
T. harzianum—5 kg/ha + *P. chlamydosporia*—2 kg/ha	9.20	0.560	24.0
Carbofuran—2 kg a.i./ha	2.16	0.634	18.4
Control	18.40	0.404	45.1
CD ($P=0.05$)	*1.14*	*0.0053*	*3.45*

(i) Symptoms: The most important characteristic symptom is the presence of cysts on the root surface. Identification of 'pearly root' caused by the presence of white females is a useful symptom of *H. cajani* infestation in pigeon pea at the vegetative stage (Fig. 11.9). The symptoms of nematode injury include stunting, reduced leaf lamina size and yellowing on cotyledonary leaves. Flowers and pods are reduced in size and number and the root system may also be poorly developed. The cyst nematode retarded emergence of leaves and reduced the number of flowering buds, flowers, growing pods and yield.

(ii) Integrated Management (a) Two Bioagents: Integration of *T. harzianum* at 5 kg/ha along with *Pochonia chlamydosporia* at 2 kg/ha significantly increased the plant height and pigeon pea yield (0.56 kg/plant as compared to 0.40 kg/plant in control) and reduced the seedling mortality, eggs per cyst, parasitization of cysts by the bioagents and cyst nematode population (Table 11.3).

(b) Bioagents and Botanicals: Combined treatment of 10% neem seed kernel powder + *T. viride* at 10 g/kg seeds was found to reduce *H. cajani* in pigeon pea by 58% and increased yield by 32%. Application of neem cake at 100 kg/ha + *T. viride* at 2.5 kg/ha was also found to reduce *H. cajani* by 62% and increased pigeon pea yield by 34%.

Seed treatment with neem seed kernel powder at 10% w/w + *P. fluorescens* at 10 g/kg seed was highly effective which recorded 30.11% reduction in nematode population and 29.10% increase in yield over control. Soil application of neem cake at 10 g/m^2 + *P. fluorescens* at 2.5 kg/ha was also highly effective, which recorded 31.63% reduction in nematode population and 17.88% increase in yield over control.

(c) Physical, Botanicals and AMF: Soil solarization (transparent polythene sheet of 400 gauge thickness for a period of 4 weeks) and application of AMF at 100 kg/ha provided good plant growth and yield of pigeon pea by effectively controlling the detrimental effects of *H. cajani*. Maximum reduction in nematode population was observed in soil solarization + soil application of neem seed powder at 50 kg/ha + AMF, and soil solarization + seed treatment with neem seed powder at 10% w/w + AMF (Nageswari and Mishra 2005).

11.4.3.2 Root-Knot Nematode, *Meloidogyne* spp. and Wilt, *F. udum* Disease Complex

(i) Symptoms: Among plant-parasitic nematodes, *M. incognita* is considered most serious threat to its cultivation. Similarly, among fungi, *Fusarium* wilt is one of the most destructive diseases of pigeon pea. The wilt disease complex caused by *F. udum* in association with *M. incognita* has been reported as the most severe constraint in the cultivation of pigeon pea. When both these pathogens attack the crop, intensity of damage is increased by several folds.

Simultaneous or sequential inoculation of *M. incognita* and *F. udum* increased the severity of

Table 11.4 Effect of *Meloidogyne incognita* and *Fusarium udum* on plant growth and root galling and disease index in pigeon pea

Treatment	Plant height (cm)	Dry plant wt. (g)	Gall index	Disease index
Control	33.9	1.03	–	–
M. incognita	32.6	0.73	1.75	0.00
F. udum	32.6	0.81	–	45.32
M. incognita + *F. udum* simultaneously	23.6	0.38	2.15	38.21
M. incognita (pre) + *F. udum* (post)	27.3	0.57	2.75	32.14
F. udum (pre) + *M. incognita* (post)	30.6	0.65	1.25	42.33
CD (*P* = *0.05*)	*1.3*	*0.031*	*0.143*	*0.273*

the disease. Highest reduction in plant height, fresh/dry weight was observed in plants inoculated with *M. incognita* and *F. udum* simultaneously followed by *M. incognita* prior and *F. udum* 7 days later and *F. udum* prior and *M. incognita* 7 days later. Reproduction of *M. incognita* was enhanced in the presence of *F. udum* but per cent root colonization by *F. udum* was suppressed in the presence of *M. incognita*. Highest final nematode population and gall index of *M. incognita* were observed in simultaneous inoculation of *M. incognita* and *F. udum* and lowest in *F. udum* prior and *M. incognita* 7 days later, while highest per cent root colonization was found in *F. udum* prior and *M. incognita* 7 days later followed by *M. incognita* and *F. udum* simultaneously and *M. incognita* prior and *F. udum* 7 days later (Table 11.4) (Perveen et al. 1998).

(ii) Effect of Disease Complex on Wilt Resistant Accessions Among ten pigeon pea accessions (identified as resistant to *Fusarium* wilt) (Vishwadhar and Chaudhary 2000) evaluated against combined infection of *Meloidogyne javanica* and *F. udum* under pot culture conditions, increase in wilting was observed in five accessions namely, ICP 8859, AWR 74/15, KPL 44, ICPL 89049 and ICPL 12745. In these accessions wilting started 30 days after inoculation of fungus. Maximum wilting was observed in AWR 74/15 (60%) followed by ICP 8859 (50%) and ICPL 89049 (50%). Wilting increased from 8% to 33% in KPL 44, 15–60% in AWR 74/15, 25% to 50% in ICP 8859 and ICPL 89049, and 15–50% in ICP 12745 when *M. javanica* was present with *F. udum*. Whereas in other five accessions (KPL 43, PI 397430, BWR 370, GPS 33 and ICPL 89048), wilting was not influenced much in the presence of *M. javanica* (Singh et al. 2004).

The plant height was significantly lower in combined inoculation compared to either nematode or fungus alone. The root-knot index varied from 3.0 to 4.5 in these accessions in both treatments having nematode alone or nematode and fungus together. The lowest root-knot index was observed in KPL 43 (1.5) and GPS 33 (1.75) (Table 11.5) (Singh et al. 2004).

(iii) Integrated Management

(a) Botanicals and AMF: The treatment constituting FYM, karanj oilseed cake and arbuscular mycorrhizal fungus, *G. fasciculatum* reduced the disease incidence caused by root-knot nematode, *M. incognita* and root wilt fungus, *F. udum* on pigeon pea to a great extent with the most promising improvement in plant growth parameters (Goswami et al. 2007).

11.4.3.3 Cyst Nematode, *H. cajani* and Wilt, *F. udum* Disease Complex

(i) Symptoms: The wilt disease complex caused by *F. udum* in association with *H. cajani* has been reported as the most severe constraint in the cultivation of pigeon pea. Inoculation with *F. udum* and *H. cajani* together significantly increased wilt severity in pigeon pea seedlings compared with inoculation of the fungus alone.

(ii) Integrated Methods

(a) Bioagents, Botanicals and Chemicals: In a trial conducted in the field during 2002, no wilting was observed in plots treated with neem seed

Table 11.5 Effect of combined inoculation of *M. javanica* and *F. udum* on plant growth and disease complex in different accessions of pigeon pea

Pigeon pea accessions	Plant height (cm)	Gall index	% wilt incidence
KPL 43	25.9	2.45	0
KPL 44	17.4	1.97	33
AWR 74/15	18.3	1.56	60
ICP 8859	14.7	3.39	50
ICPL 89049	24.3	2.17	50
PI 397430	24.8	3.06	0
BWR 370	28.4	3.17	0
GPS 33	32.0	2.25	0
ICPL 89048	28.3	3.25	0
ICP 12745	19.4	2.50	50
CD (*P=0.05*)	*2.40*	*1.60*	–

Table 11.6 Effect of seed treatment with bioagents, chemicals and botanicals on wilt and cyst nematodes infecting pigeon pea under field conditions during 2002

Treatment	Grain yield (kg)/100 m^2	% wilting of plants	% root infection by *F. udum*	Nematodes /g of root	Cysts and larvae/ 100 mL soil
Carbofuran	23.47	5.0	35	9	27
NSP (soil application)	19.55	0.0	20	23	45
NSP (seed treatment)	18.33	0.0	20	30	43
T. harzianum	15.46	0.0	25	31	44
P. lilacinus	12.24	5.0	35	36	55
Dimethoate	11.75	10.0	50	39	58
Latex of *Calotropis*	11.34	10.0	50	39	59
NSP (soil) + dimethoate	21.05	0.0	15	16	36
NSP (soil) + *T. harzianum*	23.35	0.0	15	10	28
NSP (soil) + *P. lilacinus*	21.85	0.0	20	14	34
NSP (soil) + latex	20.75	0.0	15	18	43
Control	5.35	45.0	75	51	67
CD (*P=0.05*)	*1.22*	*2.8*	*3.9*	*0.68*	*3.1*

NSP neem seed powder

powder + dimethoate/*T. harzianum*/*P. lilacinus*/ latex, and neem seed powder and *T. harzianum* alone. Neem seed powder + *T. harzianum* was found to be the most effective treatment in increasing the yield and suppressing the pathogens, followed by carbofuran, neem seed powder + *P. lilacinus,* neem seed powder + dimethoate and neem seed powder + latex. Data regarding *F. udum* infection in roots gathered at the pre-flowering stage (90 DAS) indicated that all the treatments maintained significant protection of the roots as compared to control (Haseeb and Shukla 2005) (Table 11.6).

(b) Bioagents and AMF: The detrimental effects of a disease complex on pigeon pea involving the sedentary endoparasite *H. cajani* and the fungus *F. udum* were reduced following application of the fungi *P. lilacinus* and *P. chlamydosporia* together with the arbuscular mycorrhizal fungus *Gigaspora margarita* (Siddiqui and Mahmood 1995).

Combined application of *T. harzianum, P. chlamydosporia* and *G. mosseae* enhanced the activity against *H. cajani–F. udum* wilt disease complex in pigeon pea.

Table 11.7 Economics of IPM in Gulburga (Karnataka) during 2001–2002

Particulars	Sannur		Farthabad	
	IPM	Non-IPM	IPM	Non-IPM
Cost of plant protection (Rs./ha)	1,915	2,873	1,915	2,607
Total cost of cultivation (Rs./ha)	6,685	7,498	6,685	7,267
Seed yield (q/ha)	7.690	7.300	9.700	8.050
Gross income (Rs./ha)	12,689	12,045	16,005	13,282
Profit over non-IPM (Rs./ha)	1,457	–	3,305	–

Table 11.8 Economics of IPM on pigeon pea at different locations in Gulburga district of Karnataka during 2002–2003

Centre	Yield (q/ha)	Profit over non-IPM (Rs/ha)
Sannur—IPM Sannur—Non-IPM	9.64 9.25	1,600
Farthabad—IPM Farthabad—Non-IPM	10.81 9.75	2,687
Tadtegnoor—IPM Tadtegnoor—Non-IPM	10.50 10.25	1,400
Kodla—IPM Kodla—Non-IPM	15.62 9.50	9,590

11.4.4 Validated Integrated Pest Management (IPM) Technology for Pigeon Pea

11.4.4.1 Gulburga, Karnataka

- Fall ploughing to expose pupae to hot sun and natural enemies.
- Mixing of sorghum or mesta seeds at 250 g/ha with pigeon pea seeds, which act as live bird perches.
- Installation of pheromone traps at 5/ha to monitor the pests.
- Erecting the branched twigs at 20/ha which act as bird perches.
- First spraying with ovicide indoxacarb or methomyl at 300 g/ha or profenophos at 2 L/ha.
- Second spraying with 5% NSKE or commercial neem formulation (1,500 ppm Azadirachtin) at 2 L/ha.
- Third spraying with *Ha*NPV at 250 LE/ha.
- Fourth spraying with indoxacarb at 300 mL/ha or chlorpyriphos at 2.5 L/ha or quinalphos or endosulfan at 2 L/ha.
- If necessary, spraying of synthetic pyrethroids at 500 mL/ha.
- In case of scarcity of water, dust 4% endosulfan followed by 1.5% quinalphos or 0.4% fenvalerate at 25 kg/ha.

The Integrated Pest Management (IPM) module demonstrated on the large scale during 2001–2002 (two villages) and 2002–2003 (four villages) indicated the higher benefit to cost ratio (Tables 11.7 and 11.8) (Sharma et al. 2004).

11.4.4.2 Nanded, Maharashtra

Pre-sowing

- Deep ploughing and exposure of soil to hot summer to kill pupating larvae and fungal propagules.
- Use of FYM enriched with *T. viride* at 50 kg/ha mixed along with neem cake to reduce disease as well as nematode population.
- In areas where termite and cut worm is a problem, seed treatment with chlorpyriphos at 8 mL/kg or pre-sowing mixing of soil with chlorpyriphos dust is recommended as they are relatively low cost and initially protect the seedlings from cut worms.
- Synchronized sowing of multiple pest resistant varieties such as Sharad, Asha, Maruti, Bahar, Abhaya, BSMR-736.
- Ridge planting to prevent incidence of blight caused by *Phytophthora dreschleri*.

Sowing Time

- Intercrop sorghum to reduce wilt, conserve beneficial insects and serve as bird perches.
- Early planting around mid-June in North West Plain Zone to avoid *H. armigera*.
- Use marigold as a trap crop on border or interspersed with crop for pod borer control.

Table 11.9 Comparative level of damage in IPM and non-IPM fields during 2002–2003

Type of damage	IPM	Non-IPM
Bud damage (%)	18	24
Pod damage (%)	22	27
Pod borer damage (early) (%)	55	61
Pod borer damage (late) (%)	58	83
Leaf roller (No./plant)	1.01	36
Plume moth (No./plant)	0.13	0.30
Yield (t/ha)	1.096	0.724

Post-sowing

- Monitoring through regular field scouting along with pheromone traps (5–10/ha) to assess population build up of borers and their management. A threshold level of 5–6 moths/trap/day is indicative of its peak activity period and warrants initiation of management practices.
- Rogue out and destroy sterility mosaic virus affected plants.
- Mechanical shaking of plants and collection of larvae for preparation of *Ha*NPV locally to cut down the cost.
- Spray 5% NSKE or neem-based formulation against *H. armigera* and other Lepidopterous pests.
- Spray with *Ha*NPV at 450 LE/ha along with UV retardant.
- Spray eco-friendly pesticide like endosulfan, if pest complex exceeds ETL.

The data on per cent bud and pod damage due to *H. armigera* and leaf roller and plume moth damage indicated that Integrated Pest Management (IPM) had a significant edge over non-IPM despite use of chemical pesticides. The seed yield obtained for IPM and non-IPM fields was 1.096 and 0.724 t/ha, respectively (Table 11.9) (Sharma et al. 2004).

11.4.4.3 Varanasi, Uttar Pradesh

- Deep summer ploughing to destroy immature stages and pathogen propagules.
- Prior to sowing, soil application of *T. harzianum* at 10 g/kg of FYM for controlling the pigeon pea wilt.
- Sowing on ridges to control *Phytophthora*.
- Sowing of high yielding varieties with pest/disease tolerance—Asha and Maruthi against wilt and PSM for Andhra Pradesh and Karnataka, and Bahar for Uttar Pradesh (Varanasi).
- Installation of pheromone traps at 10/ha in the month of September.
- Erection of bird perches at 25/ha for facilitating predation of *Helicoverpa* larvae.
- One spray with 2% neem oil.
- Two applications of 5% NSKE in September and October.
- Spray *Ha*NPV at 500 LE/ha (1.5×10^{12} POB)/ha in September and October—when larvae are small.
- Shaking of plants five times a day starting from October for short duration pigeon pea.
- Need-based spray with endosulfan at 2 L/ha.

As a result of implementation of Integrated Pest Management (IPM), the grain yield was found to be twice (0.765 t/ha) in comparison to non-IPM fields (0.375 t/ha). Besides, the quality of environment improvement, favourable benefit to cost ratio (2.01) was recorded in IPM fields. The incidence of leaf roller and *Phytophthora* blight incidence in IPM and non-IPM fields is presented in Table 11.10 (Sharma et al. 2004).

11.5 Cluster Bean, *Cyamopsis tetragonoloba*

11.5.1 Nematodes

11.5.1.1 Root-Knot Nematode, *Meloidogyne javanica* and Wilt, *Fusarium solani* Disease Complex

(i) Integrated Management (a) Two Bioagents: *Pseudomonas aeruginosa* and *P. lilacinus* when used together significantly reduced infection of the disease complex on cluster bean (Perveen et al. 1998).

11.5.1.2 Root-Knot Nematode, *M. javanica* and Root Rot/Wilt, *M. phaseolina, R. solani, F. solani, F. oxysporum* Disease Complex

(i) Integrated Methods (a) Two Bioagents: *P. aeruginosa* and *P. lilacinus* used alone or together

Table 11.10 Comparative incidence of pest/disease in IPM and non-IPM fields

Pest/disease	Short duration cv. UPAS-120		Long duration cv. Bahar	
	IPM	Non-IPM	IPM	Non-IPM
Leaf roller (No./plant)	5	15	15	30
Phytophthora blight (%)	2–3	25	2–3	30

Table 11.11 Effect of *P. aeruginosa* and *P. lilacinus* on plant height and control of root rot/wilt disease complex in cluster bean

Treatment	Plant height (cm)	Root-knot index	Infection (%)			
			M. phaseolina	*R. solani*	*F. solani*	*F. oxysporum*
Control	24.5	4.1	31	0	75	81
PL	28.0	3.5	6	0	62	81
PA	27.7	2.0	19	0	44	50
PL + PA	32.0	1.4	6	0	37	44
CD (*P* = *0.05*)	*2.2*	*0.34*	*6.1*	*6.1*	*6.1*	*6.1*

PL *Paecilomyces lilacinus,* PA *Pseudomonas aeruginosa*

significantly ($P < 0.05$) reduced infection of root-knot nematode *M. javanica* and root infecting fungi viz., *M. phaseolina, R. solani, F. solani* and *F. oxysporum* on cluster bean. *P. aeruginosa* was more effective than *P. lilacinus* in reducing the *M. javanica* infection. Combined use of *P. lilacinus* and *P. aeruginosa* was more effective in reducing the infection of root-knot nematode and *F. solani* on guar than either used alone. Use of *P. aeruginosa* and *P. lilacinus* significantly ($P < 0.05$) increased plant height of guar (Perveen et al. 1998) (Table 11.11).

Fig. 11.10 Field bean pod infected with borer

11.6 Field Bean, *Lablab purpureus*

11.6.1 Insect Pests

11.6.1.1 Pod Borer, *Adisura atkinsoni*

(i) Damage: This is the major pod borer in field bean. The eggs are laid on tender pods. The young larvae bore into tender pods. They develop inside the bored pod and come out after attaining fourth instar, which is a migratory stage. It causes heavy damage by way of feeding the developing pods and reducing the marketable yield (Fig. 11.10).

(ii) Integrated Management

(a) Bioagents and Chemicals: Spraying of *A. atkinsoni* nuclear polyhedrosis virus *(Aa*NPV) at 250 LE/ha in combination with endosulfan at 0.035%, twice at fortnightly intervals significantly reduced both larval population and pod damage by *A. atkinsoni* and *Sphenarches anisodactylus* (Narayanan 1987).

*Aa*NPV at 125 LE/ha along with endosulfan (0.035%) is effective in significantly reducing the pest damage to both pods and grains (Narayanan and Gopalakrishnan 1990).

References

Devi, T. P., & Goswami, B. K. (1992). Effect of VA mycorrhiza on the disease incidence due to *Macrophomina phaseolina* and *Meloidogyne incognita* on cowpea. *Annals of Agricultural Research, 13*, 253–265.

Hasan, N., & Jain, R. K. (1992). *Field application of Paecilomyces lilacinus in combination with certain organic matters for controlling Meloidogyne incognita infecting cowpea followed by lucerne*. Paper presented at First Afro-Asian Nematology Symposium, Aligarh Muslim University, Aligarh, pp. 10–11.

Haseeb, A., & Shukla, P. K. (2005). Wilt disease complex of pigeonpea and its management. In S. Nehra (Ed.), *Plant diseases: Biocontrol management* (pp. 84–96). Jaipur: Avishkar.

Ganeshan, G. (1999). *Biological control of collar rot disease of French bean using Glomus mosseae and Trichoderma viride*. Paper presented at International Symposium on Biological Control Agents in Crop and Animal Protection, University of Wales, Swansea, UK.

Goswami, B. K., Pandey, R. K., Goswami, J., & Tiwari, D. D. (2007). Management of disease complex caused by root knot nematode and root wilt fungus on pigeon pea through soil organically enriched with vesicular arbuscular mycorrhiza, karanj (*Pongamia pinnata*) oilseed cake and farmyard manure. *Journal of Environmental Science and Health, 42*, 899–904.

Jain, R. K., & Hasan, N. (1995). Nematode problems in forage crops. In Gopal Swarup, et al. (Eds.), *Nematode pest management-An eco-friendly approach* (pp. 217–227). New Delhi: Nematological Society of India, Indian Agricultural Research Institute.

Kapil, R., & Kapoor, A. S. (2002). *Management of white rot (Sclerotinia sclerotiorum) using Trichoderma spp. and biopesticides*. Paper presented at Annual Meeting of the Indian Phytopathological Society (North Zone), Punjab Agricultural University, Ludhiana.

Kapoor, A. S., & Sharma, C. L. (2000). Integrated management of white rot of pea. In Proceedings of IPS International Golden Jubilee Conference on Integrated Plant Diseases Management for Sustainable Agriculture, Indian Agricultural Research Institute, New Delhi, Vol. II, p. 712.

Kaur, P. (1999). Integrated management studies on pea diseases. M. Sc. thesis, Y.S. Parmar University of Horticulture and Forestry, Solan, 75 pp.

Mukhopadhyay, A. N. (1994). Biological control of soilborne fungal plant pathogens-Current status, future prospects and potential limitations. *Indian Phytopathology, 47*, 119–126.

Nageswari, S., & Mishra, S. D. (2005). Integrated nematode management schedule incorporating neem products, VAM and soil solarization against *Heterodera cajani* infecting pigeonpea. *Indian Journal of Nematology, 35*, 68–71.

Narayanan, K. (1987). Field efficacy of nuclear polyhedrosis virus of *Adisura atkinsoni* Moore on field beans. *Journal of Biological Control, 1*, 44–47.

Narayanan, K., & Gopalakrishnan, G. (1988). Microbial control of Heliothis armigera. Technical Bulletin No. 6, Indian Inst. of Horticultural Research, Bangalore, pp. 13–14.

Narayanan, K., & Gopalakrishnan, G. (1990). Integrated control Heliothis armigera with the use of pathogens and pesticides in certain horticultural crops. In S. Jayaraj, S. Uttamasamy, M. Gopalan, & R. J. Rabindra (Eds.), *Heliothis Management-Proceedings of National Workshop* (pp. 165–176, 328 pp.). Coimbatore: Centre for Plant Protection Studies, Tamil Nadu Agricultural University.

Perveen, S., Ehteshamul-Haque, S., & Ghaffar, A. (1998). Efficacy of *Pseudomonas aeruginosa* and *Paecilomyces lilacinus* in the control of root rot-root knot disease complex on some vegetables. *Nematologia Mediterranea, 26*, 209–212.

Ramanujam, B., Prasad, R. D., & Rangeswaran, R. (2003). Achievements in biological control of diseases with antagonistic organisms at Project Directorate of Biological Control, Bangalore. In B. Ramanujam & R.J. Rabindra (Eds.), *Current Status of Biological Control of Plant Diseases Using Antagonistic Organisms in India* (pp. 258–271). Bangalore: Project Directorate of Biological Control.

Reddy, P. Parvatha, & Singh, D. B. (1981). Assessment of avoidable yield loss in okra, brinjal, French bean and cowpea due to root-knot nematodes. Paper presented at Third International Symposium on Plant Pathology, New Delhi, pp. 93–94.

Sharma, O. P., Sehgal, M., Jeswani, M. D., Trividi, T. P., Garg, D. K., Srivastava, C. P., Benagi, V. I., Nigam, G. L., & Lavekar, R. C. (2004). Validated Integrated Pest Management (IPM) technologies: Pigeonpea. In Amerika Singh, H. R. Sardana, & Naved Sabir (Eds.), *Validated Integrated Pest Management (IPM) Technologies for selected crops* (pp. 77–89). New Delhi: National Centre for Integrated Pest Management (ICAR).

Siddiqui, Z. A., & Mahmood, I. (1995). Biological control of *Heterodera cajani* and *Fusarium udum* by *Bacillus subtilis, Bradyrhizobium japonicum* and *Glomus fasciculatum* on pigeonpea. *Fundamental and Applied Nematology, 18,* 559–566.

Singh, B., Ali, S. S., Naimuddin, & Askary, T. H. (2004). Combined effect of *Fusarium udum* and *Meloidogyne javanica* on wilt resistant accessions of pigeon pea. *Annals of Plant Protection Sciences, 12*, 130–133.

Singh, S., Dhawan, S. C., & Goswami, B. K. (2007). Histopathology of cowpea roots co-infected with root-knot nematode, *Meloidogyne incognita* and wilt fungus *Fusarium oxysporum*. *Indian Journal of Nematology, 37*, 156–160.

Trutmann, P., Keane, P. J., & Merriman, P. R. (1982). Biological control of *Sclerotinia sclerotiorum* on aerial parts of plants by the hyperparasite *Coniothyrium minitans*. *Transactions of the British Mycological Society, 78*, 521–529.

Upadhyay, J. P., & Roy, S. 1997. Third annual report of ICAR adhoc scheme on biological control of pigeonpea wilt submitted to ICAR, New Delhi, 35 pp.

Vishwadhar, & Chaudhary, R. G. (2000). Disease resistance in pulse crops-Current status and future approaches. In Proceedings of National Symposium on Role of Resistance in Intensive Agriculture, Directorate of Wheat Research, Karnal, pp. 144–157.

Cucurbitaceous Vegetable Crops 12

12.1 Pumpkin, *Cucurbita moschata*

12.1.1 Diseases

12.1.1.1 Gummy Stem Blight, *Mycosphaerella melonis*

(i) Symptoms: A non-descript marginal necrosis followed by larger, wedge-shaped necrotic areas appear on leaves. Infected stems first show water-soaked lesions and later appear tanned. Older stems show pycnidia within the affected tissue. Stem lesions often cause exudation of gummy, reddish-brown or black beads (Fig. 12.1).

(ii) Integrated Management

(a) Bioagents and Botanicals: Soil application of neem cake enriched with *Trichoderma harzianum* minimized gummosis, root rot and collar rot.

12.1.2 Nematodes

12.1.2.1 Root-Knot Nematodes, *Meloidogyne* spp.

(i) Symptoms: Very broad-leaved plants like pumpkin, infected with root-knot nematodes, may show daytime wilting and develop much larger galls. In cucurbits, the roots react to the presence of *Meloidogyne* spp. by the formation of large, fleshy galls (Fig. 12.2).

(ii) Integrated Management

(a) Bioagents and Botanicals: Addition of 250 g of fresh neem cake or karanj cake enriched with *T. harzianum/Paecilomyces lilacinus* per planting pit effectively controlled the nematodes.

12.1.2.2 Root-Knot Nematode, *Meloidogyne javanica,* and Root Rot/Wilt, *Macrophomina phaseolina, Fusarium oxysporum* and *Fusarium solani*, Disease Complex

(i) Integrated Management

(a) Two Bioagents: *Pseudomonas aeruginosa* and *P. lilacinus* when used together significantly reduced infection of the disease complex in pumpkin (Table 12.1; Perveen et al. 1998).

P. aeruginosa and *P. lilacinus* used alone or together significantly ($P<0.05$) reduced infection of root-knot nematode *M. javanica* and root-infecting fungi, viz., *M. phaseolina, Rhizoctonia solani, F. solani* and *F. oxysporum* in pumpkin. *P. aeruginosa* was more effective than *P. lilacinus* in reducing the *M. javanica* infection. Combined use of *P. lilacinus* and *P. aeruginosa* was more effective in reducing the infection of *M. phaseolina* and *F. oxysporum* in pumpkin than either used alone. Use of *P. aeruginosa and P. lilacinus* significantly ($P<0.05$) increased plant height of pumpkin.

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_12, © Springer India 2014

Fig. 12.1 Symptoms of gummy stem blight on leaf and stem

Fig. 12.2 Root-knot nematode in pumpkin

Table 12.1 Effect of *Pseudomonas aeruginosa* and *Paecilomyces lilacinus* on growth and control of root disease complex of pumpkin

Treatment	Plant height (cm)	Root-knot index	*Macrophomina phaseolina* infection (%)
Control	26.5	3.1	87
P. lilacinus (PL)	32.2	1.2	94
P. aeruginosa (PA)	30.0	0.6	50
PL + PA	28.2	0.5	19
Critical Difference (CD) ($P=0.05$)	2.2	0.34	6.1

12.2 Cucumber, *Cucumis sativus*

12.2.1 Diseases

12.2.1.1 Damping-off, *Pythium* spp.

(i) Symptoms: In seedlings, a watery rot develops in the tap root and hypocotyl at or near the soil line. Damping-off or a slow decline may occur when seedling death is preceded by cotyledon and leaf chlorosis. Young seedlings wilt and die (Fig. 12.3).

Fig. 12.3 Damping-off of cucumber seedlings. *Left*, three seedlings infected; *right*, healthy seedlings

(ii) Integrated Management (a) AMF and Botanicals: Combined use of AMF *Gigaspora margarita* and 3–15% charcoal compost (which contained antagonistic microorganisms such as *Bacillus subtilis, Thermomonospora* sp. and *Thermoactinomyces* sp.) drastically reduced damping-off caused by *Pythium splendens* or *R. solani* in 2- and 3-week-old cucumber seedlings. Moreover, AMF and charcoal compost stimulated rooting and increased the root volume, and hence plant growth (Kabayashi 1989b).

12.2.1.2 *Fusarium* Wilt, *F. oxysporum* f. sp. *cucumerinum*

(i) Symptoms: Yellowing of leaves progresses upwards from the base of the plant. Wilting or yellowing may occur only on one side of a leaf or a branch or one side of the plant (Fig. 12.4). Yellow leaves wilt noticeably before they die. Wilting may occur at mid-day, when sunlight is bright and temperature is high. Infected plants are stunted, and both fruit size and yield are reduced.

Fig. 12.4 *Fusarium* wilt of cucumber

Fig. 12.5 Grey mold in cucumber

Fig. 12.6 *Rhizoctonia* fruit rot of cucumber

(ii) Integrated Management

(a) AMF and Botanicals: Combined use of AMF *G. margarita* and 3–15% charcoal compost (which contained antagonistic microorganisms such as *B. subtilis, Thermomonospora* sp. and *Thermoactinomyces* sp.) drastically reduced *Fusarium* wilt in cucumber. Moreover, AMF and charcoal compost stimulated rooting and increased the root volume, and hence plant growth (Kabayashi 1989b).

(b) Two Bioagents: Combinations of nonpathogenic fusaria and fluorescent pseudomonads significantly reduced *Fusarium* wilt disease incidence in cucumber, although neither group alone induced significant biological control. This suggests that mixtures of biological control agents were effective in disease control strategies.

12.2.1.3 Grey Mold, *Botrytis cinerea*

(i) Symptoms: This microfungus kills cucumber plants in a day or so, rotting through the stem near the base of the plant. Under humid conditions, fuzzy grey mold grows on the affected buds, leaves, flowers or fruit (Fig. 12.5). Above-ground parts of many plants, particularly buds and flowers, shrivel and die. *Botrytis* infection leads to a soft brown rot, often as the fruit is ripening.

(ii) Integrated Management

(a) Bioagents and Chemicals: Elad et al. (1993) used a combination of *T. harzianum* and dicarboximide for successful control of grey mold in cucumbers. However, the alternation of the antagonist with fungicides was shown to be more effective than mixtures.

12.2.1.4 *Rhizoctonia* Fruit Rot

(i) Symptoms: Symptoms occur on the underside and blossom end of the cucumber fruit and can be observed within as little as 24 h after the pathogen invades cucumbers that are in contact with soil. As the disease progresses, lesions become sunken and irregular in shape (Fig. 12.6). The entire fruit can rot in 72 hr.

Fig. 12.7 Cucumber roots severely galled due to root-knot nematode infection

(ii) Integrated Management (a) Bioagents and Cultural: *Rhizoctonia* fruit rot of cucumber was decreased with combinations of deep ploughing to bury infested soil layers and the application of *Trichoderma* sp. (VT6; Lewis and Papavizas 1980).

(b) Bioagents and Chemicals: Lewis and Papavizas (1980) reported effective control of *R. solani* in cucumber with a combination of *T. harzianum* and chlorothalonil.

12.2.2 Nematodes

12.2.2.1 Root-Knot Nematodes, *Meloidogyne* spp.

(i) Symptoms: Root-knot nematode causes galls or swellings on plant roots. In case of heavy attacks, galls can become very large, the root system being reduced to a swollen stump without hairs (Fig. 12.7). It restricts the uptake of nutrients from the root system to the foliage, resulting in a yellow and stunted plant.

(ii) Integrated Management (a) Bioagents and Botanicals: Pre-plant treatment with *P. lilacinus* (20 kg/ha) in combination with organic amendments effectively reduced root-knot infection in gherkin.

(b) Bioagents and AMF: Combined inoculation of AMF and *Pseudomonas fluorescens* had positive effect on root-knot nematode control in cucumber (Jakobsen 1999).

(c) Physical and Botanicals: Solarization alone or soil amendment alone (using poultry manure, alfalfa, cauliflower, tomato and olive-cake residues) significantly reduced densities of second-stage juveniles of *M. javanica* and root galling and increased the yield of cucumber. Organic amendments reduced densities of *Fusarium* spp., generally increased *Aspergillus* spp., while *Trichoderma* spp. was not affected. Combinations of solarization and addition of organic amendments substantially augmented each other, particularly with poultry manure, alfalfa hay and to a lesser extent cauliflower and tomato residues.

(d) Cultural and Botanicals: In commercial greenhouse trials in Spain, an integrated management system was developed, including biofumigation with sheep manure and mushroom residue and the cultivation of short-cycle vegetables acting as trap crops. Using this strategy, initial very high levels of *Meloidogyne incognita* were reduced to near zero in the main susceptible cucumber crop (Bello 1998).

(e) Physical and Bioagents: In a cucumber crop in glasshouse trial, the use of solarization and *Pasteuria penetrans* had an additive detrimental effect on *M. javanica* populations (Tzortzakakis and Gowen 1994).

(f) Bioagents and Chemicals: Oxamyl increased the efficacy of *P. penetrans* in trials against *M. javanica* infection of cucumber crop, and the effects on nematode control were additive (Tzortzakakis and Gowen 1994).

Fig. 12.8 Root-knot nematode and *Fusarium* wilt disease complex

Table 12.2 Effect of *Pseudomonas aeruginosa* and *Paecilomyces lilacinus* on growth and control of root disease complex of watermelon

Treatment	Plant height (cm)	Root-knot index	*Fusarium solani* infection percentage	*Fusarium oxysporum* infection percentage
Control	35.1	3.8	69	12
P. lilacinus (PL)	37.5	2.8	81	0
P. aeruginosa (PA)	35.0	1.5	69	0
PL + PA	38.5	1.5	44	0
Critical Difference (CD) ($P = 0.05$)	2.2	0.34	6.1	6.1

12.3 Watermelon, *Citrullus lanatus*

12.3.1 Diseases

12.3.1.1 Root-Knot Nematode, *M. javanica*, and Wilt, *F. solani*, Disease Complex (Fig. 12.8)

(i) Integrated Management

(a) Two Bioagents: *P. aeruginosa* and *P. lilacinus* when used together significantly reduced infection of *M. javanica* and *F. solani* in watermelon. *P. aeruginosa* and *P. lilacinus* used alone or together significantly ($P < 0.05$) reduced infection of root-knot nematode *M. javanica* and *F. solani* and *F. oxysporum* in watermelon. *P. aeruginosa* was more effective than *P. lilacinus* in reducing the *M. javanica* root-knot nematode infection (Perveen et al. 1998). Combined use of *P. lilacinus* and *P. aeruginosa* was more effective in reducing the infection of *F. solani* in watermelon than either used alone. Use of *P. aeruginosa* and *P. lilacinus* significantly ($P < 0.05$) increased plant height and fresh shoot weight in watermelon (Table 12.2).

12.3.2 Watermelon Pests and Diseases

(i) Integrated Management

(a) Bioagents and Chemicals: Seed treatment with thiamethoxam + Phule *Trichoderma* each at 5 g/kg was the most promising treatment against serpentine leaf miner (*Liriomyza trifolii*), thrips (*Thrips palmi*), bud necrosis disease and root rot disease in watermelon and registered highest fruit yield (17.722 t/ha), followed by imidacloprid + Phule *Trichoderma* at 5 + 5 g/kg (12.555 t/ha), imidacloprid at 5 g/kg (14.444 t/ha) and acetamiprid + Phule *Trichoderma* at 5 + 5 g/kg (12.555 t/ha), while untreated plots recorded significantly lower yield (8.333 t/ha).

12.4 Muskmelon, *Cucumis melo*

12.4.1 Diseases

12.4.1.1 Wilt, *Fusarium solani*

(i) Symptoms: On young seedlings, a hypocotyl rot and damping-off may occur. In older plants, there is marginal yellowing progressing

Fig. 12.9 *Fusarium* wilt of muskmelon

to a general yellowing of the older leaves, and wilting of one or more runners. In some cases, sudden collapse occurs without any yellowing of the foliage. On stems near the crown of the plant, a linear, necrotic lesion may develop, extending up the plant and usually on one side of the vine (Fig. 12.9). One runner on a plant may wilt and collapse, with the rest of the runners remaining healthy. A gummy, red exudate may ooze from these lesions. Vascular discolouration should be evident and is diagnostic (Fig. 12.9).

(ii) Integrated Management (a) Bioagents and Botanicals: *T. harzianum* and *Trichoderma viride* when applied as seed treatment (each at 5 g/kg) followed by soil application along with farmyard manure (FYM) or neem cake at 1 kg/basin were effective.

(b) Bioagents and Chemicals: Integration of *T. viride* T4-1 with carbendazim and KCl was most effective in reducing wilt as well as pathogen propagules in the soil and in root tissues besides increasing shoot and root length (Chattopadhyay and Sen 1996).

12.4.2 Nematodes

12.4.2.1 Root-Knot Nematode, *M. incognita*

(i) Symptoms: As *M. incognita* larvae enter the plant root, feed and mature, the surrounding cells of the plant root increase in size and divide causing galls on the roots (Fig. 12.10). The flow of nutrient and water is restricted, and plants wilt quickly when water becomes limiting. If plants are infected when young, they are often severely stunted and chlorotic. Infected vines rarely die, but are generally not productive.

Fig. 12.10 Root-knot nematode in muskmelon

(ii) Integrated Management (a) Cultural and Botanicals: Combination of crop rotation (sorghum in 2005 followed by melon in 2006 and 2007), biocidal intercropping (*Eruca sativa* cv. Nemat) and biofumigant treatments (pellet based on formulated defatted seed meals of *Brassica carinata*) was effective for the management of root-knot nematodes. The results showed that sorghum cultivation as a non-host crop halved the nematode population in the soil. The biofumigant treatment in spring 2006 caused a strong decrease in galling index (GI, based on a scale from 0 to 5) on the roots of the following melon crop in rotation (GI = 0.3) compared with the untreated control (GI = 4.2). These positive results were further confirmed in 2007, when an important increase in the quality and quantity was recorded in the yield of melon fruits. The autumn cultivation of *E. sativa* cv. Nemat and its incorporation into the soil brought a good amount of organic matter, with positive effects on melon yield. The intrinsic characteristics of the pellet based on *B. carinata* defatted seed meals in rotation with *E. sativa* highlighted an excellent biofumigant effect, fully

Table 12.3 Effect of soil solarization and sulphur on *Meloidogyne incognita* in cantaloupe

Sulphur (kg/ha)	Soil solarization	Crop yield (t/ha)	Final nematode population (eggs and J_2/mL soil)
–	–	12.6 ab	11.7 a
500	–	16.4 b	3.2 c
500	Polyethylene 0.050 mm	16.2 b	3.1 c
500	EVA 0.035 mm	19.0 bc	2.9 c
750	–	17.8 bc	4.3 c
750	Polyethylene 0.050 mm	20.4 c	2.6 c
750	EVA 0.035 mm	20.2 c	4.3 c
1,000	–	17.0 bc	3.7 c
1,000	Polyethylene 0.050 mm	20.4 c	3.4 c
1,000	EVA 0.035 mm	20.4 c	1.6 c
–	Polyethylene 0.050 mm	17.0 bc	2.1 c
–	EVA 0.035 mm	16.4 b	4.9 bc

Means followed by the same letters in the same column are not significantly different according to Duncan's multiple range test ($P=0.01$)

comparable with chemical nematicides, and a noticeable contribution in both organic matter and nitrogen that played an important fertilizing effect. The full effectiveness of pellet in decreasing the nematode population substantially suggests its application in alternate years with *Eruca* green manure, in the presence of low larval infestations in the soil (Curto et al. 2008).

(b) Physical and Chemicals: The yield of cantaloupe was significantly increased by soil solarization with or without sulphur and by sulphur as single treatment. The thickness of the polyethylene did not affect the yields, which were significantly increased by EVA 0.150 mm, compared with EVA 0.035 mm. The addition of either 750 or 1,000 kg/ha sulphur previously to soil solarization was beneficial compared with the polyethylene tarping only. The sulphur application under EVA tarping did not statistically increased the yield with respect to 500 kg/ha sulphur alone (Table 12.3). The nematode population was significantly suppressed by either solarization or sulphur treatments: No difference was found between the two films or among the sulphur dosages and no further suppression derived by the combined use of solarization and sulphur.

12.5 Bitter Gourd, *Momordica charantia*

12.5.1 Insect Pests

12.5.1.1 Fruit Fly, *Bactrocera cucurbitae*

(i) Damage: Fruit fly infestation causes oozing of resinous fluid from fruits, which become distorted and malformed. Maggots feed on fruit pulp (Fig. 12.11) causing premature dropping of fruits.

(ii) Integrated Management

(a) Bioagents and Chemicals: Application of 0.05 % acephate in combination with *Beauveria bassiana* at 1 mL commercial preparation/L of solution recorded lower level of infestation of fruit fly in bitter gourd (Maicykutty and Gopalakrishnan 2003). This botanical encouraged natural enemies, namely, *Pediobius foveolatus* and *Tetrastichus ovularum*.

12.5.1.2 Leaf Hopper, *Empoasca motti*

(i) Damge: Small 3–4-mm-long nymphs and adults are destructive, with the common hopper burn symptom on the leaves, sometimes shiny and brownish, causing premature death of the leaves.

(ii) Integrated Management

(a) Pathogens and Chemicals: Application of *Bacillus thuringiensis* (Dipel) at 1 mL/L of solution along with 0.05 % acephate gave satisfactory

Fig. 12.11 Fruit fly damage in bitter gourd fruits

control of leaf hoppers in bitter gourd (Maicykutty and Gopalakrishnan 2003).

12.5.1.3 Fruit Borer, *Eudioptis indica* (Fig. 12.12)

(i) Integrated Management (a) Bioagents and Chemicals: Weekly application of 0.05% acephate in combination with *B. bassiana* at 1 mL commercial preparation/L of solution recorded lower level of infestation of fruit borer (Maicykutty and Gopalakrishnan 2003).

Fig. 12.12 Fruit borer infestation in bitter gourd

12.6 Pointed Gourd, *Trichosanthes dioica*

12.6.1 Diseases

12.6.1.1 Stem and Fruit Rot, *Phytophthora cinnamomi*

(i) Symptoms: Infection usually starts at the middle portion of the fruits, which shrinks and dries up. If there is cloudy weather or rain or soil remains moist due to application of irrigation, white mycelial growth develops in the infected portion. After the start of monsoon, frequent rains and cloudy weather favour the spread of the disease, and more and more vines and fruits get affected. Affected tissues become water soaked and discoloured. In all cases, the affected area of the fruits is covered with white mycelial growth. During this phase, stem infection is also found mainly in the nodal region. During rainy days, oozing of sticky substances from diseased stem, leaf and fruit tissues are quite common, which usually takes places before the formation of mycelial growth.

(ii) Integrated Management (a) Bioagents and Botanicals: Singh et al. (2002) reported control of *P. cinnamoni* with certain organic amendments and *T. harzianum*.

12.6.2 Nematodes

12.6.2.1 Root-Knot Nematode, *M. incognita*

M. incognita is responsible for 30–40% loss in the yield of pointed gourd.

Table 12.4 Effect of integration of bioagents, neem cake and marigold as intercrop for the management of *Meloidogyne incognita* infecting pointed gourd

Treatment	Number of galls/5 g of root	Number of egg masses/5 g of root	Yield (kg/plant)
Neem cake (250 g) + *Paecilomyces lilacinus* (50 g) + *Trichoderma harzianum* (100 g) + marigold (three plants/pit)	10.4	30	8.5
P. lilacinus (50 g/pit)	15.3	53	6.4
Carbofuran (3 g/pit)	22.5	72	5.8
Neem cake (250 g/pit)	22.4	75	5.0
T. harzianum (100 g/pit)	25.6	45	4.2
Marigold (three plants/pit)	35.3	113	4.0
Control	80.4	186	1.3
Critical Difference (CD) (P = 0.05)	*3.5*	*9.6*	*0.5*

Table 12.5 Effect of bioagents, botanicals and chemicals for the management of *Meloidogyne incognita* infecting pointed gourd

Treatment	Gall index (0–5 scale)	Nematode population (J_2/200 mL of soil)	Yield (kg/12 m^2)
Vine dipping in 1,000 ppm monocrotophos for 6 h + organic matter at 20 t/ha	1.93	264	22.10
Vine dipping in 1,000 ppm monocrotophos for 6 h + vermicompost at 2 t/ha	1.78	232	25.53
Vine dipping in 1,000 ppm monocrotophos for 6 h + *Paecilomyces lilacinus* at 10 g/pit (two splits)	2.54	198	11.93
Vine dipping in 1,000 ppm monocrotophos for 6 h + *Trichoderma viride* at 10 g/pit in two split doses	1.75	162	33.80
Vine dipping in 1,000 ppm monocrotophos for 6 h + carbofuran at 1 kg a.i./ha	3.60	386	16.90
Vine dipping in 1,000 ppm monocrotophos for 6 h + neem cake at 500 kg/ha	2.16	280	17.43
Vine dipping in 1,000 ppm monocrotophos for 6 h alone	3.27	390	12.60
Untreated control	3.67	535	16.83
Critical Difference (CD) (P = 0.05)	*0.93*	–	*6.02*

(i) Symptoms: Root-knot nematodes attack the plant root, gall is formed in it, growth of plants is retarded, leaves become chlorotic, flower and fruit form late and the production is significantly reduced.

(ii) Integrated Management

(a) Cultural, Bioagents and Botanicals: Integration of *P. lilacinus* (50 g) + *T. harzianum* (100 g) + neem cake (250 g) + marigold as an intercrop (three plants/pit) increased plant growth parameters and yield (6.6 kg/plant compared with 1.4 kg/plant in control), and reduced root galling (14.3/5 g of root compared with 75.0/5 g of root in control), number of egg masses (40/5 g of root compared with 150/5 g of root in control) and final nematode population (66.6/100 g of soil compared with 86,660/100 g of soil in control; Verma et al. 2005; Table 12.4).

(b) Bioagents, Botanicals and Chemicals: Vine dipping in monocrotophos at 1,000 ppm for 6 h + soil application of *T. viride* at 10 g/pit in two split doses (once at planting and another at 40 days after planting (DAP)) reduced root galling caused by *M. incognita* and nematode population in soil and gave fruit yield almost double of the untreated plots (Khan et al. 2009; Table 12.5).

(c) Physical, Cultural, Chemicals and Botanicals: Integrated approaches, i.e. cultural control (deep ploughing followed by soil solarization

for 15 days and stubble burning) with or without minimum synthetic chemicals (2.0 or 3.0 kg a.i. carbofuran/ha) and with the inclusion of neem components like leaf, cake and azadirachtin, were highly effective for keeping in check the nematode population build-up and infection. The eco-friendly integrated treatments recorded very low final nematode population and good yield (Chakraborti 2000).

References

Bello, A. (1998). Biofumigation and integrated crop management. In A. Bello, J. A. Gonzalez, M. Arias, & R. Rodriguez-Kabana (Eds.), *Alternatives to methyl bromide for the southern European Countries* (pp. 99–126). Valencia: Phytoma-Espania, DG XI EU, CSIC.

Chakraborti, S. (2000). Management approaches for root knot nematode in pointed gourd. *Indian Journal of Nematology, 30*(2), 136–140.

Chattopadhyaya, C., & Sen, B. (1996). Integrated management of *Fusarium* wilt of muskmelon caused by *Fusarium oxysporum*. *Indian Journal of Mycology and Plant Pathology, 26*(2), 162–170.

Curto, G., Lazzeri, L., Dallavalle, E., & Santi, R. (2008). Management of Meloidogyne incognita (Kofoid et White) Chitw. in organic horticulture. Third International Biofumigation Symposium, Canberra.

Elad, Y., Zimand, G., Zaqs, Y., Zuriel, S., & Chet, I. (1993). Use of *Trichoderma harzianum* in combination or alternation with fungicides to control cucumber grey mould (*Botrytis cinerea*) under commercial greenhouse conditions. *Plant Pathology, 42*(3), 324–332.

Jakobsen, I. (1999). Effects of *Pseudomonas fluorescens* DF 57 on growth and P uptake of two arbuscular mycorrhizal fungi in symbiosis with cucumber. *Mycorrhiza, 8*, 319–334.

Kabayashi, N. (1989b). Suppression of *Rhizoctonia* and *Pythium* damping-off of cucumber by microorganisms in charcoal and VAM Fungi. In H. Hattori et al. (Eds.), *Research advances in microbial ecology* (pp. 242–246). Japan: Japan Scientific Press.

Khan, M. R., Bhattacharya, I., Chattopadhyay, S. B., & Ghosh, S. (2009). Integrated management of root-knot (*Meloidogyne incognita*) and other nematodes in pointed gourd (*Trichosanthes dioica*). *Indian Journal of Nematology, 39*(1), 25–28.

Lewis, J. A., & Papavizas, G. C. (1980). Integrated control of *Rhizoctonia* root rot of cucumber. *Phytopathology, 70,* 85–89.

Maicykutty, P. M., & Gopalakrishnan, T. R. (2003). Eco-friendly management of major pests of bitter gourd. In S. Ignacimuthu & S. Jayaraj (Eds.), *Biological control of insect pests* (pp. 192–196). New Delhi: Phoenix Publishing House Pvt. Ltd.

Perveen, S., Ehteshamul-Haque, S., & Ghaffar, A. (1998). Efficacy of *Pseudomonas aeruginosa* and *Paecilomyces lilacinus* in the control of root rot-root knot disease complex on some vegetables. *Nematologia Mediterranea, 26,* 209–212.

Singh, R. S., Singh, P. P., & Bedi, J. S. (2002). *Final report of DBT scheme on biocontrol of seed and soil-borne diseases of vegetables*. (90 pp) Ludhiana: Punjab Agricultural University.

Tzortzakakis, E. A., & Gowen, S. R. (1994). Evaluation of *Pasteuria penetrans* alone and in combination with oxamyl, plant resistance and solarization for control of *Meloidogyne* spp. on vegetables grown in greenhouses at Crete. *Crop Protection, 13,* 455–462.

Verma, A. C., Singh, H. K., & Khan, N. (2005). Management of root-knot nematode, *Meloidogyne incognita* through antagonistic approaches in pointed gourd. *Indian Journal of Nematology, 35,* 78–79.

Leafy Vegetable Crops

13

13.1 Lettuce, *Lactuca sativa*

13.1.1 Diseases

13.1.1.1 White Mold, *Sclerotinia sclerotiorum*

(i) Symptoms The cool, moist conditions in the solar greenhouses in winter were perfect for white mold infection. The growing fungus would deposit hard black bodies, called sclerotia, on the soil surface. Some sclerotia would quickly sprout into tiny mushrooms (Fig. 13.1) that spread millions of spores throughout the greenhouses, infecting even more lettuce plants. Others would settle into the soil, where they might sit for years before sprouting mushrooms or infecting plant roots. The fungus can also grow directly from sclerotia, infecting plant roots.

(ii) Integrated Management

(a) Biofumigation and Solarization: On-farm trails were conducted to monitor the effects of biofumigation and soil solarization on *S. sclerotiorum*. This study suggests that a month of summer soil solarization can control populations of *S. sclerotiorum* to a depth of 15 cm in Kentucky high tunnels. The effect was seen in both at the middle and at the edge of solarized plots. Biofumigation, by incorporating a mixture of *Brassicae juncea* leaves and stems at a rate of 900 g/m^2, did not reduce germination of *S. sclerotiorum* sclerotia (Fig. 13.2).

13.1.2 Nematodes

13.1.2.1 Root-knot Nematodes, *Meloidogyne incognita, M. hapla*

(i) Symptoms Root-knot nematodes feed within the roots and cause characteristic swelling galls on roots (Fig. 13.3). The northern root-knot nematode, *M. hapla* generally occurs in cooler regions than the other three *Meloidogyne* species that prefer hot summer climates. Galls formed by *M. hapla* are spherical, distinct and generally smaller than those caused by the three 'warm-climate' species. Plants infested as seedlings may be stunted, with patches of stunted plants becoming evident by mid-season. The root-knot nematode causes large decreases in yield of lettuce.

(ii) Integrated Management

(a) Biofumigation, Soil Solarization and Bioagents: Biofumigation with mustard under black polythene for 30 days followed by soil application of *Pseudomonas fluorescens* at 2.5 kg/ha at the time of planting was on par with carbofuran at 1 kg a.i./ha in reducing the root-knot nematode population by 76.39 % and increased the lettuce leaf yield by 23.29 %.

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_13, © Springer India 2014

Fig. 13.1 *Left*—A bed of young lettuce plants infested with white mold, caused by the fungus *Sclerotinia sclerotiorum*. *Right*—Sclerotia sprout into tiny mushrooms that spread *S. sclerotiorum* spores

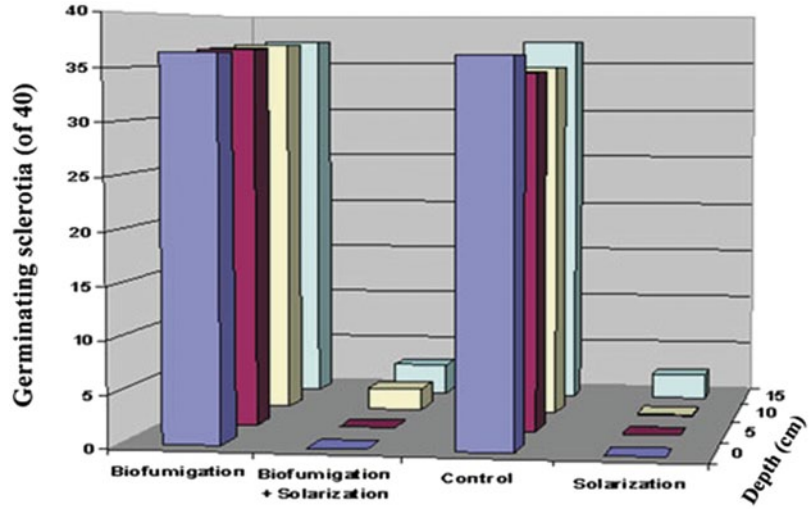


Fig. 13.2 The graph clearly shows that solarization was almost completely lethal to *S. sclerotiorum* to 15 cm, and that biofumigation had no effect on the fungus

Fig. 13.3 Root-knot nematode on lettuce

Fig. 13.4 Yellowing of ferns on *Fusarium*-infected asparagus plant

Fig. 13.5 Fruit fly on drumstick

Table 13.1 Impact of IPM components on fruit fly infestation and yield of drumstick

IPM module[a]	Fruit fly infestation (%)	Reduction over control (%)	Fruit yield (MT/ha)	Increase over control (%)
A—Components 1, 2, 3, 4	4.67	93.06	39.390	93.06
B—Components 2, 3, 4	7.33	89.11	38.291	89.11
C—Components 1, 6, 3, 4	5.67	91.58	38.977	91.59
D—Components 5, 2, 7, 4	7.33	89.11	38.291	89.11
E—Components 1, 6, 7, 4	6.00	91.09	38.840	91.09
F—Components 5, 2, 3 ,4	5.00	92.57	39.254	92.58
Control—without any treatment	67.33	0.00	13.499	0.00

[a] Components: 1 Application of Fenthion 80 Emulsifiable Concentrate (EC) 0.04% at vegetative and flowering stage; 2 Application of Nuvan 76 Water Soluble Concentrate (WSC) 0.04% at 50% fruit set and 35 days later; 3 Soil application of Endosulfan 4D (200 g/tree) at 50% fruit set; 4 Removal of affected fruits regularly at weekly intervals; 5 Application of Nimbecidine 0.03% at 60 ppm concentration during vegetative and flowering stage; 6 Application of Nimbecidine 0.03% at 150 ppm concentration during 50% fruit set and 35 days later; 7 Soil application of neem seed kernel extract 4% at 2 L/tree during 50% fruit set

13.2 Asparagus, *Asparagus officinalis*

13.2.1 Diseases

13.2.1.1 Wilt, *Fusarium oxysporum* f. sp. *asparagi*

(i) Symptoms Mature plants infected with *Fusarium* gradually decline in productivity and growth. During the summer, infected plants are characterized by one-to-several stunted, bright *yellow ferns* (Fig. 13.4). A *reddish brown vascular discolouration*, which may extend into the crown, is present at the base of stalks infected by *F. oxysporum* f. sp. *asparagi*. Crowns and below-ground portions of stems exhibit reddish flecks or sunken brown lesions, which can be seen by cutting them open. Reddish brown, elliptical lesions occur on storage roots of infected plants. Feeder roots, most of which may be rotted off completely, show reddish brown discolouration.

(ii) Integrated Management

(a) Arbuscular Mycorrhizal Fungi (AMF) and Botanicals: Addition of charcoal or manure of coffee residue to bed soil is effective for increasing the tolerance to *Fusarium* root rot in AMF-infected asparagus plants (Matsubara et al. 2002).

13.3 Drumstick, *Moringa oleifera*

13.3.1 Insect Pests

13.3.1.1 Fruit Fly, *Gitona distigma*

(i) Damage Fruit fly (Fig. 13.5) maggots cause drying and splitting of fruits from tip and oozing of gummy exudate from fruit.

(ii) Integrated Management

(a) Cultural, Botanicals and Chemicals: Integration of botanicals (Nimbecidine, neem seed kernel extract (NSKE)), chemicals (Fenthion, Nuvan, Endosulfan) and cultural methods (removal of affected fruits regularly) (Modules A–F) were effective in reducing the fruit fly infestation and in increasing the fruit yield of drumstick (Raghumoorthi and Armugam 1992; Table 13.1).

(b) Cultural, Botanicals, Resistant Cultivars and Chemicals: Application of Fenthion 0.04% during vegetative and flowering stage, spraying of Nimbecidine 0.03% at 150 ppm during 50% fruit set and 35 days after, soil application of NSKE 5% at 2 L/tree in soil during 50% fruit set and removal of affected fruits are recommended along with the use of resistant accessions such as MT_{18}, MT_{26} and MT_{28}.

References

Matsubara, Y., Hasegawa, N., & Fukui, H. (2002). Incidence of Fusarium root rot in asparagus seedlings infected with arbuscular mycorrhizal fungus as affected by several soil amendments. *Journal of the Japanese Society for Horticultural Science, 71,* 370-374.

Raghumoorthi, K.N., & Armugam, R. (1992). Control of moringa fruitfly *Gitona* sp., and leaf caterpillar *Noorda blitealis* with insecticides and botanicals. *Indian Journal of Plant Protection, 20,* 61–65.

Part IV

Biointensive Integrated Pest Management in Ornamental, Medicinal, Aromatic and Tuber Crops

Ornamental Crops

14

14.1 Rose, *Rosa* spp.

14.1.1 Diseases

14.1.1.1 Black Spot, *Marssonina rosae* (syn. *Diplocarpon rosae*)

(i) Symptoms: This disease is more of a problem in open-field cultivation. The characteristic symptom of the disease is the appearance of leaf spotswhich are coal-black, circular or irregular with black margins and yellow halos (Fig. 14.1). The spots develop on either side of the leaf. Symptoms first appear on older leaves on the lower portion of plant causing severe defoliation, reducing yield and the size of flowers. On close examination with a hand lens, the spots show small, black blister-like fruiting bodies of the fungus. Continual *defoliation* will cause weakness, *dieback* or death of the plant. Some very susceptible species may have stems affected with a considerable reduction in plant *vigour*.

The pathogen can survive in canes. Spores are spread by wind and water-splash.

(ii) Integrated Management (a) Bioagents and Chemicals: Evaluation of fungal biocontrol agents (*Trichoderma harzianum, Chaetomium globosum*) and fungicides (chlorothalonil, mancozeb) either alone or in combination against black spot on rose revealed that at 100 days after first spray, lowest defoliation rating was recorded in chlorothalonil, *T. harzianum* + chlorothalonil and *T. harzianum* + mancozeb treatments (1.00). The highest vigour index was recorded in *T. harzianum* treatment, while the highest flower yield was recorded in *C. globosum* + chlorothalonil (4.33) followed by *T. harzianum* alone and *T. harzianum* + chlorothalonil treatments (4.00; Prasad et al. 2002).

14.1.2 Nematodes

14.1.2.1 Root-Knot Nematodes, *Meloidogyne* spp.

(i) Symptoms: Nematodes of the genus *Meloidogyne* attack the roots of a wide range of plants including roses. The damaged root system develops root-knots (Fig. 14.2), which cause slow growth, wilting and yellowing of leaves. Nematodes are spread by introducing infested plants or soil to the field, and also can be carried on garden tools.

(ii) Integrated Management (a) Bioagents, Botanicals and Chemicals: Pre-plant treatment of soil with dazomet (at 25 g/m^2) followed by soil amendment with neem cake (at 1 kg/m^2) along with *Pochonia chlamydosporia* (2×10^{10} spores/m^2) recorded reduced root galling and increased flower yield (Nagesh and Janakiram 2004; Table 14.1).

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_14, © Springer India 2014

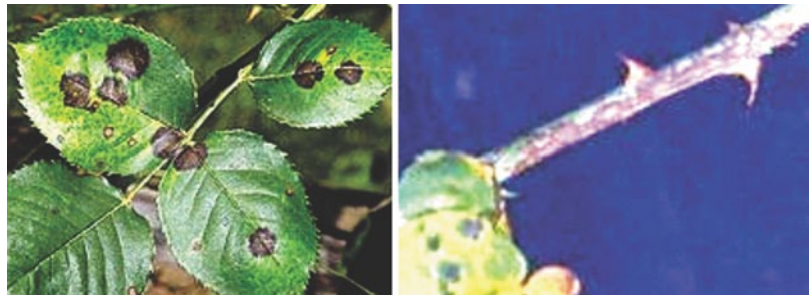


Fig. 14.1 Black spots on rose leaves and stem

Fig. 14.2 *Meloidogyne* sp. damage on rose roots

Table 14.1 Integrated management of root-knot nematode on rose

Treatment (dose/m^2)	Root gall index (1–5 scale)	Plant mortality (%)	% Increase in flower yield
Dazomet (40 g)	1.8	18	14.0
Neem cake (1 kg) + *Pochonia chlamydosporia* (2×10^{12} spores)	1.7	14	15.5
Dazomet (40 g) + *P. chlamydosporia* (2×10^{12} spores)	0.6	10	18.0
Neem cake (1 kg) + Dazomet (40 g) + *P. chlamydosporia* (2×10^{12} spores)	0.2	8	24.5
Control	3.0	40	–
Critical Difference (CD) (P = 0.05)	*0.19*	*3.11*	–

14.2 Carnation, *Dianthus caryophyllus*

14.2.1 Diseases

14.2.1.1 Wilt, *Fusarium oxysporum* f. sp. *dianthi*

(i) Symptoms: The initial symptoms are foliar yellowing and production of 'crook neck' or bent shoots (Fig. 14.3). The leaves and shoots wither and become brownish. Initially the symptoms are confined to a few branches or a part of the plant but ultimately the entire plant shows the symptoms. The symptoms are first noticed during mid-day when the temperature is quite high inside the polyhouses, but they are not visible when the temperature goes down. Stems when cut open show brown discolouration at the vascular region. Sometimes pith and cortex also get discoloured. Finally, the stems show shredding of the internal tissue.

The disease spreads through contaminated planting material as young rooted cuttings carry the pathogen without expressing the symptoms. Spread of the disease within the greenhouse occurs through root contacts, contaminated soil carried by workers and implements.

(ii) Integrated Method (a) Bioagents and Physical/Chemical: Martinez and Pinzon (1999) reported that the application of *T. harzianum* immediately after steam treatment or chemical disinfestation of soil prevented the rapid reinfestation of the soil by *F. oxysporum* f. sp. *dianthi*. By this treatment, it was possible to grow susceptible varieties of spray carnations in areas heavily infested with *Fusarium* wilt.

Fig. 14.3 *Fusarium* wilt on carnation

Fig. 14.4 Root galling on carnation due to root-knot nematodes

Fig. 14.5 Management of root-knot nematodes on carnation by integration of bioagents and botanicals. *Left*—untreated, *right*—treated

14.2.2 Nematodes

14.2.2.1 Root-Knot Nematode, *Meloidogyne incognita*

The root-knot nematode is one of the serious limiting factors in commercial cultivation of carnation under polyhouse conditions.

(i) Economic Importance: Nagesh and Reddy (2000) reported that *M. incognita* was responsible for 27% loss in flower yield of carnation. Most of the highly fetching exotic cultivars of carnation from Europe have shown 40–60% mortality in polyhouse beds due to root-knot nematode infection in and around Bangalore (Nagesh and Reddy 1996a).

(ii) Symptoms: The root-knot infected carnation plants exhibit stunted growth, leaf yellowing and premature dropping and root galling (Fig. 14.4).

(iii) Integrated Management

(a) Bioagents and Botanicals/Chemicals: Integration of neem cake at 0.5 kg/m^2 with *Trichoderma viride* at 100 g/m^2 was effective for the management of root-knot nematodes and increased flower yields.

Integration of *Paecilomyces lilacinus/T. harzianum* at 0.5 L/m^2 (aqueous spore suspension containing 2×10^4 spores/mL) with neem cake at 0.5 kg/m^2 or fenamiphos at 2 g a.i./m^2 increased plant growth parameters and flower yield of carnation. The above treatments also increased root-knot egg parasitization by the parasitic fungi (Nagesh and Parvatha Reddy 1996a; Fig. 14.5).

Three antagonistic fungi viz., *T. harzianum, Verticillium lecanii* and *P. lilacinus* at 2×10^4 spores/mL in combination with neem cake reduced *M. incognita* population in both soil and roots of carnation.

Application of *P. lilacinus* at 0.5 g/kg of soil along with neem cake at 1.0 MT/ha efficiently suppressed the nematode population and checked its build up, enhancing the plant growth parameters resulting in better flower production with increased flower stalk length and flower diameter in carnation. The plants also came to flowering early (Nirmal Johnson 2000).

Table 14.2 Integrated management of root-knot nematode on carnation

Treatment (dose/$m^{2)}$	Root gall index	Plant mortality (%)	Stem length (cm)	No. of flowers/m^2
Dazomet (40 g)	2.0	32	96.0	42.5
Carbofuran (10 g)	3.2	30	92.0	40.0
Carbosulfan (1 L of 0.03 %)	2.2	33	96.5	47.5
Chlorpyriphos (1 L of 0.03 %)	2.4	38	95.0	45.5
Neem cake (1 kg) + *Paecilomyces lilacinus* (2×10^{12} spores)	2.8	31	95.5	43.0
Neem cake (1 kg) + *P. chlamydosporia* (2×10^{12} spores)	2.8	29	98.0	46.0
Dazomet (40 g) + neem cake (1 kg) + *P. lilacinus* (2×10^{12} spores)	1.6	11	104.8	63.0
Dazomet (40 g) + *P. chlamydosporia* (2×10^{12} spores)	0.4	12	116.0	68.5
Control	4.2	52	75.5	37.5
Critical Difference (CD) (P = 0.05)	*0.18*	*1.84*	*3.43*	*1.66*

(b) Bioagents and Arbuscular Mycorrhizal Fungus (AMF): Combined inoculation of AMF and *Pseudomonas fluorescens* had positive effect on root-knot nematode control on carnation (Anusuya and Vadivelu 2002).

(c) Bioagents, Botanicals and Chemicals: Pre-plant treatment of beds with dazomet (40 g/m^2) followed by the application of neem cake (at 1 kg/m^2 15 days later) along with antagonistic fungi, *P. chlamydosporia/P. lilacinus* (at 2×10^{12} spores/m^2) significantly reduced root-knot nematode population (*M. incognita*), mortality of plants and suppressed the nematode infection for 2 years in carnation. The antagonistic fungi established better in the beds treated with dazomet. The above treatment also reduced root galling, nematode multiplication rate, and increased spike/stem length, flower yield and root colonization with the bioagents (Nagesh and Parvatha Reddy 2005; Table 14.2).

14.2.2.2 Root-Knot Nematode, *M. incognita* and Wilt, *F. oxysporum* f. sp. *dianthi* Disease Complex

(i) Symptoms: In an experiment carried out to study the role of root-knot nematode, *M. incognita* in predisposing carnation to *Fusarium* wilt, it was observed that when both pathogens were simultaneously inoculated the root galling index (RGI) was 3.1, while prior inoculation of *F. oxysporum* showed a RGI of 2.8. When *M. incognita* was inoculated alone the RGI was 3.5, while prior inoculation of *M. incognita* recorded an RGI of 4.15, 12 weeks after inoculation.

The appearance of the wilt symptoms were accelerated when *M. incognita* was inoculated 2 weeks prior to *F. oxysporum* f. sp. *dianthi*. The rate of wilting was observed to be 4.6, while the RGI value was recorded to be 4.75 during the 25th week of observation. It was observed that maximum plant mortality was recorded when *M. incognita* was inoculated 2 weeks prior to *F. oxysporum* f. sp. *dianthi*, which was 79.2 % at 25th week of observation. The plant growth parameters (plant height, plant weight) were also reduced significantly due to prior inoculation of *M. incognita* (Table 14.3; Shylaja 2004).

(ii) Integrated Management (a) Two Bioagents: The studies carried out to evaluate combination of bioagents for the biological control of wilt (*F. oxysporum* f. sp. *dianthi*) and root-knot nematode (*M. incognita*) disease complex in carnation revealed that a combination of *P. chlamydosporia* + *P. lilacinus* each at 20 g/m^2 gave significant increase in plant height and flower yield (stalk length, stalk weight). The lowest root galling (1.64) and wilting index (2.0) and plant mortality (49.5 %) was found in plants treated with *P. chlamydosporia* and *P. lilacinus* (Table 14.4; Shylaja 2004).

Table 14.3 Effect of interaction of *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *dianthi* on wilt disease complex on carnation cv. Ivonne

Treatment	Root-knot index[a]	Wilt disease index[b]	% Plant mortality	Plant height (cm)	Plant weight (g)
M. incognita	8.2	0.0	14	44.0	28.56
F. oxysporum f. sp. *dianthi*	0.0	2.5	45	40.0	27.80
M. incognita + *F. oxysporum* f. sp. *dianthi* (simultaneous inoculation)	7.4	3.3	63	22.4	25.88
M. incognita 2 weeks prior to *F. oxysporum* f. sp. *dianthi*	9.5	4.6	80	32.8	28.78
F. oxysporum f. sp. *dianthi* 2 weeks prior to *M. incognita*	7.0	2.3	40	17.4	21.5
Uninoculated control	0.0	0.0	0	71.4	62.58
Critical Difference (CD) (P=0.05)	*0.42*	*0.18*	*7.56*	*7.56*	*3.73*

[a] *Root-knot index 1–10 scale*
[b] *Wilt disease index 1–5 scale*

Table 14.4 Effect of biocontrol agents on the plant growth and flower yield of carnation infected with *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *dianthi*

Treatment	Plant height (cm)	Stalk length (cm)	Stalk weight (g)	Root galling index	Wilt disease index	Plant mortality (%)
Formulations of *Pochonia chlamydosporia* and *Paecilomyces lilacinus* each at 20 g/m^2	54.0	48.8	17.24	1.64	2	49.5
Formulations of *P. chlamydosporia* and *Trichoderma harzianum* each at 20 g/m^2	52.2	43.4	15.90	2.70	3	60.4
Formulations of *T. harzianum* and *P. lilacinus* each at 20 g/m^2	47.8	39.2	14.66	2.17	3	63.9
Control	22.8	17.6	10.82	3.66	5	95.8
Critical Difference (CD) (P=0.05)	*5.16*	*4.54*	*2.01*	*0.82*	*0.53*	*10.46*

14.3 Gerbera, *Gerbera jamesonii*

14.3.1 Diseases

14.3.1.1 Foot Rot, *Pythium* spp., *Sclerotium rolfsii, Rhizoctonia solani*

(i) Symptoms: The plants show reduced growth, smaller leaves and flowers with weak stems. Leaves show purple discolouration, with rotting of both feeder and main roots.

(ii) Integrated Management

(a) Bioagents and Botanicals: Soil application of farm yard manure (FYM) along with *T. harzianum* is helpful for initial suppression of the disease.

14.3.2 Nematodes

14.3.2.1 Root-Knot Nematode, *Meloidogyne incognita*

The root-knot nematode, *M. incognita* is one of the serious limiting factors in commercial cultivation of *Gerbera* under polyhouse conditions.

(i) Economic Importance: Nagesh and Reddy (2000) reported that *M. incognita* was responsible for 31% loss in flower yield of *Gerbera*. Most of the highly fetching exotic cultivars of *Gerbera* from Europe have shown 40–60% mortality in polyhouse beds due to root-knot nematode infection in and around Bangalore (Nagesh and Parvatha Reddy 1996a).

Table 14.5 Integrated management of root-knot nematode on *Gerbera*

Treatment (Dose/m^2)	Root gall index	Plant mortality (%)	Spike length (cm)	No. of flowers/m^2
Dazomet (40 g)	1.8	28	66.5	44.0
Carbofuran (10 g)	2.9	32	60.8	42.5
Carbosulfan (1 L of 0.03 %)	1.8	30	65.5	44.0
Chlorpyriphos (1 L of 0.03 %)	2.0	25	63.5	42.5
Neem cake (1 kg) + *Paecilomyces lilacinus* (2×10^{12} spores)	2.6	25	62.0	43.0
Neem cake (1 kg) + *Pochonia chlamydosporia* (2×10^{12} spores)	2.6	28	64.2	44.0
Dazomet (40 g) + neem cake (1 kg) + *P. lilacinus* (2×10^{12} spores)	1.4	15	72.5	55.5
Dazomet (40 g) + *P. chlamydosporia* (2×10^{12} spores)	0.4	12	75.9	58.0
Control	3.8	40	48.5	40.5
Critical Difference (CD) (P = 0.05)	*0.11*	*4.11*	*4.41*	*5.11*

(ii) Symptoms The root-knot infected *Gerbera* plants exhibit stunted growth, leaf yellowing and premature dropping and root galling.

(iii) Integrated Management (a) Bioagents, Botanicals and Chemicals: Pre-plant treatment of beds with dazomet (40 g/m^2) followed by the application of neem cake (1 kg/m^2 15 days later) along with antagonistic fungi, *P. chlamydosporia/P. lilacinus* (2×10^{12} spores/m^2) significantly reduced root-knot nematode population (*M. incognita*), mortality of plants and suppressed the nematode infection for 2 years in *Gerbera*. The antagonistic fungi established better in the beds treated with dazomet. The above treatment also reduced root galling and plant mortality, and increased spike length and flower yield with the bioagents (Nagesh and Reddy 2005; Table 14.5).

14.3.2.2 Root-Knot Nematode, *M. incognita* and Foot Rot, *Phytophthora parasitica* Disease Complex

(i) Symptoms: Sustainable production of *Gerbera* is seriously hampered by the disease complex caused by *M. incognita* and *P. parasitica*. These two pathogens reduce the productivity of *Gerbera* significantly to the tune of 40–60 %.

(ii) Integrated Management (a) Bioagents and Botanicals: Combined application of neem cake enriched with either *T. harzianum* or *P. fluorescens* [mixing 50 g of *T. harzianum* (2×10^6 cfu/g) or *P. fluorescens* (2×10^8 cfu/g) in 1 kg of neem cake] applied at 25 g/m^2 was found effective for the management of disease complex and increased the flower yield by 26 % in *Gerbera* cv. Debora (Manoj Kumar et al. 2010).

14.4 Tuberose, *Polianthes tuberosa*

14.4.1 Diseases

14.4.1.1 Leaf Spot/Blight, *Alternaria polyantha*

(i) Integrated Management (a) Two Bioagents: Treatment with *T. harzianum* and *P. fluorescens* at 4 g/kg tuber and seedling dip in *T. harzianum* suspension before planting resulted in effective control of blight and increased the plant vigour.

14.4.2 Nematodes

14.4.2.1 Root-Knot Nematode, *M. incognita*

M. incognita, Meloidogyne javanica and *Meloidogyne arenaria* have been reported as the major limiting factors in successful tuberose cultivation in Tamil Nadu (Sundarababu and Vadivelu 1988), while *M. incognita* and *M. javanica* were

Fig. 14.6 Root-knot nematode on tuberose

potential pests in Karnataka (Khan and Parvatha Reddy 1992).

(i) Economic Importance: *M. incognita* was responsible for 13.25, 9.87, 14.30, 13.78 and 28.58% reduction in plant weight, number of flowers, spike length, spike weight and number of bulblets, respectively (Khan and Parvatha Reddy 1994).

(ii) Symptoms: Affected plants exhibit stunting, yellowing and drying up of leaves and rotting of bulbs (Jayaraman et al. 1975). Further, the emergence of side shoots from the bulbs was also affected and the numbers were conspicuously less. In severely infected plants, the emergence of spike is suppressed and 65% reduction in top growth occurred (Sundarababu and Vadivelu 1988). Conspicuous galls can be observed on the root system (Fig. 14.6).

(iii) Integrated Management

(a) Bioagents and Botanicals: Split application (at planting and 45 Days after Planting (DAP)) of neem cake at 1 kg/1.5 m^2 in combination with *P. lilacinus* (25 g/1.5 m^2 containing 18×10^8 spores/g) significantly reduced root galling. The above treatment also significantly increased number of spikes, and parasitization of egg masses by *P. lilacinus* (Nagesh et al. 1998; Table 14.6).

Treatment of tuberose bulbs with neem cake extract mixed with *P. lilacinus* spores significantly reduced *M. incognita* infection and multiplication besides stimulating the plant growth. Soil application of neem cake enriched with *T. harzianum* at 1 MT/ha is also effective. Treatment of tuberose bulbs with neem and calotropis leaf extracts mixed with *P. lilacinus* spores significantly reduced *M. incognita* infection and multiplication besides stimulating the plant growth (Nagesh et al. 1997).

(b) Botanicals, AMF and Chemicals: Integration of AMF (*Glomus mosseae, Glomus fasciculatum*), a botanical (neem cake) and a nematicide (Aldicarb) gave effective management of *M. incognita* and increased plant growth and yield of bulbs (Khan and Reddy 1994) (Table 14.7).

(c) Two Bioagents: Combined application of *P. chlamydosporia* + *T. harzianum* gave significantly higher control of *M. incognita* on tuberose (Shylaja et al. 2004). Soil application of *T. harzianum* (10^9 cfu/g) + *P. lilacinus* (10^6 cfu/g) gave effective control of root-knot nematodes.

14.4.2.2 Bud and Leaf Nematode, *Aphelenchoides besseyi*

Foliar nematode, *A. besseyi* emerged as a serious problem in tuberose reported from Ranaghat areas of Nadia district of West Bengal. *A. besseyi* is becoming a major limiting factor for cultivation of tuberose in Ranaghat, Haringhata and Panskura areas of West Bengal. The 'Calcutta Single' cultivar of tuberose is more vulnerable to *A. besseyi* than the 'Calcutta Double' cultivar. Research results confirmed that *A. besseyi* is the primary causal agent for malformed flowers (Khan 2001).

(i) Symptoms: Infected flower stalk initially appears rough, stalk becomes crinkled, stunted and finally distorted and in severe cases flower buds failed to bloom. Brown streaks appear on leaf bracts and petals and subsequently develop into rusty brown spots. The severely infected flower stalk becomes rotten and brittle over drying, even gets blind and the number of flowers per stalk is also reduced. The nematode forms 'nematode wool' upon dark brown spots. The ovary contains large number of nematodes. This nematode is

Table 14.6 Effect of split application of oil cakes and *Paecilomyces lilacinus* on root galling, spike yield and propagule density on tuberose infected with *Meloidogyne incognita*

Treatment (dose/1.5 m^2)		Root-knot index	No. of spikes/1.5 m^2	% Egg mass parasitization by *P. lilacinus*
At planting	45 Days after Planting (DAP)			
Control	–	4.2	34	–
P. lilacinus (25 g) + castor cake (1 kg)	*P. lilacinus* (25 g) + castor cake (1 kg)	3.0	55	32.3
P. lilacinus (25 g) + karanj cake (1 kg)	*P. lilacinus* (25 g) + karanj cake (1 kg)	2.4	56	40.3
P. lilacinus (25 g) + neem cake (1 kg)	*P. lilacinus* (25 g) + neem cake (1 kg)	1.8	69	48.9
Carbofuran (2 kg a.i./ha)	–	3.2	45	–
Critical Difference (CD) (P = 0.05)		*0.26*	*4.82*	*5.22*

Table 14.7 Effect of integration of *Glomus mosseae, Glomus fasciculatum*, neem cake and Aldicarb on root galling, plant growth and bulb weight of tuberose infected with *Meloidogyne incognita*

Treatment	Dose	Plant weight (g)	Root-knot index	Bulb weight (g)
G. mosseae + aldicarb	100 spores/100 g soil + 0.5 kg a.i./ha	7.99	2.0	2.3
G. fasciculatum + aldicarb	100 spores/100 g soil + 0.5 kg a.i./ha	9.53	2.6	1.7
G. mosseae + neem cake	100 spores/100 g soil + 0.5 kg a.i./ha	5.46	2.5	2.8
G. fasciculatum + neem cake	100 spores/100 g soil + 0.5 kg a.i./ha	9.96	2.4	2.5
G. mosseae + aldicarb + neem cake	100 spores/100 g soil + 0.5 kg a.i./ha + 0.5 MT/ha	11.80	1.5	2.8
G. fasciculatum + aldicarb + neem cake	100 spores/100 g soil + 0.5 kg a.i./ha + 0.5 MT/ha	7.43	2.2	0.9
Control	–	3.26	4.5	1.1
Critical Difference (CD) (P = 0.05)	–	*1.35*	*0.18*	*0.50*

generally more serious during rainy season from June to September and cent per cent loss of the second year crop of the 'Calcutta Single' cultivar of tuberose is encountered. However, in 'Calcutta Double' cultivar 30–40% flower stalk renders unsalable and individual flower stalk harbours up to 45,000 nematodes (Khan and Pal 2001). In 'Calcutta Single', the yield loss may occur to the extent of 59% (Pathak and Khan 2008). The presence of nematode species in the cut flower and stalk is a constraint in export of flowers to other countries of the world for pest risk.

Infested bulbs harbour nematode in coiled anhydrobiotic condition (quiescent pre-adult and adult stages) in the scaly leaves outside the bulbs. The nematode can also survive in the dried scaly leaves, stems and flowers more than 25 months; however, they cannot survive in soil for long time (Khan and Ghadipur 2004; Khan 2006).

(ii) Integrated Management (a) Physical and Chemical: Pre-soaking of tuberose bulbs in water overnight followed by hot water treatment at 50 °C for 20 min + spraying of the crop twice with monocrotophos 36 Emulsifiable Concentrate (EC) at 0.15% (at sprouting and 30 days after first spray) in the first year and three sprays in second and third year crop at 15–20 days interval was found most effective in reducing percent nematode infestation as well as disease indices (Khan et al. 2004).

Table 14.8 Effect of interaction of *Meloidogyne incognita* with *Fusarium oxysporum* f. sp. *dianthi* on flower yield of tuberose

Treatment	Days for spike emergence	Number of spikes/plot	Spike length (cm)	Days for first flowering
F. oxysporum f. sp. *dianthi* at 10 mL (10^2 spores/mL)	63.00	17.33	74.33	74.00
M. incognita at 50 J_2/100 cm^3 soil	62.33	18.00	69.33	72.33
M. incognita at 100 J_2/100 cm^3 soil	65.07	17.00	63.67	75.33
M. incognita at 150 J_2/100 cm^3 soil	68.33	13.67	62.67	77.67
F. oxysporum f. sp. *dianthi* at 10 mL+*M. incognita* at 50 J_2/100 cm^3 soil	74.67	13.33	61.33	85.33
F. oxysporum f. sp. *dianthi* at 10 mL+*M. incognita* at 100 J_2/100 cm^3 soil	76.00	12.50	59.33	89.33
F. oxysporum f. sp. *dianthi* at 10 mL+*M. incognita* at 150 J_2/100 cm^3 soil	81.00	11.00	56.67	89.67
Control	60.67	24.00	80.67	72.00
Critical Difference (CD) (P=0.05)	*4.00*	*2.31*	*5.85*	*4.33*

14.4.2.3 Root-knot Nematode, *M. incognita* and Wilt, *F. oxysporum* f. sp. *dianthi* Disease Complex

(i) Symptoms: Rao et al. (2002b) reported that root-knot nematodes accelerate and increase *Fusarium* wilt symptom development and ultimately increase the death rate of tuberose plants infected with both the pathogens. The fungal infection was observed to aggravate in the presence of *M. incognita*.

The root-knot nematode, *M. incognita* reduced flower yield considerably and the tuberose plants became highly susceptible to the attack by *F. oxysporum* f. sp. *dianthi* (Rao et al. 2002b).

In an experiment undertaken to assess the impact of different densities of root-knot nematodes inducing *Fusarium* wilt-root knot disease complex on the flower yield of tuberose, it was observed that the spike emergence was significantly delayed (65.07 and 68.33 days) due to the high population levels of nematodes at 100 and 150/100 cm^3 soil. The longest delay in spike emergence (81 days) was recorded when *Fusarium* was present along with the highest density of nematodes at 150/100 cm^3 soil. It was observed that the disease complex drastically reduced the yield of flowers in tuberose, thereby bringing down the production of flowers in this commercial crop. It was found that the damage was maximum in the presence of both pathogens viz., *M. incognita* and *F. oxysporum* f. sp. *dianthi*, when compared to the presence of either one of these pathogens (Table 14.8; Shylaja 2004).

(ii) Integrated Management

(a) Two Bioagents: In course of the experiments carried out to evaluate combination of bioagents for the control of wilt and root-knot nematode disease complex in tuberose, the best result was obtained in plants treated with *P. chlamydosporia* + *T. harzianum* (Rao et al. 2003). The above treatment gave significant reduction in root galling, nematode population both in soil and roots, disease index, and increased egg parasitization and root colonization of bioagents and flower yield (Table 14.9).

Shylaja (2004) found that integration of *P. chlamydosporia* with *T. harzianum* gave maximum increase in plant height. Integration of *P. chlamydosporia* with *P. lilacinus* gave least root galling and wilt disease index. Integration of *P. chlamydosporia* with *T. harzianum* gave maximum flower yield characteristics (spike length, number of flowers/spike and number of spikes/plot; Table 14.10; Shylaja 2004).

14.5 Gladiolus, *Gladiolus* spp.

14.5.1 Diseases

14.5.1.1 Wilt, *Fusarium oxysporum* f. sp. *gladioli*

(i) Symptoms: This disease is often referred to as Fusarium yellows or Fusarium Wilt. The symptoms are yellowing of the leaves starting with the older outside ones, which is accompa-

Table 14.9 Effect of integration of bioagents for the management of disease complex and flower yield in tuberose

Treatment/dose (g/4 m^2)	Gall index (1–10 scale)	Disease index (1–5 scale)	No. of spikes/4 m^2	Root colonization (cfu/g)		% Egg parasitization	
				Pc	*Th*	*Pc*	*Th*
Pochonia chlamydosporia (20 g)	6.21	3.76	24	30,458	–	40.98	–
P. chlamydosporia (40 g)	4.26	3.11	26	38,943	–	54.69	–
Trichoderma harzianum (20 g)	6.56	2.82	20	–	40,369	–	50.68
T. harzianum (40 g)	5.21	2.33	23	–	45,653	–	55.84
P. chlamydosporia (20 g) + *T. Harzianum* (20 g)	4.79	2.18	29	30,879	38,789	37.49	51.69
P. chlamydosporia (40 g) + *T. Harzianum* (40 g)	4.20	1.59	24	36,278	44,926	53.96	52.38
Control	8.49	4.42	18	–	–	–	–
Critical Difference (CD) ($P=0.05$)	1.76	0.76	2.33	4,563.28	5,219.75	6.47	7.42

Pc P. chlamydosporia, Th T. harzianum

Table 14.10 Effect of bioagents on plant growth parameters and disease complex of tuberose infected with *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *dianthi*

Treatment	Plant height (cm)	Root galling index	Wilt disease index	Spike length (cm)	No. of flowers/spike	No. of spikes/plant
Formulations of *Pochonia chlamydosporia* and *Paecilomyces lilacinus* each at 20 g/m^2	33.01	2.18	1.50	70.63	29.87	22.80
Formulations of *P. chlamydosporia* and *Trichoderma harzianum* each at 20 g/m^2	33.39	2.40	2.28	75.73	45.00	24.0
Formulations of *T. harzianum* and *P. lilacinus* each at 20 g/m^2	32.01	3.36	3.10	72.89	29.90	21.60
Control	20.60	4.10	4.28	45.69	23.65	18.40
Critical Difference (CD) (P=0.05)	*4.94*	*0.36*	*0.40*	*5.09*	*6.22*	*2.64*

nied by the apparent stunting of newer leaves. In addition, the spike itself will often be stunted and faded in colour. The plant may also have blackened areas at the base which spread onto the corm (Fig. 14.7). Eventually the whole plant will wilt. The interior of the corm when opened will appear marbled with brown colour.

(ii) Integrated Management (a) Bioagents and Botanicals: T. harzianum/*T. viride* either alone or in combination with compost (mushroom, vermin, paddy straw) reduced wilt effectively (58–92 %).

(b) Bioagents, Botanicals and Chemicals: Under field conditions, the disease can be effectively controlled by application of neem cake at 1.25 MT/ha along with *T. harzianum* before planting, followed by soil drenching with 0.1 % carbendazim 1 month after planting.

(c) Bioagents and Chemicals: Mishra et al. (2002) reported significant reduction of gladiolus corm rot or wilt by integration of corm treatment with *Trichoderma virens* and carboxin.

Fig. 14.7 Fusarium infection on gladiolus

14.5.2 Nematodes

14.5.2.1 Root-Knot Nematode, *Meloidogyne incognita*

(i) Symptoms: The root-knot nematode causes stunting of plants and reduction in leaf count. The threshold population of 1,000 juveniles of *M. incognita* per plant reduced the growth of plant markedly and there was no emergence of plants at 10,000 juveniles of *M. incognita* per plant (Chandel et al. 1997).

Severe galling on roots results in yellowing of leaves, which subsequently leads to stunted growth. The nematode invades roots, daughter corms and cormels, which develop after flowering.

(ii) Integrated Management

(a) Botanicals and Bioagents: Corms of gladiolus treated with neem suspension enriched with *P. fluorescens* strains 1 and 2 (5 g/L of water) and application of neem cake enriched with *P. fluorescens* strains to beds at 20 g/m^2 was found to be effective in reducing the root population of *M. incognita* by 68% and increased the flower yield by 28%.

Soil application of neem cake enriched with *T. harzianum* at 1 t/ha is also effective.

(b) Botanicals and AMF: Both the neem cake and the AMF (*G. fasciculatum*) increased the spike length, number of florets/spike and the floret diameter, whereas the root-knot nematode (*M. incognita*) reduced these floral growth characters. The neem cake at higher doses of 1 and 2% and the AM fungus significantly increased the floral growth characters and suppressed root galls. These effects were significantly greater in the presence of neem cake/AM fungi around nematode infected plants. Lower doses of cake in combination with *G. fasciculatum* is suggested as a means to protect gladiolus from root-knot damage (Hasan and Khan 2004).

14.5.2.2 Root-Knot Nematode, *M. incognita* and Wilt, *F. oxysporum* f. sp. *gladioli* Disease Complex

(i) Symptoms: The commercial production of gladiolus is limited by soil-borne pathogens like root-knot nematodes and *Fusarium* wilt. Their combined occurrence in cultivated soils aggravated the wilt problem causing high plant mortality in gladiolus fields.

(ii) Integrated Management

(a) Bioagents and Botanicals: Gladiolus plants treated with *P. lilacinus* + *T. harzianum* + neem cake and *P. lilacinus* + *T. viride* + neem cake combinations not only controlled *M. incognita* infection, but also *Fusarium* wilt till the harvest of flower spikes. The corms and cormels obtained from plants treated with these combinations were free from *Fusarium* infection. Bioagent colonization of galled roots was maximum in *P. lilacinus* + *T. viride* combination (94%) followed by *P. lilacinus* + *T. harzianum* combination (69%). Similarly, the parasitization of eggs was maximum in *P. lilacinus* + *T. viride* combination (44%) followed by *P. lilacinus* + *T. harzianum* combination (38%), while egg mass parasitization was same in both the combinations (58%; Nagesh et al. 1998; Table 14.11).

Table 14.11 Effect of integration of antagonistic fungi with neem cake on root-knot and wilt disease complex on gladiolus

Treatment/dose/plant	% Healthy plants	% Reduction in nematode multiplication	% Infected corms and cormels	% Root colonization	% Parasitization	
					Egg masses	Eggs
Paecilomyces lilacinus—8×10^{10} spores	29	38	52	48	49	46
Trichoderma harzianum—8.8×10^{10} spores	36	16	30	50	44	32
Trichoderma viride—8.8×10^{10} spores	40	24	20	53	47	39
P. lilacinus + neem cake—8×10^{10} spores + 20 g	34	64	32	62	61	58
P. lilacinus + *T. harzianum* + neem cake ½ dose each	78	26	4	69	58	38
P. lilacinus + *T. viride* + neem cake + ½ dose each	88	47	0	74	58	44
Critical Difference (CD) (P = 0.05)	*4.36*	*6.22*	*8.54*	*3.88*	*4.11*	*3.56*

14.6 Chrysanthemum, *Dendranthema grandiflora*

14.6.1 Nematodes

14.6.1.1 Root-Knot Nematodes, *Meloidogyne* spp.

M. arenaria and *M. javanica* have been reported on chrysanthemum (Sen and Dasgupta 1977; Chandawani and Reddy 1967). Root-knot nematodes have been reported to cause economic losses in cut-flower plantations.

(i) Symptoms: The root-knot nematode, *M. javanica* causes severe plant stunting, chlorosis and extensive root galling on chrysanthemum cv. Yellow Vero in a commercial cut-flower production facility.

(ii) Integrated Management (a) Botanicals and Bioagents: Field application of two formulations of *P. lilacinus* (talc and pesta granules) in combination with neem cake reduced root gall index, nematode populations and enhanced flower yield of chrysanthemum by 23–28 % and increased the *P. lilacinus* spore viability in the rhizosphere for longer time.

14.7 Crossandra, *Crossandra undulaefolia*

14.7.1 Diseases

14.7.1.1 Foot Rot or Root Rot, *Phytophthora nicotianae*

(i) Symptoms: This disease leads to sudden death of plants. In young seedlings, symptoms appear as lesions on rootlets followed by rotting of the entire rootlet. On the collar region, peculiar berry root can be seen. Leaves show pink discolouration and drooping. In advanced stage of infection, wilting of whole plants can be noticed.

(ii) Integrated Management (a) Bioagents, Botanicals and Chemicals: Application of neem cake along with *T. harzianum* followed by soil drenching with 0.2 % Aliette gave effective control of the disease.

14.7.2 Nematodes

14.7.2.1 Root-Knot Nematode, *M. incognita*

(i) Economic Importance: The nematode is responsible for 25.62 % and 21.64 % loss in num-

Table 14.12 Effect of integration of *Paecilomyces lilacinus, Verticillium lecanii* and leaf extracts on root galling and flower yield of crossandra infected with *Meloidogyne incognita*

Treatment	Dose/plant	Rot-knot index	Flower yield (g/plant)
Control	–	4.21	18
Castor leaf extract	5%	3.8	24
Neem leaf extract	5%	3.0	28
P. lilacinus	10^4 spores/mL	3.0	25
V. lecanii	10^4 spores/mL	3.4	24
P. lilacinus + castor leaf extract	10^4 spores/mL+5%	2.8	32
P. lilacinus + neem leaf extract	10^4 spores/mL+5%	2.8	33
V. lecanii + castor leaf extract	10^4 spores/mL+5%	2.5	28
V. lecanii + neem leaf extract	10^4 spores/mL+5%	2.0	38

ber of flowers and weight of flowers, respectively (Khan and Parvatha Reddy 1994).

(ii) Symptoms: Infected plants are stunted with dried peripheral branches bearing smaller chlorotic leaves almost turning to white at later stages (Rajendran et al. 1976). Roots exhibit severe galling. Inflorescences are small and sometimes fail to produce flowers.

(iii) Integrated Management

(a) Botanicals and Bioagents: Combinations of *V. lecanii* and *P. lilacinus* (2×10^4 spores/mL each) with 5% neem leaf extract resulted in significantly higher plant growth parameters and crossandra flower yield (Nagesh and Parvatha Reddy 1995). Root galling, nematode multiplication factor were least and the parasitization of eggs and egg masses was highest in *V. lecanii*+5% neem leaf extract (Table 14.12).

Incorporating, *V. lecanii* with neem cake facilitated the effective management of *M. incognita* on crossandra. Application of neem cake enriched with *T. harzianum* at 2 kg/m^2 (2 MT/ha) in nursery beds gave effective control.

(b) Cultural and Botanicals: Incorporation of FYM in soil and intercropping of crossandra with marigold or pangola grass would reduce the root-knot nematode infection.

(c) AMF and Botanicals: *G. fasciculatum* and *G. mosseae* in combination with neem cake gave better control of nematodes over the carbofuran treatment. The root colonization of AM fungi increased significantly in the presence of neem cake, which in turn improved their efficacy in reducing *M. incognita* population in crossandra roots (Nagesh et al. 1998).

Integration of neem, karanj and castor cakes with *G. mosseae* significantly enhanced plant growth parameters and flower yield of crossandra, root colonization and sporulation of AMF. The above treatments also reduced root-knot nematode multiplication and root-galling (Nagesh and Parvatha Reddy 1996b).

(d) Bioagents, AMF and Botanicals: Integration of a bioagent (*V. lecanii*), endomycorrhiza (*G. mosseae*) with botanicals improved the growth of crossandra and reduced the population of *M. incognita*. *G. mosseae* reduced the requirement of phosphatic fertilizer and favoured the antagonistic potential of *V. lecanii* against *M. incognita*.

(e) Two or More Bioagents: Combined application of *P. lilacinus* and *Pasteuria penetrans* enhanced plant growth and flower yield of crossandra besides reducing root galling due to *M. incognita* (Nagesh et al. 1995).

Integration of *V. lecanii, P. lilacinus* and *Paecilomyces marquandii* gave effective control of *M. incognita* infecting crossandra (Khan and Parvatha Reddy 1994) (Table 14.13).

Treatment of the nursery bed with the formulations of *P. chlamydosporia* and *P. fluorescens* each at 50 g/m^2 and seed treatment with later was significantly effective in reducing the number of nematodes in roots and soil, increasing the per cent parasitization or per cent suppression of eggs by bio-control agents and also flower yield of crossandra. The seedlings were colonized by both the bioagents and when

Table 14.13 Integration of *Verticillium lecanii, Paecilomyces lilacinus* and *Paecilomyces marquandii* on final nematode population of *Meloidogyne incognita* infecting crossandra

Treatment	Dose (g)/kg soil	Final nematode population
V. lecanii	1	2,737
V. lecanii	2	2,198
P. lilacinus	1	6,165
P. lilacinus	2	1,929
P. marquandii	1	3,688
P. marquandii	2	714
V. lecanii + *P. marquandii*	1 + 1	1,563
V. lecanii + *P. lilacinus*	1 + 1	3,501
P. lilacinus + *P. marquandii*	1 + 1	1,389
V. lecanii + *P. lilacinus* + *P. marquandii*	1 + 1 + 1	453
Control	–	12,145
Critical Difference (CD) (P = 0.05)	–	*1,176*

Table 14.14 Effect of integration of *Trichoderma harzianum*/, *Pochonia chlamydosporia,* neem cake and aldicarb on plant growth and root galling in crossandra infected with *Meloidogyne incognita*

Treatment	Dose	Plant wt (g)	Root-knot index
P. chlamydosporia	4 g/kg soil	2.37	2.5
T. harzianum	4 g/kg soil	4.10	2.8
Aldicarb	1 kg a.i./ha	2.53	2.0
Neem cake	1 MT/ha	2.12	1.8
P. chlamydosporia + aldicarb	2 g/kg soil + 0.5 kg a.i./ha	4.70	1.5
T. harzianum + aldicarb	2 g/kg soil + 0.5 kg a.i./ha	5.06	1.7
P. chlamydosporia + neem cake	2 g/kg soil + 0.5 MT/ha	5.20	1.7
T. harzianum + neem cake	2 g/kg soil + 0.5 MT/ha	8.26	1.6
P. chlamydosporia + aldicarb + Neem cake	2 g/kg soil + 0.5 kg a.i./ha + 0.5 MT/ha	5.16	1.3
T. harzianum + aldicarb + neem cake	2 g/kg soil + 0.5 kg a.i./ha + 0.5 MT/ha	2.90	1.7
Control	–	0.50	4.5
Critical Difference (CD) (P = 0.05)	–	*1.23*	*0.42*

Table 14.15 Effect of *Trichoderma harzianum*, Aliette and neem cake on root-knot nematode and foot rot disease complex in crossandra

Treatment	Mortality[a]	Collar rot[a]	Root rot	Root-knot index
Nematode alone	Nil	Nil	1.60	2.80
Nematode + neem cake + *Phytophthora nicotianae*	1	Nil	1.75	1.25
Nematode + *T. harzianum* + *P. nicotianae*	Nil	Nil	1.20	1.20
Nematode + Aliette + *P. nicotianae*	Nil	Nil	0.40	1.40
Nematode + *P. nicotianae*	2	2	3.50	1.70

[a] Denotes number of plants
Scale for root rot index 0 = No root rot, 1 = 1–25 %, 2 = 25–50 %, 3 = 50–75 %, 4 = 75–100 %
Scale for root-knot index 0 = No galls, 1 = 1–10 %, 2 = 10–20 %, 3 = 20–50 %

transplanted in the field the bioagents reached the field soil as they were recovered from root to soil samples at harvest of the crop. Individual effect of bioagents was maximized when both these organisms were integrated in the nursery bed stage. This could be due to the combined effect of both organisms on root-knot nematode. Combined use of *P. fluorescens* and *P. chlamydosporia* did not affect the colonization of each other on root (Rao 2007b).

(f) Bioagents, Botanicals and Chemicals: Integrated management of root-knot nematodes infecting crossandra was achieved by rational combination of a biocontrol agent (*T. harzianum* or *P. chlamydosporia*) with a nematicide (aldicarb) or oil cake (neem cake; Khan and Parvatha Reddy 1994; Table 14.14).

14.7.2.2 Root-Knot, *M. incognita* and Foot Rot, *P. nicotianae* Disease Complex

(i) Symptoms: Infection by the root-knot nematode, *M. incognita* was shown to make the plants more prone to foot rot disease, *P. nicotianae*.

(ii) Integrated Management

(a) Bioagents and Chemicals: Combined application of *T. harzianum* (20 g/plant) and Aliette (0.3 %) did not show any mortality of plants and was also effective for the management of root rot disease and root-knot nematode disease complex (Table 14.15).

References

Anusuya, K., & Vadivelu, S. (2002). Mutualistic symbiosis of VAM fungi on plant growth promoting rhizobacteria (PGPR) on micro propagated carnation. *Journal of World Microbiology and Biotechnology, 4,* 105–107.

Chandawani, G. H., & Reddy, T. S. N. (1967). The host range of root-knot nematode, *Meloidogyne javanica* in tobacco nurseries at Rajahmundry, Andhra Pradesh. *Indian Phytopathology, 20,* 383–384.

Chandel, S. S., Khanna, A. S., & Khan, M. L. (1997). Faunistic studies on nematodes associated with gladiolus. *Journal of Agricultural Research, 18,* 44–47.

Hasan, A., & Nehal Khan, M. (2004). Interaction of root-knot nematode, VAM fungus and neem cake in amended soils on gladiolus. *Nematologia Mediterranea, 32,* 95–99.

Jayaraman, V., Rajendran, G., & Muthukrishnan, T. S. (1975). Occurrence of root-knot nematodes in *Polianthes tuberosa* L. in Tamil Nadu. *Indian Journal of Nematology, 5,* 101–102.

Khan, M. R. (2001). White-tip nematode, Aphelenchoides besseyi in rice-tuberose cropping system. In S. K. Mukho-padhyay, D. C. Ghosh, & G. C. De (Eds.), *Proceedings of National Seminar on Frontiers of Crop Management* (pp. 142–144). India: Visva-Bharati, Sriniketan.

Khan, M. R. (2006). Managing foliar nematode-a threat for tuberose cultivation. *Indian Horticulture, 51*(1), 17.

Khan, M. R., & Ghadipur, M. H. (2004). Management of root-knot disease of some Solanaceous vegetables by soil application of fly ash. *National symposium on paradigms in nematological research for biodynamic farming* (p. 92). Bangalore: University of Agricultural Sciences.

Khan, M. R., & Pal, A. K. (2001). Plant parasitic nematodes associated with tuberose (*Polianthes tuberosa* L.) in West Bengal. *Annals of Plant Protection Sciences,* 9(2), 357–359.

Khan, R. M., & Parvatha Reddy, P. (1992). Nematode pests of ornamental crops. In D. S. Bhatti & R. K. Walia (Eds.), *Nematode pests of crops* (pp. 250–257, 381 pp). Delhi: CBS Publishers & Distributors.

Khan, R. M., & Parvatha Reddy, P. (1994). Nematode problems of ornamental crops and their management. In J. Prakash & K. R. Bhandary (Eds.), *Floriculture—Technology, trades and trends* (pp. 468–472, 667 pp.). New Delhi: Oxford & IBH Publishing Co. Pvt. Ltd.

Khan, M. R., Shit, S., Pal, A. K., & Biswas, A. B. (2004). Studies on tuberose foliar nematode, *Aphelenchoides besseyi* in West Bengal. *National symposium on paradigms in nematological research for biodynamic farming* (pp. 135–136). Bangalore: University of Agricultural Sciences.

Manoj Kumar, R., Rao, M. S., & Ramachandran, N. (2010). Biomanagement of disease complex caused by *Meloidogyne incognita* and *Phytophthora parasitica* Dastur in protected cultivation of gerbera using formulation of *Trichoderma harzianum* and *Pseudomonas fluorescens. National conference on innovations in nematological research for agricultural sustainability—challenges and a roadmap ahead* (pp. 97–98). Coimbatore: Tamil Nadu Agricultural University.

Martinez, G., & Pinzon, L. (1999). New strategies in the integrated disease management of the vascular wilt of carnation (*Dianthus caryophyllus* L.) caused by *Fusarium oxysporum* f. sp. *dianthi* (Pril *et* Del.) Snyd. *et* Hans. *Acta Horticulturae, 482,* 139–144.

Mishra, P. K., Mukhopadhyay, A. N. & Fox, R. T. V. (2002). Integrated and biological control of *Gladiolus* corm rot and wilt caused by *Fusarium oxysporum* f. sp. *gladioli*. *Annals of Applied Biology, 137,* 361–364.

Nagesh, M., & Parvatha Reddy, P. (1995). Comparative efficacy of *Paecilomyces lilacinus* (Thom.) Samson and *Verticillium lecanii* (A. Zimmerman) Viegas in comb-ination with botanicals against *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 infecting *Crossandra undulaefolia* L. *Journal of Biological Control, 9,* 109–112.

Nagesh, M. & Parvatha Reddy, P. (1996a). Management of root-knot nematodes on carnation using antagonistic fungi and neem cake. *National Seminar on Integrated Crop Disease Management for Sustainable Agriculture*, Aurangabad, P. G105.

Nagesh, M., & Parvatha Reddy, P. (1996b). Eco-friendly management of *Meloidogyne incognita* on *Crossan-*

dra undulaefolia using vesicular arbuscular mycorrhiza, *Glomus mosseae* and oil cakes. *Mycorrhiza News,* 9(1), 12–14.

Nagesh, M., & Parvatha Reddy, P. (2000). Crop loss estimation in carnation and gerebera due to the root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood. *Pest Management in Hortilcultural Ecosystems, 6,* 158–159.

Nagesh, M., & Janakiram, T. (2004). Root-knot nematode problem in polyhouse roses and its management using dazomet, neem cake and *Pochonia chlamydosporia* (*Verticillium chlamydosporium*). *Journal of Ornamental Horticulture, 7,* 147–152.

Nagesh, M. & Parvatha Reddy, P. (2005). Management of carnation and gerbera to control the root-knot nematode, *Meloidogyne incognita*, in commercial polyhouses. *Nematologia Mediterranea, 33,* 157–162.

Nagesh, M., Parvatha Reddy, P., & Rao, M.S. (1995). Management of *Meloidogyne incognita* on *Crossandra undulaefolia* using *Paecilomyces lilacinus* and *Pasteuria penetrans* formulations. *National symposium on perspectives in eco-friendly approaches to plant protection* (pp. 47–48). New Delhi: Indian Agricultural Research Institute.

Nagesh, M., Parvatha Reddy, P., & Rao, M.S. (1997). Integrated management of *Meloidogyne incognita* on tuberose using *Paecilomyces lilacinus* in combination with plant extracts. *Nematologia Mediterranea, 25*(1), 3–7.

Nagesh, M., Parvatha Reddy, P., & Ramachandran, N. (1998). Integrated management of *Meloidogyne incognita* and *Fusarium oxysporum* f sp. *gladioli* in gladiolus using antagonistic fungi and neem cake. In U. K. Mehta (Ed.), *Nematology—challenges & opportunities in 21st century* (pp. 263–266). Coimbatore: Sugarcane Breeding Institute.

Nirmal Johnson, S. B. (2000). Studies on Nematode Pests of Cut Flowers with Special Reference to Carnation, Cystera, Gladiolus and Asiatic Lily. Ph. D. thesis (160 pp), Coimbatore: Tamil Nadu Agricultural University.

Pathak, B., & Khan, M. R. (2008). Yield loss potential of foliar nematode, *Aphelenchoides besseyi* in tuberose. *Indian Journal of Nematology, 38*(1), 38–40

Prasad, R. D., Rangeswaran, R., Sunanda, C. R. and Vinita, J. (2002). Biological control of black spot of rose caused by *Diplocarpon roseae. Annals of Plant Protection Sciences, 10*(2), 256–259.

Rajendran, G., Vadivelu, S., & Muthukrishnan, T. S. (1976). Pathogenicity of *Meloi-dogyne incognita* on crossandra. *Indian Journal of Nematology, 6,* 115–116.

Rao, M. S. (2007b). Management of root-knot nematode, *Meloidogyne incognita* (Kafoid & White) Chitwood, on crossandra (*Crossandra undulaefolia* Salisb.) using *Pochonia chlamydosporia* and *Pseudomonas fluorescens*. *Journal of Ornamental Horticulture, 10*(2), 110–114.

Rao, M. S., Naik, D., Shylaja, M., & Parvatha Reddy, P. (2002b). Interaction of *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *dianthi* in the manifestation of the disease complex on tuberose. *Zonal Meeting of the Southern Chapter of Indian Phytopathology Society*, Bangalore.

Rao, M. S., Shylaja, M., & Naik, D. (2003). Management of nematode induced wilt disease complex in tuberose (*Polianthes tuberosa* L.) cultivar Prajwal using *Pochonia chlamydosporia* (*Verticillium chlamydosporium*) and *Trichoderma harzianum*. *Journal of Ornamental Horticulture, 6*(4), 341–346.

Sen, K., & Dasgupta, M. K. (1977). Additional hosts of the root-knot nematode, *Meloidogyne* spp. from India. *Indian Journal of Nematology, 7,* 74.

Shylaja, M. (2004). Studies on the Development of Bio-Intensive Management Strategies of Nematode Induced Wilt Disease Complex in Tuberose (*Polianthes tuberosa*) and Carnations (*Dianthus caryophyllus*) using Biological Control Agents. Ph. D. thesis, Shimoga: Kuvempu University.

Sundarababu, R., & Vadivelu, S. (1988). Pathogenicity of *Meloidogyne* species to tuberose (*Polianthes tuberosa* L.). *Indian Journal of Nematology, 18*(1), 146–148.

Medicinal Plants

15

15.1 Coleus, *Coleus forskohlii*

15.1.1 Diseases

15.1.1.1 Wilt, *Fusarium chlamydosporum*

(i) Symptoms: In the field, the infected plants were characterized by gradual yellowing, marginal necrosis and withering of leaves followed by loss in vigour and premature death. Such plants showed discolouration of roots and complete decaying of tap and lateral root system. The bark of such plants easily peeled off. There was extensive sloughing off and shredding of affected bark. Such affected plants were finally killed due to severe root and collar rot. The infected tubers showed rotting and emitting bad odour (Fig. 15.1; Shyla 1998).

(ii) Integrated Management (a) Bioagents and AMF: Inoculation with *Trichoderma viride* + *Glomus mosseae* gave the best result in controlling the disease. The same treatment also resulted in maximum plant growth, yield and root forskolin concentration of coleus. The next best treatment was *Pseudomonas fluorescens* + *T. viride* followed by *G. mosseae* + *P. fluorescens* and *T. viride* alone (Boby and Bagyaraj 2003).

(b) Two Bioagents: Paramasivan et al. (2007) reported that the use of bioinoculants like *T. viride* and *P. fluorescens* reduced the disease incidence by 20–21 %.

(c) Bioagents and Botanicals: Combination of *T. viride* + Neemto (neem-based product applied at 500 g/5 m^2) resulted in lowest wilt incidence (12.76 %; Kulkarni et al. 2007).

15.1.1.2 Blight, *Rhizoctonia bataticola*

(i) Symptoms: Blight disease is common during monsoon or during period of high humidity. The disease initially expressed as water-soaked areas and the affected tissues soon turned into a soft, black, watery mass at the collar region of the plant. The infection was also found on roots and caused decay, which ultimately resulted in collapse of the plant. The infected plant roots showed discolouration followed by rotting of root hairs. Extensive sloughing off of affected bark was also observed. Under conditions of high humidity, the disease was found to spread rapidly. Severe infection results in defoliation and death of the plants (Fig. 15.2; Ramaprasad Shresti 2005).

(ii) Integrated Management (a) Botanicals and Bioagents: The blight incidence and colony forming units of *R. bataticola* were significantly minimum in the plots where *T. viride* (10 mL/plant spore suspension) combined with neemto (500 g/5 m^2) were applied compared to other treatments (Table 15.1; Ramaprasad Shresti 2005).

15.1.1.3 Root Rot, *Sclerotium rolfsii*

(i) Symptoms: The earliest symptom of the disease was darkening of the stem at the collar region of the plant. The leaves became flaccid and

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_15, © Springer India 2014

Fig. 15.1 Symptoms of *Fusarium* wilt on coleus

Fig. 15.2 Blight symptoms on coleus

Fig. 15.3 Root rot symptoms on coleus

Table 15.1 Management of blight of *Coleus forskohlii* using different biocontrol agents, organic amendments and chemicals. (Source: Ramaprasad Shresti 2005)

Treatment	% Blight incidence[a]
Trichoderma viride at 10 mL/plant (8×10^3 cfu/mL)[b]	21.09 (27.33)[c]
Trichoderma harzianum at 10 mL/plant (8×10^3 cfu/mL)	18.87 (25.74)
Pseudomonas fluorescens at 10 mL/plant (24×10^5 cfu/mL)	19.98 (26.51)
Pronto at 5 % soil drench	23.31 (28.84)
Neemto at 500 g/5 m^2	21.09 (27.24)
Carbofuran 3G at 15 g a.i./5 m^2	24.42 (29.57)
Farm yard manure at 5 kg/5 m^2	25.53 (30.38)
Trichoderma viride at 10 mL/plant (8×10^3 cfu/mL) + Neemto at 500 g/5 m^2	12.7 (20.93)
Carbendazim at 0.1 % soil drench	21.19 (27.33)
Propiconazole at 0.1 % soil drench	23.31 (28.84)
Control	35.52 (36.59)
CD at 5 %	*3.48*

[a] Observations recorded at harvest (150 days after planting)
[b] Figures in parentheses are arc sin angular transformed values
[c] *cfu* colony forming units

dropped off. White, fan-shaped mycelial strands crept over the stem portion, developing small light to dark brown sclerotia on the infected portion. The sclerotial initials were white at first, later turned brown with age. Finally, the plant wilted and dried (Fig. 15.3; Ramaprasad Shresti 2005).

(ii) Integrated Management (a) Cultural, Botanicals, Bioagents and Chemical: Treatment involving field sanitation + dipping stem cuttings in carbendazim (0.1 %) + one more drench with 0.1 % carbendazim 30 days after planting (DAP) recorded maximum reduction of disease incidence over control (76.50 and 72.72 % at 45 and 90 DAP, respectively). This was on par with treatment soil application of zinc sulphate at 20 kg/ha + soil drenching with neem cake and *T. viride* mixture at 50 g/plant, where reduction in disease incidence was 73.73 and 70.11 % over control at 45 and 90 DAP, respectively. The tuberous root yield was also maximum in the above treatments (5,787 and 5,759 kg/ha).

Fig. 15.4 Symptoms of bacterial wilt on coleus

15.1.1.4 Bacterial Wilt, *Ralstonia solanacearum*

Bacterial wilt is the major disease of *C. forskohlii* causing heavy losses (>50%) in south India (Chandrashekara and Prasannakumar 2010).

(i) Symptoms: The disease shows various symptoms like yellowing and wilting of leaves, brown to black roots, oozing, putrefaction and decaying of roots and unhealthy plants (Fig. 15.4). Water-soaked patches with linear streaks on the collar region of the infected plants were observed. Leaves became flaccid and drooped quickly; wilting and drying of the plants were also observed. The leaves showed roll up symptoms and the whole plant dried up (Fig. 15.4). Wilted plants came off easily with a gentle pull and vascular discolourations were observed. Such tubers when pressed exhibited oozing of bacterial exudates.

(ii) Integrated Management

(a) Bioagents and Botanicals: Application of 2 kg of *P. fluorescens* mixed with 300 kg of compost is effective.

15.1.2 Nematodes

15.1.2.1 Root-Knot Nematode, *Meloidogyne incognita*

The root-knot nematode infestation was reported on coleus from Kerala and Orissa. The dry weight of the tubers was reduced by 20% due to root-knot nematodes. The percentage of starch on fresh weight basis showed drastic reduction (16%) in the infested tubers. *M. incognita* was responsible for 70.2% loss in tuber yield of coleus.

(i) Symptoms: The galls on coleus roots are very big and pronounced. The root-knot nematode damage often leads to crop failure. The infested tubers swell in size with irregular surface and cracking of the skin (Fig. 15.5). When the infestation is severe, rotting sets in even before harvest. Infested tubers rot after harvest and rarely reach market.

(ii) Integrated Management

(a) Cultural, Botanicals and Bioagents: Integration of dipping stem cutting in 0.1% *P. fluorescens* + soil application of neem cake at 400 kg/ha + growing marigold as an intercrop followed by their biomass incorporation during earthing up increased the root tuber yield by 22.7–30.0% and reduced the root-knot nematode (*M. incognita*) population by 71.2–73.8%. However, integration of *P. fluorescens* + marigold intercrop proved to be more economical (with benefit to cost ratio of 6.4–8.8) and effective management practice for the management of root-knot nematodes in medicinal coleus (Seenivasan and Devarajan 2008; Table 15.2).

(b) Physical, Botanicals and Bioagents: Integration of soil solarization in the nursery for 15 days with 150 gauge low density polyethylene (LDPE) film and application of *Paecilomyces lilacinus* + neem cake or *P. lilacinus* + *Bacillus macerans* in the main field are the best

Fig. 15.5 Root-knot nematode on *Coleus forskohlii*. (Source: Mallesh 2008)

Table 15.2 Effect of integration of bioagents, neem cake and marigold intercrop for the management of *Meloidogyne incognita* infecting coleus

Treatment	Gall index (1–5 scale)		Yield (MT/ha)		Benefit to cost ratio	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Cutting dip in 0.1% *P. fluorescens* + neem cake at 400 kg/ha	4.3	3.6	10.41	9.86	1.8	1.3
Paecilomyces lilacinus at 2.5 kg/ha + neem cake at 400 kg/ha	4.3	3.6	10.21	9.81	1.4	1.2
Cutting dip in 0.1% *P. fluorescens* + marigold intercrop	2.3	2.1	12.08	11.07	8.8	6.4
P. lilacinus at 2.5 kg/ha + marigold intercrop	3.6	3.3	10.92	10.20	4.6	3.2
P. fluorescens + neem cake + marigold	2.3	2.1	12.11	11.12	3.4	2.5
P. lilacinus + neem cake + marigold	3.6	3.3	11.06	10.26	2.0	1.4
Carbofuran at 1 kg a.i./ha	4.3	3.6	10.36	9.85	2.1	1.6
Control	4.6	4.3	9.31	9.06	–	–
CD (P = 0.05)	*0.36*	*0.36*	*0.83*	*0.80*	–	–

treatments in increasing plant height (64.3 and 60.3 cm compared to 40.0 cm in control), number of leaves (593.3 and 583.3 compared to 310.0 in control), weight of tubers/plant (560.0 and 546.6 g compared to 350.0 g in control), yield (11.5 and 11.3 kg/plot compared to 6.9 kg/plot in control) and in reducing root galls (0.3 and 1.0 compared to 50.6 in control), nematode population in soil (25.0 and 30.0/100 mL soil compared to 196.6/100 mL soil in control) and roots (1.0 and 1.6/5 g roots compared to 79.0/5 g roots in control; Nisha and Sheela 2006).

15.1.2.2 Root-Knot Nematode (*M. incognita*) and Wilt (*F. chlamydosporum*) Disease Complex

(i) Symptoms: Among the different diseases affecting coleus , root-knot and wilt disease complex caused by *M. incognita* and *F. chlamydosporum* was observed in severe form (Kumar 2008). In the interaction studies, *M. incognita* was the most aggressive pathogen compared to *F. chlamydosporum*. However, simultaneous inoculation of *M. incognita* and *F. chlamydosporum* caused greater reduction in plant growth as well as nematode multiplication (Fig. 15.6). In case of sequential inoculation of *M. incognita* 7 days prior to *F. chlamydosporum* caused reduction in plant growth parameters. The effect of simultaneous inoculation of *M. incognita* with *F. chlamydosporum* on coleus was additive in nature. However, when *M. incognita* was inoculated with *F. chlamydosporum* the resultant effect was almost equal to sum of individual effect. These results suggest that the nematode can predispose the coleus to infection by *F. chlamydosporum* and can aggravate the disease. Reduction in number of galls per plant and final nematode population

Fig. 15.6 Complete rotting of root system due to root-knot and wilt disease complex

was observed in simultaneous inoculation of nematode and fungus.

(ii) Integrated Management

(a) Bioagents and Botanicals: Combined application of plant products (Neem seed kernel powder at 5 g/kg of soil) with biocontrol agents (*P. lilacinus, T. viride* + *P. fluorescens* at 10 g/kg of soil) was found effective in reducing the number of galls, nematode population, number of egg masses, root-knot index, root rot index and improving the plant growth parameters as compared to inoculated control.

15.1.2.3 Root-Knot Nematode and Collar Rot Disease Complex

R. bataticola, S. rolfsii, F. chlamydosporum and *M. incognita* were found to be the most commonly associated fungi with collar rot disease complex (Ramaprasad Shresti 2005).

(i) Symptoms: Inoculation with *M. incognita* 7 days prior to inoculation of all three fungal pathogens or *vice versa,* the resultant effect on plant growth parameters was more than simple additive effect. Wilt symptoms were first recorded at 45 days after inoculation when *M. incognita* was inoculated 7 days prior to inoculation of all the fungal pathogens simultaneously (*F. chlamydosporum* + *R. bataticola* + *S. rolfsii*). The highest root-knot index (Fig. 15.7) and nematode population were recorded in the treatment inoculation with *M. incognita* 7 days prior to inoculation of *F. chlamydosporum* + *R. bataticola* + *S. rolfsii* (Ramaprasad Shresti 2005).

(ii) Integrated Management

(a) Botanicals, Bioagents and Chemicals: The wilt incidence and number of galls were significantly minimum in the plots where *T. viride* (10 mL/plant spore suspension) combined with neemto (500 g/5 m^2) were applied compared to other treatments. Colony forming units of *F. chlamydosporum* and *R. bataticola* were significantly minimum in the plots treated with carbendazim and propiconazole (Table 15.3; Ramaprasad Shresti 2005).

15.1.2.4 Root-Knot Nematode, *M. incognita* and Root Rot, *Macrophomina phaseolina* Disease Complex

The productivity of coleus has been hampered by its susceptibility to root knot nematode (*M. incognita*) and root rot disease (*M. phaseolina*) complex. Due to this disease complex the yield loss ranged from 50 to 60%.

(i) Symptoms: Simultaneous inoculation of *M.* incognita and *M. phaseolina* as well as nematode inoculation followed by fungus 15 days later caused significant reduction in tuber yield and 100% root rot disease in medicinal coleus (Table 15.4; Senthamari et al. 2008).

(ii) Integrated Management

(a) Cultural and Bioagents: Integrated nematode management strategy includes dipping of stem cuttings in *P. fluorescens* (strain Pf1) + growing marigold as intercrop and their biomass incorporation during earthing up. The above treatment increased the tuber yield by 40.6% and reduced nematode infestation in terms of number of juveniles per 100 cc soil (73.2%), number of adult females per g of root (82.4%), number of egg mass/g root (85.9%), number of eggs per g of root (87.9%) with least gall index (1.6). This treatment also decreased the incidence of *M. phaseolina* root rot disease up to 50.4%. Hence, it could be concluded that dipping of stem cuttings in 0.1% *P. fluorescens* + marigold intercropping

Fig 15.7 Root-knot and collar rot disease complex of coleus. *Left*—Infected, *Right*—Healthy. (Source: Mallesh 2008)

Table 15.3 Management of collar rot complex of *Coleus forskohlii* using different biocontrol agents, organic amendments and chemicals

Treatment	% Wilt incidence[a]	No. of galls/5 g roots	Cfu[b]	
			Fusarium chlamydosporium	*Rhizoctonia bataticola*
Trichoderma viride @ 10 mL/plant (8×10^3 cfu/mL)	21.09 (27.33)[c]	21.13	7.60	12.20
T. harzianum @ 10 mL/plant (8×10^3 cfu/mL)	18.87 (25.74)	19.53	8.00	12.60
Pseudomonas fluorescens @ 10 mL/plant (24×10^5 cfu/mL)	19.98 (26.51)	18.27	8.00	14.20
Pronto @ 5% soil drench	23.31 (28.84)	17.33	10.60	15.60
Neemto @ 500 g/5 m^2	21.09 (27.24)	16.07	12.60	16.40
Carbofuran 3G @ 15 g a.i./5 m^2	24.42 (29.57)	14.93	16.20	17.60
Farm yard manure @ 5 kg/5 m^2	25.53 (30.38)	25.67	15.20	18.80
Trichoderma viride at 10 mL/plant (8×10^3 cfu/mL) + Neemto @ 500 g/5 m^2	12.76 (20.93)	10.13	6.20	9.60
Carbendazim @ 0.1% soil drench	21.19 (27.33)	23.33	3.60	6.80
Propiconazole @ 0.1% soil drench	23.31 (28.84)	23.00	3.80	7.40
Control	35.52 (36.59)	28.40	19.60	21.60
CD at 5%	*3.48*	*5.38*	*2.49*	*2.72*

[a] Observations recorded at harvest (150 days after planting)
[b] *Cfu* Colony forming units $\times 10^{-3}$ /g of soil (average of five replications)
[c] Figures in parentheses are arc sin angular transformed values

Table 15.4 Effect of *Meloidogyne incognita* and *Macrophomina phaseolina* on root galling and yield of coleus

Treatment	Tuber yield/plant (g)	No. of galls/plant	% Disease incidence
M. incognita (1 J2/g soil)	44.00	768	0
M. phaseolina (5 g/kg soil)	61.50	0	50
M. incognita (prior) + *M. phaseolina* (15 days later)	34.50	373	100
M. phaseolina (prior) + M. incognita (15 days later)	52.50	110	50
M. incognita + *M. phaseolina* (simultaneously)	13.00	316	100
Uninoculated control	84.38	0	0
CD (P = 0.05)	*10.07*	*2.08*	*43.99*

Fig. 15.8 Mealy bug infestation on ashwagandha leaf

can be commercially exploited for the management of *M. incognita* and *M. phaseolina* disease complex in medicinal coleus (Seenivsan 2010).

15.2 Ashwagandha, *Withania somnifera*

15.2.1 Insect Pests

15.2.1.1 Mealy Bug, *Ferrisia virgata*

(i) Damage: Mealy bugs suck sap from lower surface of leaves and also from pods. Infested leaves showed yellowish discolouration followed by drying symptoms (Fig. 15.8).

(ii) Integrated Management

(a) Botanicals and Chemicals: Soil application of FYM at 12.5 t/ha + azophos at 2 kg/ha + neem cake at 1 t/ha and need-based foliar spray of neem oil (3%) was found effective.

15.2.2 Diseases

15.2.2.1 Seedling Blight

(i) Symptoms: Seedling blight is known to be the major disease of ashwagandha. The disease reduced the plant population drastically by seedling mortality, which ultimately reduced the yield.

(ii) Integrated Management

(a) Bioagents and Chemicals: Seed treatment with *T. viride* at 4 g/kg of seed along with metalaxyl at 6 g/kg of seed showed minimum seedling mortality (18.7%).

15.2.3 Nematodes

15.2.3.1 Root-Knot Nematode, *Meloidogyne incognita*

(i) Symptoms: The nematode infected plants typically show chlorotic, stunted, less branched with fewer and smaller leaves and poor response to fertilizer and irrigation. Such symptoms usually are not noticeable until severe damage to root system by the nematodes. Roots of such plant were severely galled with reduced alkaloids. When stem touches the soil it was also found to be infested with root-knot nematode. The root-knot nematode infected plants are more likely to be killed early than healthy non-infected plants (Fig. 15.9).

(ii) Integrated Management

(a) Botanicals and Bioagents/AMF: Integration of neem cake + *Trichoderma harzianum,* vermicompost + *T. harzianum*, and cow urine + *T. harzianum* considerably reduced the root-knot nematode development and enhanced plant growth and yield. Maximum root-knot suppression was noticed in vermicompost + *T. harzianum* followed by mentha distillate + *Glomus aggregatum*. Highest increase in plant yield was recorded when the soil was amended with mentha/curry leaf distillates along with *T. harzianum/G. aggregatum* (Pandey and Kalra 2003; Table. 15.5). Vermicompost apart from providing a complete nutrition to the plant may also support the growth of *T. harzianum* thus helping it proliferate in the rhizosphere and improve the soil health and thus sustainability to restrict the nematode population.

(b) Three AMF: Root-knot nematode infection was drastically impaired and plant growth biomass improved when plants were inoculated with three AMF simultaneously as compared to their inoculation alone (Table. 15.6).

(c) Bioagents and Botanicals: Soil application of super *Pseudomonas* (consortia of *P. fluorescens* strains with chitinase, 1-aminocyclopropane-1-carboxylate (ACC) deaminase and neem mixture) at 2.5 kg/ha was effective to suppress the root-knot nematode incidence by 78% and to enhance the biomass of economic parts of aswagandha plants by 26.87% (dry root) and 43.19% (seed) over untreated control.

Fig. 15.9 Root knot infested plants and roots of *Withania somnifera*

Table 15.5 Effect of organic materials and bioagents on plant growth of ashwagandha infected with *Meloidogyne incognita*

Treatment	Dry weight of plant (g)	Root-knot index	Total neem population (soil + roots)
Untreated—Uninoculated	8.5	–	–
Untreated—Inoculated	5.2 (−38.8)	4.00	6,460
Carbofuran	8.0 (−5.9)	1.66	3,012
Neem cake + Davana	23.8 (+62.4)	1.66	2,820
Neem cake + Curry leaf	7.4 (−12.9)	1.33	2,261
Neem cake + Vermicompost	12.0 (+41.2)	1.66	2,649
Neem cake + *T. harzianum*	12.8 (+50.6)	1.66	2,674
Neem cake + *G. aggregatum*	14.3 (+68.2)	3.00	2,964
Neem cake + *Mentha*distillate	14.2 (+67.1)	1.66	2,409
Davana + Curry leaf	10.8(+27.1)	1.33	2,030
Davana + Vermicompost	14.1 (+65.9)	3.00	2,594
Davana + *T. harzianum*	9.6 (+12.9)	1.66	2,110
Davana + *G. aggregatum*	10.3 (+21.2)	1.33	2,050
Davana + *Mentha*distillate	13.2 (+55.3)	1.33	2,150
Curry leaf + Vermicompost	14.0 (+64.7)	1.66	2,440
Curry leaf + *T. harzianum*	15.0 (+76.5)	3.33	3,252
Curry leaf + *G. aggregatum*	13.4 (+57.6)	3.00	2,635
Curry leaf + *Mentha*distillate	15.3 (+80.0)	1.66	2,404
Vermicompost + *T. harzianum*	14.4 (+69.4)	0.66	1,400
Vermicompost + *G. aggregatum*	13.6 (+60.0)	1.99	2,480
Vermicompost + *Mentha*distillate	13.9 (+63.5)	1.33	2,000
G. aggregatum + *Mentha* distillate	15.6 (+83.5)	1.00	1,784
CD (P = 0.05)	*0.71*	*0.01*	*465.70*

Table 15.6 Effect of integration of AMF for the management of *Meloidogyne incognita* infecting ashwagandha

Treatment	Fresh wt. (g)	Dry wt. (g)	Oil yield (%)	% AMF colonization	Root-knot indices
Untreated-uninoculated	395.2	107.1	0.51	–	–
Untreated-inoculated	285.0	77.9	0.38	–	3.6
Ga	322.0	91.6	0.40	42.3	2.3
Gf	333.0	93.8	0.41	58.2	2.0
Gm	388.0	105.9	0.48	63.5	1.6
Ga + *Gf* + *Gm*	360.0	99.8	0.46	78.5	1.3

AMF arbuscular mycorrhizal fungi, *Ga Glomus aggregatum, Gf Glomus fasciculatum*, *Gm Glomus mosseae*

Table 15.7 Influence of organic and biological amendments on plant growth, yield and root knot index in *Withania somnifera* infected with *Meloidogyne incognita*

Treatments	Shoot dry weight (kg/m^2)	Root dry weight (kg/m^2)	RKI
Control (zero fertilizers)	1.3f	0.15h	3.33a
Farmyard manure	1.8e	0.20g	1.66b
Trichoderma harzianum	2.3d	0.25e	0.66cd
Cow urine	2.7b	0.28d	0.83cd
Vermicompost	2.3d	0.29bc	1.33bc
Neem oil seed cake	2.5c	0.23f	1.16bc
Farmyard manure + *T. harzianum*	2.5c	0.23f	1.16bc
Cow urine + *T. harzianum*	2.8ab	0.30b	0.33d
Vermicompost + *T. harzianum*	2.9a	0.32a	0.66cd
Neem oil seed cake + *T. harzianum*	2.8ab	0.29bc	0.33d

Mean in each column followed by same letters do not differ significantly ($P = 0.05$) according to Duncan's multiple range test
RKI root-knot index

Substantial reduction in root galling was noticed in neem oil seed cake + *T. harzianum*, vermicompost + *T. harzianum*, cow urine + *T. harzianum* treated plots as compared to untreated control. A significant and marked improvement in plant growth and yield was also noticed in plots treated with vermicompost + *T. harzianum*, cow urine + *T. harzianum*, neem oil seed cake + *T. harzianum* with maximum root yield obtained from vermicompost + *T. harzianum* treated plots (Table 15.7).

15.3 Sarpagandha, *Rauvolfia serpentina*

15.3.1 Diseases

15.3.1.1 Foliar Blight/Spot, *Alternaria tenuis*

(i) Symptoms: The pathogen attacks the leaves, resulting in minute, brownish or dark-coloured circular spots with a yellowish margin on the ventral side of the leaves. The fungus also affects the flowers and fruits.

(ii) Integrated Management

(a) Bioagents, Botanicals and Chemicals: Application of two split doses of neem cake at 50 g/plant at 30 days interval plus two sprays of *Bacillus subtilis* in September and October along with three foliar sprays of mancozeb at 15 days' interval plus two foliar sprays of carbendazim at 0.15% at 21 days' interval gave 201.5 g fresh root/plant, and 75.5% protection against foliar blight pathogens (*Alternaria alternata, Cercospora rauvolfia, Cercospora serpentina, Colletotrichum gloeosporioides, Corynespora cassiicola, Curvularia lunata, M. phaseolina* and *Rhizoctonia solani*).

15.3.2 Nematodes

15.3.2.1 Root-Knot Nematodes, *Meloidogyne spp.*

The root-knot nematodes are recognized as the major limiting factors in successful cultivation of sarpagandha crop.

Fig. 15.10 Healthy and root-knot infested plants and roots of Egyptian henbane (*H. muticus*)

(i) Integrated Management (a) Botanicals and Bioagents: Soil application of neem cake enriched with *T. harzianum* at 1 MT/ha is recommended.

15.4 Henbane, *Hyoscyamus muticus*, *Hyoscyamus niger*, *Hyoscyamus albus*

15.4.1 Nematodes

15.4.1.1 Root-Knot Nematode, *M. incognita*

Henbanes (*H. niger* and *H. muticus*) were severely infested with *M. incognita* and *M. javanica*. Even 3–4 root-knot larvae/g of soil caused significant damage to the crop (Pandey 1990).

(i) Symptoms: In the field, up to 60–70% henbane plants were chlorotic and stunted showing a patchy appearance with fewer smaller leaves and flowers. The roots of infested plants were severely galled to various degrees. Varying sizes of galls were found in the root system (Fig. 15.10).

(ii) Integrated Management (a) Bioagents and AMF: Application of bioinoculants have not only enhanced the total biomass yield of *H. niger* but also significantly decreased the multiplication of nematodes. However, a significantly higher reduction was recorded in the treatment where all bioinoculants are combined. This may be attributed to the fact that these bioagents are secreting potential chemicals which are either non-favourable for multiplication of *M. incognita* or inducing tolerance in the plant against the attack of root-knot nematodes. Hence, mixed inoculation of rhizobacterium with AMF could be considered for biomanagement for reducing the deleterious effect of root-knot nematodes in black henbane. Similar results were also obtained with different bioagents in *H. muticus* plants against *M. incognita* (Pandey et al. 2000; Table 15.8).

15.5 Aloe, *Aloe indica*

15.5.1 Diseases

15.5.1.1 Black Spot/Rust

(i) Symptoms: Aloe rust causes round brown or black spots on aloe leaves.

(ii) Integrated Management (a) Bioagents and AMF: Among four selected bioinoculants namely, *B. subtilis, G. aggregatum, Glomus intraradices* and *T. harzianum* evaluated against black spot disease either alone or in different combinations; maximum plant height attained was 56 cm in *G. intraradices* treated plants followed by 53 cm in *B. subtilis* and *B. subtilis* + *G. aggregatum* treatments. Maximum plantlet production (14) was recorded in the treatments of *B. subtilis* + *T. harzianum* + *G. aggregatum* followed by other treatments (12). Maximum herb yield obtained was 3.65 kg/plant in *G. aggregatum* treated pots, followed by 3.35 kg/plant in *G. aggregatum* + *B. subtilis* and *G. intraradices* treated pots.

Table 15.8 Effect of bioagents for the management of *Meloidogyne incognita* infecting henbane

Treatment	Fresh biomass wt. (g)	Reproduction factor	Root-knot index
Control	120.6	8.14	4.00
Pf	171.0	4.24	1.33
Ga	172.7	4.52	1.66
Gf	144.6	5.78	2.66
Gm	142.0	6.05	3.00
Pf + *Ga* + *Gf* + *Gm*	202.0	4.03	1.00
CD (P = 0.05)	*12.01*	–	*1.16*

Pf Pseudomonas fluorescens, Ga Glomus aggregatum, Gf Glomus fasciculatum, Gm Glomus mosseae

15.6 Babchi, *Psoralea corylifolia*

15.6.1 Diseases

15.6.1.1 Collar Rot

(i) Integrated Management

(a) Bioagents, Botanicals and Chemicals: Soil application of neem cake at 400 kg/ha + seed treatment with *T. viride* at 4 g/kg + spraying of carbendazim at 0.05 % in December–January significantly reduced the collar rot incidence.

15.7 Soda Apple, *Solanum viarum*

15.7.1 Diseases

15.7.1.1 Wilt, *Fusarium oxysporum* f. sp. *lacimiti*

(i) Symptoms: The disease generally appears after first showers and is characterized by wilting and sudden death of plants. The disease spreads very fast and within a fortnight majority of the plants in a field show wilting symptoms, which ultimately die irrespective of age of the plant.

(ii) Integrated Management

(a) Bioagents and Botanicals: Mixing 2.5 kg *T. viride* in 50 kg of FYM and applying along plant lines gave effective management of *Fusarium* wilt.

References

Boby, B. U., & Bagyaraj, D. J. (2003). Biological control of root rot of *Coleus forskohlii* Briq. using microbial inoculants. *World Journal of Microbiology and Biotechnology, 19,* 175–180.

Chandrashekara, K. N., & Prasannakumar, M. K. (2010). New host plants for *Ralstonia solanacearum* from India. *New Disease Reports, 22,* 6.

Kulkarni, M. S., Ramprasad, S., Hedge, Y., Laxminarayan, H., & Hedge, N. K. (2007). Management of collar rot complex disease of *Coleus forskohlii* (Wild) Briq. using bioagents, organic amendments and chemicals. *Biomed, 2,* 37–40.

Kumar, B. (2008). *Studies on Root-knot and Wilt Complex in Coleus forskohlii (Wild.) Briq. Caused by Meloidogyne incognita (Kofoid and White) Chitwood and Fusarium chlamydosporum (Frag. and Cif.) Booth*. M.Sc. (Agri) thesis in Plant Pathology, University of Agricultural Sciences, Dharwad.

Nisha, M. S., & Sheela, M. S. (2006). Bio-management of *Meloidogyne incognita* on Coleus, *Solenostemon rotundifolius* by integrating solarization, *Paecilomyces lilacinus, Bacillus macerans* and neem cake. *Indian Journal of Nematology, 36,* 136–138.

Pandey, R. (1990). Pathogenicity and reproduction of *Meloidogyne incognita* on *Hyoscyamus albus* and rhizospheric association of other phytoparasitic nematodes. *International Nematology Network News, 7*(4), 34–37.

Pandey, R., Gupta, M. L., Singh, H. B., Singh, H. N., & Kumar, S. (2000). *Disease management potentiality of VAM fungi to Meloidogyne incognita on Hyoscyamus muticus*. In Proceedings of an International Conference on Integrated Plant Disease Management for Sustainable Agriculture. Indian Agricultural Research Institute, New Delhi, pp. 1239–1240.

Pandey, R., & Kalra, A. (2003). Root-knot disease of Ashwagandha, *Withania somnifera* and its ecofriendly and cost effective management. *Journal of Mycology Plant Pathology, 33,* 240–245.

Paramasivan, M., Mohan, S., & Muthukrishnan, N. (2007). Management of *Coleus* dry root rot pathogen *Macrphhomina phaseolina* by fungal and bacterial antagonist. *Indian Journal of Plant Protection, 35,* 133–135.

Ramaprasad Shresti, A. Y. (2005). *Studies on collar rot complex of Coleus forskohlii (Wild.) Briq*. M. Sc. (Agri.) thesis, University of Agricultural Sciences, Dharwad, Karnataka, India.

Seenivasan, N., & Deevrajan, K. (2008). Integrated approach for the management of root-knot nematode,

Meloidogyne incognita in medicinal coleus. *Indian Journal of Nematology, 38,* 154–158.

Seenivasan, N. (2010). Biointensive management of *Meloidogyne incognita* and *Macro-phomina phaseolina* disease complex in medicinal coleus. *Indian Journal of Plant Protection, 38,* 186–192.

Senthamari, K., Poornima, K., Subramanian, S., & Sudheer, J. (2008). Nematode-fungal disease complex involving *Meloidogyne incognita* and *Macrophomina phaseolina* on medicinal coleus, *Coleus forskohlii* Briq. *Indian Journal of Nematology, 38,* 30–33.

Shyla, M. (1998). *Etiology and Management of a Root-rot of Coleus forskohlii*. M.Sc. (Agri.) thesis, University of Agricultural Sciences, Bangalore.

Aromatic Plants

16

16.1 Jasmine, *Jasminum spp.*

16.1.1 Diseases

16.1.1.1 Collar Rot and Root Rot, *Sclerotium rolfsii*

(i) Symptoms: Plants at all stages are infected. First, the older leaves become yellow, followed by younger leaves and finally death of the plant. In the root, black discolouration can be seen. White strands of mycelia and mustard-like sclerotia are seen on the infected tissues and stem surface. The young leaves turn yellow and the twigs start drying from tip downwards (Fig. 16.1). The plants wilt in patches.

(ii) Integrated Management

(a) Bioagents and Botanicals: Heavy application of farmyard manure (FYM) with *Trichoderma viride* is helpful.

16.1.2 Nematodes

16.1.2.1 Root-Knot Nematode, *Meloidogyne incognita*

Meloidogyne incognita was reported on *Jasminum sambac* and *Jasminum flexile* from Tamil Nadu by Rajendran and Rajendran (1979).

(i) Symptoms: The roots exhibited very small swellings and enlarged rootlets. The minute galls were more in *J. sambac*. Pale-coloured leaves and dieback symptoms were associated (Rajendran and Rajendran 1979).

(ii) Integrated Management

(a) Botanicals and Chemicals: Application of phorate at 4 g a.i. per plant during May and September months and incorporation of 20 kg of FYM per plant increased flower yield of jasmine by 50% and reduced the root-knot nematode population by 70% (Sundarababu 1992).

(b) Cultural, **Bioagents and Botanicals:** Cuttings or planting material should be raised in nematode-free or treated nursery beds. Application of neem cake enriched with *Trichoderma harzianum* at 1 t/ha is recommended.

(c) Botanicals and Arbuscular Mycorrhizal Fungi (AMF): Nursery beds should be treated with neem or *Pongamia* cakes enriched with mycorrhizal spores at 1 kg/m^2.

16.2 Mints, *Mentha* spp.

16.2.1 Nematodes

16.2.1.1 Root-Knot Nematodes, *Meloidogyne* spp.

Root-knot disease of menthol/Japanese mint, spearmint, Scotch spearmint, peppermint and Bergamot mint caused by *M. incognita* and *Meloidogyne javanica* was observed for the first time in Lucknow and Terai region of Uttar Pradesh, which reduces the herbage yield and oil content (Haseeb and Pandey 1989). *M. incognita* dominates over *M. javanica* in mixed infection. The quality of mint oil was also adversely affected due to nematode infection. The root-knot

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_16, © Springer India 2014

Fig. 16.1 Collar rot and root rot symptoms on jasmine

nematode, *M. incognita*, caused 40.2% loss in herbage yield and 46.6% loss in oil yield in menthol mint (Pandey 2001).

(i) Symptoms: Initial symptoms of the disease include occasional yellowing of leaves, which in a month's time spread to a large portion of the foliage. Growth ceases soon after yellowing. Leaves turn yellow and thin, scorching easily and eventually turning brown. Initially, symptoms appear in patches as the reduced plant growth with smaller leaf size and temporary wilting under slight stress of water during hot sun. As the crop grows, especially after first harvest, symptoms become more severe and appear as stunted growth with yellowing of leaves, while veins remain green.

The below-ground symptoms are the large numbers of small-sized galls with large egg masses on the roots (Fig. 16.2). Under severe infection, initiation of lateral roots and rootlets on suckers is checked. As a result, uptake of nutrients is inhibited, which in turn produces deficiency symptoms on the aerial portion of the plants (Haseeb and Pandey 1989).

(ii) Integrated Management (a) Three AMF: Application of arbuscular mycorrhizal fungi such as *Glomus aggregatum, Glomus fasciculatum* and *Glomus mosseae* improved plant growth, enhanced herbage and oil yield and effectively inhibited root-knot nematode infection (Pandey et al. 1997; Table 16.1).

(b) Botanicals and Chemicals: Application of carbofuran and neem cake in combination improved the growth of Japanese mint and oil yield and reduced root-knot nematode population very effectively.

(c) Botanicals, Bioagents and AMF: Pandey (2005) conducted field trial to determine the efficacy of *T. harzianum* isolate U, *G. aggregatum*, oil seed cakes of neem (*Azadirachta indica*) and mustard (*Brassica campestris*) in the management of *M. incognita* and their impact on yield of menthol mint (*Mentha arvensis*) cv. Kosi. Significant reductions in nematode populations and root-knot indices were noticed in plots receiving oil seed cakes and bioagents, the effects of which were equal to those of carbofuran. The maximum reduction in *M. incognita* population was recorded in beds treated with mustard cake along with *T. harzianum*, which also produced significantly higher herbage and oil yields (Pandey 2005).

The maximum enhancement of plant dry weight was recorded in *T. harzianum* + *Glomus intraradices* (20.0%) followed by *T. harzianum* + *Pseudomonas fluorescens* (14.4%), *G. intraradices* + *P. fluorescens* (5.0%), *G. intraradices* + *Bacillus megaterium* (1.2%) and *B. megaterium* + *P. fluorescens* (1.5%) as compared with untreated-uninoculated control (Table 16.2). Root galling was minimum in *T. harzianum* + *G. intraradices* (1.33) followed by *T. harzianum* + *P. fluorescens* (1.66). Root colonization by *G. intraradices* was maximum in *T. harzianum* + *G. intraradices* (78%) followed by *P. fluorescens* + *G. intraradices* (74%; Pandey et al. 2011).

Fig. 16.2 *Left*, root-knots on suckers of menthol mint. *Right*, infested runners of menthol mint

Table 16.1 Effect of arbuscular mycorrhizal fungi on the productivity of mint infected with *Meloidogyne incognita*

Treatment	Fresh herbage weight (g)	Percent oil yield	Percent mycorrhizal colonization	Root-knot index
Untreated-inoculated	285.0	0.38	–	3.6
Glomus aggregatum (Ga)	322.0	0.40	42.3	2.3
Glomus fasciculatum (Gf)	333.0	0.41	58.2	2.0
Glomus mosseae (Gm)	388.0	0.48	63.5	1.6
Ga + Gf + Gm	360.0	0.46	78.5	1.3

Table 16.2 Effect of mutualistic endophytes and Plant Growth Promoting Rhizobacteria (PGPRs) on root-knot and mycorrhizal population development and on yield of menthol mint

Treatment	Plant dry weight (g)	Root-knot index	*G. intraradices* percent root colonization
Control-uninoculated	34.0	–	–
Control-inoculated	25.7 (−24.4)[a]	3.66	–
Carbofuran	31.4 (−7.6)	2.33	–
Trichoderma harzianum	34.8 (−2.4)	2.00	–
Glomus intraradices (*Gi*)	33.3 (−2.1)	2.66	65
Bacillus megaterium (*Bm*)	30.9 (−9.1)	3.00	–
Pseudomonas fluorescens (*Pf*)	33.4 (−1.8)	2.66	–
T. harzianum + *Gi*	40.8 (+20.0)	1.33	78
T. harzianum + *Bm*	36.0 (+5.9)	2.00	–
T. harzianum + *Pf*	38.9 (+14.4)	1.66	–
G. intraradices + *Bm*	34.4 (+1.2)	2.00	70
G. intraradices + *Pf*	35.7 (+5.0)	2.00	74
B. megaterium + *Pf*	34.5 (+1.5)	2.66	–
Critical Difference (CD) at 5%	–	*0.7433*	*4.321*

Inoculated with 5,000 freshly hatched juveniles of *Meloidogyne incognita* per pot

[a] Percent increase (+) or decrease (−) over untreated-uninoculated control

Fig. 16.3 Root-knot nematode-infested plant of patchouli and infested root

16.3 Patchouli, *Pogostemon patchouli*

16.3.1 Nematodes

16.3.1.1 Root-Knot Nematodes, *Meloidogyne* spp.

Root-knot nematodes (*M. incognita*, *M. javanica*, *M. hapla*) have become most important constraints for the successful cultivation of patchouli in India. Prasad (1978) and Prasad and Reddy (1979, 1984) reported 47.0 and 86.7% loss in shoot weight and shade-dried leaf yield, respectively, in patchouli by *M. incognita*. They further reported that the multiplication of *M. incognita* was more in sandy soil on patchouli than in clay soil.

(i) Symptoms: Infection of root-knot nematodes occurs when plants are in their early stage of development. Root-knot-infested plants are weak and grow slowly. Heavy galling on root system with root-knot nematode on patchouli results in stunting, wilting, defoliation and chlorosis of the plant. Sometimes root galls are very small or the surrounding galls coalesce to form large ones up to 2–5 cm or even more (Fig. 16.3).

(ii) Integrated Management: Treat nursery beds with neem/*Pongamia* cake at 1 kg/m^2 along with *G. fasciculatum* at 50 g/m^2.

16.3.1.2 Root-Knot Nematode and Root Rot Disease Complex

(i) Integrated Management (a) Bioagents and Botanicals: Combined mortality due to root rot and root-knot nematode could be minimized by the application of *T. harzianum* + karanj cake at 5 Mt/ha.

16.4 Chamomile, *Matricaria chamomilla*

16.4.1 Nematodes

16.4.1.1 Root-Knot Nematode, *M. incognita*

(i) Symptoms: *M. incognita* causes considerable reduction in growth, flower buds and essential oil yield of chamomile (Pandey et al. 1999).

(ii) Integrated Management (a) Botanicals and AMF: Integration of *G. mosseae* and neem cake reduced the severity of root-knot disease

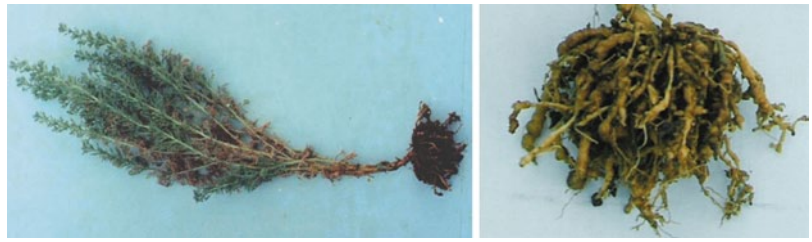


Fig. 16.4 Root-knot-infested plant and roots of davana

and enhanced the growth, biomass and flower yield of chamomile by 12–37%.

16.5 Davana, *Artemisia pallens*

16.5.1 Nematodes

16.5.1.1 Root-Knot Nematode, *Meloidogyne incognita*

The root-knot nematode is a major problem in the cultivation of davana. *M. incognita* is responsible for more than 30% reduction in oil yield of davana (Haseeb and Pandey 1990).

(i) Symptoms: The main symptoms are chlorotic and stunted plants with less number of flower buds (which are the major source of essential oil) showing patchy appearance in the field. Their roots are severely galled by root-knot nematodes (Fig. 16.4). One larva per 2 g of soil has been found as an economic threshold level of *M. incognita* on this crop.

(ii) Integrated Management

(a) Two Botanicals: Increase in nematicidal efficacy of neem cake along with FYM for 90–120 days in comparison with 60 days for fenamiphos has been noticed (Anitha and Vadivelu 1997).

References

Anitha, B., & Vadivelu, S. (1997). Management of root-knot nematode, *Meloidogyne hapla* on scented geranium, *Pelargonium graveolans*. *Indian Journal of Nematology, 27,* 123–125.

Haseeb, A., & Pandey, R. (1989). Observation on *Meloidogyne* spp. infesting Japanese mint. New disease records. *Nematropica, 19,* 93–97.

Haseeb, A., & Pandey, R. (1990). Root-knot nematodes—a constraint to cultivation of davana, *Artemisia pallens*. *Tropical Pest Management, 36,* 317–319.

Pandey, R. (2001). Influence of *Meloidogyne incognita*, *Pratylenchus thornei* and *Tylenchorhynchus vulgaris* on growth and oil yield of menthol mint. *Indian Journal of Nematology, 31,* 111–114.

Pandey, R. (2005). Field application of bio-organics in the management of *Meloidogyne incognita* in *Mentha arvensis*. *Nematologica Mediterranea, 33,* 51–54.

Pandey, R., Singh, H. B., & Gupta, M. L. (1997). Antagonistic impact of vesicular arbuscular mycorrhizae (VAM) on *Meloidogyne incognita* population development in Japanese mint. *International Journal of Tropical Plant Diseases, 15,* 237–245.

Pandey, R., Singh, H. B., & Kumar, S. (1999). Pathogenicity of *Meloidogyne incognita* (Kofoid & White) Chitwood on *Matricaria chamomilla* L. *Journal of Spices and Aromatic Crops, 8,* 201–203.

Pandey, R., Mishra, A. K., Tiwari, S., Singh, H. N., & Kalra, A. (2011). Enhanced tolerance of *Mentha arvensis* against *Meloidogyne incognita* (Kofoid and White) Chitwood through mutualistic endophytes and PGPRs. *Journal of Plant Interactions, 6*(4), 247–253.

Prasad, P. R. K. (1978). *Studies on the root-knot nematodes infecting patchouli (*Pogostemon cablin *Benth)*. MSc (Agriculture) thesis, University of Agricultural Sciences, Bangalore.

Prasad, P. R. K., & Reddy, D. D. R. (1979). Study on the root-knot nematode infecting patchouli (*Pogostemon cablin* Benth). *Mysore Journal of Agricultural Sciences, 13,* 367–368.

Prasad, P. R. K., & Reddy, D. D. R. (1984). Pathogenicity and analysis of crop losses on patchouli due to *Meloidogyne incognita*. *Indian Journal of Nematology, 14,* 36–38.

Rajendran, B., & Rajendran, G. (1979). Report of *Meloidogyne incognita* in *Jasminum flexile*. *South Indian Horticulture, 27,* 70.

Sundarababu, R. (1992). Nematodes in jasmine. *Tamil Nadu Agricultural University Newsletter, 21*(11), 2.

Tuber Crops

17

17.1 Sweet Potato, *Ipomea batatas*

17.1.1 Insect Pests

17.1.1.1 Weevil, *Cylas* spp.

(i) Damage Tubers and vines are tunneled by small white, legless larvae. The tunnels may be partially filled with frass. Ant-like weevils, either having glassy blue black elytra, reddish brown legs and thorax and a black head (*Cylas formicarius*) or entirely shiny black (*Cylas punctipennis* or *Cylas brunneus*) may be found on the leaves or in the tunnels (Fig. 17.1). Yield, storage life and plant vigour are reduced.

(ii) Integrated Management (a) Cultural and Bioagents: The solitary ectoparasitoid, *Rhaconotus menippus* (at 10 pairs/5 m^2) and the green muscardine fungus, *Metarhizium anisopliae* (at 3×10^9/mL) in combination with reridging (putting an additional layer of soil around the plant) at 65 days after planting is highly effective in reducing the weevil damage. This method is equally effective as that of chemical method. The fungus and parasitoid are recovered from the treated plots.

(b) Cultural, Biological and Chemical: The following integrated pest management (IPM) technology was developed at Central Tuber Crops Research Institute, Tiruvanthapuram, Kerala (Palaniswami 2002):

- Removal and destruction of *Ipomoea* weeds.
- Selection of weevil-free planting material.
- Dipping the vines in 0.05 % Fenthion or fenitrothion or monocrotophos for 10 min.
- Installation of traps with septa (sex pheromone impregnated in 4 mm rubber tube uniformly in such a way, that 1 cm bits of such tube contains 1 mg sex pheromone) at 100 traps/ha. The traps are placed with the commencement of planting and continued a fortnight after the harvest. The male weevils trapped inside the bin trap (bottom of the trap contains water with a pinch of detergent) are removed on alternate days.
- Reridging (putting an additional layer of soil around the plant) the crop at 30 and 50 days after planting.
- Conserving the naturally occurring braconid solitary ectoparasitoids of weevil by not spraying insecticides especially on the vines.
- Harvesting the crop at 100–110 days maturity.
- Removal and destruction of crop residues like infested tubers and vines.
- Practicing crop rotation.

The above IPM technology was assessed, refined and validated at National level in ten different centres under All India Coordinated Research Project on Tuber Crops. The farmers from different sweet potato growing areas were convinced about the benefits of this technology in enhancing tuber production and reducing weevil infestation.

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_17, © Springer India 2014

Fig. 17.1 *L*—Sweet potato weevil damage, *R*—Adult beetle

17.2 Colocasia, *Colocasia esculenta*

17.2.1 Diseases

17.2.1.1 Leaf Blight, *Phytophthora colocasiae*

The leaf blight of *Colocasia* is a major and widespread disease causing 50% loss in tuber yield. This disease occurs widely in India, Indonesia, Malaysia, Sarawak and the Pacific. It has also been recorded from parts of Africa and the Caribbean.

(i) Symptoms Lesions are initially small, dark and round but rapidly enlarge to 2.5–5.0 cm in diameter and become purplish to brownish in colour (Fig. 17.2). Drops of a clear liquid exude from the spots, and turn yellow, orange or purple when dry. There is usually chlorotic halo around the spots. As the disease progresses, the spots coalesce and have characteristic rings of yellow or brown colour. Eventually the whole leaf may be affected and may die. Leaf blight is common in wetland and is favoured by humid, cloudy conditions and poor soil fertility. Losses up to 50% have been reported. Spores are produced on the leaf spots and are readily spread by rain.

Fig. 17.2 Leaf blight damage on *Colocasia*

(ii) Integrated Management

(a) Bioagents and Chemicals: Tuber treatment with *Trichoderma viride* +0.25% mancozeb spray after the first appearance of the disease +0.2% ridomil spray 20 days after mancozeb spray was effective in reducing the percent leaf area damaged and increased the yield.

17.3 Elephant Foot Yam, *Amorphophallus paeoniifolius*

17.3.1 Diseases

17.3.1.1 Collar Rot, *Sclerotium rolfsii*

(i) Integrated Management

(a) Botanicals and Bioagents: Corm treatment with *T. viride* at 5 g/L along with soil application of neem cake at 250 g/pit effectively controlled collar rot disease.

References

Palaniswami, M. S. (2002). *Advances in integrated approaches for sweet potato weevil management. Proceedings of the International Conference on Vegetables* (pp. 304–308). Bangalore: Dr. Prem Nath Agricultural Science Foundation.

Part V

Biointensive Integrated Pest Management in Plantation and Spice Crops

Plantation Crops

18

18.1 Coffee, *Coffea arabica, Coffea canephora*

18.1.1 Diseases

18.1.1.1 Brown Root, *Fomes noxius*; Red Root, *Poria hypolaterita;* Black Root and Santavery Root Disease, *Corticium koleroga*

1. Symptoms: Stump or brown root-rot affected bushes show a gradual yellowing of leaves and defoliation and death. Affected roots are brittle and show dark brown wavy lines of the fungus. Stem near the ground level becomes soft and spongy. Brown fungal encrustation can be seen on the affected roots (Fig. 18.1).

The pest infestation causes blackening and rotting of affected leaves, young twigs and berries. Affected leaves get detached and hang down by means of slimy fungal strands. Defoliation and berry drop occur.

2. Integrated Management (a) Bioagents and Botanicals: Application of 5–10 kg/plant of well decomposed farmyard manure (FYM)/compost fortified with *Trichoderma* sp. to the surrounding healthy plants is effective.

Soil application of 2 kg *Trichoderma harzianum* or *Trichoderma viride* in compost/plant in drip circle during June and October gave good control of brown root and red root diseases (Nirmala Kannan et al. 1997) (Table 18.1). Mix 2.5 kg of *Trichoderma* spp. in 100 kg of FYM. Leave it overnight. Spread these equally around plant basins twice a year (September–October and May–June).

18.1.1.2 Pink Disease, *Corticium salmonicolor*

1. Symptoms: The symptoms include pink encrustation on infected branches and development of longitudinal cracks through which pink encrustation bursts. Cobweb like mycelial branches develop on affected branches. Infected branches lose leaves and die (Fig. 18.2).

2. Integrated Management (a) Bioagents and Botanicals: Mix 2.5 kg of *T. viride* in 100 kg of FYM. Leave it overnight. Spread these equally around plant basins twice a year.

18.2 Tea, *Camellia sinensis*

18.2.1 Insect Pests

18.2.1.1 Diaspine Scale, *Fiorinia theae;* Purple Scale, *Chrysomphalus aonidum*

1. Damage: The most common insect pests of tea are scales. Scale insects feed on plants by piercing plant tissue and sucking sap. Scales do not look like typical insects. They are small, immobile and have no visible legs. They vary in appearance depending on species and sex. Some look like small fish scales attached to the plant.

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_18, © Springer India 2014

Fig. 18.1 Black root and red root on coffee

Table 18.1 Effect of *Trichoderma viride* and *Trichoderma harzianum* on red and brown root diseases of coffee

Disease	Antagonistic fungi	Type of application	Dose/plant	% disease control
Red root	*T. viride* and *T. harzianum* (10^{-8}–10^{-9})	Soil application along with 5 kg FYM	0.5–1.0 kg twice yearly (June and Oct.)	83–91
Brown root	*T. viride* and *T. harzianum* (10^{-8}–10^{-9}) in compost	Soil application	2.0 kg	87

As a result of their unusual appearance, populations can reach damaging levels before they are noticed.

On tea, scales usually attach to leaves but some species also attach to stems. Their feeding weakens the plant. With a heavy infestation, symptoms include yellowing of the upper leaf surface (Fig. 18.3), fewer and smaller blossoms, leaf drop, twig dieback and sometimes death.

Fig. 18.2 Pink disease in coffee

2. Integrated Management

(a) Two Bioagents: Combined action of reduviid bug (predator) and parasitoids (*Aphytis* sp.) keeps the diaspine scale (*F. theae*) population very low.

18.2.2 Diseases

18.2.2.1 Blister Blight, *Exobasidium vexans, Exobasidium camelliae*

1. Symptoms: The blister blight is the major disease affecting the tender harvestable shoots of tea resulting in enormous crop loss. Translucent spots appear on tender leaves. Tender stem also gets affected. Leaf galls are most often observed during the spring flush of growth. New shoots and leaves become enlarged, thickened and fleshy, and appear abnormal (Fig. 18.4). The colour of the affected areas turns from light green to nearly white or pink. The galls later rupture on the undersides of the leaves revealing a whitish mass of spores. The galls eventually harden and become brown. Plants are seldom severely damaged.

2. Integrated Management

(a) Bioagents and Chemicals: Field evaluation of *T. harzianum, Trichoderma virens, Pseudomonas fluorescens* and *Bacillus subtilis* revealed that they could provide moderate control of the disease; but when they were supplemented with external nutrients (salicylic acid and vermiwash), their efficacy was improved (Balasuriya and Kalaichelvan 2000) (Table 18.2).

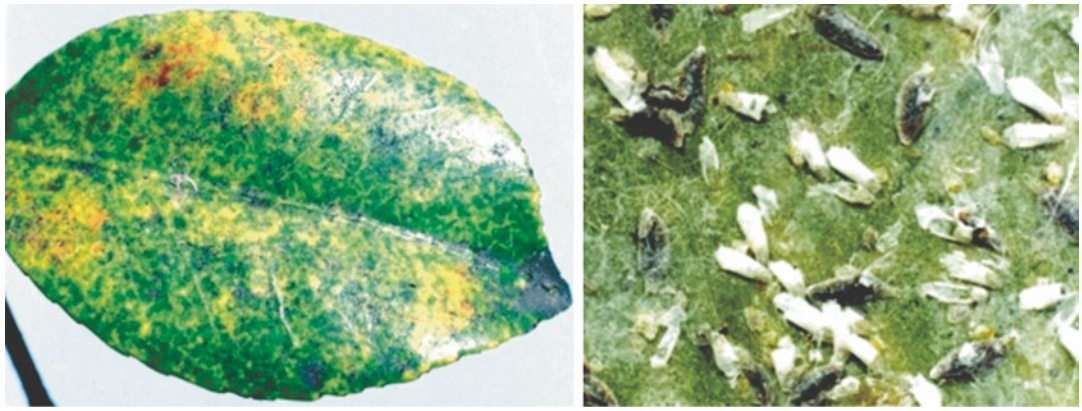


Fig. 18.3 *L*—Tea scale damage to top of leaf, *R*—Adult tea scales on underside of leaf (males are snowy white and females are dark)

Fig. 18.4 Tea leaves infected by blister blight disease

Table 18.2 Impact of nutritional supplements on the efficacy of biocontrol agents in controlling blister blight disease of tea

Biocontrol agents	Disease incidence (%)	Protection (%)
Trichoderma virens	52.4	38.7
T. virens + Vermiwash	52.7	38.4
Trichoderma harzianum	60.5	29.2
T. harzianum + Vermiwash	57.8	32.4
Pseudomonas fluorescens	60.4	29.3
P. fluorescens + Salicylic acid and Ammonium sulphate	52.3	38.8
Bacillus subtilis	57.0	33.3
B. subtilis + Salicylic acid and Ammonium sulphate	47.1	44.9
Control (unsprayed)	85.5	–

18.2.2.2 Grey Blight and Dieback, *Pestalotia theae/Pestalotiopsis theae*

1. Symptoms: Mature leaves (Fig. 18.5), young shoots and bare stalks are affected by this pathogen. Infection on young shoot results in dieback of shoots. Dieback of shoots became a major problem mainly due to continuous shear harvesting. Grey blight adversely affects the health of the bushes, which in turn affects yield while dieback of young shoots directly leads to substantial crop loss. Studies indicated that the disease incidence is in its peak during July to December. The crop loss due to the disease is 17%. The economic

Fig. 18.5 Grey blight infection on tea leaf

Table 18.3 Effect of biocontrol agents on grey blight incidence in tea

Treatment	Disease incidence (%)	
	Pre-treatment	Post-treatment
Pseudomonas fluorescens	28.1	20.3 (−27.8)
P. fluorescens + vermiwash	20.5	10.6 (−48.4)
Trichoderma harzianum	22.1	16.3 (−50.8)
T. harzianum + salicylic acid and ammonium sulphate	20.4	10.0 (−50.8)
Mancozeb	20.7	8.4 (−59.7)
Carbendazim	20.6	6.6 (−68.0)
Control (unsprayed)	34.3	39.2 (+14.1)

Values in parenthesis indicate the % decrease (−) or increase (+) in disease incidence

threshold level of the disease is fixed as 18% at a sale price of ₹ 50/- per kg of made tea.

2. Integrated Management

(a) Bioagents and Chemicals: Field testing of biocontrol agents like *T. harzianum* and *P. fluorescens* could check grey blight disease. Efficacy of these organisms was improved when they were supplemented with nutrients (Table 18.3) (Chakraborty et al. 1994).

18.2.2.3 Collar Canker, *Phomopsis theae*

1. Symptoms: A wound pathogen, *Phomopsis theae* is responsible for the disease (Fig. 18.6). It is prevalent in young tea and clones are more susceptible than seedlings. *In vitro* studies indicated that the pathogen completes its life cycle in 10–13 days. Impact of predisposing factors on disease development indicated that the nature of soil is an important factor. Disease incidence was more in gravelly soil.

2. Integrated Management

(a) Bioagents and Chemicals: The biological control agents like *T. harzianum* and *T. virens*, when applied both to the soil around the bush and used for wound dressing were superior for the management of collar canker compared to chemical treatments. These plants were more healthy and vigorous (Table 18.4) (Ponmurugan and Baby 2005).

Fig. 18.6 Collar canker on tea

Table 18.4 Effect of chemicals and biocontrol agents on collar canker disease of tea

Treatment	Canker size (cm^2)	
	Pre-treatment	Post-treatment
T. harzianum soil application + wound dressing	11.3	5.6 (−50.4)
T. virens soil application + wound dressing	17.0	5.5 (−67.6)
T. harzianum wound dressing + carbendazim soil drenching	39.9	27.9 (−30.1)
T. virens wound dressing + carbendazim soil drenching	12.1	7.1 (−41.3)
Carbendazim soil drenching	13.8	10.2 (−26.1)
Copper oxychloride wound dressing	3.0	4.8 (+60.0)
Untreated control	45.2	97.2 (+115.0)

18.2.2.4 Black Root, *Rosellinia arcuata*

The black root disease generally occurs in soils that are rich in organic litter, in cool or cold habitat. It is a major problem in southern India at elevations of 1,500 m above Mean Sea Level (MSL) and Darjeeling (West Bengal). Occasionally, it is also noticed at mid and low elevations.

1. Symptoms: The fungal mycelium is cobwebby in appearance, whitish grey or black in colour, spreading rapidly on the surface of the soil on organic debris. When the mycelium

Fig. 18.7 Brown root of tea

comes in contact with tea roots, it penetrates the bark and produces typical star-shaped mycelial structures on the surface of the wood beneath the bark. Very rarely black spherical perithecia are seen at the collar region of the plant. Apart from tea, the disease also affects certain green manure and shade plants commonly grown in tea plantations.

2. Integrated Management (a) Cultural and Bioagents: Black root disease can be controlled by avoiding burial of prunings in infested field and incorporation of *T. virens/T. viride* at 200 g/plant at the time of planting. Rehabilitating the soil with Guatemala grass and use of biocontrol agents at 200 g/plant of *T. viride* effectively check the disease (Baby and Chandramouli 1996).

18.2.2.5 Brown Root, *Phellinus noxius*

1. Symptoms: The brown root is the most common root disease of tea. This pathogen mainly spreads by root contact. Hence, the disease occurs in distinct concentric patches in tea fields. The fungal mycelium is fawn in colour. *P. noxius* affected roots become soft and spongy. The infected root disintegrates in advanced stages of the disease and becomes spongy. When such roots are split longitudinally, typical brownish honeycomb-like reticulations are seen. The surface of the root is heavily encrusted with soil. The fructifications are typical bracket-shaped (Fig. 18.7), but occur rarely.

2. Integrated Management (a) Cultural and Bioagents: Rehabilitating the soil with Guatemala grass and use of biocontrol agents at 200 g/plant of *T. harzianum/T. viride/Trichoderma hamatum/ Trichoderma reesei/Trichoderma koningii/T. virens* effectively check the disease (Baby and Chandramouli 1996).

18.2.2.6 Red Root, *Poria hypolateritia*

1. Symptoms: The red root disease is extremely common in all tea areas of southern India. *P. hypolateritia* produces blood red mycelium on affected roots. The fungal mycelium is initially white, then turns pink to pale red and in later stages it is dark red, almost black in colour. The mycelium is generally present as a sheet on the root surface and the typical red colour is invariably seen, when the root is rubbed vigorously under running water and held to bright light. The disease spreads both by root contact as well as by free mycelial spread to a limited extent. Roots of the affected bushes are encrusted with soil. In advanced stages, the affected root becomes spongy. It takes almost 5 years for a mature bush to succumb following the attack.

Fig. 18.8 Collar crack on tea

2. Integrated Management
(a) Cultural and Bioagents: Rehabilitating the soil with Guatemala grass and use of biocontrol agents at 200 g/plant of *T. harzianum/T. virens* effectively checks the disease (Baby and Chandramouli 1996).

18.2.2.7 Root Rot or Collar Crack, *Armillaria mellea*

1. Symptoms: The collar crack disease occurs in isolated areas, mainly in South India. It derives its name from longitudinal fissures observed on the bark of the invaded tea roots (Fig. 18.8). It can also be observed readily by the characteristic black rhizomorphs, which resemble a shoe lace and are seen in large numbers. The fungal mycelium, which is white in colour, grows densely under the bark and due to the pressure the bark splits. The fungus invades the host plant either by root contact or rhizomorphs, which are capable of traversing long distances through the soil from the food base. The fruiting body is typical mushroom-like basidiocarp, and although it is rarely recorded, when it occurs, it is found in abundance around the collar of the diseased plant.

2. Integrated Management
(a) Cultural and Bioagents: Rehabilitating the soil with Guatemala grass and use of biocontrol agents at 200 g/plant of *T. harzianum/T. virens* effectively checks the disease.

(b) Physical and Bioagents: Talam and Otieno (2002) reported that soil solarization and application of *T. harzianum* were effective in controlling root splitting disease. They also found that the control achieved with *T. harzianum* was excellent when applied after soil solarization.

18.2.3 Nematodes

18.2.3.1 Root-Knot Nematodes, *Meloidogyne incognita* (in nurseries)

The first report of root-knot nematode in young tea was from South India, where large numbers of seedlings were found infected (Barber 1901). *M. incognita, Meloidogyne javanica* and *Meloidogyne hapla* have been found associated with tea in India.

1. Symptoms: Young nursery plants, both seedlings and vegetatively propagated clonal plants, are severely damaged by root-knot nematodes. Seedling plants in which both the tap-root and lateral rots are severely attacked suffer greater damage than do clonal tea plants of equivalent age, probably because seedling tea plants possess less than half the root bulk of clonal plants of similar age. A marked increase in resistance is observed between 8 and 15 months.

2. Integrated Management
(a) Botanicals and Chemicals: Combination of neem cake at 5 g/seedling + carbofuran 3G at 1.5 g/seedling improved plant growth characters and reduced number of galls, egg masses and eggs/egg mass (Kalita and Bora 2006).

(b) Cultural and Bioagents: The rehabilitation crops such as Mana grass (*Cymbopogon confertiflorus*) or Guatemala grass (*Tripsacum laxum*) (which help to improve the soil) and use of biocontrol agents at 200 g/plant of *T. harzianum/T. virens* effectively check the disease.

Fig. 18.9 Rhinoceros beetle damage on coconut and adult beetle

The above grasses are resistant to *Meloidogyne* spp. The soil population of parasitic nematodes decline rapidly when these grasses are grown for one or more years before replanting tea.

18.3 Coconut, *Cocos nucifera*

18.3.1 Insect Pests

18.3.1.1 Rhinoceros Beetle, *Oryctes rhinoceros*

1. Damage: Rhinoceros beetle feeds on unopened fronds and spathes of coconut. Characteristic fan like geometric cuts in the newly emerged frond are observed (Fig. 18.9). Infestation on spathe often destroys the inflorescence and prevents the production of nuts.

2. Integrated Management (a) Physical, Bioagents and Chemicals: Integrated pest management includes hooking out of beetle, placement of perforated polythene sachets containing phorate in leaf axil and adoption of biological control measures using baculovirus.

18.3.2 Diseases

18.3.2.1 Basal Stem Rot or Thanjavur Wilt, *Ganoderma lucidum, Ganoderma applanatum*

1. Symptoms: In Tamil Nadu and Andhra Pradesh, Thanjavur wilt, otherwise called Ganoderma wilt is a serious problem. The symptoms are presence of bleeding patches at the stem base (Fig. 18.10), premature yellowing and drooping of outer whorl of leaves and gradual drying of spindle. The other symptoms include decay of root system, flaccid spindle leaves, browning of outer leaves, and appearance of bleeding patches on the basal region of the stem.

2. Integrated Management (a) Bioagents and Botanicals: Application of *T. harzianum/T. viride* along with neem cake at 5 to 10 kg/plant has been found to control the multiplication of the pathogen in sick soils. When combined with phosphobacteria or plant growth promoting rhizobacteria, synergistic effects have been noticed. *T. harzianum* applied along with neem cake reduced the disease index and increased the yield of coconut.

Raising seedlings in *T. harzianum/P. fluorescens* amended compost and soil application of *T. harzianum/P. fluorescens* along with neem cake/compost in the main field was useful in minimizing the incidence of basal stem rot of coconut.

18.3.2.2 Stem Bleeding, *Thielaviopsis paradoxa*

1. Symptoms: The characteristic symptom of stem bleeding is the dark gummy exudation from the trunk. Exudation of reddish brown liquid is observed through longitudinal cracks in the trunk, generally at the base of the trunk (Fig. 18.11). Bleeding patches spread throughout as the disease advances. The liquid oozing out dries up and turns black. Tissues below the lesions rot and turn yellow and then black. Premature yellowing

Fig. 18.10 Basal stem rot in coconut

Fig. 18.11 Stem bleeding on coconut

of leaves is observed in the outer whorl. Trunk gradually tapers at apex and crown size becomes reduced (Fig. 18.11).

Growth cracks on trunk, severe summer followed by sudden wetting, imbalanced nutrition, and excess salinity are the predisposing factors for the disease.

2. Integrated Management

(a) Bioagents and Botanicals: Control measures include application of neem cake along with antagonistic fungi like *Trichoderma*. Neem cake enriched with *T. virens, T. hamatum* and *T. harzianum* has been found to be very effective in reducing the population of the pathogen in the soil. These antagonistic fungi thrive well in neem cake supplemented with a small quantity of rice/wheat bran thus effecting their multiplication an easy task. *T. harzianum, T. viride, T. hamatum* and *T. virens* grow very well in rice bran and neem cake (1:1 w/w) and reduced stem bleeding when applied to the soil. Soil application of neem cake and FYM mixed with *T. virens* showed reduction of stem bleeding up to 31.3 %, least disease index and the highest yield.

Raising seedlings in *T. harzianum/P. fluorescens* amended compost and soil application of *T. harzianum/P. fluorescens* along with neem cake/compost in the main field was useful in minimizing the incidence of stem bleeding disease of coconut.

(b) Bioagents, Botanicals and Chemicals: Treatment with 4 % tridemorph root feeding and wound dressing + coal tar sealing + soil applica-

Fig. 18.12 Burrowing nematode symptoms on coconut

tion of *T. virens*, neem cake, FYM and NPK fertilizers showed the lowest disease index and the highest yield followed by treatment with carbendazim root feeding and wound dressing + coal tar sealing + soil application of *T. virens*, neem cake, FYM and NPK (Ramanujam et al. 1997).

18.3.3 Nematodes

18.3.3.1 Burrowing Nematode, *Radopholus similis*

The burrowing nematode was reported from coconut palms in Kerala, India by Weischer (1967). *R. similis* is the most important nematode pest of coconut and is responsible for considerable amount of root rotting (Koshy et al. 1978). It causes 30% yield loss in coconut (Koshy and Geetha 1992). The threshold inoculum density required to cause significant reduction in various growth parameters of coconut is 100 nematodes/625 mL sandy loam soil over a period of 5 years under field conditions (Koshy 1986).

1. Symptoms: The burrowing nematode infested coconut palms exhibit general decline symptoms like yellowing, button shedding, reduction in number and size of leaves and leaflets (Fig. 18.12), delay in flowering and reduced yield which are non-specific. Symptoms on the root are more specific. *R. similis* on infestation produces isolated elongate orange coloured lesions on tender and semi-hard roots (Fig. 18.12). Consequent to nematode parasitization and multiplication, these lesions enlarge and coalesce to cause extensive rotting of roots. Tender roots on heavy infestation become spongy in texture. On semi-hard orange-coloured roots, surface cracks are commonly seen. As high as 4,000 nematodes were recovered from 1 g (1-in. length) of main roots. The drastic reduction in the number and mass of tertiary feeder roots on parasitization by the nematode limits plant growth (Koshy and Sosamma 1987).

2. Survival and Spread: Under field conditions, *R. similis* survives for 6 months in moist soil (27–36 °C) and 1 month in dry soil (29–39 °C). In roots of stumps of felled coconut palms, the nematode survives for up to 6 months. The infested coconut roots yielded maximum number of *R. similis* during October–November and minimum during March–July. A mean soil temperature below 25 °C and light rainfall coupled with availability of tender fleshy roots are

the factors favourable for *R. similis* multiplication (Koshy and Sosamma 1978).

Infested coconut seedlings help in the dissemination of the nematode to distant places. Apart from coconut, infested planting materials of intercrops such as areca nut, banana, pepper, ginger, turmeric also serve as sources of inoculum.

3. Integrated Management

(a) Botanicals and Chemicals: Thirty per cent increase in yield and 5–10% decrease in disease indices of palms affected with root wilt disease was recorded by the application of *Hydnocarpus* oil cake and phorate granules at 10 g a.i./palm in June–July and in October–November.

(b) Cultural, Botanicals and Chemicals: Application of FYM or oil cakes, cultivation of *Crotalaria juncea* in the basin and interspaces (and used as green manure), and application of phorate 10G at 100 g/palm/twice a year (during May–June and September–October) is effective against burrowing nematode.

18.4 Arecanut, *Areca catechu*

18.4.1 Nematodes

18.4.1.1 Burrowing Nematode, Radopholus similis

1. Symptoms: Plants infested with *R. similis* induces 'yellow leaf' disease. Infestation produces small, elongate, orange lesions in young, succulent, creamy-white to light-orange portions of the main and lateral roots. The adjoining lesions coalesce and cause extensive rotting.

Large number of crops like banana, coconut, black pepper, ginger, turmeric, betel vine, etc. are known hosts of *R. similis*.

2. Integrated Management

(a) Botanicals and Chemicals: Integration of neem oil cake application at 1 kg/plant with phorate at 15 g a.i./plant gave effective control of *R. similis* in areca nut. In areca nut + banana + black pepper cropping system, integration of phorate at 15 g a.i./plant with neem oil cake at 500 g/plant was found most effective in reducing the nematode population (Sudha and Sundararaju 1998).

(b) Botanicals and Bioagents: Soil amended with glyricidia leaves and bioagents (*Paecilomyces lilacinus*, *Pasteuria penetrans* and AMF) was very effective in increasing plant height, leaf area and root growth; and in reducing burrowing nematode population (95%) and root lesion index.

18.5 Betel Vine, *Piper betel*

18.5.1 Diseases

18.5.1.1 Collar/Basal Rot, *Sclerotium rolfsii*

1. Symptoms: The plants are usually attacked at ground level (collar region). Dense white cottony mass of threads (mycelium) are seen on stems and soon many small mustard-like sclerotia appear in the soil near collar region. Bark shredding is seen on infected stem. This causes rotting of affected portion causing wilting and ultimate death of plants (Fig. 18.13).

2. Integrated Management

a. **Bioagents and Chemicals:** Maiti and Sen (1988) integrated *T. harzianum* with nitrogenous fertilizers for managing *S. rolfsii*.
b. **Bioagents and Botanicals:** Application of *T. viride* at 5 kg mixed in 125 kg FYM/ha is useful.
c. **Two Bioagents:** Field trials demonstrated that strain *P. fluorescens* NBRI-N6 was better than *P. fluorescens* NBRI-N in increasing the yield of betel vine significantly, whereas a consortium of the two strains controlled the collar rot disease more than either of the strains (Singh et al. 2003).

18.5.2 Nematodes

18.5.2.1 Root-knot Nematode, *Meloidogyne* spp.

Root-knot disease caused by *M. incognita* and *M. javanica* is the most common disease affecting betel vine plant in more than 90% of the fields. *M. incognita* was responsible for 21–38% loss in leaf yield of betel vine (Saikia 1992; Jonathan et al. 1990).

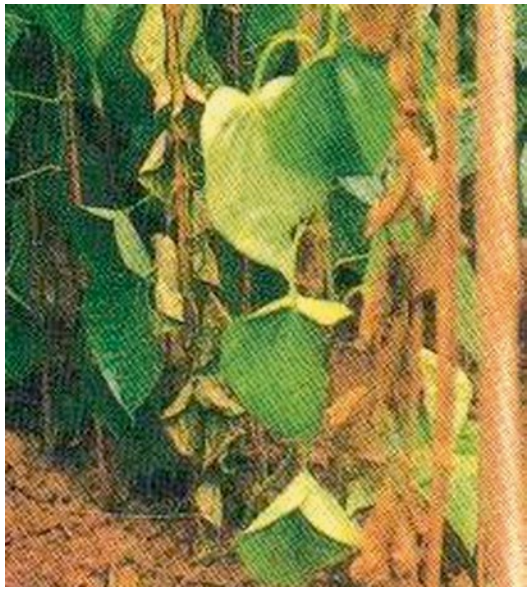


Fig. 18.13 Collar rot symptoms on betel vine

1. Symptoms: The affected plants show growth reduction and yellowing and abnormal thickening of leaves with necrosis commencing from the tip and margins of leaf and extending inwards. The disease causes reduction in quality and quantity of leaves, sometimes leading to serious wilt disease that greatly affect the growth of plants and produce heavy losses to the farmers. Blackening and drooping of the growing tip and yellowing of leaves occurs due to root-knot nematode infestation. Galls of varying sizes and shapes develop in roots leading to quick root decay.

2. Integrated Management

(a) Botanicals and Bioagents: *T. viride* mixed with mustard oil cake at 100 g/10 kg cake applied in three split doses reduced the nematode infestation and enhanced the leaf yield.

18.5.2.2 Root-Knot Nematode, *M. incognita* and Foot Rot, *Phytophthora capsici* Disease Complex

1. Symptoms: The population of root-knot nematode had been found to be positively correlated with *Phytophthora* wilt disease incidence in diseased betel vine gardens.

2. Integrated Management

(a) Cultural, Bioagents, Botanicals and Chemicals

- Summer ploughing and exposing the field to sunlight during May prior to sowing of *Sesbania* sp. (live standard) minimizes the initial load of inoculum of both the nematode and the fungus.
- Selection of healthy seed vines from nematode-free and disease-free mother plants for planting.
- Dipping seed vines in 0.25% Bordeaux mixture solution for 5 min before planting.
- Application of FYM at 30 MT/ha to promote multiplication of antagonistic microbes which in turn kills nematodes.
- Spot application of neem cake enriched with *P. lilacinus* at 3 MT/ha in three split doses—first dose at 45 DAP and remaining two splits at 45 days interval during Northeast monsoon season (October–December).
- Rotation of betel vine crop with rice.

(b) Two Bioagents: Combined application of *Pseudomonas* sp. (Pfbv 22) and *Bacillus* sp. (Bbv 57) gave significant reduction in nematode infestation (gall index, number of egg laying females and soil population), wilt disease incidence and increase in leaf yield. The treatment also enhanced the biochemical markers responsible for induced systemic resistance such as peroxidase, polyphenol oxidase and phenylalanine ammonia lyase (Jonathan et al. 2006) (Table 18.5).

(c) Bioagents and Botanicals: Spot application of neem cake enriched with *P. lilacinus* at 3 MT/ha in three split doses—first dose at 45 DAP and remaining two splits at 45 days interval during Northeast monsoon season (October–December).

18.6 Cocoa, *Theobroma cacao*

18.6.1 Diseases

18.6.1.1 Black Pod Rot, *Phytophthora palmivora*

1. Symptoms: Black pod disease is the major disease of cocoa prevalent during monsoon season. The affected pods become pale brownish spoiling the quality of beans. Infection appears

Table 18.5 Effect of rhizobacterial formulations on leaf yield, nematode and wilt incidence in betel vine under glasshouse conditions

Treatment/Dose (2.5×10^8 cfu/g)	No. of leaves/vine	Gall index (0–5 scale)	Wilt index (0–5 scale)
Pseudomonas spp.—Pfbv 22	195	3.0	2.4
Bacillus spp.—Bbv 57	201	3.0	2.6
P. fluorescens—Pf 1	190	3.5	2.4
Pfbv 22 + Bbv 57	225	2.5	1.7
Pfbv 22 + Pf 1	197	3.0	2.2
Bbv 57 + Pf 1	190	3.5	2.4
Pfbv 22 + Bbv 57 + Pf 1	191	3.0	2.4
Metalaxyl (0.2%) + Carbofuran (2 g/vine)	211	2.4	1.9
Control	163	5.0	3.3
CD (P = 0.05)	*6.5*	*0.5*	*0.4*

Fig. 18.14 Black pod on cocoa

as chocolate brown spot, which spreads very rapidly and soon occupies the entire surface of the pod (Fig. 18.14). As disease advances, a whitish growth of fungus consisting of fungal sporangia is produced over the affected pod surface. Affected pods become dark brown or black.

2. Integrated Management

(a) Bioagents and Chemicals: Application of *Trichoderma* at 100 g/tree to the tree base during June and September and spraying of fungicides (Ridomil/Akomin) to the trunk and canopy pods at monthly intervals from June to September gave effective control of black pod disease.

18.7 Rubber, *Hevea brasiliensis*

18.7.1 Diseases

18.7.1.1 Brown Root, *Phallinus noxius*

1. Symptoms: The incidence of the disease can be detected by the discolouration of the foliage along with cessation of growth. Roots become encrusted with a mass of soil, sand and small stones, which cannot be washed off easily. Wood also shows brown discolouration and in advanced stages, honey combing is seen.

2. Integrated Management

(a) Bioagents and Chemicals: An integrated approach using both fungicide (Tridemorph) and the antagonistic fungus (*Trichoderma*) has been observed to improve the disease control (Hashim 1990).

References

Baby, U. I., & Chandramouli (1996). Biological antagonism of *Trichoderma* and *Gliocla-dium* spp. against certain primary rot pathogens of tea. *J. Plantn. Crops, 24,* 249–255.

Balasuriya, A., & Kalaichelvan, J. (2000). Is there potential in natural tea phylloplane microorganisms in the control of blister blight leaf disease of tea (*Camellia sinensis*)? *The Planter, Kaula Lumpur, 76,* 409–417.

Barber, C. A. (1901). *Department Land Records and Agriculture*. Madras Agri. Branch 2, Bull. No. 45, pp. 227–234.

Chakraborty, B. N., Chakraborty, U., Das, G., & Das, S. K. (1994). Phyllosphere micro-flora of tea and their interaction with *Glomerella cingulata* the causal agent of brown blight disease. *Tea, 15,* 27–34.

Hashim, I. (1990). Possible integration of *Trichoderma* with fungicides for the control of white root disease of rubber. Root diseases of *H. brasiliensis*. Proceedings of IRRDB Symposium, Kunning, Chiang, pp. 1–8.

Jonathan, E. I., Nagalakshmi, S., & Padmanabhan, D. (1990). Estimation of yield losses in betel vine due to *Meloidogyne incognita. International Nematology Network Newsletter, 7*(4), 26.

Jonathan, E. I., Umamaheswari, R., & Bommaraju, P. (2006). Bioefficacy of native plant growth promoting rhizobacteria against *Meloidogyne incognita* and *Phytophthora capsici*. *Indian Journal of Nematology, 36,* 230–233.

Kalita, S., & Bora, B. C. (2006). Effect of nematicides and organic amendments in the management of *Meloidogyne incognita* in tea nursery. *Indian Journal of Nematology, 36,* 148–149.

Koshy, P. K. (1986). The burrowing nematode, *Radopholus similis* (Cobb, 1893) Thorne, 1949. In G. Swarup & D. R. Dasgupta (Eds.), *Plant Parasitic Nematodes of India-Problems and Progress* (pp. 223–248). New Delhi: Indian Agri. Res. Inst.

Koshy, P. K., & Geetha, S. M. (1992). Nematode pests of palms and cocoa. In D. S. Bhatti & R. K. Walia (Eds.), *Nematode Pests of Crops* (pp. 214–227). Delhi: CBS Publishers & Distributors.

Koshy, P. K., & Sosamma, V. K. (1978). Studies on the population fluctuations of *Radopholus similis* in coconut and areca nut roots. *Indian Phytopathology, 31,* 180–185.

Koshy, P. K., & Sosamma, V. K. (1987). Pathogenicity of *Radopholus similis* on coconut (*Cocos nucifera* L.) seedlings under greenhouse and field conditions. *Indian Journal of Nematology, 17,* 108–118.

Koshy, P. K., Sundararaju, P., & Sosamma, V. K. (1978). Occurrence and distribution of *Radopholus similis* (Cobb, 1893) Thorne, 1949 in South India. *Indian Journal of Nematology, 8,* 49–58.

Maiti, D., & Sen, C. (1998). Integrated biological control of *Sclerotium rolfsii* with nitro-genous fertilizers and *Trichoderma harzianum*. *Indian Journal of Agricultural Sciences, 55,* 464–468.

Kannan, N., Devasikhamani, S., Bhat, S., Naidu, R., & Sreenivasan, C. S. (1997). Biological control of root disease in coffee (Abstr.). International Conference on Integrated Plant Disease Management for Sustainable Agricuture. *Indian Phytopathology Society*, Indian Agri. Res. Inst., New Delhi, p. 210.

Ponmurugan, P., & Baby, U. I. (2005). Management of *Phomopsis* canker of tea with fungicides and biocontrol agents. *Journal of Plantation Crops, 33,* 175–178.

Ramanujam, B., Nambiar, K. K. N., & Iyer, R. (1997). Management of stem bleeding disease of coconut with fungicides and a biocontrol agent. *Journal of Plantation Crops, 25,* 175–179.

Saikia, B. (1992). Pathogenicity, crop loss assessment and biological control of *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 on Betel Vine (*Piper betle* L.). M. Sc. (Agri.) thesis, Assam Agri. Univ., Jorhat.

Singh, A., Mehta, S., Singh, M. H. B., & Nautiyal, C. S. (2003). Biocontrol of collar rot disease of betelvine (*Piper betle* L.) caused by *Sclerotium rolfsii* by using rhizosphere-competent *Pseudomonas fluorescens* NBRI-N6 and *P. fluorescens* NBRI-N. *Current Microbiology*. http://link.springer.com/journal/284. *47,* 153–158.

Sudha, S., & Sundararaju, P. (1998). Effect of neem oil cake and nematicide for the control of burrowing nematode, *Radopholus similis* in the areca nut based cropping system. In U. K. Mehta (Ed.), *Nematology—Challenges & Opportunities in 21st Century* (pp. 251–257). Coimbatore: Sugarcane Breeding Inst.

Talam, D. K., & Otieno, W. (2002). Temperature relations in *Armillaria* spp. associated with root rot of tea in Kenya: Implications in disease management by soil solarization. *Tea, 23*(1), 22–28.

Weischer, B. (1967). *Report to the Government of India on Plant Parasitic Nematodes*. PL 24/52 Report No. TA 2332, FAO, Rome, 15 pp.

Spice Crops

19

19.1 Black Pepper, *Piper nigrum*

19.1.1 Diseases

19.1.1.1 Quick Wilt/Foot Rot, *Phytophthora capsici*, *Phytophthora palmivora*

The disease is more severe in Karnataka and Kerala. The pathogen is responsible for 25–70 % loss in yield in Cannanore of Kerala. The mortality of pepper vines due to this disease ranged from 5.15 to 61.75 % in Cannanore and Kasargod districts. If management practices are not initiated at early stage, 7.0–78.8 % loss in yield has been reported (Jahagirdar and Siddaramaiah 2000).

(i) Symptoms The pathogen causes black spots on leaves with fine fibre-like projection from advancing margins, which rapidly enlarge and cause defoliation (Fig. 19.1). Tender leaves and succulent shoot tips of new runner shoots trailing on the soil, turn black. When the main stem is affected, the entire vine wilts followed by shedding of spikes with or without black spots.

(ii) Epidemiology In areca nut-black pepper mixed cropping system, high rainfall (1,000 mm) and microclimatic conditions like high relative humidity (84–89 %), low temperature (22.7–29.6 °C) and short sunshine hours (2.8–3.5 h/day) favoured the disease development (Ramachandran et al. 1988). Soil and infected plant debris in a plantation are the main sources of inoculum. The pathogen spreads through rain splashes. The survival of the pathogen in the infected plant debris was recorded up to 240 days and on alternate hosts up to 140 days. The incidence of quick wilt was maximum during July and minimum during January–May. A significant positive correlation has been established between total rainfall, number of rainy days and relative humidity; and a negative correlation with maximum temperature and sunshine hours.

(iii) Integrated Management

(a) Bioagents and Botanicals: Application of *Trichoderma* spp. at 75 g/vine along with neem cake at 2 kg/vine during May–June (pre-monsoon) with suitable carrier medium such as coffee husk and well-rotten cow dung followed by second round of application during August–September (post-monsoon) gives effective control of the disease.

In disease-affected gardens, plants treated with *Trichoderma harzianum* (IISR 1369 strain with 10^{10} cfu/g) at 50 g/vine along with 10 kg of farm yard manure (FYM) or 1 kg neem cake during May–June period immediately after the receipt of first early monsoon shower and second dose of inoculum applied during August–September around the base of the vine gave effective control of foot rot and slow decline (*Meloidogyne incognita, Radopholus similis*).

Pre-monsoon application of *T. harzianum* culture mixed with pre-wetted neem cake or FYM at 1 kg/100 kg and incubated for 2 days applied at 5 kg/vine below 10 years and 10 kg/vine above 10 years gave good control of wilt disease.

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems*,
DOI 10.1007/978-81-322-1844-9_19, © Springer India 2014

Fig. 19.1 Symptoms of foot rot on different parts of black pepper. (Courtesy of Shashidhara 2007)

Effective package for integrated management of pepper wilt with soil application of *T. viride* at 75 g/vine or combination of *T. viride* + modified panchagavya-3 (10 dilution at 2.3 L/vine) applied twice, once during pre-monsoon (April–May) and another during post-monsoon (August–September) was developed by Jahagirdar and Siddaramaiah (2003).

(b) Bioagents and Chemicals: *T. harzianum* can be integrated with potassium phosphonate (Akomin) to get effective management of foot rot since the latter was compatible with *T. harzianum* and *Trichoderma virens* (Rajan and Sarma 1997).

(c) Bioagents, Botanicals and Arbuscular Mycorrhizal Fungus (AMF): Fortification of nursery mixture with *Glomus fasciculatum* (AMF) (100 g containing 10^{11} cfu/g), *T. harzianum* or *T. virens* (containing 10^{11} cfu/g) and using this nursery mixture to raise the nursery stock, ensured production of healthy and robust plants. Pre-plant application of the bioagent to the planting pit along with farmyard manure (FYM) and also field application of neem cake (1 kg/vine) mixed with 50 g of the bioagent to the standing crop, during May–June and subsequently one more dose of the bioagent at 50 g/vine during August decreased the foliar yellowing and vine death (Sarma et al. 1996).

(d) Chemicals and AMF: Integration of chemicals (metalaxyl or potassium phosphonate) with AMF was effective in reducing the plant mortality and increasing the yield (Table 19.1).

(e) Bioagents and AMF: Integration of *Pseudomonas fluorescens* (IISR 16) with AMF was found to be highly beneficial for the growth and vigour of black pepper rooted cuttings. The rooted cuttings raised in nursery mixture fortified with the biocontrol inoculum showed field establishment as high as 90–98 % (Sarma and Saju 2004).

Table 19.1 Effect of AMF and agrochemicals on foot rot and yield of black pepper

Treatment	Mortality of vines (%)			Yield (kg/vine)		
	AMF	Non-AMF	Mean	AMF	Non-AMF	Mean
Control	444	60.9	52.7	1.323	1.226	1.275
AMF	10.8	27.7	19.7	6.313	1.828	4.070
Copper oxychloride, Bordeaux mixture	27.6	33.8	30.4	8.920	2.973	2.460
Metalaxyl 100 ppm (Ridomil mancozeb)	21.9	38.8	30.4	2.821	0.456	1.639
Potassium phosphonate (Akomin)	10.8	21.9	16.4	4.745	3.633	4.181
Critical Difference (CD) (P = 0.05)	*NS*	*NS*	*18.12*	*2.122*	–	*1.294*

Table 19.2 Effect of bioagents, botanicals and chemicals on the management of foot rot on black pepper

Treatment	Leaf infection (%)	Leaf yellowing (%)	Defoliation (%)	Collar infection (%)	Wilting (%)
T1	2.44	1.65	0.62	5.56	0.00
T2	5.97	6.58	5.56	10.07	5.56
T3—Control	52.92	62.76	52.67	77.77	50.00
Critical Difference (CD) (P = 0.05)	*1.229*	*3.733*	*4.646*	*2.567*	*2.966*

T1—Metalaxyl spray and soil drench (1.25 mL/L) + soil application of *T. harzianum* (50 g/vine) + soil application of *P. fluorescens* (100 mL/vine) + soil application of neem cake (1 kg/vine)
T2—Potassium phosphonate spray and soil drench (3 mL/L) + soil application of *T. harzianum* (50 g/vine) + soil application of *P. fluorescens* (100 mL/vine) + soil application of neem cake (1 kg/vine)

(f) Two Bioagents: Integration of *T. harzianum* (IISR 1369) with *P. fluorescens* (IISR-41) gave very effective control of foot rot (10% disease incidence as compared to 90% in control) and increased plant height under field conditions. Integration of *T. harzianum* (IISR 1369) with *P. fluorescens* (IISR-11 or 6) suppressed the root rot to the extent of 63% over control and improved the vigour of pepper vines (Saju 2004; Saju et al. 2003). Combined formulation of *T. harzianum* and *P. fluorescens* (IISR-6) was more effective for production of healthy black pepper rooted cuttings (Thankamani et al. 2003, 2005).

(g) Bioagents, Botanicals and Chemicals: Reduction in intensity of leaf infection, yellowing, defoliation, collar infection and wilting was maximum in treatment metalaxyl spray and soil drench (1.25 mL/L) + soil application of *T. harzianum* (50 g/vine) + soil application of *P. fluorescens* (100 mL/vine) + soil application of neem cake (1 kg/vine) (T1) followed by potassium phosphonate spray and soil drench (3 mL/L) + soil application of *T. harzianum* (50 g/vine) + soil application of *P. fluorescens* (100 mL/vine) + soil application of neem cake (1 kg/vine) (T2) (Table 19.2) (Shashidhara 2007).

19.1.1.2 Leaf Rot, *Rhizoctonia solani*

(i) Symptoms The disease is often serious in nurseries during April–May when warm humid conditions prevail. The fungus infects both leaves and stems. Greyish sunken spots and mycelial threads appear on the leaves. The infected leaves are attached to one another with the mycelial threads. On stem, the infection occurs as dark brown lesions, which spread both upwards and downwards. The new flushes subtending the points of infection gradually droop and dry up.

(ii) Integrated Management

(a) Bioagents and Chemicals: Foliar spray with liquid formulation of *P. fluorescens* and drenching at both pre- and post-monsoon treatment with 1% Bordeaux mixture provided good protection. The treated plants had 35% disease index as compared to 61% in control and the yield was 2.34 kg/vine as compared to 0.78 kg/vine in control.

Fig. 19.2 Black pepper roots infected with root-knot nematode

19.1.2 Nematodes

19.1.2.1 Root-Knot Nematodes, *Meloidogyne* spp.

Butler (1906) reported root-knot nematodes in black pepper from Wynad, Kerala, India. *M. incognita* and *Meloidogyne javanica* have been reported from India. The root-knot infestation is a serious problem in Government nurseries in Kerala. Up to 91% root-knot infestation was reported from Para, Brazil (Ichniohe 1975) and Kerala, India (Ramana et al. 1987).

An initial inoculum level of 10 J_2 per rooted cutting was found to reduce growth by 15%, while at 100,000 J_2 level, 50% reduction in growth was observed over 1-year period. More than 50% death of transplants occurs in field planting of infected cuttings. *M. incognita* was responsible for 46% loss in yield of black pepper (Mohandas and Ramana 1991).

(i) Symptoms Prominent symptoms of root-knot infestation on black pepper are unthrifty growth and yellowing of leaves. Interveinal yellowing of the foliage is also noticeable. The leaves exhibit dense yellowish discolouration of the interveinal areas making the leaf veins prominent with deep green colour. Heavy galling of the root system is also present (Fig. 19.2).

(ii) Integrated Management

(a) Two Bioagents: Black pepper vines combinedly inoculated with *Paecilomyces lilacinus* and *Pasteuria penetrans* had put out 23–112% increase in plant growth over control and were very effective in the management of root-knot nematodes (Sosamma and Koshy 1995).

Under field conditions, plants treated with the consortial formulation of *P. fluorescens* Pf 123 and *Bacillus subtilis* Bs 214 significantly enhanced the yield parameters and reduced nematode infestation both in soil and roots (Table 19.3) (Devapriyanga et al. 2012).

(b) Botanicals and Chemicals: Integration of neem cake application at 1 kg/ vine along with phorate/carbofuran at 3 g a.i./vine during May–June and again during September–October gave effective control of nematodes infesting black pepper.

(c) Cultural and Chemicals: Application of aldicarb at 1 g a.i./vine twice a year (May/June and October/November) integrated with fertilizers (N—100 g, P—40 g, K—140 g/vine) in two equal splits, earthing up to 50 cm radius at the base of the vines and mulching the base of the vines with leaves reduces foliar yellowing by 83% and *M. incognita* population by 33–38% (Venkitesan and Jacob 1985).

(d) Physical, Bioagents, Botanicals and AMF: Integrated management of foot rot (*P. capsici*) and nematodes (*M. incognita* and *R. similis*) on black pepper was achieved by (1) mixing AMF and *T. harzianum* in solarized nursery mixture to raise healthy and robust seedlings, (2) application of *T. harzianum* and farmyard manure (FYM) in planting pit, (3) field application of neem cake at 1 kg/vine mixed with 50 g of *T. harzianum* during August.

19.1.2.2 Burrowing Nematode, *Radopholus similis*

(i) Symptoms *R. similis* on black pepper is associated with pepper yellows (slow-wilt) disease, which appears as pale yellow or whitish-yellow drooping leaves on the vines. The number of such leaves increases gradually until large numbers of leaves, or even the entire foliage, become yellow (Fig. 19.3). Yellowing is followed by shedding of leaves, cessation of growth and dieback symptoms. The symptoms are well pronounced when soil moisture is depleted. Within 3–5 years of initiation of yellowing, all the leaves are shed

Table 19.3 Efficacy of talc formulations of *Pseudomonas* and *Bacillus* isolates on root-knot nematode and yield parameters of black pepper cv. Paniyur 1 under field conditions

Treatments	No. of spikes/ vine	Wt. of spikes/ vine (g)	No. of yellow leaves/vine	No. of egg masses/5 g roots	No. of eggs/ egg mass	Gall index
Pf 123	270.30	1928.00	13.60	30.80	155.00	2.02
Bs 214	251.00	1898.20	17.80	37.20	169.60	2.36
Pf 123 + Bs 214	294.20	2192.40	9.40	25.60	143.60	1.10
Carbofuran	247.00	1838.60	17.40	37.60	176.60	2.16
Control	172.20	906.80	26.20	48.60	260.00	4.08
CD (P=0.05)	*3.7298*	*57.9689*	*1.6746*	*1.8914*	*1.1727*	*0.2523*

Fig. 19.3 Yellows disease of black pepper plants caused by *R. similis* destroying roots

and death of the vine takes place; hence the name slow-wilt disease.

In bearing vines, shedding of inflorescences is a major symptom. Large numbers of shed inflorescences are seen at the base of affected vines. In large plantations, affected patches become conspicuous initially as yellowed plants, and later with large numbers of barren standards that have lost the vines, or standards supporting dead vines without any leaves. Young and old plants are affected and the replanted vines normally die within 2 years.

The tender, thin, white feeding roots show typical orange-to-purple-coloured lesions (Fig. 19.3). Lesions are not clearly seen on older roots, being brown in colour. The root system exhibits extensive rotting and this results in a lack of fine feeder roots from the main roots. Extensive necrosis of larger lateral roots develops subsequently.

(ii) Integrated Management

(a) Cultural, Botanicals and Chemicals: Integrated methods of the burrowing nematode management that can be suggested are:

- Planting of nematode-free rooted cuttings.
- Uprooting of affected vines and replanting after a period of 9–12 months.
- Use of non-living supports or standards.
- Exclusion of *R. similis*-susceptible trees as standards for trailing black pepper vines.
- Exclusion of susceptible intercrops such as banana, ginger and turmeric.
- Application of organic amendments, such as neem oil cake, green foliage, or farmyard manure (FYM).
- Earthing-up after application of nematicides, NPK fertilizers and organic amendments.

19.1.2.3 Nematodes, *M. incognita*, *R. similis* and Foot Rot, *P. capsici* Disease Complex

(i) Symptoms Increased susceptibility of *M. incognita* and *M. javanica* infested cultivars of black pepper to *Phytophthora* infestation has been reported.

(ii) Integrated Management

(a) Bioagents, Botanicals, AMF and Physical Methods: Integrated management of foot rot (*P. capsici*) and nematodes (*M. incognita* and *R. similis*) on black pepper was achieved by:

- Mixing vesicular arbuscular mycorrhiza (VAM) and *T. harzianum* in solarized nursery mixture to raise healthy and robust seedlings.
- Application of *T. harzianum* and farmyard manure (FYM) in planting pit.
- Field application of neem cake at 1 kg/vine mixed with 50 g of *T. harzianum* during August (Sarma 2003).

19.2 Cardamom, *Elettaria cardamomum*

19.2.1 Diseases

19.2.1.1 Damping-off, *Pythium vexans*, *R. solani*

(i) Symptoms Infection is observed at the collar region. Infected leaves become pale, yellow and ultimately the young leaves die. Older leaves die prematurely and new shoots that arise are weak, decay and the rhizomes rot at the base of the stem. The diseased shoot can be pulled out easily.

(ii) Integrated Management

(a) Physical and Bioagents: Solarization of nursery beds before sowing seeds and incorporation of *T. harzianum* has resulted in prevention of damping-off and production of pathogen-free healthy seedlings.

(b) Physical, Bioagents and AMF: Soil solarization can be done for sterilizing the nursery mixture. To the sterilized mixture, biocontrol agents such as arbuscular mycorrhizal fungus at 100 g/kg and *T. harzianum* (10^{10} cfu/g) may be added at the time of filling of nursery mixture in polybags.

19.2.1.2 Capsule Rot/Azhukal, *Phytophthora* spp.

(i) Symptoms This disease occurs during the rainy season. It affects the leaves, tender shoots, panicles and capsules. On the infected leaves, water-soaked lesions appear first and rotting and shedding of leaves along the veins occur thereafter (Fig. 19.4). The infected capsules become dull greenish brown and decay. This emits a foul smell and subsequently capsules are shed. Infection spreads to the panicles also.

(ii) Integrated Management

(a) Bioagents and Botanicals: *Trichoderma* spp. can be used along with cow dung for controlling this disease. For field application, *T. viride* and *T. harzianum* inoculum in decomposed coffee pulp and farmyard manure (FYM) in 1:1 ratio at 1 kg/plant was found to be the best (Suseela Bhai et al. 1994). Application of *T. harzianum* along with neem cake at the base of the clump reduced *Phytophthora* propagules and consequent reduction in the disease incidence.

(b) Two or more Bioagents: Soil application of *T. viride, T. harzianum, B. subtilis* and *Latiseria aravalis* reduced *Phytophthora* population and suppressed the disease to the extent of 30–50% (Suseela Bhai et al. 1993; Joseph et al. 1993).

(c) Bioagents and Chemicals: Spraying of Bordeaux mixture followed by two applications of *T. harzianum* at 1 kg/plant (28×10^8 cfu/g) during May and July significantly reduced the disease incidence. Spraying of *T. harzianum* followed by two applications of Bordeaux mixture reduced the disease potential index. Three applications of *T. harzianum* combined with Akomin recorded maximum population of *T. harzianum* (Table 19.4) (Suseela Bhai 1998).

(d) Botanicals, Bioagents and Chemicals: Management of capsule rot (*Phytophthora* spp.) of cardamom was achieved by two applications of *T. harzianum* at 1 kg/plant (grown on decomposed coffee pulp and farmyard manure (FYM) in 1:1 ratio) during May and July integrated with foliar spray of Akomin (potassium phosphonate) (Anandraj and Eapen 2003).

(e) Physical and Bioagents: Solarization of nursery beds and subsequent soil application

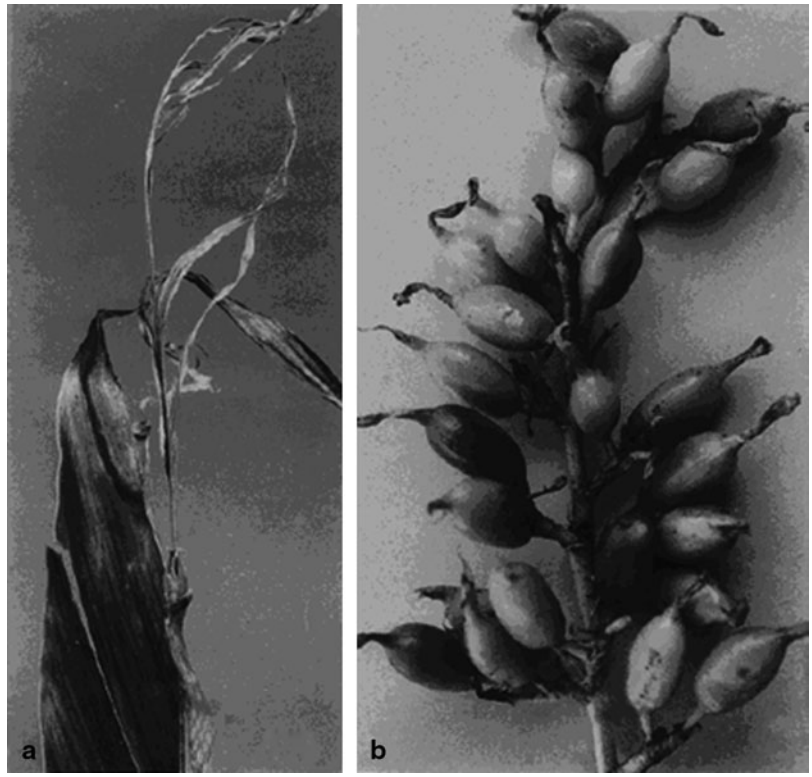


Fig. 19.4 Capsule rot of cardamom. **a** Rotting and shredding of leaves. **b** Rotting of capsules

of *T. harzianum* reduced root rot infection and also nematode infection caused by *M. incognita* (Eapen and Ramana 1996).

19.2.1.3 Rhizome Rot or Clump Rot, *Pythium vexans, Fusarium oxysporum, R. solani*

(i) Symptoms The disease occurs during South West monsoon. The symptoms include pale yellow colour on the foliage and premature death of older leaves. Collar portion of the aerial shoots becomes brittle and tiller breaks easily from the rhizome at the bulbous base (Fig. 19.5). Water-soaked lesions appear first on leaves. The pathogen causes rotting and shredding of leaves along the veins. Rotting develops in the collar region emitting a foul smell. Capsules turn dull greenish brown emitting a foul smell.

(ii) Integrated Management

(a) Physical and Bioagents: Solarization of nursery beds before sowing seeds and incorporation of *T. harzianum* has resulted in prevention of damping-off and production of pathogen-free healthy seedlings (Eapen and Ramana 1996).

(b) Bioagents, AMF, Chemicals and Physical: Soil solarization can be done for sterilizing the nursery mixture. To the sterilized mixture, biocontrol agents such as AMF at 100 g/kg and *T. harzianum* (10^{10} cfu/g) may be added at the time of filling of nursery mixture in polybags. Since the biocontrol agents protect the root system only, the aerial portion may be protected with 1% Bordeaux mixture spray.

(c) Bioagents, Botanicals and Chemicals: Incorporation of *Trichoderma* spp. multiplied in suitable organic medium (1 kg/clump) prior to the onset of monsoon season is a prophylactic operation. Spraying of 1% Bordeaux mixture at 3 L/plant with an adhesive by the commencement of monsoon and continuing the spraying operation up to November–December is effective.

(d) Two Bioagents: Integration of *T. harzianum* (IISR 1369) with *P. fluorescens* (IISR-11 or 6) suppressed the clump rot to the extent of 36% over control.

Table 19.4 Integrated management of capsule rot of cardamom

Treatment	Disease incidence (%)	Disease potential index	Population of *Trichoderma* × 10^3
BM *Th Th*	0.30	7.56	18.76
Th BM BM	0.72	2.00	17.94
Ak + *Th* Ak + *Th* Ak + *Th*	0.28	16.17	29.69
Ak Ak Ak	0.10	15.89	3.03
BM BM BM	0.13	4.28	2.47
Th COC COC	0.37	15.78	15.47
COC *Th Th*	0.20	21.17	27.10
Th Th Th	0.20	34.44	28.99
COC COC COC	0.03	5.11	2.08
Control	6.61	96.89	1.50
CD (P = 0.05)	*2.96*	*32.45*	*9.24*

BM Bordeaux mixture, *Th Trichoderma harzianum* (1×10^7), *Ak* Akomin, *COC* copper oxychloride

Fig. 19.5 Clump rot of cardamom

19.2.2 Nematodes

19.2.2.1 Root-Knot Nematodes, *Meloidogyne* spp.

M. incognita and *M. javanica* have been reported as widely occurring in the cardamom nurseries and plantations in Kerala, Karnataka and Tamil Nadu (Kumar et al. 1971; Koshy et al. 1976; Ali 1982, 1986). An yield loss of 32–47% due to root-knot infestation has been reported (Ali 1984, 1986). An initial population of 100 nematodes/plant causes discernible damage to cardamom (Eapen 1987).

(i) Symptoms Heavy infestation of root-knot on mature plants in a plantation causes stunting, reduced tillering, yellowing, premature drying of leaf tips and margins, narrowing of leaf blades, delay in flowering, immature fruit drop and reduction in yield. Infested roots are characterized by excessive branching. Galling of roots is not conspicuous on mature plants (Fig. 19.6).

In primary nursery, the second stage juveniles infest the radical and plumule as a result of which even 50% of the germinating seeds do not emerge. At the two-leaf stage itself, the infested seedlings show marginal yellowing and drying of leaves and severe galling of roots. Up to 40% of such seedlings do not establish in the secondary nursery. The infested secondary nursery plants exhibit stunting, yellowing, poor tillering, drying of leaf tips and margins and heavy galling of roots (Ali and Koshy 1982).

(ii) Integrated Management

(a) Physical and Bioagents: Soil solarization of nursery beds and application of bioagents such as *P. lilacinus* or *Trichoderma* spp. improved growth of cardamom seedlings by suppressing root-knot nematode population (Eapen and Venugopal 1995).

Fig. 19.6 Cardamom roots damaged by root-knot nematode. Healthy (*left*) and infested (*right*)

Besides soil solarization of nursery beds, subsequent soil application of *T. harzianum* reduced root rot infection and also infection caused by the root-knot nematode, *M. incognita* (Eapen and Ramana 1996).

(b) Botanicals and Bioagents: Application of *T. harzianum* multiplied on decomposed coffee husks (7-day old) at the time of sowing at 2.5 kg/bed (4.5 m × 1.0 m) and repeating after 3 months is recommended for the control of root-knot nematodes and damping-off in nurseries.

19.2.2.2 Root-Knot Nematode, *Meloidogyne* sp. and Rhizome Rot, *R. solani* Disease Complex

(i) Symptoms *M. incognita* was found to predispose cardamom seedlings to *R. solani* infection, which causes damping-off and rhizome rot in the primary nursery (Ali and Venugopal 1992, 1993).

(ii) Integrated Management

(a) Physical and Bioagents: *P. lilacinus* in combination with *Trichoderma* spp. suppressed *Meloidogyne* spp. and rhizome rot disease (*R. solani*) complex when incorporated in solarized cardamom nursery beds (Eapen and Venugopal 1995).

(b) Botanicals and Chemicals: Application of carbofuran along with neem cake was found to reduce immature fruit-drop and increase capsule yield.

(c) Physical, Bioagents and Chemicals: Soil solarization alone enhanced the germination by 25.5 % and suppressed weed growth by 82.0 %. Solarization also enhanced the growth and vigour of cardamom seedlings. The disease complex was suppressed by incorporation of *P. lilacinus/T. harzianum* and phorate into the solarized nursery beds. This approach is being adopted on a large scale for the production of nematode-free cardamom seedlings.

19.3 Ginger, *Zingiber officinale*

19.3.1 Insect Pests

19.3.1.1 Shoot Borer, *Dichocrocis punctiferalis*

(i) Damage The larvae bore into the shoots. They can cause them to wilt and die. Caterpillar bores the rhizomes and pseudo stem causing dead heart. Extrusion of frass through holes can be observed (Fig. 19.7).

(ii) Integrated Management

(a) Cultural and Chemical: Pruning and destroying freshly infested pseudo stems (at fort-

Fig. 19.7 Shoot borer infestation on ginger

nightly intervals) during July–August and spraying 0.1 % malathion (at monthly intervals) during September–October is effective against the pest.

19.3.2 Diseases

19.3.2.1 Rhizome Rot, *Pythium aphanidermatum, Pythium myriotylum*

(i) Symptoms Soft rot is the most serious disease of ginger in India and in some other countries. It is caused by *Pythium* spp., of which *P. aphanidermatum* is the principal species in India, although *Pythium butleri*, *Pythium gracile*, *P. myriotylum*, *Pythium nigriotilum* and *P. vexans* have also been recorded. The bases of the aerial shoots become soft, watery and then rot. The affected plants become pale; the tips of the leaves turn yellow, followed by complete yellowing and drying up of the leaves (Fig. 19.8). The shoots fall and cease to produce rhizomes. The infection extends to the rhizomes; the inner tissues being reduced to a soft and black putrefying mass. Losses can be high. The disease is favoured by high moisture content of the soil with insufficient drainage.

(ii) Integrated Management

(a) Bioagents and Botanicals: Application of *T. harzianum* along with neem cake at 1 kg/bed helps in preventing the disease. *T. harzianum, T. viride, Trichoderma hamatum* and *T. virens* as seed treatment and also as soil application along with neem cake at 1 kg/m^2 reduced the disease incidence and increased the yield. The treatment was even superior to mancozeb treatment. The population stability of biocontrol agent was maintained up to 60 days. In Rajasthan, *T. viride* applied along with wood saw dust or karanj or neem cake has been effective against rhizome rot caused by *P. myriotylum* and *Fusarium solani* (Lodha et al. 1994). Raising seedlings in *T. harzianum/P. fluorescens* amended compost and soil application of *T. harzianum/P. fluorescens* along with neem cake/compost in the main field was useful in minimizing the incidence of rhizome rot of ginger.

(b) Physical and Bioagents: Soil solarization prior to planting followed by application of biocontrol agents showed synergistic effects in disease reduction and increased yield (Sarma et al. 1996) (Table 19.5).

Usman et al. (1996) successfully utilized the native strains of *Trichoderma* and *Gliocladium* against rhizome rot of ginger caused by *P. aphanidermatum, P. myriotylum* and *F. solani* complex. The disease suppression was enhanced when biocontrol was succeeded by soil solarization.

As a seed disinfection procedure, a novel technique called rhizome solarization has been devised at the Indian Institute of Spices Research, Calicut. The disinfected rhizomes when treated with *T. harzianum* and rhizobacterial strain consortia as seed treatment and soil application resulted in higher yields and growth promotion and soft rot suppression.

Fig. 19.8 Rhizome rot of ginger

Table 19.5 Effect of soil solarization and biocontrol agents on germination, rhizome rot incidence and yield of ginger

Biocontrol agent	Solarized soil			Non-solarized soil		
	Germination (%)	Disease index (%)	Yield (kg/plot)	Germination (%)	Disease index (%)	Yield (kg/plot)
T. viride	77.69	13.70	2.846	71.52	35.25	1.225
T. harzianum 1	79.61	15.80	3.552	79.43	32.07	2.673
T. harzianum 2	77.87	19.38	2.910	72.91	43.61	1.439
T. hamatum	75.00	16.16	2.744	73.23	39.26	1.602
T. virens	74.48	18.25	2.641	74.43	36.63	1.705
Mancozeb	79.23	36.22	2.260	73.89	46.70	0.818
Control	81.53	57.58	1.692	79.86	53.80	0.992
Mean	77.92	25.30	2.278	74.90	41.08	1.485
CD (P = 0.05)	*NS*	*6.26*	*0.430*	*NS*	*6.26*	*0.430*

(c) Bioagents and Chemicals: The biocontrol was further integrated with chemical control using metalaxyl as seed treatment since it is compatible with *Trichoderma* spp. (Balakrishnan et al. 1996; Sarma 1997; Lodha and Mathur 1997).

Integration of soil application of bioagents with fungicidal rhizome treatment using bavistin (carbendazim) + ridomil MZ (metalaxyl + mancozeb) increased the efficiency of disease control as compared with their individual treatments. Soil application of *T. harzianum* and rhizome treatment with *Pseudomonas* sp. and fungicides was the most effective among all the tested treatments (Ram et al. 1999).

(d) Two Bioagents: Combined application of *P. fluorescens* (IISR-11) and *T. harzianum* (IISR-1369) imparted 66.2% survival of ginger tillers, reduced the rhizome rot infection and improved the vigour and yield of ginger plants (Sarma 2000).

19.3.2.2 Yellows, *Fusarium oxysporum* f. sp. *zingiberi*

(i) Symptoms Fusarium yellows is a very common and serious fungal disease that is specific to ginger. Infected plants are stunted and yellow (Fig. 19.9), lower leaves dry out and turn brown. Eventually, all above-ground shoots dry out completely. Plant collapse is very slow (up to several weeks) compared with the rapid collapse associated with bacterial wilt infection. Diseased rhizomes show a brown internal discolouration, are normally shriveled in appearance and eventually decay leaving the outer shell intact with fibrous internal tissue remaining. Increased nematode infestations are usually associated with *Fusarium* rhizome rot, accentuating yield losses. *Fusarium* is also responsible for serious loss of planting pieces and poor germination. The disease spreads rapidly in the field during wet weather.

(ii) Integrated Management

(a) Bioagents and Botanicals: Application of *T. harzianum, T. viride, T. hamatum* and *T. virens*

Fig. 19.9 Ginger yellows symptoms

as seed treatment and soil application along with neem cake at 100 kg/ha gave protection and increased yield. Application of *T. viride* along with saw dust/neem cake was found to be highly effective in suppression of Fusarium yellows.

Soil application of *Trichoderma* bioformulation mixed with farmyard manure (FYM) gave highest yield of 12.274 MT/ha which was 56% more than the control plots (7.833 MT/ha) (Selvakumar et al. 2009).

(b) Physical and Bioagents: Hot water treatment of ginger rhizomes along with soil application of *Trichoderma* spp. gave effective control of the disease and increased the yield (Selvakumar et al. 2009). There was synergistic effect in protection where soil solarization followed by biocontrol was adopted.

19.3.2.3 Storage Rot, *Sclerotium rolfsii*

(i) Symptoms This disease has caused serious losses on some farms. Infection first occurs beneath the scales on the rhizomes and may progress to produce a deep brown rot over the entire surface. Affected rhizomes become enveloped in a white fungal mycelial growth which may extend up to the basal stem. Mild infections usually produce no above ground symptoms. Severe infections cause the stems to turn yellow and slowly dry out.

(ii) Integrated Management

(a) Physical and Bioagents: The disinfected rhizomes (through solarization) when treated with *T. harzianum* and rhizobacterial strain consortia as seed treatment and soil application resulted in higher yields and growth promotion and storage rot suppression and minimal bacterial wilt. In addition, in combination with *Glomus* spp., the disease was absent probably through growth mediation.

(b) Two Bioagents: *T. harzianum* in combination with *P. fluorescens* showed a synergistic effect in reducing the storage rot infection.

19.3.2.4 Bacterial Wilt, *Ralstonia solanacearum*

A bacterial wilt of ginger was recorded from Australia, Hawaii, India, Mauritius and Malaysia. Bacterial wilt is a very serious disease that can spread very rapidly through an area, causing complete destruction.

(i) Symptoms The first symptoms of the disease are yellowing and wilting of the lower leaves, which quickly spread upwards, affecting the whole plant (Fig. 19.10). In advanced stages, the base of the pseudo stem becomes water-soaked, readily breaking away from the rhizome at ground level and the plants eventually collapse. The vascular tissues become dark brown or black. When an infected stem or rhizome is cut transversely, and a little pressure applied, a milky white exudate flows freely from the cut surface. Diseased rhizomes are much darker than healthy ones. Biotype 4 was found to produce the most severe symptoms.

(ii) Integrated Management

(a) Botanicals and Bioagents: Lowest disease incidence (15.63) was recorded in the treatment of *P. fluorescens* mass cultured in the mixture of vermicompost (VC) and mustard oil cake (MOC) applied as seed treatment and soil application. It was followed by *T. harziamum* mass cultured in MOC (21.88%), which was statistically at par with the application of copper oxychloride (22.50%) (Bora and Bora 2009).

(b) Physical, Bioagents and AMF: The disinfected rhizomes (through solarization) when treated with *T. harzianum* and rhizobacterial

Fig. 19.10 Bacterial wilt symptoms in zinger

strain consortia as seed treatment and soil application resulted in higher yields and growth promotion and minimal bacterial wilt. In addition, in combination with *Glomus* spp., the disease was absent probably through growth mediation.

19.3.2.5 Soft Rot, *Erwinia* sp.

(i) Symptoms Normally bacterial soft rot is only a storage rot. The bacteria are present in most soils but field infection usually occurs only in waterlogged areas. *Erwinia* sp. has caused severe losses of stored rhizomes on some farms, but is not considered a serious storage problem where precautions are taken. Softening of the tissue is accompanied by production of a strong odour and the rhizome eventually collapses completely. Bacterial soft rot differs from other rhizome rots in that putrid odour is produced in this soft rot.

(ii) Integrated Management

(a) Physical, Bioagents and AMF: The disinfected rhizomes (through solarization) when treated with *T. harzianum* and rhizobacterial strain consortia as seed treatment and soil application resulted in higher yields and growth promotion and soft rot suppression. In addition, in combination with *Glomus* spp., the disease was absent probably through growth mediation.

(b) Two Bioagents: *T. harzianum* in combination with *P. fluorescens* showed a synergistic effect in reducing the soft rot infection.

(c) Physical, Botanicals and Bioagents: Solarization of beds before planting and addition of *T. harzianum* formulation (with 10 cfu/g) at 50 g/3 m^2 bed along with neem cake/FYM reduced the disease incidence.

19.3.3 Nematodes

19.3.3.1 Root-Knot Nematodes, *Meloidogyne* spp.

M. incognita, M. javanica, Meloidogyne arenaria and *Meloidogyne hapla* have been reported to be associated with ginger from various countries. Under pot conditions, an initial inoculum level of 10,000 nematodes per plant over a period of 6 months caused 74% reduction in rhizome weight. A population level of one juvenile/30 g of soil was found to cause significant reduction in yield (Sukumaran and Sundararaju 1986a). Kaur (1987) estimated 41–59% yield loss in ginger when the crop was raised using apparently healthy rhizomes in nematode infested fields.

(i) Symptoms Heavily infested plants exhibit stunting and chlorotic leaves with marginal necrosis. The root-knot nematodes cause galling

Fig. 19.11 Rhizome rot of turmeric

and rotting of roots and underground rhizomes. Infested rhizomes show brown, water-soaked lesions in the outer tissues, particularly in the angles between shoots. The J2 of *M. incognita* invade the rhizome through the axils of leaf sheaths in the shoot apex. In fibrous roots, penetration occurs in the area of differentiation and in fleshy roots, the entire length of root is invaded. In the rhizomes and fleshy roots extensive internal lesions develop.

(ii) Integrated Management

(a) Two Bioagents: *P. lilacinus* along with *T. harzianum/P. chlamydosporia* was effective in suppression of root-knot nematodes under field conditions.

(b) Botanicals and Chemicals: Application of neem cake at 1 t/ha at planting, followed by carbofuran at 1 kg a.i./ha at 45 DAP gave effective control of nematodes associated with ginger.

19.3.3.2 Lesion Nematode, *Pratylenchus coffeae* and *Fusarium* Wilt, *F. oxysporum* f. sp. *zingiberi* Disease Complex

(i) Integrated Management

(a) Physical and Bioagents: The efficacy of biocontrol agents like *Aspergillus niger*, *T. harzianum, T. hamatum* and *T. virens* either alone or in combination with soil solarization has been reported for the management of yellows disease (*Fusarium+P. coffeae)* in Himachal Pradesh (Dohroo 1995). Similar results have been reported by Eapen and Ramana (1996).

19.4 Turmeric, *Curcuma longa*

19.4.1 Diseases

19.4.1.1 Rhizome Rot, *Pythium aphanidermatum*

(i) Symptoms Rhizome rot shows progressive drying-up of the leaves of infected plants. The base of the aerial shoots shows water-soaked soft lesions. As the disease progresses, infection gradually spreads to the rhizomes, which begin to rot and become soft. The bright orange colour of the rhizomes changes into brown. The disease may be confined to a few isolated plants or may occur in patches (Fig. 19.11). In severe attacks, the yield is considerably reduced.

(ii) Integrated Management

(a) Physical, Bioagents and Botanicals: Treatment of rhizomes with hot water at 51 °C for 10 min and soil application of *T. harzianum* mixed with neem cake resulted in minimum incidence of rhizome rot and maximum yield.

(b) Botanicals and Bioagents: Application of *T. harzianum, T. viride, T. hamatum* and *T. virens* as seed treatment and soil application along with neem cake at 100 kg/ha gave protection and increased yield. Application of *T. viride* along with saw dust/neem cake was found to be highly effective in suppression of rhizome rot.

Seed treatment with *T. viride+P. fluorescens* at 4 g/kg seed and soil application of *T. viride* (12.5 kg/ha) and *P. fluorescens* (25 kg/ha) along

with FYM at 10 MT/ha resulted in minimizing rhizome rot to 11.7% compared to 37% in control, and higher yield of 28.6 MT/ha in treated compared to 10.3 MT/ha in control (Anon 2005).

(c) Two Bioagents: *T. harzianum* in combination with *P. fluorescens* showed a synergistic effect in reducing the rhizome rot infection.

(d) Physical and Bioagents: There was synergistic effect in protection where soil solarization followed by biocontrol (*T. harzianum*) was adopted.

19.4.1.2 Soft Rot, *Erwinia* sp.

(i) Integrated Management

(a) Physical, Bioagents and AMF: The disinfected rhizomes (through solarization) when treated with *T. harzianum* and rhizobacterial strain consortia as seed treatment and soil application resulted in higher yields and growth promotion and soft rot suppression and minimal bacterial wilt. In addition, in combination with *Glomus* spp., the disease was absent probably through growth mediation.

(b) Two Bioagents: *T. harzianum* in combination with *P. fluorescens* showed a synergistic effect in reducing the soft rot infection.

19.4.2 Nematodes

19.4.2.1 Root-Knot Nematodes, *Meloidogyne* spp.

M. incognita and *M. javanica* have been reported on turmeric of which *M. incognita* is more important. In pot experiments, 100,000 nematodes/plant resulted in 76.6% reduction in the rhizome weight after 6 months (Sukumaran and Sundararaju 1986b).

(i) Symptoms Turmeric plants infested with *M. incognita* exhibit stunting, yellowing, reduced tillering and marginal and tip drying of leaves. Galling and rotting of roots can also be noticed. Infested rhizomes have brown, water-soaked areas in the outer tissues and lose their bright yellow colour (Mani et al. 1987). High populations of *M. incognita* in field cause stunting, yellowing and withering of plants in large patches. Premature death of plants takes place leaving a poor crop stand.

(ii) Integrated Management

(a) Botanicals and Bioagents: Soil application of *T. harzianum* + neem cake at 1 t/ha is recommended.

19.5 *Vanilla, Vanilla planifolia, Vanilla andamanica*

19.5.1 Diseases

19.5.1.1 Wilt, *Fusarium oxysporum* f. sp. *vanillae*

(i) Symptoms *Fusarium* wilt is the most serious disease of vanilla. The disease is more prevalent in younger plantation especially during the monsoon season. The infection starts at leaf axil and spreads to the internodal region resulting in rotting and drying of the stem above the point of infection. The fungus also causes leaf rot on the plant.

(ii) Integrated Management

(a) Bioagents and Botanicals: Soil application of compost mounds enriched with *T. harzianum* twice resulted in substantial reduction in wilt.

(b) Two Bioagents: Soil application of rhizobacterial strain consortia (IISR-147 and IISR-148) with *T. harzianum* was effective in disease suppression of both *Phytophthora meadii* and *F. oxysporum* f. sp. *vanillae*.

Combined applications of *T. harzianum* and *P. fluorescens* gave maximum reduction in percentage leaf infection (Table 19.6) (Athul Sandheep et al. 2012).

19.5.1.2 *Phytophthora* Rot, *P. meadii*

(i) Symptoms The pathogen causes rotting of beans, leaves and stems (Fig. 19.12). In severe cases, all the beans in a bunch are completely rotten. The disease is more severe during the monsoon especially in shaded plantations and poorly drained soils.

(ii) Integrated Management

(a) Bioagents and Botanicals: Soil application of compost mounds enriched with *T. harzianum* twice resulted in substantial reduction in *Phytophthora* rot.

Table 19.6 Evaluation of microbial antagonists against *Fusarium oxysporum* of vanilla plants

Pre-inoculation with biocontrol agents	Percentage of leaves infection[a]
T. virens	12.37
T. harzianum	8.49
P. flourescens	7.18
Pseudomonas putida	20.74
P. flourescens + *T. harzianum*	7.03
T. harzianum (std)	8.50
P. fluorescens (std)	8.37
P. flourescens + *T. harzianum* (std)	8.42
Control (no biocontrol agent)	90.27
CD (P = 0.05)	*1.95*

[a] Values are mean of three replicates

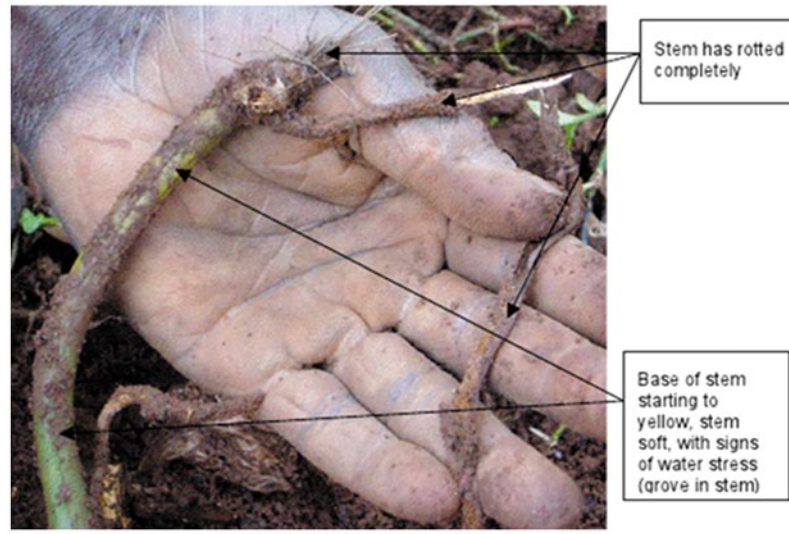


Fig. 19.12 *Phytophthora* rot symptoms on vanilla

(b) Two Bioagents: Soil application of rhizobacterial strain consortia (IISR-147 and IISR-148) with *T. harzianum* was effective in disease suppression of both *P. meadii* and *F. oxysporum* f. sp. *vanillae*.

19.6 Fenugreek, *Trigonella foenumgraecum*

19.6.1 Diseases

19.6.1.1 Root Rot, *Rhizoctonia solani*

(i) Integrated Management

(a) Botanicals and Bioagents: The efficacy of seed pelleting with *Trichoderma* spp. and soil application of *Trichoderma* spp. along with neem cake at 150 kg/ha showed greater protection against root rot in fenugreek and increased the yield (Table 19.7).

19.6.2 Nematodes

19.6.2.1 Root-Knot Nematode, *Meloidogyne incognita*

(i) Integrated Management

(a) Botanicals and Bioagents: Seed treatment with *T. viride* (4 g/kg) followed by soil application (5 kg/ha) along with 150 kg/ha of neem cake consistently suppressed root-knot.

Table 19.7 Biocontrol of root rot disease of fenugreek

Treatment	Root rot incidence (%)		Yield (MT/ha)	
	Kharif 1992	Rabi 1992	Kharif 1992	Rabi 1992
T 1. Seed treatment + soil drenching with carbendazim	4.8	10.8	0.422	0.315
T 2. Seed treatment with *Trichoderma viride*	4.8	4.4	0.384	0.365
T 3. *T. viride* 20 days before sowing	26.3	20.4	0.288	0.285
T 4. Neem cake at 150 kg/ha	3.9	3.2	0.427	0.385
T 5. T4 + T2	3.2	3.4	0.424	0.360
T 6. T4 + T3	5.4	12.4	0.288	0.325
T 7. T4 + T1	12.8	14.3	0.345	0.340
T 8. Seed treatment with carbendazim	27.9	24.5	0.294	0.265
T 9. Control	36.2	32.8	0.163	0.184
CD (P = 0.05)	*5.7*	*4.3*	*52.4*	*27.0*

Table 19.8 Effect of farm yard manure on disease control efficacy of *Trichoderma* spp. against cumin *Fusarium* wilt

Treatment	Disease incidence (%)	Disease control (%)	Dry weight of plant at 90 DAS (mg)	Increase in dry wt. over control (%)
T. harzianum ST 4 g/kg seed	36.7 (37.3)[a]	45.0	284.3	78.5
T. harzianum ST 4 g/kg seed + SA 5 g/kg soil	28.5 (32.3)	57.3	305.0	91.4
T. harzianum ST 4 g/kg seed + FYM 5 g/kg soil	29.4 (32.8)	55.9	341.0	114.0
T. harzianum ST 4 g/kg seed + SA 5 g kg soil + FYM 5 g/kg soil	23.3 (28.7)	65.0	369.7	132.0
T. harzianum ST 4 g/kg seed + FYM 10 g/kg soil	20.7 (27.1)	69.0	392.3	146.2
T. harzianum ST 4 g/kg seed + SA 5 g kg soil + FYM 10 g/kg soil	15.3 (23.0)	77.1	417.0	162.0
T. viride ST 4 g/kg seed	44.5 (41.9)	33.3	229.0	43.7
T. viride ST 4 g/kg seed + SA 5 g/kg soil	34.1 (35.7)	48.9	263.7	65.5
T. viride ST 4 g/kg seed + FYM 5 g/kg soil	34.2 (35.8)	48.7	323.3	102.9
T. viride ST 4 g/kg seed + SA 5 g kg soil + FYM 5 g/kg soil	28.3 (32.4)	57.6	345.0	116.5
T. viride ST 4 g/kg seed + FYM 10 g/kg soil	29.1 (32.7)	56.3	367.7	130.7
T. viride ST 4 g/kg seed + SA 5 g kg soil + FYM 10 g/kg soil	20.3 (26.7)	69.5	389.3	144.3
Control (pathogen inoculated)	66.7 (54.8)	–	158.3	–
CD (P = 0.05)	*3.7*	–	*34.3*	–

[a] Figures in parentheses are angular transformed values

DAS days after sowing, *FYM* farm yard manure, *ST* seed treatment, *SA* soil application

The better reduction in the root-knot nematode population was observed on the substrates (goat dung, sesame oil cake) + *P. lilacinus* treatment as compared to substrate alone. The root-knot index was lower in the sesame oil cake + *P. lilacinus* combination than in goat dung + *P. lilacinus*. The fungus (*P. lilacinus*) penetrated the eggs and fed upon their contents leaving empty cells. Invaded eggs were swollen in comparison with uncolonized ones (Sharma and Trivedi 1989).

19.7 Cumin, *Cuminum cyminum*

19.7.1 Diseases

19.7.1.1 Wilt, *Fusarium oxysporum* f. sp. *cumini*

Wilt of cumin is an endemic problem in most of the cumin growing areas of Rajasthan and usually causes substantial yield losses.

(i) Symptoms Infected plants show peculiar symptoms of drooping of tips and leaves, leading to mortality of the entire plant. Attack of wilt is severe in younger plants.

(ii) Integrated Management

(a) Botanicals and Bioagents: *T. harzianum* with neem cake as soil application reduced the incidence of wilt. Seed and soil treatment with *T. harzianum* was also found significantly effective for wilt disease.

Maximum reduction in disease incidence was recorded when *T. harzianum* was used as seed treatment at 4 g/kg seed + soil application at 5 g/kg soil along with soil amendment of farmyard manure (FYM) at 10 g/kg soil (Table 19.8) (Gangopadhyay and Ram Gopal 2010).

References

Ali, S. S. (1982). *Occurrence of root-knot nematodes in cardamom plantations of Tamil Nadu*. Proceedings of fifth symposium on plantation crops, Kasaragod, Kerala, India, pp. 615–620.

Ali, S. S. (1984). *Preliminary observations on the effect of some systemic nematicides and neem oil cakes in a cardamom field infected with root-knot nematodes (Abstr.)*. Proceedings of the sixth symposium on plantation crops, Kottayam, Kerala, India, pp. 215–223.

Ali, S. S. (1986). *Root-knot nematode problem in cardamom and its management*. Proceedings of the second group discussion on the nematological problems of plantation crops, Central Coffee Research Institute, Balehonnur, pp. 10–12.

Ali, S. S., & Koshy, P. K. (1982). Occurrence and distribution of root-knot nematodes in cardamom plantations of Kerala. *Nematologica Mediterranea, 10,* 107–110.

Ali, S. S., & Venugopal, M. N. (1992). Interaction between *Meloidogyne incognita* and *Rhizoctonia solani* in damping-off and rhizome rot disease of cardamom seedlings. *Nematol. Medit. 20,* 65–66.

Ali, S. S., & Venugopal, M. N. (1993). Prevalence of damping-off and rhizome rot disease in nematode infected cardamom nurseries in Karnataka. *Curr. Nematol. 4,* 19–24.

Anandraj, M., & Eapen, S. J. (2003). Achievements in biological control of diseases of spice crops with antagonistic organisms at Indian Institute of Spices Research, Calicut. In B. Ramanujam & R. J. Rabindra (Eds.), *Current status of biological control of plant diseases using antagonistic organisms in India* (pp. 189–215). Bangalore: Project Directorate of Biological Control.

Anon. (2005). Annual report for 2003–-2004 of all India coordinated research project on spices, Indian Institute of Spices, Calicut, Kerala, India.

Athul Sandheep, R., Aju, K., & Asok Ans Jisha, M. S. (2012). Biocontrol of *Fusarium* wilt of vanilla (*Vanilla planifolia*) using combined inoculation of *Trichoderma* sp. and *Pseudomonas* sp. *International Journal of Pharma and Bio Sciences, 3*(B), 706–716.

Balakrishnan, P., Usman, N. M., & Sarma, Y. R. (1996). Management of rhizome rot disease of ginger by soil solarization. *Journal of Plantation Crops, 24* (Suppl.), 192–199.

Bora, P., & Bora, L. C. (2009). *Bioformulation of antagonists for management of bacterial wilt of ginger*. International Conference on Horticulture, Bangalore.

Butler, E. J. (1906). The wilt disease of pigeon-pea and pepper. *Indian Journal of Agricultural Sciences, 1,* 25–36.

Devapriyaga, R., Jonathan, E. I., Sankarimeena, K., & Kavitha, P. G. (2012). Bioefficacy of *Pseudomonas* and *Bacillus* isolates against root-knot nematode, *Meloidogyne incognita* in black pepper cv. Paniyur 1. *Indian Journal of Nematolology, 42*, 57–65.

Dohroo, N. P. (1995). Integrated management of yellows of ginger. *Indian Phytopathology, 48*, 90–92.

Eapen, S. J. (1987). *Plant parasitic nematode problem in small cardamom*. Proceedings of the third group discussion on the nematological problems of plantation crops, sugarcane breeding institute, Coimbatore, pp. 43–44.

Eapen, S. J., & Ramana, K. V. (1996). Biological control of plant nematodes of spices. In M. Anandraj & K. V. Peter (Eds.), *Biological control in spices* (pp. 20–22). Calicut: Indian Institute of Spices Research.

Eapen, S. J., & Venugopal, M. N. (1995). *Field evaluation of Paecilomyces lilacinus and Trichoderma spp. in cardamom nurseries for the control of root-knot nematodes and rhizome rot disease*. National symposium on nematode problems of India—An appraisal of the nematode management with eco-friendly approaches and biocomponents, Indian Agriculture Research Institute, New Delhi.

Gangopadhyay, S., & Gopal, R. (2010). Evaluation of *Trichoderma* spp. along with farm yard manure for the management of *Fusarium* wilt of cumin (*Cuminum cyminum* L.). *Journal of Spices and Aromatic Crops, 19,* 57–60.

Ichniohe, M. (1975). Infestation of black pepper vines by the root-knot nematode, Meloidogyne incognita

at Tome-Acu, Para, Brazil. *Japanese J. Nematol. 5,* 36–40.

Jahagirdar, S., & Siddaramaiah, A. L. (2000). Association of pathogens in disease complex of black pepper (*Piper nigrum* L.) in Karnataka. *Karnataka Journal of Agricultural Sciences, 31,* 757–760.

Jahagirdar, S., & Siddaramaiah, A. L. (2003). *Etiology and management of foot rot of black pepper (Piper nigrum)*. National symposium on plant pathogens diversity in relation to plant health, Hyderabad.

Joseph, T., Suseela Bhai, R., Vijayan, A. K., & Naidu, R. (1993). Evaluation of antagonists and their efficacy in managing rot disease of small cardamom. *Journal of Biological Control, 7,* 29–36.

Kaur, D. J. (1987). *Studies on nematodes associated with ginger (Zingiber officinale Rosc.) in Himachal Pradesh*. Ph. D. thesis, Y.S. Parmar University of Horticulture and Forestry, Solan, India, 198 pp.

Koshy, P. K., Nair, R. C. P., Sosamma, V. K., & Sundararaju, P. (1976). On the incidence of root-knot nematode in cardamom nurseries. *Indian Journal of Nematology, 6,* 174–175.

Kumar, A. C., Viswanathan, P. R. K., & D'Souza, G. I. (1971). A study of plant parasitic nematodes of certain commercial crops in coffee tracts of South India. *Indian Coffee, 36,* 1–3.

Lodha, B. C., & Mathur, K. (1997). Management of rhizome rot of ginger—progress and perspective. In V. P. Agnihotri, A. K. Sarabhoy, & D. V. Singh (Eds.), *Management of threatening plant diseases of national importance* (pp. 249–262). New Delhi: Malhotra Publishing House.

Lodha, B. C., Mathur, K., & Shekawat, P. S. (1994). Management of rhizome rot of ginger. In U. Kant, T. Singh, & P.C. Trivedi (Eds.), *Vistas in seed biology* (Vol. 1 pp. 334–335). Jaipur: Printwell Publications.

Mani, A., Naidu, P. H., & Madhavachari, S. (1987). Occurrence and control of *Meloidogyne incognita* on turmeric in Andhra Pradesh, India. *International Nematology Network Newsletter, 4,* 13–18.

Mohandas, C., & Ramana, K. V. (1991). Pathogenicity of *Meloidogyne incognita* and *Rad-opholus similis* on black pepper (*Piper nigrum* L.). *Journal of Plantation Crops, 19,* 41–43.

Rajan, P. P., & Sarma, Y. R. (1997). Compatibility of potassium phosphonate (Akomin-40) with different species of *Trichoderma harzianum* and *Gliocladium virens*. In S. Edison, K. V. Ramana, B. Saikumar, K. Nirmal Babu, & S. J. Eapen (Eds.), *Biotechnology of spices, medicinal and aromatic plants* (pp. 150–155). Calicut: Indian Society for Spices, Indian Institute of Spices Research.

Ram, P., Mathur, K., & Lodha, B. C. (1999). Integrated management of rhizome rot of ginger involving biocontrol agents and fungicides. *Journal of Mycology and Plant Pathology, 29,* 416–417.

Ramana, K. V., Mohandas, C., & Balakrishnan, R. (1987). Role of plant parasitic nematodes in the slow wilt disease complex of black pepper (*Piper nigrum* L.) in Kerala. *Indian Journal of Nematology, 17,* 225–230.

Ramachandran, N., Sarma, Y. R., Anandraj, M., & Jose, A. (1988). Effect of climatic factors on *Phytophthora* leaf infection in black pepper mixed cropping system. *Journal of Plant Crops, 16,* 140–148.

Saju, K. A. (2004). *Factors affecting the biological control of Phytophthora capsici Infections in black pepper (Piper nigrum L.)*. Ph. D. thesis, University of Calicut, 232 pp.

Saju, K. A., Anandraj, M., & Sarma, Y. R. (2003). Evaluation of *Trichoderma* spp. and *Pseudomonas fluorescens* for suppression of *Phytophthora capsici* infecting black pepper (Abstr.). In M. S. Reddy, M. Anandraj, S. J. Eapen, Y. R. Sarma, & J. W. Kloepper (Eds.), *Sixth International PGPR Workshop* (pp. 52–58). Calicut: Indian Institute of Spices Research.

Sarma, Y. R. (1997). *Antagonistic fungi and their role in plant disease management (Abstr.)*. In TCDC international workshop on application of biotechnology in biofertilizers and biopesticides, IIT, New Delhi, pp. 60–64.

Sarma, Y. R. (2000). *Integrated management of rhizome rot of ginger*. Final report of ICAR AP Cess Fund Scheme, Indian Institute of Spices Research, Calicut, Kerala, India.

Sarma, Y. R. (2003). Recent trends in the use of antagonistic organisms for the disease management in spice crops. In B. Ramanujam & R. J. Rabindra (Eds.), *Current status of biological control of plant diseases using antagonistic organisms in India* (pp. 49–73). Bangalore: Project Directorate of Biological Control.

Sarma, Y. R., & Saju, K. A. (2004). *Biological control for the management of foot rot and slow decline diseases of black pepper* (*Piper nigrum L)* (Vol. 1, pp. 25–51). Jakarta: International Pepper Community .

Sarma, Y. R., Anandraj, M., & Venugopal, M. N. (1996). Biological control of diseases of spices. In M. Anandraj & K. V. Peter (Eds.), *Biological control in spices* (pp. 1–19). Calicut: Indian Institute of Spices Research.

Selvakumar, R., Singh, A. K., Sureja, A. K., & Raja, P. (2009). Evaluation of *Trichoderma* isolates against rhizome rot of ginger incited by *Fusarium* spp. (Abstr.). *Indian Phytopathology, 62,* 408.

Sharma, A., & Trivedi, P. C. (1989). Influence of inoculum levels of fungus *Paecilomyces lilacinus* (Thom.) Samson on the biocontrol of root-knot nematode, *Meloidogyne incognita* (Chitwood). *International Nematolology Network Newsletter, 6*(2), 27–29.

Shashidhara, S. (2007). *Studies on foot rot of black pepper caused by Phytophthora capsici Leonian, emend, Alidezeh and Tsao*. M. Sc. (Agri.) thesis in plant pathology, University of Agricultural Science, Dharwad.

Sosamma, V. K., & Koshy, P. K. (1995). Effect of *Pasteuria penetrans* and *Paecilomyces lilacinus* on population build up of root-knot nematode, *Meloidogyne incognita* on black pepper. National symposium on nematode problems of India—An appraisal of the nematode management with eco-friendly approaches and biocomponents, Indian Agricultural Research Institute, New Delhi, p. 47.

Sukumaran, S., & Sundararaju, P. (1986a). Pathogenicity of *Meloidogyne incognita* on ginger (*Zingiber officinale* Rosc.). *Indian Journal of Nematology, 16,* 258.

Sukumaran, S., & Sundararaju, P. (1986b). *Effect of root-knot nematode, Meloidogyne incognita on the growth of turmeric (Abstr.)*. Seventh symposium of plantation crops, Coonoor, Nilgiris, Tamil Nadu, India, p. 33.

Suseela Bhai, R. (1998). *Studies on Capsule Rot (Azhakul) Disease of Cardamom*. Ph. D. thesis, Univ. of Calicut, Calicut, Kerala, India.

Suseela Bhai, R., Joseph, T., & Naidu, R. (1993). Biological control of 'Azhakul' disease of small cardamom caused by *Phytophthora meadii* McRae. *Journal of Plantation Crops, 21*(Suppl.), 134–139.

Suseela Bhai, R., Joseph, T., & Naidu, R. (1994). Evaluation of carrier media for the field application of *Trichoderma* sp. in cardamom growing soils. *Journal of Plantation Crops, 22,* 50–52.

Thankamani, C. K., Anandraj, M., Diby P., & Kandiannan, K. (2003). Compatibility of *Pseudomonas fluorescens*, VAM (*Glomus fasciculatum*), *Trichoderma harzianum*, pesticides on establishment and growth of black pepper under nursery conditions (Abstr.). In M. S. Reddy, M. Anandraj, S. J. Eapen, Y. R. Sarma, & J. W. Kloepper (Eds.), *Sixth international workshop on PGPR* (pp. 82–88). Calicut: Indian Institute of Spices Research.

Thankamani, C. K., Sreekala, K., & Anandraj, M. (2005). Effect of *Pseudomonas fluorescens* (IISR 6) and *Trichoderma harzianum* (P-26) on the growth of black pepper (*Piper nigrum* L.) in the nursery. *Journal of Spices and Aromatic Crops, 14,* 112–116.

Usman, N. M., Balakrishnan, P., & Sarma, Y. R. (1996). Biocontrol of rhizome rot of ginger. *Journal of Plantation Crops, 24*(Suppl.), 184–191.

Venkitesan, T. S., & Jacob, A. (1985). Integrated control of root-knot nematode, infecting pepper vines in Kerala (Abstr.). *Indian Journal of Nematology, 15,* 261–262.

Part VI

Transfer of Crop Protection Technology and Conclusion

Transfer of Crop Protection Technology and Conclusions

20

20.1 Transfer of Crop Protection Technology

The transfer of new crop protection technologies from research to practice is running unsatisfactorily in India. Many promising new technologies are not picked up by the growers, and consequently, the national targets for pesticide reduction are not met. There is scope for reduction in pesticide usage.

The constraint for wider adoption of eco-friendly crop protection technologies is transfer of technology. Crop protection technologies developed have not reached the small and marginal farmers. Unless these technologies are assessed in farmers' fields and refined to suit local conditions, the fruits of research will not benefit the farmers. Researchers and extension personnel should work hand in hand for successful transfer of crop protection technologies. Communication media such as radio, TV, audio and video cassettes, agri-portals, farmer's field schools and Krishi Vigyan Kendras (KVKs) should be used for effective transfer of technologies.

Agromedical training, pest management workshops, adequate libraries, onsite demonstration projects, crop protection research and extension and others will be required to develop the necessary knowledge bank and to implement vigorous, effective biointensive integrated pest management (BIPM) programmes. It is estimated that 50 % of the extremely high pest-caused losses in the developing world may be prevented through application of appropriate BIPM systems.

20.1.1 Crop Protection Technology Transfer Methods

The aim of transfer of technology programmes is to promote client-oriented on-farm research and technology assessment, refinement and transfer through participatory approaches and by promoting the Institute–Village Linkage Programmes. Transfer of technology involves organizing the field demonstrations, farmer–scientist meetings, krishi melas and other activities.

20.1.1.1 Institutional and Off-Campus Training Programmes

Institutional and off-campus training programmes on various aspects of crop protection should be organized at the headquarters, regional stations and research centres of the State Agricultural Universities (SAUs)/Indian Council of Agricultural Research (ICAR) institutes to benefit farmers and extension personnel. Besides, training programmes are also conducted on selected topics on request from individuals and organizations, for which training fee may be charged (Fig. 20.1).

20.1.1.2 Front-Line Demonstration Programmes

Front-line demonstration programmes on selected technologies relating to BIPM should be organized in farmers' fields for convincing the farmers about the viability of the technologies and to obtain proper feedback from farmers on the constraints in the adoption of the recommended technologies (Fig. 20.2).

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9_20, © Springer India 2014

Fig. 20.1 Training programme on crop protection

Fig. 20.2 Front-line demonstration on crop protection

20.1.1.3 Utilization of Media and Other Extension Methods for Transfer of Technology

The following activities are to be regularly taken up to effectively utilize various media and methods of extension for effective Transfer of Technology (TOT):

- *Publication of extension pamphlets, CD-ROM, etc.:* Extension literature in the form of books, leaflets, pamphlets, bulletins, articles, etc. is prepared and printed. Extension literature is distributed to farmers to provide horticulture information related to crop protection (Fig. 20.3).
- *Organization of film shows:* Film and CD show of a recommended package of practices on crop protection plays an important role in transfer of technology among a group of farmers. After watching a particular technique/

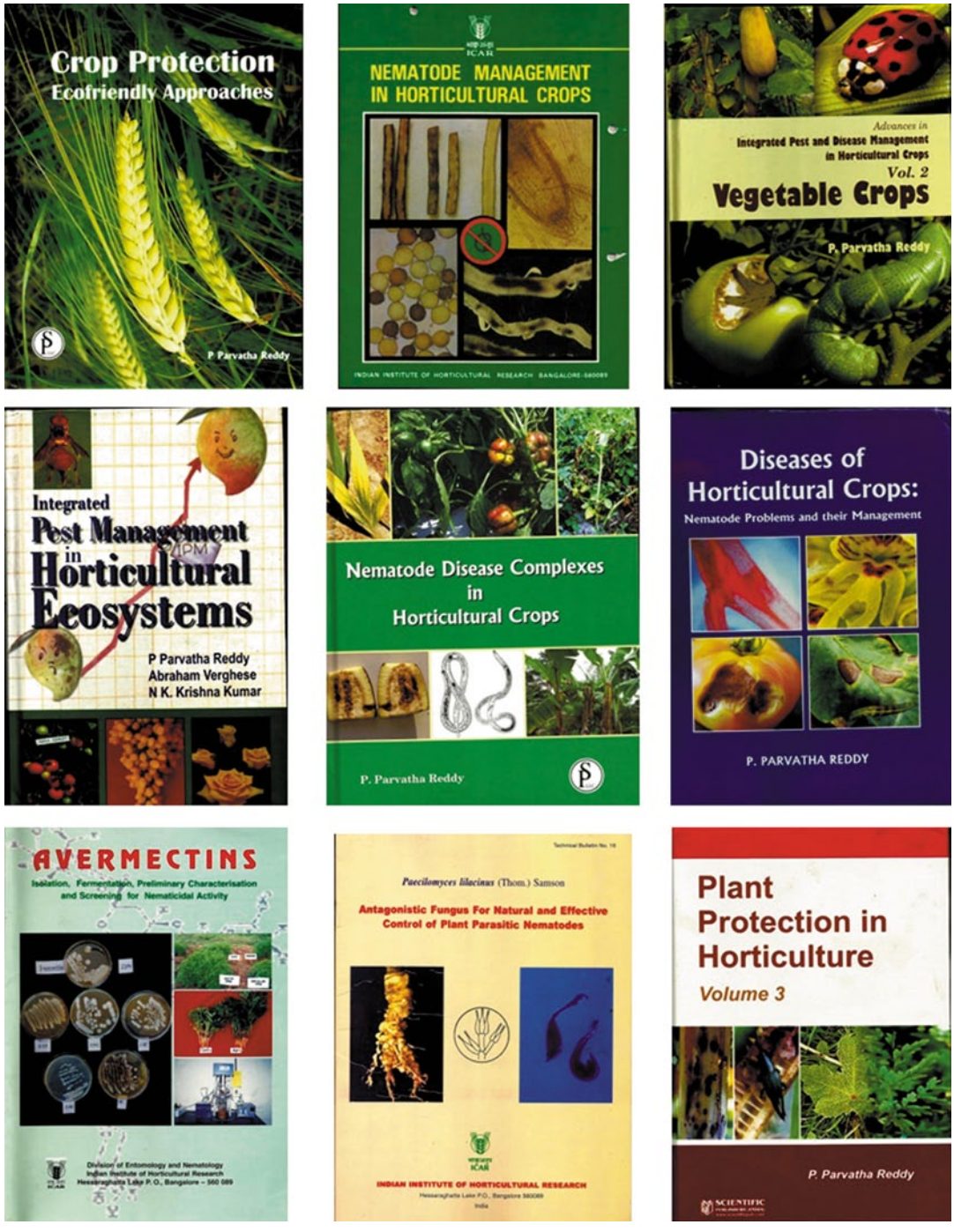


Fig. 20.3 Publication of books and bulletins on crop protection

Fig. 20.4 Organization of film shows

Fig. 20.5 Organization of Kisan Melas

method and guidance by scientists, farmers can adopt that beneficial practice (Fig. 20.4).

- *Organizing Kisan Melas:* The Kisan Melas should be organized to provide the latest crop protection information and guide/motivate farmers to adopt new scientific and profitable practices. Farmers get benefited by knowing about the latest eco-friendly technologies in crop protection.

Through the Kisan Melas, the farmers can interact with scientists, which helps in transfer of new crop protection technologies in different areas. Farmers get acquainted with the latest and recent developments in crop protection sector (Fig. 20.5).

- *Organizing field days:* Farmer–scientist–extension worker discussion is an important feature of field days. These are arranged to demonstrate new crop protection technologies in front of a large manageable group of interested farmers. Through this activity, farm experts, extension workers and farmers are involved and learn from each other (Fig. 20.6).

Fig. 20.6 Organization of field days

- *Organizing campus exhibitions:* Campus exhibitions should be organized on different themes for dissemination of new crop protection technologies, to increase their knowledge and interest about agriculture information/technique (Fig. 20.7).
- *Technology dissemination through newspapers, farm journals and radio/TV talk programmes:* The popular articles of scientists on crop protection in local languages are published in agriculture newspapers and magazines.
- Radio and TV talks play a major role in dissemination of crop protection and allied technologies among the farming community through mass communication. All the scientists of the SAUs/ICAR institutes should prepare programmes on different crop protection topics and give answers to farmers' questions in Q&A sessions. The programmes should be telecasted on Doordarshan and TV channels and broadcasted on All India Radio.
- *Organizing exposure visit-cum-training programmes for farmers:* Institutes should arrange farmers' meet from time to time for discussion with a group of farmers. Scientist replies should be given to the queries of farmers about current issues, crop problems or other agricultural activity.
- *Institute visit by farmers and other clients:* Farmers visit institutes and its instructional farms, demonstration plots/units and information centres for acquiring knowledge about the latest agricultural practices and to solve their queries. KVK scientists also visit farmers' fields to solve their problems.
- Production of video programmes on selected technologies.
- Farm advisory services.
- Participation in agricultural seminars.

20.1.1.4 Cyber Extension Activities

The Information and Communication Technology (ICT) initiatives on the lines of web-based

Fig. 20.7 Organization of campus exhibitions on crop protection

Fig. 20.8 Cyber extension activities on crop protection

systems, interactive software and cyber extension activities should be implemented (Fig. 20.8). To place SAUs/ICAR institutes in the arena of Internet to communicate research results to the end users, websites should be developed and hosted under URLs. Farmers and extension personnel seek clarifications on queries through online query facilities provided at the website.

Agricultural Technology Information Centre (ATIC) also should utilize the advances in ICT in transfer of technology to farmers in single-window concept. Kiosks, web-based consultancies

Fig. 20.9 Interface of research–extension–farmer facilitated through video conferencing

and e-mail- and mobile-based queries for technological clarification of farmers are some of the initiatives to be implemented through ATIC.

20.1.1.5 Software Development

- Interactive and auto executable softwares should be developed on pest and disease management technologies for the benefit of farmers and extension workers.
- IPM softwares should be developed to include description of pests, life cycles, symptoms (with photographs) and management methods (chemical, physical, cultural, chemical, biological, host resistance and IPM). A few video clippings could also be included.

20.1.1.6 Research–Extension–Farmer Interface Facilitated through Video Conferencing

Cyber extension activities should be launched utilizing the video conferencing facility covering several states as part of strengthening the technology transfer programmes of the SAUs/ICAR institutes in mandate crops. A group video conferencing system through Integrated Services Digital Network (ISDN) can also be installed at the ATIC to facilitate interaction between various stakeholders for enhancing technology utilization. The video conferencing facility should be effectively utilized for scheduling and implementing interface programmes at regular intervals involving various stakeholders, including researchers, extension personnel, farmers and entrepreneurs. It enables interaction of farmers at remote villages with the subject-matter specialists of the SAUs/ICAR institutes, thereby reducing the time, effort and cost in transfer of know-how from laboratory to field (Fig. 20.9).

20.1.2 Extension Research

Besides organizing extension activities, research studies also should be undertaken on various aspects of technology generation, transfer and utilization as follows:

- Studies on knowledge and adoption of recommended technologies and feedback to research systems.
- Action research projects on the performance of technologies in farmers' fields.
- Collection and documentation of indigenous technical knowledge.
- Studies on women empowerment through micro-enterprises.
- Action research projects on group approach for enhancing income through effective technology integration.

Trade publications were identified by both researchers and producers as a good way to introduce a new technology to the producers, but limited in detailed information.

Table 20.1 Technology transfer methods used by principal investigators and producers in descending order

Rank	Principal investigators	Hawaii producers	California producers	Wyoming producers
1	Workshops/field days	University and agricultural professionals	Peers	Trade publications
2	Periodicals/handouts	Peers	University professionals	University and agricultural professionals
3	University professionals	Trade publications	Trade publications	Internet
4	Internet	Workshops/field days	Workshops/field days	Peers
5	Books	Internet	Internet	Workshops/conferences

The Internet was used the most by producers in remote locations. Internet usage, and its importance as a source of information, may increase as advances are made and more producers use computers.

In general, field days and workshops were considered by principal investigators to be one of the best methods for transferring information to the producers. Yet, producers tended to think that they (especially workshops) were redundant and held at inopportune times. Many producers said that they carefully chose which field days or workshops to attend. One of the primary benefits of attending the workshops was the interaction with the other producers. Farmers receive the greatest satisfaction when they are able to share experiences with peers in group interaction.

Demonstrations located on a producers' farm were most favoured by producers, followed by field days in which producers conducted some of the presentations. Although there was great respect for university studies, concerns were often expressed that the small plots and conditions associated with research farms were not indicative of what they might encounter on their own farm. When the practice was tried on a producers' farm, they tended to believe what they saw.

Principal investigators found that on-farm demonstration projects were difficult to implement and monitor for research purposes. Often, the researcher has limited control: the producer may decide to plant a different crop than originally planned or alter the proposed management procedure. Successful on-farm trial demonstrations are the result of a coordinated effort between researchers and producers. Research studies conducted on a strategically located producers' farm seemed to have the attention of all the neighbours and were highly effective in transferring information.

Before a new technology was adopted, almost all the producers contacted someone else (even if located across the country) who was using the technology before they made the decision to adopt the new practice. This was especially true for those technologies that were costly or required a major shift in the farming operation. This extreme need to see the new practice in operation, or talk to someone who is using it, indicates that one of the most effective ways to speed up the technology transfer process is to use producers in demonstrations and field days. This is especially true for those technologies that are costly, complex or require a major shift in the operation.

The qualitative study described here examined the technology transfer preferences of early adopters of sustainable agricultural practices, which may or may not represent the preferences of all producers (Table 20.1).

20.2 Conclusions

Globalization driven by World Trade Organization is opening up fantastic opportunities for export of horticultural products and processed food from India. It is a revolution, which is taking place, and our farmers will miss this golden opportunity if they are not equipped with the right crop protection technologies to produce horticultural products of international standards without pesticide residues. The challenge faced by the crop protection scientists is to prevent crop losses due to pests before and after harvest with-

out harming the environment. There is a need to develop low input and eco-friendly crop protection technologies so as to be very competitive in the international market.

There is a need to revamp the extension system in SAUs/ICAR institutes to bridge the gap between technology generation and technology dissemination, since 60% of farmers have no access to technology as revealed by the latest National Sample Survey Organization Report (Suryamurthy 2005).

Padma Vibhushan Prof. M. S. Swaminathan, an eminent agricultural scientist of international repute, stated that 'The ever-green revolution will be triggered by farming systems that can help produce more from the available land, water and labour resources without either ecological or social harm' (Swaminathan 2000). Let us rededicate ourselves to achieve Prof. Swaminathan's dream of 'ever-green revolution'.

References

Suryamurthy, R. (2005). ICAR revamp to benefit farmers. *The Tribune* (Sept. 2), 2.

Swaminathan, M. S. (2000). For an evergreen revolution. *The Hindu Survey of Indian Agriculture, 2000,* 9–15.

Index

P. P. Reddy, *Biointensive Integrated Pest Management in Horticultural Ecosystems,*
DOI 10.1007/978-81-322-1844-9, © Springer India 2014