Innovations in Horticultural Science
Mohammed Wasim Siddiqui, Series Editor

Advances in Pest Management in Commercial Flowers

Suprakash Pal | Akshay Kumar Chakravarthy
Editors

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ADVANCES IN PEST MANAGEMENT IN COMMERCIAL FLOWERS

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Edited by

Suprakash Pal, PhD

Akshay Kumar Chakravarthy, PhD

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INNOVATIONS IN HORTICULTURAL SCIENCE

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The horticulture sector is considered as the most dynamic and sustainable segment of agriculture all over the world. It covers pre- and postharvest management of a wide spectrum of crops, including fruits and nuts, vegetables (including potatoes), flowering and aromatic plants, tuber crops, mushrooms, spices, plantation crops, edible bamboos etc. Shifting food pattern in wake of increasing income and health awareness of the populace has transformed horticulture into a vibrant commercial venture for the farming community all over the world.

It is a well-established fact that horticulture is one of the best options for improving the productivity of land, ensuring nutritional security for mankind and for sustaining the livelihood of the farming community worldwide. The world's populace is projected to be 9 billion by the year 2030, and the largest increase will be confined to the developing countries, where chronic food shortages and malnutrition already persist. This projected increase of population will certainly reduce the per capita availability of natural resources and may hinder the equilibrium and sustainability of agricultural systems due to overexploitation of natural resources, which will ultimately lead to more poverty, starvation, malnutrition, and higher food prices. The judicious utilization of natural resources is thus needed and must be addressed immediately.

Climate change is emerging as a major threat to the agriculture throughout the world as well. Surface temperatures of the earth have risen significantly over the past century, and the impact is most significant on agriculture. The rise in temperature enhances the rate of respiration, reduces cropping periods, advances ripening, and hastens crop maturity, which adversely affects crop productivity. Several climatic extremes such as droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, and heat waves cause a negative impact on agriculture and are mainly caused and triggered by climate change.

In order to optimize the use of resources, hi-tech interventions like precision farming, which comprises temporal and spatial management of resources in horticulture, is essentially required. Infusion of technology for an efficient utilization of resources is intended for deriving higher crop productivity per unit of inputs. This would be possible only through deployment of modern hi-tech applications and precision farming methods. For improvement in crop production and returns to farmers, these technologies have to be widely spread and adopted. Considering the above-mentioned challenges of horticulturist and their expected role in ensuring food and nutritional security to mankind, a compilation of hi-tech cultivation techniques and postharvest management of horticultural crops is needed.

This book series, Innovations in Horticultural Science, is designed to address the need for advance knowledge for horticulture researchers and students. Moreover, the major advancements and developments in this subject area to be covered in this series would be beneficial to mankind.

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ABBREVIATIONS

AIL	aesthetic injury level
ASSOCHAM	Associated Chambers of Commerce and Industry of India
BCAs	biological control agents
BPH	brown planthopper
CO_2	carbon dioxide
CSIs	chitin synthesis inhibitors
DI	days interval
EIL	economic injury level
EPF	entomopathogenic fungi
ETL	economic threshold level
GABA	γ-aminobutyric acid
Ha NPV	*Helicoverpa* nuclear polyhedrosis virus
HWT	hot-water treatment
IGR	insect growth regulators
IPCC	Intergovernmental Panel on Climate Change
IPM	integrated pest management
IPPC	International Plant Protection Convention
ITK	indigenous technical knowledge
JHAs	juvenile hormones and their analogs
JHs	juvenile hormones
MIs	molting inhibitors
nAChR	nicotinic acetylcholine receptors
NEs	natural enemies
NPVs	nuclear polyhedrosis viruses
NSKE	neem seed kernel extract
NSO	neem seed oil
NSPE	neem seed powder extract
PCS	photon correlation spectroscopy
PFA	pest-free area
PHMB	pink hibiscus mealybug
PHS	porous hollow silica
PHSNs	porous hollow silica nanoparticles
PL	*Purpureocillium lilacinum*

PMB	pink mealybug
PPO	polyphenol oxidase
RNAi	RNA interference
SLN	solid-lipid nanoparticle
VAM	vesicular-arbuscular mycorrhiza
WTO	World Trade Organization

PREFACE

Flowers are intricately entwined in the social life of people all over the world. The use of flowers is increasing every day due to changes in the life-styles of people, concern for the environment, conscious efforts towards greening, and better purchasing capacity of people. Nowadays, flowers are auspiciously used on ceremonies, New Year's Day, Deepavali, Dussehra, Christmas, Valentine's Day, cultural gatherings, and interior decorations. Hence, commercial floriculture has become a profitable venture today. Commercial floriculture includes the production of both loose flowers and cut flowers, nursery plants and potted plants, and seeds and bulbs as well as, micropropagation and extraction of essential oils. Vertical and green farms in urban environments have further enlarged the scope of commercial floriculture.

Floricultural crops all over the world are challenged by a number of insect and mite pests. The pests scenario is changing, and under the regime of climate change concern, the instances of new pest incidence have become a more common feature. Like other crops, the intensive cultivation of commercial flowers has accentuated the pest problems, as the farmers tend to use more agricultural chemicals, which, in turn increase the problems of pesticide resistance, pest resurgence, and residues leading to health hazards.

The use of synthetic insecticides is widely adopted for managing these pests. But growing concerns over the hazardous effects of pesticides on the ecosystem as a whole have prompted policymakers and growers to adopt alternative pest suppression methods. Great advances have been made during the last few decades in insect science and pest management. Immense progress has been achieved in the employment of select novel integrated pest management tactics for the suppression of pest complex to reduce the crop losses.

The conceptualization of this work is very timely and valuable toward the sustainable management of pests of commercial flowers. It is expected that this book will be of value and use to floriculturists, entomologists, plant protection specialists, and students worldwide.

PART I

Commercial Flowers and Pest Problems

CHAPTER 1

WORLDWIDE PESTS OF IMPORTANT COMMERCIAL FLOWERS

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ABSTRACT

The commercial flowers like rose, carnation, chrysanthemum, gerbera, gladiolus, and marigold are infested by a number of pests. Carnations are infested by aphids and thrips. The two-spotted spider mite, *Tetranychus urticae*, has been found as a common pest of carnations in India as well as abroad. The bud borer, *Helicoverpa armigera*, has been reported to damage flowers and buds of carnation. Sucking pests like aphids, Mealybugs, and spider mites seriously damage the chrysanthemums. The cotton mealybug, *Phenacoccus solenopsis*, is an invasive pest reported to occur on chrysanthemum. The gram pod borer has been reported to infest buds and flowers of chrysanthemums in Shimla and Darjeeling hills. Gladiolus thrips, *Taeniothrips simplex*, has been reported as a serious pest on gladiolus buds, flowers, and corms world over. Different species of aphids infest roses. The aphid, *Macrosiphum rosae* is a widely distributed species, whereas *Macrosiphum rosaeformis* and *Macrosiphum centranthi* are confined to the Indian sub-continent. Major foliage feeding insects on rose include *Achaea janata*, *Euproctis fraterna*, *E. lunata*, and *E. scintillance*. The rose beetle, *Adoretus versutus*, and *A. lasiopygus* (Scarabaeidae) feed on leaves of roses in many parts of India as well as abroad. Aphids, thrips, and mites are the important sucking pests

infesting marigold. The different sap-sucking pests infesting gerbera include the green peach aphid, *Myzus persicae*, whitefly, *Bemisia tabaci*, red spider mite, *Tetranychus urticae* and yellow mite, *Polyphagotarsonemus latus*. The caterpillar of *Homona menciana* and *Plusia orichalcea* feeds on the leaves and petals of gerbera. The leaf miner, *Liriomyza trifolii* (Agromyzidae), infests the leaves and the larvae of *Helicoverpa armiger*a bore into the buds and flowers of gerbera. The important sucking pests infesting anthurium include aphids, thrips, and different types of scale insects.

1.1 INTRODUCTION

Commercial floriculture was first started in Europe and the United States. In developed countries, the flowers for commercial purposes are mostly grown under glasshouses or hi-tech fully controlled polyhouses. In developing countries like India, the open polyhouses or naturally ventilated, low cost, shade houses are more common. Some commercial flowers like marigold, gladiolus, and chrysanthemum are also being cultivated commercially in the open fields. In India, the commercial floriculture is going through a paradigm shift, where traditional flower cultivation is giving way to modern hi-tech flower cultivation, which is evident from India's rising production and exports.

Earlier studies on the pest scenario of ornamental plants have been initiated by the Europeans and Americans. Naegele and Jefferson (1964) reviewed the literature on the insect pests of ornamentals under glasshouse conditions. Weigel and St. George (1952) categorized different groups of insect pests of ornamental plants on the basis of their feeding habits. Pirone (1978) described diseases and pests that attack nearly 500 genera of ornamental plants grown outdoors, under glass, and in the home.

Butani and Dadlani (1983) reviewed the literature on insects, mites, and nematode pests of ornamental plants. Bindra and Singh (1970) reviewed the literature on mites associated with ornamental plants. Atwal (1986) described some important insect pests of ornamental plants. Sood (1988) reviewed the insect pests of ornamental plants with special reference to four important ornamental crops of Himachal Pradesh, India viz., roses, chrysanthemum, carnation, and gladiolus. Ramesh (1994) compiled the information on pests of floriculture crops in a book. Sohi and Singh (1995) reviewed the insect pests of ornamental plants. Sharma and Bhattacharya (2002) summarized the diseases and insect pests of major ornamentals.

Chauhan and Sharma (2004) published an identification and management manual on insect pests of ornamental crops (Figures 1.1 and 1.2).

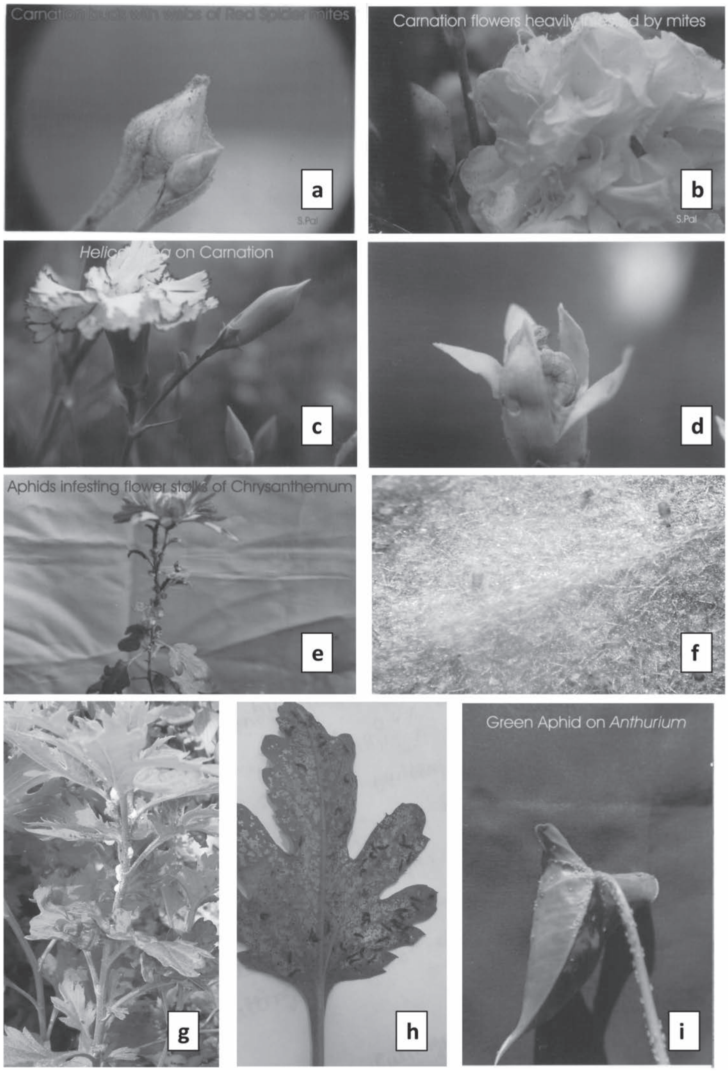

FIGURE 1.1 (See color insert.) Pests of commercial flowers. (a) Red spider mite webs on Carnation buds, (b) Flower of Carnation with webs of spider mite, (c) *Helicoverpa* on Carnation buds & flowers, (d) *Helicoverpa* boring into Carnation bud, (e) Aphid infestation of chrysanthemum, (f) Different life stages of red spider mite, (g) Cotton mealybug infesting chrysanthemum, (h) Tobacco caterpillar feeding on chrysanthemum leaf, (i) Green aphid on Anthurium leaf.

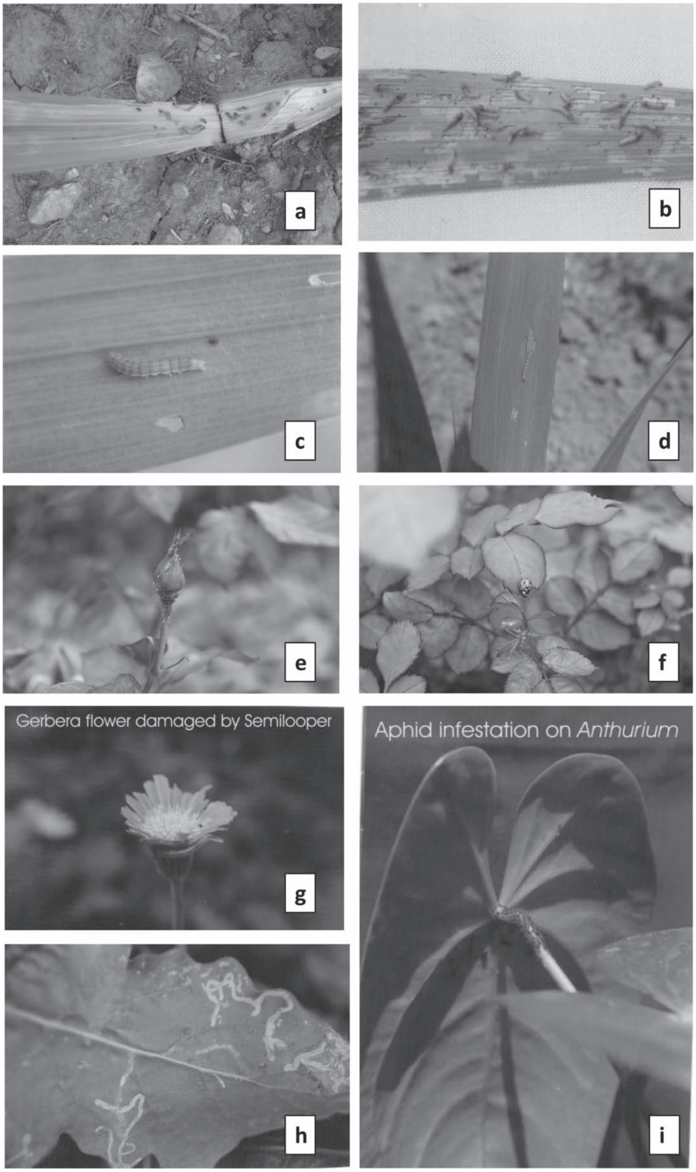

FIGURE 1.2 (See color insert.) Pests of commercial flowers. (a) Leaf caterpillar infestation on Gladiolus, (b) *Spodoptera* caterpillars on Gladiolus, (c) *Helicoverpa* damage on Gladiolus, (d) Semilooper damage on Gladiolus, (e) Aphid infestation in rose, (f) *Coccinella septempunctata* on rose aphid, (g) Green semilooper feeding on Gerbera flower, (h) Serpentine leafminer damage on Gerbera, (i) Black aphid on Anthurium leaf.

1.2 PESTS OF CARNATION

Carnation, *Dianthus caryophyllus* Linnaeus (Caryophyllaceae) is native to the Mediterranean region and is an important commercial plant in the United States and England. It is mainly used as cut flowers and is in high demand during any celebration or festival. In recent times, it is considered the most important cut flower crop next only to rose. In India, Himachal Pradesh, Punjab, West Bengal, Jammu and Kashmir, and Karnataka are the major states producing carnations. Carnations are grown commercially in India in places having mild climate such as Solan, Shimla, Kalimpong, Kodaikanal, Mandi, Kullu, Srinagar, Ooty. In Pune and Bangalore, it is grown under controlled conditions (Shiragur et al., 2004).

1.2.1 SAP SUCKING PESTS

Three species of aphids, namely, *Myzus persicae* (Sulzer), *Myzus dianthicola* Hille Ris Lambers, and *Aphis gossypii* Glover were observed infesting carnations by Jefferson et al., (1964), Hille Ris Lambers (1966), and Atanov and Ionova (1980).

Two species of thrips, *Taeniothrips atratus* (Hal.) and *Haplothrips cottei* Vuielet were reported on carnations by Morison (1957) and Abdel Aziz (1932) from Britain and Egypt, respectively. In India, three species of thrips, *Thrips tabaci* (Lindeman), *Taeniothrips simplex* (Morison), and *Frankliniella dampfi* (Priesner), were reported to infest flowers by Ananthakrishnan (1973). While considering the pest problems of carnation; spider mites (*Tetranychus urticae* Koch.) and thrips (*Thrips tabaci* Lindeman and *Frankliniella occidentalis* Pergande) are the most common pests in Karnataka, India (Manju, 2013). Pink and red-colored varieties of carnation were found to harbor higher populations of thrips, *T. tabaci* (Lindeman) population compared to white or yellow-colored varieties (Manju et al., 2015). But earlier, Buss (2006) reported that white or yellow flowers are apparently preferred by flower thrips (*Frankliniella* spp.) in Florida, USA.

Two-spotted spider mite, *Tetranychus urticae* Koch., was found in Poland on carnation flowers and leaves by Jesioter (1978) (Figures 1.1a and 1.1b). Poe and Wilfret (1973) studied the relative susceptibility of 18 different cultivars and reported that cultivars with curled, bent, or reflexed leaves had a larger mite population than those with straight flat leaves.

1.2.2 DEFOLIATORS

Grasshopper, *Atractomorpha crenulata* (Fabricius) feeds on leaves and cause considerable damage to carnation in Himachal Pradesh, India (Sood and Kakar, 1990). Tortrix moths, *Cacoecimorpha pronubana* (Hb.), and *Epichoristodes acerbella* (Walk.) are found on carnation in the summer and early autumn (Quaglia, 1993).

1.2.3 STEM BORERS AND LEAF MINERS

Serpentine leaf miner, *Liriomyza trifolii* (Burgess), has been recorded as a pest of carnations in Turkey (Akbulut and Zumreoglu, 1992).

1.2.4 BUD AND FLOWER FEEDING PESTS

Helicoverpa armigera (Hubner) has been reported to damage flowers and buds of carnation (Pietanza, 1969; Mckay, 1981) from Italy and Queensland, respectively. *H. armigera* has been reported as a predominant pest of ornamental plants during the spring season in the eastern Himalayan region of India (Satpathi et al., 1996) (Figures 1.1c and 1.1d). The extent of damage by *H. armigera* in terms of percentage in bud infestation ranges from 10% to even 80% in various cultivars in Himachal Pradesh, India (Chauhan and Sharma, 2004). Amongst several species of ornamental plants, the most preferred host of *H. armigera* is carnation, wherein 48% of plants were damaged, and in most of the cases, the caterpillars were seen boring the flower buds and completely damaging them (Singh, 1983). Carnation also exhibited higher *H. armigera* infestation (2.6 larvae per plant and 27.36% flower and bud damage) amongst several ornamental crops in Karnal, Haryana, India (Sinha and Chakrabarti, 1983). The attack by this pest is more on carnation when grown near the field of Egyptian clover (Singh, 1983; Singh and Arora, 1989). Spray type carnation was more susceptible to *H. armigera* in comparison with standard type carnation (Multani and Sohi, 2002).

1.2.5 PEST COMPLEX

Carnation is infested by about 40 serious pests under glasshouse in Michigan state (McDaniel, 1931). Jannone (1967) enumerated the insects and mites on carnations grown commercially in Italy, viz., *Gryllotalpa gryllotalpa* (Linn.), *Phaneroptera falcate* (Poda.), wireworms, cutworms, *Heliothrips haemorrhoidalis* Fab., thrips, *Thrips tabaci* Lindeman, aphids, coccids, *Forficula auricularia* Linn. and the phytophagous mite *T. urticae* and *Aceria* sp. In Bulgaria, Veselinov, and Boikov (1967) recorded *Taeniothrips vulgatissimus* (Hal.), *Taeniothrips fedorovi* Priesn., *Frankliniella intosa* (Trybom), *Heliothis incarnate* Friv., *H. maritima* Graslin., *Mamestra suasa* (Schiff.) and *Agrotis segetum* (Schiff.) on carnations. Mckay (1981) reported spider mites, aphids, and thrips causing damage to carnations. Carnation is one of the major crops grown in polyhouses in Himachal Pradesh, India. The insect pests infesting carnation in these polyhouses include the green peach aphid, *M. persicae*, thrips, *T. tabaci* (Lindeman) and gram pod borer, *H. armigera* (Vashisth et al., 2013). Carnation is attacked by a number of pests out of which the bud borer, *H. armigera* and red spider mite, *T. urticae* are serious in the hilly region of Kalimpong, West Bengal (Pal and Sarkar, 2010).

1.3 PESTS OF CHRYSANTHEMUM

Chrysanthemum (*Chrysanthemum* spp.), commonly known as 'autumn queen' or 'queen of the East' is a popular flower crop of commercial importance. It is native to China, and its flowers are of a wide range of shapes, sizes, and colors. In many countries, including the United States and Japan, it is considered as the number one commercial flower, while in several other flower producing countries, it is next only to rose in crop value.

1.3.1 SAP SUCKING PESTS

The aphids, *Aphis craccivora* Koch, *Aphis gossypii* Glover, *Coloradoa rufomaculata* (Wilson) and *Macrosiphoniella sanborni* (Gillette) suck sap from the stem, leaves, flowers, and flower buds (Bindra and Sekhon, 1969; George, 1927; Ghosh, 1975; Nair, 1975) (Figure 1.1e). Monison et al., (1969) observed *Coloradoa rufomaculata* (Wilson), *Brachycaudus helichrysi*

Kaltenbach, and *Macrosiphoniella sanborni* (Gillette) on chrysanthemum in France. Habib and Elkady (1959) and Abul Nasr et al., (1975) reported *M. sanborni* (Gillette), *Pleotrichophorus* (*Capitophorus*) *chrysanthemi* Theobald, *Coloradoa rufomaculata* (Wilson), *A. gossypii*, *Brachycaudus* sp. and two coccids *Icerya purchasi* Maskell and *Ferrisia virgata* (Cockerell) to attack the leaves, stems, and flowers. Ghosh (1975) reported *M. sanborni* (Gillette), *Coloradoa rufomaculata* (Wilson), *Dactynotus tanaceti indica* Ghosh, *Macrosiphum centranthi* Theobald, and *Pleotrichophorus chrysanthemi* Theobald on chrysanthemum from different parts of India.

The cotton mealybug, *Phenacoccus solenopsis* Tinsley, is an invasive pest reported to occur on chrysanthemum in all the cotton growing zones, i.e., North, Central, and South zones (Vennila et al., 2014) (Figure 1.1g).

The bugs, *Nysius* sp. and *Oxycarenus laetus* Kirby (Lygaeidae), have been recorded attacking *Chrysanthemum* spp. in Himachal Pradesh, India. Nymphs and adults of both species infest flowers due to which they wither and dry (Sood, 1990). *Lygus* sp. (Miridae) and *Cadmilos retiarius* Dist. (Tingidae) suck sap from leaves, which affect flowering adversely (Sood and Kakar, 1990; Atwal, 1986; Patel et al., 1964a). The capsid bug, *Lygus pratensis* Linnaeus infest chrysanthemum and cause deformation of flower buds, leaves, and shoots (Tullgren, 1917; Bodenheimer, 1921; Caesar and Ross, 1922; Fox Wilson, 1925). Tullgren (1915, 1917) reported *Lygus pabulinus* (Linnaeus), *Lygus pabulorum* (Linnaeus), and *Lygus campestris* (Linnaeus) on young shoots and buds of *Chrysanthemum indicum* in Sweden. The mirid bug, *Creontiades pallidifer* (Walker) feeds by sucking the sap from the tender portions of the chrysanthemum plant (Ramesh, 1994).

The thrips, *Haplothrips ramakrishnai* (Karny) (Phloeothripidae) and *Microcephalothrips abdominalis* (Crawford) (Thripidae) infests chrysanthemum and cause lesions on petals (Ananthakrishnan, 1973; Nair, 1975). *T. tabaci* and *Frankliniella tritici* (Fitch) also attack chrysanthemum (Ramesh, 1994). Of late, Western flower thrips, *Frankliniella occidentalis* (Pergande) is reported to cause damage in chrysanthemum with *Thrips palmi* Karny, which is found to attack flowers (Kher et al., 2002). Seven species of thrips were collected in Kenya by Bullock (1963) on *Chrysanthemum cinerariaefolium* of which two species, namely, *Thrips nigropilosus* Uzel feeding on vegetative shoots and *T. tabaci* on flowers were considered injurious. Wood and Paik (1971) and Wang (1982b) reported *Frankliniella intosa* Trybom and *Thrips hawaiiensis* (Morgan) from Korea and Taiwan. Further, Woo and Paik (1971) reported *Haplothrips chinensis* Priesn and *Microcephalothrips abdominalis* (Crawford) to occur in Korea. In India, only *Microcephalothrips abdominalis* (Crawford) was reported by Ananthakrishnan (1973) to infest flowers.

The red spider mite, *Tetranychus telarius* Linnaeus was reported on many cultivars of chrysanthemum in Finland by Markulla et al., (1969) (Figure 1.1f). In India, Bindra, and Singh (1970) reported four species of mites, *Paraphytoptus chrysanthemi* Keifer, *Bryobia* sp., *B. eharei* Pritichard and Keifer and *T. telarius* Linnaeus whereas Sadna et al., (1981) recorded *Brevipalpus obovatus* Donn. and *B. phoenicis* on chrysanthemum from Punjab. Reddy et al., (2004) screened chrysanthemum germplasm for resistance to two-spotted spider mite, *Tetranychus urticae* Koch.

1.3.2 DEFOLIATORS

The larvae of hairy caterpillar, *Spilosoma obliqua* (Walker), skeletonize the foliage by feeding gregariously (Ramesh, 1994). The caterpillar of *Hedylepta* (=*Lamprosema*) *indicata* (Fab.) feeds on the leaves (Nair, 1975; Pal and Sarkar, 2009). The leaves are also fed upon by the caterpillars of tobacco caterpillar, *Spodoptera litura* Fab. (Ramesh, 1994) (Figure 1.1h). The nymphs and adults of *Atractomorpha crenulata* (Fab.) feed on the leaves from the margin (Sood and Kakar, 1990). The white-spotted flea beetle, *Monolepta signata* Oliv. cut numerous holes on leaves (Pal and Sarkar, 2009).

1.3.3 STEM BORERS AND LEAF MINERS

The leaf-miner, *Phytomyza atricornis* Meign. was reported on chrysanthemum leaves by French et al., (1967) and Penzes (1983) in England and Hungary, respectively. The pea leaf miner, *Chromatomyia horticola* (Gour) make zigzag silvery lines on the upper surface of leaves (Singh and Ipe, 1973; Gokalpure, 1966, 1972).

1.3.4 BUD AND FLOWER FEEDING PESTS

The gram pod borer, *Helicoverpa armigera* (Hubner) has been reported to infest the buds and flowers of chrysanthemum from Shimla and Darjeeling by Singh (1983) and Pal and Sarkar (2009), respectively.

1.3.5 PEST COMPLEX

Weigel (1923) reported twelve insects and mites from the United States damaging chrysanthemum, namely, *Diarthronomyia hypogaea* Low., *Phlyctaema ferrugalis* Hub., *Trialeurodes vaporariorum* Westw., *Macrosiphoniella sanborni* (Gillette), *Coloradoa* (=*Rhopalosiphum*) *rufomaculata* (Wils.), *Heliothrips haemorrhoidalis* (Bch.), *Lycophotia margaritosa* Haw., *Orthezia insignis* Dougl., *Saissetia hemisphaerica* Targ., *Pseudococcus citri* Risso., *Pseudococcus adonidum* Linnaeus and *Tetranychus telarius* Linnaeus. In greenhouse chrysanthemums, Wardlow, and Gould (1981) considered aphids, *M. persicae*, *M. sanborni* (Gillette), *Brachycaudus helichrysi* (Kalt.), *Aulacorthum circumflexum* (Buckt.) and *A. gossypii* together with *T. urticae*, *Phytomyza syngenesiae* (Hardy), *L. trifolii*, *Rhopalomyia chrysanthemi* (Ahlberg), *Scutigerella immaculosa* (Newp.), *Psila nigricornis* Mg., *Phlogophora meticulosa* (L.), *Forficula auricularia* L., *Lygus rugulipennis* Pop. and thrips as pest complex on chrysanthemum.

1.4 PESTS OF GLADIOLUS

Gladiolus (*Gladiolus* spp.), commonly known as "Sword lily" (Iridaceae) is a popular cut-flower crop having great demand in domestic as well as international markets. According to the Indian Horticulture Database 2014 of National Horticulture Board, it ranks fourth in the area followed by marigold, rose, and chrysanthemum and second in the cut-flower production. Being native to Africa, it is adored all over the world for its attractive spikes having florets of attractive forms, dazzling colors, and varying sizes.

1.4.1 SAP SUCKING PESTS

Two aphid species *A. gossypii* and *Macrosiphum centranthi* Theobald were reported from gladiolus leaves by Pirone (1978). The aphid, *A. craccivora* has been recorded feeding on gladiolus in Himachal Pradesh, India. Its nymphs and adults suck sap from tender shoots. The attacked plants produce small flowers of low quality (Sood, 1988). Other species of aphids reported to infest the crop include *A. gossypii*, *M. persicae*, and *Macrosiphum euphorbiae* Theobald (Ramesh, 1994).

Tarnished plant bugs, *Lygus lineolaris* (P. de B) puncture the terminal shoot below the flower bud and injects toxic saliva causing the flowers to drop and wither (Ramesh, 1994).

Gladiolus thrips, *Taeniothrips simplex* Morison has been reported as a serious pest on gladiolus buds, flowers, and corms all over the world. In India, *T. simplex* was first noted on gladiolus in 1940 from Coonoor and subsequently in large numbers from Nilgiris and Kodaikanal hills (Ananthakrishnan, 1971). Thakur et al., (1973) reported *T. simplex* damaging flowers and buds from Solan, Himachal Pradesh. The species of thrips, namely *Liothrips* sp. (Phlaeothripidae) and *Thrips hawaiiensis* feed on flowers (Sood and Kakar, 1990). Other species of thrips reported on gladiolus include Honeysuckle thrips, *Thrips flavus* Schrank (Ramesh, 1994).

The polyphagous mite, *Tetranychus cucurbitae* Rahman and Sapra was reported from India by Bindra and Singh (1970). Other species of mites feeding on gladiolus are red spider mite, *T. urticae* and bulb mite, *Rhizoglyphus echinopus* (Fum and Rob) (Ramesh, 1994).

1.4.2 DEFOLIATORS

The cutworm, *Agrotis segetum* (Schiff) and tobacco caterpillar, *Spodoptera litura* (Fabricius) have been recorded on gladiolus from the Darjeeling hills (India) (Pal and Sarkar, 2009) (Figures 1.2a and 1.2b). Other lepidopteran pests found infesting gladiolus include cabbage green semilooper, *Trichoplusia ni* Hubner and cabbage butterfly, *Pieris brassicae* Linnaeus (Ramesh, 1994) (Figure 1.2d). *Altica* sp. has been reported to make numerous holes on leaves by feeding (Sood and Kakar, 1990).

1.4.3 BUD AND FLOWER FEEDING PESTS

Mckay and Huges (1982) reported *H. armigera* and *Helicoverpa punctigera* Wlgr. damaging buds and flowers from Queensland, Australia. *H. armigerea* was also reported on spikes of gladiolus from Himachal Pradesh (Singh, 1983) and Darjeeling (Pal and Sarkar, 2009), India (Figure 1.2c). The blister beetles, *Mylabris* spp. were found feeding on the flowers (Pal and Sarkar, 2009).

1.4.4 PEST COMPLEX

In Central Taiwan, Wang (1982b) reported 15 pests of which the more important were *S. litura*, *Trichoplusia ni* (Hubner), *Agrotis ipsilon* (Hfn.), *Sesamia inference* (Walker), *Euproctis taiwana* (Shiraki) and *Rhizoglyphus robini* Claparede. The principal pests of gladiolus in the flower gardens have also been reviewed by Kelsheimer (1956), Hibbs (1958), and Smith (1962).

1.5 PESTS OF ROSE

Rose is one of the nature's beautiful creations and is universally acclaimed as the "Queen of Flowers." Roses are of foremost commercial importance, and cut-roses have the highest demand throughout the world and year-round.

1.5.1 SAP SUCKING PESTS

Among aphids Abul Nasr et al., (1975) reported seven species of aphids from Egypt, namely, *M. persicae*, *Pleotrichophorus chrysanthemi* (Theobald), *Aphis punicae* Passerini, *A. nasturtii* Kaltenbach *A. gossypii* Glover, *Acyrthosiphon porosum* (Sanderson) and *Macrosiphum rosae* (Linnaeus). From India, fifteen species, namely, *A. porosum*, *Chaetosiphon chaetosiphon* Nevsky, *Chaetosiphon chaetosiphon indicum* Chakrabarty, and Ghosh, *Chaetosiphon tetrahoda* (Walker). *Longicaudus himalayensis* Hille Ris Lambers, *Macrosiphum centranthi* Theobald, *M. rosae*, *M. rosaeformis* Das, *Matsumuraja capitophoroides* Hille Ris Lambers, *Myzaphis aurilosa* David, Rajasingh, and Narayanan, *M. rosarum* (Kaltenbach) and *M. turanica* Nevsky were reported by Ghosh (1975). *M. rosae* is a widely distributed species, whereas *M. rosaeformis* and *M. centranthi* are confined to the Indian sub-continent (David, 1957, 1975) (Figures 1.2e and 1.2f).

Agarwala and Raychaudhuri (1981) made observations on the population trends of rose aphids, *M. rosae*, and *M. rosaeformis* in Kalimpong (West Bengal). The first peak during April and the other during November were noticed. The simple correlation coefficient of the population with abiotic factors like maximum temperature, minimum temperature, the percentage in relative humidity, and rainfall was found to be + 0.61, + 0.31, + 0.51, and –0.28, respectively.

Aphid, *A. gossypii* is present on cultivated varieties of roses from September to December with a peak period of activity in October (Dhingra, 1968). *Cinara* sp. of aphid infests shoots of roses. This was a new record from Himachal Pradesh (Sood and Kakar, 1990). The rose aphid, *Macrosiphum rosaeformis* Das infests roses in Punjab, Delhi, Mysore, Andhra Pradesh, and Nilgiri Hills (Ullah, 1940).

The parasites, *Aphidius rosae* Hal. and *Aphelinus* sp. parasitize the aphid whereas, *C. septempunctata* predates upon it (Atwal and Dhingra, 1971; Das, 1918; Dhingra, 1968).

The nymphs and mature females of *Aonidiella aurantii* Maskll. (Diaspididae) suck sap from leaves, shoots, and stems of the plant. The infested plant gets weak and bears a few small flowers (Ali, 1968; Butani, 1974; Nandakumar et al., 1988). The scales, *Aspidiotus dictyospermi* Newst., *A. orientalis* Newst. and *A. transparens* Gr. (Diaspididae) infest shoots and leaves of roses (Nair, 1975). The scales, *Chionaspis* sp. and *Chripomphalus aurantii* Maskll. (Diaspididae) infests tender shoots in South India (Ayyar, 1919; David, 1957). The scale, *Ferrisia virgata* (Cockll.) (Pseudococcidae) infests shoots in rose in South India (Nair, 1975), while *Icerya aegyptiaca* (Dough.), *I. formicarum* Newst., *I. purchasi* Maskll. (Margarodidae) and *Lindingaspis rossi* (Maskll.) (Pseudococcidae) infest twigs of roses in different parts of India (Glover, 1934; Nair, 1975; Prabhakar Rao, 1950; Ramachandra Rao and Cherian, 1944; Srinivasan et al., 1974).

Cottony cushion scale, *Icerya purchasi* Maskll. and *Icerya aegyptiaca* (Dgl.) were found on rose plants by Abul Nasr et al., (1975) in Egypt. Tandon et al., (1972) reported the occurrence of *Quadraspidiotus perniciosus* (Comstock), which caused serious damage to roses in Himachal Pradesh. The jassid, *Empoasca* sp. was recorded on roses by Butani (1974). Frog hoppers, *Philaenus spumarius* Linnaeus (Cercopidae) produce conspicuous masses of froth commonly called ‘cuckoo spit’ on the stems and leaves. They feed on plant sap and distort young growths (Cavendish, 1969).

The whitefly, *Aleurocanthus rosae* Singh sucks sap from leaves (Singh, 1931). *Amrasca biguttula* sucks sap from leaves and causes stipplings (Sohi et al., 1988). *Evacanthus* sp. was found feeding on leaves of roses in Himachal Pradesh (Sood, 1988). The leafhoppers, *Motschulskyia serrata* (Mats.) and *Zygina* (*Hypericiella*) *bicornia* Dwor. (Cicadellidae) suck sap from leaves causing stippling (Sohi and Mann, 1986). *Dysdercus* sp. causes moderate to serious damage to rose flowers in India (Verghese and Prasad, 1983). Blossom thrips associated with roses are *Thrips flavus* (Schrank), *T. coloratus* (Priesner), *T. hawaiiensis* (Morgan), *Rhipiphorothrips cruentatus* (Hood), *Retithrips syriacus* (Mayet), *Taeniothrips traegardhi* (Trybom) and *Aelothrips collaris* (Priesn.) as reported by Ananthakrishnan (1973). From Himachal Pradesh, Bhalla, and Thakur (1974) reported *Aelothrips meridionalis* Priesner, *Taeniothrips traegardhi* (Trybom), *T. flavus*, and *T. hawaiiensis*. *Lefroyothrips lefroyi* (Bagn.) was recorded infesting rose flowers in Himachal Pradesh (Sood, 1988). *Megalurothrips usitatus* (Bagn.) feeds on flowers in many parts of India (Verma et al., 1980). *Physothrips andrewsi* Bagn. also lacerates petals of rose flower and destroys its beauty (Bagnall, 1921).

A phytophagous mite, *Tetranychus kanzawai* Kishida was reported on roses by Wang (1982a) from Central Taiwan. In India, six species of mites, *Brevipalpus phoenicis* (Geijskes), *B. rugulosus* Chaudhri, Akbar, and Rasool, *Oligonychus biharensis* (Hirst.), *Tetranychus cucurbitae* Rahman and Sapru, *T. neocaledonicus* Andre, *T. telarius* (Linn.) were reported by Bindra and Singh (1970), Sadna et al., (1981), and Sharma and Pande (1984).

1.5.2 DEFOLIATORS

The larvae of *Achaea janata* (Linnaeus) feed on leaves of rose in South India. In cases of severe infestation, the whole plant is defoliated (Fletcher, 1917). *Euproctis fraterna* Moore, *E. lunata* Wlk. and *E. scintillance* Wlk. (Lymantridae) defoliate the rose plant (Atwal, 1986; Lefroy, 1909; Nair, 1975). *Parasa lepida* Cram. (Lymantridae) larvae feed on leaves occasionally (Nair, 1975). The larvae of *Peronia schalleriana* Linn. (Tortricidae) feed on leaves by rolling them (Nair, 1975). *Spodoptera litura* (Fab.) larva feeds on rose leaves (Nair, 1975). Among the lepidopteran larvae, *S. litura* and *Euproctis taiwana* (Shir.) were reported on roses in Central Taiwan by Wang (1982a). Lever (1942) recorded *A. Janata* on roses from Fiji.

The beetle, *Holotrichia consanguinea* Blanchard feeds on rose leaves from June to August. The beetles emerge from soil with the first shower of monsoon in June. After emergence, they feed on leaf lamina leaving behind veins and veinlets (Bindra and Singh, 1971). The rose beetle, *Adoretus versutus* Harold, and *A. lasiopygus* Burm. (Scarabaeidae) feed on leaves of roses in many parts of India (Deol, 1974; Fletcher, 1917). *Anthaxia baconis* Thomas (Buprestidae) feeds on the leaves of ornamental hedging rose in Himachal Pradesh (Hameed, 1978). The grubs of *Apogonia rauca* Fletcher (Scarabaeidae) feed on roots, and adults feed on leaves of rose in

South India (Patil and Veeresh, 1984). The beetle, *Colaspis hypochlora* Lef. (Chrysomelidae) feeds on rose leaves (Nair, 1975).

The occurrence of *Adoretus versutus* Har. and *Oxycetonia versicolor* Fabr. was reported in Fiji and Madagaskar by Lever (1942) and Dupont (1918); scarabid, *Dichelonyx backi* Kay on foliage by Robertson (1923). Fleury (1934) recorded in California *Phyllotreta atra* F. and *P. nemorum* L. on roses. Wang (1982a) reported *Anomala expansa* Bates, *A. cupripes* (Hope) and *Adoretus sinicus* Burm. damaging roses in central Taiwan. Rose curculio, *Rhynchites bicolor* F. and *Rhynchites hungaricus* (Hbst.) were found puncturing the buds in varieties Monitoba and Turkey by Robertson (1923) and Tutany (1963), respectively. Moznette (1917) reported *Haltica probata* Fall. as a destructive pest of cultivated roses in British Columbia and California.

1.5.3 STEM BORERS AND LEAF MINERS

The grubs of the beetle *Celosterna scabrator* var. *Spinator* Fab. (Cerambycidae) bore into the stem and twigs of rose (Beeson, 1931). The larvae of bark eating caterpillar, *Indarbela tetraonis* Moore (Metarbelidae), feed on the bark of rose plant. They make L-shaped hole in stem for shelter. The larvae come out of the hole during night and feed on bark. The fecal pellets of larvae are found embedded in silken web at the site of infestation (Nair, 1975).

1.5.4 BUD AND FLOWER FEEDING PESTS

The larvae of *Olethreutes aprobola* Meyr. (Tortricidae) bore into flower buds due to which the buds remain unopened (Nair, 1975).

1.5.5 PEST COMPLEX

In 1914, Dessitov in his book on ‘Rose cultivation in soil and under glass’ reported 70 species of insects injurious to roses in Russia. Wang (1982a) found 28 species of insects and one species of mite associated with rose in Taiwan. Butani (1974) reported about 50 insect pests and a few species of mites and nematodes that occurred on rose plants in India.

1.6 PESTS OF MARIGOLD

Marigold or Genda (*Tagetes erecta* Linn.) is a native of Mexico and is grown for its flowers, which are extensively used in religious and social functions. The plant is attacked by a number of insect pests all throughout the growth stages of the crop.

1.6.1 SAP SUCKING PESTS

The tingid bug, *Cadmilos retiarius* Dist. attacks the leaves of marigold. The nymphs and adults suck sap, and the infested leaves turn yellowish-brown and finally dry up (Atwal, 1986). Sekhon et al., (1982) reported *M. persicae* from Punjab and Himachal Pradesh. *A. gossypii* infests flowers on lower side and at the base of the petals and suck the sap causing discoloration, withering, and deformation of flowers (Jhansi Rani, 2001). The black aphid, *A. craccivora* has been reported to damage marigold at Kalimpong, India in the Eastern Himalayan region (Satpathi et al., 1996). The thrips, *Macrocephalothrips abdominalis* Crawford feed on flowers (Nair, 1975). *M. abdominalis* was reported to infest the flowers of *Tagetes erecta* by Ananthakrishnan (1973) and Raizada (1976).

The two-spotted spider mite (*T. urticae*) frequently causes damage to the marigold in West Bengal. With the warming of temperature from February onwards till March, the mite appears suddenly and builds up population fast (Mahato et al., 2008). Kulkarni (1922) reported the occurrence of a tarsonemid mite on Tagetes from Calcutta. Five species of mites, *T. telarius* L., *T. neocaledonicus* Andre, *Eutetranychus orientalis* (Klien), *Brevipalpus californicus* (Banks) and *B. rugulosus* Chaudhri, Akbar, and Rasool were reported on Tagetes by Bindra and Singh (1970), Sadna and Chabra (1981) and Sadna et al., (1981).

1.6.2 DEFOLIATORS

The grasshopper, *Atractomorpha crenulata* (Fab.) feeds on the leaves and petals in Himachal Pradesh (India) (Sood, 1988). The lepidopteran caterpillars like *Homona menciana* Wlk. (Tortricidae), *Plusia crassipalpus* Swin. (Noctuidae) and *Diacrisia obliqua* Wlk. (Arctiidae) damage the foliage of marigold (Satpathi et al., 1996).

1.6.3 STEM BORERS AND LEAF MINERS

The maggots of *Chromatomyia horticola* (Gour.) make small irregular white galleries on leaves (Singh and Ipe, 1973).

1.6.4 BUD AND FLOWER FEEDING PESTS

Marigold was recorded as a host of *H. armigera* by Manjunath et al., (1970), Subba Rao et al., (1974) and Singh (1983) from Karnataka, Tamil Nadu, and Himachal Pradesh, respectively. This pest occurred in the epidemic form at Ludhiana in 1990 (Singh and Sohi, 1990). Marigold is one of the preferred hosts of *H. armigera*, and an average of 4–5 larvae are seen per plant. The trypetid, *Trypanea amoena* Ferfed. (Trypetidae) maggots attack flowers and interfere with the opening of flower buds. The maggots and puparia are found in thalamus at the disc florets (Trehan, 1947).

1.7 PESTS OF GERBERA

Gerbera is one of the most popular flower crops grown and used as a cut-flower. It is the fifth most used cut-flower in the world after rose, carnation, chrysanthemum, and tulip.

1.7.1 SAP SUCKING PESTS

The different sap-sucking pests infesting gerbera include the green peach aphid, *M. persicae*, whitefly, *B. tabaci* and red spider mite, *T. urticae* (Pal and Sarkar, 2009). Heavy infestation of thrips, *T. palmi* Karny is observed during September-November and March-May on gerbera (Jhansi Rani, 2001).

Important mite species that infest gerbera include spider mite, *T. urticae*, Cyclamen mite, *Phytonemus pallidus* (Banks) and yellow mite, *P. latus*. The yellow mite, *P. latus* was observed as a major and serious pest affecting gerbera in West Bengal throughout the year under polyhouse condition with maximum infestation taking place during the hot and humid period of the year (Pal and Karmakar, 2017).

1.7.2 DEFOLIATORS

The caterpillar of *Homona menciana* Wlk. (Totricidae) feeds on the leaves during December–January in the Darjeeling Hills (Satpathi et al., 1996). The green semilooper, *P. orichalcea* feeds on the leaves (Pal and Sarkar, 2009) (Figure 1.2g).

1.7.3 STEM BORERS AND LEAF MINERS

The leaf miner, *L. trifolii* infests the leaves and the damaged leaves bear extensive mining marks, turn brown and dry (Jhansi Rani, 2001) (Figure 1.2h).

1.7.4 BUD AND FLOWER FEEDING PESTS

The larvae of *H. armiger*a were found boring inside the buds devouring the inner content as well as on the flower petals in the Darjeeling Hills (Satpathi et al., 1996; Pal and Sarkar, 2009). The larvae of bud caterpillar, *S. litura* cause severe damage to flower buds before they open as the larvae are protected by bracts on both open and greenhouse-grown gerbera plants (Jhansi Rani, 2001).

1.8 PESTS OF ANTHURIUM

Anthurium, commonly known as ‘Flamingo Flower’, is one of the most important cut flowers in the world. It is native to the Americas. The pests of anthurium are primarily sucking pests, as their thick leaves are infested less by chewing type of pests.

1.8.1 SAP SUCKING PESTS

Two species of aphids have been found regularly to infest the leaves and flower buds in the hilly region of West Bengal, India (Pal and Sarkar, 2009). The black aphid has been identified as *Toxoptera aurantii* (B. De F), which is having a wide host range belonging to different families and also infests other ornamental plants including orchids (Figure 1.2i). The green-colored aphid has been identified as *Myzus persicae* Sulz (Figure 1.1i). Other reports also indicate that the aphids on anthurium usually involves green peach aphid, *M. persicae*. Other species are *A. gossypii*, *Macrosiphum euphorbiae* Thomas, and *Aulacorthum solani* Kaltenbach. Seven species of scale insects infest anthurium, all over the world, i.e., Boisduval scale, brown soft scale, distyospermum scale, fern scale, green shield scale, hemispherical, and proteus scale (Sharma and Bhattacharjee, 2002). Hard scale insects (unspecified) have also been recorded on the older leaves mainly along the midribs and on stems from Darjeeling, India (Pal and Sarkar, 2009). The whitefly, *Aleurotulus anthuricola* Nakahara and thrips, *Chaetanaphothrips orchidii* (Molton) infests anthurium (Jhansi Rani, 2001; Anonymous, 2007). One species of thrips has been found infesting the flowers of anthurium during the month of April-May from Kalimpong, India (Satpathi et al., 1996). Other sucking pests infesting anthurium include citrus red mite, *Panonychus citri* (McGregor), thrips, *Chaetanaphothrips orchidii* (Molton) and banana rust thrips, *C. signipennis* (Bagnall) reported from Hawaii (Hara et al., 2004). Colonies of mite, *Brevipalpus* spp. are seen on lower surface of mature leaves (Anonymous, 2007). The red spider mites, *T. urticae* occurs in the anthurium on the old leaves. With severe damage, this takes on a yellow discoloration. The damage is visible on the flowers in the form of brown dots on the spathe. The worst red spider mite attack takes place in warm conditions (Sharma and Bhattacharjee, 2002).

1.8.2 DEFOLIATORS

The caterpillars of *Cyana bianea* Wlk. and *Diacrisia obliqua* Wlk. (Arctiidae) infests the leaves at the hilly region of West Bengal, India (Satpathi et al., 1996).

1.9 SUMMARY AND CONCLUSION

The commercial flowers all over the world are invaded by a wide array of pests with a different mode of injury inflicted on the crop. Amongst the different broad groups of pests, the sucking pest problems like aphids, scale insects, mealybugs, whiteflies, thrips, mites, etc., are the most important ones and it is expected to accentuate in the near future. The pest situation in the flower ecosystem is changing day by day, mostly due to the intensive input management and changing pattern of crop cultivation techniques along with changing weather conditions.

KEYWORDS

- **chrysanthemum**
- **commercial flowers**
- **defoliators**
- **insect pests**
- **leafminers**
- **stem borers**

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CHAPTER 2

SPECIALTY FLOWER PRODUCTION AND TRADE AFFECTED BY INSECT PESTS AND QUARANTINE ISSUES

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ABSTRACT

The floriculture industry has been transforming from traditional flowers to cut-flowers for export. Global demand-driven trends for growing high-valued commercial ornamental plants, especially for the specialty flowers is increasing day-by-day due to their immense use on various occasions. Floriculture products mainly consist of cut flowers, potted plants, cut foliage, seeds bulbs, tubers, rooted cuttings, and dried flowers or leaves. The data of area and production of flower crops in India during the year 2015–2016 is 278 thousand ha and 2184 thousand MT (Loose and cut flowers), respectively. A dozen of specialty flower spikes like Bird of paradise, Carnation, Chrysanthemum, Flamingo flower (Anthurium), Gerbera, Red Ginger, Gladiolus, Lily, Orchids, Parrot Heliconia, Rose, and Tuberose for Indian sub-continent, Latin America (especially Brazil) and

the Caribbean, South Africa as well as Australia have potential for inter and intraregional trade. Systems Approach for Plant Quarantine Security includes harvesting from pest-free areas/containment sites, culling, and grading, Washing, Brushing, Treatment, and Packaging, Certification, and Shipment to the importing/exporting/trading destinations. Keeping in view, a glossary containing 25 terms used by the importing and exporting countries has been included. This will help in case of disputes between trading partners. A systems approach is to protect flower production from insect and mite pests along with safe-guard of inter and intraregional marketing, often suffer due to technical trade barriers to facilitate good practices and effective trading.

2.1 INTRODUCTION

The floriculture industry has been shifting from traditional-flowers to cut-flowers for export world over. In India, the area under flowers has crossed to 2.32 lakh hectares during 2012–2013, which is concentrated mostly in Tamil Nadu, Andhra Pradesh, Maharashtra, West Bengal, Karnataka, Kerala, Himachal Pradesh and Uttarakhand with a production of 1729.21 thousand MT of loose flowers and 76731.85 million of cut flowers. The country has exported 27,121.88 MT of floriculture products to the world worth Rs. 423.46 crores in 2012–2013. An increasing trend of area and production of flower crops in India during the year 2015–2016 is 278 thousand ha and 2184 thousand MT (Loose and cut flowers), respectively, has been noticed. Floriculture products mainly consist of cut-flowers, pot plants, cut foliage, seeds, bulbs, tubers, rooted cuttings, and dried flowers or leaves. The important floricultural crops in the cut flower trade are rose, carnation, chrysanthemum, gladiolus, gypsophila, orchids, anthuriums, tulips, lilies, etc. Global demand-driven trends for growing high valued commercial ornamental plants, especially for the specialty flowers is increasing day by day due to their immense use on various occasions (Safeena et al., 2014).

The specialty/Specialty flowers are often cut-flowers. These are less known and grown in small pockets possessing better prospects in florist trade (Janakiram, 2005). Important specialty flower spikes like Bird-of-paradise, Carnation, Chrysanthemum, Flamingo-flower (Anthurium), Gerbera, Red Ginger Lily, Gladiolus, Orchids, Parrot Heliconia, Rose, and

Tuberose (Figure 2.1) for Indian sub-continent, Latin America (especially Brazil) and the Caribbean, South Africa as well as Australia have potential for inter and intraregional trade. It may be noted that major importing countries of mentioned flowers and foliage are the USA, Europe, and Japan, South East Asia and the Pacific, Latin America, and the Caribbean. The technical trade barriers often restrict the movement of floral consignments due to the risk of pest (s), including contaminants like other products and commodities traded in the overseas market.

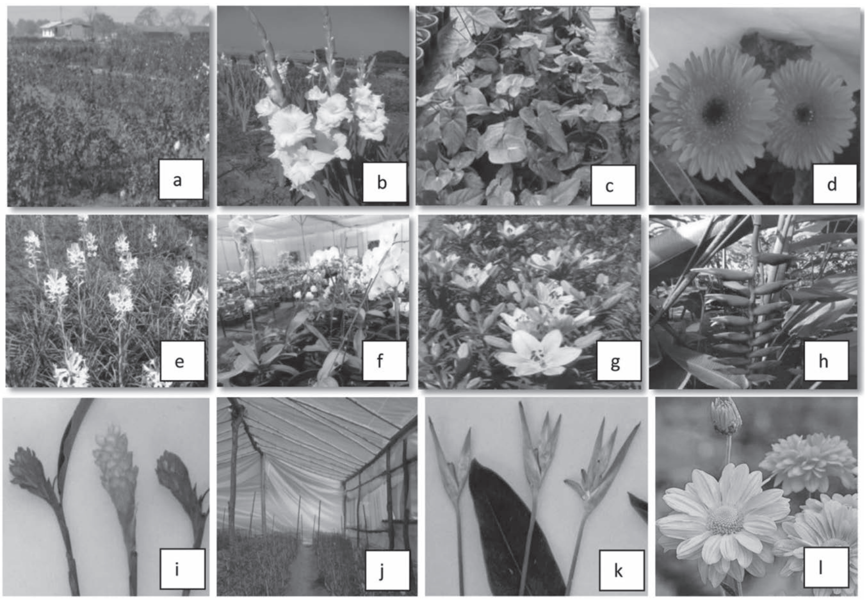

FIGURE 2.1 (See color insert.) Specialty flowers: (a) rose, (b) gladiolus, (c) anthurium, (d) gerbera (e) tuberose, (f) orchids, (g) lilium, (h) heliconia, (i) ginger lily, (j) carnation, (k) bird-of-paradise, (l) chrysanthemum.

A systems approach involves pre-harvest crop management, post-harvest culling, and final product inspection and certification (Moffitt, 1989; Pilgrim, 1997). More confidently, certificate may be issued if the systems approach to quarantine security is followed as demonstrated by Hata et al., (1992) for red ginger (*Alpiniapurpurata)* infested with Mealybugs, aphids, ants, thrips, and earwigs where in field infestation was reduced by Chloropyriphos at two weeks interval and pesticidal dip using fluvalinate in combination with insecticidal soap (potassium salts of fatty acids) with agitation for 5 minutes and culling of infested material to achieve zero level of pest. This is considered the ideal situation for certification. Pilgrim (1997) elaborated reception area soaking produce (washing site), sorting, and grading, treatment site, port of exit, and entry being the critical inspection points for Pink Hibiscus Mealybug (PHMB). He successfully demonstrated the activity levels in the light of systems approach to achieve quarantine security from pink mealybug targeted for revival of inter-regional trade. However, Gautam et al., (2000) cautioned that the systems approach vary for different commodities and its effectiveness in reducing the infestation at each component level namely field cleaning site (90% PHMB mortality), washing with soap and bleach (95–100% PHMB mortality) and treatment with methyl bromide/magnesium phosphide or hot water (100% PHMB mortality) is highly dependent on the vigilance by the management and workers. This chapter deals with the means of quality produce and approaches to safeguard the trading communities, and catalyze researchers to work on various aspects for quarantine security.

2.2 SYSTEMS APPROACH

A systems approach for plant quarantine security includes harvesting from pest-free areas (PFA)/containment sites, culling, and grading, washing, brushing, treatment, packaging, certification, and shipment to the importing/exporting/trading destination. Pre-harvest (use of bio-intensive IPM with an emphasis on conservation of bioagents) and use of biopesticides as well as harvesting of flowers from PFA and their culling based on consumer preference and demand) and post-harvest Post Harvest Options (Fumigation, Pesticidal Dip, Water Treatment, Pulsing, and Irradiation with gamma rays) to be executed in the packhouse followed with trade protocols (import permit and phytosanitary certificate) for quarantine security are mainly discussed in this chapter. I hope, these strategies will go a long way in the protection of quality floral production and trade and boost the import and export in the light of the World Trade Organization (WTO) requirements. Besides, the terms (Glossary: 1–25) often used *viz*., Cut flowers and branches; Biological control; Pest; Certificate; Control. International Plant Protection Convention (IPPC) is also defined as per the agreement between IPPC and the trading countries (often, commonwealth countries).

2.3 POTENTIAL SPECIALTY FLOWERS

It is difficult to decide a flower appropriately to qualify the category of Specialty flowers due to commercial in nature that depends on demand and supply. However, considering the demand-driven market, a total of 12 flowers *viz.,* Bird-of-Paradise, Carnation, Chrysanthemum, Flamingo Flower (Anthurium), Gerbera, Gladiolus, Lily, Orchids, Parrot Heliconia, Red Ginger, Rose, and Tube Rose are included. Important insect pests of these flowers are aphids, Mealybugs, scale insects, thrips, and mites. Their population could be reduced by the following ways without applying chemicals. There are many parasitic wasps and predatory insects that feed on Mealybugs (Gautam, 2008, 2017). Growers (commercial) of many plants in a large greenhouse may wish to consider the use of one or more parasitic or predatory insects to help keep Mealybugs under control. However, large-scale growers in open conditions may opt for inoculative releases with an emphasis on natural enemy conservation. Biological control agents (BCAs) available commercially include a variety of tiny parasitic wasps, brown lacewings, green lacewings, and ladybird beetles as well as biopesticides. Mealybug destroyer, *Cryptolaemus montrouzieri* Mulsant accompanied by *Scymnus coccivora* Ayyar are highly effective for control of Mealybugs in greenhouses (Gautam, 2008, 2017).

Basic information on the origin, importance of flowers; their important insect and mite pests, pre-harvest IPM practices including chemical pesticides in use and natural enemy (parasitoid and predators) complex (Table 2.1, Figure 2.2), potential entomophagous microbes/biopesticides (Table 2.2) along with post-harvest treatment protocols (Table 2.3a, b) are summarized. A brief about these (14 spp.) flowers is also given below:

2.3.1 BIRD-OF-PARADISE (STRELITZIA SPP.)

The bird-of-paradise plants are evergreen perennials with fan-like flowers that resemble the heads of tropical birds. These are good container plants often found along with swimming pools in different colors. Native to South Africa, the bird-of-paradise is commonly grown in subtropical parts of the United States and is popular in cut-flower arrangements in several countries. The common insect pests are: aphids; California red scale (*Aonidiella aurantii* Maskell), Cycad scale (*Aulacaspis yasumatsui* Takagi), Dictyospermum scale (*Chrysomphalus dictyospermi* Yasnosh), Greedy scale (*Hemiberlesia*

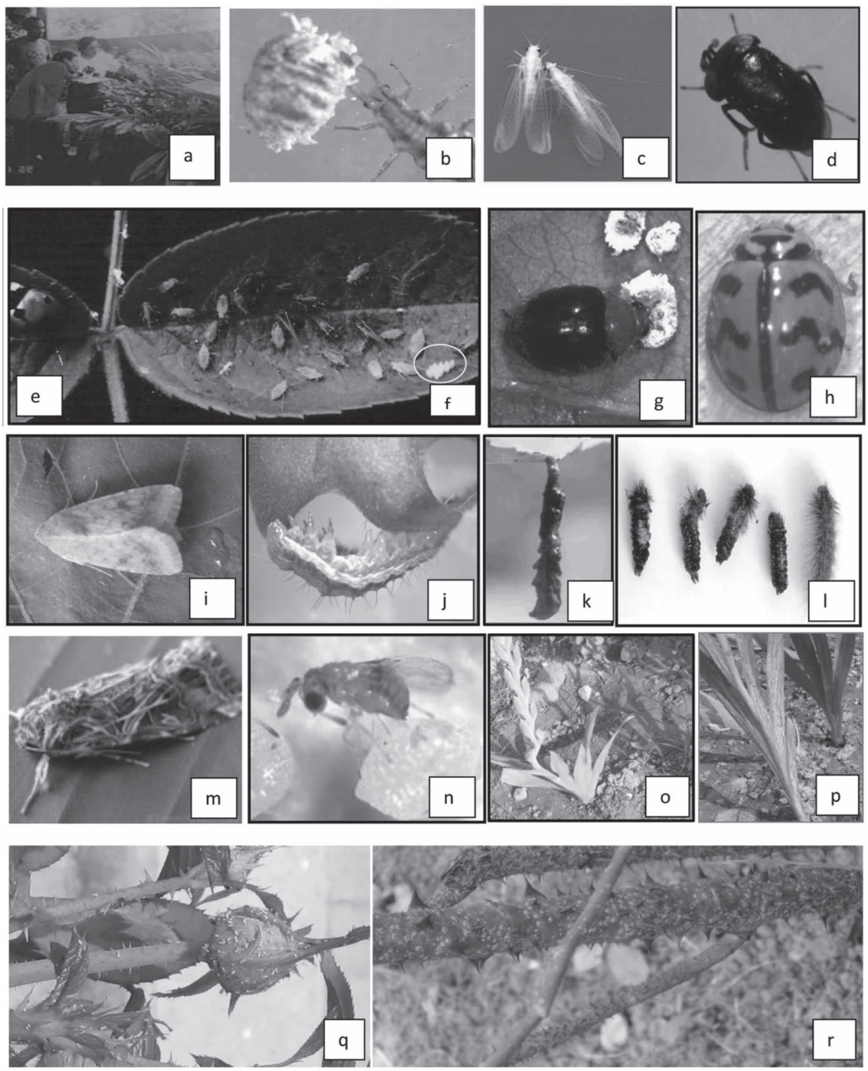

FIGURE 2.2 (See color insert.) Important insect pests and natural enemies associated with flower crops: Monitoring of natural enemies in (a) ginger lily field, (b) green lacewing larva preying on mealybug, (c) adults of green lacewing, (d) encyrtid parasitoid of mealybug, (e) adult ladybird *Coccinella septempunctata* predatory on rose aphids, (f) egg mass of *C. septempunctata*, (g) *Cryptolaemus montrouzieri* predator of mealybugs, (h) adult ladybird *Cheilomenes sexmaculata* predatory on aphids, (i) adult *Helicoverpa armigera*, (j) larva of *H. armigera*, (k) NPV infected caterpillar of *Spodoptera litura*, (l) caterpillars showing bacterial death, (m) adult *S. litura*, (n) egg parasitoid *Trichogramma* sp, (o) mite infested gladiolus, (p) thrips infested gladiolus, (q) aphid infested rose, (r) scale insects on rose stems.

arapax Ferris), Latania scale, *Hemiberlesia lataniae* (Signoret), Oleander scale (*Aspidiotus nerii* Bch.); Citrus mealybug (*Planococcus citri* Rosso), Ground mealybug (*Rhizoecus bituberculatus McKenzie*), Long-tailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti), Obscure mealybug (*Pseudococcus pertusus* McKenzie); Brown soft scale (*Coccus hesperidum* Linnaeus) and Nigra scale, *Parasaissetia nigra* (Neitner); Greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) and Iris whitefly (*Aleyrodes spiraeoides* Quaintance).

2.3.2 CARNATION (DIANTHUS CARYOPHYLLUS)

A perennial plant native to Greece is grown as borders for shrubs or in containers. They have double flowers that may be white, pink, purple, red, yellow, or orange. Flowers bloom in spring through early summer and attract butterflies. Leaves are bluish-green, and stems are leafy with a woody base. Thrips (*Thrips tabaci* Lind.); mite (*Tetranychus urticae* Koch); bud caterpillar, *Spodoptera litura* (Fabr.); Black bean aphid (*Aphis fabae* Scopoli), Foxglove aphid (*Aphis armata* Hausmann), Green peach aphid (*Myzus persicae* Sulzer); Beet armyworm, *Spodoptera exigua* (Hubner); Cabbage looper, *Trichoplusia ni* (Hübner); Carnation leaf roller, *Cacoecimorpha pronubana* (Hübner); Greenhouse leaftier, *Udea rubigalis* (Guenee); Oblique banded leaf roller, *Choristoneura rosaceana* (Harris); Omnivorous leaftier, *Cnephasia longana* (Haworth); Variegated cutworm, *Peridroma saucia* (Hubner);Carnation gall and bud mite, *Pediculopsis graminum* (Reuter)., Brown soft scale (*Coccus hesperidum* Linnaeus), Two-spotted spider mite, *T. urticae*; Western flower thrips, *Frankliniella occidentalis* (Pergande);Fuller rose beetle, *Naupactus godmani* (Crotch) infest the crop.

2.3.3 CHRYSANTHEMUM (DENDRANTHMA GRANDIFLORA)

The chrysanthemum, a native to Europe and Asia, is one of the most important flower crops commercially grown in different parts of the world. In India, commercial cultivation of this flower (Guldaudi in Hindi) has good demand. The flowers are mainly used for garland making, religious offerings, and as cut-flower for party arrangements. Chrysanthemum aphid

(*Macrosiphoniella sanborni* Gillette), Green peach aphid (*M. persicae*), Leaf curl plum aphid (*Brachycaudus helichrysi* Kaltenbach). Melon aphid (*Aphis gossypii* Glover); Broad or Cyclamen mite, *Polyphagotarsonemus latus* (Banks); Beet armyworm, *Spodoptera exigua* (Huebner); Cabbage looper (*T. ni*); Corn earworm**,** *Helicoverpa zea* (Boddie); Chrysanthemum gall midge, *Rhopalomyia chrysanthemi* (Ahlberg); Leafhoppers, *Eupteryx melissae* Curtis; Leafminers, *Phytomyza syngenesiae* (Hardy); Pea leafminer, *Liriomyza huidobrensis* (Blanchard); Serpentine leafminer, *Liriomyza trifolii* (Burgess) and Mealybugs (*Planococcus* spp, *Phenacoccus* spp, *Pseudococcus* spp) infest the crop. However, aphid, *Macrosiphoniella sanborni* (Gillette); Thrips (*Microcephalothrips abdominalis* Crawford), and bud caterpillar, *S. litura* are almost regular and damaging to the crop.

2.3.4 FLAMINGO FLOWER (ANTHURIUM SPP.)

The flamingo flower is often known as *Anthurium*, commonly, a native to tropical America, Mexico, Costa Rica, Cuba, and Brazil has nearly 1,000 species, making it the largest genus in Araceae. Florida has been dominating in potted *Anthurium* production (Henny et al., 1988). Broad, brightly colored spathe is the standout feature of this plant. However, anthurium pests are a constant problem, especially when grown outdoors. The major insect pests are aphid (*Myzus circumflexus* Buckt); mealybug, *Maconellicoccus hirsutus* (Green); thrips (*Chaetanaphothrips orchidii* Molton); whiteflies, *Bemisia tabaci* (Gennadius) and *Aleurotulus anthuricola* Nakahara); red spider mite, *Tetranychus cinnabarinus* (Boisduval).

2.3.5 GERBERA (GERBERA JAMESONII)

It is commonly known as Transwal Daisy or African daisy and is native to South African and Asiatic regions. An important commercial flower is distributed in the temperate Himalayas from Kashmir to Nepal, although grown throughout the world under a wide range of climatic conditions. The specific insect pests are: Whitefly (*T. vaporariorum*), Leaf miner (*L. trifolii*), aphid (*M. persicae*), and bud borer (*Helicoverpa armigera* (Hubner), cutworm (*Agrotis segetum* Denis and Schiffermüller), Thrips (*Thrips palmi* karny), Red spider mite (*T. urticae*), and gerbera mite (*P. latus*).

2.3.6 GLADIOLUS (GLADIOLUS HORTENSIS)

The queen of bulbous flowers is one of the most popular ornamental plants grown commercially for its fascinating flowers. Demand for its cut-flower for bouquet and other floral arrangements are increasing day-by-day due to its long vase-life and economic value (Safeena et al., 2014). It is attacked by a variety of insect and mite. Slipping on some gardening gloves and plucking these pests off the plant drop them in a bucket of water to drown them is the best way to get rid of them. In addition, removing weeds in gladiolus field can help cut down the caterpillar population. Thrips, *Taeniothrips simplex* (Morison); Cutworm, *A. segetum;* Leaf Eating Caterpillar, *S. litura;* Mite, *Tetranychus equatorius* McGregor and Mealybug, Ferrisia virgate Cockerell are specific insect pests (Table 2.1).

2.3.7 LILY (LILIUM LONGIFLORUM)

Lily flowers native of Northern Hemisphere and Greece are valued for their large, very showy, often fragrant flowers, and come in a range of colors including whites, yellows, oranges, pinks, reds, and purples. If lilies are grown strictly for cut flowers, consider planting them in a designated cutting garden, where you can plant fresh bulbs each year. Some lilies, especially *L. longiflorum*, form important cut flower crops for particular markets like the Easter trade, when it may be called the Easter lily. Lilies are easy to grow and add an exotic touch to garden, whether grown in borders or containers. Many varieties also have a powerful sweet fragrance which is fantastic on summer evenings. Aphids (*Macrosiphum lilii* (Monell) and *Myzus circumflexus* (Buckton)); lily leaf beetle, *Liliocerislilii* (Scopoli); lily thrips (*Liothrips vaneeckei* Priesne) and lily weevil (*Agasphaerops nigra* Horn) are important pests.

2.3.8 ORCHIDS (DENDROBIUM SPP. AND MANY MORE)

The orchids are native to tropical Asia and Australia. These are beautiful, fragrant, wonderfully varied, and surprisingly affordable. Mealybugs and scale insects are common pests of orchids and difficult to control, especially in home gardens and greenhouses. The Mealybugs problem are reported

TABLE 2.1 Pre-Harvest Management of Insect and Mite Pests of Spatiality Flowers

Pest	Pesticides Used	Potential Parasitoids and Predators	Other IPM Practices
Aphids	Spray imidacloprid 200SL@ 0.5ml/l, Imidacloprid 17.8% SL @ 1 ml/l, Dimethoate 30 EC 2 ml/l, fipronil 5% SC@ 1.5 ml/l water	Parasitoid, *Aphidius colemani* Viereck@ 5/m^2; (TNAU, 2015; Gautam, 2017)	Remove and destroy damaged plant parts if feasible, Natural enemy conservation
Ants	Foliar applications of acephate 75S.P, fluvalinate 2F and cyfluthrin 2EC, Disulfoton 15G and foliar applications of chlorpyrifos	*Phoridflies, Pseudacteonlasciniosus Coq* (Philpott et al., 2004)	Natural enemy conservation, Avoid alternate hosts in the endemic areas
Beetles	Systemic insecticide imidacloprid 17.8% @ 1ml/l applied either as a foliage spray or soil drench depending on the label of invasion	Mymarid egg parasitoid, *Anaphes* sp; Larval eulophid parasitoid, *Tetrastichus setifer* Thomson; ichneumonid parasitoids; *Lemophagus errabundus* (Gravenhorst), *L. pulcher* (Szepligeti) (Haye, 2000; Schaffner and Muller, 2001; Christopher and Laurent, 2008)	Natural enemy conservation, avoid alternate hosts in the endemic areas
Caterpillars	Profenfos1 ml/l, Acetamiprid @ 0.3 g/lit, chlorpyriphos 20EC @ 2 ml/l, indoxacarb 14.5SC@1 ml/l	Release of egg parasitoids *Telenomus remus* Nixon, *Trichogramma* spp., and predatory wasp, *Polistes erythrocephalus* Latreille	Natural enemy conservation, avoid alternate hosts in the endemic areas
Grasshoppers	Disulfoton 15G and foliar applications of chlorpyrifos	Eggs are eaten by bee flies, ground beetles, and blister beetles; adults and nymphs preyed by ants, robber flies and sphecid wasps, spiders, and Indian Myna, *Acridotheres tristis* (Linnaeus)	Collection and destruction of egg pods, manual collection of nymph and adults, raking the egg-laying sites to expose for biotic and abiotic stresses
Leaf-cutting bees	Disulfoton 15G and foliar applications of chlorpyrifos	*Pteromalus venustus Statz, a pre-pupal parasitoid of* alfalfa leaf-cutting bees, *Megachile rotundata* (Fabricius)	Natural enemy conservation, avoid alternate hosts in the endemic areas

TABLE 2.1 *(Continued)*

Pest	Pesticides Used	Potential Parasitoids and Predators	Other IPM Practices
Mealybugs	Phosalone (0.07%), or methyl parathion (0.01%), insecticidal soap	Predatory ladybugs: inoculative release of *Cryptolaemus montrouzieri* Mulsant, *Scymnus coccivora* Ayyarand *Nephus regularis* (Sicard); parasitoid, *Anagyrus kamali* Moursi (Gautam, 2008, 2017)	Cutting the infested sites and proper disposal in the garbage bags to avoid further spread
Midges	midge and spike borer chlorpyriphos @ 2 ml/l	Spiders and other predators	Natural enemy conservation, avoid alternate hosts in the endemic areas
Mites	Spray profenofos 1ml/l or cyfluthrin 2EC and chloryphos 1 ml/l or dimethoate 30EC @1 ml/l, Spray Abamectin 1.9 EC @ 0.5 ml/l or Propargite @ 1 ml/l	Predator, *Phytoseiulus persimilis* Athias-Henriot@ 6/ m^2 (TNAU, 2015)	Natural enemy conservation, avoid alternate hosts in the endemic areas, Prevent spider mites with proper watering; avoiding excessively hot growing temperatures
Sapsuckers	Sprays of cyfluthrin 2EC and chloryphos 1 ml/l or dimethoate 30EC @1 ml/l	Spiders and other predators	Natural enemy conservation, avoid alternate hosts in the endemic areas
Scale insects	Phosalone (0.07%), or methyl parathion (0.01%), insecticidal soap	Ladybirds like *Stethorus* spp and other predatory coccinellids; green lacewings	Natural enemy conservation, avoid alternate hosts in the endemic areas
Thrips	Spray imidacloprid 200SL@ 0.5ml/, Acetamiprid @ 0.3 g/l or Indoxacarb @ 1 ml/l, Fipronil @ 2 ml/l or Dimethoate 30EC @ 2 ml/l, Acephate75S.P @ 1%)	Predator, *Amblyseius cucumeris* (Oudemans), @ 500,000/ha (TNAU, 2015)	Natural enemy conservation, avoid alternate hosts in the endemic areas

TABLE 2.1 *(Continued)*

Pest	Pesticides Used	Potential Parasitoids and Predators	Other IPM Practices
Weevils	Imidacloprid 17.8% @ 1 ml/l, Spray carbaryl 50 WP at 2g/lit	Insectivores birds and spiders	Collect and destroy the adults, avoid alternate hosts in the endemic areas
Whiteflies	Spray Imidacloprid 17.8% SL @ 2 ml/l or Dimethoate 30 EC @ 2 ml/l, fipronil 5% SC@ 1.5 ml/l water	Parasitoid, *Encarsia perniciosi* (Tower)@3/ m^2 (TNAU, 2015)	Field sanitation, Removal of host plants, Installation of yellow sticky traps, avoid alternate hosts in the endemic areas

Note: Refer to natural enemy conservation methods (Gautam, 2008, 2017).

on many orchid species like *Cymbidium, Dendrobium, Cattleya, Calanthe, Phaius, Phalaenopsis, Pholidota*, etc., worldwide. Pineapple mealybug (*Dysmicoccus brevipes* (Cockerell), long-tailed mealybug, *P. longispinus*), jack fruit mealybug (*Pseudococcus jack beardsleyi* Gimpel and Miller), obscure mealybug (*Pseudococcus viburni* (Signoret), and orchid Mealybugs (*Pseudococcus microcirculus* McKenzie and *Pseudococcus dendrobiorum Williams*) are the major species due to occurrence in serious proportions in many parts of the world (Bronson, 2009). Only *P. dendrobiorum* and *P. longispinus* are known to infest orchids in greenhouses of tropical and subtropical regions of India (Meena et al., 2016).

2.3.9 PARROT HELICONIA (HELICONIA PSITTACORUM)

These are grown for the florist's trade and as landscape plants in tropical regions world over (Ong, 2007). It is a native to Latin America, and the Caribbean popularly known as parrot heliconia is especially distinctive; its greenish-yellow flowers with black spots and red bracts reminding of the bright plumage of parrots. *Heliconia* needs an abundance of water, sunlight, and humus-rich soils in order to grow well, the environmental conditions that also favor the foliage feeders and pollinators. It provides shelter for a diverse range of insects (Hispini beetles (*Strong and Donald, 1977)*; Chrysomelid beetles, mosquito larvae (Siefert, 1982); and Mealybugs (Gautam *and* Cooper, 2003) within their young rolled leaves and water-filled floral bracts. Predatory wasp species such as *Polistes erythrocephalus* Latreille build a nest on the protected underside of large leaves (John, 1971).

2.3.10 RED GINGER (ALPINIA PURPURATA)

Red ginger-a native to India and China is used as a landscape ornamental and as a cut-flower. In general, inflorescences are widely used in flower arrangements, from cemetery bouquets to extravagant hotel centerpieces. The floral arrangements are not placed in direct sunlight or near heat vents, air conditioners, or drafts. Daily water, dying blooms, and foliage are removed. Stem bases are cut every 4–5 days, cleaning the container thoroughly, and rearranging the remaining flowers, adding a mixture of warm water and the floral preservative (Hara et al., 1993). It is a tall, upright, herbaceous, evergreen quite popular cut-flower both for the home and for commercial sale. The plant from the South Pacific, with bright red floral bracts and inconspicuous white flowers are native to New Caledonia, New Hebrides, Yap, British Solomon Islands (Kent et al., 2007). The important insect pests are *viz;* Banana aphid*, Pentalonia nigronervosa,* cotton aphid*, Aphis gossypii;* Banana mealybug*, Pseudococcus elisae* Borchsenius*, P. longispinus,* Citrus mealybug*, P. citri,* Obscure mealybug*, Pseudococcus affinis* (Maskell)*,* grapevine mealybug/PHMB, *M. hirsutus;* black earwig*, Chelisoches morio* (Fabricius)*;* Cardamom thrips*, Scirtothrips cardamom* Ramk.*;* soft green scale*, Coccus viridis* (Green)*;* soft shield scale*, Pulvinaria psidii* Maskell.

2.3.11 ROSE (ROSA HYBRIDA)

Rose a native to Northern hemisphere is a woody perennial flowering plant. There are over a hundred species and thousands of cultivars. Although, a hardy crop and is affected by attacks of insect except aphid, *Macrosiphum rosae* (Linnaeus), thrips (*Scirtothrips dorsalis* Hood), red scale (*A. aurantii, Icerya purchasi* Maskell*, Aulacaspis rosae* Newstead), bud borer (*H. armigera*), grasshoppers, weevils (*Myllocerus* spp), The tortrix moth (*Lozotaenia forsterana* Fabricius), Japanese beetles (*Popillia japonica* Newman), Leafcutter bees (*Megachile* spp, *Megachile rotundata* (Fabricius) and red spider mite (*T. urticae* and *T.* spp) under certain situations.

2.3.12 TUBE ROSE (POLIANTHESTUBEROSA)

Tuberose a native to Mexicois popularly known as Rajanigandha or Nishigandha in India. It is one of the most important tropical ornamental bulbous flowering plants cultivated for the production of long-lasting flower spikes. It is an important commercial cut as well as loose flower crop due to pleasant fragrance, longer vase-life of spikes, higher returns, and wide adaptability to varied climate and soil. Aphid (*Aphis spiraecola* Patch); Thrips (*Thrips* spp); bud borer (*H. armigera*) are important insect pests (Table 2.2).

TABLE 2.2 Potential Biopesticides for the Suppression of Insect Pests of Specialty Flowers

Target Pest	Microbial Bioagents	Remark
Aphids	*Beauveria bassiana*, *Entomo phthora* spp, *Lecanicillium lecanii*, *Metarhizium anisopliae*, *Macrosiphoniella sanborni*, *Neozygitesfresenii*, *Paecilomyces fumosoroseus*	except for Chrysanthemum aphid
Ants, flies	*B. bassiana,* 447 baits, *M. anisopliae*	
Beetles	*B. thuringiensis* subsp. *Tenebrionis*	
Caterpillars	*Bacillus thuringiensis* subsp. *Kurstaki*, *B. bassiana, M. anisopliae*	
Grasshoppers and roaches	Bacteria (*Serratia marcescens* and *Pseudomonas aeruginosa*), fungi (*M. anisopliae, B. bassiana*), viruses, and protozoa	Some people enjoy these as food recipes
Helicoverpa zea	NPV, *B. thuringiensis* subsp. *Kurstaki*	
H. armigera	NPV, *B. thuringiensis* subsp. *Kurstaki*	
Mosquito larvae	*B. sphaericus* Serotype H5a5b strain 2362 ATCC1170, *B. thuringiensis* subsp. *Israelensis*	Develop on plant axils and flowers where water is retained
Spodoptera exigua	*Spodoptera exigua* NPV, *B. thuringiensis* subsp. *Kurstaki*	
S. litura	*Spodoptera litura* NPV, *B. thuringiensis* subsp. *Kurstaki*	
Thrips	*B. bassiana, P. fumosoroseus*	Difficult to control in without strong biointen-sive IPM
Whiteflies	*B. bassiana*, *Lecanicillium muscarium* (formerly *Verticillium lecanii*, *Macrosiphoniella sanborni*, *P. fumosoroseus*	

Source: Modified after Kunimi, 2007; Kabaluk et al., 2010; Gautam, 2017.

2.4 POST-HARVEST TREATMENT

With a view to achieving quarantine security against insect pests, several methods namely, irradiation, hot-water treatment (HWT), cold-water treatment, pesticidal dip, fruit coating with carnuba wax emulsions and fumigation have been advocated (Jeffery, 1994; FAO, 1984). Steven (2005) described the first line of defense as well as the second line of defense against orchid pests namely aphids, Mealybugs, scales, thrips, and spider mites using non-toxic methods to reduce the pest population as post-harvest strategies for each pest (Table 2.3a) including irradiation (Table 2.3b). Siddhu (2010) reported post-harvest activities of cut flower varieties developed at IIHR, namely bougainvillea, carnation, China aster, chrysanthemum, crossandra, gerbera, gladiolus, rose, and tuberose pertaining mainly to vase-life, lacking information for quarantine security. Gautam et al., (2000) studied and validated some of the Post-harvest options except irradiation against Pink Mealybug (PMB) infesting about 100 fresh agricultural commodities including Specialty flowers following systems approach for quarantine security in order to safeguard the resumption of inter and intra trade of flowers from the Caribbean affected due to exotic PHMB (*Maconellicoccus hirsutus*). A few strategies are mentioned below:

i. **Use of IPM Components in the Field (Pre-Harvest):** IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms. The potential components are cultural practices, natural enemy colonization, conservation, and biological control, judicious use of chemical fertilizers and chemical pesticides. Some of these are enlisted in Tables 2.1 and 2.2. It may be noted that Insecticides used in the field for the same insect should not be used as pesticidal dip due to the risk of developing resistance.
ii. **Culling:** The process of culling becomes an integral part of post-harvest treatment activities as it is experienced that in spite of precautions undertaken in harvesting the healthy produce along with certain fruits either undersized or infested are bound to come. Such fruits may be discarded for outside trades in order to maintain quality and pest-free produce and thus reducing the pressure on pest risk during subsequent post-harvest handling. Notification or demarcation of PFA as a guideline in the case of quarantine pest is followed as suggested by FAO for harvesting.
iii. **Brushing:** Certain commodities like avocado, dasheen, yam, eddoes, ginger, sweet potato, golden apple, tannia, plum, mango, and citrus need to be thoroughly brushed (CARAPHIN NEWS, 1997) which eliminates 80–90% of PMB population. Besides manual brushing, powerhouse may also be used wherever necessary to remove all traces of visible pest, including those associated with floral consignments.

iv. **Washing:** The washing of produce, as mentioned above is recommended in combination with brushing. Washing water should contain soap detergent (5 ml in 10 gallons of water) plus bleach (10 ml of any commercial bleach containing sodium hypochlorite 5.2%) in order to kill microbes on the surface of the fruits, change the water solution frequently. A good indication is when water becomes cloudy or with a high level of floating of Pink Mealybug.
v. Water treatment and pulsing recommendation for shelf-life/vase life of cut flowers are given in Table 2.3a.
vi. Pesticidal dip is one of the most common post-harvest disinfestations treatments for tropical cut flowers (Table 2.3a and Figure 2.3).
vii. Fumigants in use are aluminum phosphide, magnesium phosphide, and methyl bromide with restrictions world over. According to OEPP/EPPO (2009), the fumigation in quarantine on receipt of consignment should be carried out using only methyl bromide. It may be noted that methyl bromide normally marketed contains 2% chloropicrin that phytotoxicity to the flowers depending on species, cultivar, temperature, etc. (Gautam, 2003a; OEPP/EPPO, 2009). The tolerance of various cut flowers to fumigation is indicated by Witt *and* Van de Vrie (1985a); Wang *and* Lin (1984). FAO (2008) referred replacement or reduction of the use of Methyl Bromide as Phytosanitary Measure (IPPC Recommendation). FAO, Rome (IT).
viii. In-lieu of phasing out the status of methyl bromide, magnesium phosphide (registered in India-DPPQ&S, 2016) recommended for foodstuffs, fresh produce, and flowers (Benzing, 1994; Gautam, 2003a) need to be studied and adopted.
ix. **Irradiation:** The improvement of the quality of some radiosensitive flowers can be a step to increase the tolerance to the radiation and to other kinds of stress that shorten the vase-life of the cut-flowers (Van Gorsel, 1994; Wang *and* Lin, 1984). Observations made by researchers reveal that for commercial use species as well as variety-specific doses are required for each flower for the export purpose under the WTO regime (Table 2.3b).

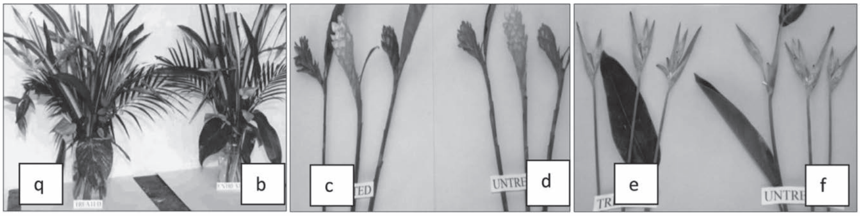

FIGURE 2.3 (See color insert.) Treatment with a pesticidal dip of cut flowers: (a) a group of treated flowers *viz.; Anthurium*, *Heliconia*, Bird-of-paradise, ginger lily, and a few foliages placed in vase water, (b) untreated control, (c) ginger lily treated, (d) ginger lily untreated, (e) bird-of-paradise treated, (f) bird-of-paradise untreated.

2.5 GLOSSARY

1. **Specialty Crops/Flowers:** Specialty crops are defined in law as "fruits and vegetables, tree nuts, dried fruits and horticulture and nursery crops, including floriculture."(https://www.ams.usda.gov/sites/default/files/media/USDASpecialtyCropDefinition.pdf); (Specialty flowers are the cut flowers, which are less known and grown in small pockets, having high prospects in florist trade (Jankiram, 2005)).
2. **Systems Approach(es):** The integration of different risk management measures, at least two of which act independently, and which cumulatively achieve the appropriate level of protection against regulated pests (ISPM No. 14, 2002; revised ICPM, 2005).
3. **Quarantine:** Official confinement of regulated articles for observation and research or for further inspection, testing, and/or treatment (FAO, 1990; revised FAO, 1995; CEPM, 1999).
4. **Pest Free Area (PFA):** An area in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained (FAO, 1995).
5. **Containment:** Application of phytosanitary measures in and around an infested area to prevent spread of a pest (FAO, 1995).
6. **Integrated Pest Management (IPM):** This means the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other

TABLE 2.3a Post-Harvest Treatment of Specialty Flowers for Quarantine Security

Common Name of Flower	Common Pest	Post-Harvest Practices for Disinfestations/ Disinfection	Protocol for Shelf-Life of Flowers
Bird of paradise	Aphids, scale insects, Mealybugs, whiteflies	Flowers are washed to remove field dust, insects, and exudates followed with suitable pesticidal dip (Janakiram, 2005)	Flower stalks are usually pulled. Packaging should be in the boxes containing shredded moist newspapers free from contaminants
Carnation	Thrips, mite, bud caterpillar	-do-	Pulsing in 3% sucrose+ aluminum sulfate 300ppm enhance floret opening and shelf-life
Chrysanthemum	Aphids, Thrips, bud caterpillar	-do-	Chrysanthemum can be stored at 2°C for 3 weeks
Flamingo flower/ Anthurium	Aphids, Mealybugs, thrips, whitefly and red spider mites	Five minutes dipping of with salut (a combination of Dursban and Perfekthion) @ 5 ml/l water did not adversely affect quality and shelf-life of these flowers and killed 100% PMB while actellic and decis gave phytotoxicity (Gautam et al., 1998; Gautam and Cooper, 2003)	Stem dipped in normal water
Gerbera	Thrips, bud borer, aphids, whiteflies, red spider mite	Flowers are washed to remove field dust, insects, and exiduates followed with a suitable pesticidal dip	Gerbera Cut ends are dipped immediately into a bucket containing water of floral preservatives of 2% sucrose+ aluminum sulfate to keep fresh for longer period
Gladiolus	Aphids, whiteflies, Mealybugs, scale, and thrips	Flowers are washed to remove field dust, insects, and exiduates followed with pesticidal dip	Pulsing in 15% sucrose + aluminum sulfate 300ppm enhance floret opening and shelf-life

TABLE 2.3a *(Continued)*

Common Name of Flower	Common Pest	Post-Harvest Practices for Disinfestations/ Disinfection	Protocol for Shelf-Life of Flowers
Lily	Aphids, lily leaf beetle, lily thrip	For lily thrips Treat bulbs with hot water treatment at 44°C (111°F) for one hour to eradicate; or Wash or dip bulbs in a solution of an insecticide such as Orthene, mineral oil or Neem	Immediately after bunching, the cut flowers should be placed in cold water in the cold storage room at 2°C to 3°C. Add 2% sucrose and 100ppm GA3 as a preservative agent to water to improve vase life of flower. When dispatching lily flowers use only perforated boxes to maintain a proper temperature during transport.
Orchids	Mealybugs, Aphids, Mealybugs, Scales, Thrips, and Spider mites	Five minutes dipping of with salut (a combination of Dursban and Perfekthion) @ 5 ml/l water did not adversely affect quality and shelf-life of these flowers and killed 100% PMB while actellic and decis gave phytotoxicity; Wash off with warm water for aphids, Use a cotton swab drenched with isopropyl alcohol, Dip a cotton swab into isopropyl alcohol and wipe across the armored shell of scale insect, Wash off with a strong stream of warm water to reduce mite population and other contaminants	In the Cymbidium hybrid 'Red Princess' pulsing with 5% sucrose increases vase life (56 days) followed by sucrose at 8% (54.78 days) (source: https:// www. degruyter.com/down load pdf/ books/9783110426403/9783110426403.13/9783110426403.13.pdf
Parrot Heliconia	Mealybugs, scale insects, aphids, thrips, and red spider mite	Cleaning, brushing, and washing of insects followed with Pesticidal dip of inflorescence for 5 minutes and then rinsed; Five minutes dipping of with salut (a combination of Dursban and Perfekthion) @ 5 ml/l water did not adversely affect quality and shelf-life of flowers and killed 100% PMB while actellic and decis gave phytotoxicity (Gautam et al., 1998; Gautam and Cooper, 2003)	Harvest with one or two open bracts, Water uptake of cut heliconia flowers through stalk is negligible, and no floral preservatives are very effective in maintaining vase life. These can be shipped in boxes containing moist packaging material

TABLE 2.3a *(Continued)*

Common Name of Flower	Common Pest	Post-Harvest Practices for Disinfestations/ Disinfection	Protocol for Shelf-Life of Flowers
Red Ginger	Aphid, Mealybugs, Scale insect	Five minutes dipping of with salut (a combination of Dursban and Perfekthion) @ 5 ml/l water did not adversely affect quality and shelf-life of these flowers and killed 100% PMB while actellic and decis gave phytotoxicity (Gautam et al., 1998; Gautam and Cooper, 2003)	Stem should be removed and placed in warm water or floral preservatives containing 2% sucrose and 200 ppm 8-hydroxyquinoline citrate to improve shelf-life of 2–3 weeks, Shipping temperature should not be less than 10°C (Janakiram, 2005)
Rose	Aphid, thrips, red scale, bud borer, grasshoppers, weevils, tortryx moth, Japanese beetles, Leafcutter bees and red spider mite	Flowers are washed to remove field dust, insects, and exiduates followed with suitable pesticidal dip.	Cut ends of roses are dipped immediately into a bucket containing water of floral preservatives of 3% sucrose + aluminum sulfate to keep the flowers turgid
Tuberose	Aphid, Thrips, bud borer	Flowers are washed to remove field dust, insects, and exiduates followed with suitable pesticidal dip (Janakiram, 2005)	Use floral preservatives of 8% sucrose+ aluminum sulfate to keep the flowers turgid.

TABLE 2.3b Influence of Gamma Radiation on Vase Life and Quality of Specialty Flowers

Flower Species	Flower Modification	Leaf Modification	Dose (Gy)	References
Bird of paradise	None	Not tolerant	300	Olivia, 2003
Carnation	None	None	900	Olivia et al, 1995
Chrysanthemum	Blackening in the insertion region of the petals	Yellowing and blackening	900	Olivia et al, 1995
Flamingo flower/ Anthurium	Not tolerant	Not tolerant	200	Kdcuchi et al., 1999
Gerbera	None	None Not tolerant	400 300	Tanabe et al., 1995; Olivia, 2003
Gladiolus	No adverse effect on viability of bulbs but controlled thrips and other	Tolerant	500	Wit and Van De Vire, 1985b
Red Ginger	None	Tolerant	500	Olivia, 2003
Lily	None	Tolerant	500	Olivia, 2003
Orchids	None	Not tolerant	300	Olivia, 2003
Parrot Heliconia	None	Not tolerant	300	Olivia, 2003
Rose	Failed to open, blackening in the insertion region of petals	None	900	Olivia et al., 1995
Tuberose	Flowering affected	None	2kr	Singh et al., 2017

Note: Normally recommended dose required to kill insect and mite pests is up to 900Gy depending on the tolerance of the pest.

interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. Conservation: Conservation of natural enemies (NEs) involves manipulation of the environment to enhance the survival, fecundity, longevity, and behavior of NEs to increase their effectiveness (Gautam, 2018).

7. **Bioagents (Biological Control Agents):** A natural enemy, antagonist or competitor, or other organisms, used for pest control (FAO, 2005-ISPM # 3, 1996; revised in 2006).
8. **Biopesticides (Biological Pesticide):** A generic term, not specifically definable, but generally applied to a biological control agent, usually a pathogen, formulated, and applied in a manner similar to a chemical pesticide, and normally used for the rapid reduction of a pest population for short-term pest control (ISPM No. 3, 1996).
9. **Fumigation:** Treatment with a chemical agent that reaches the commodity wholly or primarily in a gaseous state (FAO, 1990; revised FAO, 1995).
10. **Pesticidal Dip:** An Insecticide Dip for Tropical Cut Flowers and Foliage (Hasan et al., 1992).
11. **Water Treatment:** Water quality affects flower life. Both hard water (containing many dissolved materials) and hard water that has been "softened" with a home water-softener are unsatisfactory for keeping flowers fresh. Hard waters are often alkaline (pH 7 to 10) rather than acid (pH 4 to 6). The only satisfactory means of improving hard or softened waters is to distill or deionize them, or you can buy water that has been so treated. Rainwater that is relatively clean is also useful. Floral preservatives contain some acidifying material that helps make water more acid and desirable. However, hard alkaline waters may require twice the amount of preservative as distilled, acid, or naturally soft water.
12. **Pulsing:** The absorption of chemical solutions containing sugars and germicides through the lower cut bases of flower stems is known as pulsing. Pulsing may be used by growers, wholesalers, or retail florists in order to enhance the subsequent vase life of cut flowers in water. Pulsing is employed with higher concentrations of sugar, mainly sucrose, the percentage of which varies with species and cultivars. Other chemicals used in pulsing treatments are STS, $AgNO_3$, HQ, MH, AOA, $CaCl_2$, $CoCl_2$, nickel sulfate, aluminum sulfate, and benzyl adenine. Pulsing is found to be of

great value in prolonging life, promoting opening and improving the color and size of petals through osmoregulation.

13. **Irradiation:** Treatment with any type of ionizing radiation (ISPM No. 18, 2003).
14. **Packhouse:** A building where fruit and vegetables are packed prior to distribution to shops.
15. **Import Permit:** Official document authorizing the importation of a commodity in accordance with specified phytosanitary import requirements (FAO, 1990; revised FAO, 1995; ICPM, 2005).
16. **Phytosanitary Certificate:** Certificate patterned after the model certificates of the IPPC (FAO, 1990).
17. **World Trade Organization (WTO):** It is the only global international organization dealing with the rules of trade between nations. At its heart are the **WTO** agreements, negotiated, and signed by the bulk of the world's trading nations and ratified in their parliaments.
18. **Cut Flowers and Branches:** A commodity class for fresh parts of plants intended for decorative use and not for planting (FAO, 1990; revised ICPM, 2001).
19. **Biological Control:** Pest control strategy making use of living NEs, antagonists, competitors or other BCAs (formerly biological control/biocontrol), (FAO, 2005-ISPM # 3).
20. **Pest:** Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products (FAO, 2005).
21. **Certificate:** An official document which attests to the phytosanitary status of any consignment affected by phytosanitary regulations (FAO, 1990).
22. **Control (of a Pest):** Suppression, containment or eradication of a pest population (FAO, 1995).
23. **International Plant Protection Convention:** As deposited with FAO in Rome in 1951 and as subsequently amended (FAO, 1990).
24. **Commonwealth Countries:** An association comprising the United Kingdom, its dependencies, and many former British Colonies that are now sovereign states, including Canada, Australia, India, and many West Indian and African countries. It was formally established by the Statute of Westminister in 1931 (http://www.thefreedictionary.com/Commonwealth+countries).

KEYWORDS

- **culling**
- **insect and mite pests**
- **integrated pest management (IPM)**
- ***Parrot heliconia***
- **quarantine**
- **tuberose**

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CHAPTER 3

GLOBAL FLORICULTURE SCENARIO

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ABSTRACT

The global industry of commercial flowers is very dynamic with a wide variety of floral varieties, and the trade volume accounts for 6–9% of the annual growth rate. Due to globalization, continuous progress of protected cultivation technologies, advancement in plant biotechnology, and conditions of transit, marketing strategies, and its effect on income generation in the different parts of the world, floriculture has acclaimed a historical maximum hub of activity with competitiveness. Production of floricultural products grows faster than consumption, which leads to perpetual price competition. All over the world, more than 145 nations are involved in commercial floriculture. The production of flower crops has increased significantly both in the traditional production countries (USA, Japan, Italy, The Netherlands, Columbia) and in new emerging economies in Latin America, Africa, and Asia (India, China, Vietnam, etc.). This huge competition from the different countries has resulted in the vigorous growth of international flower trade. In the traditional producing countries, the total areas under production remain stable or slightly increased. The Productivity of floriculture crops are increased in these countries. The floriculture products are facing competition due to the marketing system changes. In the past, these kinds of products were mainly sold by florist shops. Nowadays, retailers have taken a greater role. This has a huge impact on the commercial floriculture trade as there is pressure on the traditional market places such as auctions and retail markets. The impact

of the modern communication system will propel this development. Nowadays, consumers' taste is changing awareness of buying preferences. They are becoming more professional in flower buying habits. After all, procurement and production will remain a regional affair, but there will always be some worldwide trade. This worldwide trade will be restricted to certain times of the year, to certain items, to specific production conditions, and to accidents caused by nature.

3.1 INTRODUCTION

Floriculture is emerging as the most diversified, and potential component in the horticulture industry owing to its rapid growth rate, increase in purchasing power, and awareness among the masses. Nowadays, floriculture is the principal component in the trade of diversified range of items, viz., cut flower, loose flowers, dried flowers and their products, bulbs, and tubers, pot plants, nutraceutical, and pharmaceutical compounds, essential oils, natural colorants, plug plant production, protected cultivation, seed production, tissue culture, nursery etc. there is a paradigm shift from sustenance production to commercial production in this era and thereby significant increase in trade of flowers at domestic level and profit to farmers because of rapid urbanization, increase in income level, etc. commercial floriculture has acclaimed the status of most important component of export basket nowadays. The demand for floricultural items in the domestic and international markets is growing at a fast pace, too, and a large number of people earn their livelihood by both producing or marketing flowers and ornamental plants.

3.2 WORLD SCENARIO

About 305,105 hectares are under floriculture in different countries worldwide., of which the total coverage in Europe is 44,444 hectares, North America 22,388 hectares, Asia, and Pacific 215,386 hectares, the Middle East and Africa 5,282 hectares and central and south Africa 17,605 hectares. Flowers cultivation under protected conditions in different countries around the world totals 46,008 hectares. India leads in the area under ornamental crops 88,600 hectares followed by China 59,527 hectares, Indonesia 34,000 hectares, Japan 21,218 hectares, USA 16,400 hectares, Brazil 10,285 hectares, Taiwan 9,661 hectares, The Netherlands 8,017 hectares, Italy 7,654 hectares, The United Kingdom 6,804 hectares, Germany 6,621 hectares and Colombia 4,757 hectares. The maximum area under greenhouse floriculture is in Japan 10,048 hectares, followed by the USA 7,121, The Netherlands 5,518 hectares, Colombia 4,710 hectares, Italy 4,402 hectares, Germany 2,713 hectares Spain 2,442 hectares Korea 2,229 and France 1,747 hectares.

The world consumption of floricultural products is increasing day by day. Maximum per capita flower and plant consumption is in Norway ($146), followed by Switzerland ($126), Germany ($88), Denmark ($84), Sweden ($79), Austria ($78), Italy ($47), The Netherlands ($70), France ($58), Belgium ($56), the U.S.A. ($50), Japan ($44), Greece ($32), U.K. ($29), and Spain ($26). The consumption of cur flowers is mainly concentrated in West Europe, North America, and Japan. The highest growth is expected in Japan and the U.S.A. The world consumption of potted plants was about $14.2 billion in 1990 and $19 billion in 1995, which is supposed to rise further. It is hoped that with the stabilization of East European countries, these countries would merge as new consumers in the coming years.

Every year, there is an upsurge in the world import of cut flowers. In 1982, the total amount of imports was $2.5 billion, which rose to $7.5 billion in 1996. It may be pointed out here that from the total production of cut flowers and potted plants, only a small part is exported to the foreign trade market. About 75% of international trade comes from European countries only. The total world imports of cut flowers amounted to $3.72 billion in 1995, in which Germany's import was $1.5 billion, which is the largest imported, followed by the U.S.A., France, The Netherlands, and Switzerland. In cut flowers, The Netherlands dominated the world export market with 57% share followed by Colombia (14%), Israel (4%), Kenya (3%), Ecuador (3%), Italy (2%), Thailand (2%), and Spain (2%), the share of developing countries in the world trade in 1995 was estimated at 28.4%, up from 20.8% in 1991. The maximum trade for cut flowers in the international market is witnessed in rose, carnation, and chrysanthemum. Besides the already existing international auction centers for flowers in Amsterdam (The Netherlands), Miami (U.S.A), Bogota (Colombia), and Tel Aviv (Israel), new centers are emerging in Japan, Thailand, and Mauritius. In global trade, these new centers will play an increasing role, as more and more developing countries from Asia and cost-effective producers enter the market. The top 10 pot plants, cut flowers, and their destinations in the world are listed in Table 3.1.

TABLE 3.1 Top 10 Pot Plants, Cut Flowers and Their Destinations in World

Rank	Potplants	Cutflowers	Destination
1	*Kalanchoe*	*Rosa*	Germany
2	*Hedera*	*Tulipq*	France
3	*Ficus*	*Chrysanthemum*	UK
4	*Saintpaulia*	*Gerbera*	Italy
5	*Chrysanthemum*	Carnation	Belgium
6	*Dracaena*	*Freesia*	Switzerland
7	Pot rose	*Lilium*	Austria
8	*Hyacinthusi*	*Alstroemeria*	United States
9	*Primula*	*Iris*	Denmark
10	*Begonia*	*Gypsophila*	Sweden

The top 10 flower producing countries in the world are listed in Table 3.2.

TABLE 3.2 Top 10 Flower Producing Countries in the World

Rank	Country Name	Capital
1	Netherlands	Amsterdam
2	USA	Washington, D.C.
3	Sweden	Stockholm
4	Brazil	Brasilia
5	Denmark	Copenhagen
6	Switzerland	Bern
7	Australia	Canberra
8	Malaysia	Kuala Lumpur
9	Cambodia	Phnom Penh
10	India	New Delhi

3.3 INDIAN FLORICULTURE INDUSTRY

India is one of the leading countries in flower production with an area of 2.49 lakh hectares producing 4.84 lakh cut flowers and 16.59 lakh tones of loose flowers during 2014–2015. The floriculture industry in India is characterized by b growing traditional flowers and cut flowers under open field and protected environmental conditions, respectively. The major loose flower growing states are Tamil Nadu, Karnataka, Madhya Pradesh, Mizoram, Gujarat, and Andhra Pradesh. The major cut flower growing states are West Bengal, Karnataka, Orissa, Jharkhand, Assam, Kerala, and Andhra Pradesh. North Eastern and other Himalayan states have become major centers for growing quality flowers in the recent years. India also has a strong dry flower industry, which contributes a major share to the overall trade. Other segments like fillers, potted plants, seeds, and planting material, turfgrass industry and value-added products also contribute a share in the overall growth of the floriculture sector, which is generating higher income, profit, and employment opportunities to the Indian youth, promoting more involvement of women and enhancement of exports. India has now become the second-largest grower of flowers in the world after China. The country has exported 22,519 tonnes of flower products to the world in 2015–2016. India's total export of floriculture in 2015–2016 was Rs 479.42 crores. The major importing countries were the United States, The Netherlands, Germany, United Kingdom, United Arab Emirates, Japan, Canada, Belgium, and Australia. There are more than 300 export-oriented units in India, and more than 50% of these are in Karnataka, Andhra Pradesh, and Tamil Nadu. With the technical collaboration from foreign companies, the Indian floriculture industry is poised to increase a share in world trade.

3.4 CONCLUSIONS

Worldwide the production of commercial flowers has expanded. In these countries, the entrepreneurs see opportunities to enter markets combined with good growing conditions. The international trade of ornamental products has increased, following the development in the consumption of ornamentals in the different continents and countries. Consistent reputation is therefore very important, so those delivering the goods of reputed high quality continuously than irregular and little known suppliers even if their quality is superb, so they will have to wait for some time to gain this reputation.

Thus, it is required to upgrade the floriculture industry with proper training and high-tech farming to fetch a better price in the international market. Certainly, flower cultivation is more remunerative than any other agricultural farming, but the crop should be grown by providing optimum conditions, harvested at the proper stage, and given proper conditioning after cutting such as grading, storage, packing, and transportation so that it may meet the international requirements.

KEYWORDS

- **commercial floriculture**
- **floriculture trade**
- **global floriculture industry**

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CHAPTER 4

PESTS OF ORCHIDS AND THEIR MANAGEMENT

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ABSTRACT

Orchids belong to one of the largest families of flowering plants, Orchidaceae. Orchids are fascinating, diverse, and beautiful of all flowers, and with the added advantage of longevity, these flowers are becoming all the more popular. Of the several limiting abiotic and biotic factors, the insects and other related pests are the major factors to decrease the quality and production of orchids. Based on regular monitoring, orchid plants were found to be infested by several insect pests and mites during certain parts of the year at different levels of infestation. Two-spotted spider mite, *Tetranychus urticae,* few scale insects like Biosduval scale (*Diaspis biosduvali*), Cymbidium scale (*Lepidosaphes pinnaeformis*), soft brown scale (*Coccus hesperidum*) and Lecanium scale (*Lecanium* sp.), aphids (*Toxoptera aurantii*, *Macrosiphum luteum*), thrips (*Dichromothrips nakahari*) were found to infest several orchid species and hybrids. Besides these, Mealybugs, grasshoppers, cockroaches, and snails and slugs were found feeding on flowers at minor levels. This chapter outlines a brief description of insect and non-insect pests found in the Himalayan region along with their hosts, life-cycle, and nature of the damage, seasonal incidence and overall Integrated Pest Management (IPM). Some of the pests described are reported to damage orchids the first time; hence, it may receive great importance in orchid protection in the near future.

4.1 INTRODUCTION

Orchidaceae is the second largest family of flowering plants, with an estimated 25,000 species (Atwood, 1986). However, the numerical strength of the family in terms of species has been assessed at between 17,000 and 35,000 (Garay, 1960; Willis, 1973). India is blessed with 1229 species distributed from tropical to temperate regions of the country (Ram et al., 2011). The commercial cultivation of orchids in India began in the 1980s and emerged as an important segment of the Indian floriculture industry (Upadhyaya et al., 2006). Orchids are cultivated for the trade of orchid species, cut-flowers, potted plants, and many other value-added products (Kuehnle, 2007). The most popular and commercially cultivated genera are: Cymbidium, Dendrobium, Oncidium, Phalaenopsis, Vanda, and Paphiopedilum. In their production zones, abiotic components and insect pests are the major factors limiting the quality and production of the crop. Orchids collected from different parts of the country and more than 100 hybrids have been conserved under polyhouse conditions at ICAR-National Research Centre for Orchids, Pakyong, Sikkim located at 1,400 m between 27°4’–28°7’48””N and 88°58”–88°5’25” E longitude. The region has an average maximum temperature of 17–28°C and a minimum of 6–20°C, the maximum relative humidity of 81–95%, and a minimum of 43–73%. Pakyong receives an average annual rainfall of about 2500–3000 mm.

Globally several pests have been reported on Orchids, thrips, *Helionothrips errans* on orchids *Cymbidium*, *Cattleya* hybrids, *Dendrobium*, *Dockrillia*, *Sarcochilus*, and *Bulbophyllum* from Australia (Gillespie, 2008); *Dichromothrips smithi* (Zimmermann) on bamboo orchid, *Arundina graminifolia* from Hawaii (Hollingsworth et al., 2012); lema beetle *Lema pectoralis* on orchids from Thailand and Malaysia (Jolivet, 1971). Aphids like *Macrosiphum luteum* have been reported to infest orchids of the genera *Oncidium, Cattleya, Lycaste, Brassia, Epidendrum, Laelia, and Castsetum* (Swezey, 1945) and fringed orchid aphid, *Cerataphis orchidearum* on various Orchidaceae, including Vanilla (Blackman *and* Eastop, 1984; Klara et al., 1997).

In India, insects namely grasshopper *Oxya chinensis,* spiraling whitefly *Aleurodicus dispersus,* flower thrips *Megalurothrips distalis,* Bihar hairy caterpillar *Diacrisia obliqua,* tobacco caterpillar *Spodoptera litura,* red ant

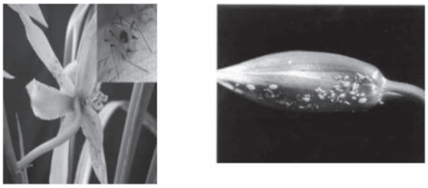
Monomorium indicum, beetle *Lema* sp. and banded blister beetle *Mylabris pustulata* and non-insects like sow bug *Oniscus aseltus,* land snail *Ariop-lianta* sp., black slug *Anon* sp. and grey slug *Umax* sp. were reported from Kerela (Kumari *and* Lyla, 2001). From Sikkim Himalayan orchids, several pests were reported to cause damage like aphids, *Toxoptera aurantii* and *Macrosiphum luteum* (Nagrare, 2004, 2006), Orchid Shoot borer, *Peri-daedala* sp. (Nagrare, 2005), thrips, *Dichromothrips nakahari* (Meena et al., 2011), the two-spotted spider mite, *Tetranychus urticae* (Nagrare *and* Rampal 2008).

In this chapter, a brief description of pests found in the Sikkim sub-Himalayas, their hosts, nature of the damage, seasonal incidence, and IPM are given.

4.2 INSECT PEST OF ORCHIDS

4.2.1 APHIDS

- **Scientific Name:** *Toxoptera aurantii* (B. De F), *Macrosiphum luteum* (Bukton).
- **Family:** Aphididae.
- **Order:** Hemiptera.
- **Host Plants:** *Toxoptera aurantii* was first reported to infest the orchid, Oncidium Grower Ramsay (Nagrare, 2004) in India. Acampe, *Cattleya,* Coelogyne, *Dendrobium nobile,* Epidendrum species, Cymbidium hybrids.
- **Identification:**
    a. Black aphids are black, oval in shape, small size of about 2–3 mm in length, wingless in nymphal stage and wingless as well as winged in adult stage. One pair of cornicles on the tip of abdomen that secretes honeydew.
    b. Yellow aphids are pale green in color during nymphal stage and greenish-yellow to yellow in adult stage. It has an oval-shaped body with a size of about 2–3mm in length. Blackish two cornicles are present on the tip of the abdomen. Adults are winged or wingless with a brownish patch on the top of the abdomen.



Yellow aphid, *Macrosiphum luteum*

Black aphid, *Toxoptera aurantii*

- **Seasonal Incidence:** November to March.
- **Biology:** The adult female gives birth to several female nymphs, which starts to feed and grow immediately molting several times to mature to an adult female capable of reproducing within seven to ten days, all without maturing. The life cycle completes within a week at high temperatures. Winged forms appear when the colonies become overcrowded, which flies to establish new colonies. The insects can cycle continuously under greenhouse conditions; their rate of development affected only by temperature. In the autumn, females begin producing a few males. Females born at the same time have eggs within their bodies; they mate and lay the eggs to provide next season's offspring.
- **Nature of Damage:** Both nymphs and adults attack buds, flowers, and new growths of the plant. They also excrete honeydew on which sooty molds develop. Usually, when sooty mold and ants are present, inspect the plants for aphids, Mealybugs, and soft scale insects. High humidity and cloudy weather favor multiplication. The affected plants retard growth (flower may fail to open in some cases) and ultimately deteriorate the flowers' quality.

4.2.2 THRIPS

- **Scientific Name:** *Dichromothrips nakahari.*
- **Family:** Thripidae.
- **Order:** Thysanoptera
- **Host Plants:** Cymbidium species and hybrids, *Dendrobium nobile, D. chrysanthum, D. moschatum, D. densiflorum*, D. *fimbriatum*, Coelogyne species *Pholidota articulate*, *Thunia marshelina* and *Vanda cristata.*

- **Identification:** The adults are slender, dark brown to black in color having apically pointed fringed wings, and measure about 1–2 mm length. Nymphs resemble the adult in shape but pale yellow/orange, wingless, and smaller size with black eyes. Their presence can be seen by the presence of black coal-tar like resinous exudates.

Adults, Dichromothrips nakahari

Nymphs, black resinous secretions were seen

Infested Dendrobium flowers

- **Seasonal Incidence:** Occurs during the flowering season of Dendrobium from March onwards and is found attacking Cymbidium plants during the winter season.
- **Biology/Life Cycle:** Females insert cylindrical to kidney-shaped eggs into leaves, buds, and flowers. Nymphs hatch from an egg and pass through four instars before becoming an adult. Late-instar larvae change greatly in appearance and behavior and are called prepupae and pupae, even though thrips do not have a true pupal stage. Pupation takes place within the soil/media. The life cycle is highly influenced by temperature and humidity.
- **Nature of Damage:** Damage is caused by both the nymphs and the adult. They suck the cell sap, and the infested leaves become discolored and shrivel. In the case of severe infestation, there is malformation of leaves, flower buds, and flowers. Thrips mainly attack flowers of several Dendrobium species and mostly attack the leaves incase of Cymbidium and Coelogyne species preferring the young seedling stages. The attacked plants are stunted and may finally dry up. Infested buds may not open, and flowers may be deformed exhibiting water-soaked spots. Leaves may appear pitted, stippled, silvery, or bleached. Feeding of thrips is usually accompanied by black flecks of varnish-like exudates.

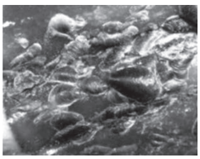
4.2.3 SCALE INSECTS (LEPIDOSAPHES, LECANIUM SCALE, BOISDUVAL, SOFT BROWN SCALE, AND TI SCALE)

The scales insects belong to two categories-hard scales and soft scales. In hard scales, the scale cover is not attached to the body and can easily be removed, whereas in soft scales, the scales cover is attached to the body and hence cannot be removed. The hard scales do not secrete honeydew, whereas the soft scales does. The hard scales or armored scales belong to family Diaspididae, and soft scales belong to Coccidae. There are four predominant species of scale insects viz., Lepidosaphes (*Lepidosaphes pinnaeformis*), Boisduval (*Diaspis boisduvalii*), Lecanium scale (*Lecanium* sp.), and Soft Brown scale (*Coccus hesperidum*). Of these, *Lepidosaphes* and Boisduval scale are the major pest on orchids and the most difficult ones to manage.

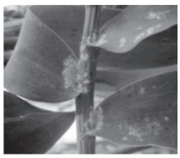
- **Host Plants:** Cymbidium species and hybrids, Dendrobium, Coelogyne species, *Phaius tankervillae, Epidendrum* species, *Dendrobium* species, *Phalaenopsis, Cattleya* hybrids, *Papiolionanthe teres,* and several other orchids.
- **Identification:**
    a. **Boisduval (*Diaspis boisduvali*):** Biosduval scales are hard scales. The females of Boisduval scales are circular to oval-shaped; thin flat, about 1.2–2.25mm in diameter while the male scales are narrow, elongated with the presence of grooves or ridges on the scale covering. The adult male scales have one pair of wings, white to semi-transparent in appearance with the body covered with white cottony growth and look similar in appearance to Mealybugs**.**
    b. ***Lepidosaphes pinnaeformis*:** This hard scale is also known as the Cymbidium scale because they attack mostly the Cymbidium group of Orchids. They are hard scales. The adult female cover is oyster-shell shaped, usually curved, moderately convex, brown often with lighter periphery; shed skins marginal, orange, or tan. Body of adult female white to light violet; eggs and crawlers are light pink to white in color. Male cover shorter, narrower than female cover, same color and texture; shed skin marginal orange or tan and the adult males have one pair of wings.

c. **Lecanium Scale (*Lecanium* sp.):** Lecanium scales are soft, usually turtle or dome-shaped, slightly longer than its width up to 4–6mm in diameter. These types of insects are the shiny brown-colored bearing protective covering of wax secreted from their body.

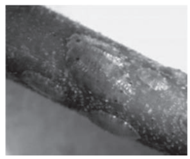
d. **Soft Brown Scale (*Coccus hesperidum*):** Soft brown scale is circular or oval-shaped shiny brown to pale brown, light green in color of about 2–3mm in diameter.



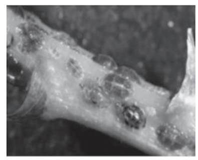
Lepidosaphes pinnaeformis



Diaspis boisduvalii



Coccus hesperidum



***Lecanium* sp.**

- **Seasonal Incidence:** Biosduval scale and Cymbidium scales are found throughout the year. Soft Brown and Lecanium scales are mostly found during the summer season in small populations. Once the plants are infested with Boisduval and cymbidium scales, they are difficult to eradicate.
- **Biology/Life Cycle:** Scales have three life stages: egg, larva (or nymph) adult. Hundreds of eggs are laid under the female's shell and remain thereafter, she dies. These hatch into mobile nymphs called crawlers. After finding a suitable place, crawlers settle to feed and remain there, and their locomotive organs drastically reduce as they grow into an adult. The females then form a light yellowish protective scale covering, which enlarges as the insect grows and darkens to tan or brown as it matures. Male scales are small with one pair of wings and are generally weak fliers. The primary role of males is to mate and die. Scales have short life cycles, but several overlapping generations a year. Typically, a month or more is required for completion of a scale generation, but a mere two to three weeks is possible in favorable conditions.
- **Nature of Damage:** Scales are sucking insects that attach and suck the plant sap by feeding on the underside of leaves, leaf axils, pseudobulbs, and rhizomes. Being different in appearance from other insects, one may fail to recognize scales as insects. They often are

hidden under old leaves and pseudobulb and in between the leaf sheaths. Severe infestations cause chlorotic areas to appear on the leaves and plant surfaces, which turn yellow, darken, and cause the leaf to drop prematurely. The most visible damage caused by soft scales is the sticky honeydew excreted on which the development of black sooty molds takes place**.**

4.2.4 SHOOT BORER

- **Scientific Name:** *Peridaedala* sp.
- **Family:** Tortricidae.
- **Order:** Lepidoptera
- **Host Plants:** *Dendrobium nobile, Dendrobium chrysanthum, Dendrobium densiflorum*, Dendrobium hybrids, Aranda hybrids, Mokara hybrids, Vanda, *Papiolionanthe, Aerides, Acampe, Eria, Epidendrum, Liparis.*
- **Identification:** The adult moths are small, black in color with beautiful light bluish scales present over the wings, measuring about 8–10 mm. The newly hatched larvae are almost transparent in color, with a big head and body tapering towards the end. As the larva develops, it turns to greenish-yellow.
- **Seasonal Incidence:** The infestation of this particular insect starts with the onset of the rainy season from April up to October–November. The hibernating larvae pupate and emerged as adults from April onwards.
- **Biology/Life Cycle:** The adults lay transparent to white eggs, which look like bird droppings singly on the new young leaf/leaf axil in between the flag leafs. There are five larval instars with four molts. The last larval instar makes an exit hole just before pupation in the stem. The pupa is brown in color, obtect type with hair-like bristles or markings on the ten visible segments. One important characteristic is that the adult moth on emergence from the pupal case drags along with it the pupal case, which can be seen half hanging from the stems from where the adult moth has emerged. The adult moths are small, black in color with beautiful light bluish scales present over the wings, and measuring about 8–10 mm. The total life cycle varies from one to three months, depending on temperature and

humidity. There are several generations in a year. The larvae hibernate during the cold winter months (Table 4.1).

TABLE 4.1 Duration of Life Stages of Orchid Shoot Borer (n = 20)

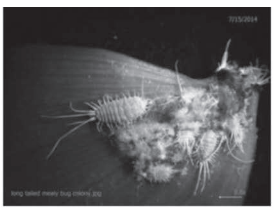
Insect Stages	Duration (Days)	
	Range	Mean ± SD
Incubation period/egg	7–10	8.4 ± 0.97
I instar	3–6	3.9 ± 0.99
II instar	4–8	4.8 ± 1.39
III instar	5–8	6.0 ± 1.05
IV instar	6–10	7.5 ± 1.58
V instar	6–13	8.4 ± 2.59
Pre-pupal period	2–3	2.3 ± 0.48
Pupal period	6–18	8.7 ± 3.62
Total developmental period	39–76 days	50.0 ±14.75

- **Nature of Damage:** The damage is caused by the larval stage, which is the most active stage in the life cycle. As the eggs are laid in between the two young leaf axis (flag leaf), the newly hatched larvae roam about for few minutes and then bores inside the leaf for a short period. Mines on the leaves are the first symptoms along with the presence of small blackish regions with the presence of excreta/frass. Later on, as the larva develops and continues to feed, a blackish region, which is almost rotting can be seen at the junction of the two leaves. This leaf can easily be pulled out and represents the typical dead-heart symptom caused by borers. The larva then bores inside the shoot and feeds on the central pith. Masses of frass and excreta can be seen on infested shoots. If the infestation is not checked, the larvae continue to bore inside and may result in the death of the entire plant, as in the case of orchids like Dendrobium. In some orchids like Aranda and Mokara (species and hybrids) infestation of shoot, borer causes the plants to develop side shoots.

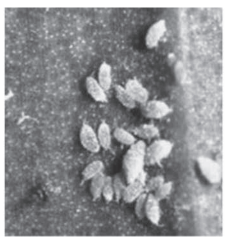
4.2.5 MEALYBUGS

There are two species of Mealybugs found to infest orchid-long tailed mealybug and another *Pseudococcus* species.

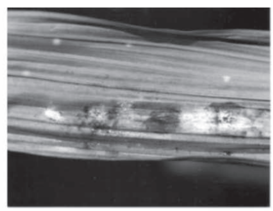
- **Scientific Name of Long Tailed Mealybug:** *Pseudococcus longispinnus*.
- **Family:** Pseudococcidae.
- **Order:** Hemiptera
- **Host Plants:** *Pseudococcus longispinus* is so far found infesting only *Dendrobium fimbriatum, Dendrobium chrysanthum*. However, *Pseudococcus* sp. is found to infest *Cymbidium, Dendrobium, Cattleya, Coelogyne, Bulbophyllum, Acampe, Epidendrum, Luisia, Pholidota, and* others.
- **Identification:** Adults are soft-bodied, filamentous, covered with white powdery wax-like cottony growth in an irregular shape. It has piercing and sucking mouthparts. Long-tailed mealybug is identified by the presence of long filamentous waxy growth at the tip of its abdomen.



Mealybug colony



Crawlers



Infested leaves

- **Seasonal Incidence:** Occurs at any time of the year.
- **Biology/Life Cycle:** The long-tailed Mealybugs gives birth to live young, and males are necessary for reproduction to take place. In *Pseudococcus* sp. there is an egg stage too. The immature nymphal stages are called crawlers as they crawl, select a suitable site where they can feed and mature. They will develop into adults in about 1–2 months. There are several overlapping generations in a year. Mature females die after egg-laying. Eggs hatch in 5 to 10 days, but unhatched eggs or young nymphs sometimes remain inside the protected cottony sac during unfavorable environmental conditions. Adult males are small, winged insects without functional mouthparts whose primary role is to fertilize females.
- **Nature of Damage:** Both young and adult cause damage to the plants. Mealybugs attack any part of the plant but tend to stay

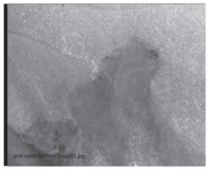
stucked away at the junction of leaf and stem. Severe infestations cause chlorotic areas to appear on the leaves, which may darken, causing the leaf to be yellow and drop prematurely. They also secrete honeydew that attracts ants, and in case of severe infestation black sooty mold can be seen on the infested plant parts. The attacked plant looks wilted and unhealthy.

4.2.6 SAP SUCKING BEETLE

- **Scientific Name:** *Nitidulid* sp. Family: Nitidulidae order: Coleoptera.
- **Host Plants:** The adult was found to feed on the pollens and suck the sap from the flowers of orchids, mainly species namely, *Dendronium nobile, D. chrysotoxum, Dendrobium fimbriatum, D. densiflorum,* and other *Dendrobium* species.
- **Seasonal Incidence:** Appears during the flowering period of Dendrobium species from March and last up to May.
- **Identification:** The adult beetles are black in color, slightly flattened and oval in shape, and with the presence of texture or hairs. The body is covered with shortened elytra exposing certain segments of the abdomen. The antennae are 11 segmented and lamellate types. The grubs are whitish cream in color, the head is well sclerotized, brown in color, and the abdomen is equipped with well-sclerotized cerci.
- **Biology/Life Cycle:** During the flowering season, all the stages are found in flowers. The larvae feed on the flowers, which later pupate within the floral tissue or in the fallen floral debris. There are 2–3 generations in a year.
- **Nature of Damage:** Both the adults and the grubs cause the damage. The adults feed on the pollens and suck the cell sap from flowers while the grubs bore within the floral tissue and eat away the tissue leaving the membranes, which results in the lace-like appearance of the infested flowers.

4.2.7 GRASSHOPPERS

There are several grasshoppers and katydids found feeding on flowers of different orchid species.

Grub **Grub inside the floral tissue** **Pupa** **Adult**


Damage symptoms on flowers of *Dendrobium nobile*

- **Scientific Name:** *Hieroglyphus banian.*
- **Family:** Acrididae.
- **Order:** Orthoptera
- **Scientific Name:** *Chrotogonus trachypterus.*
- **Family:** Pyrgomorphidae
- **Order:** Orthoptera
- **Host Plants:** Cymbidium, Dendrobium, Phalaenopsis, and other orchid species.
- **Identification:** The adults of *Hieroglyphus banian* are medium-sized insects, uniformly greenish without any spot. They measure about 5 cm in length.
- **Nature of Damage:** Grasshoppers and katydids do the damage by eating flowers, new growths, and sometimes roots. Flowers with irregular petals and half-eaten buds and notches indicate infestation by grasshoppers.

4.3 NON-INSECT PESTS

4.3.1 TWO SPOTTED SPIDER MITE

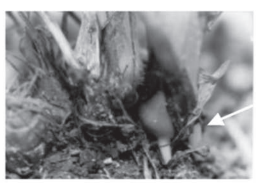
- **Scientific Name**: *Tetranychus urticae* Koch.
- **Family:** Tetranychidae.
- **Order:** Arachnida

- **Distribution:** In India, it is found in all orchids growing states and is abundant in Sikkim, West Bengal, Assam, Arunachal Pradesh, Meghalaya, Mizoram, Andaman, and Nicobar group of islands and Kerala.
- **Occurrence:** The incidence of pests on orchids is being active throughout the year under-protected (open polyhouse) conditions.
- **Host:** Cymbidium sp. and hybrids, Dendrobium, Epidendrum,
- **Identification**: Mites are not insects; they are members of the spider family Arachnida. Adult is oval shape, about 0.4–0.6 mm length with well-marked four pairs of legs. Coloration varies throughout the year. During the growing season, mites are greenish-yellow in color with a black spot on each side of the body. Overwintering females and mites in the non-feeding stage are orange-red. Nymphs are pale green with darker margins. The larvae look like small adults but only have three pairs of legs. Eggs are transparent to off-white in color.
- **Biology/Life History:** Both two-spotted spider mites and flat mites have five life stages: egg, larva, protonymph, and deutonymph (or nymphs), and adult. The larva has only six legs, but the nymphs and adults have eight legs. Eggs are laid by females on the surface of plant structures and are often hidden in crevices. A good hand lens is useful for seeing even the adults. This is a warm-season mite and is active during the hot temperatures of summer. They prefer hot and dry conditions. Several generations are there in a year. A single female of *T. urticae* Koch produced 36–52 eggs on orchid (Cymbidium) under 26 ± 2°C average temperatures and 65 ± 5% relative humidity. Among the orchids, Cymbidium was noted as the preferred host for *T. urticae*, on which it completed its life cycle in 9–12 days (Meena et al., 2013).
- **Nature of Damage:** All active stages (nymph and adult) feed on the undersurface of leaves and flowers by puncturing and sucking the cell sap from the epidermal layer with their needle-like mouthparts. They remove plant juices from leaves, which cause stippling of white silvery to yellow dots to occur on the foliage as chlorophyll is removed. The stipples gradually turn grayish bronze in color. Fine webbing will be present in case of severe infestations. There is premature dropping of leaves, and plant vitality is seriously affected. Flower buds do not open properly, and flowers

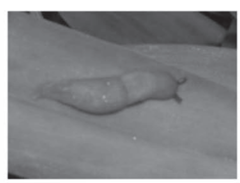
are usually abortive, turn brown and fall down before maturation. Plants become covered with webbing, and pests spread from one plant to another plant.

4.3.2 SNAILS AND SLUGS

- **Scientific Name*:*** *Cryptaustenia verrucosa* and *C. heteroconcha* (Godwin-Austen)
- **Class:** Gastropoda.
- **Phylum:** Mollusca
- **Host Plants:** Cymbidium, Dendrobium, Phalaenopsis, and Cattleya
- **Identification:** Snails are a soft-bodied organism with the asymmetrical body, which is spirally coiled and enclosed in a shell. They have a small flat muscular foot, which is used for creeping/crawling. This muscle constantly secretes mucus, which facilitates their movement and later dries to form the silvery "slime trail" that signals the presence of either pest. Slugs are devoid of shell cover.
- **Biology/Life Cycle:** Adult brown garden snails lay an average of 80 spherical, pearly white eggs at a time into a hole in the soil. They can lay eggs up to 6 times a year, and it takes about 2 years for snails to mature. Slugs reach maturity after about 3 to 6 months, depending on the species, and lay clear, oval to round eggs in batches of 3 to 40 beneath leaves, in soil cracks, and in other protected areas.
- **Seasonal Incidence**: Found during the rainy season. Generally, snails prefer shady, dark, and highly humid conditions and are active during the night time.

Snails



Slug

- **Nature of Damage:** Both young and adult stages of snails feed on orchid roots, leaves, flower buds, and fully opened flowers. They are nocturnal in nature. These mollusks will leave holes and notches in the leaves, flowers, flower buds, roots, and may chew off the growing tips. Excreta are also seen in infested portions. During day time, they seek hiding places out of the heat and bright light.

4.4 INTEGRATED PEST MANAGEMENT (IPM)

The most effective, long-term way to manage pests is by using a combination of methods that work better together than separately. Approaches for managing pests are often grouped in the following categories

4.4.1 INSPECTION AND MONITORING OF PLANTS

Regular monitoring and inspection of the plants for any insect pest is a key to any successful pest management. Early detection and diagnosis of pest infestations will help in taking control actions before it becomes a major problem. Insect pests are usually brought into the greenhouses along with new plant materials. Therefore inspect the plants for any kind of pests before keeping them with the common lot. Check the lower surface of the leaves for mites and thrips, in between leaf sheaths and leaf axils for scale insects and Mealybugs.

4.4.2 CULTURAL PRACTICES

a. Clean cultivation and removal of the infested plant parts (leaves/flowers) and destroy them to reduce further multiplication of all pests. Removing old flowers reduces the number of thrips. Thrips lay eggs that hatch in grassy areas, so keep the grasses mowed and weeds controlled.
b. Remove old leaves and leave sheaths to eliminate scale hiding places and allow easy inspection. New plants need careful inspection before being added to the growing area.
c. Proper ventilation and application of balanced fertilizer doses and irrigation to curtail the thrips, mites, and other pest populations.
d. Infestations can be eliminated by discarding or removing heavily infested plants from the polyhouses.
e. Clipping off of new apical leaves when infestation by shoot borer is seen, as the first instar larva first feeds on the young leaves

before boring down. The pest can be suppressed by cutting and destroying the infested branches on which dead shoots produced or by observing the symptom of its infestation like frasses or excreta in the axil or base of the apical leaves.

4.4.3 MECHANICAL METHODS/PHYSICAL METHODS

a. The best way to manage snails and slugs is to collect and kill them in a 10% salt solution. Ash and diatomaceous earth can be spread on horizontal surfaces to create a barrier. However, one must be careful so that they don't come in contact with water; otherwise, it will deactivate it.
b. Traps for snails and slugs: Place cabbage leaves during the day time to trap both snails and slugs. Place wooden planks and moist gunny bags on the ground during the day time to provide a hideout for them. Later on, collect them and kill in saline water. Since snails and slugs are attracted to beer, small cups with a little amount of beer in it can be laid out for trapping them.

4.4.4 BOTANICAL PRODUCTS

a. Initially spray the crop with Neem oil (Azadirachtin) 5 ml/l of water to reduce the mite population. IPM module (tobacco extract 5%, Neem oil 0.03% EC 5 ml/l.
b. Application of neem oil 0.03% @ 5 ml/l of water and *Allium sativum* 10% help in a mean population reduction of two-spotted spider mites of 85.13% and 83.17%, respectively.
c. As soon as the pest appears on the new spikes or flower buds initially spray the plants with neem oil 0.03% EC (Azadirachtin) 5 ml/l or botanical extracts like tobacco leaf extract 10 ml/l, Chiluane leaf extracts, titapat leaf extracts, etc. to reduce the pest population.
d. Neem oil 0.03% EC, NSKE 1500 ppm, tobacco leaf extract 5%, Garlic extract 5%, and Dhatura leaf extract 10% can be applied for management of thrips on orchids at 15 days interval (DI) (Meena *and* Medhi, 2010).

e. Spraying of plants with Azadirachtin 5 ml/l of water or econeem 3 ml/l of water before egg-laying or at the time of adult emergence during the month of February-March can prevent the infestation by shoot borer considerably.
f. It was found that NSKE 1500 ppm (5 ml/l) and neem oil 0.03 EC (5 ml/l) was effective against shoot borer on *Dendrobium nobile* (Meena, 2009),
g. IPM module consisting by tobacco extract 5%, neem oil 0.03 EC @ 5 ml/l and bifenthrin 10 EC 0.025%) was effective against mite, whereas, neem oil @ 5 ml/l and imidacloprid 17.8 SL @ 0.003% provides good control for aphid.

4.4.5 BIOLOGICAL CONTROL

a. Predators are very important in regulating spider mite populations and should be protected whenever possible. Important genera include the predatory mites, *Amblyseius*, *Metaseiulus*, and *Phytoseiulus*; the lady beetles, *Stethorus*; the minute pirate bugs, *Orius*; the thrips, *Leptothrips*; and the lacewing larvae, *Chrysopa*.
b. Encourage natural enemies (NEs) like coccinellid predators *Scymnus* sp predatory on scale insects.
c. Encourage NEs like coccinellids, syrphid flies in the vicinity of the polyhouses, which are efficient predators of aphids and other soft-bodied insects.
d. Mites can effectively be managed by entomopathogenic fungi (EPF) *Paecilomyces fumosoroseus* @ 2 g/l of water.
e. EPF like *Beauveria bassiana*, *Metarhizium anisopliae*, and *Verticillium lecanii* @ 2 ml/l of water can be applied for the management of aphids, scales, thrips, and Mealybugs.
f. *Coccophagus ceroplastae* (Howard), an aphelinid parasitic wasp, was found to parasitize populations of the soft brown scale, *Coccus hesperidum* Howard infesting the orchids in Sikkim, India. Parasitization under natural conditions was found to range from 5–45% (Sangma et al., 2015).
g. The natural parasitization of Cymbidium scale, *Lepidosaphes pinnaeformis* by Aphelinid wasp parasitoid, *Aphytis* sp. under polyhouse conditions was found to range from 6–38% (Sangma et al., 2014).

h. Different formulations of entomopathogenic bacteria, *Bacillus thuringiensis* var. *kustaki* @ 2 ml/l of water can be sprayed at 15 DI for management of shoot borer.
i. Spray with Spinosad 45 SC 0.3 ml/l and *Emmamectin benzoate* @ 1 ml/l of water for management of shoot borer in orchids.

4.4.6 INSECTICIDAL SOAPS AND HORTICULTURAL OILS

a. To conserve the NEs of spider mites, apply biorational pesticides like horticultural oils and soap sprays. Probably the most popular home remedy is to spray plants with a mixture of isopropyl (rubbing) alcohol and liquid mild dish detergent.
b. Spray the crop with plain water twice a day or with a mild soapy mixture to check the infestation of mites. Minor mite infestation can possibly be discouraged from becoming a major, damaging one by the frequent wetting of the leaves—top and bottom—with a mild soap and water solution. This not only disturbs the mites, it leads to the build-up of a soapy film on the leaf surface, something which is unappealing to many pests.

4.4.7 CHEMICAL CONTROL

a. **Mites:** In severe conditions or as a last resort spray the crop with any one of the following miticides alternatively by dicofol (Kelthane) or fosmite or omite (propagite) or bifenthrin (talstar) at 0.025% and repeat the spray at 10–15 DI to provide effective control against mites.
b. **Thrips:** Apply fipronil 5SC 1.6–2.0 ml/l, and Imidacloprid 17.8 SL @ 0.3 ml/l at 15 DIs.
c. **Scale Insects:** In severe conditions spray with Acephate 75 SP 0.05% and Imidacloprid 17.5 SL 0.003% at 15 DIs.
d. **Shoot Borer:** In severe conditions, spray with Flubendiamide, Fipronil, or Chlorpyriphos @ 1.5 ml/l of water at 15 DI.
e. **Snails and Slugs:** Spray of Mesurol (Methiocarb) 75 SP 0.05% water on foliage will also provide good protection against the pests.

Alternatively, rotate these insecticides so as to avoid the development of insecticide/pesticide resistance in these pests.

4.5 CONCLUSION

The major insect and non-insect pests of orchids found in Sikkim Sub-Himalayas are diverse and important. However, the possibility of finding new insects attacking orchids is not ruled out. If new insect pests on orchids are being documented, it is essential to study their biology, habitat, nature of the damage, and develop suitable IPM techniques for their management. Combinations of different methods of pest control like cultural, physical, mechanical, botanicals, biological, etc., should be applied, and chemical control methods should be applied only on a need basis. New molecules of insecticides with a different mode of action and which are fast degradable as compared to old conventional insecticides should be tested. With IPM, pest populations as well as beneficial parasite and predator populations are monitored and also the use of insecticides are considerably reduced leading to minimized environmental problems benefitting the farmers and society as a whole.

KEYWORDS

- **grasshoppers**
- **integrated pest management (IPM)**
- **orchids**
- **pests**
- **sub-Himalayan**
- **thrips**

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CHAPTER 5

INSECT PESTS OF ROSES AND THEIR MANAGEMENT

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ABSTRACT

Rose plant is affected by several insects, mites, diseases, and nematodes posing a serious threat to rose cultivation. Insects and mites attack different parts of rose plants at every phenophase of growth. Commonly found and regular pests are thrips, aphids, scales, whiteflies, leafhoppers, chaffers, termites, and mites. Several of these pests are found throughout the year damaging the rose plants and affecting the flower yield. However, in polyhouse, the sucking pests *viz.* thrips, aphids, leafhoppers, whitefly, and mites are considered as the major ones. All these sucking pests occur in large numbers in clusters under the surface of the leaves, on shoots, buds, and flowers in field and polyhouse. Insect and mite pests on rose can cause 28–95% damage individually or in groups both in field and polyhouse.

Cultural practices and botanicals do reduce the pest population. Insecticides should be applied as and when required.

5.1 INTRODUCTION

Rose, acclaimed as the queen of flowers, native to Asia, is one of the most beautiful nature's creations. For thousands of years, the rose has symbolized love, adoration, innocence, and other Nobel virtues. It is certainly the best known and most popular of all cut flowers the world over. Rose is used for worshiping, making garlands, flower arrangements, and bouquets. Rose oil is incorporated in ayurvedic medicines, perfumes soaps and cosmetics, flavoring soft drinks, and alcoholic beverages. Rose-water is extensively used for cooking and confectionery, especially in the oriental region. It is also used in flavoring wines, jams, jellies, cakes, and syrups (Bose and Yadav, 1989). Rose flowers are popular landscape plants grown for their beauty. Rose plants/creepers are vulnerable to the attack of many insects and pathogens that reduce flower growth and quality as well as frustrate rose gardeners. Pests and diseases reduce the market value considerably. In general, the insects and mites do not kill the plant, but may stunt or kill plant parts, affect flowering, or cause aesthetic damage. The Economic Threshold level (ETL) and Economic Injury levels (EILs) are based on the quality or reduction in aesthetic value. Since the commercial rose cultivation under open field and protected structure is gaining popularity and increasing in area day-by-day. There is an urgent need to give proper protection against different insect pests to improve the quality and yield of flowers. In certain areas, nematodes pose a threat to rose-flower cultivation.

In this chapter, a description of insect and mite pests, damaging rose plants, identification, life history, nature of the damage, and their management strategies are dealt with, but briefly.

5.2 INSECT PESTS OF ROSE

5.2.1 APHIDS: MACROSIPHUM ROSAE L.

Aphids are found and colonize the new shoots and buds. Aphids are small soft-bodied insects 1–2mm long. Often green but occasionally light-brown, and sometimes with wings. The aphids may cover (in a colony) the complete growing tip of the plant and are most active during spring and summer seasons. Aphids multiply at an exceedingly rapid rate, feeding on the sap of the plant by piercing the plant cells via stylets. Other species of aphids found on the rose plant are Rose aphid: *Macrosiphum rosaeformis D.,* Cotton aphid: *Aphis gossypii* Glover, and Green peach aphid: *Myzus persicae.* The species of aphids share almost the same niche on the rose plant, co-exist, and multiply.

1. **Life-History:** Aphids are slow-moving, soft-bodied insects with piercing and sucking mouthparts. Many species may occur on roses, but the rose aphid (*M.* rosae) is one of the most common and dominant. Female aphids give birth to young aphides-nymphs that are able to become mothers themselves within a week to a few days. Besides, most aphids are females, which are able to reproduce without mating parthenogenetically. Consequently, under favorable conditions, aphids can rapidly reach higher populations.
2. **Damage:** Both nymphs and adults of aphids cause damage by sucking the plant-sap. Aphids often colonize and concentrate on tender growing tissues, like terminals and flower buds; they can cause distorted or stunted growth. Aphids excrete a sticky substance known as honeydew, which contains large amounts of undigested sugars. Honeydew accumulates on leaves and supports a black fungal growth known as sooty mold. Sooty mold fungi are not pathogenic, but the accumulation of sooty mold is unsightly and interferes with plant photosynthesis (Figure 5.1), making stunted growth and development.
3. **Management:**
   - There are many naturally occurring factors like predators, parasites, and diseases that help keep aphid populations under check. Inimical climate/weather conditions can severely impact aphid populations.
   - When large populations of aphids are detected on terminals or buds, a forceful spray of water to physically wash them off the plant may be effective.
   - Excessive amounts of nitrogen fertilizers must be avoided as this encourages aphids.
   - NSKE 5% or dimethoate 30 EC 2 ml/l or imidacloprid 0.5 ml/l can be sprayed to reduce the aphid populations.

FIGURE 5.1 Rose infestation with Aphid *Macrosiphum rosae.*

5.2.2 WHITEFLIES

Bemisia tabaci Genn. Adult whiteflies are small, moth-like insects, covered with a white waxy powder. Whiteflies most often occur on the undersides of leaves, but clouds of adults will fly around infested plants when disturbed. They are flattened, stalked, and oval-shaped, and have waxy filaments protruding from their bodies. However, these traits are difficult to see without the use of a hand lens, as they are tiny insects.

1. **Damage:** Like aphids and thrips, whiteflies suck plant sap from rose plants, because of continuous sucking light yellow patches that appear on leaves and tender plant parts. They have a tendency to build to high populations and their ability to produce large amounts of honeydew, which eventually results in a sooty mold that imparts black color to the plant (Figure 5.2).
2. **Management:**
   - Unnecessary insecticide treatments, which can disrupt natural biological control can be avoided.
   - Excessive amounts of nitrogen fertilizers can be avoided as this encourages whitefly populations and increase the cost of cultivation.
   - Yellow sticky traps can be used at the rate of 4 per acre in order to attract the whiteflies.

- NSKE 5% or dimethoate 30 EC 2 ml/l or imidacloprid 0.5 ml/l or thiamethoxam 25 WDG 0.3 g/l can be sprayed for quick reduction in the pest population.

FIGURE 5.2 Rose infestation with whiteflies *Bemisia tabaci*.

5.2.3 THRIPS: RHIPIPHOROTHRIPS CRUENTATUS HOOD

Thrips constitute one of the most important insect pests on roses. There are many species with flower thrips, but the above-mentioned species are destructive and most common. Thrips are tiny, elongate insects about 1/16th inches long when fully mature. Immature thrips are usually light yellow to lemon-colored and are spindle-shaped, and leaves are required to precisely detect and identify them.

1. **Damage:** On roses, thrips (both nymphs and adults) cause damage mainly by feeding on flowers. Thrips injury reduces the aesthetic value of the rose blooms, and severe infestations can prevent buds from opening. The feeding injury results in silvery or bleached damaged areas, on flower petals, that eventually turn brown and dry up. Because feeding is often concentrated on young, actively growing tissues, petals, and leaves are often crinkled or distorted as they continue to expand after being damaged (Figure 5.3) by thrips.

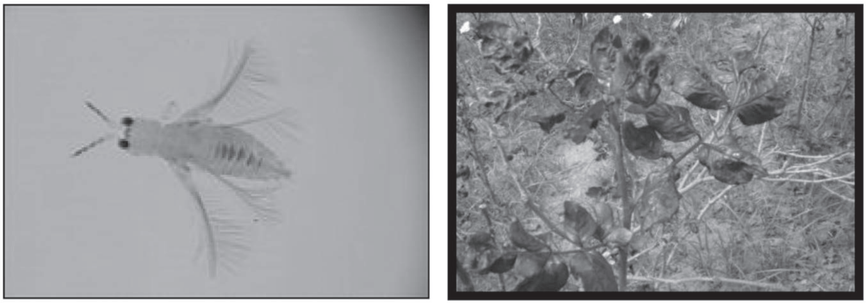

FIGURE 5.3 Rose infestation with *Rhipiphorothrips cruentatus*.

2. **Management:**
   - Excessive amounts of nitrogen fertilizers should be avoided as this encourages thrips populations.
   - Blue sticky traps at the rate of 4 per acre may be placed in order to attract the thrips and kill them.
   - NSKE 5% or Acephate 75 SP 1.5 g/l or imidacloprid 0.5 ml/l or thiamethoxam 25 WDG 0.3 g/lt can be sprayed for rapid recovery of damaged plant parts.
   - Spinosad is one of the more effective foliar treatments for thrips control on roses.

5.2.4 LEAFHOPPERS: EDWARDSIANA ROSAE

Leafhoppers are active, elongate, and wedge-shaped insects. There are many different species; most are green to yellow, but some species are brightly marked with yellow, red, or blue.

1. **Damage:** Both nymphs and adults feed on the undersides of leaves and on tender stems, sucking the sap and causing leaves to become spotted or yellow. A white or yellow stippling of the leaves is one of the most common symptoms on roses. In many situations of rose cultivation, leafhoppers are minor pests that seldom cause serious damage to rose plants.
2. **Control:**
   - Foliar, timely sprays with Lamda cyhalothrin @ 1 ml/l provides good control of nymphs or adults.

- Imidacloprid 0.5 ml/l or dimethoate 1.7 ml/l of water or neem oil spray can effectively suppress the leafhopper populations.
- Soil drenches of imidacloprid provide some control, but are rarely applied specifically to control leafhoppers on roses.

5.2.5 SPIDER MITES: *TETRANYCHUS CINNABARINUS*

Mites are not insects. Adult spider mites are so tiny that microscopes are required to see them. However, one can see them through a 10x hand lens also. Adults of most species are somewhat globular in shape and have eight legs. One of the more common species of spider mites is the two-spotted spider mite that has a dark spot on either side of the body. Adults and nymphs cause similar injuries. Feeding by low numbers of mites is inconsequential, but these pests have a high reproductive potential and can complete a generation in as little as seven days.

Another mite species is *Tetranychus urticae* that is phytophagous and causes injury to roses and other tender parts (Figure 5.4).

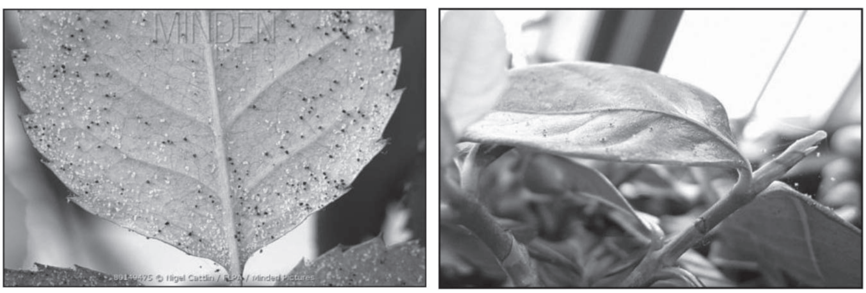

FIGURE 5.4 Rose infestation with spider mites *Tetranychus cinnabarinus.*

1. **Damage:** Both nymphs and adults suck the sap from the lower sides of the leaves. Heavy infestations cause severe injury and even kill plants. Feeding by individual mites because localized cell death, resulting in light-colored 'stippling.' Severely injured leaves may curl and drop from the plant. Initially, mite infestations are normally confined to the undersides of leaves, but under heavy infestations, the mites produce webbing. Because of this, the name spider mite has been accorded. Spider mites usually occur and colonize on the tops of leaves and on other plant parts (Figure 5.4).

2. **Management:**
    - Populations of phytophagous mites are often kept in check by species of naturally occurring predatory mites and other predators, inimical environmental factors, and other factors. So judicious applications of insecticides are called for.
    - Outbreaks of spider mites often occur following insecticide treatments targeted against other pests, because these treatments destroy the predatory mites, parasitoids, and predators of not only mites, but other predators.
    - Dicofol 2 mL (or) wettable sulfur 2 g/l can be applied when necessary.

5.2.6 SCALE INSECTS – LINDINGASPIS ROSSI, AONIDIELLA AURANTII, ASPIDIOTUS SPP

Scale insects do not look-like insects. Bodies of scales are covered with a hard scale-like covering. These scales cover often blend in with the bark of the plant, making the scales difficult to detect. Female scales deposit eggs that hatch into tiny crawlers.

1. **Damage:** Scale insects damage plants using sucking mouthparts to suck the sap from the plant. Heavy infestations also cause tissue damage as they probe and feed on plant cells. Scale insects completely cover the stem. Affected portions of the plant dries up. In server infestations, the whole plant may dry and collapse (Figure 5.5).
2. **Management:**
    - The affected branches of rose plants can be cut and burn.
    - The scale insects can be rubbed off with cotton soaked in Kerosene or Diesel.
    - Malathion 2 ml/l at the time of pruning can be applied.
    - Carbofuran 5 g/plant (or) fish oil resin soap 25 g/l can be applied as and when required.

5.2.7 JAPANESE BEETLES

Japanese beetles are robust, shiny metallic green and copper-colored insects. The adults also have a row of white tufts of hairs on each side, around the edge of the abdomen. The larvae of beetles are white grubs feeding on the roots of grasses, and it is not reported from India, but from western countries like the UK and the USA.

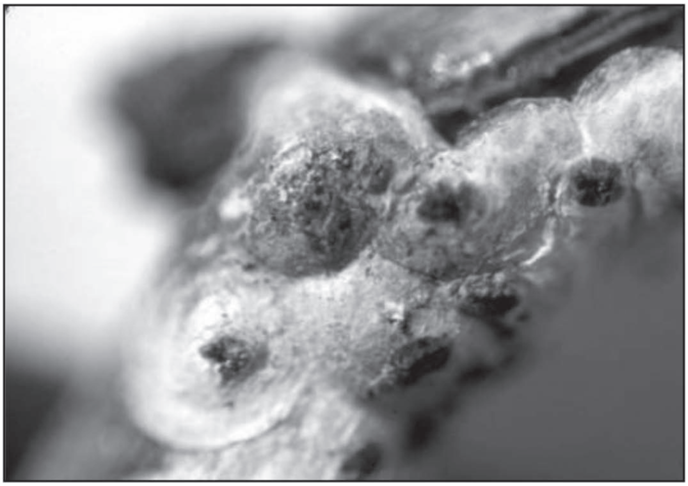

FIGURE 5.5 Rose infestation with scale insects: *Lindingaspis rossi.*

1. **Damage:** Japanese beetles are one of the most important insect pests of roses. It is the adult beetles that cause damage to roses. They are strong fliers and migrate from nearby turf grass, where the larvae develop, to feed on blooms of roses and other tender parts of plants. Japanese beetles cause injury by feeding and disfiguring blooms of buds and flowers that are marketable. They are especially attracted to light-colored blooms.
2. **Management:**
   - Handpicking and destroying beetles is a non-insecticidal method of pest suppression that can be effective in small areas when infestations are light to moderate.
   - Use of protective mesh cages to protect the buds and blooms of especially prized specimens are warranted.
   - Foliar sprays containing azadirachtin repel away from the Japanese beetles from blooms of roses.
   - Imidacloprid, cyfluthrin, cyhalothrin, permethrin are the insecticides proven effective against the Japanese beetles.

5.2.8 SPOTTED CUCUMBER BEETLES

Adults emigrate to roses from larval hosts. The larvae feed on the roots of other plants, but they are not major pests on roses. There are many species of beetles that attack rose blooms by feeding on them, and earwigs too feed on rose blooms.

1. **Damage:** Adult cucumber beetles feed on rose petals. A beetle usually does not cause enough damage to be aesthetically important, unless blooms are ready for cut and sales or exhibition, but blooms can be disfigured by several beetles feeding on the same bloom, simultaneously.
2. **Management:**
   - Acephate, imidacloprid, cyfluthrin, cyhalothrin, permethrin: Foliar sprays of pyrethroid insecticides (cyfluthrin, cyhalothrin, or permethrin) are effective against cucumber beetles and applications can be given when sufficient damage has been affected.
   - Carbaryl is also effective, but is even more likely to flare mites than pyrethroids and is currently being phased out.

5.2.9 CATERPILLARS AND SAWFLIES

Many species of lepidopterous larvae and sawflies occasionally attack roses. Sawflies are the caterpillar-like larvae of a special group of wasps that feed on plant leaves. 'Rose-slugs' are referred to as some of the most common sawflies that attack rose plants. There are actually several species of rose slugs, but few only are major pests.

1. **Damage:** Caterpillars and sawflies result in causing feeding injury on the leaves, resulting in skeletonization or defoliation. Severe defoliation is possible and can interfere with plant growth and development. Sawflies feeding generally lead to skeletonizing leaves. Some species of lepidopterous caterpillars feed as leaf rollers. A few caterpillars, like tobacco budworms and some of the armyworms, feed on the blooms, but this is uncommon (Figure 5.6).

2. **Management:**
   - Hand-picking of larvae can be an effective way to control isolated infestations of caterpillars or rose slugs, especially on small plantings.
   - Acephate, Bacillus thuringiensis, cyfluthrin, cyhalothrin, permethrin, spinosad: Foliar sprays of spinosad are probably the best against caterpillar pests and sawflies, because they are less disruptive of the beneficial insects and mites that help control pest species.
   - *Bacillus thuringiensis* products are also effective against leaf-feeding caterpillars, but not against rose slugs. Because they are slow-acting *Bt* work best when applied to caterpillars that are tiny or small in size.

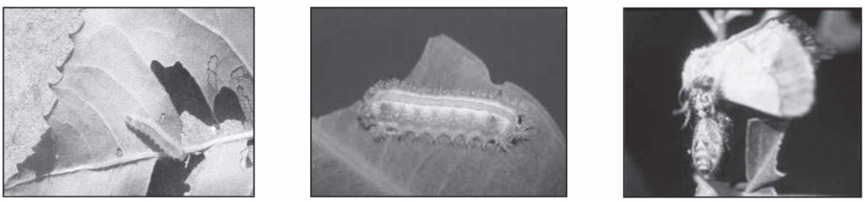

FIGURE 5.6 Rose leaves infestation with caterpillars.

5.2.10 ROSE MIDGE

The adults of the midge are tiny mosquito-like flies. The larvae are legless maggots, only about 1/12 inch long that feed inside the tissue of growing plant tips. Because of size, this insect can be easily overlooked, at least when larvae are young. It is hard to overlook the damage that heavy infestations can cause, but this damage is often not recognized as an insect injury in most of the situations or areas.

1. **Damage:** Maggots of midge cause the damage. They feed at the tips of developing shoots, making them blackened and distorted, and they fail to produce blooms. Heavy infestations can result in greatly reduced bloom production.

2. **Management:**
   - The infested tips of plant parts can be destroyed.

- Imidacloprid @ 0.3 ml/lt can be sprayed on infested plants.
- These insects overwinter as pupae in leaf litter at the base of the plant. A soil drench containing imidacloprid @ 0.3 ml/lt is applied in early spring will control emerging adults before they have a chance to lay eggs.

5.2.11 LEAFCUTTING BEE: MEGACHILE ANTHRACINA

This solitary bee builds nests in hollow stems, reed, or pipes. It stuffs the nests with pieces of leaves that it cuts from various plants and uses this as food for its developing larvae. Rose plants are one of the preferred plants for bees for cutting leaves.

1. **Damage:** Adult bees cut semicircular holes in rose leaves, usually affecting only a few leaves on any one plant. These bees sometimes build their nests in the ends of garden hoses, and gardeners sometimes discover the tightly packed columns of leaf material when they turn on the water.
2. **Management:**
   - Insecticides are ineffective for preventing leaf cutting, bees.
   - Cover susceptible plants with cheesecloth or loose netting for preventing leaf injury damage.
   - Breeding sites of bees should be eliminated.
   - Application of sawdust on the tunnel or thick-stemmed plants with hollowed openings.
   - Rotting wooden boards with sawdust pushed out of excavated tunnels.
   - To prevent leafcutter bees from tunneling into rose canes, seal exposed pith as canes are pruned (Figure 5.7).

5.2.12 FLOWER CHAFER BEETLE: OXYCETONIA VERSICOLOR

An adult beetle is about ½ inch long and has a metallic green body and legs with coppery-brown wing covers. It can be distinguished from similar beetles by the tufts of white hairs that are clearly visible at the end of the abdomen.

1. **Damage:** A number of several species of beetle species feed on roses. Many of the beetles feed mainly on flower buds or open blossoms. But can feed on leaves. Since several beetles feed mainly at night, the gardener rarely sees them, only the damage that they cause.

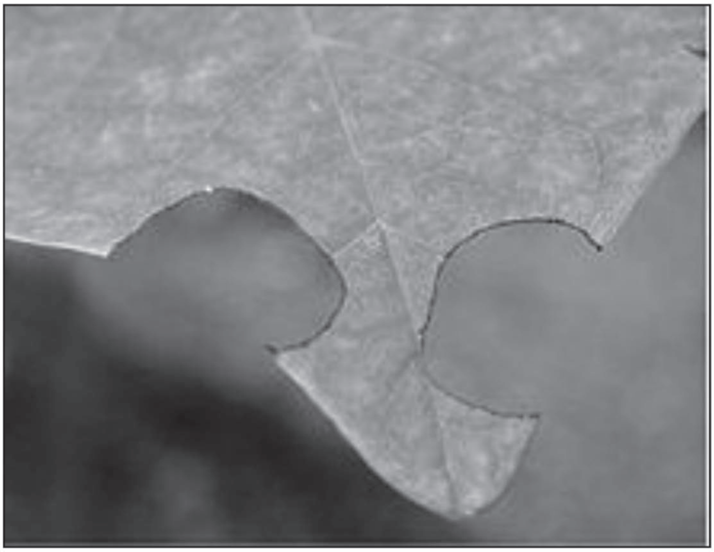

FIGURE 5.7 Leafcutting bee damage, *Megachile anthracina.*

2. **Management:**
   - Hand-picking and destruction of adult beetles.
   - Milky Spore, bacterium (*Bacillus popilliae)* against the grubs can be applied.
   - NSKE 5% or Azadiractin can be sprayed on the affected plants.
   - Soil drenches or granular applications of imidacloprid or dinotefuran, suppresses the beetle numbers (Figure 5.8).

5.2.13 TERMITE (WHITE ANTS) ODONTOTERMES OBESUS

The workers are small and have a soft, white body with a brown head (Figure 5.9).

1. **Damage:** Feed on the roots of young and old plants. Attacks the plants during the dry season due to continuous feed on the stem and bark plant will wither, dry, and ultimately die (Figure 5.9).

FIGURE 5.8 Flower chaffer beetle: *Oxycetonia versicolor.*

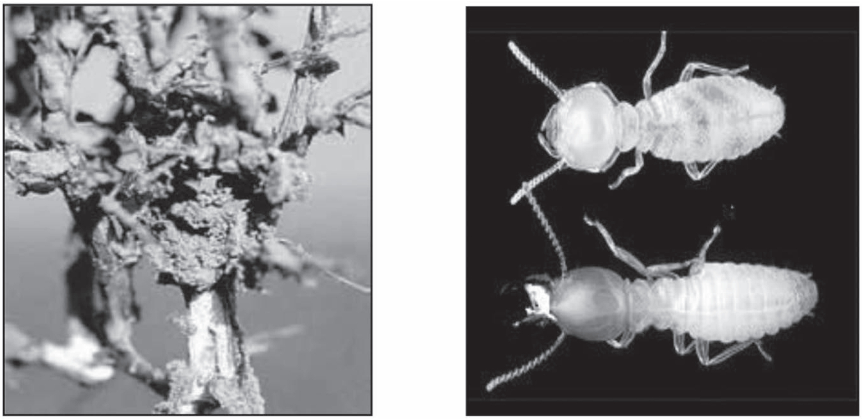

FIGURE 5.9 Termite (White ants) *Odontotermes obesus.*

2. **Management:**
   - Drench the soil with chlorpyriphos or lindane 2 ml/l of water.

5.2.14 BLACKFLY: *ALEUROCANTHUS SPINIFERUS*, *ALEUROCANTHUS ROSAE*

Adults with grayish wing and yellow body.

1. **Damage:** Nymphs and adults suck the sap of the leaves, due to continuous feeding plants show symptoms like crinkling, curling, and puckering of leaves. Black oval puparia are seen on the undersurface of the leaves.
2. **Management:**
   - Spray Fish Oil Resin Soap 25 g/l (or) Neem oil 0.5% (or) Methyl demeton 2 ml/l of water (Figure 5.10).

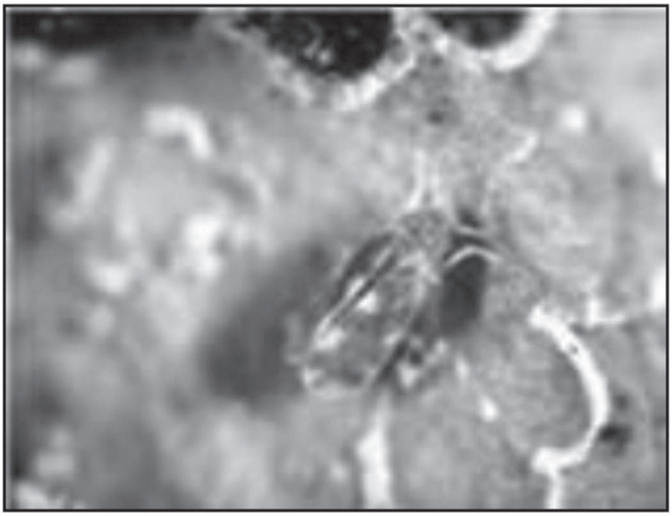

FIGURE 5.10 Blackfly, *Aleurocanthus spiniferus*.

5.2.15 CASTOR SEMILOOPER: *ACHAEA JANATA* L.

Moth-stout, grayish-brown with black blotches on hind wings. Female lays blue-green, rounded, and ridged eggs singly on the leaf. Full-grown caterpillar - smooth, dull grayish-brown with white or brown stripes along the body (Figure 5.11).

1. **Damage:** Caterpillars feed voraciously on the foliage.
2. **Management:**
    - Hand picks grown up larvae and destroy.
    - Spray Chlorpyriphos 1 ml/l of water.

FIGURE 5.11 Castor semilooper: *Achaea janata* L.

5.2.16 GRASSHOPPERS

Grasshoppers are general feeders that feed on the foliage of many kinds of plants.

1. **Management:** Keep weeds and grass near roses under control because these are the breeding sites for grasshoppers. Insecticidal sprays with acephate, bifenthrin, carbaryl, cyfluthrin, lambda-cyhalothrin, malathion, and permethrin or pyrethrin was control grasshoppers.

5.3 CONCLUSION

Roses are popular and demanding landscape plants grown for their beauty. Roses are susceptible to several insects and diseases, which reduce flower growth and quality. In general, the insect pests do not kill the plant, but may stunt or kill parts, affecting flowering, or cause aesthetic damage.

KEYWORDS

- *Aleurocanthus rosae*
- *Aleurocanthus spiniferus*
- **grasshoppers**
- **microscopes**
- **termite**
- **thrips**

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CHAPTER 6

INSECT PESTS OF JASMINE AND THEIR MANAGEMENT

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ABSTRACT

Jasmine is one of the oldest traditional flower grown in India. It is infested by a number of insect and mite pests. The lepidopteran pests like bud borer, *Hendecasis duplifascialis* (Hampson) (Crambidae; Lepidoptera); bud borer/gallery worm, *Elasmopalpus jasminophagus* (Hampson) (Pyralidae: Lepidoptera); and leaf web-worm, *Nausinoe geometralis* (Guenee) (Crambidae; Lepidoptera) are of major importance. Sucking pests like eriophyid mite, *Eryophes* spp (Acarina: Eriophyidae); tingid bug, *Corythauma ayyari* (Drake) (Hemiptera: Tingidae); white fly, *Dialeurodes kirkaldyi* (Kotinsky) (Hemiptera: Aleyrodidae) and flower thrips, *Isoneurothrips orientalis* (Bagn.) (Thysanoptera: Thripidae) cause minor damage to the crop. Dipteran pest like blossom midge, *Contarinia maculipennis* Fabricius (Diptera: Cecidomyiidae) sometimes infests the crop. This chapter outlines brief descriptions of insect pests along with their hosts, life cycle, nature of damage, seasonal incidence and overall integrated pest management.

6.1 INTRODUCTION

Jasmine is one of the oldest fragrant flowers and is especially appreciated in India. Term jasmine is probably derived from the Persian word 'Yasmin' meaning 'fragrance.' Jasmine is considered as the "Queen of fragrance." Jasmines are widely grown in warm parts of southern Asia, Europe, Africa, and the Pacific region. It is the national flower of the Philippines adopted by its government in 1937, and in 1990, the Indonesian government also adopted it as the national flower. Jasmine belongs to the family Oleaceae. The genus *Jasminum* comprises of more than 200 species, mostly tropical in distribution (Abdul Khader and Kumar, 1995). It is exquisitely scented to soothe and refresh, and is one of the oldest fragrant flowers cultivated by man. Jasmine flower is native to India cultivated in 12,250 ha with a production of 65,230 tonnes of loose flowers and 1,700 tonnes of cut flowers. India exports jasmine flowers to the neighboring countries like Sri Lanka, Singapore, Malaysia, and the Gulf. Large quantities of jasmine flowers are used by women folk for adorning their hairs. The flowers are also used for the production of perfumes and attars (Arumugam et al., 2002).

Commercially grown important *Jasminum* species are *Jasminum sambac* (L.) Aiton, *Jasminum auriculatum* Vahl, *Jasminum grandiflorum* L., *Jasminum multiflorum* (Burm. f.) Andrews. In India, Jasmines are cultivated throughout the country. Apart from internal trade, fresh flowers are exported to Malaysia, Singapore, and Srilanka. Since jasmine crop requires a lot of manpower for harvesting and other operations, small farmers can only efficiently cultivate the crop. It is an ideal crop for small farmers. Essential oils of Jasmine are primarily used in the perfumery industry and have a high commercial value due to therapeutic properties. The world-famous jasmine oil is extracted from the flowers of Spanish jasmine, *Jasminum grandiflorum* Linn (Sulong, 2006). The jasmine oil is regarded as unique as it blends well with floral extracts and is highly valued throughout the world. The oil finds a place in soap and cosmetic industries also. Jasmine fragrance is said to give a feeling of optimism, confidence, and euphoria and is helpful against depression, nervous exhaustion, and stress-related conditions. Jasmine is also used for coughs, laryngitis, dysmenorrhea, labor pains, uterine disorders, and many skin problems. Different parts of jasmine-like leaf, stem, bark, and roots are also used for medicinal purposes (Bose and Yadav, 1989).

There are about 90 *Jasminum* species in India (Muthukrishan and Pappiah, 1980), only 20 are cultivated in South India. Among these, *Jasminum sambac* Ait. (Gundu mallige), *Jasminum auriculatum* Vohl. (Sooji mallige), *J. grandiflorum* L. (Jaji mallige) are commercially exploited and other *Jasminum* species, i.e., *Jasminum multifloum* Andr. (Kakada or Bangalore jasmine) is commercially cultivated for cut flower production (Khader and Kumar, 1995).

Jasmine is affected by diseases, insects, mites, and nematodes, which pose a serious threat to jasmine cultivation. Among the insect pests, bud borer, *Hendecasis duplifascialis* (Hampson) (Crambidae; Lepidoptera); bud borer/gallery worm *Elasmopalpus jasminophagus* (Hampson); (Pyralidae: Lepidoptera); and leaf web-worm, *Nausinoe geometralis* (Guenee), (Crambidae; Lepidoptera) cause major damage. The minor pests include jasmine eriophyid mite, *Eryophes* spp (Acarina: Eriophyidae); tingid bug, *Corythauma ayyari* (Drake) (Hemiptera: Tingidae), whitefly, *Dialeurodes kirkaldyi* (Kotinsky) (Hemiptera: Aleyrodidae); shoot webworm, *Margaronia unionalis* (Lepidoptera: Pyraustidae); jasmine bug, *Antestia cruciata* Fabricius (Hemiptera: Pentatomidae); flower thrips, *Isoneurothrips orientalis* (Bagn.) (Thysanoptera: Thripidae); green plant hopper, *Flata ocellata* Fabricius (Hemiptera: Flatidae); brown planthopper (BPH), *Ricania fenestrate* Fabricius (Hemiptera: Ricaniidae) and blossom midge, *Contarinia maculipennis* Fabricius (Diptera: Cecidomyiidae) are minor pests (David, 1958).

Among the different pests attacking jasmine, bud worm, *Hendecasis duplifascialis* Hampson, blossom midge, *Contarinia maculipennis* felt, flower thrips *Isothrips orientalis* Bagnall are the major flower damagers causing greater yield loss. Budworm *H. duplifascialis* causes damage to the extent of 40 to 50%, which eventually reflects on the quality of the flowers and yield loss of up to 30 to 70% (Anonymous, 1984). In India, first report of midge, *Contarinia maculipennis* Felt was made at Bapatla Guntur district (Krishna, Godavari zone) during March 1954 and reported 44% flower bud damage (Rao et al., 1954). Sucking pests like flower thrips *Isothrips orientalis* Bagnall and red spider mites *Teranychus* spp., also inflict injury to jasmine crop reducing the size of flower buds, besides imparting dull coloration, which brings down market value loss. The leaf webworm *N. geometralis* and whitefly *D. kirkaldyi* also infest the foliage. The severity of these pests leads to a reduction in plant vigor, thereby minimizing the vitality of the plants. In recent seasons, many of the jasmine farmers complain about losses due to insect pests. These farmers are guided both by experts and traders to resort to the application of chemical insecticides that are handy tools for pest control. Subsequently, the jasmine farmers started applying insecticides on a scheduled basis. Thus a situation raised that their returns from this crop started dwindling due to high investment on plant protection inputs. Besides, there were a lot of complaints on the out-break of innocuous insect and mite pests in the jasmine ecosystem. In addition, serious cases of pesticide poisoning effects among jasmine crop producers.

6.2 INSECT-PESTS OF JASMINE

- Jasmine Budworm: *Hendecasis duplifascialis* Hampson (Pyralidae: Lepidoptera).
- Jasmine Gallery worm: *Elasmopalpus jasminophagus* Hampson (Pyralidae: Lepidoptera).
- Jasmine Blossom midge: *Contarinia maculipennis* Felt (Cecidomyiidae: Diptera).
- Jasmine Leaf webworm: *Nausinoe geometralis* Guenee (Pyralidae: Lepidoptera).
- Jasmine Eriophid mite: *Aceria jasmini* Chanana (Eriophyidae: Acarina).
- Jasmine Flower Thrips: *Isothrips orientalis* Bagnall (Thysanoptera: Thripidae).
- Defoliator: *Spodoptera litura* Fabricius (Noctuidae: Lepidoptera).
- Redspider mite: *Tetranychus cinnabarinus* Koch (Tetranychidae: Acarina).
- Jasmine Leaf Roller: *Glyphodes unionalis* (Pyraustidae: Lepidoptera).

6.2.1 JASMINE BUDWORM – HENDECASIS DUPLIFASCIALIS HAMPSON (PYRALIDAE: LEPIDOPTERA)

Larva is greenish with pale body hairs and blackhead. Adult has a small white moth with black wavy lines on hind wings and abdomen. Egg is laid singly or in groups of 2–3 on leaves, pupation takes place in soil (Figure 6.1).

Bore holes on bud **caterpillars seen inside the bud** **Infested flower**

FIGURE 6.1 Jasmine bud worm damage symptoms

1. **Life-History and Damage Symptoms:** Freshly laid eggs are round, creamy, and glued to the flower. The duration of egg, larval, and pupal stages of budworm lasted for 4.2, 10.34, and 6.4 days, respectively. The prepupal period on an average lasted for 2.7 days. The total life cycle is completed in 21–29 days.

   The larvae bore into immature buds and feed on the internal contents. The larva feeds voraciously on the corolla leaving only the corolla tube in mature buds. In the case of younger buds, the larva remains outside the buds and feeds on the inner floral whorl through a small hole in the corolla tube. The infested flower turns violet and eventually dries out. A single larva may damage up to 6 flower buds. During a heavy infestation, the adjacent buds along the inflorescence are webbed together by a silken thread.

2. **Management:**
   - Rake the soil during the offseason to expose the pupae and apply carbaryl 10 D around the basin.
   - Apply carbofuran at 40 g/plant basally.
   - Set up a light trap during the peak emergence of adult moths.
   - Collect the damaged pinkish flowers once in a week and destroy to arrest further multiplication.
   - Spray neem seed kernel extract (NSKE) 5% or monocrotophos 36 SL 1.0 L or chlorpyriphos 20 EC at 750 ml or dimethoate 30 EC 500 ml or cypermethrin 25 EC 200 ml in 500–750 L of water per hectare in the evening hours.
   - Conserve larval parasitoids, *Perilampus* sp, *Phanerotoma* sp, and *Mesochrous* sp.

6.2.2 JASMINE GALLERY WORM–ELASMOPALPUS JASMINOPHAGUS (PYRALIDAE: LEPIDOPTERA)

The adult moth is narrow, long, and dark grey with plane hind wings (Figure 6.2).

FIGURE 6.2 Jasmine gallery worm damage symptoms.

1. **Life-History and Damage Symptoms:** Female lays eggs singly on calyx of buds or near the base of the green bud. Larva green in color with dark brown prothoracic shield and brown streak. Pupation takes place on the web itself.

   Caterpillar web together with the terminal leaves, shoots, and flower heads and feed on them. Fecal matter is seen attached to the silken web.

2. **Management:**
   - Rake the soil during the offseason to expose the pupae and apply carbaryl 10 D around the basin.
   - Apply carbofuran at 40g/plant basally.
   - Set up a light trap during the peak emergence of adult moths.
   - Collect the damaged pinkish flowers once in a week and destroy to arrest further multiplication.
   - Spray NSKE 5% or monocrotophos 36 SL 1.0 L or chlorpyriphos 20 EC at 750 ml or dimethoate 30 EC 500 ml or cypermethrin 25 EC 200 ml in 500–750 L of water per hectare in the evening hours.
   - Conserve larval parasitoids, *Perilampus* sp., *Phanerotoma* sp., and *Mesochrous* sp.

6.2.3 JASMINE BLOSSOM MIDGE–CONTARINIA MACULIPENNIS FELT (CECIDOMYIIDAE: DIPTERA)

Adult is a small fly with long slender legs, transparent wings with few veins and an orange-colored abdomen. The maggot is yellowish in color and found inside unopened buds at the base of the tubular corolla. When the bud is opened, the maggot wriggles out actively.

Early instars of maggots were whitish in color and grown-up stages yellowish in color (Figure 6.3).

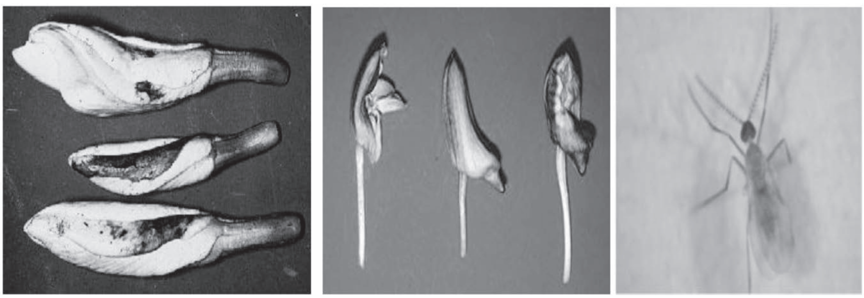

FIGURE 6.3 Feeding damage to flower buds by blossom midge.

1. **Life-History and Damage Symptoms:** The egg period, larval period, pupal period, and whole life cycle lasted for 1–2, 4–5, 7–8, and 13 to 18 days, respectively. The maggots are capable of flipping themselves several inches into the air to exit the buds and burrow into the soil to pupate, like other ground pupating fly larvae.

   The maggots of the blossom midge enter into the buds at the base of the corollas, which results in swelling at the base of the buds. Initially, midge attack to young buds was recognized by light purple discoloration and later turned dark, the infestation leads to stunting and drying of plants.

2. **Management:**
   - Remove and destroy all dropped buds and infested buds still on the plant
   - Spray Thiamethoxam 2.5% WG @ 0.75 g/l or Flufenoxuron @ 1.5 g/l
   - Spraying of Rynaxypyr @ 0.5 ml/l or Novaluron 3 ml/l. of water

6.2.4 JASMINE LEAF WEBWORM: *NAUSINOE GEOMETRALIS* GUENEE (PYRALIDAE: LEPIDOPTERA)

Adult is a medium-sized moth, having light brownish wings with white spots. Caterpillar is green with dark warts (Figure 6.4).

Webbing on leaves

Leaf webber on leaves

FIGURE 6.4 Jasmine Leaf webworm damage symptoms.

1. **Life-History and Damage Symptoms:** Female lays 15–30 greenish-yellow eggs on the leaf lamina, egg period 3–4 days. Larva pupates within the web, larval, and pupal period is 12–15 days and 6–7 days respectively. Life cycle is completed in 22–24 days.

   Caterpillars attack leaves of the plant mostly in the lower bushy and shaded portions. The leaves are webbed in an open and loose manner. The silk threads are seen as a cobweb on the surface of the leaves. Larvae skeletonize the leaves by eating away the parenchyma.

2. **Management:**
   - Use predators include Green lacewings, *Scymnus*, and *Chrysoperla oculata.*
   - Yellow-orange sticky traps @ 5/acre can be used to monitor population
   - Insecticidal soaps or neem oil may reduce population
   - Spray NSKE 5%

- Imidacloprid 2 ml/l or Dimethoate 2 ml/l give season-long systemic control

Acetamiprid 20P @ 80 g ai./ha or neem oil @ 3 ml/l of water

6.2.5 ERIOPHID MITE–ACERIA JASMINI CHANANA (ERIOPHYIDAE: ACARINA)

Female is cylindrical and vermiform with two pairs of legs and measures about 150,160μ long and 44μ thick (Figure 6.5).

FIGURE 6.5 Eriophid mite damage symptom.

1. **Life-History and Damage Symptoms:** Adult females overwinter in cracks and crevices of twigs and in bud scales. Females lay eggs in the spring. The young insects that hatch from the eggs resemble the adult. Numerous generations are produced each year. They are primarily spread by wind.

   Feeding causes felt-like hairy outgrowth (Erineum) on the surface of leaves, tender stem, and flower buds. Makes web, which looks like felt and appears to be a white hairy growth on the leaf surface, tender stems, and flower buds.

2. **Management:**
   - Grow resistant variety Parimullai (TNAU).
   - Remove and destroy mite-infested plant parts.
   - Spray triazophos 1.5 ml/l in combination with neem oil 5 ml/l twice or thrice

6.2.6 JASMINE FLOWER THRIPS: *ISOTHRIPS ORIENTALIS* BAGNALL (THYSANOPTERA: THRIPIDAE)

The adult male is about 1 mm long; the female is slightly larger, about 1.4 mm in length. Males are rare, and are always pale yellow, while females vary in color, often by season, from red to yellow to dark brown. Each adult is elongated and thin, with two pairs of long wings. The eggs are oval or kidney-shaped, white, and about 0.2 mm long. The nymph is yellowish in color with red eyes (Figure 6.6).

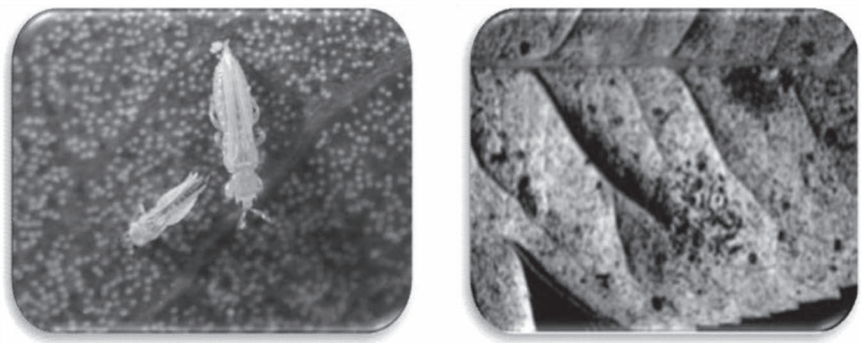

FIGURE 6.6 Jasmine flower thrips *Isothrips orientalis.*

1. **Life-History and Damage Symptoms:** Each female may lay 40 to over 100 eggs in the tissues of the plant, often in flower, but also in the foliage. The newly hatched nymph feeds on the plant for two of its instars, and then falls off the plant to complete its other two instar stages.

   The insect damages the plant in several ways. The major damage is caused by the adult ovipositing in the plant tissue. The plant is also injured by feeding, which leaves holes and areas of silvery discoloration when the plant reacts to the insect's saliva. Nymphs feed heavily on new flushes just beginning to develop from the flower.

2. **Management:**
   - Use natural enemies (NEs) include pirate bugs of genus *Orius*. and the mirid *Dicyphus hesperus*
   - Spray NSKE 5% or dimethoate 30 EC 2 ml/l or methyl demeton 25 EC 2 ml/l.

6.2.7 DEFOLIATOR–SPODOPTERA LITURA FABRICIUS (NOCTUIDAE: LEPIDOPTERA)

The moths are about 22 mm long and measure 40 mm across the spread wings. The forewings have a beautiful golden and grayish-brown pattern. The caterpillars are velvety black with yellowish-green dorsal stripes and lateral white bands (Figure 6.7).

FIGURE 6.7 Defoliator *Spodoptera litura.*

1. **Life-History and Damage Symptoms:** The female lays about 300 eggs in clusters. These clusters are covered over by brown hair, and they hatch in about 3–5 days. Larvae pass six stages and are full-fed in 15–30 days. The full-grown larvae enter the soil where they pupate. Pupal stage lasts 7–15 days and moths start emergence live for 7–10 days. The life cycle completed in 32–60 days.

   Larvae feed on leaves and fresh growth. They are active in the night and cause extensive damage, which leads to defoliation.

2. **Management:**
   - The larvae of this insect are parasitized by *Apanteles glomeratus* in natural populations.
   - Handpicking and mechanical destruction of caterpillar during the early stage of attack can reduce infestation.
   - Spray 1-liter malathion 50EC per ha.
   - Repeat spraying at 10 days interval (DI) if necessary.

6.2.8 REDSPIDER MITE–TETRANYCHUS CINNABARINUS KOCH (TETRANYCHIDAE: ACARINA)

Both nymphs and adults are red in color. The overall body shape and the pattern of pigmentation spots on the back. The dark green spots are caused by food particles that accumulate in their gut (Figure 6.8).

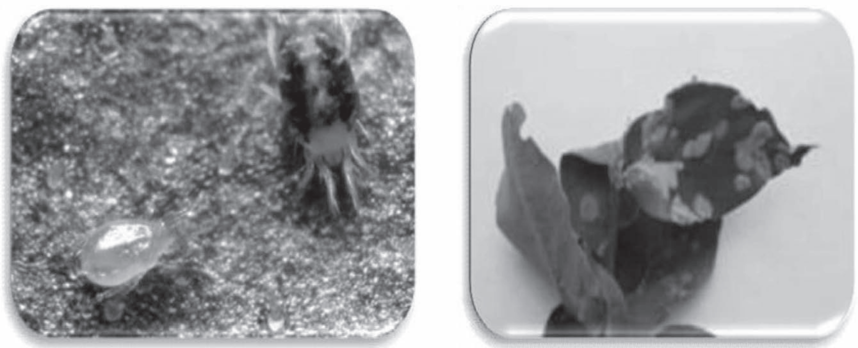

FIGURE 6.8 Red spider mite damage symptom.

1. **Life-History and Damage Symptoms:** Eggs are laid on ventral surface of leaves and are whitish and spherical. Female lays 200 eggs. Egg period is 4–7 days. Larval and pupal period lasts for 3–5 and 8–12 days, respectively. Life cycle is completed in 15–20 days. There are 15 generations/year.

   Damage Mites feed on the undersurface of leaves and are found covered with silken webs. As a result of feeding, yellow spots appear on the upper surface of leaves and gradually turn reddish infested leaves wither away.
2. **Management:**
   - Remove and destroy the webbed and damaged leaves along with mites.
   - Spray dicofol 18.5 EC 1.5 L or wettable sulfur 40 WP 3.75 kg in 500–750 L of water per ha.

6.2.9 JASMINE LEAF ROLLER–*GLYPHODES UNIONALIS* (PYRAUSTIDAE: LEPIDOPTERA)

The leaf roller is brown with three dark bands on the front wings. Wing-spread is about one inch. Larva is small and green with blackheads. Larva is green, slender, and will reach a length of about 2/3 inch (Figure 6.9).

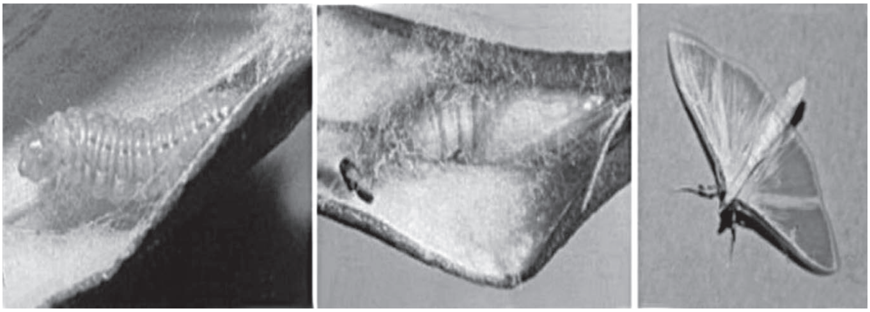

FIGURE 6.9 Damage symptom of Jasmine leaf roller.

1. **Life-History and Damage Symptoms:** Adults emerge in early spring and lay eggs in masses on undersides of leaves. Egg hatch occurs at about bloom. Newly hatched larvae fold or roll leaves together with webbing and feed on foliage. There are two to four generations each year. Hatching will occur about the time buds begin to open. Larvae feed on buds, blooms, leaves, and fruits. In June, full-grown larva transform into pupae, inside folded or rolled up leaves. Moths appear in about two weeks, lay their eggs, and die**.** Larvae are defoliators, feeding only on leaf tissue of legumes. Initially, the larva cuts a small, triangular patch at the edge of the leaf, folds over the flap, and takes up residence within this shelter. The larva leaves the shelter to feed, and lines the shelter with silk. These flaps are used until the third or fourth instar, when the larva constructs a larger shelter formed by folding over a large section of the leaf by webbing together two separate leaves. Again, the leaf fold is used for shelter, the larva leaving to feed.
2. **Management:**
   - NEs help to keep leaf roller at low, non-damaging levels certain Tachinid flies and Ichneumonid wasps, which parasitize the larvae.

- Microbial insecticide *Bacillus thuringiensis*, which is effective against the larval stages of leafroller.
- Insecticidal soaps or neem oil may reduce the population.
- Spray chlorpyriphos 20 EC at 750 ml/ha.

6.3 CONCLUSION

Insect pests are one of the major biotic factors, which contribute to major economic losses both quantitatively and qualitatively. The insect pests attack different growth stages of the crop. Over the decades, continuous and indiscriminate use of synthetic chemicals has resulted, not only in the problems of resurgence and resistance. A few sets of practices have been standardized for commercial application, and provide better pest control and crop economics than the conventional chemical control when used in conjunction with other pest control measures. The strategy is often referred to as 'IPM.' Recently new technologies and practices in IPM offer better protection against insect pests, improve crop yields, and net benefits to the farmers. Our ancestors, though not having the benefit of scientific evaluation, still had adequate common sense and over the centuries, have evolved many indigenous practices that may seem to us primitive in the era of insect pest management.

KEYWORDS

- ***Contarinia maculipennis***
- **dysmenorrheal**
- **insect pests**
- **jasmine**
- **Lepidoptera**
- **prepupal period**
- **thrips**

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CHAPTER 7

NEMATODE PEST PROBLEMS OF TUBEROSE

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ABSTRACT

Among the biotic stress factors in the cultivation of tuberose, plant-parasitic nematodes are one of the major constraints. Root-knot (*Meloidogyne* spp.) and foliar (*A. besseyi*) nematodes are considered as the most devastating nematode pests of tuberose. An infestation of nematode affects the quantity and quality of flowers. Severe distortions due to foliar nematode in the above-ground parts of tuberose induce floral malady, and the affected flower often becomes unmarketable. Root-knot nematodes typically produce root galls or swelling, and the infected plant suffers maximum when *Fusarium*-*Meloidogyne* concomitantly develops disease complex conditions. Nematode problems of tuberose are difficult to control because of the non-availability of effective nematicides, targeted control of harmful nematodes in the subterranean habitat, long duration of cropping period, and adaptive biology of nematodes. Several attempts have been made for the control of root-knot nematodes by application carbofuran, vesicular-arbuscular mycorrhiza (VAM), oilcakes of neem, pongamia, and castor either alone or in combination with *Purpureocillium lilacinum* (PL) and combined application of PL + *Trichoderma harzianum* under disease complex conditions. The adoption of resistant/tolerant cultivars of tuberose has been found effective for the control of foliar nematode, but managing root-knot in tuberose is still challenging. Integration of several approaches helps to reduce the nematode infestation and to harvest quality flowers.

7.1 INTRODUCTION

Tuberose (*Polianthes tuberosa* L.) is of Mexican origin, and it is commercially cultivated for its fragrance, white waxy loose flower, cut flower, and for extraction of essential oils. The crop is propagated by daughter bulbs from older mother bulbs. This vegetative means of propagation make the crop conducive for the spread of many pests and diseases. The commercial cultivation of tuberose is confined in West Bengal, Orissa, Maharashtra, Karnataka, and Tamil Nadu. Phytoparasitic nematodes are easily spread through daughter bulbs as planting material. Several studies have confirmed the occurrence of many phytonematode species (*Meloidogyne incognita*, *M. javanica*, *Rotylenchulus reniformis*, *Helicotylenchus* spp., *Tylenchorhynchus mashhoodi*, and *Hoplolaimus indicus*) around the rhizosphere of tuberose (Khan *and* Pal, 2001; Saha *and* Khan, 2016a). However, the most economically important nematodes are root-knot (*Meloidogyne* spp.) and foliar (*Aphelenchoides besseyi*) nematodes (Saha *and* Khan, 2016b). An infestation of nematode can cause quantitative and qualitative losses. The infection of *M. incognita* induces severe root galling in tuberose (Rao *and* Singh, 1976). All the three species viz., *M. incognita*, *M. javanica* and *M. arenaria* are pathogenic to the crop (Sundarababu *and* Vadivelu, 1987, 1988; Das *and* Mohanty, 1996; Kumar, 2000; Kumar et al., 2001) and considered as the major limiting factors for successful cultivation of tuberose in Tamil Nadu (Sundarbabu *and* Vadivelu, 1988). *M. incognita* causes reduction in plant height (13%), number of flowers (10%), spike length and weight (14%), and number of bulbs (29%) (Reddy *and* Rao, 2001). The concomitant infection and high frequency of occurrence of *M. incognita*, *M. javanica*, and *Rotylenchulus reniformis* have been reported from Karnataka and West Bengal (Khan *and* Pal, 2001). Besides root-knot nematode, pathogenic potential of *R. reniformis* is also a pathogen of tuberose (Mohanty *and* Das, 1995). The combined attack of *M. incognita* and a mite species (*Tyrophagus putrescentiae*) developed a complex symptom on tuberose (Ganguly et al., 1993). The foliar parasitic nematode, *Aphelenchoides ritzemabosi* in Venezuela and *A. besseyi* in Hawaii (Holtzmann, 1968), in West Bengal (Chakraborti *and* Ghosh, 1993, Khan et al., 1999), and Orissa of India (Khan, 2006a, b) and Mekong Delta of Vietnam (Cuc *and* Pilon, 2007) are potential concerns for profitable cultivation of tuberose. Among the phytoparasitic nematode, root-knot (*Meloidogyne* spp.) and foliar (*A. besseyi*) nematodes are considered as the most devastating nematode pests of tuberose.

7.2 FOLIAR NEMATODE, *APHELENCHOIDES BESSEYI*

The area under tuberose in India is estimated to be about 20,000 ha, out of which 8,000ha is cultivated in West Bengal. The state still ranks first in both area and production. Its commercial cultivation in West Bengal was started in the second half of the 19th century to meet the aesthetic needs of the English people harbored in Calcutta. Currently, the cultivation of tuberose is mainly confined in Kolaghat-Panskura, Ranaghat, Rajarhat, and Haringhata areas of West Bengal. The foliar nematode, *A. besseyi* is now a serious problem in tuberose in West Bengal and the disease, 'floral malady' induced by the nematode species is recorded the first time from Ranaghat areas of Nadia district of West Bengal (Chakraborti *and* Ghosh, 1993) in India. This nematode species is also a major problem in the Mekong Delta of Vietnam, where the tuberose crop is severely damaged or completely destroyed (Cuc *and* Pilon, 2007). It is now a major limiting factor for the cultivation of tuberose in Ranaghat and Haringhata regions of Nadia, Rajarhat of 24-Parganas (North), Bangaon of 24-Parganas (South) and some pockets of Howrah and Midnapore districts of West Bengal. The high population of *A. besseyi* is also recorded from the fields of Kolaghat-Panskura-II of Midnapore district. The 'Calcutta Single' cultivar of tuberose is most vulnerable to nematode damage as compared to 'Calcutta Double' cultivar. The nematode species causes a severe infestation of tuberose and induces malformed flowers (Khan et al., 1999, 2001). The populations of *A. besseyi* causing 'white tip disease' in rice are the same population infecting tuberose and causing floral disease (Khan, 2001). The foliar nematode is now a key nematode pest of tuberose, and it causes yield losses to the extent of 59% in West Bengal (Pathak *and* Khan, 2009). An infestation of foliar nematode is a potential threat for the cultivation of tuberose in West Bengal and Orissa of India (Khan, 2006c) and Mekong Delta of Vietnam (Cuc et al., 2010).

7.2.1 SYMPTOMS

The disease incidence of foliar nematode in tuberose (cv. Calcutta Single and Calcutta Double) is estimated on a 0–4 scale (Plate 7.1): 0 (no malady symptoms on flower stalk); 1 (distortions at basal part of flower stalk but exhibit flower bloom); 2 (entire flower stalk exhibit distortions but few flowers bloom at the tip); 3 (entire flower stalk distorted but no flower bloom) and 4 (complete sterility of flower stalk or blind head) (Khan, 2004). While Cuc et al., (2010) also proposed to estimate disease severity of foliar nematode into four categories: DS1 (normal plant height, slightly short panicle compared to healthy plants, some flowers fail to open); DS2 (short plant height, short panicle, many flowers fail to open); DS3 (very short height, very short panicle, many flowers fail to open); DS4 (very short height, very short panicle, flowers buds fail to develop, severe browning of stems, leaves, and buds). Early symptoms are rather restricted to small water-soaked spots near the midrib. These spots enlarge along the midrib, causing elongated, black, greasy spots measuring from 2 to 6 inches long and finally cause the leaf to bend, wilt, and dry. Nematodes are usually found in great abundance at the margin of the spots (Trujillo, 1968). However, in Indian conditions, the diseased flower is characterized as a floral malady of tuberose (Chakarborti *and* Ghosh, 1993). The foliar nematode infected tuberose flower stalk initially appears rough, stalk becomes crinkled, stunted, and finally distorted (Plate 7.2), and in severe cases, flower buds fail to bloom. These brown streaks appear on leaf bracts and petals and subsequently develop rusty brown spots. The severely infected flower stalk becomes rotten and brittle over-drying, even gets blind-head. The nematode, *A. besseyi* remains in masses forming 'nematode wool,' which could be easily recovered from dark brown spots (Khan *and* Pal, 2001). The ovary contains a large number of nematodes. Nematode infection induces midrib necrosis later to form black greasy leaf streaks and snapping under wet weather conditions; the atmospheric temperature of 28.5°C–29.6°C and relative humidity of 83.5–86.5%. Infected flower stalks exhibit stunting, crinkling, distortion, and stalk often fail to open depending upon the varying degree of necrosis and discoloration (Das et al., 2011a).

This nematode is more serious during the rainy season generally from July to September, and cent percent loss of second-year crop occurs particularly in tuberose cv. 'Calcutta Single. However, in the cv. 'Calcutta Double, 30–40% flower stalk rendered unmarketable and individual flower stalk contained up to 45,000 nematodes (Khan 2004, 2006b). Das et al., (2011b) observed the pathogenic potential of *A. besseyi* in tuberose; the initial inoculum density of 100 nematodes/plant was considered for a pathogenic significant reduction in plant height, number of spike and overall flower yield of tuberose.

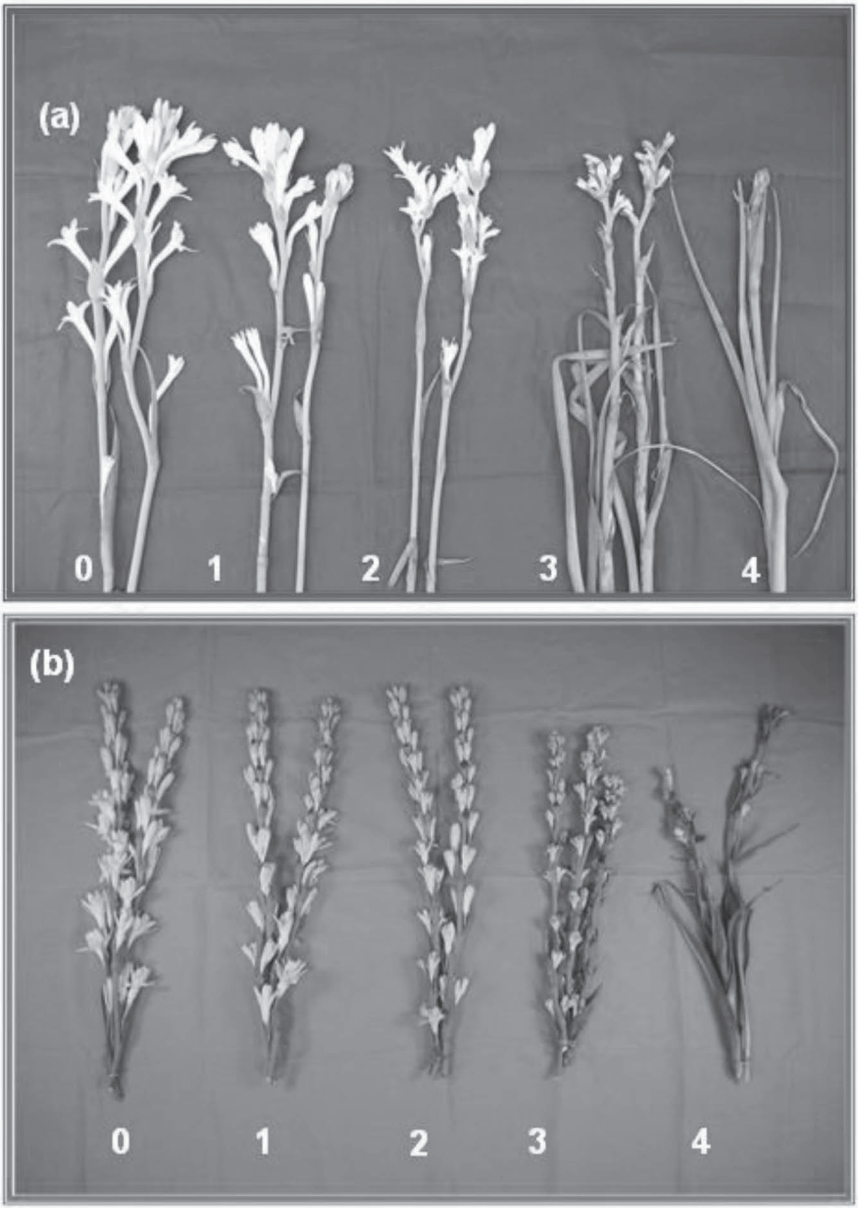

PLATE 7.1 (See color insert.) Rating scale on a 0–4 scale (a) Calcutta single (b) Calcutta double.

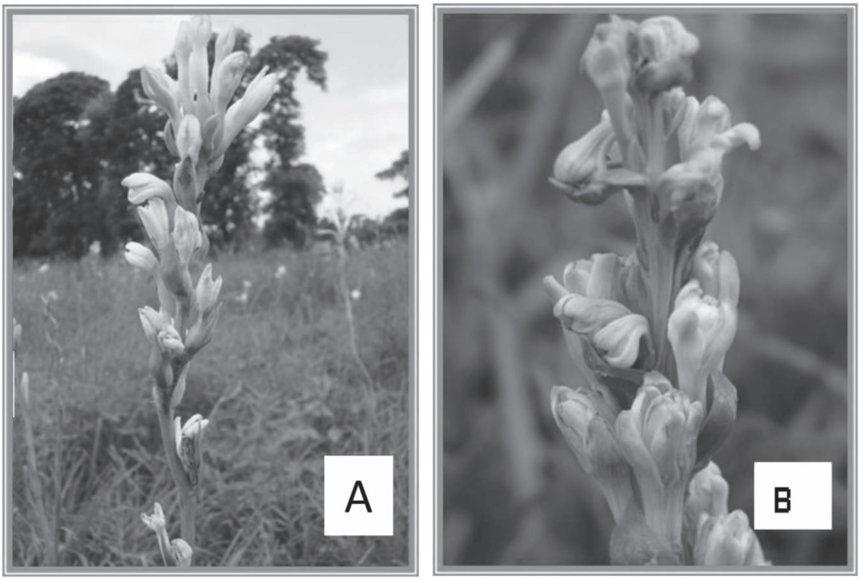

PLATE 7.2 (See color insert.) Distortion of (a) Calcutta single, and (b) Calcutta double due to infection of *Aphelenchoides besseyi.*

7.2.2 BIONOMICS

The nematode is a foliar ecto- and endoparasite on tuberose. *Aphelenchoides besseyi* primarily disseminates through infested bulbs, dry plant parts, run-off, and irrigation water from one field to other fields. The nematode survives in coiled anhydrobiotic condition (quiescent pre-adult and adult stages) in the scaly leaves outside the bulbs. The nematode can also survive in all stages (eggs, juveniles, and adults) on the flower stalk of tuberose. It takes 10–12 days to complete the life cycle at 30°C (Khan *and* Ghosh, 2009). The nematode can also survive in the dried scaly leaves, stems, and flowers more than 25 months; however, they cannot survive in soil under field conditions (Khan, 2004; Khan *and* Ghosh, 2011a). The nematode is a serious problem in areas where rice and tuberose are cultivated in the cropping sequence. The association of two fungi, *Fusarium oxysporum*, and *Alternaria alternata* are with the floral malady in tuberose (Chakraborti *and* Ghosh, 1993); however, they do not play any role in the development of typical foliar disease in tuberose (Khan, 2004).

The peak period of multiplication occurs during March to August under West Bengal conditions, but the least multiplication occurs during winter months. The temperature and RH (relative humidity) influenced the nematode infestation in tuberose. The nematode maintains high population (1084–2768 per flower stalk) during July-November (at a temperature of 25°C–33°C) and the lowest population (87 per stalk) in the month of January (at a temperature of 10°C–26°C) in tuberose (Khan, 2004). A significantly positive correlation between canopy temperature (y = 77.721x–835.57), RH (y = 53.645x–2528.7), dew deposition (in summer), and nematode population was found (Figures 7.1–7.3). The incident and reflected PAR (photosynthetic active radiation) above the crop canopy showed a significant negative correlation and nematode population after 2 weeks lag. Further, the high CGR (crop growth rate) and LAI (leaf area index) value obtained in the treated plots of nematode infested fields than that of untreated plots. The canopy temperature of nematode infested plants is higher than that of healthy crops, and morning dew deposition is significantly correlated with nematode infestation. Further, dew deposition at 7 days lag phase is considered as a good indicator for predicting the nematode population in tuberose (Chowdhury et al., 2010).

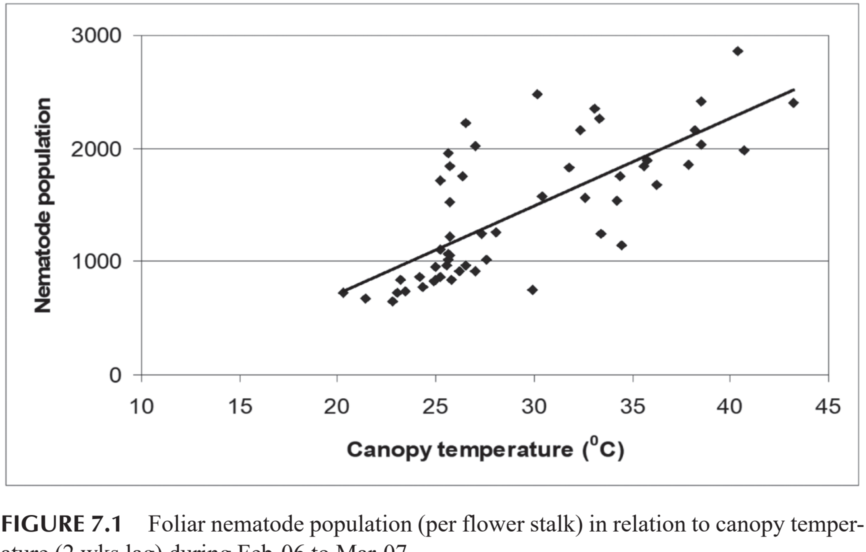

FIGURE 7.1 Foliar nematode population (per flower stalk) in relation to canopy temperature (2 wks lag) during Feb-06 to Mar-07.

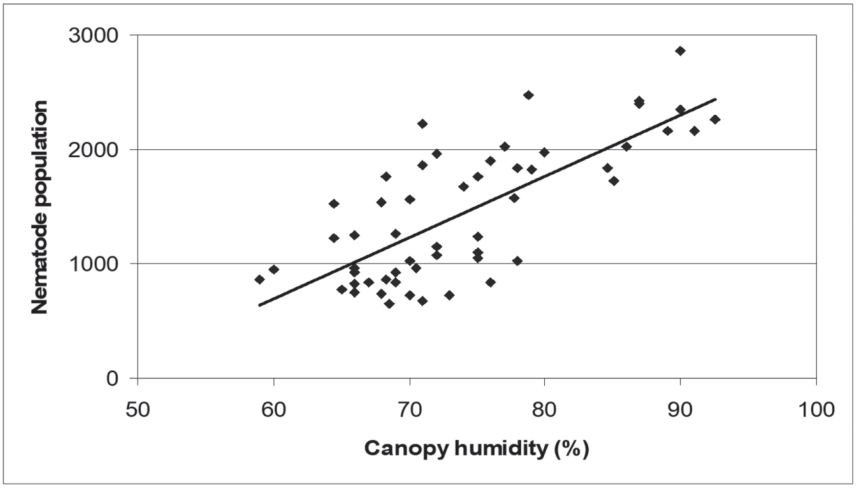

FIGURE 7.2 Foliar nematode population (per flower stalk) in relation to canopy humidity (2 wks lag) during Feb-06 to Mar-07.

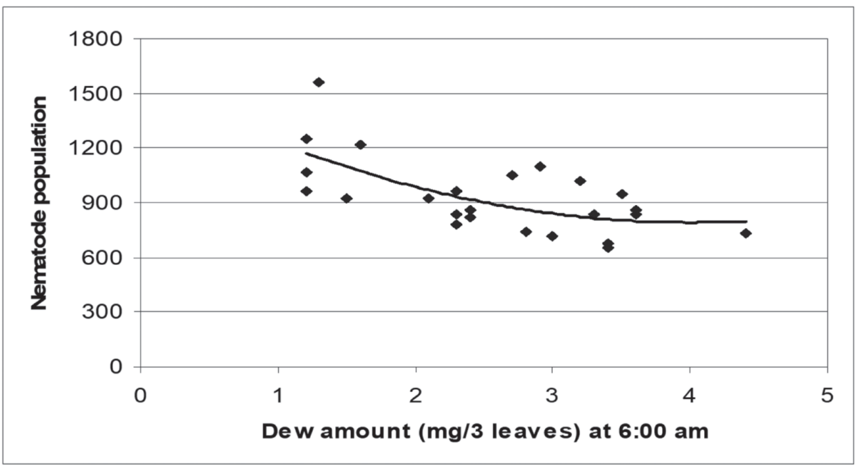

FIGURE 7.3 Trend of foliar nematode population (per flower stalk) as related to the amount of dewfall (2 wks lag) during Feb ’06 to Mar ’07.

The population dynamics of *A. besseyi* on tuberose has been investigated under West Bengal and Orissa conditions. In West Bengal, the high population of *A. besseyi* coincides with active growth growing periods (April-July) and low population when crop enters senescence during

September to December (Khan *and* Ghosh, 2011). While Bala et al. (2016) observed the maximum population during July to September, the period coincides with a good flush of flowers and a minimum during December to February when average temperature, RH with scanty rainfall. In Orissa, *A. besseyi* population remains low during December and January, further rises from May to August and then declines (Das *and* Swain, 2013).

7.2.3 MANAGEMENT

Several chemicals like nuvacron (monocrotophos) at 0.15% and met acid (parathion-methyl) at 0.15% have been found effective to control foliar disease in tuberose (Chakraborti, 1995; Khan et al., 2002, 2006, 2008). The monocrotophos 36SL proved to be highly effective against *A. besseyi* in rice (Kumar *and* Sivakumar, 1998). The field efficacy results of carbosulfan 25EC at 750 ppm, cartap hydrochloride at 700 ppm, NSKE 10,000 ppm, and *Pseudomonas fluorescens* at 2 g/l of water are found in decreasing order. However, in terms of cost-benefit ratio, the order of choice is *P. fluorescens* at 2 g/l of water > NSKE 10,000 ppm at 2 ml/l of water > carbosulfan 25 EC at 750 ppm > cartap hydrochloride 50 SP at 700 ppm (Pathak *and* Khan, 2010). Among the other chemicals, carbosulfan 25EC at 0.1% (Chakraborti, 1995) and cartap hydrochloride at 1.5 g/l of water and neemazal 1% at 2 ml/l (a neem-based formulation) are effective as bulb treatment for disinfection of *A. besseyi* (Khan et al., 2009). The foliar application of Pongamia oil (nomite) and neemazal 1% (azadirachtin) along with bulb treatment and foliar spraying with benomyl, carbosulfan, metacid, and monocrotophos are also effective against the nematodes (Khan et al., 2006, 2008).

The hot-water treatment (HWT) of bulb is most effective for managing the foliar nematode (Khan et al., 2002, 2005a). The thermal death point of *A. besseyi* is 48 ± 2°C for 5 minutes while the tolerance of the bulbs is 50 ± 2°C for 30 minutes for germination to temperature (Khan et al., 2005a; Khan *and* Ghosh, 2011b). The pre-soaking of bulbs overnight followed by HWT at 50°C for 30 minutes + dipping of bulbs in monocrotophos 36SL in 500 ppm for 6 hours + two sprayings with monocrotophos 36SL at 500 ppm in first, second, and the third year of crop with three sprayings with monocrotophos 36SL at 500 ppm at 15 days interval (DI) effectively reduced foliar disease, suppressed nematode population and yielded quality flowers (Khan et al., 2005b). Integration of bulb treatment (presoaking overnight followed by HWT at 50°C for 20 minutes) and 2–3 foliar spraying with monocrotophos 36SL at 0.15% at 30 DI effectively controlled (Khan *and* Ghosh, 2009). The HWT consisting of soaking bulbs in water for 30 minutes at 57°C is the most efficacious method to protect tuberose from *A. besseyi* and to produce healthy flowers in a cost-effective manner in Mekong Delta of Vietnam (Cuc et al., 2010). Dipping of bulbs in carbosulfan 25EC at 0.05% reduces nematode infestation and population in fields. Pre-soaking of bulbs followed by dipping in carbosulfan 25EC at 0.05% for 30 min to 1 hr can be effective to control foliar nematode and harvesting quality flowers (Bala et al., 2016).

Among the varieties of tuberose tested (Shringar, Calcutta Single, Calcutta Double, Hyderabad Single, Hyderabad Double, Suvasini, Vaibhav, Prajwal, and Phule Rajani), Prajwal, and Shringar are tolerant to *A. besseyi* (Khan *and* Ghosh, 2007, 2009). The following strategy for managing foliar nematode in tuberose has been developed (Khan, 2006a, b):

- The planting material (bulbs) should be soaked overnight either in plain water or in 5% neem-seed-kernel-extract (home preparation from locally available neem) or dipping of bulbs in monocrotophos 36SL at 500ppm for 6 hours.
- After sprouting of the bulb, 3 to 4 sprays with monocrotophos 36 SL at 500ppm at 15 to 20 DI should be given.
- In the second and third-year crop, spray with monocrotophos 36 SL at 500ppm at 15 to 20 DI starting from the month of May onwards to reduce the nematode infestation.
- Clean cultivation of tuberose and any infested parts of plants found in the field should be removed and burnt immediately.
- Growing tolerant cultivars Prajwal, Phule Rajani, and Shringar of tuberose.

7.3 ROOT-KNOT NEMATODES, *MELOIDOGYNE* SPP.

Root-knot nematode (*Meloidogyne* spp.) infects a large number of crops and has widespread distribution across the world. *Meloidogyne* spp. is an important nematode pest of tuberose and is one of the major factors for 'tuberose decline' in India (Jayaraman et al., 1975). Both *M. arenaria* and *M. incognita* (Mohanty *and* Das, 1996) are potential pathogens of tuberose. The infected plants' root system displays swelling and galling. The symptoms of root-knots or galls are almost similar to those described for other crops infected with the nematode. The affected plants are usually stunted, and leaves become yellow at the tip when the root system is heavily infested with nematode gall (Plate 7.3). The planting material (bulb) infected with the nematode spread the nematode one place to another, and even the soil adhered with the bulbs are also contaminated with the nematode. In fact, the symptoms produced on the freshly planted crop by the population which emerged from the infected tubers and contaminated soil. The nematode affected plants exhibit yellowing, drying up of leaves, and retarded growth. The emergence of the spike is also suppressed in the severally affected plant. *M. incognita* causes a severe reduction to the extent of 65% of the top growth of plant at the high population level (Sunderababu *and* Vadivelu, 1988b). The crop suffers extensively from *Fusarium*-*Meloidogyne* disease complex when two pathogens occur concomitantly (Shylaja, 2004).

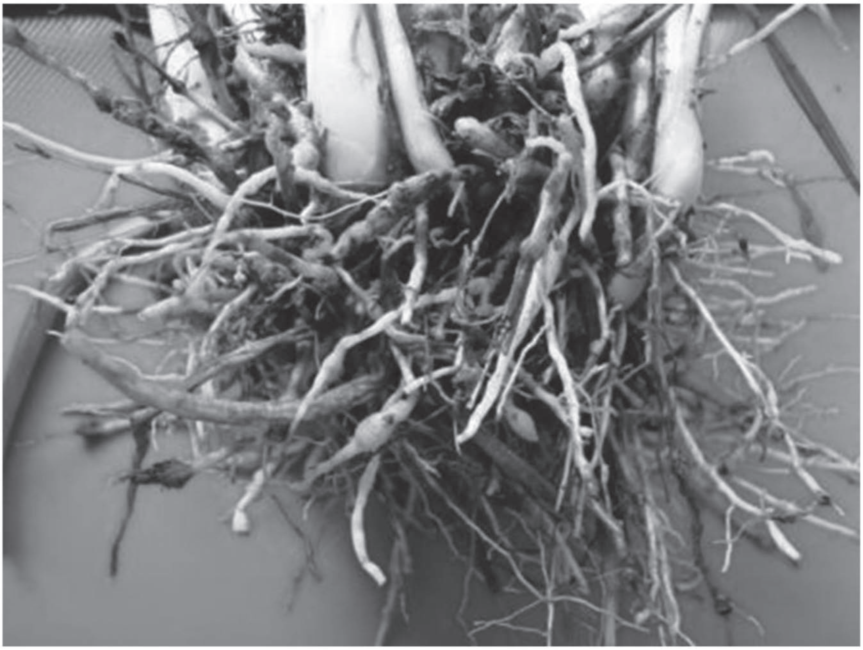

PLATE 7.3 (See color insert.) Tuberose (cv Calcutta single) infected by *Meloidogyne incognita.*

7.3.1 MANAGEMENT

The treatment of nursery beds with carbofuran or phorate at 60g/m^2 is effective (Parvatha Reddy *and* Rao, 2001). Soil application of neem cake at 1t/ha or carbofuran 3G at 2g/plant is also effective to manage the nematode (in Parvatha Reddy, 2008). Tuberose cv., Shringaris reported to be resistant and cv. Suvasini as tolerant to *M. incognita* (Nagesh et al., 1995). Use of VAM, oil cakes of neem, pongamia, and castor either alone or in combination with *P. lilacinum* (egg parasitic fungus) is effective to manage root-knot nematode problems in tuberose (Nagesh et al., 1998). Soil application of *Pochonia chlamydosporia* + *Trichoderma harzianum* (Shylaja, 2004) or *P. lilacinum* + *T. harzianum* (in Parvatha Reddy, 2008) is effective to disease complex in tuberose. Tuberose genotypes Shringar, Suvasini, Prajwal, and Phule Rajani contained high phenol and polyphenol oxidase (PPO) activities when infected by *M. incognita* as compared to healthy ones. The high phenol and PPO activities imparted resistant response against *M. incognita* race 2. While infected Calcutta single, Calcutta double, Vaibhav, and Hyderabad double displayed low phenol and PPO activity over healthy ones and, therefore, categorized as susceptible (Saha *and* Khan, 2017a). The application of bioformulation of *P. lilacinum* @ 5kg enriched with FYM 5t/ha was found to be most effective and economic for reduction of root-knot nematode infestation, nematode population, and enhancement of cut-flower yield of tuberose. The application of *T. harzianum* @ 5kg with FYM 5t/ha was also comparable to carbofuran @ 1 kg a.i./ha for root knot nematode management in tuberose. Further, they demonstrated the efficacy of a single application of bioformulations against *M. incognita* infecting tuberose (Saha *and* Khan, 2016b).

7.4 SUMMARY AND CONCLUSIONS

Phytonematode is one of the potential biotic constraints for the cultivation of bulbous ornamental crops, including tuberose. Root-knot (*Meloidogyne* spp.) and foliar (*A. besseyi*) nematodes are considered as the most devastating nematode pests of tuberose. An infestation of nematode affects the quantity and quality of flowers. Root-knot nematodes are a root endoparasite, typically induce root-knot or root gall affecting plant health. Nematode affected plants are reduced in height; they produce a reduced number of flowers and bulbs, and small size of spikes. The crop suffers maximum when *Fusarium-Meloidogyne* concomitantly develops disease complex conditions. The foliar nematode (*A. besseyi*) is an above-ground parasite typically produce floral malady. Infected plants develop symptoms initially as leaf spot, and more severe rusty brown spot appears on floral stalk and flowers. In case of severe infestation, the flower stalk deformed as twisted or crinkled, and often becomes blind, which bears no blooms. Nematode problems of tuberose is difficult to control for many reasons; non-availability of effective nematicides, targeted control of harmful nematodes in the subterranean habitat, long duration of cropping period, and adaptive biology of nematodes are considered as most important. Control of root-knot nematodes has been recommended by application carbofuran/phorate 60g/m^2 or 2g per plant, VAM, oilcakes of neem, pongamia, and castor either alone or in a combination of PL and combined application of PL +*Trichoderma harzianum* under disease complex conditions. Control of foliar nematode in tuberose has also been tried with several chemicals, botanicals, and biopesticides. However, this nematode has a different adaptive biology to overcome conventional approaches. The nematode species is a short-lived animal in soil and highly sensitive to water stress and flooded conditions in the soil environment. The primary source of nematode infection and contamination of the field is infected bulbs of tuberose. In storage conditions, nematode undergoes anhydrobiosis and remains in a quiescent state. The activation of nematode and killing them either by hot-water (at least 50C for 10minutes) or chemical (monocrotophos as bulb treatment 700ppm per liter of water for 4–6 hours) before planting of bulbs is crucial to prevent nematode to reach in the field. No practice is cent percent perfect; adoption of this cannot completely eliminate nematode from the bulbs. Therefore, field inspection and destruction of infected leaves, flower stalk, and even the entire plant are considered as good practices. Along with this, 2–3 foliar sprays with monocrotophos 36SL (500–700ppm per liter water) at 15 DI during early growth stages reduces nematode infestation in tuberose. The nematode prefers moist and hot-humid weather conditions and multiplies relatively faster during March-August under West Bengal conditions and mostly remains at a very low population in the field. The problems of managing foliar nematode in the second year crop are much more challenging and entirely depend on the maintenance of the field sanitation and crop management practices. As a prophylactic measure, 3–4 sprays from (March onwards) with monocrotophos at 500ppm at 15DI is useful to ward off nematode and reduce a load of carryover population during peak flowering period of the crop. However, the more promising approach is the cultivation of field tolerant cultivar Prajwal or relatively less susceptible cultivars like Shringar and Phule Rajani.

KEYWORDS

- **bionomics**
- **endoparasite**
- **monocrotophos**
- **nematode**
- **symptoms**
- **tuberose**

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CHAPTER 8

ROLE OF CLIMATE CHANGE ON INSECT PESTS OF COMMERCIAL FLOWERS

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ABSTRACT

Arthropods, including insects, serve as effective benchmarks of global warming on different floriculture based ecosystems. Spatial-ships in the cultivation pattern of the flower crops influences the spread of insect pests. The oviposition development and longevity of sucking pests like whiteflies, aphids, thrips, and leafhoppers injuring flower crops are intimately associated with temperature. Farmers cultivating flower crops are likely to encounter impacts of climate change on plans for pest management. Farmers will have to diversify crops and also cultivation practices, and farmers may expect enormous numbers of key pests in India like leafhoppers, aphids, thrips, and whiteflies, necessitating more insecticide applications to maintain low damage thresholds. The cultural practices adopted by the farmers need changes following the variations in climate. Farmers need to document the changes in the populations of pests in their field and the cost of reducing pest overtime.

8.1 INTRODUCTION

Global warming will adversely affect the surface temperature of the earth, and its profound effects will impact on all organisms and ecosystems. Each and every living being will be impacted by climatic changes and insects being an integral biotic component of all most all ecosystems without an exemption (Deutsch et al., 2008). Impacts of global warming on insect pests embrace changes in phenology, physiology, development, distribution, community composition, and ecosystem dynamics. Impacts of global warming can be either direct, through the influence that weather may have on the insect's physiology and behavior and indirect impacts can happen through the influence of climate on the host plants, natural enemies (NEs) and inter-specific interactions with other insects (Walther et al., 2002).

Variations in a climate with an increase in atmospheric temperature and carbon dioxide (CO_2) has a lot of implication in the agriculture sector. Recent reports from the Intergovernmental Panel on Climate Change (IPCC) projects an increment in mean atmospheric temperature from 1.1 to 6.4°C toward the year 2100 with a parallel increase in atmospheric CO_2. Such changes in the earth's temperatures can drastically change insects both directly, i.e., seasonal shifts in insects populations and indirectly, i.e., changing plant productivity and quality, dwindling populations of predators, and increasing the insect pest population (IPCC, 2007). Insects are cold-blooded organisms - the temperature of their bodies is almost the same as that of the surrounding environment. So, the temperature is the most important environmental factor influencing insect behavior, distribution, development, survival, reproduction, and the capacity to damage crops (Bale et al., 2002). Yet another important factor that adds for global warming with the temperature is CO_2, a key greenhouse gas. The concentrations of CO_2 in the atmosphere are increasing at an exceedingly rapid rate from one decade to another. CO_2, besides temperature also influences the growth and development of the insects (Deutsch et al., 2008).

Temperature and CO_2 two factors potentially important for future global climate change scenarios, with respect to fruit flies and other pests. Understanding how increasing temperatures and CO_2 shall affect fruit fly biology, behavior, and pestilence potential will assist agricultural scientists to orient their research on different futuristic possibilities that can help in mitigating and adapting the ill-effects of climate change in future.

Flowers are an important, integral part of the social life of human beings. Flowers being adorable creation of God, befits all occasions, be it at birth, marriage, or death. In the past, flowers were not accorded much economic value. Government of India has now identified floriculture as an important industry and granted 100% export oriented status. Owing to the steady increase in demand of flower floriculture has become one of the important Commercial trades with people, the world over. Hence, commercial floriculture has emerged as a hi-tech activity-taking place under controlled climatic conditions inside the greenhouse. Floriculture in India is being considered as a commercially important Industry. Floriculture is an important enterprise from the export angle (APEDA) too.

8.2 MAJOR COMMERCIAL FLOWER CROPS

The estimated area under flower cultivation in India is about 65,000 hectares. The major flower growing states are Karnataka, Tamil Nadu, and Andhra Pradesh in the South, West Bengal in the East, Maharashtra in the West, and Rajasthan, Delhi, and Haryana in the North. Rose is the principal cut-flower cultivated all over India, though in terms of total area, it may not be so. The higher percentage of the area in several states is used for growing scented rose, usually local varieties akin to the Grussen Tepelitz, the old favorite to be sold as loose flowers. These are used for offerings at places of worship, for the extraction of essential oils and also for making garlands. For cut flower use, the old rose varieties like Queen Elizabeth, Super Star, Montezuma, Papa Meilland, Christian Dior, Eiffel Tower, Kiss of Fire, Golden Giant, Garde Henkel, First Prize, and others are still popular. Presently, with production for export gaining ground in the nation, the latest varieties like First Red, Grand Gala, Konfitti, Ravel, Tineke, Sacha, Prophyta, Pareo, Noblesse. Virsilia and Vivaldi are also being cultivated on a large scale.

Gladiolus is the second most important cut-flower crop in India. Earlier gladiolus was a major crop for temperate regions, and its cultivation was restricted to the hilly areas, particularly in the northeastern region in India, which continues to supply the planting material to most parts of the country. However, with the advent of improved agronomic techniques and better management practices, the northern plains of Delhi, Haryana, Punjab, Uttar Pradesh, and Maharashtra and Karnataka in the south have emerged as the key production areas for gladiolus.

Tuberose, a highly popular cut-flower crop in India, is cultivated primarily in the eastern part, i.e., West Bengal, and also in northern plains and parts of south India. Both single and double flower varieties have become popular. Tuberose flowers are also sold loose in several zones for preparing garlands and wreaths. The other chief cut flower crop is orchid. Production of orchids is restricted mainly to the northeastern hill regions, besides in southern states of Kerala and Karnataka. The main species cultivated are Dendrobiums, Vanda, Paphiopedilums, Oncidiums, Phalaenopsis, and Cymbidiums.

Of the conventional flower crops cultivated for loose flowers, the maximum area is under marigold, grown all over India. In several parts of the country, only local varieties are grown for generations. African marigolds occupy more area as compared to the small-flowered French types. Jasmine flowers due to its aroma are also highly popular as loose flowers and for use in garlands and *Veni* (ornament for decoration of hair by women). The principal areas of this crop are in Tamil Nadu, Karnataka in South and West Bengal in East. The varieties are chiefly improved clones of *Jasminum grandiflorum, J. auriculatum,* and *J. sambac*. The chrysanthemum, particularly the white varieties, are in great demand as loose flowers during autumn (October-December) when other flowers like jasmine and tuberose are not available for use in garlands and other items. Among other conventional flowers grown in large areas is Cassandra in south Indian states of Tamil Nadu, Karnataka, and Andhra Pradesh and aster in Maharashtra.

8.3 CUT FLOWER PRODUCTION

The requirements for scientific and commercial floriculture are not properly planned and understood in India, as yet. The developmental initiatives of the government have to keep in mind the low knowledge or resource base, small landholdings, unorganized marketing, and poor infrastructural support. While the continuous experience of flower growing in the open field conditions enables sufficient flower production for domestic needs, the quality of the flower cultivated due to its exposure to several types of biotic and abiotic stresses are not favorable for the ever-growing export market. The production technology for flowers under greenhouses or polyhouses needs to be refined. There is hardly any post-harvest management of flowers targeted for the domestic market. Research efforts are also needed for integrated pest management (IPM), development of the location-specific package of practices for traditional flowers, value addition to traditional flowers, and a new avenue for commercial flowers. The major problems faced in the production of cut-flowers, as pointed out by the hi-tech growers, included pest and disease attack on crops as reported by 47.27% of the growers (Sudhagar, 2013).

8.4 EFFECT OF CLIMATE CHANGE ON PESTS OF COMMERCIAL FLOWERS

Increased temperatures accelerate the growth and development of arthropod pests– possibly resulting in a higher number of generations (increased crop damage) per year. Parasitism or predators could be reduced if host populations emerge and pass through vulnerable life stages prior to the emergence of parasitoids. Hosts may pass through vulnerable life stages more rapidly at higher temperatures, reducing the chances for parasitism. Temperature can modify gender ratios of some pest species, such as thrips (Lewis, 1997), potentially affecting reproduction rates. Insects that spend important parts of their life histories in the soil may be more gradually affected by temperature changes than those that are above ground simply because soil provides an insulating medium that will tend to buffer temperature changes more than the air (Bale et al., 2002). Lower winter mortality of insects due to warmer winter temperatures can be important in increasing insect populations (Harrington et al., 2001). Higher average temperature might result in some crops being able to be cultivated in regions further north – it is likely that at least some of the insect pests of those crops will follow the expanded crop areas. Insect species diversity per area tends to decrease with higher latitude and altitude (Gaston *and* Williams, 1996; Andrew *and* Hughes, 2005), meaning that rising temperatures could result in more insect species attacking more hosts in temperate regions (Bale et al., 2002). Based on the evidence developed by studying the fossil record, some researchers (Bale et al., 2002) conclude that the diversity of insect species and the intensity of their feeding have increased historically with higher temperatures.

8.5 EFFECT OF CLIMATE CHANGE ON GEOGRAPHICAL RANGE

Climate is an important factor for the geographical distribution of species (e.g., Moen, 1999; Figure 8.1) and, although precise information on the species-geographic range is relatively difficult to get, certain generalizations on climate warming effects may be advanced. Large climatic oscillations have occurred during historical times and have caused alterations in species composition and distributions. For instance, during major glaciations, the spread of species compressed towards the Equator and then descended from the mountains. However, in the warmer interglacial periods, species migrated toward higher latitudes and altitudes (e.g., Taberlet et al., 1998; Hewitt, 2000). Recent range expansions of lepidopterans and treeline dynamics revealed similar patterns; they are moving towards higher latitudes and altitudes as forecasted by climate warming scenarios (Parmesan, 2006). Kelly and Goulden (2008) pointed out that nine out of ten dominant plant species on a Southern California mountain had made a mean (+ 65 m) elevational shift upwards the last 30 years. In Norway, for instance, alpine vascular plants have exhibited altitudinal expansions and increases in abundance and diversity during the last century (e.g., Klanderud and Birks, 2003).

Lower temperatures sometimes are more important than higher temperatures in deciding the geographical distribution of insect pests. Increasing temperatures lead to a greater capacity to overwinter in insects restricted by low temperatures at higher latitudes, extending their geographical area (EPA, 1989; Hill and Dymock, 1989). Spatial patterns in the distribution of crop plants in changing climatic conditions will also influence the distribution of insect pests in a geographical region (Parry and Carter, 1989). However, whether or not an insect pest moves with a crop into a new habitat will depend on other environmental conditions such as the presence of overwintering sites, soil type, and moisture, e.g., populations of the corn earworm *Heliothis zea* (Boddie) in North America may progress towards the higher latitudes/altitudes, leading to a greater damage in maize and other crops (EPA, 1989). For several of the insect species, higher temperatures, below the species' upper threshold limit, may limit to faster development, leading to the rapid increase of pest populations as the period for reproductive maturity is reduced. Besides the direct impacts of temperature variations on development rates, increases in food quality due to plant stress may result in dramatic increases in the growth of insect pest populations, while the growth of certain insect pests may be adversely affected (Maffei et al., 2007). Pest outbreaks are likely to increasingly occur with stressed plants as a result of the weakening of plants' defensive system and thus, increasing the level of susceptibility to insect pests. Global warming will lead to earlier infestation by *Helicoverpa armigera* (Hub.) in North India (Sharma, 2010), leading to higher crop loss. An increase of 1 and 2°Causes northward shifts in the potential distribution of the European corn borer, *Ostrinia nubilalis* (Hub.) of up to 1,220 km, with an additional generation in nearly all regions where it is currently known to occur (Porter et al., 1991). Overwintering of insect pests will increase as a result of climate change, producing larger spring populations as a base for a build-up in numbers in the following season. Several insects like species *Helicoverpa* spp. are migratory, and so can be well adapted to harness new opportunities by moving quickly into newer areas as consequences of climate variations (Sharma, 2005).

8.6 HOST RANGE, FLOWERING PLANTS, AND POLLINATORS PHENOLOGY

A variety of organisms react to variations in temperature by changing their activity and physiology. So, man-induced temperature increases have the capacity to alter the phenology of both plants and pollinators. Of late, the strength and direction of the phonological responses to rising temperatures were primarily not documented precisely.

In fact, it had not been shown whether phenological shifts occurred at all in wild animal communities in response to climate change. However, in the last decade, there has been increasing interest in phenological responses to global warming (Post *and* Inouye, 2008; Rosenzweig et al., 2008), and much of the knowledge on climate warming effects comes from plant phenological datasets.

Flowering in plants is regularly used to measure the arrival of spring in temperate habitats. Many plants appear to have reacted to increasing temperatures by earlier flowering during the last 20–50 years (Fitter and Fitter, 2002; Figure 8.1). In Europe, 78% of the recorded time series provided such a trend (Menzel et al., 2006), which concurs with findings from other parts of the northern hemisphere (Sparks et al., 2000; Miller-Rushing et al., 2006, 2007). Insect-pollinated plants generally respond more intensely to higher warming than wind-pollinated plants, and plants of flowering species early in the season may be the most sensitive (Fitter *and* Fitter, 2002; Miller-Rushing et al., 2007), an index that these species have temperature-sensitive life histories. In general, the onset of flowering appears to be related to the mean temperature in the periods of flowering or the months prior to flowering (Sparks et al., 2000; Menzel et al., 2006). However, other factors can change with temperature and be vital for the recorded patterns. The reactions of flowering onset to increasing temperatures were linear in most cases (Sparks et al., 2000; Fitter *and* Fitter, 2002; Gordo *and* Sanz, 2005; Menzel et al., 2006), which could be important for plant interactions with pollinators. Although it is obvious that such linear responses cannot continue perpetually, Sparks et al., (2000) found significant linearity within the observed range of temperature variations for 24 of 25 British plant species from which 23 flowered earlier with increased temperatures. To better understand the impacts of global warming, the above-mentioned generalizations of species responses are important. We emphasize, however, that some species may not flower earlier as a response to increased temperatures (e.g., 22% of the species included in Menzel et al., (2006)). Also, other potential cues for flowering initiation include photoperiodicity, precipitation, soil humidity, and snowmelt (Inouye et al., 2003; Price *and* Waser, 1998) as well as a particular combination of cues (e.g., Lambercht et al., 2007). If climate change disrupts the relationships among the environmental cues which plants use to initiate flowering, past combinations of cues might reappear at novel times in the season (Price *and* Waser, 1998; Stenseth *and* Mysterud, 2002; Visser *and* Both, 2005), resulting in bizarre flowering times.

Synchronized timing of mutualistic partners may be crucial for efficient pollination of plants and survival of pollinators (e.g., Figure 8.1). So, one of the key considerations correlated with global warming and pollination interactions are the demographic result of mismatches between plants and pollinators.

A mismatch with important pollinators could reduce pollen deposition through altered visitation in plants (quantity or quality of floral visits), potentially increasing pollen limitation (e.g., Figure 8.1). Among plant species, limitation of reproduction due to insufficient pollination is common (Ashman et al., 2004). However, the effect of pollen limitation (i.e., a top-down force) on population dynamics, and its relative importance compared to resource limitation (i.e., bottom-up forces), is still poorly understood, although a few studies have revealed that enhanced seed set or seed mass after supplemental pollination can positively influence recruitment, survival, and population growth rates of flowering plants (Hegland *and* Totland, 2007; Price et al., 2008; see Figure 8.1). Another result of mismatches is the cascading effects they might have on species interactions happening later in the season. A downfall in early-emerging pollinator populations may affect both early and later flowering species, and sequentially flowering species may facilitate each other through the maintenance of pollinator populations (Waser and Real, 1979). Moreover, in northern regions, several plants depend on bumblebees for adequate pollination and successful reproduction. If nest development is restricted by a mismatch between early emerging bumblebee queens and their main food plants, such early season events can influence pollination services later in the season.

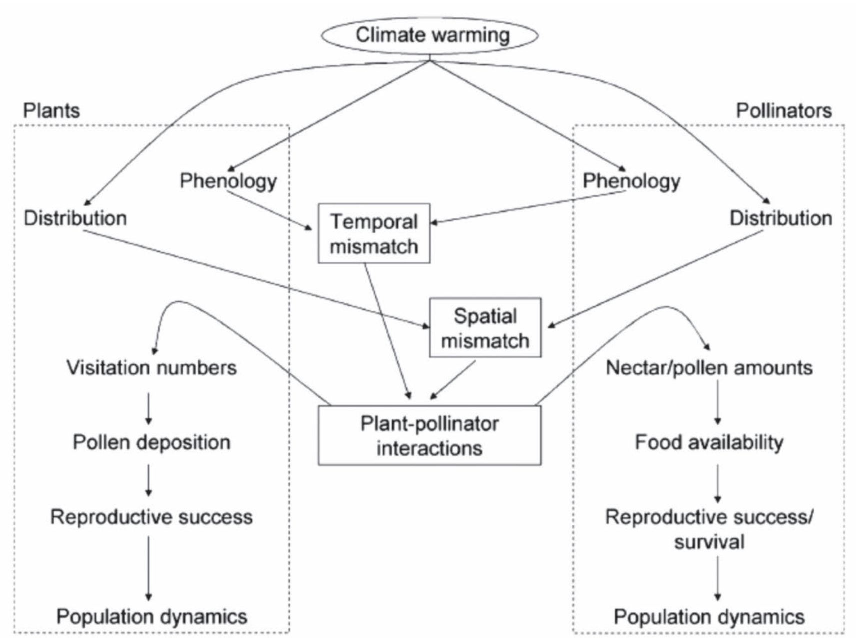

FIGURE 8.1 Framework showing how climate warming may affect the phenology and distribution of plants (left panel) and pollinators (right panel) and thereby creating temporal or spatial mismatches in plant-pollinator interactions. In the lower half of the panels, we show how and by which key factors the demography of the mutualistic partners are likely to be affected. The pathway until the mismatches are largely known, whereas the mismatches and the subsequent effects are still mostly unknown and require additional research.

8.7 DIRECT EFFECTS OF CLIMATIC PARAMETERS ON POPULATION

Dynamics: Global warming may involve a rising frequency of abiotic disturbances. Based on the dimensions of the disturbances, local to regional dynamics of insect populations and species composition will be intensely impacted on insects and find favorable conditions for growth and development within a certain range of temperatures restricted by species requirements lower and upper developmental thresholds. These changes and progressive variations may alter the population characteristics like growth, development, and reproduction, natality, mortality, and flight and distribution (Moore *and* Allard, 2008).

8.7.1 DEVELOPMENT AND REPRODUCTION

Insects may respond favorably to increasing temperature as long as optimum conditions for development are not met with. Insect species that pass through several generations example, select economically important bark beetles like *Ips typographus* will benefit from enhanced development rates permitting an earlier completion of life cycles and the establishment of additional generations within a unit period of time. Temperatures exceeding the specific condition may lead to decreased growth rates, reduced reproductive rate, and higher rates of mortality for a multitude of species of insects. Favored by milder winters and decreasing frequencies of temperature rise, higher reproductive capacity and alterations in distribution (if host plants are found) are to be expected for a variety of pest species. For example, higher survival of hibernating eggs in fringe areas of occurrence is prognoses for the winter moth, *Operophthera brumata* and the autumnal moth, *Epirrita autumnata,* and the gypsy moth, *Lymantria dispar* in North America or the European pine sawfly, *Neodiprion sertifer*. Temperature rise combined with reduced snowfall and earlier snowmelt, on the one hand, lead to reduced overwinter survival of insect species hibernating under the protection of snow (Jönsson et al., 2009; Moore and Allard, 2008).

8.7.2 TEMPERATURE EFFECT ON SURVIVAL RATE

Rising temperatures reduced the period necessary for reproduction (Spruce beetle, *Dentroctonus rufipennis*). The population of pine beetles is decreased considerably at -16° (lethal) but enhanced survival and geographical spread at warm winters (Berg et al., 2006).

In the case of sucking insects like aphids, a 2°C temperatures increase result in one to five more life cycles per season. The survival of adults of brown planthopper (BPH), *Nilapavata lugens* stands almost unchanged between 25 and 35°C, but was drastically reduced at 40°C. The oviposition of females at 35 and 40°C was relatively higher than at 25 and 30°C, but the survival of eggs was significantly affected at 35°C (Yamamura *and* Kiritani, 1998).

At the rising temperatures, periods of pre-oviposition times were also decreased. Precisely, temperatures above 35°C tend to restrict BPH development based on these studies. Global warming is likely to rise the BPH population in areas with temperatures below 30°C (Heong et al., 1995).

In another pest species, the survival of the different stages of the rice leaf folder *Cnaphalocrocis medinalis* was drastically affected at 35°C. Adults emerging from pupae raised at 35°C couldn't oviposit. The upper-temperature limits for the survival of this species apparently to lie between 30 and 35°C. Changes in climate can variably impact the development rates of pest and predator species. In addition, temperatures can affect predator search. The egg predator (*Cyrtorhinus lividipennis*) had increased instantaneous attack rates and decreased handling times with increasing temperatures until 32°C. At 35°C, the attack rate and handling time decreased drastically. This means that predator behavior tends to enhance with increasing temperatures up to a limit temperature of about 35°C. In addition to influencing biological characters, global warming may result in temporal asynchrony between interacting populations. The insect can also escape climate change stress through altering in life history. Insect populations from environments with rising temperatures can have greater fecundity and reduced growth stage durations to increase fitness. The egg duration was 10.4 days at 25°C and 7.9 days at 27–28°C. The viability of eggs of *H. armigera* and day degrees adequate for egg hatching reduced with a rise in temperature from 10 to 27°C and egg age from 0 to 3 days (Heong et al., 1995).

KEYWORDS

- **climate change**
- **floriculture**
- **insect pest**
- **tropics and subtropics**

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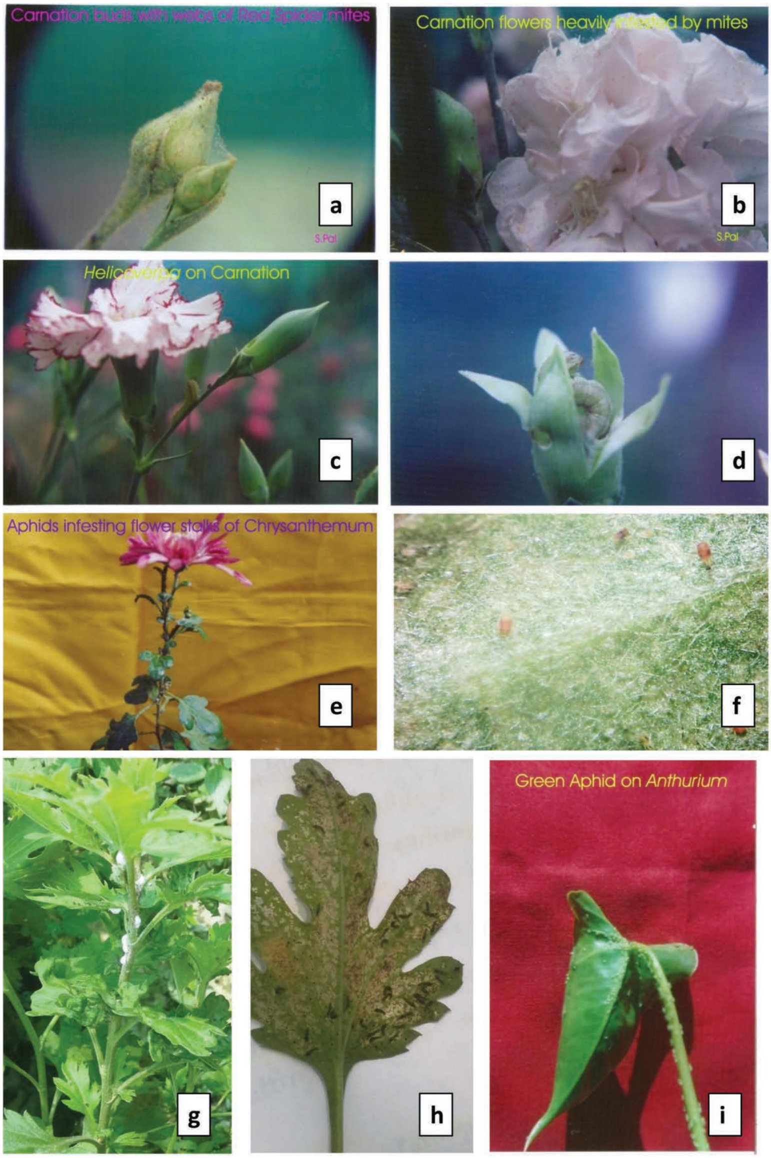

FIGURE 1.1 Pests of commercial flowers. (a) Red spider mite webs on Carnation buds, (b) Flower of Carnation with webs of spider mite, (c) *Helicoverpa* on Carnation buds & flowers, (d) *Helicoverpa* boring into Carnation bud, (e) Aphid infestation of chrysanthemum, (f) Different life stages of red spider mite, (g) Cotton mealybug infesting chrysanthemum, (h) Tobacco caterpillar feeding on chrysanthemum leaf, (i) Green aphid on Anthurium leaf.

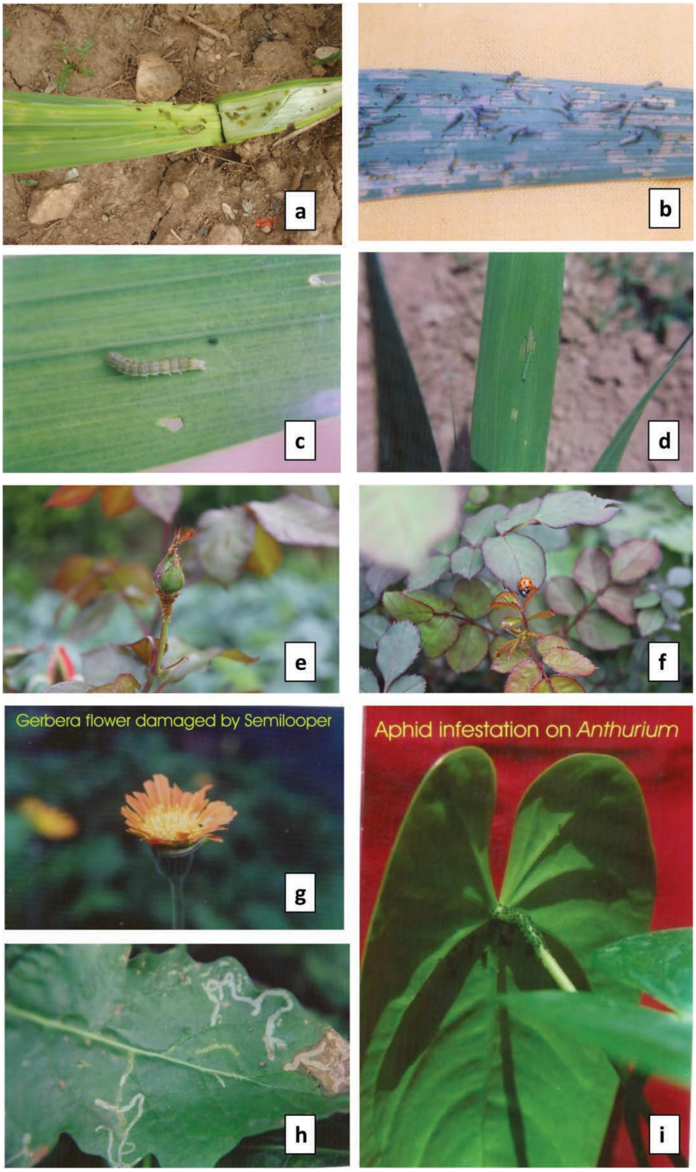

FIGURE 1.2 Pests of commercial flowers. (a) Leaf caterpillar infestation on Gladiolus, (b) *Spodoptera* caterpillars on Gladiolus, (c) *Helicoverpa* damage on Gladiolus, (d) Semilooper damage on Gladiolus, (e) Aphid infestation in rose, (f) *Coccinella septempunctata* on rose aphid, (g) Green semilooper feeding on Gerbera flower, (h) Serpentine leafminer damage on Gerbera, (i) Black aphid on Anthurium leaf.

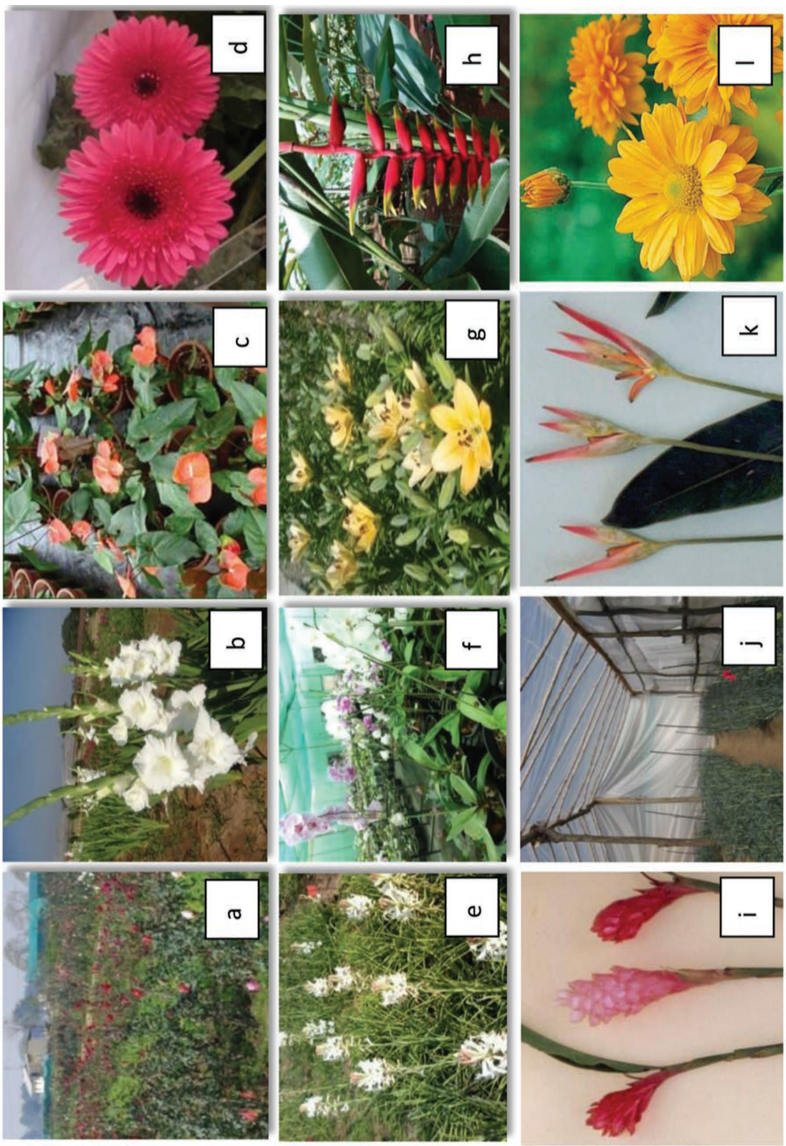

FIGURE 2.1 Specialty flowers: a-rose, b-gladiolus, c-anthurium, d-gerbera e-tuberose, f-orchids, g-lilium, h-heliconia, i-ginger lily, j-carnation, k-bird-of-paradise, l-chrysanthemum.

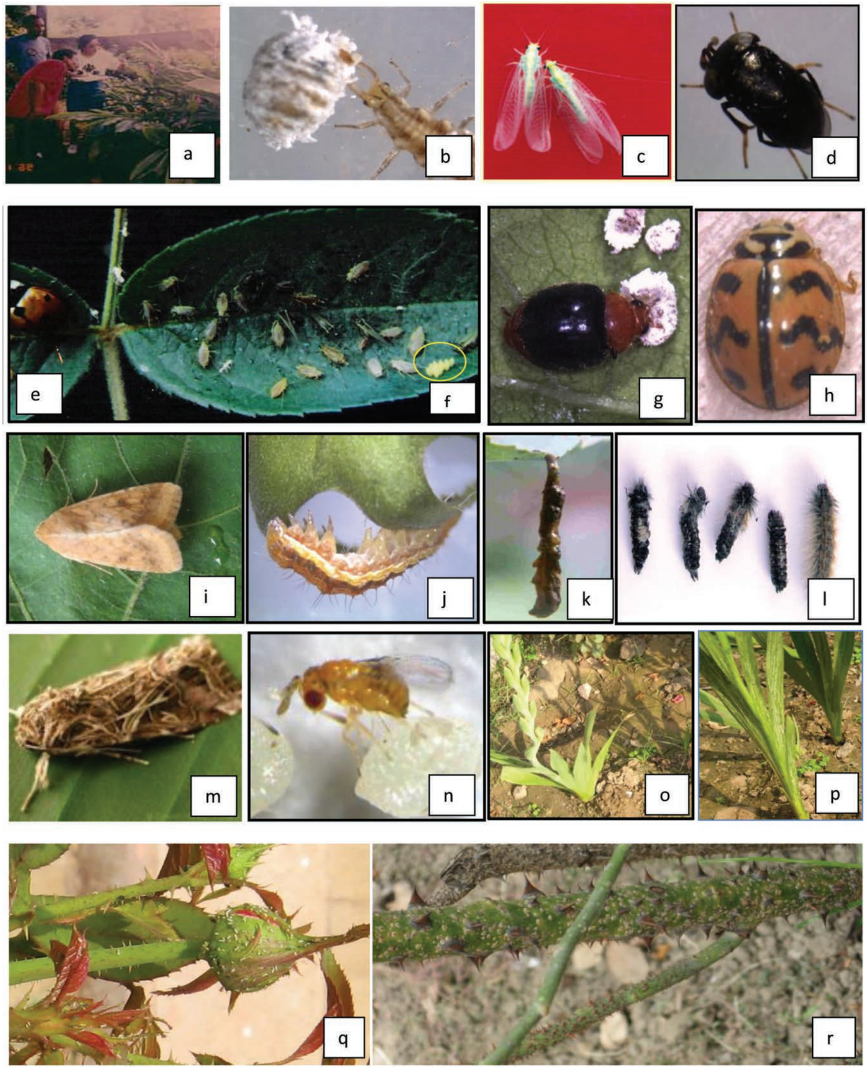

FIGURE 2.2 Important insect pests and natural enemies associated with flower crops: Monitoring of natural enemies in ginger lily field, b-green lacewing larva preying on mealybug, c-adults of green lacewing, d- encyrtid parasitoid of mealybug, e- adult ladybird *Coccinella septempunctata* predatory on rose aphids, f- egg mass of *C. septempunctata*, g- *Cryptolaemus montrouzieri* predator of mealybugs, h-adult ladybird *Cheilomenes sexmaculata* predatory on aphids, i-adult *Helicoverpa armigera*, j-larva of *H. armigera*, k-NPV infected caterpillar of *Spodoptera litura*, l-caterpillars showing bacterial death, m-adult *S. litura*, n-egg parasitoid *Trichogramma* sp, o-mite infested gladiolus, p-thrips infested gladiolus, q- aphid infested rose, r- scale insects on rose stems.

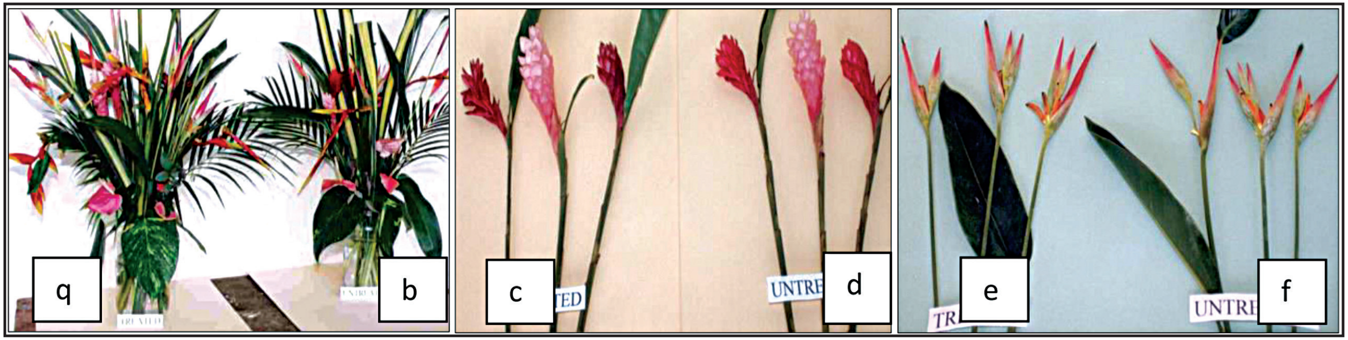

FIGURE 2.3 Treatment with a pesticidal dip of cut flowers: (a) a group of treated flowers *viz.; Anthurium*, *Heliconia*, Bird-of-paradise, ginger lily, and a few foliages placed in vase water, (b) untreated control, (c) ginger lily treated, (d) ginger lily untreated, (e) bird-of-paradise treated, (f) bird-of-paradise untreated.

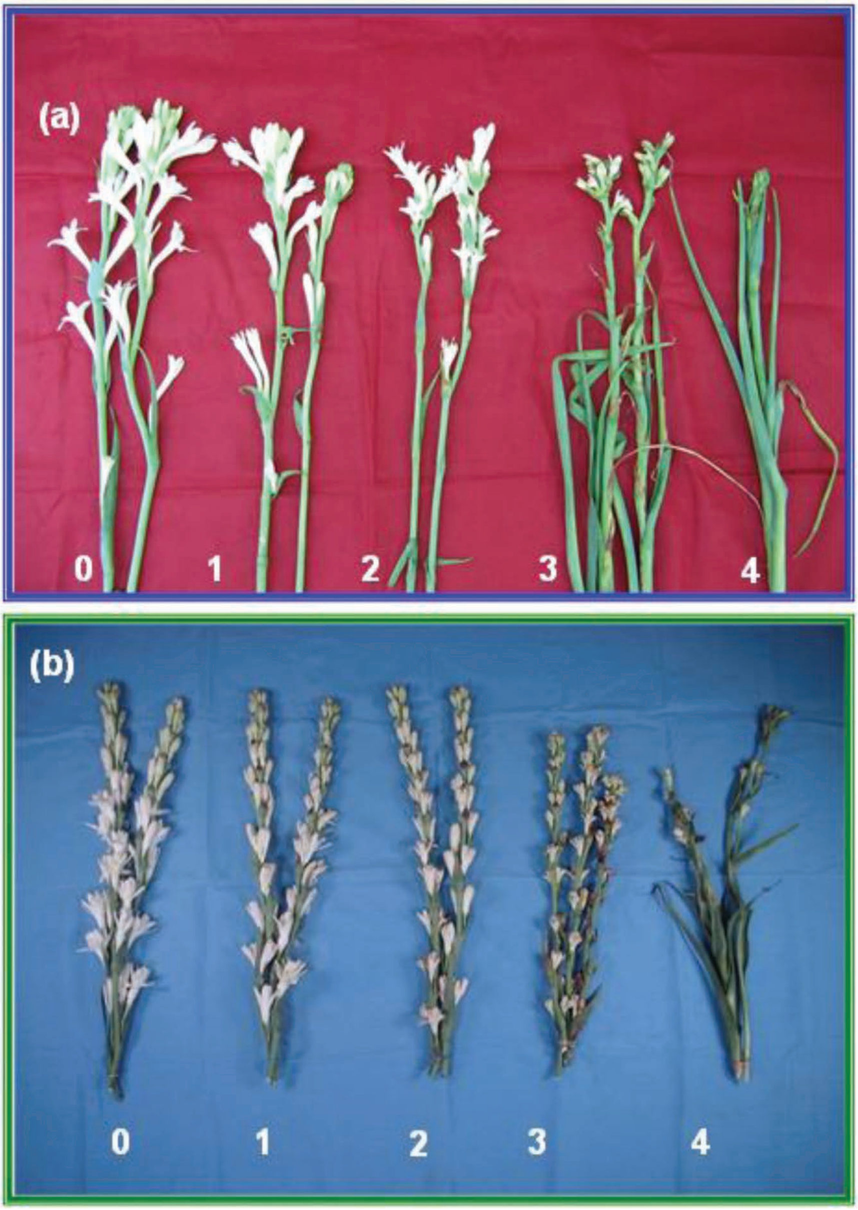

PLATE 7.1 Rating scale on a 0–4 scale (a) Calcutta single (b) Calcutta double.

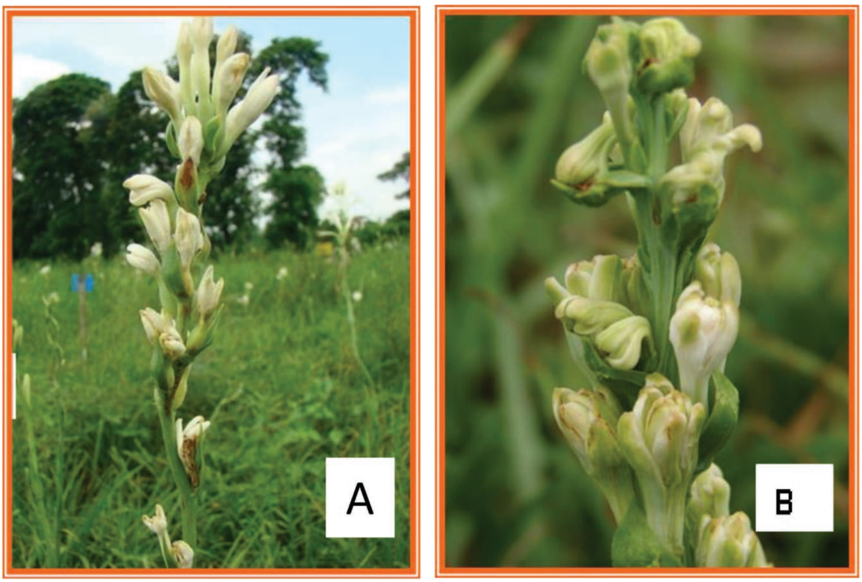

PLATE 7.2 Distortion of (a) Calcutta single, and (b) Calcutta double due to infection of *Aphelenchoides besseyi.*

PLATE 7.3 Tuberose (cv Calcutta single) infected by *Meloidogyne incognita.*

PART II
Pest Management in Commercial Flowers

CHAPTER 9

INTEGRATED PEST MANAGEMENT IN HORTICULTURAL ECOSYSTEMS WITH SPECIAL REFERENCE TO FLOWERS AND ORNAMENTAL PLANTS

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ABSTRACT

An effective IPM program for flowers and ornamental foliage production demand regular visual inspection and surveillance. The focus should be on key pests on target plant parts. In polyhouses and greenhouses, sucking pests pose a problem. In fields, lepidopterans, and beetles generally may attack flower plants. Spot treatments, use of yellow sticky cards, pheromone traps, prophylactic cultural and mechanical tools, insecticidal soaps, botanicals, and microbials are important for IPM in flower crops. Valid sampling and scouting plans should be adopted for healthy and quality flowers, cut-flowers, and ornamental foliage production. Impetus, funding, and attention are being now given to IPM in flowers and ornamental foliage production globally. This is indeed a welcome trend.

9.1 INTRODUCTION

Flowers among horticultural crops represent unique ecosystems. The diversity of flower crops is incredible. But the number of scientists working on flower crops is low compared to other crops like fruit crops. Flower crops till about the beginning of the 20th century were neglected a lot. So the pace of research on flower crops was generally slow. Flower crops received in the past and currently, lesser funding compared to other crops. Flowers and ornamental foliage have a short shelf-life and in some cases, are highly delicate. Flower crops are endowed with unique characteristics and have aesthetic value. The concept of the economic threshold level (ETL) and economic injury level (EIL) cannot be directly applied to flower crops (Stern et al., 1959). A modified version of this concept is the aesthetic injury level (AIL) prepared by Olkowski (1974). Fruit and plantation crops are perennial, while flowers and vegetable crops mostly are annual or seasonal. The former are woody plants, while the latter are mostly herbaceous. Mango (*Mangifera indica*), for instance, both as a tree and at orchard level, sustains several kinds of arthropods. The diversity, species abundance, and interactions play an important role in shaping the faunal communities and ecology at the micro-habitat level (Reddy *and* Sridevi, 2016) Similarly, Cashew (*Anacardium occidentalae*) an economically important plantation crop serves as a perennial reservoir for species assemblages (Bhat et al., 2016). If the above two trees are widely spaced, leveraging a considerable scope for cultivation of flower crops like marigold, asters, chrysanthemum, and tuberose, that are widely cultivated. Vegetable crops, on the other hand, serve as ephemeral habitats for arthropods, and the characteristics of faunal communities inhabiting such cultivated ecosystems are different from those that exist in fruit or plantation crops. Interestingly, flower crops represent both perennial (e.g., Jasmines, roses) and annual plants (e.g., Asters, marigolds). Weeds are a major and regular component of fruit and plantation crop ecosystems, but not in vegetable and flower crops cultivated ecosystems. Weeds can hold beneficial or can act as alternate hosts supporting pests and diseases. So the pest management principles and practices in these horticultural cultivated ecosystems will be specific and different.

Coconut is another plantation, palm crop attacked by few major pests, including the mite, *Aceria guerreronis* Keifer. Because of the structure and architectural disposition of the palm-ecosystems, coconut plantation is a potential area for the flower crops like crossandra, jasmines, carnations, or mutants of carnations and roses. Although the above flower crops may not fulfill the local market needs, this kind of farming system is mostly undertaken by small and marginal farmers. It is a well-accepted fact that monocultures are favorable for pest populations than mixed cropping systems. This holds good for pests of flower crops too. Therefore, it is suggested that flower crops should form an essential part of several cultivated horticultural ecosystems as far as possible.

9.2 THE PEST SCENARIO

The sucking pests, *viz*., aphids, thrips, whiteflies, and hoppers have developed resistance or may soon develop resistance to insecticides, not only to conventional but also to modern molecules like nicotinoids, diamines, and others. This poses a great challenge for plant protection specialists and policymakers. For example, the two-spotted spider mite, *Tetranychus urticae* Koch, remains the most serious pest of greenhouse roses. Secondly, the sucking insect pests act as vectors of viral diseases that rapidly destroy the crops often without appropriate management options in place. Both in the greenhouse and open cultivated flowers and ornamentals, Mealybugs are increasingly causing injury affecting marketability. Commercial flowers are now increasingly cultivated in polyhouses or under confined conditions. These flower species are exportable items, and each flower counts. So growers are inclined to protect flowers at any cost. To combat pests, especially sucking pests like whiteflies, farmers are applying highly toxic insecticides. As Parrella and Jones (1987) point out, growers of floriculture products rely almost on insecticides to suppress pests according to the calendar rather than the estimates of pest populations. Bulbous and tuberose plants are generally sold as cut-flowers and include bulbs, tubers, tuberous roots, and rhizomes (Hartmann et al., 1990). These are generally with multi-flowered or single-flowered inflorescences/shoots (Van Scheepen, 1991). Aphids, scales, mites, whiteflies, Mealybugs, spider mites generally attack these plants, which can be suppressed using insecticides (Larson, 2014). Foliage plants are being grown as ornamentals from centuries, but economic significance came with the start of the 20th century. Foliage plants, because of their attractive ornamental leaves, are used in the interiors or indoors.

These include palms, ferns, *Ficus, Philodendron, Dracaena*, etc. Aphids, scales, mealybugs, thrips, spider mites, and lepidopteran caterpillars and nematodes infest these indoor plants. It is imperative that stocks of these plants are kept free from aerial and soil pests as frequent, and regular applications of insecticides on these plants are undesirable (Osborne et al., 1985). Pesticides used outdoors or under shade structures are advocated against pests of foliage plants (Larson, 2014). Most of the flower crop pests are not amenable for biocontrol agents and biopesticides. So prevention is better than control. In this context, growers are deploying nylon nets, yellow traps, and botanicals like neem (*Azadirachta indica*) and Pongamia (*Pongaemia pinnata*). Yet, growers are not satisfied with the efficacy of these modern insecticides that are costly and have diverse modes of action. With this background, the scope of using management options for the suppressing pest populations effectively in floricultural ecosystems is discussed, but briefly.

9.3 HOST-PLANT RESISTANCE

Utilizing resistant/ tolerant varieties to keep pests under check is ideal for flower crops. This method is considered economically viable, technically feasible, and socially acceptable as flowers are used extensively in human-social gatherings and rituals. This method is also ecologically acceptable. Concerted research efforts are being initiated to identify, exploit, and utilize flower varieties possessing resistance traits to pests and diseases. Across flower species, only a few varieties are cultivated/domesticated, but there are enough numbers of wild and related species that may act as a source for resistance. There are also many 'types' in each genus of flower crops, *viz*, in Jasmine like Arabic Jasmine (*J. Sambac*), Winter jasmine (*J. nudiflorum*), and Italian Jasmine (*J. humile*), etc.

So in flower crops, wider gene pool offers diverse sources for exploiting pest/diseases resistance. For example, IIHRSG-1, a rose variety with creamish white flowers, is ideal for cut-flower production under protected cultivation. This variety is moderately resistant to mites. Similarly, Arka Flame, an in-vitro mutant selection of carnation from IIHRS-1, produces red flowers that are tolerant to nematodes and Fusarium wilt. Arka Parimala- a rose variety exhibits field tolerance to thrips and black spots.

9.4 RNA INTERFERENCE (RNAI) OR GENE SILENCING

It is now possible to suppress insect pests by silencing or rendering the gene function inactive that plays a vital role in insect-host plant interaction, growth, and development, flight, and reproduction. While RNAi is a novel approach, it is species-specific and hence cannot be used generally against all insect pests. To use RNAi against pests, one has to establish the function of genes involved in different metabolic processes (Mutti et al., 2006). Mao et al., (2007) effectively silenced the alkaloid and principal moiety in the cotton-gossypol detoxifying gene of the bollworm, *Helicoverpa armigera* (Hub.) through an artificial diet containing dsRNA for CYP450 mono-oxygenase gene (HaECR), a steroid hormone to silence the gene regulating growth and development of *Helicoverpa armigera* and *Spodoptera exigua*.

Both species of *Helicoverpa* and *Spodoptera* infest flower crops, on vegetative and reproductive plant parts. Pitino et al., (2011) utilized the PMRNAi for the control of the green peach aphid, *Myzus persicae* Sulzer, which transmits more than 100 types of plant viruses by silencing RACK1 (Receptor of Activated Kinase 1) and COO_2 genes (Pitino et al., 2011). *M. persicae* infests a number of flower crops in the tropics and sub-tropics.

Insect pests develop insecticide resistance by changing the target site or proteins involved in growth and development processes (Palli, 2016). According to Palli (2016), RNAi technology can also be used to produce sterile male insects. Whitefly, *Bemesia tabaci* Genn infests several flower crops like gerbera, asters, chrysanthemum, etc. However, as yet, the role of RNAi for the containment of insect pest is at the infancy. Nevertheless, RNAi holds a great potential for evolving target specific ecologically sound environmentally friendly pest management methods.

9.5 INSECT PHEROMONES

Pheromones can be defined as the substances secreted by an insect and received by a conspecific, which elicits a specific response (Karlson *and* Luscher, 1959). In IPM, pheromones can be used to monitor, mass trap, and/or disrupt the mating process of insect pests in horticultural crops, particularly flower crops. Besides sex pheromones, aggregation pheromones or food attractants are also being used to attract and kill insect pests. Several lepidopterans such as Jasmine Leaf Webbers, *Nausinoe geometralis.* Several coleopterans like Chrysomelids and cerambycids have been documented to produce aggregation pheromones (Teale et al., 2011). For instance, much research has been conducted on the defoliator, *Spodoptera litura* Fab. (Tu et al., 2010). Researchers have verified that sex pheromone lures can be effective for major pests of horticultural crops, including flower crops (Arida et al., 2002).

Since sucking pests constitute the major pests on flower crops, as also on ornamentals, studies, and recommendations against these pests are yet to be standardized. In view of the reason that most sucking pests like thrips, aphids, whiteflies do respond to semiochemicals, efforts in this direction are needed to find potent phyto-semiochemicals and utilize them in IPM.

9.6 BIOLOGICAL CONTROL

Biological control is feasible during the first phase of crop growth in the production ranges (wk 1–5). At this time, marketable foliage is not present, and inundative releases of leafminer parasites may provide control such that no insecticides for leafminers are needed (Jones et al., 1986). Other pests may be controlled by a variety of biorational methods.

The fungus, *Cephalosporium lecanii* (Zimm.) Viegas (Vertalac), has shown potential against *M. persicae* on chrysanthemums, and registration is considered (Markle, 1985). Several isolates of *Bacillus thuringiensis* Berliner have shown activity against *S. exigua* and other lepidoptera on chrysanthemums (Yoshida et al., 1986). *Phytoseiulus persimilis* Athias and Henriot are used in England on chrysanthemums (Cross et al., 1983); this predator has been utilized to a limited extent on chrysanthemums in the United States. *Typhlodromus occidentalis* (Nesbitt) may also impart good control in greenhouse situations (Field *and* Hoy, 1984). There are no successful biological control agents (BCAs) of *F. occidentalis* presently formed. The strategy behind predators and parasites for biological control in floriculture is to bring a rapid decline in the pest population. Accurate monitoring of the impact of beneficial insects is essential to the success of this strategy.

Biological control programs permit substantial reductions in the applications of insecticides, pollution of groundwater, and enhance human quality life. Indigenous parasitoids play a major role in the suppression of major pests because they are species-specific and are well adapted to the local environmental habitat and farming systems. For instance, the

Coccinellids, *Cryptol emus montrouzieri*, an effective predator for pests, was introduced to India in June 1898 for the suppression of soft green scale *Coccusviridis* which infests certain fruit and plantation crops like citrus and coffee. Depending on the type of crop and the size of the canopy 5–50 beetles/plant are released. The release of beetles is repeated based on the severity of the infestation of sucking pests. Interestingly, when these predatory beetles are released, it does not adversely affect the other local natural enemies (NEs) and other beneficials. The predatory activity of the beetle, *C. montrouzieri* on jasmines, jacaranda, and roses are proved effective under Karnataka, South Indian conditions. Thrips, as an order of insects, are particularly problematic on flower crops like roses, jasmines, tuberose, and others. The anthocorid predators viz., species of *Orius* are promising against thrips. However, systematic efforts to effectively control thrips in most of the under-developed and developing countries are lacking. Singh (2002) recommended several practices for conserving and augmenting biocontrol agents in cultivated ecosystems. He mentioned refugia, certain species of weeds, hedges, bushes, spot application/strip applications of selective insecticides, and release of egg parasitoids and predatory beetles as practices for sustaining NEs of pests in cultivated ecosystems. But careful monitoring of the impact of beneficial on flowers and ornamental foliage is necessary.

9.7 PHYSICAL AND CULTURAL TOOLS

This is particularly important for small and marginal flower growers. Scouting, preliminary surveys, and visual searches of tender twigs, foliage, buds, and opening-flowers can be valuable and help to reduce pests and pesticide load. The use of yellow sticky cards and light traps also helps in reducing pests and monitoring them. Plants from nurseries and mother-block areas should be free from pests and their infestations. Balanced fertilization and irrigation schedules improve the health of plants and aid in defending pests and pathogens. Growers should not use cuttings infested with pests and pathogens. Leafminers, for example, of *Liriomyza* spp. build up rapidly populations under high nitrogen situations (Harbaugh et al., 1983; Parrella and Jones, 1987). In greenhouses and polyhouses, mesh screens over doors and vents, catch-and-kill, using separators or physical barriers for blocking and no pest residues on previous crops can help protect plants from pests and diseases.

9.8 CHEMICAL CONTROL

Flower growers prefer chemicals over other methods because they are effective and easy to execute relatively. Flowers cultivated for exports, and as cut-flowers, the cost of pest control in such situations is insignificant compared to their worth of the produce. The judicious management of insecticide applications delays or prevents the development of insecticide resistance, and applications are often prophylactic. Under polyhouse conditions, generally on flower crops, pests like *Liriomyza trifolii*, *Trialeurodes vaporariorum* (Westwood); the two-spotted spider mite, *Tetranychus uritae* Koch, western flower thrips, *Frankliniella occidentalis* (Pergande), green peach aphid, *Myzus persicae* (Sulzer), defoliator, *Spodoptera* spp.-all damage the crops and growers apply the pesticides against the above pests frequently. Increasing problems of insecticide resistance under polyhouse conditions can be reduced or delayed by using appropriate dosages, frequency, and time of insecticide applications.

In sum, judicious insecticide applications, the appropriate time for the release of biocontrol agents, and the adoption of physical and cultural practices, supported by research, extension, and training units will lead to rational management packages on flower crops and ornamentals.

KEYWORDS

- **environmentally friendly management tools**
- **flower crops**
- **integrated pest management (IPM)**
- **ornamental foliage**

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CHAPTER 10

PEST MANAGEMENT OF FLOWERING PLANTS UNDER PROTECTED CULTIVATION

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ABSTRACT

The production of crops under protected conditions, whether in climate-controlled greenhouses and glasshouses or covered by plastic sheets or 'insect-proof screening' ('tunnels') with little or no climate control is increasing worldwide. The warm, humid conditions and abundant food under protected conditions provide an excellent, stable environment for pest development. Often, the natural regulating factors such as predators and parasitoids that keep pests under control outside are not present in a protected environment. For these reasons, pest situations often develop in the indoor environment more rapidly and with greater severity than outdoors. The damage inflicted by arthropod pests on greenhouse crops varies with the pest and season. The level of damage that can be highly tolerated is greatly dependent on the type of crop, as ornamental crops cannot accept a high level of damage due to their production for the aesthetic value. Mainly, added-value crops grown under protected cultivation are rose, carnation, gerbera, and chrysanthemum. Several insect-pest and mite species have been recorded in association with the

crops under protected environment. Some of the important pest groups are aphids (*Myzus persicae, Aphis gossypii*), leafminer (*Liriomyza trifolii*), mites (*Tetranychus urticae* and *Polyphagotarsonemus latus),* thrips (*Thrips tabaci* and *Scirtothrips dorsalis*) and whiteflies (*Trialeurodes vaporariorum* and *Bemisia tabaci*). The suitable way of managing these insect-pests can be integrated pest management (IPM). It is a systematic approach to manage pests that combine a variety of techniques and strategies to either reduce pest populations or lessen their economic impact. It is a site-specific strategy for managing pests that relies on correct pest identification and understanding the pest biology. It also includes an emphasis on avoidance, selective use of pesticides, and safe waiting intervals based on harvest time pesticide residues needed to be established for the crop under protected cultivation. Apart from this, emphasis on improving the awareness level of the growers for timely diagnosis and judicious use of insecticides needs to be taken up on priority.

10.1 INTRODUCTION

Protected cultivation practices can be defined as a cropping technique wherein the microenvironment surrounding the plant body is controlled partially/fully as per the plants' need during their period of growth to maximize the yield and resource-saving. The greenhouse is the most practical method of achieving the objectives of protected cultivation of flowering plants, where the natural environment is modified by the use of sound engineering principles to achieve optimum plant growth and yield (more produce per unit area) with increased input use efficiency (Nagarajan et al., 2002). The production of flowering plants under protected conditions, whether in climate-controlled greenhouses and glasshouses or covered by plastic sheets or insect-proof screening with little or no climate control is increasing worldwide. Crops may be grown in-ground bed soil, usually amended with peat or farmyard manure, in benches, in pots containing soil or soil mixtures or soil substitutes, and in hydroponic systems, such as sand or rock wool cultures and flowing nutrient systems, without a matrix for the roots. The purpose of growing crops under greenhouse conditions is to extend their cropping season and to protect them from adverse environmental conditions, such as extreme temperatures and precipitation, and from diseases and insect-pests (Hanan et al., 1978). Modern technology has given the growers some powerful management tools for production. Generally, added-value crops are grown under protection such as rose, carnation, gerbera, and chrysanthemum (Chandra et al., 2000). Greenhouse production, therefore, normally requires a high level of technology to obtain adequate economic on investments. Quality is a high priority aspect for greenhouse crops, requiring much care for insect-pest and disease management, not only to secure yields but also to obtain a high cosmetic standard. Although technological changes are ultimately intended to reduce costs and maximize profits, precise environmental and nutritional control push plants to new limits of growth and productivity (Singh *and* Singh, 2016). This can generate chronic stress conditions, which are difficult to measure, but apparently conducive to some pests and diseases. Historically, not enough attention has been paid to exploiting and amending production technology for the control of insect pests and diseases. This makes the control of insect pests and diseases in protected crops even more challenging, with many important problems being unresolved and new ones arising as the industry undergoes more changes in production systems.

Additionally, the international trade in ornamental and flowering plants facilitates the spread of insect-pests and diseases around the world and their establishment in new areas. In Europe, for example, at least 40 new pests have been recorded in protected crops during the last 25 years. Some of the important pest groups are aphids (*Myzus persicae, Aphis gossypii*), caterpillars (*Spodoptera* spp., *Helicoverpa armigera*), leaf miner (*Liriomyza trifolii*), mites (*Tetranychus urticae*, *Polyphagotarsonemus latus*), thrips (*Thrips tabaci, Scirtothrips dorsalis*) and whiteflies (*Trialeurodes vaporariorum, Bemisia tabaci*). The increasing complexity of insect and mite pests and disease problems and the high cosmetic standards of vegetable, ornamental, and flower products have led growers to apply intensive preventive chemical programs, which result in pests and pathogens becoming resistant to the most frequently used pesticides in a few years, which, in turn, increases control costs. Integrated systems for greenhouse pests and disease control have been developed and implemented in northern Europe and Canada, but implementation is still cumbersome in other parts of the world. Each crop has a set of typical pests that attack under certain conditions. This information should be available with the grower to aid in diagnosis and to help understand the life cycle of the pests.

10.2 WHITEFLY

Whiteflies are serious pests under greenhouse conditions. Greenhouse plastics themselves may have a significant influence on the initial attraction of insects into greenhouses. A study from the late 1990s showed that silver-leaf whiteflies preferred to enter greenhouses covered with a film that transmitted higher levels of ultraviolet light (Costa and Robb, 1999). Two species of whiteflies are prevalent under protected environment, namely, greenhouse whitefly (*Trialeurodes vaporariorum*) and cotton whitefly (*Bemisia tabaci*). A major host of these whitefly species are gerbera, poinsettia, chrysanthemum, bird of paradise, etc. The former is prevalent in temperate regions, whereas the other is a serious pest in tropical and subtropical parts of the country. Both the nymphs and adults of whitefly feed on phloem cell sap and causes chlorotic spots. As a result, the leaves dry up prematurely, and plant growth is affected. Nymphs also secrete honeydew, which is a sticky material and covers leaf surfaces and flowers on which the sooty growth takes place. High humidity conditions favor the development of sooty growth. The female of these sap-sucking insects may lay up to 150 eggs at the rate of 25 per day. The entire life cycle takes 21–36 days, depending on the greenhouse environment. They can complete more than 12 generations in a year (Gerling and Mayer, 1996).

10.2.1 MANAGEMENT STRATEGIES

10.2.1.1 PHYSICAL CONTROL

There are two forms of physical control for whiteflies:

a. **Sticky Traps:** Yellow sticky traps in various forms can be used to trap large numbers of adult whiteflies. Use large, yellow sticky boards or 30-cm yellow sticky tapes in “hot spots.” Alternatively, drape large quantities of yellow sticky tape between posts along plant rows (Figure 10.1). These sticky traps will also attract thrips, fungus gnats, shore flies, and parasitic wasps (especially under low whitefly populations) (McHugh, 1991; Singh *and* Singh, 2016).
b. **Vacuuming:** A Hand-vacuuming adult in “hot-spots” is very effective in rapidly removing adult whiteflies but is not cost-effective over large areas (Figure 10.2).

FIGURE 10.1 Use of yellow tapes for mass trapping.

FIGURE 10.2 Hand-vacuuming adult whiteflies in gerbera.

10.2.1.2 BIOLOGICAL CONTROL

Biological control of the greenhouse whitefly by parasites appears to be an especially advantageous and practical alternative in greenhouses (Hussey and Bravenboer, 1971; Tauber *and* Helgesen, 1970) because the biotic and abiotic factors are amenable to manipulation. In fact, biological control of the greenhouse whitefly was practiced in the late 1920s and 1930s when the parasite *Encarsia formosa* Gahan was utilized in Great Britain, Canada, New Zealand, and Australia, principally to control whiteflies during greenhouse tomato production (Hussey and Bravenboer, 1971). There are currently a number of commercially available biological control agents (BCAs) for whiteflies:

I. Three parasitic wasps: *E. formosa, Eretmocerus eremicus*, and *Eretmocerus mundus* (Figures 10.3 and 10.4).
II. Ladybeetle, *Delphastus catalinae.*
III. Predatory bug, *Dicyphus hesperus* (Price, 1999).

These agents more efficiently reduces insect and mite pest problems in gerbera, poinsettia, and marigold. Additionally, there are two microbial products, *Beauveria bassiana* and *Isaria fumosorosea*, which are fungal pathogens of whiteflies.

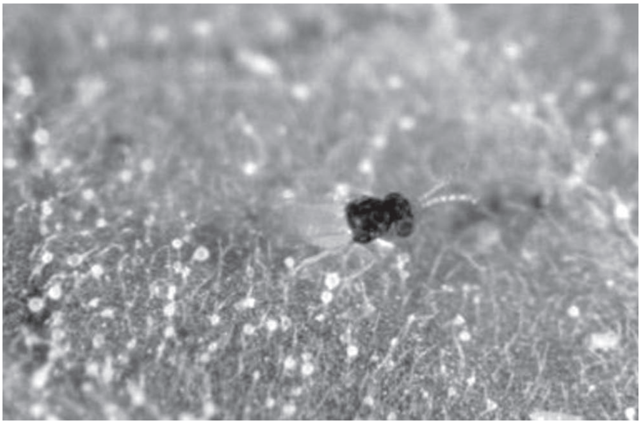

FIGURE 10.3 Adult *Encarsia formosa.*

10.2.1.3 CHEMICAL CONTROL

Whiteflies are difficult to control with pesticides. Immature develop on the lower surface of the leaf where thorough spray coverage is difficult.

Pesticide resistance readily develops, and adults migrate into crops from many other hosts. Whiteflies have multiple, overlapping generations that allow rapid population increase. Eggs and pupae are not susceptible to most insecticides. Early-stage nymphs and adults are most susceptible to pesticides than later stage nymphs. When spraying, spot application is more effective than widespread treatments. Unlike most other materials, oil kills whitefly eggs. Thorough oil coverage also has been found to repel adult whiteflies from landing for about 1 week after application to certain crops like a chrysanthemum. There are some insecticides, fungicides, and miticides compatible with *Encarsia* and *Eretmocerus* spp. are abamectin, azadirachtin, chlorothalonil, fenoxacarb, kinoprene, iprodione, etc.

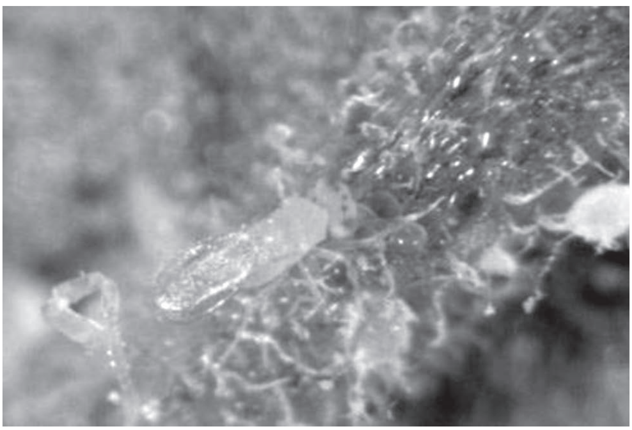

FIGURE 10.4 Adult *Eretmocerus eremicus.*

10.3 THRIPS

Thrips are one of the most difficult pests to control in greenhouses. They are tiny insects that reproduce rapidly, congregate in tight places that make pesticide coverage difficult and feed with rasping–piercing-sucking mouthparts, resulting in deformation of flowers and leaves. Tolerance to thrips on floriculture crops is particularly low. The western flower thrips, *Frankliniella occidentalis*, is one of the most significant pests of cut flower production. Greenhouse thrips (*Heliothrips haemorrhoidalis*), thrips (*Hercinothrips femoralis*), onion or tobacco thrips (*Thrips tabaci*) and banded greenhouse flower thrips (*Frankliniella tritici*), are other species, which are found on rose, gerbera, chrysanthemum under protected cultivation (Murphy et al., 1998). Apart from leaves, thrips usually feed on flower petals, because scarring to them resulting in aesthetic damage, leading to problem in marketing of flowers. For many flower crops, most of the pesticide sprays applied to target thrips.

10.3.1 MANAGEMENT STRATEGIES

10.3.1.1 PHYSICAL CONTROL

Crop scouting program that includes both sticky traps and visual inspection is critical. Scouting should be done once a week and more often when an infestation is detected. Hot-pink sticky cards have been found to be the most attractive color for trapping thrips, though blue is often still used. Singh and Singh (2016) have observed blue sticky traps to be effective for thrips in gerbera. Sticky traps should be placed 2.5–5.0 cm above the crop canopy so that the bottoms of the traps are just above the crop, at the rate of one or two per 400 m^2. A threshold level of 20 WFT/trap/week was figured to be appropriate for chrysanthemums in Switzerland (Parella, 1995). In contrast, a greenhouse in New Mexico initiates pesticide application when 5 thrips/trap/week are detected, and chrysanthemums make up 80% of its crop mix (Aylsworth, 1994). The following suggestions on effective integration of sticky cards and indicator plants were given by Pundt et al., (1992).

a. Sticky cards should be placed throughout the operation to detect location and number of thrips.
b. Indicator plants should be placed among crops at bench or floor level. One plant every 20–30 ft seems to work well.
c. Incoming plant material should be placed with indicator plants and isolate for at least 3–4 days to allow thrips scars to develop and show viral lesions.

10.3.1.2 BIOLOGICAL CONTROL

Biological control of greenhouse thrips can be achieved through release of biocontrol agents such as predators (predatory mites, lady beetles, and soil-dwelling mites), parasitoids, and pathogens (Tables 10.1 and 10.2).

TABLE 10.1 Some of the Predators Available for the Management of Insect Pests of Flowering Plants Under Protected Cultivation

Organism	Supplier	Application/Comments
Chrysopa carnea	Natural Pest Controls, Beneficial Insectary, Caltec, Arbico, A-1 Unique Insect Control, Praxis, Rincon-Vitova, Hydro-Gardens	1 lacewing/5–30 aphids; 1000 eggs/67 m^2 Apply every 1–3 weeks as needed. May arrive as eggs, immature, or adults
Coleomegilla maculata	Arbico	3 predators/m^2; shipped as larvae and eggs
Deraeocoris brevis (predator)	Green Spot	-
Neoseiulus cucumeris and *N. barkeri*	Hydro-Gardens	3 predators/m^2; humidity should be moderate, temperature 70°F. Establish population early. Repeat every month during periods of warm, dry weather
Orius insidiosus (minute pirate bug) (predator)	Florikan, IPM Labs., Harmony Farm Supply, Arbico, Hydro-Gardens, Praxis, Koppert, Intl. Tech. Services, Green Spot	1/3 m^2 (preventive), 2 every m^2 when pests are present. Temperature should be 70–90°F. *Orius* spp. are dormant during September–April. Reapply every 2–3 weeks. Very susceptible to pesticides. Works well in combination with *Neoseiulus cucumeris*

TABLE 10.2 Pathogens Available for Biological Control of Insect Pests of Flowers Under Protected Cultivation

Brand Name	Supplier	Application/Comments
Beauveria bassiana	Naturalis-O SePro	Apply when insects first appear and repeat every 7–10 days. Good spray coverage is needed. Not compatible with other fungicides.
Beauveria bassiana	BotaniGard Mycotech	-do-

There are some case studies which show the biological control method is one of the best ways to manage insect-pest under-protected cultivations:

- Adult pirate bugs (*Orius* sp.) consume 5–20 thrips (all stages) in one day. They can even survive on pollen if the prey is absent.

Both adults and nymphs are predatory in nature. *Orius* is the only predator that attacks thrips in tight places like flower buds. Since *Orius* is a strong flyer, it moves easily throughout the greenhouse.

- In laboratory trials and caged rose trials, the entomopathogenic fungi (EPF) *Beauveria bassiana* spray killed up to 82% of the thrips on rose foliage (Murphy et al., 1998). It has been observed that mortality increased along with humidity. Oil formulations of *B. bassiana* worked more quickly than wettable powders.
- Four applications of Naturalis-O over a period of 15 days controlled thrips well on gerbera (Gilrein, 1999).

10.3.1.3 CHEMICAL CONTROL

Most stages of thrips are protected from sprays as eggs are imbedded in the tissues, larvae live in developing terminals leaves or buds, and pupae are found in the media/soil. These are the reasons that chemical control is difficult in thrips. Reinfestation occurs when thrips are carried into crops by wind or fly from nearby hosts. WFT is resistant to many pesticides. Therefore, pesticides should be used only in combination with good sanitation and exclusion. Besides, biorational pesticides are effective against the thrips. Major biorational pesticides are *Azadirachtin,* Azatin, Neemazad, Hot pepper wax–contains capsaicin, paraffin, and mineral oil and *Neem oil*. Neem extracts (trade names Azatin, Neemazad, and Neemix) prevent the development of flower thrips in the early larval stages, but they have no effect on adults. Repeated applications are most effective. Biorational control of flower thrips was achieved with either (i) M-Pede insecticidal soap mixed with emulsified crop oil or (ii) weekly applications of neem seed oil (NSO) for four straight weeks.

10.4 APHID

Aphids rank among the most serious pests of greenhouse crops like rose, chrysanthemum, gerbera, and orchids (Ebert *and* Cartwright, 1997). There are approximately 4000 aphid species in the world. Life cycles and preferred hosts vary with each type of aphid. Common aphid pests of greenhouse crops include the green peach aphid (*Myzus persicae*), the melon/cotton aphid (*Aphis gossypii*), the chrysanthemum aphid (*Macrosiphoniella sanborni*), the rose aphid (*Macrosiphum rosae*) and the foxglove aphid (*Aulacorthum solani*) (Lindquist, 1991). The green peach aphid, *M. persicae* is probably the most notorious aphid pest of greenhouse crops. The reasons behind this are its wide host range, worldwide distribution, and difficulty of control and its nature as a vector of a number of viral diseases (Sunderland, 1992).

10.4.1 MANAGEMENT STRATEGIES

10.4.1.1 PHYSICAL CONTROL

Plants should be visually inspected regularly for signs of aphid attack. Plant parts like the undersides of leaves, stems, and new growth need to be properly checked (Singh *and* Singh, 2016). Choose plants randomly throughout the greenhouse and inspect undersides of leaves, buds, or tip growth and watch for honeydew and cast skins. Yellow sticky cards placed can be used to monitor winged aphids. However, since winged aphids caught during the summer months may have blown in from the outdoors; sticky cards are not as reliable as visual inspections. Signs of an aphid infestation include honeydew or sooty mold on leaves, yellow spots on upper leaf surfaces, cast skins on leaves, curling of leaves, and distortion of newly emerged leaves (Figure 10.5).

10.4.1.2 BIOLOGICAL CONTROL

There are several biological control options for greenhouse aphid pests. Some common BCAs include green lacewings (*Chrysoperla carnea, C. rufilabris, Chrysopa* spp.), aphid midges (*Aphidoletes aphidimyza*), parasitic wasps (*Aphidius colemani* and *A. matricariae*) and lady beetles (*Hippodamia convergens*). Gissella et al., (2006) reported that *A. colemani* was effectively controlling the cotton aphid, *Aphis gossypii* in greenhouse-grown chrysanthemums, *Dendranthema grandiflora* (Tzvelev), as compared with a pesticide imidacloprid (Marathon 1% G) and an untreated check. According to the Heinz (1998), in greenhouse-grown chrysanthemums and rose, aphids like *Myzus persicae* and *A. gossypii* can be effectively controlled by *C. rufilabris* and *A. colemani*.

Strains of the fungus *B. bassiana* provide good control of aphids, including green peach aphids. The fungus works by attaching to the outside of the pest and then penetrating into the body and killing it. The fungus is available commercially for greenhouse ornamentals as Naturalis-O and for vegetables as BotaniGard (Table 10.3).

FIGURE 10.5 Rose plant infested with aphid.

TABLE 10.3 Biopesticides Based on *Beauveria Bassiana*

Brand Name	Supplier	Application/Comments
Naturalis-O	SePro	Apply when insects first appear and repeat every 7–10 days. Good spray coverage is needed. Not compatible with other fungicides.
BotaniGard	Mycotech	-do-

10.4.1.3 BIORATIONAL PESTICIDES

Least-toxic pesticides used against aphids in greenhouses include insecticidal soap (M-Pede), horticultural oil (SunSpray Ultra-Fine Spray Oil), and botanical insecticides such as neem (Azatin, Neemazad, and Neemix) or natural pyrethrums (Table 10.4).

TABLE 10.4 Biorational Pesticides

Brand Name	Supplier	Application/Comments
Azatin	Green Spot	Apply when pests first appear
Neemazad	Thermo Trilogy	It cannot be applied through irrigation. A low rate can be used as a preventative
Garlic Barrier	Green Spot	Use late in the day. It can be mixed with fish oil or horticultural oil. Do not use in combination with bumblebees or honeybees
Hot Pepper Wax	Green Spot	It also contains herbal essential oils. Not compatible with beneficials
M-Pede	Mycogen	Phytotoxicity is often a concern, especially after repeated applications

10.5 MITES

They are much smaller in size than many insects, feature prominently in greenhouses, both as pests causing economic injury to greenhouse crops and natural enemies (NEs) used in biological control of pest insects and mites in greenhouse (Singh *and* Singh, 2016). Common pest mites found in greenhouse are Two-spotted spider mite (*Tetranychus urticae*), Carmine spider mite (*Tetranychus cinnabarinus*), Broad mite (*Polyphagotarsonemus latus*), Cyclamen mite (*Phytonemus pallidus*) and Bulb mite (*Rhizoglyphus echinopus*) which are infesting rose, gerbera, chrysanthemum, lily, gladiolus, and tulip. These mites feed by piercing tissue with their mouthparts and sucking out cell contents.

10.5.1 MANAGEMENT STRATEGIES

10.5.1.1 BIOLOGICAL CONTROL

The common predatory mites, which are present in greenhouse, are *Neoseiulus californicus*, *Phytoseiulusper similis, N. cucumeris*, *P. macropilis*, *N. fallacis*, *N. longispinosus*, and *Galendromus occidentalis* (Table 10.5). Predatory midges are also useful biocontrol agents against spider mites in rose. For example, *Feltiella acarisuga*, is commercially available for use in many countries. Adults of *F. acarisuga* looks like mosquito but are smaller in size. They mate within 24 h of emergence and locate spider mite colonies, where they lay about 30 eggs over a 5-day life span. Development occurs over a range of 15–25°C and is slowed down at 27°C. The eggs and larvae are killed at 30°C and above. The larvae hatch from eggs in a couple of days and feed on all stages of spider mites. They feed for 4–6 days and consume a total of about 150 spider mite eggs. Opit et al., (2004) opined that *P. persimilis* were worked as a suppressive agent of the two-spotted spider mite, *T. urticae* on greenhouse ivy geranium.

TABLE 10.5 Greenhouse Crops, Their Pests, and the Mites used for Their Control

Crop	Target Pest	Predator	References
Chrysanthemum	*F. occidentalis*	*N. cucumeris*	Skirvin et al., 2006
	T. urticae	*Stratiolaelaps scimitus*	Bennison et al., 2002
		P. persimilis	
		G. aculeifer	
Gerbera	*F. occidentalis*	*T. montdorensis*	Steiner *and* Goodwin, 2002
Lilies	*Rhizoglyphus robini*	*G. aculeifer*	Lesna et al., 2000
Rose	*T. urticae,* *F. occidentalis,* *T. vaporariorum*	*N. californicus* and *P. persimilis*	Blumel *and* Walzer, 2002
		N. cucumeris	Vanninen *and* Linnamaki, 2002
		E. ovalis	
			Pijnakker, 2005

10.5.1.2 CHEMICAL CONTROL

Chemical control of spider mites is becoming more and more difficult due to the rapid development of resistance in mites and decrease in the number of registered acaricides for use (Table 10.6). For example, clofentezine resistance in *T. urticae* was recorded in Australia in 1987 after mites in Queensland greenhouse roses had been exposed to 40 applications of clofentezine over a 10-month period.

Chemical control of *T. urticae* can be integrated with biological control by using selective chemicals that are less or not toxic to NEs or by using chemicals in selected areas of the crop. In greenhouses of Belgium, a stable equilibrium between *T. urticae* and the predator *P. persimilis* is achieved by selective use of chemicals and creating an asynchronous development in the predator population. The predators are introduced into one end of the greenhouse, while acaricides (Torque 50% (fenbutatin oxide) and hexythiazox (Nissorun 10%)) are sprayed into the other end. Only 3300 predators per 100 m^2 combined with three acaricide treatments applied to half the plants are required to control the pest for 30 weeks. After establishment, this system is self-regulating and so the use of acaricides is needed only initially. It may also be possible to apply chemical control to some part of the plants while giving biological control a chance in other parts. For example, integrated control might be possible for spider mites on roses if different injury levels are assigned to the upper and lower canopies and sprays are confined to upper canopies. The upper portion of a rose canopy has an extremely low injury level because it bears the flowers and foliage which are cut for sale. Low population of spider mites may not affect the quantity of the product, but they destroy its aesthetic appearance. Confining pesticide applications to only a portion of the canopy may create refugia for pesticide susceptible individuals of *T. urticae* that may breed with resistant ones and thereby retard the development of pesticide resistance. This also allows *P. persimilis* to be used for biological control of spider mites on lower canopies.

TABLE 10.6 Chemical Control Measures for Greenhouse Mites

Chemical	Trade Name	Effective On
Abamectin	Avid	Broad mites, cyclamen mites, eriophyid mites, false spider mites, two-spotted spider mites
Bifenthrin	Talstar	Broad mites, eriophyid mites, false spider mites, two-spotted spider mites
Bifenazate	Floramite	Red spider mites, two-spotted mites
Deltamethrin	DeltaGard	Mites (general)
Dicofol	Kelthane	Broad mites, cyclamen mites, red, and two-spotted spider mites
Fenpyroximate	Akari	Red and two-spotted spider mites
Pyridaben	Sanmite	Two-spotted spider mites
Propargite	Omite	Red and two-spotted spider mites
Spinosad	Conserve	Red and two-spotted spider mites
Spiromesifen	Forbid	Broad mites, cyclamen mites, eriophyid mites, false spider mites, two-spotted spider mites

10.6 LEAFMINERS

The dipterous leafminers belong to the family Agromyzidae, which includes 1800 described species of which 156 species are reported as pests. However, under greenhouse conditions only a handful of polyphagous species are of economic importance (Spencer, 1973). Four main species of leafminer are important in greenhouses; *Liriomyza bryoniae,* a European species, *Liriomyza trifolii*, a polyphagous American species on a wide range of greenhouse crops, *Liriomyza huidobrensis* and *Phytomyza syngenesiae*, the chrysanthemum leafminer, is a widely distributed Western European species. It has a broad host-plant range among ornamental crops but is a serious pest mainly on chrysanthemum. Leafminers cause two types of damage. Direct damage occurs as a consequence of larval feeding inside the leaf and adult feeding punctures on the leaf upper side. Feeding punctures made by adult females can be particularly damaging for seedlings and young plants. Besides the direct damage caused by larval mining and adult host feeding, leafminers may cause severe indirect damage by providing infection sites for damaging fungi such as *Verticillium* spp. and *Fusarium* spp.

Chemical control of leafminers is quite complicated due to their endophytic habits and high reproductive rate. Resistance to insecticides in leafminers has been repeatedly reported, particularly in *L. trifolii.* Most insecticides are toxic for the parasitoids that control leafminers and that have shown an excellent capacity to naturally parasitize exotic leafminers that have been successively introduced into Europe.

10.6.1 MANAGEMENT STRATEGIES

10.6.1.1 BIOLOGICAL CONTROL

Many NEs can develop on larvae and pupae of the *Liriomyza* miners. Many species have been identified as parasitoids of *Liriomyza* larvae. Parasitoids recorded on *L. trifolii* and *L. sativae* and on *L. huidobrensis* in the have been reviewed by Minkenberg and van Lenteren (1986) and van der Linden (1990) respectively. Braconids parasitoids include *Opius pallipes* and *Dacnusa sibirica*. Eulophids belong *Chrysocharis parksi* and five *Diglyphus* species: *Diglyphus isaea*, *Diglyphus begini*, *Diglyphus* *intermedius*, *Diglyphus pulchripes,* and *Diglyphus websteri*. Mirid bug *Cyrtopeltis modestus* is usually included as a predator of leaf miners (Parrella and Bethke, 1983). The entomopathogenic nematode *Steinernema carpocapsae* (Weiser) may be effective against *L. trifolii* pupae in the soil.

10.7 CONCLUSION

The increasing importance of international trade of flowers will probably result in an acceleration of the establishment of exotic insect and mite pests in old and new greenhouse areas. Despite efforts devoted to preventing or reducing the entrance of exotic phytophagous species, the list of new pests in greenhouses becomes longer every year. A global distribution of all important greenhouse pests in the future seems difficult to avoid. Globalization of pest occurrence is a common phenomenon in all crops, but particularly prevalent in protected cultivation. The international trade in an increasing variety of ornamentals, the favorable conditions of greenhouse environment for a rapid increase in the pest population, and the capacity of some insects and mites to establish in open field explain the special relevance of the problem in protected cultivation. Several actions to mitigate the problem need to be undertaken. Firstly, a list of potential pests that are likely to arrive and establish in new areas should be compiled. Then, biological data on the potential pests should be collected in order to identify ways to prevent their importation and establishment. Complete information on the potential pests with accurate data on their life history, plant hosts, climatic preferences, biocontrol agents, and other control tactics and tools would allow the areas and crops with the major risks to be defined. There is an urgent need for effective quarantine programs, which though do not completely prevent pest entry but may delay it and will provide time to prepare for management programs in case, there is any attack of pests. Quick and reliable tools and mobile apps for detection and identification would help in adopting the right ways to avoid the spread of the pest from the infestation origin and eventually its eradication. If finally the pest becomes established, the potential control methods that have been previously defined may be more rapidly tested *in situ.*

KEYWORDS

- **insect-pests**
- **mites**
- **ornamental plants**
- **protected cultivation**

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CHAPTER 11

ECO-FRIENDLY MANAGEMENT OF *HELICOVERPA ARMIGERA* IN COMMERCIAL FLOWERS

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ABSTRACT

The bud borer, *Helicoverpa armigera* (Hubner), is an important pest of several commercial flower crops and inflicts serious damage by feeding on the buds and flowers. The pest is managed mainly by applying insecticides, which poses a serious threat to the non-target organisms as well as leads to environmental pollution. Therefore, following an integrated approach for the management of this pest will be ecologically sustainable and economically viable. Forecasting technology of actual field infestation of bud borer based on pheromone trap monitoring of adult moths could be an important tool in formulating IPM strategy against the pest. Different morphological and floral characters of carnation and chrysanthemum lead to the non-preference mechanism of resistance against this pest and can be exploited for the production of tolerant varieties. Different biopesticides like *Bacillus thuringiensis* var *kurstaki* (Btk), *Helicoverpa* Nuclear Polyhedrosis Virus (Ha NPV), and Neem Seed Kernel Extract (NSKE) are effective against *H. armigera* in flower crops when applied alone or in combination with synthetic contact insecticides. The insects

like *Chrysopa* spp., *Chrysoperla* spp., *Nabis* spp., *Geocoris* spp., *Orius* spp., and *Polistes* spp. constitute the most common predatory fauna of *H. armigera* whereas, *Campoletis chlorideae* is the most widely distributed larval parasitoid of this pest. The new chemistry insecticides like indoxacarb and flubendiamide can be good IPM compatible chemicals for the management of *H. armigera* with less hazardous impact on the natural enemy complex of this pest.

11.1 INTRODUCTION

Floriculture industry comprises of flower trade of loose flowers and cut-flowers, production of nursery plants and potted plants, seed, and bulb production, micropropagation, and extraction of essential oils. Flower crops are cultivated under open field as well as protected conditions. Due to large scale commercial cultivation of flowers under intensive input use, the problems of pest infestation have increased manifold in the past 2–3 decades. The flower crops are invaded by several insects, mites, and nematode pests. The bud borer, *Helicoverpa armigera* (Hubner), is one of the most important pests causing serious damage to the various commercial flowers like carnation, gerbera, chrysanthemum, etc. (Singh, 1983; Sood, 1988; Singh and Sohi, 1990; Pal and Sarkar, 2009). It is a cosmopolitan and widely distributed insect pest in the world.

The caterpillars of *H. armigera* bore inside the buds of carnation, gerbera, gladiolus, chrysanthemum, etc. devouring the inner content as well as on the flower petals (Pal *and* Sarkar, 2009). Young caterpillars are pale green in color, but the later instars may be of different colors (yellowish-green to dark brown) and markings. But the caterpillars can be easily identified by the presence of white wavy lines along the lateral sides of the body. The caterpillars are voracious feeders, occasionally carnivorous on other smaller insects and, sometimes even cannibalistic. The adult moths are good fliers and are mostly active at night (nocturnal). The pest has an affinity to feed on the reproductive parts of crops inflicting serious economic losses. In the warmer areas like tropics, the pest is active throughout the year, but in cooler regions, the pest undergoes diapauses in the pupal stage in winter months.

This pest is reported damaging flowers and buds of carnation to the extent of 62–80% by a number of authors from various parts of the world (Pietanza, 1969; Mckay, 1981; Singh, 1983). The application of synthetic insecticides is the widely followed means of controlling this pest. But growing concerns over the harmful effects of pesticide use have prompted growers to opt for alternative pest management strategies. Moreover, there are reports from all over the world, which indicates that *H. armigera* has developed resistance to most of the conventional insecticides (Kranthi et al., 2002). Therefore, pursuing a comprehensive integrated approach to combat this pest menace is the need of the hour.

11.2 PEST MONITORING

Monitoring of adult moths of *H. armigera* with pheromone traps is one of the important components in the integrated pest management (IPM). The monitoring of populations by pheromones is useful for forecasting future pest infestation. The major sex pheromone component of *H. armigera* has been identified as (Z) 11- hexadecenal (Piccardi et al., 1979; Gothief et al., 1978). Two compounds that elicited an electro-antennographic response from the male moth were identified as (Z) 11-hexadecenal and (Z) 9-hexadecenal (Nesbitt et al., 1980). Pawar et al., (1988) and Srivastava et al., (1990) extensively studied the monitoring of *H. armigera* using pheromone traps. However, the pest monitoring is only reliable, if the relationship between the pheromone trap catches and the corresponding field population estimate is good and consistent across time. A number of workers like Srivastava et al., (1990), Kaushal (1997) and Visalakshmi et al., (2000) studied the relationship between moth activity and actual field infestation with a view to explore the possibility of predicting larval population in the field on the basis of pheromone trap catch data. The result of one such experiment conducted by Pal et al., (2014) in carnation crop revealed out that the adult activity could be best correlated with the larval population one week later as it was found that the larval count in the n^{th} week registered significant positive association with the moth catch data of the preceding week, i.e., $(n–1)^{th}$ week for both the seasons (Table 11.1).

The correlation between egg counts and pheromone trap catches, recorded in the same week and 1 week earlier were also significantly positive for both the years signifying a close and consistent relationship between moth activity and corresponding field infestation. Similarly, the adult activity was found to have a closer positive association with the percentage in bud damage data recorded one and two weeks later (though significantly positive for only one season).

TABLE 11.1 Correlation Coefficient (r) Between Male Moth Trap Catches of *H. armigera* and its Field Infestation

Male Moth Trap Catches of *H. armigera*	**Field Incidence**					
	No. of Eggs		**No. of Larvae**		**% Borer Infestation**	
	2008–2009	**2009–2010**	**2008–2009**	**2009–2010**	**2008–2009**	**2009–2010**
Current week (n)	0.599*	0.745**	0.194	0.645*	0.133	0.517
One week back (n–1)	0.629*	0.736**	0.590*	0.676*	0.476	0.588*
Two weeks back (n–2)	0.643*	0.292	0.488	0.405	0.429	0.652*

*Significant at 5% level.

**Significant at 1% level.

Source: Adapted from Pal et al., (2014).

The use of pheromone traps to forecast egg density of *H. armigera* on tomato and carnation crops on the coast of Catalonia, Spain, was analyzed. Maximum egg densities were in July and September for tomato and carnation, respectively. The host selection throughout the study explained these differences. Phenology and the situation of the alternative host in the areas were important for the interpretation of egg densities on a specific crop. Positive correlations between egg densities and pheromone catches were found for tomato and carnation. The use of phenological or time parameters in the predictive models is basic to improve their adjustment. The accuracy of the predictions is debatable (Izquierdo, 1996) (Figure 11.1).

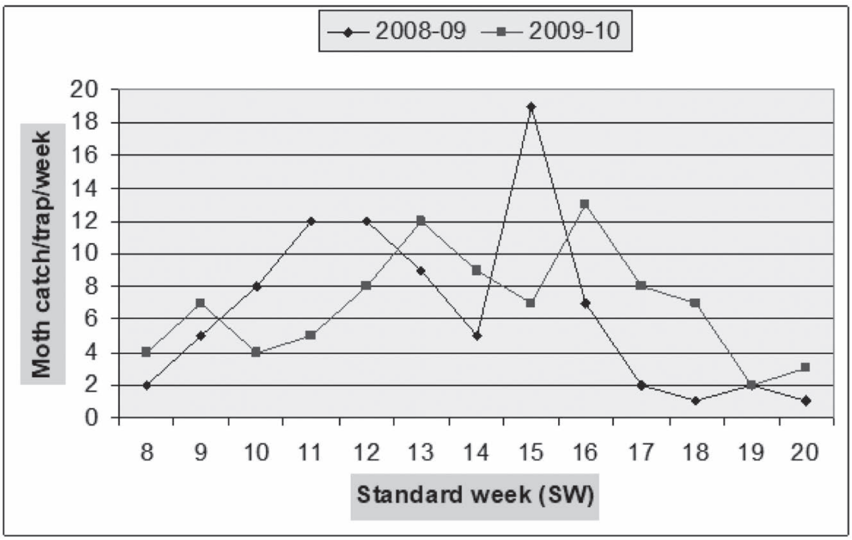

FIGURE 11.1 Weekly catches of *H. armigera* male moths in pheromone traps at Kalimpong, India

Source: Pal (2013), Thesis submitted to Visva-Bharati, Santiniketan.

In mid-hills of Himachal Pradesh, India, the adult activity of *H. armigera* on carnation started by the last week of March and ended by the last week of June with the maximum population of the pest in last week of April to mid-May (Kaushal, 1997). Jhansi Rani (2001) observed its infestation from May to September on carnation in polyhouse under Bangalore (India) conditions. This pest caused extensive damage to flowers at Ludhiana (India) from the end of March to the first week of April during 1990 in an epidemic form (Singh *and* Sohi, 1990). Pal and Sarkar (2010) studied the pest incidence on spray type carnation under mid-hill conditions of Kalimpong (India) and recorded *H. armigera* in more numbers during hot summer months of April-May.

11.3 HOST PLANT RESISTANCE

Host plant resistance to insect pests feeding is probably the most economically and environmentally sound method of pest management. Because it is less labor-intensive and more secure compared to other methods. This method of pest control is very appropriate for resource-limited flower growers of developing countries of Asia and Africa. To minimize the use of synthetic insecticides and problems arising out of their frequent use, it is very essential to identify resistant or tolerant varieties that hold immense value in the IPM program. Based on the pooled mean of two seasons, four varieties of carnation namely Dover, Lavender Lace, Tikar, and Madras were categorized as least susceptible to bud borer, *H. armigera* showing less than 10% bud infestation (Pal et al., 2015). The presence of a large amount of variation in morphological and floral characters among the genotypes of carnation has been reported by a number of workers like Lal et al. (1998) and Sharma and Srivastava (2008). Some of these plant characters may result in the possible non-preference mechanism of resistance to bud borer (Kashyap, 1983; Khanam et al., 2003; Rath *and* Tripathy, 2006). The bud borer infestation in carnation was found to be significantly and positively correlated with plant height, number of branches per plant, and bud/flower number per plant. A negative correlation was found between bud borer infestation and thickness of calyx (Pal et al., 2015) (Figure 11.2).

Kaushal (1997) recorded varying levels of damage on different carnation varieties. The extent of damage in terms of percentage in infestation ranged between 10–80% on six cultivars of carnation viz., Candy, Espana, Irma, Orange Triumph, Red Corso, and White Candy. Pal and Sarkar (2010) also recorded varying levels of bud borer infestation on different germplasm of spray-type carnation under the mid-hill conditions of Kalimpong, India, and recommended the germplasm Acc. No. 19 and Atletic Schubert for commercial exploitation due to multiple tolerances to all the pests.

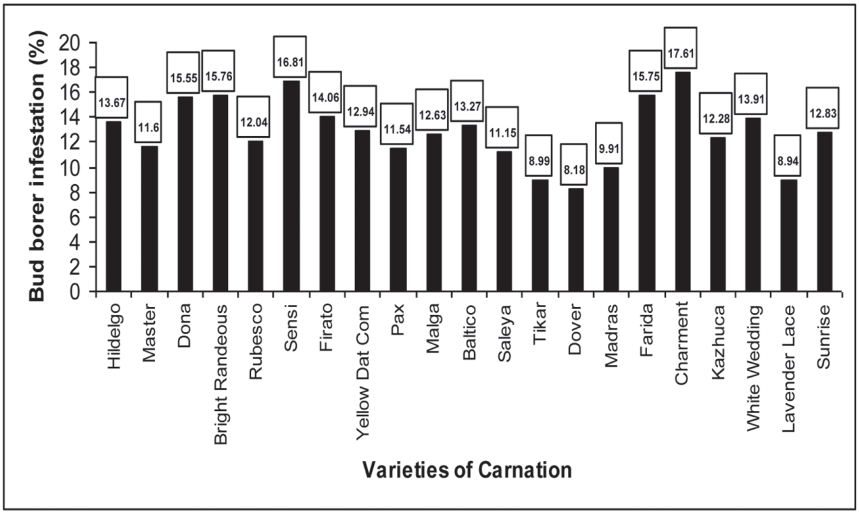

FIGURE 11.2 Bud borer (*H. armigera*) infestation on Standard Carnation varieties at Kalimpong, India.

Source: Pal (2013), Thesis submitted to Visva-Bharati, Santiniketan.

The chrysanthemum varieties, namely Angel Bell, Arka Swarna, Chandrika, Nilima, Snow Ball, Collection No. 9 were found to be less susceptible to the bud borer, *H. armigera* damage (< 10% flower damage) (Reddy et al., 2004).

11.4 BIOPESTICIDES AND BIOAGENTS

The bud borer, *H. armigera*, is reported to be infected by a number of microorganisms in its natural environment (Majumdar et al., 1955; Sankhyan, 1992). Most natural populations of *H. armigera* have at least some degree of infection by species-specific nuclear polyhedrosis viruses (NPVs). If the degree of NPV infection can be enhanced, then the *Helicoverpa* larval population can be decimated, without deleterious effects on any other organism (Wubneh, 2016). Biopesticides like *Bacillus thuringiensis* (Bt), *Helicoverpa* Nuclear Polyhedrosis Virus (Ha NPV), and NSKE were found as effective as endosulfan against *H. armigera* (Prasad et al., 2003). Biopesticides, when applied in combination or in rotation with the synthetic insecticides, were quite effective for the management of

H. armigera (Sharma, 2004). In an experiment with carnation, the chemical insecticides were superior to biopesticides like *Bacillus thuringiensis,* Neem Seed Powder Extract (NSPE), and Ha NPV in reducing the infestation of carnation bud borer, *H. armigera* and providing higher net return per rupee invested. The treatments with a combination of a half dose of endosulfan with NPV and NSPE recorded moderate level of effectiveness in efficacy and economics against *H. armigera* but were superior to individual treatments with biopesticides (Pal et al., 2013) (Table 11.2).

The relative toxicity of NSKE, neem leaf extract, neem leaf powder, karanj oil, neem oil, henge oil, with, and without insecticide was studied at different AICRIP centers in the country against *H. armigera* infesting chickpea and pigeon pea and it was found that all the treatments were significantly superior over control both in the pest control as well as yield (Sachan *and* Lal, 1990).

Predators for *Helicoverpa* spp. such as *Chrysopa* spp., *Chrysoperla* spp., *Nabis* spp., *Geocoris* spp., *Orius* spp., and *Polistes* spp. are the most common in India (Wubneh, 2016). Of the various parasitoids of *H. armigera*, *Campoletis chlorideae* Uchida is most widely distributed. It parasitizes *H. armigera* larvae on all host crops. Parasitization is as high as 83% (Singh, 1990). Also, Sankhyan (1992) reported *C. chlorideae* to cause high larval mortality in *H. armigera* in the mid-hills of Himachal Pradesh. Fatma and Pathak (2011) reported that *H. armigera* (Hubner) was heavily parasitized on chickpea and pigeonpea in different districts of northeastern Uttar Pradesh, India. Two parasitic wasps, one egg parasitoid *Trichogramma chilonis* Ishii and another larval parasitoid *Campoletis chlorideae* Uchida, were naturally occurring and can be used in the control of *H. armigera* on crops where natural parasitism seemed to be high.

11.5 CHEMICAL CONTROL

The bud borer, *H. armigera*, is considered a rather difficult pest to control as it develops resistance at a very fast rate and has already been reported resistance against many pyrethroids, carbamates, and organophosphorus insecticides (Elzen et al., 1992). On ornamental plants, *H. armigera* is controlled principally by chemical means. The insecticides most commonly used against this pest included deltamethrin and fenvalerate. Kulibaba and Ignatova (1973) reported various insecticides for the control of this pest

TABLE 11.2 Economics of Biopesticides and Insecticides Against Carnation Bud Borer, *Helicoverpa armigera* (Hb.)

Treatments	Marketable Flower (No./Plot)		Marketable Flower (No./100 sq.m.)		Additional Flower Over Control (No./100 sq.m.)		Additional Income Over Control (Rs. /100 sq.m.)		Cost of Protection (Rs. /100 sq.m.)		Net Income (Rs. /100 sq.m.)		Net Gain (Rs.)/Rupee Invested	
	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011
T_1 –Endosulfan @ 1.5 ml/l	8.83c	8.50ab	441.50	425.00	108.00	133.50	108.00	133.50	11.25	11.25	96.75	122.25	8.60	10.87
T_2 – Indoxacarb @ 0.3 ml/l	10.33a	9.83a	516.50	491.50	183.00	200.00	183.00	200.00	12.90	12.90	170.10	187.10	13.19	14.50
T_3 – Flubendiamide @ 0.1 ml/l	10.17ab	9.67a	508.50	483.50	175.00	192.00	175.00	192.00	19.50	19.50	155.50	172.50	7.97	8.85
T_4 – Btk @ 1 g/l	8.50cd	6.83bc	425.00	341.50	91.50	50.00	91.50	50.00	16.02	16.02	75.48	33.98	4.71	2.12
T_5 – NSPE @ 40 g/l	7.50de	7.17bc	375.00	358.50	41.50	67.00	41.50	67.00	14.50	14.50	27.00	52.50	1.86	3.62
T_6 – NPV @ 1.5 ml/l	8.33cd	7.00bc	416.50	350.00	83.00	58.50	83.00	58.50	40.50	40.50	42.50	18.00	1.05	0.44
T_7 – NPV + Endosulfan (@ 1.5 ml + 0.75 ml/l)	9.67abc	9.17a	483.50	458.50	150.00	167.00	150.00	167.00	43.88	43.88	106.12	123.12	2.42	2.81
T_8 – NSPE + Endosulfan (@ 40g + 0.75 ml/l)	9.00bc	8.50ab	450.00	425.00	116.50	133.50	116.50	133.50	17.88	17.88	98.62	115.62	5.52	6.47
T_9 - Control	6.67e	5.83c	333.50	291.50	-	-	-	-	-	-	-	-	-	-
C.D. (P=0.05)	1.24	1.80												

Figures in the same column indicated by the same alphabet are not statistically different.
Price of carnation flower at the farm level: Rs. 1/flower
Cost of biopesticides and insecticides: Endosulfan (Thiodan 35 EC) @ Rs. 45/100 ml, Indoxacarb (Avaunt 14.5 SC) @ Rs. 280/100 ml, Flubendiamide (Fame 480 SC) @ Rs. 150/10 ml, *Bacillus thuringiensis* var. *kurstaki* (Halt 5% WP) @ Rs. 1152/kg, Neem fruit powder (Agri Life) @ Rs. 25/kg, NPV (Heli-cide) @ Rs. 240/100 ml
Labor charges for insecticidal application: Rs. 450/spray/ha
Source: Adapted from Pal et al., (2013).

on flowering plants. Spraying of endosulfan 0.07% or methyl parathion 0.05% or etofenprox 0.01% when eggs are observed on buds controls damage by the pest effectively in ornamental crops (Jhansi Rani, 2001).

Sood and Kakar (1990) reported the efficacy of endosulfan 0.05%, Malathion 0.05%, cypermethrin 0.0075%, deltamethrin 0.002%, and fenvalerate 0.015% for the control of *H. armigera* on ornamentals in Solan. Satpute and Mote (2002) tested the less hazardous insecticides including biopesticides and plant-derived pesticides, i.e., cypermethrin (0.0075%), NPV (500 LE/ha) and Nimbitor (azadirachtin, 0.5%) alone or in combination, against *H. armigera* on chickpea in Rahuri, Maharashtra, India, and found that the combination of Cypermethrin + NPV recorded significantly less larval population at the end of the third spray given at an interval of 15 days starting 45 days after sowing. The minimum pod damage and highest yield were recorded with the combination of cypermethrin + NPV.

Amongst new insecticides, the indoxacarb and spinosad are promising substitutes for the effective control of cypermethrin resistant population of *H. armigera* (Dhawan *and* Gill, 2005). Hewa et al. (2003) also reported that indoxacarb is potentially suitable for inclusion in IPM strategies for the management of *H. armigera* because it does not influence adult survival or development of immature stages of natural enemies (NEs). Tatagar et al. (2009) conducted the bioefficacy of flubendiamide 20 WG against chili fruit borers, *H. armigera*, and *S. litura* and reported that flubendiamide 20 WG @ 50 g a.i./ha was superior in reducing the incidence of fruit borers with the highest yield. Pal et al. (2013) also reported that the newer molecules like indoxacarb and flubendiamide were superior in reducing the infestation of carnation bud borer, *H. armigera*, and providing a higher monetary return.

11.6 CONCLUSION

In spite of the availability of various non-chemical tools of IPM, the chemical means of pest management is still one of the best viable options for effective control of bud borer, *H. armigera* in commercial flowers. However, keeping in mind, the concerns of the hazardous impact of pesticides, various eco-friendly chemicals with a less harmful effect on the non-target organisms should be incorporated in the management scheme against this pest.

KEYWORDS

- **commercial flowers**
- **endosulfan**
- **flubendiamide**
- ***Helicoverpa armigera***
- ***Helicoverpa* nuclear polyhedrosis virus (Ha NPV)**
- **integrated management**

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CHAPTER 12

NOVEL CHEMICALS IN THE MANAGEMENT OF PESTS OF COMMERCIAL FLOWERS

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ABSTRACT

Flowers are closely associated with mankind from the dawn of human civilization. Aesthetic values are crucially important in the daily livelihood of mankind. Worldwide more than 140 countries are involved in commercial floriculture. The leading flower producing countries in the world are the Netherlands and Germany. India's share in the global floriculture is still not prominent. However, there has been a huge developmental approach in this decade to commercialize floriculture and enhance the export of flowers. However, optimum production is still a major concern due to rising pest problems. To combat the increasing pest situation, farmers use conventional pesticides irrationally, which aggravates the problem further. Therefore, the cry for safer and eco-friendly approaches has led to the development of new molecules having a novel mode of action. These novel chemicals are not only used in pest management of food crops but also in the successful production of flowers and ornamentals. Encouragement of use in floriculture might be an inspiring step towards optimum flower production.

12.1 INTRODUCTION

Besides food and nutritional security, aesthetic values are also equally important for livelihood as well and enhance environmental purity, and flowers have the ultimate aesthetic value crop (Hole, 2005). Floriculture includes the cultivation of flowering and ornamental plants for use as raw materials in the cosmetic, pharmaceutical, and perfume industry (Bose, 1989; Sohi *and* Singh, 1995). Worldwide more than 140 countries are involved in commercial Floriculture (Gurav et al., 2003). In India, the floriculture industry comprises flower trade, production of nursery and potted plants, seed, and bulb production, micropropagation, and extraction of essential oils (Immaraju et al., 1992; Bhaskaran, 2003). About 248.51 thousand hectares area was under cultivation in floriculture in 2014–2015. Production of flowers in the world is estimated to be 1,658 thousand tons loose flowers and 472 thousand tones cut flowers in 2014–2015. India has exported 22,086.10 MT of floricultural products to the world for the worth of Rs. 548.74 crores/ 82.05 USD Millions in 2016–2017 (APEDA website, 2017).

However, in spite of all the efforts by the floriculture industry, India's share in the International market for these flowers is negligible (<0.70%). Besides the economic and social constraints, the biotic and abiotic stresses hinder the optimum flowers production (Casey, 2000). The changing climate is increasing the biotic stress as disease and insects are greatly influenced by rising temperatures, elevated carbon dioxide and fluctuating precipitating patterns as range expansion, increased epizootics, and new species introduction in regions where previously these were not reported (David, 2015). In order to manage the increasing pest problems, farmers all over the world are imposing harmful chemical pesticides in an indiscriminate and irrational manner this will create ecological disturbance and nontarget toxicity but further subject the pests to high selection pressure (Dreistadt, 2001; Blelza, 2007; Heyler et al., 1992).

Therefore the hue and cry to develop sustainable management programs have led to the introduction of the concept of Integrated Pest Management (IPM) (Herron, 2007; Otieno et al., 2016). Extensive approaches to create awareness and disseminate IPM strategies among farmers have been carried out all over the world in the past three decades (Jayachandran, 2003; Wang et al., 2016). However, the role of chemical pesticides cannot be ignored as it provides immediate attention to pest situations and serves as the ultimate tool to combat the economic losses caused due to pests (Jhansi Rani, 2001; Rami Reddy, 2004). This has inspired scientists all around the world to look towards the development of safer and more selective chemicals to manage the target pests effectively (Jayachandran *and* Chaudhury, 1996; HTC, 2005). This approach has gained considerable attention leading to an upsurge in the production of novel compounds that have a selective approach towards target organisms (Duraimurugan *and* Jagdish, 2004).

Novel chemicals have new modes of action like that of disruption of developmental processes, inhibiting or enhancing the activity of biochemical sites such as respiration, the nicotine acetylcholine receptor, GABA gated chloride channel, ryanodine receptors, salivary glands of sucking pests, etc. (IRAC, 2007). Progress has been made to introduce improved biocontrol agents like bacteria, fungus, viruses, nematodes for pest management. Extracts of plants like neem, custard apple, garlic, chili, etc. have also been found effective. This chapter is aimed at presenting novel chemicals with a mode of action for pest management of commercial flowers.

12.2 NOVEL CHEMICALS FOR PEST MANAGEMENT

12.2.1 INSECT GROWTH REGULATORS (IGR)

The term IGR was coined by Staal (1975) to describe a class of bio-rational compounds that are highly selective in action and act by disrupting the normal development of insects (Henrick et al., 1973). Based on the mode of action chemicals are grouped into three categories *viz*., (1) juvenile hormones (JHs) and their analogs (JHAs) also called as juvenoids; (2) ecdysone receptor agonists; and (3) chitin synthesis inhibitors (CSIs) or molting inhibitors (MIs).

12.2.1.1 JUVENILE HORMONES (JHS) AND THEIR ANALOGUES (JHAS)

Juvenile hormone (JH) agonists mimic the effect of naturally occurring JHs. They do not kill adult or early larval stages of insects, but they have an anti-metamorphic effect on insect physiology. They also have ovicidal properties, important for many management purposes. JH, due to a novel mode of action are relatively non-toxic to mammals and is known to possess less persistency. Prof. Williams, in 1967, gave the term “Third Generation Pesticides” for these chemicals.

The most frequently used JH mimics in agriculture and horticulture for the management of soft-bodied insects are:

i. Fenoxycarb 25WG (Insegar, Logic). It is a carbamate growth regulator. It prevents immature insects from reaching maturity by mimicking JH.
ii. Pyriproxyfen 10EC (Cyclio, Admiral). It mimics a natural hormone in insects and disrupts growth.

12.2.1.2 ECDYSONE RECEPTOR AGONISTS

Ecdysone receptor agonists induce premature molting in insects by mimicking the action of the molting hormone ecdysone. Their activity is limited to Lepidoptera and Coleoptera, and because the compounds do not penetrate the cuticle, they must be ingested. Ecdysone receptor agonists provide rapid action by causing feeding cessation within 3 to 14 hours. Diacylhydrazines are the only group of ecdysone receptor agonist insecticides having the following insecticides for management of insect pests:

i. Chromafenozide 80WP/5SC (Matric)–Cessation of feeding and insect movement.
ii. Halofenozide 2SC (Mach 2)–It works by mimicking the action of ecdysone, the hormone that regulates insect molting. Because of the unique mode of action of halofenozide, insects may be less likely to become resistant as compared to conventional insecticides.
iii. Methoxyfenozide 2F/240SC (Intrepid, Runner)–Ecdysone agonists/Molting disrupters.
iv. Tebufenozide 2F/240SC (Confirm, Mimic) – It mimics the action of the insect molting hormone, ecdysone. Lepidoptera larvae cease to feed within hours of exposure and then undergo a lethal, unsuccessful molt.

12.2.1.3 CHITIN SYNTHESIS INHIBITORS (CSIS) OR MOLTING INHIBITORS (MIS)

Chitin is an essential structural component of insect cuticle. When an insect falls to produce chitin, it dies during the molt. Chitin biosynthesis inhibitors interfere with the formation of chitin during molting, resulting in a weak, soft exoskeleton and deformed appendages and sexual organs. They are relatively non-toxic to nontarget organisms.

There are, however, two Types of CSIs. Type 0 is meant for the management of Lepidopteron pests, and Type 1 is meant for the management of Homopteran pests.

Insecticides under Type 0 are:

i. Chlorfluazuron 5EC/5.4EC (Atabron, Ishipron);
ii. Fluazuron (Acatak);
iii. Diflubenzuron 25 WP (Dimilin);
iv. Flufenoxuron 10DC (Cascade, Tenopa);
v. Hexaflumuron (Shatter);
vi. Lufenuron 5.4EC (Match);
vii. Novaluron 10 EC (Diamond, Rimon);
viii. Teflubenzuron15SC (Nomolt, Nomax);
ix. Triflumuron480SC (Alsystin, Baycidal, Starycide).

Inhibitors of chitin Biosynthesis

Insecticides under Type 1 are:

i. Buprofezin 25 SC (Applaud, Addvant, Bupro).

12.2.2 NEO-NICOTINYL COMPOUNDS OR NEO-NICOTINOIDS

Synthetic "nicotine-like" chemical binds tightly to the acetylcholine receptor site on the post synapse nerve cell, nerve overstimulation. Nicotinyl insecticides interact with nicotinic acetylcholine receptors (nAChR) in central and peripheral nervous systems resulting in excitation followed by death.

Neo-Nicotinoids are classified into different generations. They are discussed in subsections.

12.2.2.1 CHLORONICOTINYL COMPOUNDS (1ST GENERATION)

These are mostly used against sucking pests and can be used as seed treatment chemicals also.

i. Imidacloprid 17.8 SL (Confidor, Imidagold, Tatamida).
ii. Acetamiprid 20 SP (Pride, Record, Lift, Manik).

12.2.2.2 THIONICOTINYL COMPOUNDS (2ND GENERATION)

The broad-spectrum insecticide used against both sucking pests and foliage feeders.

i. Thiamethoxam 25WG (Actara, Avanth, Cruiser).

12.2.2.3 THIRD GENERATION NEO-NICOTINOID

Used mostly against sucking pests.

i. Dinotefuran 20SG (Safari, Osheen)

12.2.2.4 FOURTH GENERATION NEO-NICOTINOID

Newest neo-nicotinoids and a systemic action insecticide mainly used as a seed treatment.

i. Clothianidin 25/50 WDG (Dantop 25, Dantotsu 50).

12.2.3 NOVEL INSECTICIDES FROM MICROORGANISMS

12.2.3.1 AVERMECTINS

Novel insecticides belonging to this group are as follows:

i. Abamectin 1.9 EC (Vermitec, Abacin).
ii. Milbemycin 1EC (Milbeknock): Mixture of milbemycin-Aa and milbemycin-A4 in the ratio of 3:7.

It is a GABA antagonist, which acts on the peripheral nervous system enhancing the binding of GABA, resulting in increased chloride ion flow. It has contact and stomach poison with the limited systemic property but significant translaminar action. This novel compound is effective against two-spotted spider mite in rose and also against the yellow mite.

iii. Emamectin benzoate 5SG/5SC (Proclaim, Bioclaim, Missile) Semi-synthetic derivative of avermectin, which is highly effective against lepidopteran pests. Also effective against slugs as bait with husk and jiggery.

12.2.3.2 SPINOSYN INSECTICIDE

The spinosyns are a large family of unprecedented compounds produced from the fermentation of two species of naturally occurring bacteria *Saccharopolyspora spinosa*. The spinosyns and spinosoids have a novel mode of action, primarily targeting binding sites on nAChRs of the insect nervous system that are distinct from those at which other insecticides have their activity. Spinosoid binding leads to the disruption of acetylcholine neurotransmission. Spinosad also has secondary effects as a Ɣ-aminobutyric acid (GABA) neurotransmitter agonist. It kills insects by hyperexcitation of the insect nervous system. Spinosad so far has proven not to cause cross-resistance to other known insecticide. It is relatively non-toxic to nontarget organisms like predators and parasites. It is highly effective against Lepidoptera. It is an admixture of A and D isomers.

i. Spinosad 45 SC/2.5 SC (Tracer, Conserve, Success, Spintor).

12.2.3.3 MICROBIALS

The microbial insecticides used in commercial floriculture are fungal and bacterial.

i. **Fungal Insecticide:** The infection pathway consists of the following steps: (a) attachment of the spore to the insect cuticle, (b) spore germination on cuticle, (c) penetration through the cuticle, (d) overcoming the host immune response, (e) proliferation within the host, (f) saprophytic outgrowth from the dead host and production of new conidia.

Beauveria bassiana 1.15WP (Boverin, Biorin, Kargar) is used most commonly against Lepidoptera and Coleoptera.

Verticillium lecanii 1.15WP (Vertilec, Verticel, Biolin) is commonly used to control soft-bodied sucking pests, usually under protected cultivation.

Metarhizium anisopliae (Biomax, Biomet, Ankush) is used mostly in the management of grubs of Coleoptera and caterpillars of Lepidoptera.

ii. **Bacterial Insecticide:** *Bacillus thuringiensis* (Bt) is a common gram-positive, spore-forming, soil bacterium. They are relatively non-toxic to nontarget organisms and are effective against Lepidopteran, Coleopteran, and Dipteran pests.

Trade name: Dipel 8 L, Delfin WG, Thuricide, Biolep, Bioasap.

iii. **Viral Insecticide:** Nuclear polyhedrosis virus (NPV) Occlusion bodies are ingested by insect larvae. They are highly selective in nature and are effective against Lepidopteran pests like *Helicoverpa armigera* and *Spodoptera litura.*

    i. HaNPV (Biovirus-H)
    ii. SlNPV (Biovirus-S)

12.2.4 BOTANICALS

There has been an upsurge in the development of botanical pesticides recently so as to manage pests with an eco-friendly approach. However, the most commonly used botanical pesticides in commercial floriculture have been stated below:

i. Azadirachtin 1500/10,000 ppm (Econeem, Field Marshall)-Azadirachtin is the most prominent constituent of a series of limonoids (tetranor triterpenoids) present in neem seed kernel. It affects growth, development, reproduction, and metamorphosis in diverse insect taxa.
ii. Karanjin from *Pongamia glabra.*
iii. Beta-Asaron from sweet flag (*Acorus calamus*).
iv. Diallyl sulfide from garlic (*Allium cepa*).

v. Lantarin/Camerin from big-sage (*Lantana camera*).
vi. Globulin from Eucalyptus (*Eucalyptus globulus*).
vii. Parthenin from Parthenium (*Parthenium hysterophorus*).
viii. Anonaine, Squamosine from custard apple (*Annona squamosa*).
ix. Ricinus from castor (*Ricinus communes*).
x. Menthol from mint (*Mentha arvensis*).
xi. Capsicin from chili or its water extract.

12.2.5 OTHER INSECTICIDES WITH NOVEL MODE OF ACTION

12.2.5.1 PYMETROZINE 50 WG (FULFILL, ENDEAVOR)

It belongs to the pyridine azomethine group and is commonly known as stylet blocker. It is highly effective against soft-bodied Homopteran pests.

12.2.5.2 DIAMIDES

This new generation insecticide has a novel mode of action as it acts at the ryanodine receptor modulator. As a result, there is regurgitation, muscle paralysis, cessation of feeding, followed by death.

These can be divided into two groups:

i. **Anthranilic diamides:** Chlorantranilipole 18.5 SC/0.4 G (Coragen, Ferterra); and
ii. **Pthalic diamides:** Flubendiamide 20WG/39.35SC (Fluton, Takumi, Fame, fluid).

12.2.5.3 THIOUREA DERIVATIVE

This group acts by inhibiting oxidative phosphorylation. These are highly effective against soft-bodied Homopteran pests. The insecticide of this group is Diafenthiuron 50 WP (Pegasus, Polo).

12.2.5.4 TETRONIC ACID DERIVATIVES

This group has a unique mode of action by inhibiting lipid biosynthesis. The biological activity correlates with inhibition of lipogenesis, especially triglycerides and free fatty acids. It is effective against soft-bodied sucking insects, thrips, and also mites. The insecticide in this group is Spiromesifen 22.9 SC (Oberon, Voltage)

12.2.5.5 OXADIAZINE GROUP

This group insecticide has a novel mode of action and acts by inhibiting sodium ion entry into nerve cells, resulting in paralysis and subsequent death of pests. It is very effective in the management of Lepidopteran pests, including those that have developed resistance to most conventional insecticides. The insecticide in this group is Indoxacarb 14.5 SC (Avaunt, Steward.

12.3 NOVEL CHEMICALS IN THE MANAGEMENT OF MITE PESTS

12.3.1 MITE GROWTH REGULATORS

Clofentezine 50SC (Appolo), hexythiazox 5.45EC (Maiden, Endurer, Dimite), and diflovidazin are acaricides with mite growth-regulating the mode of action. Hexythiazox has ovicidal, larvicidal, and nymphicidal activities. Clofentezine and Diflovidazin are close analogs and are grouped with Hexythiazox because they commonly exhibit cross-resistance, despite being structurally distinct. The target site of these compounds is considered unknown.

Etoxazole 10 SC (Zeal) has been shown to inhibit chitin biosynthesis. Etoxazole 10 SC controls mites resistant to hexythiazox and clofentezine. All of these compounds are relatively non-toxic to nontargets.

12.3.2 QUINAZOLINE GROUP

Fenazaquin 10 EC (Magister) belongs to this group. It is ovicidal in action.

12.4 NOVEL CHEMICALS IN THE MANAGEMENT OF NEMATODE PESTS

Botanicals – Use of neem cake as soil amendment

KEYWORDS

- **floriculture**
- **integrated pest management (IPM)**
- **novel chemicals**
- **pests**

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CHAPTER 13

SUCKING PESTS MENACE AND THEIR MANAGEMENT ON FLORICULTURAL CROPS

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ABSTRACT

Sucking pests are recognized as one of the major biotic constraints to flower production in India. Apart from their direct damage by sucking the sap from the plant and thereby devitalizing them, many of them serve as vectors for many viral diseases. They also secrete the sugary honeydew, which favors the development of black sooty mold, which hinders the photosynthesis of the plants. Whitefly, aphids, thrips, scales, and Mealybugs amongst the insects and red spider mite amongst the Acarina are important in the list. Distribution, host-range, brief biology, damage symptoms, and eco-friendly management of these sucking pests infesting five major flower crops in India are discussed in this chapter.

13.1 INTRODUCTION

Indian floriculture Industry stands second in the world's flower production only after China. India has a very rich bio-diversity in ornamental plants. But India's share in world trade is only 0.61% in 2014 and 0.89% in 2015, according to Associated Chambers of Commerce and Industry of India (ASSOCHAM). Amongst the flower crops that grown commercially, Marigold, Rose, Tuberose, Chrysanthemum, and Gladiolus are important. These flower crops in India are often attacked by many insect pests throughout growth. The major sucking pests infesting flower crops include whitefly (*Bemisia tabaci*), cotton aphid (*Aphis gossypii*), Mealybug (*Phenacoccus solenopsis*) among the insect as well as red spider mite (*Tetranychus* spp.) among Acarina. They are mainly phloem feeders, sucking the sap via specially adapted mouthparts. They secrete the sugar-rich honeydew, which favors the development of black sooty mold, which hinders the normal photosynthesis of the plants. Besides these, many of them serve as a vector of many viral diseases, which have aggravated the problems still further. To control these sucking pests, Indian farmers are commonly using many synthetic insecticides which may lead to problems like resurgence of target insects, resistance to insecticides, secondary pest outbreak and residues in food and beverages, contamination of groundwater, adverse effect on human health, and widespread killing of non-target organisms (Halder et al., 2013, 2014; Rai et al., 2014). It is therefore needed to adopt integrated approaches to suppress the pest population through proper and judicious use of chemicals. This chapter, therefore, critically reviews the major sucking pests scenario in ornamental crops and the work done on different IPM components for the eco-friendly management of major sucking pests of flower crops in India and abroad.

13.2 BIOLOGY, HOST-RANGE, AND DAMAGE SYMPTOMS OF MAJOR SUCKING PESTS

Knowledge of the biology of any pest is imperative as it will help us to identify the weakest link of its life-cycle, and accordingly, suitable management practices can be adopted. Information on the host-range of the pest helps to develop ideal cropping sequence as cultural measures, whereas identifying the damage symptoms and proper diagnostics of insect prerequisites for any IPM program, therefore, timely and suitable control measures to be initiated to avoid economic damage. The details distribution, host-range, life-cycle, identification of the pest, and damage symptoms are briefly enumerated hereunder (Table 13.1).

TABLE 13.1 List of Major Sucking Insect Pests of Important Flower Crops in India

Name of the Sucking Pest	Taxonomic Affiliation	Plant Part(s) Affected
Rose, *Rosa* spp.		
Scale insect: *Aulacaspis rosae* Bouché, 1833; *Lindingaspis rossi* (Maskell, 1891); *Aonidiella aurantii* Maskell	Hemiptera: Diaspididae	Old stems, branches, and sometime on growing tips
Rose aphid: *Macrosiphum rosae* (Linnaeus, 1758); Cotton aphid: *Aphis gossypii* Glover, 1877; Green peach aphid: *Myzus persicae* (Sulzer, 1776)	Hemiptera: Aphididae	Young shoots, flowers, and flower buds
Grape thrip: *Rhipiphorothrips cruentatus* Hood, 1919: 94.	Thysanoptera: Thripidae	Flowers, flower buds and leaves
Red spider mite: *Tetranychus urticae* Koch, 1836	Acarina: Tetranychidae	Leaves
Gladiolus, *Gladiolus communis* Linn.		
Gladiolus thrips: *Thrips simplex* (Morison); Honeysuckle thrips: *Thrips flavus* Schrank, 1776; Flower thrips: *Frankliniella* spp.	Thysanoptera: Thripidae	Flowers, flower buds and leaves
Mirid bug: *Lygus lineolaris* (Palisot de Beauvois, 1818)	Hemiptera: Lygaeidae	Terminal shoots
Whitefly: *Bemisia tabaci* (Gennadius, 1889)	Hemiptera: Aleyrodidae	Leaves
Red spider mite: *Tetranychus urticae* Koch, 1836	Acarina: Tetranychidae	Leaves
Marigold, *Tagetes* spp.		
Aphids: *Myzus persicae* (Sulzer, 1776); *Aphis fabae* Scopoli, 1763; *Lipaphis erysimi* (Kaltenbach, 1843)	Hemiptera: Aphididae	Tender shoots, young buds, flowers, and leaves
Thrips: *Thripstabaci* Lindeman, 1889; *Caliothrips phaseoli* (Hood, 1912); *Microcephalothrips abdominalis* (D.L. Crowford)	Thysanoptera: Thripidae	Tender shoots, flowers, and leaves
Chrysanthemum, *Chrysanthemum indicum* Linn.		
Chrysanthemum aphid, *Macrosiphoniella sanborni* (Gillette, 1908)	Hemiptera: Aphididae	Tender shoots, flowers, and leaves
Solenopsis mealybugs: *Phenacoccus solenopsis* Tinsley	Hemiptera: Pseudococcidae	Tender shoots, flowers, and leaves

TABLE 13.1 *(Continued)*

Name of the Sucking Pest	Taxonomic Affiliation	Plant Part(s) Affected
Thrips, *Microcephalothrips abdominalis* (Crawford)	Thysanoptera: Thripidae	Sepals and petals of the flower, flower bud
Chinese hibiscus or China rose, *Hibiscus rosa-sinensis* Linn.		
Solenopsis mealybug: *Phenacoccus solenopsis* Tinsley; Striped mealybug: *Ferrisia virgata* Cockerell, 1893; Pink Hibiscus Mealybug: *Maconellicoccus hirsutus* Green, 1908; Papaya mealybug: *Paracoccus marginatus;* Williams *and* Granara de Willink, 1992	Hemiptera: Pseudococcidae	Young shoots, flowers, and flower buds
Aphid, *Aphis gossypii* Glover, 1877	Hemiptera: Aphididae	Young shoots and tender leaves, flowers, and flower buds
Scale insects, *Saissetia coffeae* (Walker, 1852)	Hemiptera: Diaspididae	Old stems, branches, and sometime on growing tips
Red spider mite, *Tetranychus urticae* Koch, 1836	Acarina: Tetranychidae	Leaves

13.2.1 ROSE (ROSA SPP.)

Roses are commonly grown and appreciated primarily for their characteristics color, aesthetic value, and aroma. The plants—and especially the flowers—should be free from pest damage to fetch a higher return. However, this important commercial crop is often attacked by a number of insects and acarine pests (Table 13.1). The descriptions on their brief biology, host range, distribution, damage potential are herewith.

13.2.1.1 SCALE INSECTS

Following three species of scales *viz*., *Aulacaspis rosae*, *Lindingaspis rossi, Aonidiellaa urantii* occur in rose gardens. The three scale insects have a similar biology. Scale insects are sac-like and do not have functional legs. The adult females are sedentary while the adult males, smaller than females, only have one pair of functional legs and wings. Males are short-lived, do not feed and live to mate with females. Adult females are parthenogenetic, comparatively long-lived, and reproduce by laying hundreds of eggs in a lifetime. First instar nymphs, known as crawlers, are generally small (about 0.5–1 mm in length), with functional antennae and legs. After molting to second instar, they became sessile for the rest of their life. Female nymphs generally have three, rarely two, nymphal instars before attaining an adult. Males always have four nymphal instars, of which the last one is metamorphic and called a pupa.

Scale insects infest on young, growing tips causing distorted foliage. Reddish-brown waxy scales are commonly visible on the lower portion of the old stem. Feeding on stems often leads to yellow, and plants may appear water-stressed. Heavy infestations may cause stems and branches to dieback, and unhealthy plants often die. They excrete copious amount of honeydews which deposit on the plant and create the black sooty mold.

13.2.1.2 ROSE APHIDS

Small, pear-shaped, or globular, tiny, soft-bodied insects are noted in clusters on young shoots, flowers, and flower buds. Generally, three species of these aphids are found to attack on roses. These aphids can easily be identified by their body color and shape. *Microsiphum rosae* (rose aphid) are reddish in color with red eyes and black cornicles. *Aphis gossypii* (cotton aphid) are yellowish-green to brown in color, whereas *Myzus persicae* (green peach aphid) are yellowish-green in color. Both the alate and apterous females can multiply by means of parthenogenesis and viviparously. In a single day, a female may give birth to 8–22 nymphs, which molt four times to become adults completing the life-cycle in 7–9 days. Both the stages (nymphs and adults) suck the sap from the growing points resulting in drying of tender shoots. Under severe infestation, buds fall-off pre-maturely and the flowers lose luster.

13.2.1.3 GRAPE THRIPS

Thrips pose an emerging threat to rose cultivation by causing typical scab formation on flowers and flower buds. Damage is caused by rasping and sucking by both nymphs and adults with their stylets from the petals of flowers and flower buds. The injured surface is often marked by the number of spots and thereby producing a speckled silvery effect, which can easily be visible from a distance. They also often feed in groups, generally on the undersurface of the leaves. In case of severe incidence, the curling of the leaves is recorded. Rose petals are also damaged by consumption, oviposition, and brown spot formation (Wang *and* Wenje, 1997).

The adult thrips are minute, elongated, fast-moving, and about 2 mm in length with four fringed wings. The female thrips produce 50–100 eggs during her lifetime. Eggs are small, minute, and inserted in the tender leaf tissues. Incubation period varies from 5–8 days. Nymph drops down to the soil and pupates in soil (top 8–18 cm depth). The life-cycle is completed in about 15 days, depending on weather conditions. Adult thrips survive for about 10 days.

13.2.1.4 RED SPIDER MITE

This red spider mite is a common polyphagous non-insect sucking pest of rose, found to attack on a large number of agricultural and horticultural crops. Both nymphs and adults suck the plant sap from the undersurface of the leaves. Infested plants turn yellow, gradually dry up, and in severe infestation, entire plants are covered with webs. The flower-bearing capacity of the affected plants is also drastically reduced. Adult mites are small, minute, red-colored with four pairs of legs. Eggs are globular, whitish, and lay undersurface of the leaves singly. Eggs hatch 3–6 days and first instar protonymphs (larvae) are light brown in color with three pairs of legs. They feed by scraping from the undersurface of the leaves and within 3–4 days turned on to deutonymphs having four pairs of the legs. They complete their life-cycle within 20–22 days. In a year, on an average of 30–35 generations are completed.

13.2.2 GLADIOLUS (GLADIOLUS COMMUNIS LINN.)

Gladiolus, also called "Queen of Bulb," is one of the important bulbous plants known for its beautiful flower spikes. Flowers with brilliant colors, varying sizes, attractive shapes, and excellent keeping quality make it popular cut flower thorough out the world. It is ideal both for garden and floral decoration. This flower crop is attacked by several insect pests, and major ones are as described in subsections.

13.2.2.1 GLADIOLUS THRIPS

It is cosmopolitan in distribution (Denmark *and* Price, 2010). Both nymphs and adults cause discoloration and deformities of gladiolus flowers resulting in dull in appearance. Infected flower spikes lose its characteristic luster and market value. Occasionally they also feed on corms (bulbs), which gradually become soft and are finally prone to decay. Adult thrips morphologically are milky-white immediately after emergence, but soon turn brown and start feeding. The adult female is about 1.65 mm long and slightly bigger than the male counterpart. The fringe wings with a light transverse band near the base. Eggs are inserted in the leaf tissues and corms. This is a major pest of gladiolus feeding on flower spikes and corms; however, it is also recorded from *Rhododendron indicum*, *Eleusine indica*, *Calendula* spp.

13.2.2.2 TARNISHED PLANT BUG

Tarnished plant bug, *Lygus lineolaris*, is cosmopolitan in distribution, polyphagous in nature and damages vegetables, fruits, greenhouse crops, *Brassica napus* L. and *B. rapa* L. (Brassicaceae) and legume crops, primarily those grown for seed e.g., lucerne, *Medicago sativa* L. (Fabaceae) (Broadbent et al., 2002). Nymphs are greenish in color while adult bugs are mottled yellowish or reddish-brown with flat, oval bodies. Both adults and immature feed by piercing the plant tissues, secreting digestive enzymes, and pumping out the liquefied plant material (Tingey *and* Pillemer, 1977). They puncture the terminal shoot below the flower bud, causing pre-mature flower drop.

13.2.2.3 WHITEFLY

These have been termed as whitefly because of the whitish appearance of the adults. Being polyphagous in nature, whitefly is observed throughout the year in different crops and weeds. Being polyphagous, they attacked on cotton, okra, brinjal, tomato, chilies, cucumber, pumpkin, pointed gourd, tobacco, soybean, and many other horticultural and agricultural crops.

The adult whitefly is tiny (about 1–1.5 mm long), yellowish white-bodied clustered together under the surface of the leaves with whitish-grey wings, densely covered with a waxy powder. The newly emerged nymphs are oval-shaped and light yellow in color but later change to pale greenish-yellow. A single fertilized female lays around 36 to 109 yellow, stalked eggs on the undersurface of leaves. The eggs are minute, <0.2 mm long. The yellow color of the egg changes to dark brown color before hatching. They feed approximately 7–14 days before molting into a pupal stage. The pupae are oval-shaped and black in color. Adults emerge within 8 to 14 days. Generally, 10–11 generations are completed in a year. The infestation starts right from the early crop stage and continues till the crop remains green. The nymphs and adults both suck the sap from the leaves resulting in lowering the vitality and thus causes stunted plant growth. They also secrete sugar-rich "honey-dew" which deposited on the leaves result in the development of a black sooty mold on the leaves, thus hampering the photosynthesis of the plants.

13.2.2.4 RED SPIDER MITE (TETRANYCHUS EQUATORIUS; T. URTICAE)

As describe in rose (Sections 13.2.1 and 13.2.1.2).

13.2.3 MARIGOLD (TAGETES SPP.)

Marigold is an important medicinal and ornamental evergreen herb and known for its aesthetic, nematicide, insecticide, anti-microbial, cosmetics, allelopathic, and medicinal properties. A native of south and Central America, more precisely Mexico, today, it is one of the most valuable commercial flowers grown in India, accounting for more than half of the nation's loose flower production. The genus "*Tagetes*" comprises about 33 species, of which *Tagetes erecta* (African/American tall marigold), *T. patula* (French/dwarf marigold), *T. signata* (Signet marigold) and *T. minuta, T. lucida* are commercially important cultivated species. These are following important sucking insect pests that attack the marigold enumerated here:

13.2.3.1 APHIDS

Small soft-bodied greenish yellow color in groups found on flower, flower buds and apical shoots. Three aphid species *viz*., *Myzus persicae, Aphis fabae* and *Lipaphis erysimi* are reported to infest this valuable ornamental flower. Adult apterous female has oval body, about 1.2–1.5 mm long. Body color varied to blackish-green, dark green to yellowish-green or yellow. Presence of prominent paired cylindrical, long, and blackish "*Siphuculi*" or "*Cornicle*" at the 5 or 6th dorsum abdominal segments is the identifying taxonomic character of this aphid. Winged female is about 1.2–1.4 mm long with a fusiform body. Antennae are longer than the apterous female. Both the alate and apterous females can multiply by means of parthenogenesis and viviparously. In a single day, a female may give birth to 8–22 nymphs which molt 4 times to become adults completing the life-cycle in 7–9 days. The both adults and nymphs of the aphid suck the plant juice from the lower side of leaves or on the growing tips of shoots and flower buds. The affected portions become chlorotic, droop down and dry prematurely. Honeydew is secreted by the aphid favors sooty molds to grow hindering the efficient photosynthesis of the plants (Halder et al., 2011).

13.2.3.2 THRIPS

Thrips are small, flying insects that suck the sap out of a marigold's leaves, resulting in curling and premature dropping of leaves. They prefer to feed in rapidly growing tissues. Damaged leaves become papery and distorted. Infested terminals may also be discolored, rolled. Petals may exhibit typical color break, which is pale tissue that was killed by thrips feeding before buds opened. Healthy plants tend to tolerate an average thrips attack. *Caliothrips phaseoli* could be identified by brown colored body and legs, with 8-segmented antennae and III–IV segments with forked sensorium. Another recently introduced pest is the Western flower thrip; *Frankliniella occidentalis* is an American origin, cosmopolitan, polyphagous pest and is rated as one of the most destructive thrips of the world. Adult thrips are small (< 1/20 inch long), slender with long hairy-fringed wings. Immature thrips are similarly shaped with a narrow, long abdomen but lack wings. Color ranges from translucent white or yellowish to black or dark brownish, depending on the species and life stage. However, there are few species that are brighter in color.

Thrips feeding on plant leaves results in necrotic spotting, leaf scarring, and/or distorted growth. In addition, adults feeding on flowers and/or unopened buds may lead to deformed flowers or flower bud abortion.

13.2.4 CHRYSANTHEMUM (CHRYSANTHEMUM INDICUM LINN.)

Chrysanthemum is one of the most popular seasonal flowers grown in our country for its diversified beauty of colors, shapes, shades, and keeping quality. It is highly useful for floral decoration in different festivals, functions, and exhibition purposes. Due to its origin and commercial production in Asia, it is also called *'Queen of East'* or '*Glory of East*' and sometimes '*Winter Queen*' as the flowers are available mostly during winter. Although it has a good market value, its production is highly hampered by an infestation of many numbers of insect pests, among the sucking insect pests; mainly Chrysanthemum aphid, thrip, and mealybug are important.

13.2.4.1 CHRYSANTHEMUM APHID

A very serious pest of chrysanthemum, mainly feeds on young leaves, apical shoots and developing flower buds. Adult winged insect is about 2–2.5 mm long, soft-bodied, dark, shining mahogany brown in color. Whereas, wingless adults are only 1.5 mm long; small, black with sturdy cornicles. Nymphs are dull, brick-red in color with relatively longer legs and antennae. The cornicles are short and dark in the initial stages. Although they are East-Asian in origin, presently, they prevail throughout the world where chrysanthemums are grown in the garden as well as in greenhouses. They reproduce by both in parthenogenesis and sexual ways and spend their overwinter stage in greenhouses, and during the warmer periods, they leave the greenhouses in search of new plants. Each female can produce four to eight young aphids per day. Within about a week the new nymphs mature into wingless females, which begin to reproduce young ones. As the plant becomes over-crowded or begins to deteriorate, they develop into winged females and start migrating to infest other plants. Their developmental time, daily fecundity, total fecundity, and adult longevity were

8.94 days, 2.71, 29.1, and 20.4 days, respectively (Sadegian et al., 2003). They completed almost 15–18 generations per year under suitable climatic conditions.

They damage the plants by sucking the plant sap from growing shoots and apical leaves causes; loss of vigor, yellowing of leaves, premature leaf fall, and stunted growth. In flower-bearing plants, flowers become deform and dry up prematurely. They also excrete honeydew on which sooty-mold develops, which interferes with the photosynthesis of the plants. Besides these, they also transmit different viral diseases; namely chrysanthemum vein mottle virus and chrysanthemum virus B (Blackman *and* Eastop, 1984).

13.2.4.2 MEALYBUG

They are polyphagous in nature and infesting many plant species comprising a field, horticultural crops, ornamentals, weeds, and trees. Presently, they are widely distributed in Africa, Asia, North America, South America, and Oceanic regions, including the Caribbean nations. They are pale yellowish in color and oblong in shape. The dorsal body surface is covered with dense waxy powder-like materials and two dark stripes on the back. The female insects are wingless; whereas, male adults are having only one pair of wings. A female lays almost 300–700 eggs, usually in an ovisac, beneath her body. The incubation period is a few minutes to two days. The newly emerged nymphs, i.e., crawlers emerge out and start feeding on tender plant parts. The female mealybug passes through three nymphal instars in almost 12–17 days. Whereas, the male mealybug has four nymphal instars complete in almost 14–18 days. The longevity of the adult female is longer (14–19 days) compared to the male counterpart (1–3 days). In the case of females, it takes almost 25–38 days to complete its total life-cycle, whereas in the case of males, it is around 17–24 days.

Both nymphs and adults suck the plant sap from phloem tissues of leaves, petioles, flower buds, and twigs of the plants and causing curling and distortion of plant tissue. Infested buds may not open, and flowers can be deformed and reduce the vitality of the plants. In severe cases, they produce copious amounts of honeydew, which helps to develop sooty-mold affecting the photosynthetic activity of the plants.

13.2.4.3 Thrips

It is widely distributed throughout the tropical and subtropical regions of the World. It infests several ornamental plants *viz*., Chrysanthemum, Dahlia, Marigold, Zinnia, Calendula, Cosmos, Gerbera, Sunflower, Daisy, etc. Both males and females are either fully winged or with wings shorter than thorax width. They are brown in color. Males are smaller and paler than females. Reproduction is both sexual and parthenogenetic. A fertilized female lays almost 76–104 eggs in flowers, especially in the ovary wall. The oviposition period ranges from 15–18 days. It takes almost 9–20 days from egg to the adult stage to complete its life-cycle (Ananthakrishnan, 1971). The unmated female gives rise to males only.

On feeding, they cause scars on the floral parts, and in severe infestation, flowers become decolorized and destroyed later. Young buds are also infested, remain unopened, and the developing florets shrivel up (Ananthakrishnan, 1971).

13.2.5 China Rose (Hibiscus rosa-sinensis L.)

China rose, or Chinese Hibiscus is a popular, out-door ornamental shrub that flowers almost thorough out the year. The plant is mainly grown for its characteristic showy; five-petal flowers in various colors, including few that are bicolored. It is widely used for puja to Hindu deities apart from its known pharmacological properties. This important commonly grown plant is often attacked by a wide range of sucking pests *viz*., mealybugs, aphids, scale insects, and phytophagous mites thorough out its growth period.

13.2.5.1 Mealybugs

This plant is prone to attack by several species of mealybugs of which Solenopsis Mealybugs (*Phenacoccus solenopsis*), Striped mealybug (*Ferrisia virgata*), Pink Hibiscus Mealybug (PHMB) (*Maconellicoccus hirsutus*), and Papaya mealybug (*Paracoccus marginatus*) are important. *P. solenopsis* is a polyphagous, invasive, emerging insect attacks a series of crops

(Halder et al., 2013). Its infestation was first reported from cotton in India. Adults are elongated to broadly oval-shaped insect, body covered with the whitish waxy powdery coating with characteristic two pairs of black spots. Nymphs are smaller in size. Striped mealybug (*Ferrisia virgata*), is a small insect that is a pest of a broad range of plants, whose adult females are oval, grayish-yellow in color with 4–4.5 mm long, with two longitudinal, sub-median, interrupted dark stripes on the dorsum. The dorsum also bears numerous straight, glassy threads of wax. Papaya mealybug (*P. marginatus*) could be identified by its oblong shape with yellow in color. The male counterpart was pink colored with reduced body size. Adult females are yellow in color, dusted with characteristics with white mealy wax, and eight segmented antennae. Although adult female was significantly bigger in size than the male but later had bristle shaped ten segmented antennae, which were longer than that of female antennae (Chatterjee *and* Halder, 2017). The PHMB, *M. hirsutus*, is another serious pest of many plants in tropical and subtropical regions, including southeast Asia, Africa, and northern Australia. Both eggs and crawlers are pink in color, whereas immature and newly matured females are grayish-pink, dusted with white mealy wax. Adult females are soft-bodied, oval, and slightly flattened with 9-segmented antennae, long, flagellate dorsal setae, and numerous dorsal oral rim ducts on all parts of the body except the limbs.

The reproduction of these mealybugs is mostly by means of parthenogenesis. Adult females lay around 150–500 eggs in ovisac. Eggs hatch within 3–9 days; first instar nymphs are highly mobile and called as 'crawlers.' The nymphal stage generally lasts for 19–26 days, depending upon the weather. *P. solenopsis* during winter remains in eggs in ovisac or other stages in cracks and crevices of the soil or in plant parts, whereas during the summer season, they are very active breed round the year. On an average 12–15 generations are completed in a year.

Both nymphs and adults suck the sap from the twigs, buds, tender stems, flowers, petals, and resulting plants lost its vitality. Affected flowers, twigs, and buds become wrinkled. Besides these, Mealybugs also secret sugar-rich honeydew deposited on the leaves that create black sooty-mold and thereby hindering the photosynthesis activity of the plants. Honeydew also attracts the ants, and through this symbiotic association by they get protection from their natural enemies (NEs). Ants also help to Mealybugs to transport from one plant to another.

13.2.5.2 SCALE INSECTS

Hemispherical scale, *Saissetia coffeae* (Walker) (=*S. hemisphaerica* (Targioni-Tozzetti)), is a polyphagous pest reported to attack a series of crops including coffee, guava, mango, citrus, okra, *Hibiscus rosa-sinensis*, *Achraszapota*, etc. (David *and* Ananthakrishna, 2004). Both nymphs and adults suck the plant sap from leaves, stems, and trunks. They spread mostly in crawler stage by man, birds, other animals and sometime by wind currents. If timely not controlled, they can cause leaf drops, dead twigs, and branches. They cause damage by sucking the juices from the plant mainly from the undersides of leaves resulting in yellow spots appearing on the upper leaf surfaces, which gradually become coalesces to become larger as the scales continue to feed. Their serious infestations often lead to premature leaf drop, reduced growth, and possible twig dieback. Mature scales are also visible, although sometimes they are well hidden in crevices. Immatures or crawlers, are tiny and sometimes require a hand lens to detect. The presence of black sooty-mold attended by black ants is also often associated with soft scales.

13.2.5.3 MELON APHID OR COTTON APHID

Cotton aphid, *Aphis gossypii* is an extremely polyphagous, cosmopolitan, polymorphic aphid species that feed on a wide range of agricultural and horticultural crops, including eggplant, okra, cucumber, watermelon, pumpkin, squash, asparagus, cotton, citrus, and *Hibiscus rosa-sinensis*. The wingless female melon aphid could be identified by its ovoid body with varying shades of green, whereas the winged female has a fusiform body. Head and thorax are black in color, and the abdomen is yellowish-green with several black lateral spots. The nymphs vary in color, being shades of green, gray, and tan. They usually have a dark head, thorax, and wing pads, whereas the distal portion of the abdomen is usually deep green. The cornicles or siphunculi are cylindrical in shape and black in color. The oval eggs are yellow immediately after laying but soon turn black. Females produce directly young ones within a week. Alate and apterous forms multiply both parthenogenetically and viviparously and give birth about 7–24 nymphs per day depending upon the host plants and environmental conditions and become adults in 4–7 days. The nymphs molt four times to become adult and completing the life cycle in about 7–10 days.

Nymphs and adults colonize mostly on the lower surface of the young leaves, tender shoots, flowers, and flower buds. They suck the sap from the phloem and secrete sugar-rich honeydew, which favors sooty-mold development and thereby causing hindrance to the plant's normal photosynthesis. In severe infestations, curling, crinkling, and chlorotic appearance of the leaves and/or shoots and the foliage may die prematurely. Highly infested plants bear very few numbers of healthy flowers.

13.2.5.4 RED SPIDER MITE

Red spider mite, occasionally become serious, is a type of arachnid that also includes spiders. They are smaller in size, often resemble red moving dots on the lower side of leaves, feed, and reproduce mostly during the dry period. They spread rapidly during warmer weather, and the damage is more serious in dry prone areas. Two-spotted spider mites have prominent dark spots situated on both sides of the abdomen. Both the nymphs and adults spin the webs on the leaves of plants, and suck the cellular contents from leaves resulting light, stippled irregular dots on leaves, followed by yellowing, stippled or bronzed appearance and dropping of leaves. In severe infestations, the entire plant may have web covering on its leaves and stems.

The mite is mostly active from March to October and passes the winter as a gravid female in India. As the season warms up in March, it spins webs on the bottom surface of leaves and lays around 50–75 eggs. The eggs are spherical and hatch in 3–6 days depending upon weather conditions. The first instar larvae are light brown with three pairs of legs. Larvae feed on the lower surface, underneath of the webs, and changes into nymphs within 3–4 days with four pairs of legs. The nymphs grow to maturity within 4–11 days, and the adults live for 7–10 days. Red spider mite completes its life-cycle within 9–19 days during the active period.

13.3 INTEGRATED PEST MANAGEMENT (IPM)

To save the these flower crops from ravages of sucking insect pests, it is very essential to adopt suitable, need-based, and quick result-oriented control measures, keeping in mind development of pest resistance to insecticides, resurgence of minor pests, minimum environmental pollution as well as less harm to NEs such as parasitoids, predators, and pollinators. For this, an integrated approach should be adopted to suppress the pest population below the economic threshold level (ETL) through proper and judicious use of suitable control measures at the right time. Prior to understanding sucking insect pests IPM comes, there is a need to know the crop plant and its growth throughout the season and adequate knowledge of the threshold of economic damage. The crop growth stage is the most important criterion because the relationship between insect injury and crop damage is dependent on the stage when the maximum injury occurs. Research has shown that injury during the vegetative stages is usually not as detrimental to the plant as that during reproductive stages (Dey *and* Halder, 2011). Periodical survey and monitoring of insect pests is an important task to obtain information on population dynamics of all pests and their NEs and to estimate the damage to the plants. Integrated pest management (IPM) thereby involves various methods of control, *viz.,* mechanical, cultural, and use of chemical pesticides, both biopesticides and chemicals.

13.3.1 MECHANICAL CONTROL

Deep summer plowing of fields to expose the soil-inhabiting stage of the insects particularly, pseudo-pupa of whiteflies, soil-inhabiting stage of some thrips, mealybugs hiding in the cracks and crevices in the soil to their NEs. Collection and destruction of developing stages (egg/nymph) and adults of serious pests and also of infested plants from the fields will help in reducing the pest incidence. Installation of yellow and blue sticky traps attracts whiteflies, jassids, aphids, and thrips, respectively. By using such traps in the fields, the first appearance of the pest and pest densities can be monitored for taking timely measures to achieve cent percent in control (Dey *and* Halder, 2011). Similarly, high-pressure water sprays, via hose-end devices, can dislodge mites and other sucking pests from their host plants. These devices produce a hard spray to the lower side of leaves and plant terminals. Begin the treatments when pests are first detected and repeat periodically to maintain clean plants (http://theurbanrancher.tamu.edu).

13.3.2 CULTURAL CONTROL

Cultural management is always advisable and better as they are often economical, easy to adopt, and do not leave harmful residues on the crops.

Regular monitoring of the crops, especially new stock, carefully reduces the incidences of pests. Clean cultivation, crop rotation, judicious use of nitrogenous fertilizers is important for the management of sucking pests of flower crops. The varieties that are prone to scale insects (or other pests) should be monitored more consistently, and periodical removal of plants with heavy infestations would reduce the spread of scale insects. If infestations are limited to a particular branch/twig and it can be pruned, remove this infested plant material to ensure the rest of the plant is clean. Selection of healthy and clean mother stock plants should be selected and better to avoid cuttings from the infested plants. Crop debris should preferably be burnt as scales may survive for several weeks on crop debris. Movement of infested plant materials to the newer area must be avoided. Similarly, restriction of staff movement in areas from its endemic areas as well as regular disinfection of cloths and farm equipment after working in such infested areas should be followed. Removal of weeds, particularly *Parthenium* that serves as an alternate host for *P. solenopsis* should be done. Ants act as transporters for Mealybugs, so the destruction of ants' colony in and around the field restricted its migration. Uprooting and burning of severely infested (mealybugs, mites) plants minimize future pest infestation. Spider mites can produce the worst effects on stressed plants. Keeping this in mind, rose, hibiscus, and other flower plants infested by red spider mites should be well-watered, and that will help them withstand mite-induced damage. Because mites prefer dry conditions, use of an overhead spray when watering the plants, wetting the leaves and branches to raise humidity. Nitrogen plays an important role in the intensity of insect pests, and a positive correlation between insect pests and nitrogen were found. A direct correlation of yield and nitrogen was also found; however, after a certain limit of nitrogen use, the yield did not increase significantly. So, the judicious use of nitrogenous fertilizers during the crop growth stage must be followed.

13.3.3 USE OF RESISTANT VARIETIES

Some lines or varieties of a crop possess some inherent genetic characters that prevent them from attacking certain pests. These resistant varieties can be cultivated without much change in the normal practice of cultivation, and these can also be incorporated into insect pest management practices. Resistant varieties are being continuously developed by the various ICAR

Institutes, State Agricultural Universities, and State Agriculture Departments of that particular region.

13.3.4 BIOLOGICAL CONTROL

NEs may be released into green and poly-houses to help control sucking insect and mite pests. Releasing NEs like predators, parasites, and pathogens to control pests is a typical type of biological control method called augmentation. In this approach, commercially available NEs are applied in a timely manner to suppress/prevent pest population (http://theurbanrancher.tamu.edu). These agents include Green lacewings, *Chrysoperla zasrtrowi sillemi*, a well-known predator of aphids, scales, mealybugs, phytophagous mites, thrips, and small caterpillars and many other insects' pest. *Orius* spp., a true bug, predator of larval and adult thrips, aphids, mites, and whitefly pupae were also found effective. Release of predatory mites *viz*., *Phytoseiulus persimilis*, *Metaseiulus occidentalis*, and *Neoseiulus californicus* (*Amblyseius californicus*)—predatory mites of spider mites; *Amblyseius cucumeris*, *Neoseiulus cucumeris*, and *Neoseiulus barkeri* —predatory mites of thrips were also found promising. Parasitic wasps like *Aphelinus abdominalis*, *Aphidius colemani* are recorded as parasitic wasps of aphids; *Encarsia formosa* and *Eretmocerus* sp. are the parasitic wasps of whiteflies. There are also a few entomopathogenic fungi (EPF) that may kill scale insects. Almost all pesticides will negatively impact beneficial insect populations (i.e., predators, and parasites). If chemical pesticides have been applied, ensure that a sufficient time period elapses before releasing beneficial insects. An Australian ladybird beetle, *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae), popularly known as the mealybug destroyer, is widely used to control mealybugs as well as scale insects. Both grubs and adults voraciously feed on eggs and early instar nymphs of mealybugs and other soft-bodied insects. EPF like *Lecanicillium* (=*Verticillium*) *lecanii* and *Beauveria bassiana* were found promising against scales and other soft-bodied sap-sucking insects. Recently, the compatibility of these EPF with neem oil was established (Halder et al., 2013, 2017) and could be an important tool in the organic pest management program. Kulkarni et al., 2017 reported that spraying of fungal entomopathogens *viz*., *Lecanicillum lecanii*, or *Beauveria bassiana* @ 5 ml or 5 g/l help in reducing thrips population in cold and humid climate especially when the atmospheric temperatures lie between 20–25°C and humidity of above 80%. For the management red spider mites infesting major flower crops conservation of predators such as anthocorid bugs/minute pirate bugs (*Orius* spp.), mirid bugs, syrphid/hoverflies, green lacewings (*Mallada basalis* and *C. z. sillemi*), predatory mites (*Amblyseius alstoniae*, *A. womersleyi*, *A. fallacies* and *Phytoseiulus persimilis*), predatory Coccinellid beetle (*Stethorus punctillum*), cecidomyiid (*Anthrocnodax occidentalis*), gall midge (*Feltiella minuta*). Muraleedharan and Ananthakrishnan, 1978 documented that *Orius maxidentex* and *O. tantillus* were found promising controlling the phytophagous thrips, *Microcephaholthrips abdominalis* infesting marigold and Chrysanthemum.

13.3.5 BOTANICALS AS A TOOL FOR IPM

Pesticides derived from plants have the potential to play a major role in insect pest management in sustainable agricultural production. They are renewable, cheap, non-persistent in the environment, and comparatively safe to NEs, non-target organisms, and human beings (Halder et al., 2010). So, plant-derived insecticides play a pivotal role in the insect pest management of the flower crops. Insecticidal soap and horticultural oil are biorationals for mites, although the subsequent application is necessary (Stroom et al., 1997). Kathiriya and Bharpoda (2010) studied the different formulation of products and found that Neem Azal–F 5EC and Econim 1EC were better in suppressing the chrysanthemum aphid population compared to other neem-based formulations.

13.3.6 CHEMICAL CONTROL

The chemical pesticides are mostly curative in action and are one of the major tools to check the large built-up of pest populations. Many problems are generally associated with chemical pesticides use, but one of the major draw-back within those is the residues on crops. However, need-based judicious and safe uses of chemical pesticides are the need of the hour to minimize the risks of pesticide use. Under protected environment, in order to avoid the contamination of farm produce from pesticide residues, use of pesticides having green chemistry and strictly follow the recommended dose and the waiting period between last insecticidal application(s) and harvesting.

Soil application of Carbofuran at 1 kg a.i/ ha after pruning or use of Malathion 50 EC or Dimethoate 30 EC or Chlorpyriphos 20 EC at 0.1% is helpful for red scale management in Rose (Kumar, 2001). It is found that the application of Acephate, Azadirachtin, Malathion, Imidacloprid, Bifenthrin, Cyfluthrin, Cyhalothrin, insecticidal soap, and soil drench treatments of Imidacloprid will help control foliage feeding aphids and thrips, but aphids and thrips feeding in flowers are very difficult to manage. Weekly sprays may be necessary to minimize the damage (Layton, 2011). Acetamiprid, Azadirachtin, Imidacloprid, insecticidal soap, Neem oil, horticultural oil are useful for the control of mealybugs and whiteflies. When attempting to control whiteflies and mealybugs with foliar sprays, apply at least two successive treatments at 5 to 7 days interval (DI) (Layton, 2011). Recently, Bhattacharyya et al., (2016) reported that rose aphid, *Macrosiphum rosae* when treated with rose leaves treated with synthesized biologically silver nanoparticles had shown the highest mortality at 500 ppm concentration. Chemical acaricides like Flufenoxuron 10% DC @ 1 ml/l or Milbemectin 1% EC @ 0.5 ml/l or Dimethoate 30% EC @ 2–2.5 ml/l are effective against mites in roses (www.cibrc.nic.in).

13.4 FUTURE STRATEGIES

The detailed analysis of the past research works on major sucking pests of important flower crop management revealed that the focus on biological control and host plant resistance, which lacks in-depth basic information. The physiological basis of insecticide resistance and pest resurgence yet to be explored and depending on that suitable IRM strategy have to be formulated. Besides, in host plant resistance multidisciplinary and consortia based collaborative approaches to be initiated. The role of agroecosystem analysis, ecological engineering, and biological control with special reference to entomopathogens and plant-derived toxins need to be explored.

- Development of suitable screening techniques for aphids, jassid, whitefly, mealybug, and spider mite resistant based on population grade, injury grades, and marketable yield.
- Hunt for new resistance cultivar against these sucking pests and exploitation of interspecific resistance.

- Development of suitable forecasting method for the sucking pests and model crop loss due to these sucking pests under different agroclimatic zone has to be formulated.
- Periodical validation and refinement of resistance source under different agroclimatic regions. Emphasis should be to explore the mechanisms of resistance (biochemical, molecular, and biophysical) against these pests.
- Biological pest control is the backbone of the IPM program. In the IPM program, proven and established bioagents have to be included. Similarly, hunt for the potential biocontrol agents and newer botanicals to reduce pesticide contamination in the environment.
- Development of suitable technology for the low-cost mass production of the potential bioagents and standardization of their field release method(s) needs to be addressed.
- Search has to be made out for the newer biorational insecticides/acaricides molecules.
- Monitoring the insecticides resistance is need of the hour.
- Suitable IPM module and IRM strategies need to be developed.

KEYWORDS

- **damage**
- **ecofriendly management**
- **flower crops**
- **sucking pests**

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CHAPTER 14

ROLE OF NANOTECHNOLOGY IN THE PEST MANAGEMENT OF COMMERCIAL FLOWERS

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ABSTRACT

Nanotechnology has the enormous potential to revolutionize various fields like pharmaceuticals, drug delivery, agriculture, analytical chemistry, etc. In agriculture sector it can be applied for enhancing nutrient uptake by plant, crop improvement, precision farming, and pest management. This technology has the capability to increase the use efficiency of agricultural inputs. Like other agricultural inputs, pesticides can also be used efficiently if nanotechnology is applied successfully. It enhances the water solubility of some insecticides, increases the stability of the active ingredients, helps in uniform coverage, and increase the uptake by plants. Nano formulation of different pesticides like nano-encapsulation, nanoemulsion, etc. helps in pest management through controlled release of the active ingredient and by stabilizing bio-pesticides. Hence, better efficacy is achieved. The large scale field level application of this technology for pest management is still in its infancy. So, more critical researches need to be carried out to solve many problems and to make the technology popular.

14.1 INTRODUCTION

Indian agricultural production systems have been facing so many changes and challenges to increase the productivity for providing nutritional security to the increasing population under conditions of uncertain climatic extremes, water scarcity, limited land area, and rapid depletion of natural biodiversity. The infestation of insect pests and diseases under changing climatic conditions itself is a challenge. Although IPM strategies are advised to adopt, but farmers of our country still depend on the application of insecticides to protect their crops from insect pests. The injudicious, unplanned, and rampant use of different plant protection chemicals, especially insecticides, causes various problems like secondary pests to outbreak and pest resurgence. This over-reliance on pesticides has caused serious consequences to our environment as a whole and ultimately leading to health hazards of various types. It is a well-established fact that a small quantity of active ingredients ultimately reaches to the target. As a result, repeated applications become necessary. Since the application of some chemicals leads to increased environmental risk, we should be cautious enough to treat such compounds in such a way that they do not have negative impacts on the environment (Farre et al., 2005; Banks et al., 2005; Cohen, 2006). We have to ensure food security as well as food quality with zero environmental risks, and for this, the importance of plant protection chemicals and its formulation, as well as application technology, need to be emphasized with utmost importance. Here the promising role of this nanotechnology comes into the picture.

The flowers have become an integral part of our culture resulting cultivation of flower crops a profitable enterprise. Recently the cultivation and export of flower crops have received a remarkable interest because of its versatile uses and increasing demand both in domestic as well as international markets. Moreover, there is an increasing demand of flower crops for manufacturing essence, perfumes, confectioneries, and bio-pigments. Flower crops satisfy the aesthetic needs of the people, and the cultivation of this crop also ensures a good return to the farmers. In addition to these, there is a huge scope of export of flower crops and earning more foreign exchange. All of these have, ultimately, attracted the attention of the policymakers, researchers, agricultural, and horticultural planners in this sector.

Cut flowers play an important role in floriculture trade in India. The major cut flowers in India are rose, tuberose, gerbera, gladiolus, carnation, chrysanthemum, lily, and marigold. Rose, carnation, orchid, anthurium are also important from an export point of view. In spite of having enormous potentiality, there are some constraints too in the successful cultivation of commercial flower crops. Among various production-related constraints, an infestation of insect pests is one of the limiting factors for the successful cultivation of these crops. These problems have to be tackled scientifically to make this sector more remunerative to the farmers. However, research works related to the field level application of nano-insecticide in pest management of commercial flower crops are very limited. The data on efficacy, non-target toxicity, and environmental fate of the nano-formulations are also scarce. But still, every effort has been made to present the topic with relevant information.

14.2 DEFINITION OF NANOTECHNOLOGY

Numerous definitions of nanotechnology are available in the literature. But the most widely accepted definition is "Nanotechnology is the understanding and control of matter at dimensions of approximately 1 to 100 nanometers. A nanometer is 1 billionth of a meter. Or, to put it another way, there are 25,400,000 nanometers in an inch." It can also be defined as " Nanotechnology deals with research and development that involves measuring and manipulating matter at the atomic, molecular, and supramolecular levels at scales measured in approximately 1 to 100 nanometers (nm) in at least one dimension."

14.3 NANOTECHNOLOGY IN PEST MANAGEMENT

Nanotechnology can redefine modern-day agriculture, if applied successfully. This technology, by virtue of nanomaterial related properties, has the potentiality to solve various problems like environmental pollution, the emergence of agricultural pests and pathogens, and loss of biodiversity. Nanotechnology may play an important role in minimizing the pesticidal load in agriculture through the smart delivery system in various forms of pesticide *viz*., nano-encapsulation, nanoemulsion, and solid lipid nanoparticles, etc. Some of the potential applications of nanotechnology in pest management are: delivery of nanocides–pesticides encapsulated in nanomaterials for controlled release; stabilization of bio-pesticides with nano-materials and field applications of agrochemicals, nanosensors for plant pathogen and pesticide detection.

14.4 NANO-PESTICIDES

Nanomaterials of both inorganic and organic origin are generally used for the synthesis of nano-pesticides. It involves size reduction by top-down methods *viz.*, milling, high-pressure homogenization, and sonication, while bottom-up processes involve reactive precipitation and solvent displacement (Sasson et al., 2007). Li et al. (2007) reported that Porous hollow silica nanoparticles (PHSN) has remarkable UV-shielding properties and thus protect the active ingredient. They used avermectin in their experiment and found that the release of avermectin was very slow when it was loaded into the inner core of the carrier.

14.4.1 SOME FORMULATIONS OF NANOPESTICIDE

Scientists have prepared various formulations of nano-pesticides. Some of these formulations have been discussed precisely.

14.4.1.1 NANO-ENCAPSULATION

In this formulation, the active ingredient, such as insecticides, is encapsulated by a synthetic or biological polymer, and it helps in the prolonged and efficient release of the active ingredient. It also ensures uniform coverage and better absorption of the chemical into the plants, unlike the case of larger particles. Some essential oils have good insecticidal properties, but these are highly volatile and degrade quickly. These essential oils are suitable for nano-encapsulation.

14.4.1.2 NANO-EMULSIONS

Nano-emulsions have greater stability and low surface tension. So, it shows increased coating of leaves and increased uptake through the cell wall of plants. The most important advantage of nano-emulsion is the solubilization of hydrophobic pesticides, and usually, no precipitation or creaming occurs. It was reported that the nano-emulsion formulation of β-cypermethrin did not precipitate within 24 hours of dilution (Wang et al., 2007), and the release of the active ingredient is also slower than that of commercial formulation (Zeng et al., 2008).

14.4.1.3 SOLID-LIPID NANOPARTICLE (SLN)

These are nanoparticles having a mean photon correlation spectroscopy (PCS) diameter of ~50 to1000 nm. Lai et al. (2006) extracted the essential oil from *Artemisia arborescens* L., and incorporated in SLN, and they reported that this SLN formulation reduces the rapid evaporation, and it exhibited stability over a period of two months.

14.4.1.4 POROUS HOLLOW SILICA (PHS)

Li et al. (2006) investigated the characterization of PHSNs, with various shell thicknesses in the range of 5–45 nm and a pore diameter of about 4–5 nm. They revealed that the shell thickness is one of the main controlling factors for the release of the active ingredient.

14.4.1.5 NANO-SILICA

Nano-silica can be used to control a wide range of agricultural insect pests (Ulrichs et al., 2005). The application of nano-silica in tomato plants can minimize the *Spodoptera littoralis* infestation (El-bendary *and* El-Helaly, 2013). It influences the feeding preference of *S. littoralis,* ultimately increasing the resistance in plants.

14.5 NANOTECHNOLOGY AS POTENTIAL TOOL FOR INSECT PESTS MANAGEMENT OF COMMERCIAL FLOWER CROPS

Like other crops, commercial flowers are also infested by various insect and acarine pests at different stages of their growth. The most commonly associated pests with flower crops are thrips, aphids, whiteflies, Mealybugs, *Helicoverpa armigera* (Hubner); *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) and mites, *Tetranychus urticae* Koch (Acarina: Tetranychidae). But studies regarding management of these pests in flower crops are scarce, although some studies have been made in other commercial crops. There is no doubt that tremendous advancements have been achieved through nanotechnology in many fields of science like engineering, biotechnology, analytical chemistry, medicine, etc. But as far as the agriculture sector is concerned, the field level implementation of this technology by the farmers, especially for plant protection, is still in its infancy (Resham et al., 2015) and an under-explored research area (Khot et al., 2012). Therefore, there is a dire need and enormous scope for a detailed study of the application of nano-technology in the pest management of commercial flower crops. However, some studies have been made for the management of some polyphagous insect pests, which also attack the commercial flower crops as their host.

Nanotechnology is, no doubt, an attractive tool for the formulation and delivery of active ingredients of pesticides. Consequently, various formulations of pesticides have been designed using this technology for the controlled release of active ingredients as well as enhanced delivery. The nanocapsules designed in such a way that it releases the active ingredient in specific environmental conditions or in specific physiological environments. A nanosuspension of pyridalyl has been prepared by Saini et al., (2014). They prepared it using sodium alginate, and they reported that it was two times more effective as stomach poison against *Helicoverpa armigera* than the technical product and six times more effective than commercial formulation. However, its efficacy in commercial flower crops was not evaluated. Silica nano particles coated with 3-mercaptopropyl triethoxysilane exhibited better efficacy in *S. litura* than those coated with hexamethyldisilazane (Debnath et al., 2012). The antifeedant activity of α-pinene and linalool was enhanced when formulated with SiO2 nanoparticles against *Spodoptera litura* (Usha Rani et al., 2014), and they also reported the 25 times increase of biological activity of the product against this lepidopteran pest. It has also been revealed that nano-silica has the ability to reduce the reproductive capacity of insects, and it also affects other biological parameters of insects (El-bendary *and* El-Helaly, 2013). Kang et al. (2012) observed behavior modification ability of chitosan-coated nanoformulations of pyrifluquinazon in *Myzus persicae.* It caused rapid cessation of feeding, and the insect eventually starved to death.

Pradhan et al. (2013) conducted an interesting experiment with the nano-formulation of acephate synthesized by them. They revealed that the nano-formulation of acephate is helpful to break the resistance among the pest population and reported it as cost-effective and bio-safe. They suggested that it has excellent activity against a wide range of pests. They noticed significant mortality of *S. litura* and reduction in hatching efficiency. They also claimed a good acaricidal activity of nanoacephate against red spider mites (*Oligonychus coffeae*).

14.6 POSSIBLE RISKS OF NANO PRODUCTS

Like several other technologies, nanotechnology also may have some disadvantages. Nano products may have some hazardous effects on the environment as a whole. So, these hazardous effects need to be resolved through intensive research before wide application at field level. Silver Nanoparticles can penetrate the cell membrane (Verma et al., 2008) and cause toxicity (Morones et al., 2005; Nel et al., 2006). Even it may cause liver toxicity if inhaled or ingested orally (Kim et al., 2009). Effects of alumina nanoparticles on root growth of five plants *viz.*, cucumber, cabbage, carrot, corn, and soybean were studied by Yang et al., (2005). They observed that it slowed the growth of the roots of these plants. Silver occurs in different natural environments, most often as a mineral ore, in association with other elements. Yet even in its bulk form, it is toxic to fish (Hogstrand *and* Wood, 1996), crustaceans, some plants, fungi (Eisler, 1996), and bacteria (Albright *and* Wilson, 1974). The toxic effect of nanosilver to mammalian liver cells (Hussain et al., 2005), stem cells (Braydich-Stolle et al., 2005), and even on brain cells (Hussain et al., 2006) have been observed by scientists.

14.7 CONCLUSION

Nanotechnology has tremendous potential to redefine and revolutionize agricultural production in the near future. It may play a vital role in the successful pest management of several crops, including flower crops. At a time when we have been facing several problems due to the rampant use of pesticides, nanotechnology may appear as a ray of hope. Due to the controlled release of active ingredient over a period of time, the nano-formulations may be effective for a long time and thereby helps to reduce the frequent use of pesticides and ultimately reduce the pesticide load on the environment. It is a fact that several nano products are still under research, and few products are also in the market. But still, there is an urgent need to conduct more and more focused research to resolve many problems, to answer many questions before the wide popularity of this technology. The related risks and hazards should never be ignored. Once we overcome the negative effects, only then mankind will start harvesting the wonderful benefits of this technology.

KEYWORDS

- ***Artemisia arborescens* L.**
- **nano pesticides**
- **nanosensors**
- **nanosuspension**
- **nanotechnology**
- **pest management**

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CHAPTER 15

INDIGENOUS TECHNICAL KNOWLEDGE (ITK) IN MANAGING PESTS OF ORNAMENTAL PLANTS

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ABSTRACT

A number of indigenous practices are followed to manage pests and diseases in ornamental plants. This traditional treasure of knowledge perpetuates from our ancestors and forefathers without any form of written documents and is still practiced throughout the world. Application of ash, various neem products, cow urine, cow dung, cow milk, and different plant materials are some of the techniques practiced by the growers. The use of traditional practices for the management of insect pests serves as a better option than using harmful pesticides and maintains the population of natural enemies (NEs), maintains the ecological balance and sustainability.

15.1 INTRODUCTION

Ornamental plants are mostly grown for their exquisite blooms and attract many people. They could be herbs, shrubs or trees, lianas, and creepers, terrestrial, and aquatic in habitat and have originated in different habitats representing different ecosystems and environments. Several ornamental plants are commonly known for their exquisite beauties such as gardenia, pansy, bougainvilleas, roses, daisies, petunias, dahlia, chrysanthemum, gerbera, aster, sunflowers, lilies, orchids colorful ornamental grasses, etc. Besides, these plants attract the people, they also cleans and purify the air and excludes stress when kept as an indoor plant; many beautifully textured ornamentals prevent soil erosion, and few of them are also considered as a good remedy for small ailments.

Ornamental crops have been found infested by many insect pests. Insect pests such as aphids (*Macrosiphum luteum* Buckton, *Toxoptera aurantii* Boyer De Fonscolombe), thrips (*Dichromothrips nakahari* Mound), Forest, and Western Tent caterpillars (*Malacosoma disstria*), Fall webworm (*Hyphantria cunea*), Elm leaf beetle (*Pyrralta luteola*), Mealybug (*Pseudococcus* sp.), Two-spotted red spider mite (*Tetranychus urticae* Koch), Scale insects (*Diaspis boisduvalii* Sig), Shoot borer (*Peridaedala* sp.) slugs and snails, black weevil, *Sipalinus* sp. reduces the vitality and productivity of ornamental plants. Farmers practice indigenous methods in various corners of our country to manage various insect pests and diseases in ornamental plants.

Traditional knowledge refers to the knowledge obtained from the local traditional culture or community which has been passed from elders or ancestors. Indigenous traditional knowledge has been taken and followed as a responsibility albeit a paid one. This knowledge is expressed in their local language, local songs, folk songs, and dance. These traditional treasure of knowledge has been imparted from our ancestors and forefather without any kind of written documents and is still a good number have been retained and practiced by various tribes to save their crops from pest menace.

15.2 DIFFERENT INDIGENOUS TECHNIQUES PRACTICED

The followings are some of the indigenous technologies applied to control the pests and diseases of ornamental plants among our country. However, not only in ornamental plants but also for other crops, these technologies are applicable, and farmers use them to protect their crops.

15.2.1 APPLICATION OF ASH

Ash was applied at wet seedbed before sowing seed. The soil in the seedbed becomes porous leading to proper root growth followed by the seedlings. Less root damage occurred at the time of seedling uprooting that helped in the early establishment of seedlings in the main field. The tillers/hills became strong, healthy, and attain the ability to tolerate or resist any kind of stress or injuries that ultimately reflected in good yield. Ashes were available in the household of farm families. It involved no extra cost, and the technology was easy to apply (Laskar et al., 2016). Ash powder is sprayed on the soil or foliage to inhibit insect pests infestation. Its strong physical action on the crop plant produces a chemical effect that obstructs the location of hosts by insect pests.

15.2.2 USE OF NEEM, AZADIRACHTA INDICA

The parts of the Neem plant (*Azadirachta indica*), such as neem seed, leaves, and even bark, are beneficial in controlling the pests (Meena et al., 2018). Tender neem leaves are taken and grounded by adding water, and leaf extract was taken by filtering it with muslin cloth. After that, the 100 ml of neem extract is dissolved in water and then sprayed on ornamental crops which have been found effective against sucking pests. To obtain seed kernel extract, neem fruits are smashed to separate the pulp, and then dried seeds are grinded with water.

15.2.2.1 NEEM LEAF EXTRACT

Leaf extract of neem is prepared by taking neem leaves and placing in a pot with 2 liters of water. The mouth of the pot will be closed with a cloth, and then it is left as such for 1–2 days. Neem leaf extract is mixed with the water at the ratio of 1:9 with water, and before spraying of the extract soap has to be added. This neem leaf extract prevents the infestation of aphids, grasshoppers, leafhoppers, planthoppers, scales thrips, weevils, and beetles. They are eco-friendly and can get easily and used as an eco-friendly bio-pesticides against shoot borer, thrips, and other sucking insect pests. The low cost, environment-friendly technology may safely and easily be incorporated in the control of pests of ornamental crops.

15.2.3 USE OF MIXTURE OF COW URINE, COW DUNG, AND BUTTERMILK

According to Meena et al. (2018), applying the mixture of the product obtained from cow viz. cow urine, cow dung, and buttermilk helps to manage thrips. The earthen pot is taken off the required size and two parts of cow urine, one part each of cow dung slurry and buttermilk in the equal ratio are mixed, and the closed the mouth of pot with cloth. The pot is kept as such for a complete fermentation. A solution is obtained by filtering the mixture. To prepare the spraying fluid, a 50 ml solution is to be added with water (1000 ml) and then followed by spraying on the crop. Spraying of an aqueous solution of fresh cow dung on the orchid plant during the vegetative stage provides protection against thrips. Cow urine 5%, in addition with NSKE 5% along with cow dung 5% showed antifeedant and antiovipositional effects, especially against gram pod borer.

15.2.4 FERMENTED CURD WATER

Buttermilk is obtained by keeping the water that has come out from the curd covered in an earthen pot for several days or weeks, and this has been practiced among the farming community in India, and it has been reported to be beneficial against sucking pests.

15.2.5 COW MILK

Apart from cow's dung and urine, milk of cow also consists of certain volatiles, which plays an important role in the management of viral diseases such as powdery mildew, leaf curl, etc.

15.2.6 COW URINE AND DUNG

Cow urine mixed along with water in a 1:20 ratio protects the crop from pathogens and insects, it also plays the role of growth promoter of crops. Cow urine have been found effective against Mealybugs, thrips, and mites

(Peries, 1989) and against post-flowering insect pests of some crops. The urine of cow possesses certain repelling and deterrent properties that inhibit the crop from the attack of certain borers (e.g., fruit borer) Narayanasamy (2002). Dung obtained from the cow is sometimes used for making a thick layer over bamboo, mixed along with some clay particles, which had been practiced by the farmers in some parts of India mainly to prevent any insect pests to enter into the storage structure made especially for grains, large cardamom, etc. Cow dung also like that of Cow urine possess certain properties that have been found to inhibit certain pest infestation e.g., rice pest.

15.2.7 MULCHING

Mulch is a layer of material that is applied on the soil surface for moisture conservation, to make the soil fertile, decrease weed population and to keep the area clean. Farmers used to practice this, after the planting of the crop, the planting beds are layered with the mulch such as leaves of some medicinal plants, bark chips, fallen leaves, and plastic sheets. Compost and manures, when used as mulch, will convert naturally in soil-by-soil organisms such as earthworms. Mulch prevents washing away of the soil, especially in the hilly terrain, it prevents continuous watering of the crop, gives a clean look. When the layered mulch materials decompose, they will improve the soil condition, strengthens the root, helps in maintaining optimum soil temperature, and maintains a weed-free environment.

15.2.8 APPLICATION OF KHIRA (CUCUMISSATIVUS L.) LEAF EXTRACT

Spraying of extract solution on orchid obtained after grinding of the cucumber leaf after filtering has resulted in preventing borer attacks (Meena et al., 2018). Its use, along with the irrigation in the rice field has been reported to be effective against stem borer. These practices are effective in managing the pest in rice, vegetables, and many ornamental plants, and moreover, they are easily available and cheap and eco-friendly.

15.2.9 USE OF LEAVES OF VARIOUS INDIGENEOUS PLANTS

Spreading of the tender leaves of Artemisia (*Artemisia vulgaris* Mugwort), Domisak (*Croton caudatus* Geiseler), Khedzi (*Adhotoda vasica* L.), and Re' no-bol (*Aesculus assamica* Griffith) prevent the infestation of shoot borer on Dendrobium and other orchids (Meena et al., 2018). These leaves possess certain properties after which after decomposition repels the pests from the plant sources. Northeastern tribal farmers use such wild plants and have been reported to have insecticidal properties against a wide range of pests in orchid. These plants are available in every nook and corner of villages of the northeastern region. It can be collected from the field easily. Leaves release certain volatiles, which may be responsible to repel the pests that result in the uninfested healthy crop.

15.2.10 USE OF CHILAUNE LEAVES (SCHIMA WALLICHII) EXTRACT

Spraying of Chilaune leaves (*Schima wallichii*) extract on orchid plants provide protection against aphids (Meena et al., 2018). In this method, farmers take fresh leaves and prepare the extract by grinding Chilaune leaves along with the water.

15.2.11 CORIANDER (CORIANDRUM SATIVUM) EXTRACT FOR SPIDER MITE CONTROL

Coriander acts as a repellent of different pests, particularly mite pests. To prepare the extract of coriander, 200 grams of crushed seeds has to be boiled in water for a few minutes. Dilute coriander extract with 2 liters of water, which then will be ready for application. Spraying will be effective during the morning hours on infested plant parts to manage spider mites in various crops (Bissdorf, 2008), including ornamentals.

15.2.12 EXCRETA OF SILKWORM (BOMBYX MORI L.)

Spraying of dissolved excreta of silkworm (*Bombyxmori* L.) checks the lepidopteran pests population (Meena et al., 2018). Farmers allow silkworm excreta to dry completely inside the rearing place and then ground it to make it in a powder form for the field application.

15.2.13 USE OF BLACK POLYTHENE SHEET

Farmers practice the application of black polythene/plastic sheets at 2–3m distance above the crop canopy level. Pests like mites used to get aggregated on these sheets. When a sufficient number of pests are found in the sheet, it will be taken out of the field, and the pests will be killed either by washing/putting in Kerosinized water (Meena et al., 2018).

15.2.14 APPLICATION OF DRIED TOBACCO LEAVES (NICOTIANA TABACUM L.)

Dusting of finely dried tobacco (*Nicotiana tabacum* L.) leaves powder, plays an important role against sucking insect pests. Some tribal farmers in the northeast apply fine-grounded powder of dried tobacco leaves and hookah water on orchids to check scale's infestation (Meena et al., 2018).

15.2.15 USE OF LATEX OF CROWN FLOWER'S CALOTROPIS GIGANTEAN (L.)

Latex of crown flower's *Calotropis gigantean* (L.) leaves, fruits, and roots are used as a foliar spray on orchid to manage shoot borer and leaf folder infestation. Meena et al. (2018) reported that the solution of latex with water 1:15 ratio could be applied on crops at a one-month interval has been found to be effective as observed by orchid growers.

15.2.16 APPLICATION OF ORGANIC SPRAY

Organic sprays prepared by using chilies, onions, and garlic after grinding them and mixing them with water. After mixing them, spraying it on the plant have been found to control many insect pests, e.g., Aloe Vera. Apart from that, neem sprays are also efficient in killing pests.

15.2.17 USE OF SOAP WASHES

Soap washes are used to kill Aloe Vera pests. Mixing of the soap with water can be used to prepare a liquid. Spraying this on the Aloe Vera plants will kill and help to control the pest.

15.2.18 USE OF LIME SOLUTION

Spraying of the lime solution ($CaCO_3$) mixed with the cow urine and left for one day @ 1 kg/20 liter of water has been found to be effective against the mite in carnation as reported by Meena et al. (2018).

15.2.19 USE OF POULTRY MANURE

The use of poultry manure in dried form at the time of planting of Eucalyptus helps in the proper growth and development, as reported by Meena et al., (2018).

15.2.20 CREATING SOUND TO SCARE AWAY THE BIRDS

Creating sound to scare away birds is one of the indigenous traditional practices followed by farmers in some parts. To protect sunflower, farmers use a typical indigenous technology (Meena et al., 2018). A bamboo stem of about 6–7 feet is inserted deep at the middle core of the field, and then above it is a one side open tin (preferably a tin used for packaging mustard oil) placed inversely. A long rope fits at one edge of the tin and another end of the rope kept inside the house. Anyone from the house intermittently pulls the rope and automatically creates a loud sound in the tin. Birds that have come to eat rice immediately fly, and leftover grains are saved. This practice is indigenous and traditional in order to protect the crop from bird menace (Laskar et al., 2016). No harmful chemicals need to be applied in the fields. This is a simple but interesting and effective technique to avoid crop loss from bird menace. Production of loud sound makes the birds to fly away.

15.2.21 PINCHING

The practice of pinching of jasmine shoots helps in obtaining higher flower yield at the peak flowering time (Meena et al., 2018).

15.2.22 USE OF KEROSENE OIL

Kerosene is readily available with the farmers and can be used with soap instantly to suppress the insect pests at the beginning of the outbreak situation, and subsequently, the desired/recommended strategies may be followed. Kerosene emulsion possesses insecticidal action against scale insects, bugs, mites, aphids, and leaf miners. At more concentration, it shows a phytotoxic effect, and its use as foliar spray should be restricted up to 1 or 2% (Meena et al., 2018).

15.2.23 USE OF COMMON SALT

Farmers practice the use of common salt for repelling snails and slugs below the benches of orchid in case of epiphytic orchid and also the surrounding area of beds for the terrestrial orchid. Farmers collect them manually and kill them by putting in a 5% salt solution. Spreading of cabbage leaves (Brassica oleracea var. capitata L.) also attracts snails and slugs. Farmers have been practicing the use of leaves of cole crops like cabbage by spreading it over the orchid bed and were found that the slugs and snails feed on cabbage leaves instead of orchid (Meena et al., 2018). However, several local plants have good insecticidal properties against various insect pests and have recorded 47–73 to 55% reduction. NSKE@ 5 ml/L provided the highest percent reduction against sucking pests, whereas Artemisia leaf extract 10% treatment gives less% shoot damage (14.7%).

Such findings validate the most of indigenous approaches that were used by farmers of northeastern region for pest management on orchid inside polyhouses, partial shade as well as under natural habitation. Indian farming, which is going through a transition phase, is slowly but surely adopting the ways and means for crop protection for sustainable agriculture. Adoption of ITK based crop protection measures as one of the effective methods compared to that of harmful pesticides might help in restoring the population of beneficial insects, but as IPM is a knowledge-based and farmer-driven approach, education of farmers on alternatives to pesticides must be given a priority.

KEYWORDS

- ***Azadirachta indica***
- **indigenous knowledge**
- **ornamentals**
- **pest management**
- **pinching**
- **thrips**

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CHAPTER 16

PEST MANAGEMENT IN 'VERTICAL' AND 'GREEN' FARMS: A NEWER DIMENSION IN COMMERCIAL FLORICULTURE

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ABSTRACT

Vertical or green farms are a relatively new phenomenon in urban areas and cities in developing and underdeveloped countries. In developed countries, it is well practiced and is a growing science and business. Interest in this new form of cultivating plants, be it ornamental, flowering, vegetable, or fruit plant is catching-up worldwide. This chapter is confined to only ornamental foliage and flowering herbs and shrubs. New innovations and technologies are supportive to the concept of vertical and green farms to make it more efficient, smart, and profitable, across the world. Pest management in vertical and green farms should focus on softer, greener approaches that are effective hold biodiversity elements and sustainable. These patches of greenery, especially in urban areas are intended to provide a mix of aesthetics, health, and cleaner environments.

16.1 INTRODUCTION

As cultivated land for the growing human population is diminishing, there is an increasing demand for a shift in the food production system. The world is witnessing a massive movement of population from rural to urban areas. People need food production system that can reduce Green House Gas emissions and adverse impacts of global climate change. One of the options has been implementing the concept of 'Vertical' and 'Green' farms (Ake Olsson, 1980; Kheir Al- Kodmany, 2018). This concept is not new. It dates back to the ancient times when the Hanging Gardens of Babylon in Italy, one of the Philon's Seven Wonders of the world, was built in about 600 B.C. Gilbert Elli's Baily in 1915 for the first time coined the term and wrote a book on "Vertical farming," but not on a commercial scale. Today, a man out of compulsion is resorting to 'vertical' and 'green' farms (Corvalan et al., 2005; Despommier, 2014).

Kheir-Al-Kodmany (2018) has, in a review, traced the history of the development of the concept of 'vertical farming' to promote sustainable agricultural practices for commercial purposes in skyscrapers. This chapter, however, deals with the pest management in vertical farming, green walls, green spaces, indoor farming, and sky greens confined to flowering and ornamental foliage plants in urban areas and cities (Despommier, 2014). This system of floriculture is fast catching up and emerging as a pass-time for the urban populace with multiple merits in and around cities, the world over.

16.2 WHY VERTICAL AND GREEN FARMS?

Demographers project that the human population in urban areas will dramatically increase in the future. The United Nations anticipates that 80% of the world population will live in and around cities in 2050. The demand for food in urban areas will surpass supply. The cost for food, oil, water, gas, energy, and other agricultural resources will skyrocket, and the urban and suburban areas will engulf more and more of the agricultural lands. In cities there will be human congestion and commotion for daily resources. Consequently, people's health and social life, psychology is likely to be adversely affected. With buildings and high-rise structures, there is no or little space for greenery and natural flowers and foliage. So urbanites have increasingly become interested in embracing greenery and ornamental foliage, wherever possible- walls, small spaces, roof-tops, corners, balcony, interiors, and edges, paths in homes, offices, sit-outs, shops, restaurants, and open-spaces (Figures 16.1–16.3) (Muller et al., 2014; Mukherji *and* Morales, 2010).

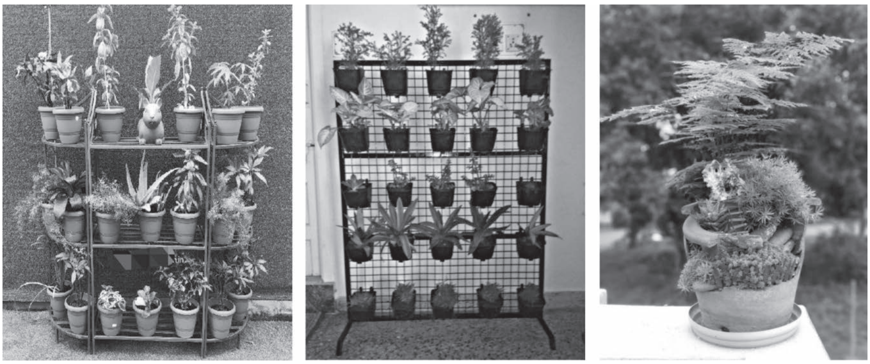

FIGURE 16.1 Ornamental foliage plants used in vertical farming, India.
Source: Vinay Kumar, Chiguru.

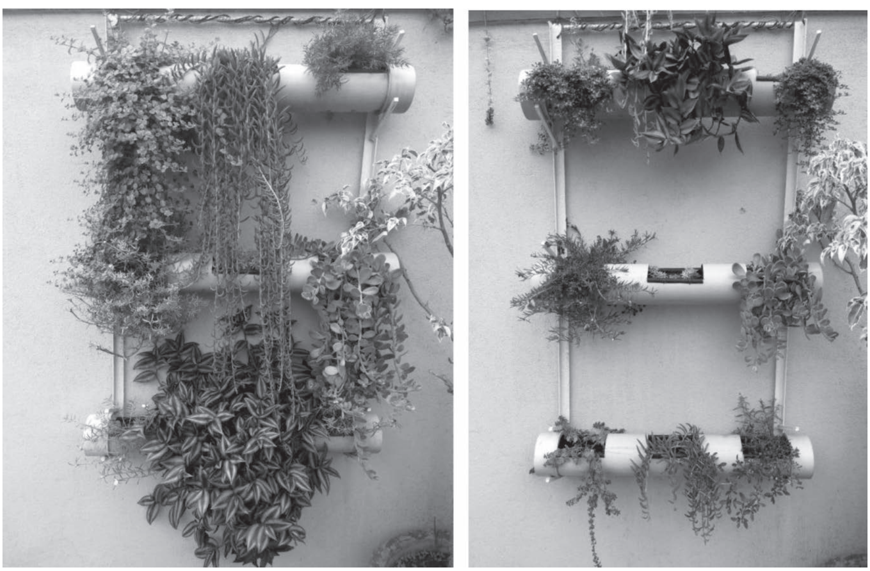

FIGURE 16.2 Ornamental trailing plants used in vertical farming in residential complexes, India.
Source: Vinay Kumar, Chiguru.

FIGURE 16.3 A sample of green farming adjacent to a residential, along a path, on walls.
Source: IHA.com; Flickr.com; HelechoEcotelhado; Longwood gardens.

The vertical and green farm is a simple concept, i.e., to have greenery-plants, foliage, and flowers along with vertical axis/space and not in horizontal space, i.e., more greenery in less horizontal space.

Urban planners, architects, doctors, social workers, environmentalists, engineers, gardeners, and nature lovers, among others are joining in transforming urban landscapes and filling it up with greenery along vertical heights. These set of people are constructing tall structures with levels of growing beds.

16.3 MERITS

Proponents of vertical and green farms claim that this idea will accrue multiple benefits to the human populace and will assist in maintaining environmental quality. It would enliven the lives of people, provide pass-time, employment, keep stretches of the area clean and neat, will keep people in good health and spirits, save space, water, energy, and reduce pollution and emissions of carbon dioxide into the surroundings. The surroundings will look beautiful and revealing. Fortunately, the recent adoption of greenhouses and related technologies such as aeroponics, soil-less cultures, hydroponics, and aquaponics support vertical and green farming, it goes well with these concepts (Figure 16.4). Flowers and ornamental foliage on rooftops will have a cooling effect during summer (see, Integrated Pest Management (IPM) in the Commercial Ornamental Nursery, 2015).

16.4 TIPS

- Remove diseased/weak/injured plants.
- Adopt appropriate cultural and management practices. Maintain plants healthy.
- Grow plants that have few pests.
- Scout plants regularly for pests and other disorders.
- Encourage and conserve beneficial like predators, pollinators.
- Spray only on target plant parts/spots.
- Use botanicals, oils, soaps (least toxic), etc., wherever possible.
- Release beneficial like ladybird beetle when pests first detected.

Certain pests may be carried from nursery to the plots or pots. One has to use pest-free seeds, cuttings, or plants. Soil or cultures used for raising plants should be free from soil pests like termites and root grubs. In south India, for example, the soil contains eggs or grubs of Scarabaeid beetles like species of *Holotrichia*, *Mimela*, *Adoraetus, Ctonia, Anamola, Gomphrena, and* others. Grubs of these species are root feeders, and adults are defoliators. Soils especially red, sandy, loams harbor termites of species of *Odontotermes, Microtermes, Macrotermes, and* other species in South India. A sample of pests in vertical and green farms is given in Figure 16.5. Before using or potting, such soils should be made free of all these pests. Water needs to be released to the soil surface. Eliminate weeds or plants that harbor pests or pathogens. Screens or barriers or blocking can help to reduce pests. Plants affected by pests or diseases should be removed or destroyed so that re-infestation does not occur. In vertical or green farms, only certain plants or plant species are attacked by pests and diseases. Such plants or species should be closely monitored. There are

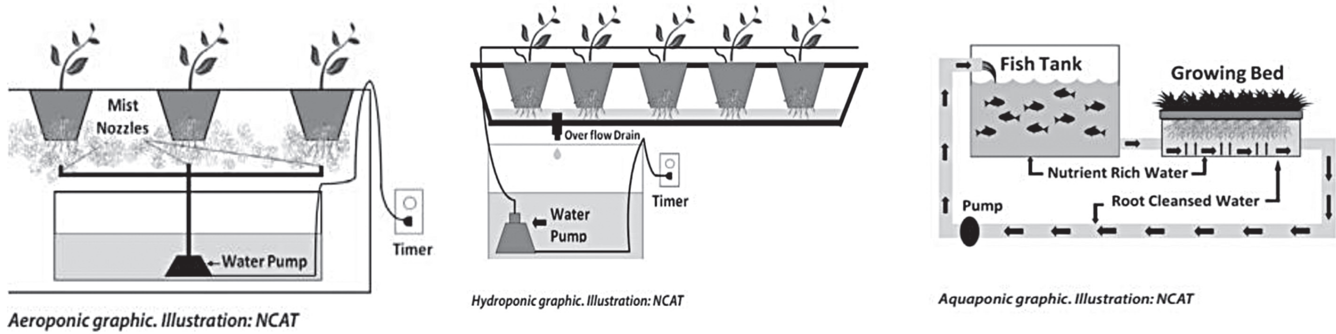

FIGURE 16.4 Diagram illustrating aeroponic, hydroponic, and aquaponic technologies.

Source: JeffBirkby, NCATSmart Growth Specialist Published., www.attra.ncat.org.

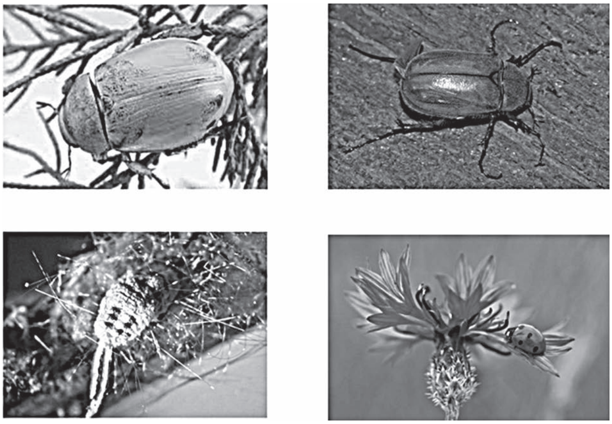

FIGURE 16.5 Commonly found insect pests in vertical and green farms.

Source: Wood's Jewel Scarab (Scarabaeidae, Chrysina woodi); www.Flickr.com: berniedup; Chamaiporn Buamas, Department of Agriculture, Thailand Wikimedia Commons; https://www.pexels.com/photo/red-and-black-lady-bug-on-purple-flower-during-daytime-70335/)

certain pests like crape myrtle aphid, which feeds only on a crape myrtle. Another example is Azalea leaf miner and lace bugs that feed specifically in a plant or plant species (IPM in the commercial ornamental nursery, 2015). The two-spotted spider mites and silver leaf whitefly have hundreds of host plants. Bark beetles (Scolytidae) and clearwing moths (Sessidae) are opportunist feeders. Currently, in India, many invasive like whiteflies, Mealybugs, thrips, and others are infesting ornamental and flowering plants. Some of the select pests are as follows:

- Spiraling whitefly, *Aleurodicus disperses* (Russel).
- Rugose whitefly, *Aleurodicus rugioperculatus* Martin.
- Silver leaf or polyhouse whitefly, *Bemisia argentifolii* Bellows and Perrings.
- Papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink.
- Striped mealybug, *Feriasia virgata* (Cockerell).
- Flower thrips, *Frankliniella* spp.

The above insects are recently introduced in India. These pests are difficult to manage because of no or few natural enemies (NEs), polyphagous nature, and exhibit resistant to almost all insecticides (Chakravarthy et al., 2017).

16.5 PEST MANAGEMENT

Vertical and green farms are not free from insect pests and microbial diseases. These marauders gain entry into the indoors through windows, water, wind, and human interventions. Indoor plant growers across the world will come across almost similar pests and diseases. Vertical and green patches suffer due to sucking, tiny insects like hoppers, aphids, whiteflies, thrips, spider mites, scales, and Mealybugs. Often, only one category of the pests or pathogens dominates in these farms. Foliage plants like *Colacacia,* Foxtail ferns, *Dieffenbachia*, *Coleus*, grasses, Coral bells, Plantain lilies, Crotons, Acalypha, Pothos, *Hedera helix*, and others in South India (Table 16.1) are often infested with whiteflies, Mealybugs, and other sucking pests. Growing tips and under the surface of leaves are colonized by these pests. To protect the plants, regular removal of these insects is required. Flowering plants for borders of green farms include Daisies, geraniums, tulips, marigolds, asters, magnolias, petunias, hollyhock, orchids, and others are also infested by sucking pests like mites, leafhoppers, aphids, thrips, and whiteflies.

One has to be pro-active against diseases too. To protect plants from Botrytis infection, plants should not be wounded. The cuts on plants should be proper so that they heal without any fungus infections. Pruning has to be done properly. Watering should be regulated, and microhabitat conditions should be proper or appropriate. Pythium is a fungus that infects underground parts like roots, bulbs, corns, etc. It also affects basal crown and plant parts just above the soil. Proper water management and maintaining optimum soil moisture ameliorate the disease faster. Adding few earthworms in the container or space also helps to maintain soil fertility (Karlie Haywood, 2017) Following steps may be adopted to implement IPM in vertical and green farms. The best way to protect flowering and green foliage plants is to avoid pests and pathogens.

16.5.1 VISUAL INSPECTION AND MONITORING

Through scouting, one has to assess the population densities of pests and portions of plants infested. Early detection of pests enables one to reduce and restrict pest damage, maintain plant quality, reduce costs, and sustain the aesthetic value of the space. The detection of pests should be followed

TABLE 16.1 Commonly Grown Plants for Vertical Farming and Green Gardens

Sl. No.	Common Name	Scientific Name
1	Boston fern, sword fern	*Nephrolepis*sp.
2	Bird nest fern	*Asplenium nidus*
3	Pothos, golden pathos, devil's ivy	*Epipremnum* sp.
4	Geranium	*Geranium* sp.
5	Petunias	*Petunia* sp.
6	Verbena, Canadian vervain	*Verbena canadensis*
7	Sweet alyssum	*Lobularia maritime*
8	Nasturtium	*Tropaeolum majus*
9	Chives	*Allium schoenoprasum*
10	Oregano	*Origanum vulgare*
11	English ivy	*Hedera helix*
12	Giant lilyturf	*Lirope gigantea*
13	Philodendron	*Philodendron scandens*
14	Geranium varieties	*Geranium dissectum*
15	Wedding vine	*Stephanotis floribunda*
16	Peace lily	*Spathiphyllum wallisii*
17	Star jasmine	*Trachelospermum jasminoides*
18	Lipstick plant	*Aeschynanthus radicans*
19	Limelight bower wattle	*Acacia Cognata*
20	Dracaena	*Dracaena*
21	Australian native monstera	*Epipremnum aureum*
22	Croton	*Codiaeum variegatumpictum*
23	Stonecrop	*Sedum album*

Source: https://wallgarden.com.au/vertical-garden-plant-species-guide.

by interventions. The entire nursery should be divided into logical units or blocks. Short duration plants require scouting once in 3–4 days. Long duration plants such as potted flowers and foliage plants may require weekly monitoring. Long duration woody plants may require scouting once in 15 days. Mainly the new growth of the tender shoot and foliage should be examined for any deformities. Plants with symptoms of disease or insect injury should be closely examined.

Yellow sticky traps/cards or plates are effective in trapping sucking insect pests like whiteflies, aphids, hoppers, thrips, leaf miners, etc., but not on all occasions. Often they serve as an index for the activity of the pests. The traps are placed at the height of the plant canopy. The traps are checked once in a week. The first plant showing symptoms is an indicator plant. The plant is marked with red cloth or tagged in some way. Pests on indicator plants are daily inspected for presence, increase or decrease of numbers. For instance, in the case of mealybug and scales, eggs and crawlers are most vulnerable. Schefflera plants are a good trap crop for most pests in a foliage plant in greenhouse or interiors. Some of the plants that can serve as indicator plants in green or vertical farming are sunflowers (seedlings), *Ficus* spp., *Poinsettia* (whiteflies), *Hedera* spp. (Spider mites), chrysanthemum, and roses (aphids) and hibiscus, marigold (mealybugs, thrips, etc.). Records must also be made of any beneficial found on or near the infested plants.

16.6 COMMERCIAL PROPOSITIONS

A number of social and economic benefits may emerge due to vertical and green farms, particularly to the local community. Ladybird beetles or Coccinelids are one of the most common predators used in gardens, green, and vertical farms. Individual companies or entrepreneurs can culture and sell these insects in hundreds/thousands packed in a linen/cotton bags. Ladybird beetle are released during evening hours after watering the plants. The lighting along the vertical layers of beds should not affect beetles. If lighting is intense, beetles get dis-oriented and do not feed on aphids, planthoppers, thrips, and whiteflies- pests on foliage. The beetles can be directly released on seedlings when lights are turned off. Suitable seedlings and species of plants for vertical and green farms are often not easy to get. Again commercial nurseries can sell the seedlings at competitive prices. Wastes, leftovers, or unused open spaces can be used to raise nurseries. This will entice the younger generation to practice gardening, and vertical and green farms can give impetus for the development of connected innovative technologies.

KEYWORDS

- **green farms**
- **pest management**
- **urban areas**
- **vertical farming**

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