Chapter 21
Implementation of IPDM in Strawberries and Other Berries

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Abstract Several high value small fruit crops are grown under greenhouse conditions around the world. Integrated pest and disease management (IPDM) in greenhouse production of small fruits can take advantage of a number of practices for maintaining optimal crop health while ensuring good yields and sustainability. These practices include the use of resistant cultivars and clean plant material free of pests and diseases, effective substrate, irrigation, and nutrient management, regular monitoring and good sanitation practices, substrate disinfestation and sterilization with fumigation alternatives, modifying the environmental conditions to reduce pest and disease pressure, chemical and non-chemical control options, along with biostimulants and beneficial microbes. Several examples of successful use of these tactics are discussed and general IPDM guidelines are presented in this chapter.

Keywords Small fruits · Strawberry · Cultural practices · Non-chemical alternatives · Beneficial microbes · Induced resistance · Substrate disinfestation · Fumigation alternatives · Microbial control · Entomovectoring

21.1 Introduction

Strawberries, raspberries, blackberries, and blueberries are high value crops. Although they are primarily grown in open fields or under high tunnels in major producing regions in the world, considerable amounts of greenhouse production also take place, especially in Europe and other areas. Greenhouses offer a unique opportunity to regulate the environment or administer specific production practices that are required for these specialty crops. However, the same conditions that promote plant growth can also be ideal for arthropod pests and diseases, which warrant

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aggressive management tactics that include pesticide applications. Greenhouses used for producing nursery plants need to maintain a higher standard of crop protection to produce pest and disease free berry transplants. Many a time, pest-infested or disease-infected transplants lead to major problems in the fruit production. While the basic IPDM principles for greenhouse berry production are same as those employed under field conditions, some approaches can be different.

Compared to the pest and disease management in the fields, pesticide applications can be higher in greenhouses, and IPDM is necessary to reduce their use and residue levels. A comparison made among greenhouse, conventional, and organic cucumber production systems in Egypt revealed highest levels of pesticide residues in greenhouse cucumbers (Mansour et al. 2009). Similarly, a study in Colombia showed that greenhouse tomatoes had a higher number of pesticide residues per sample compared to those produced in open fields (Bojacá et al. 2013). A Norwegian greenhouse study recommended 7–14 days of preharvest interval for certain fungicides, which is a challenge because strawberries are harvested more frequently (Stensvand 2000; Baker et al. 2002). On the other hand, pesticide residues are reported to be generally higher in strawberry (Safi et al. 2002) warranting a need for non-chemical pest management strategies.

Although several biocontrol options are available for pest management in greenhouses, chemical pesticides are still important tools and IPDM practices are also necessary for resistance management. While there are several mechanisms for the development of pesticide resistance, in general, there is an increased risk of breeding resistant pest populations or pathogen propagules in greenhouses due to a high selection pressure as well as the lack of unexposed, wild alleles dilute the frequency of resistant mutants. Pesticide resistance is frequent around the world in twospotted spider mite, *Tetranychus urticae*, greenhouse whitefly, *Trialeurodes vaporariorum*, and western flower thrips, *Frankliniella occidentalis*, which are some of the common greenhouse pests of strawberry and other small berries (Gorman et al. 2001; Bi et al. 2002; Herron and James 2005; Van Leeuwen et al. 2010). Fungicide resistance is also an issue in disease management. For example, there are several reports of fungicide resistance in *Botrytis cinerea*, an important pathogen of strawberry, blackberry, raspberry and blueberry causing gray mold or blight (Elad et al. 1992; Raposo et al. 1996; Yourman and Jeffers 1999).

This chapter will cover the key aspects of IPDM for strawberry and other berries with examples from both field and greenhouse studies. Some examples of from other crops will also be included as those management practices are applicable to berries or similar pests or diseases affect berries.

21.2 Resistant Cultivars

Cultivar choice usually depends on the berry quality, yield potential, shelf life, and consumer preference, among other factors. Selection of appropriate cultivars suited for the local conditions based on the risk of a particular pest or disease in the region can be one of the key steps in IPDM. In general, berry cultivars are bred more for disease resistance than for pest resistance. An earlier review of strawberry breeding programs around the world identified fruiting season, fruit size, firmness, quality, and disease resistance as the main objectives in developing new cultivars (Faedi et al. 2002). Resistance in strawberry cultivars Aromas, Camino Real, Festival, Portola, San Andreas, Ventana to *Fusarium oxysporum* f. sp. *fragariae* (Fang et al. 2012; Koike and Gordon 2015), cultivars Bounty, Cabot, and Cavendish to black root rot caused by *Rhozoctonia fragariae*, *Pythium*, an *Patylenchus penetrans* (Particka and Hancock 2005), and cultivars Camino Real, Marquis, Pataluma, San Andreas to *Verticillum dahliae* (Ivors, personal communication) were reported in multiple studies in Australia and United States. However, some cultivars that were highly resistant in some studies were susceptible in others and it is important to verify the performance of each cultivar under local conditions. Averre et al. (2002) reported relative resistance of several strawberry cultivars to anthracnose, leaf spot, leaf blight, powdery mildew, and red stele where most of the cultivars recommended for North Carolina were resistant to powdery mildew, but had varying levels of resistance to other diseases. Such information helps the growers to choose an appropriate cultivar for the local conditions.

While a few strawberry cultivars possess pest resistance to some extent, breeding for arthropod resistance does not seem to be a focus even today for a major berry crop, like strawberry, that has several pest problems (Ferrer et al. 1993; Hancock et al. 2008). Although the development of aphid resistant raspberry cultivars has been practiced for several decades, the primary focus is to manage different viruses that aphids transmit (Keep and Knight 1967; Birch and Jones 1988).

In blackberry, varying levels of resistance to various diseases, such as anthracnose (*Elsinoe veneta*), botrytis fruit rot (*Botrytis cinerea*), and double blossom/rosette (*Cercosporella rubi*) is seen among cultivars and some thornless ones are more resistant to certain diseases (Bruzzese and Hasan 1987; Ellis et al. 1991; Gupton 1999; Kidd et al. 2003). An older study also reported that cultivars having the germplasm of North American species are more resistant that those with European blackberry species to European blackberry rust (*Phragmidium violaceum*). However, blackberry breeding centered around improving fruit quality, thornlessness, environmental adaptation, and primocane fruiting especially in cultivars released between 1985 and 2005 (Clark and Finn 2008).

In blueberries, lowbush varieties or others that have a higher level of lowbush blueberry germplasm are resistant to *Monilinia vaccinia-corymbosi* that causes blight in emerging shoots and leaves and mummy berry in fruits (Ehlenfeldt et al. 2010). Susceptibility of highbush blueberry to *M. vaccinia-corymbosi* also varies among cultivars and there are several resistant or moderately resistant cultivars to be considered (Schilder et al. 2008). The incidence of another important blueberry disease, anthracnose, caused by *Colletotrichum acutatum* is less in cultivars that grow vigorously and produce higher yields (Polashock et al. 2005). Half-high blueberry cultivars appear to be more resistant than lowbush, highbush, southern highbush, and rabbiteye cultivars to botryosphaeria stem blight caused by *Botryosphaeria dothidea* and phomopsis twig blight caused by *Phomopsis vaccinia* (Polashock and Kramer 2006).

21.3 Cultural Practices

Cultural practices such as choosing a clean source of transplants, appropriate type of soil/substrate, spacing, irrigation, nutrient management, sanitation, and pest and disease monitoring play a significant role in reducing pest and disease occurrence and spread.

In general, plants that receive optimum irrigation and nutrient inputs maintain good health and withstand pests and diseases better than those under water stress and excessive or insufficient nutrient inputs. For example, excessive nitrogen fertilizers, water stress, high temperatures, or dust on foliage can increase infestations of the twospotted spider mite, *Tetranychus urticae* in strawberry, raspberry, and other crops (Alston 2017; Garcia 2017; Ruckert 2017). On the other hand, soil amendment with poultry litter in greenhouse strawberry effectively reduced the viability of microsclerotia of *Macrophomina phaseolina*, causal organism of charcoal rot or crown and root rot (Pratt 2006) and poultry manure and compost suppressed root-lesion nematode, *Pratylenchus penetrans* in raspberry (Forge et al. 2015). While high irrigation reduced western flower thrips (*Frankliniella occidentalis*) adult numbers, high nitrogen and phosphorus promoted thrips populations (Schuch et al. 1998; Chow et al. 2012; Chen et al. 2014). Very low soil moisture (0 or 25% water holding capacity) or flooded conditions (125% moisture) reduced the viability of *M. phaseolina* microsclerotia (Pratt 2006). Other studies had also indicated that high soil moisture content affects their viability (Short et al. 1980; Zveibil et al. 2012). Maintaining good soil fertility, particularly optimal levels of phosphorus, along with avoiding water and heat stress are recommended for mitigating *M. phaseolina* severity in strawberry (de los Santos et al. 2016). Manipulating irrigation and nutrient management practices can be an effective tool in pest and disease management.

Several pests and diseases can be introduced into greenhouses through infested or infected transplants and multiply when the soil or substrate or contaminated. Obtaining clean transplants from a reputable source and using a substrate free of pests and disease propagules is a critical a step in IPDM. If the substrate is used multiple times or there is a risk of pests or diseases, there are multiple ways to disinfest using non-chemical alternatives, which are discussed later in this chapter.

Regular monitoring for early identification of problem areas and timely administration of corrective actions will reduce potential yield losses and pest and disease problems. Sanitation practices, such as the removal of infected fruit or plant material, play a big role in reducing pathogen inocula or pest infestations in the environment. Removal of discarded or fallen berries is a recommended management practice for anthracnose (*C. acutatum*), Rhizopus fruit rot (*Rhizopus* spp.) and Mucor fruit rot (*Mucor* spp.) in strawberry (Dara 2015a), mummy berry in blueberry (Schilder et al. 2008), and spotted-wing drosophila (*Drosophila suzukii*) in different berries (Leach et al. 2016).

21.4 Substrate Disinfestation with Fumigation Alternatives

Compared to the field production of berries, where chemical fumigation is frequently practiced for managing several soilborne pests, pathogens, nematodes, and weeds, using a clean substrate in greenhouses eliminates the need for fumigation and reduces the risk of those problems. However, techniques such as solarization, steam sterilization, anaerobic soil disinfestation (ASD), or biofumigation can be used when there is a risk of contamination (Stapleton 2000; Tanaka et al. 2003; Bañuelos and Hanson 2010; Shennan et al. 2017).

Solarization can be done in multiple ways depending on the greenhouse conditions, but passive solar energy is employed for heating moist substrate usually covered by transparent plastic mulch. In addition to killing parasitic and pathogenic organisms, solarization increases the availability of soluble mineral nutrients and the activity of beneficial microorganisms (Stapleton 2000; Candido et al. 2008). In a field study in Turkey, several weeds and pathogens (*Rhizoctonia* spp. and *Phytophthora cactorum*) were effectively controlled and strawberry fruit yield was maintained from soil solarization at a level comparable to the methyl bromide treatment (Benlioğlu et al. 2005). Compared to metam sodium fumigation, soil solarization resulted in a higher strawberry yield in another study conducted in Spain (Camprubí et al. 2007). It also appeared that arbuscular mycorrhizal fungi were not affected by both solarization and fumigation in this study.

Steam sterilization is another non-chemical soil disinfestation process where soil or substrate are exposed to steam. This technique is especially useful in temperate regions where solarization is not possible. In a field study conducted in California strawberries, weed control from steam or steam+solarization was similar to that achieved by methyl bromide+chloropicrin fumigation (Samtani et al. 2012). Some stream treatments were also as effective as chemical fumigation in reducing *Verticillium dahliae* microsclerotia at a depth of 15 cm. Steam sterilization decreased soil fungi and bacteria (including those that oxidize ammonia and nitrite) to a greater extent and for a longer duration than methyl bromide fumigation in a Japanese study while increasing the ammonical nitrogen content in the soil (Tanaka et al. 2003).

Biofumigation generally refers to pest, disease, or weed suppression through soil incorporation of Brassica plant material or seed meal as green manure that releases phytochemicals. Use of microbes, manure or other organic waste that produce volatile compounds or gases is also considered as biofumigation. Glucosinolates in Brassica plants produce allyl isothiocyanate, nitriles, and other compounds that have antimicrobial and insecticidal properties (Fenwick et al. 1983; Mattner et al. 2008). These plant-based isothiocynates or sulfur-containing compounds are similar to methyl isothiocyanate, a byproduct of chemical fumigants metam sodium, metam potassium and dazomet. The combination of steam sterilization with mustard seed meal resulted in good weed and pathogen (*M. phaseolina*, *Pythium ultimum*) suppression along with improved strawberry yields comparable to chemical fumigation in a California study (Fennimore et al. 2014). In Spain, the combination of solarization and biofumigation with chicken manure was superior to solarization alone in weed control and improving strawberry growth and yield (Medina-Mínguez 2002). Bañuelos and Hanson (2010) reported improved weed suppression and strawberry yield in a California study with selenium-enriched mustard and canola seed meals that served as both bioherbicides and green fertilizers. Some degree of weed and pathogen (*P. cactorum*) suppression was seen from soil incorporation of *B. rapa/B. napus* crop in a field evaluation, but a higher degree of suppression in six soilborne pathogens of strawberry was seen from isothiocyanates of these plants in laboratory assays (Mattner et al. 2008). It also appeared the roots of *B. rapa/B. napus* plants have higher quantities of isothiocyanates than the shoots. A combination of techniques that included summer irrigation, solarization, mulching, and biofumigation with cruciferous residues caused a significant reduction in *M. phaseolina* populations and viability (Lodha et al. 1997). Similarly, biofumigation with mustard seed meal followed by solarization, mustard seed meal supplemented with steaming, and steaming followed by solarization resulted in significant yield improvement compared to untreated control (Daugovish and Fennimore 2011) and incorporation of mustard pod residues followed by solarization nearly eradicated *M. phaseolina* and *F. oxysporum* f.sp. *cumini* propagules in soil (Israel et al. 2005).

Preliminary studies in California strawberries with a new commercial formulation of the fungus *Muscodor albus* showed its potential as a biofumigant (Melissa O'Neal, personal communication). Isobutyric acid and 2-methyl-1-butanol from *M. albus* have antifugal properties against a variety of pathogens including *Botrytis* spp., *Colletotrichum* spp., and *Rhizopus* spp. (Mercier and Jiménez 2004).

Antagonism by beneficial bacteria, fungi, and yeasts is another strategy for managing soilborne pathogens. Several species of *Azorhizobium*, *Azospirellum*, *Azotobacter*, *Bacillus*, *Comamonas*, *Citrobacter*, *Enterobacter*, *Glomus*, *Paecilomyces*, *Pseudomonas*, *Rhizobium*, *Rhizophagus*, *Streptomyces*, *Saccharomyces*, and *Trichoderma* are sold as biopesticides (fungicides and nematicides), biostimulants, or soil builders which are expected to improve crop health and yields through antibiosis, antagonism, competitive displacement, or induced systemic resistance (Table 21.1). Although some of these microorganisms are independently sold as biopesticide formulations, various combinations of multiple species are currently marketed as biostimulants or soil amendments. Field studies conducted in California strawberry suggested that beneficial microbes could play a positive role in improving crop yield or health especially when there is a disease pressure (Dara and Peck 2016, 2017). Beneficial microbes were applied as transplant dip at the time of planting and/or through drip irrigation at periodical intervals. Preplanting dip allows inoculation of transplants with beneficial microbes before they are exposed to plant pathogens. Greenhouse and field studies conducted in Germany demonstrated that rhizobacteria, *Raoultella terrigena*, *B. amyloliquefaciens*, and *P. fluorescens* were very effective in antagonizing *Phytophthora fragariae* var. *fragariae*, causal agent of red stele, and *P. cactorum*, causal agent of crown rot, sometimes equal to the chemical fungicide aluminum tris (O-ethyl phosphonate) in strawberry (Anandhakumar and Zeller 2008). In another German field study, transplant dip in the chitinolytic rhizobacterium, *Serratia plymuthica* strain

Table 21.1 Examples of commonly used beneficial microbes formulated as biostimulants and biopesticides

Microorganism		Intended purpose or target pests/pathogens
Biostimulants or soil conditioners – promote plant and root growth, health, soil structure, and yields		
Bacteria	*Azorhizobium* spp.	Crop and soil health
	Azospirillum spp.	Crop and soil health
	Azotobacter spp.	Crop and soil health
	Bacillus spp.	Crop and soil health
	Citrobacter spp.	Crop and soil health
	Enterobacter spp.	Crop and soil health
	Pseudomonas spp.	Crop and soil health
	Rhizobium spp.	Crop and soil health
	Rhizophagus irregularis	Crop and soil health
	Streptomyces spp.	Crop and soil health
Fungi	*Glomus* spp.	Crop and soil health
	Rhizophagus spp.	Crop and soil health
	Trichoderma spp.	Crop and soil health
Yeast	*Saccharomyces cerevisiae*	Crop and soil health
Biopesticides – pest, disease, and nematode management		
Bacteria	*Agrobacterium agrobacter*	Plant pathogens
	Bacillus amyloliquefaciens	Plant pathogens
	B. firmus	Plant parasitic nematodes
	B. thuringiensis	Insect pests
	B. subtilis	Plant pathogens
	Burkholderia rinojensis[a]	Arthropod pests
	Chromobacterium subtsugae	Arthropod pests
	Panibacillus popilliae	Lepidopteran pests
	Streptomyces lydicus	Plant pathogens
Fungi	*Beauveria bassiana*	Arthropod pests
	Coniothyrium minitans	Plant pathogenic fungi
	Gliocladium spp.	Plant pathogens
	Glomus spp.	Plant pathogens
	Hirsutella thompsonii	Insect pests
	Isaria fumosorosea	Arthropod pests
	Lecanicillium giganteum	Mites
	L. lecanii	Scale insects
	L. longisporum	Aphids
	L. muscarium	Thrips and hemipteran pests
	Metarhizium anisopliae	Arthropod pests
	M. brunneum	Arthropod pests
	Paecilomyces lilacinus	Plant parasitic nematodes
	Pseudomonas spp.	Plant pathogenic fungi
	Pseudozyma flocculosa	Plant pathogenic fungi
	Trichoderma spp.	Plant pathogens

(continued)

Table 21.1 (continued)

Microorganism		Intended purpose or target pests/pathogens
Nematodes	*Heterorhabditis* spp.	Insect pests
	Steinernema spp.	Insect pests
Viruses	Granuloviruses	Lepidopteran pests
	Nucleopolyhedroviruses	Lepidopteran pests
Yeast	*Aureobasidium pullulans*	Plant pathogenic fungi
	Candida spp.	Plant pathogenic fungi

Sources: Product labels and Dara et al. (2017)

[a]No live microbes are present

HRO-C48 reduced Verticillum wil (caused by *V. dahliae*) and crown rot (*P. cactorum*) and improved strawberry yields (Kurze et al. 2001).

Entomopathogenic fungi also appear to have an impact on strawberry health and yield through their direct interaction with plants and potentially pathogenic organisms (Dara and Peck 2016). In a greenhouse study conducted in California, commercial formulations of *B. bassiana* (BotaniGard ES), *I. fumosorosea* (PFR-97), and *M. brunneum* (Met52) effectively antagonized *F. oxysporum* f. sp. *vasinfectum* and improved the health of cotton seedlings as effectively, or superior, to botanical (Regalia, based on the giant knotweed extract) and microbial (Actinovate AG, based on *Streptomyces lydicus* strain WYEC108 and Stargus, *B. amyloliquefaciens* strain F727) fungicides (Dara et al. 2017a). Lozano-Tovar et al. (2013) showed antagonism of *B. bassiana* and *M. brunneum* in a laboratory study in Spain. Compared to *Trichoderma atroviride* which resulted in a 64–79% reduction in the mycelial growth of *Phytophthora* spp. and *V. dahliae*, entomopathogenic fungi caused a 42–62% reduction in *Phytophthora* spp. and 40–57% reduction in *V. dahliae* growth. Another recent study also demonstrated that culture filtrates of two Korean isolates of *B. bassiana* and *M. anisopliae* had antifungal activity against *B. cinerea* (Yun et al. 2017). These studies shed light on the potential of entomopathogenic fungi in managing plant pathogens in addition to arthropod pests.

ASD technique involves adding a carbon source such as rice bran or molasses to the soil followed by irrigation and covering with plastic mulch to create anaerobic conditions. Anaerobic decomposition of the carbon source results in the production of organic acids and volatile compounds that are toxic to pathogens and other soil pests. In a recent report based on multiple California studies, varying levels of suppression of *Fusarium* spp., *Rhizoctonia* spp., *Pythium* spp., and *V. dahliae* resulted from ASD, but it was dependent on soil temperature, the type of carbon source used, the extent of anaerobic conditions, and the location of the experiment (Shennan et al. 2017). ASD did not provide weed control in these studies. Inoculating the substrate with beneficial microbes following the disinfestation process can be a good strategy to promote microbial activity for additional protection.

While several studies demonstrated the potential of nonfumigation alternatives in reducing disease or weed pressure, it is important for the suppression to translate into increase fruit yields.

21.5 Manipulating Environmental Conditions

Environmental conditions that promote plant growth and reproductive development also influence pests and diseases. A thorough understanding of optimal conditions that are ideal for good yields while limiting the pest and disease proliferation help manipulate the greenhouse environment as an IPDM strategy.

Adequate chilling of strawberry plants is critical for plant vigor, which indirectly impacts the ability of plants to withstand pests and diseases (Husaini and Xu 2016). Additionally, cooler temperatures favor root rot causing pathogen *Pythium* spp. and botrytis fruit rot/gray mold causing pathogen *B. cinerea*, while warmer conditions favor *Fusarium* spp. that cause wilt and *M. phaseolina* (Bulger et al. 1988; Olaya and Abawi 1996; Maas 1998; Husaini and Xu 2016). On the other hand, the powdery mildew causing *Podosphaera macularis* (=*Sphaerotheca macularis* f. sp. *fragariae*) favored relative humidity above 75% and temperatures between 15 and 30 °C for conidial germination (Amsalem et al. 2006). However, disease severity was the lowest at 10 and 30 °C, a relative humidity of 95%, and light intensity of 7000 lux in growth chambers. In a different study, the efficacy of microbial control of *B. cinerea* with beneficial fungi appeared to increase when temperatures increased from 10 to 25 °C (Sutton and Peng 1993).

High relative humidity above 80% favored the development of second instar larvae and promoted pupation of *F. occidentalis* on plants rather than in the soil (Steiner et al. 2011). However, increasing relative humidity by 15% increased *B. bassiana* infections by 17–25% and helped reduce *F. occidentalis* and the greenhouse whitefly, *Trialeurodes vaporariorum* populations in greenhouse (Shipp et al. 2003). Relative humidity and temperature will also influence the natural enemies and their biocontrol efficacy. Predation of *T. urticae* by the predatory gall midge, *Feltiella acarisuga* increased with increasing greenhouse temperatures from 15 to 27 °C and with increasing relative humidity at 27 °C (Gillespie et al. 2000). Predation was affected by extended periods of low relative humidity below 60%.

Moisture on the flower or fruit surface favors *B. cinerea*, which is a major pathogen of strawberry, raspberry, blackberry and other hosts (Jarvis 1962; Ellis 2008). Good air circulation and plant spacing that allows a quick drying of wet plant surfaces helps reduce gray mold development. Early morning heating in the greenhouse can help dry the plant surface and reduce *B. cinerea* incidence (Dik and Wubben 2004). Williamson et al. (2007) discussed manipulating ventilation, UV light, and temperature among other control options for managing *B. cinerea* in blackberry, raspberry, strawberry and other crops. Disease forecasting models have been developed based on ambient temperature and leaf wetness to predict the time for fungicide applications for *B. cinerea* (MacKenzie and Peres 2012; Rasiukevièiûtë et al. 2013). Under greenhouse conditions, such models are not only useful for curative actions, but may also help manipulate the environment to avoid or delay disease onset.

Anthracnose infections in blueberry increased with increasing May temperatures (Polashock et al. 2005). On the other hand, class II chitinases that accumulate in stems at low temperatures and important in cold hardiness imparted resistance to anthracnose (Miles et al. 2011). Cold acclimation or exposure to sublethal cold temperatures increase the accumulation of pathogenesis-related proteins, abscisic acid, total phenolics, and other compounds that aid plants in fighting diseases (Meyer and Kirkpatrick 2011). Cold tolerant strawberry species, for example, possessed resistance to a wide variety of diseases, nematodes, and environmental stress factors (Sjulin and Dale 1987). Zveibil et al. (2012) reported that the viability of microsclerotia of *M. phaseolina* reduced when the soil temperatures were kept at 25 °C or fluctuated between 18 and 32 °C under greenhouse conditions compared to a constant temperature at 30 °C. Dara et al. (2017) discussed manipulation of relative humidity, temperature, soil moisture and other environmental conditions to improve microbial control of arthropod pests including greenhouse pests.

Since CO_2 levels are elevated in the greenhouses for improved plant growth and yields, it is important to determine optimal levels that do not interfere with pest and disease management efforts. Increasing atmospheric CO_2 is reported to have an impact on pests and diseases and also affect the resistance of some crops (Ziska and Runion 2007; Zavala et al. 2008; Gregory et al. 2009). While elevated CO_2 promoted the growth and development of some pests, it negatively impacted the others (Ziska and Runion 2007). *Tetranychus urticae*, a significantpest of many berry crops, is one of those pests that benefits from increased nonstructural carbohydrate content as a result of elevated CO_2 level (Heagle et al. 2002). However, the negative impact of elevated CO_2 on resistant alleles on rendering some resistant cultivars susceptible is a significant one to consider. For example, aphid resistance of a red raspberry cultivar broke down by elevated CO_2 levels (Martin and Johnson 2010). The European large raspberry aphid, *Amphorophora idaei* grew faster and larger at 700 μmol/mol of CO_2 compared to plants grown at 375 μmol/mol on of the two resistant cultivars. It is necessary to understand such interactions with different cultivars and either use the ones whose resistance is not altered or use appropriate CO_2 levels.

Positive pressure ventilation system can also be used a means of pest management in greenhouses. In addition to the screening that prevents the entry of pests, maintaining air velocity higher than the flying speed of insects through positive internal greenhouse pressure and adjusting the ventilation windows is recommended by Mears and Both (2002) to exclude pests in tropical and subtropical regions.

UV light transmission has an impact on greenhouse production and pest management practices. For example, photodegradation of insecticides such as bifenthrin, esfenvalerate, imidacloprid, thiamethoxam, and spinosad was significantly reduced in raspberry under tunnels with UV-reducing plastic compared to uncovered or tunnels with transparent plastic (Leach et al. 2017). Residual activity of the insecticides and their efficacy against *D. suzukii* also improved under UV-reducing plastic. However, UV-protection did not have such a positive impact on insecticides acetamiprid, cyantraniliprole, cypermethrin, and malathion in this study. Preliminary studies conducted by Janisiewicz et al. (2015) suggested UV-C irradiation of strawberry plants followed by a dark period and application of beneficial microbes as a strategy for managing *B. cinerea*, *C. acutatum*, and *P. aphanis*.

21.6 Biological Control

Biological control is an integral part of greenhouse pest management and predators and parasitoids have been successfully used against insect and mite pests for several decades (Van Lenteren and Woets 1988). With the increase in greenhouse acreage, the use of predatory phytoseiid mite *Phytoseiulus persimilis* against *T. urticae*, prasitoid *Encarsia formosa* against *T. vaporariorum* significantly increased in 1970s and 80s in Europe. Commercial production and use of other natural enemies also proliferated during this period. Currently, several species of natural enemies are produced on a commercial scale for greenhouse and field pest management around the world (Table 21.2). Releasing predatory mites is a popular practice for managing spider mites in strawberry, blackberry, and raspberry in California (Godfrey 2011; Zalom et al. 2016). Several species of predators and parasitoids are recommended and released for augmentative biological control for managing various greenhouse pests (Van Lenteren 2000; Smith 2015; Van Lenteren et al. 2017). Selection of the right natural enemy, releasing at appropriate times and numbers, maintaining ideal environmental conditions to promote their activity, providing refuge, and avoiding pesticide sprays that are harmful to natural enemies are among some of the tactics to enhance biocontrol efficacy.

21.7 Botanical Control

Azadirachtin, essential oils, giant knotweed extract, and pyrethrum are some of the plant extracts that are used as antifeedants, repellents, acaricides, insecticides, fungicides or insect growth regulators. Azadirachtin, extracted from the seeds of neem (*Azadirachta indica*), has insecticidal and antifeedant properties and also acts as an insect growth regulator. Neem oil, also extracted from neem seeds, is used as a fungicide, acaricide, and insecticide. Studies conducted in California strawberry showed its potential for managing *L. hesperus* and other insect pests (Dara et al. 2013; Dara 2016). Extract of the giant knotweed (*Reynoutria sachalinensis*) effectively antagonized *Fusarium oxysporum* f.sp. *vasinfectum* (Dara et al. 2017a). Pyrethrum, extracted from *Chrysanthemum cinerariaefolium* flowers, is an effective pesticide, but it is also very toxic to natural enemies. Simmonds et al. (2002) reported that azadirachtin and pyrethrum to be very effective against *T. vaporariorum*, but found pyrethrum to be very harmful to the parasitoid *Encarsia formosa*. Similarly, Contreras et al. (2006) reported very effective control of *F. occidentalis* by spinosad and pyrethrum, but the latter was highly toxic to the predator *Orius* spp. Essential oils extracted from aromatic plants are used for pest management in stored grains, agriculture, and urban enviroments (Isman 2000). The green peach aphid, *Myzus persicae* and *T. urticae* are among the pests that can be effectively controlled by essential oils (Isman 2000; Miresmailli and Isman 2006; Dara 2015b). Neem and essential oils can also be effective against plant pathogens. Essential oils of rose-

Table 21.2 Examples of commercially available natural enemies and their target pests

Natural enemy		Target pests
Parasitoids		
Hymenoptera	*Aphidius* spp.	Aphids
	Cotesia spp.	Lepidopterans
	Dacnusa spp.	Leafminers
	Encarsia spp.	Whiteflies
	Trichogramma spp.	Lepidopterans
Predators		
Acari	*Amblyseius* spp.	Mites and thrips
	Euseius spp.	Thrips, whiteflies
	Galendromus spp.	Mites
	Hypoapsis spp.	Fungus gnats and thrips
	Mesoseiulus spp.	Mites
	Neoseiulus spp.	Mites
	Phytoseiulus spp.	Mites
Coleoptera	*Adalia* spp.	Aphids, other small insects and mites
	Atheta spp.	Fungus gnats
	Coccinella spp.	Aphids, other small insects and mites
	Cryptolaemus spp.	Mealybug
	Harmonia spp.	Aphids, other small insects and mites
	Hippodamia spp.	Aphids, other small insects and mites
	Stethorus spp.	Mites
Diptera	*Aphidoletes* spp.	Aphids
	Feltiella spp.	Mites and thrips
Hemiptera	*Diaeretiella* spp.	Aphids
	Geocoris spp.	Aphids, hemipterans, mites, thrips, and whiteflies
	Macrolophus spp.	Whiteflies
	Orius spp.	Aphids, hemipterans, mites, thrips, and whiteflies
	Pediobius spp.	Coleopterans
	Tamarixia spp.	Psyllids
	Thripobius spp.	Thrips
	Trissolcus spp.	Hemipeterans
	Xylocoris spp.	Aphids, hemipterans, mites, thrips, whiteflies
Neuroptera	*Chrysoperla* spp.	Aphids, mites, thrips, and whiteflies
	Micromus spp.	Aphids
Thysanoptera	*Scolothrips* spp.	Mites and thrips

Sources: Hale and Hensley (2010) and Van Lanteren et al. (2017); several commercial insectary listings

mary, lavender, and origanum were very inhibitory to *B. cinerea* in both in vivo and in vitro (Soylu et al. 2010). In an in vitro study, essential oils of dictamnus, oregano, and thyme completely inhibited the growth of *B. cinerea*, *Fusarium solani* var. *coe-*

ruleum, and *Clavibacter michiganensis* subsp. *michiganensis* (Deferera et al. 2003). Koul et al. (2008) discussed various insecticidal, ovicidal, larvicidal, oviposition inhibitory, antifeedant, repellent, attractant, antifungal, antiviral, and fumigant of cinnamon, clove, eucalyptus, holy basil, lavender, lemongrass, mint, orange, rosemary, thyme, turmeric, and other essential oils against a variety of arthropod pests and plant pathogens suggesting their potential as green pesticides.

21.8 Chemical Control

Chemical pesticides are widely used for managing pests and diseases around the world and are generally considered as an affordable and effective control option. While insecticides and acaricides are typically applied when pest populations are present and reach damaging levels, prophylactic fungicide treatments are not uncommon to protect crops from common diseases. For example, some protectant fungicides are applied to control *M. vaccinia-corymbosi* in blueberry before environmental conditions become conducive for fungal infections (Schilder et al. 2008). Since *B. cinerea* can multiply in plant debris and be present in the crop environment throughout the production season, frequent fungicide applications are made starting before flowering in blackberry, raspberry, and strawberry to manage grey mold (Eckert and Ogawa 1988). In California strawberries, chemical fungicides are routinely used for controlling *B. cinerea*, *Podosphaera aphanis*, *Rhizopus* spp., and other foliar and fruit diseases and fumigation continues to be the main choice for managing soilborne pathogens *C. acutatum*, *Fusarium oxysporum* f. sp. *fragariae*, *M. phaseolina*, *Phytophthora* spp., and *Xanthomonas fragariae* which cause crown or root rot and foliar diseases (Dara 2015a). Chemical fungicides are also commonly used or recommended for controlling several diseases in blueberry (Scherm and Stanaland 2001; Cline et al. 2006), blackberry (Ivey et al. 2016), raspberry (Heidenreich 2006) and other berries. Since the efficacy of fungicides varies depending on the crop, disease, and other factors, treatment decisions based on the crop needs and efficacy data from local or regional data would be useful. For example, in a study was conducted in North Carolina blueberries against leaf spot fungi, *Septoria albopunctata* and *Gloeosporium minus* (Cline 2002) fungicide efficacy varied among various parameters evaluated. Fenbuconazole (Indar®) was very effective in reducing defoliation and improving bud set and fruit yield. While fenhexamid (Elevate®) and cyprodinil + fludioxonil (Switch®) were not effective, captan (Captan®) + bonomyl (Benlate®) combination was moderately effective in improving bud set and berry yields. In a recent Serbian study, tebuconazole, fluopiram, and boscalid provided 95–100% control of the spur blight (*Didymella applanata*) of raspberry (Stević et al. 2017). Chlorothalonil, copper-hiroxide, dithianone, and mancozeb resulted in a 64–82% disease suppression while the efficacy of azoxystrobin, fluazinam, and pyraclostrobin was low and varied from 14% to 38% suppression.

Although chemical pesticides play an important role in pest and disease suppression, preventing yield losses, and ensuring returns, excessive reliance on chemical control led to several resistance problems around the world. For example, high levels of resistance to both an older (carbendazim) and a newer (cyprodinil) fungicide among others was seen in *B. cinerea* from greenhouse strawberry in China (Fan et al. 2017). Similarly, high levels of neonicotinoid, pyrethroid, and ketoenol resistance to *T. vaporaiorum* in Greece (Kapantaidaki et al. 2017) and pyrethroid and avermictin resistance in *T. urticae* in Cypress and Greece (Ilias et al. 2017), and resistance to several groups of insecticides in *F. occidentalis* (Gao et al. 2012). Considering the high risk of pesticide resistance, non-chemical control options should be fully exploited before chemical insecticides, acaricides, and fungicides are used. When necessary, chemical pesticides should be used at the recommended rates when treatment thresholds have reached. It is also important to avoid the repeated use of same pesticide and rotating those among different mode of action groups.

21.9 Mechanical or Physical Control

Pest exclusion through proper screening of doors and ventilation windows is a common practice in greenhouse production. Yellow sticky cards/tapes or traps equipped with attractants or pheromones, reflective materials, barriers, footbaths, and other such mechanical and physical control tactics are also frequently used for managing several arthropod pests, disease vectors, or diseases. Bug vacuums can also be used to aspirate larger insects and for spot treatments. Yellow sticky cards are also useful for monitoring pests and help with treatment decisions.

21.10 Microbial Control

Microbial control refers to the use of beneficial microorganisms for controlling pests and diseases. Several bacterial and fungal formulations are commercially available as fungicides for controlling a variety of diseases. Bacteria such as *Bacillu* spp., *Pseudomonas* spp. *Streptomyces* spp., and fungi such as *Gliocladium* spp., *Penicillium* spp., *Trichoderma* spp. have been used for disease control.

Sutton and Peng (1993) reported a very high level of *B. cinerea* control in strawberry using *Gliocladium roseum*, a *Penicillium* sp., and *Trichoderma viridae*. Efficacy of the three mycofungicides was as effective as chlorothalonil in several field and greenhouse studies. Three applications of the commercial formulations of *Gliocladium catenulatum* (Prestop) and *T. harzianum* (PlantShield) resulted in up to 45% of reduction in anthracnose by *C. acutatum* in blueberry (Verma et al. 2006). Similarly, inhibition of *M. vaccinia-corymbosi*, which causes mummy berry disease in blueberries, was reported by commercial formulations of *B. subtilis* (Serenade) and *Pseudomonas fluorescens* (BlightBan) in a laboratory study (Scherm et al. 2004). Scherm and Krewer (2008) discussed mummy berry and foliar disease management in organic rabbiteye blueberries using *B. subtilis* and fish oil-based products among others with varying levels of disease control.

Several studies demonstrated the efficacy of *Trichoderma* spp. against multiple strawberry diseases. Ahmed and El-Fiki (2017) reported that root rot causing fungi *Fusarium oxysporum*, *F. solani*, *M. phaseolina*, and *Rhizoctonia solani* were effectively controlled by *Trichoderma album*, *T. harzianum*, *T. hamatum*, and *T. viridae* in a strawberry field study in Egypt. Plant growth, fruit yield, and total chlorophyll, nitrogen, and phenol content was also improved from these treatments that included both commercial and local isolates of *Trichoderma* spp. Barakat and Al-Masri (2017) reported a complete control of *B. cinerea* in greenhouse strawberry with the combination of *T. harzianum* (at 10^9 spores/ml) and pyrimethanil or cyprodinila+flydioxonil. Compared to the stand-alone treatments of fungicide and *T. harzianum* or their combination with 10^8 spores/ml rate of *T. harzianum* that provided 38–70% of control, the higher rate of fungus made a significant difference in providing 100% control. Good control of damping off (*R. solani*) of multiple greenhouse crops was also achieved with a formulation of *Trichoderma* spp. and *Gliocladium* spp. growing on vermiculite-bran mixture (Lewis and Lumsden 2001).

Studies with yeasts also showed promising results in post-harvest control of *B. cinerea* in strawberry. *Sporidiobolus pararoseus* suppressed natural infections of *B. cinerea*, *Mucor* spp., *Penicillium* spp., and *Rhizopus* spp. in strawberry (Huang et al. 2012). Volatile organic compounds produced by *S. pararoseus* also suppressed mycelial growth and conidial germination of *B. cinerea* in vitro. Another yeast *Rhodotorula mucilaginosa* was also found to be effective in post-harvest protection of strawberry from *B. cinerea* (Zhang et al. 2013). Combining phytic acid, with *R. mucilaginosa* enhanced the efficacy of post-harvest protection in this study. Phytic acid is the primary storage form of phosphorus mainly found in cereal grains, legumes, and nuts and used as a food preservative.

Several entomopathogenic bacteria, fungi, nematodes, and viruses are also commercially available for managing a variety of arthropod pests on small fruits and greenhouse crops (Dara 2017; Wraight et al. 2017). Since bacteria (e.g., *B. thuringiensis* subsp. *kurstaki* against lepidoptera and *B. thuringiensis* subsp. *tenebrionis* against coleoptera) and viruses (e.g., Spodoptera exigua multiple nucleopolyhedrovirus) need to be ingested by the host insect to be infective, they are more suited for insects such as lepidopteran larvae that have chewing mouthparts. However, formulations based on metabolites of bacteria such as *Chromobacterium subtsugae* and *Burkholderia rinojensis* are also available as insecticides and acaricides. Entomopathogenic fungi (e.g., *Beauveria bassiana*, *Isaria fumosorosea*, *Lecanicillium lecanii*, and *Metarhizium brunneum*) infect hosts through contact and are popular in greenhouse management of thrips, whiteflies, aphids, mealybugs, scales, and other sucking pests and mites. The fungus, *Paecilomyces lilacinus* is available as a myconematicide for controlling plant parasitic nematodes. Entomopathogenic nematodes (e.g., *Heterorhabditis* spp. and *Steinernema* spp.), on the other hand, are ideal for soil pests or pests that have soil inhabiting life stages.

In general, entomopathogenic bacteria are used for lepidopteran and coleopteran pests, viruses for lepidopteran pests, nematodes for soil inhabiting stages, and fungi for mites, thrips, and sucking pests. Because of their contact mode of infection, entomopathogenic fungi can be used against almost all kinds of arthropod pests for soil and foliar treatments.

Multiple studies conducted in field or greenhouse strawberries in California showed that *B. bassiana*, *I. fumosorosea*, and *M. brunneum* can be potential control options for managing various arthropod pests (Dara et al. 2013; Dara 2015b, 2016). These studies suggested that combining or rotating entomopathogenic fungi with botanical or chemical pesticides is a better strategy for pest management. Synergism between *M. anisopliae* and entomopathogenic nematodes, *Heterorhabditis bacteriophora*, *Steinernema feltiae*, and *S. kraussei* was also seen against the black vine weevil, *Otiorhynchus sulcatus* under greenhouse conditions (Ansari et al. 2008, 2010).

Rhizosphere bacteria, mycorrhizae, and even entomopathogenic fungi that endophytically colonize plants are reported induce systemic resistance in plants to pests and diseases (Van Loon et al. 1998; Van Wees et al. 2008; Lopez et al. 2014; Mauch-Mani et al. 2017; When plants are treated or primed with these beneficial microbes, certain defensive genes are upregulated in a manner similar to pathogen-induced immune response helping them withstand pests and diseases. These beneficial microbes directly and indirectly contribute to improving crop health and yields and managing pests and diseases.

21.11 Entomovectoring or Beevectoring of Beneficial Microbes

Honey bees and bumble bees, which are used to enhance pollination in greenhouse berries can also be used to dispense the inocula of mycopesticides. This technology is referred to as beevectoring or entomovectoring and is now commercialized by companies such as Biobest (Flying Doctors®) and Bee Vectoring Technologies, which equip bee hives/boxes with trays that hold microbial pesticides. Since bees are employed to improve pollination in greenhouse berries, using them to deliver the inocula of beneficial microbes is an added advantage. Bees pick up the microbial pesticide formulations as they exit their hives and disperse them as they visit different flowers. *Gliocladium roseum* and *T. harzianum* have been successfully used for managing *B. cinerea* in strawberry for a long time (Peng et al. 1992; Kovach et al. 2000; Bilu et al. 2003). Bumble bee (*Bombus terrestris*) dissemination of *Gliocladium catenulatum* over 3 years resulted in a significant decrease in *B. cinerea* infections in field strawberry (Karise et al. 2016). Field study in lowbush blueberry reported a 10–20% decline in *B. cinerea* infections by *Clonostachys rosea* vectored by *B. impatiens* (Reeh et al. 2014).

Beevectoring can also be used for delivering entomopathogens for insect and mite control. In a caged field study in UK, Butt et al. (1998) demonstrated effective control of the pollen beetle, *Meligethes aeneus* with *Metarhizium anisopliae* delivered by honey bee, *Apis mellifera*. In a different study, *A. mellifera* carried and dispersed *Heliothis* nucleopolyhedrovirus in crimson clover fields causing significant infections in corn earworm (*Helicoverpa zea*) populations (Gross et al. 1994). They had observed 100% of beetle mortality in spring rape especially when the beetle and bee activity was the highest. Jyoti and Brewer (1999) reported that *Bacillus thuringiensis* delivered by *A. mellifera* was equal or superior to manual application in controlling the banded sunflower moth, *Cochylis hospes* and resulted in higher sunflower yields. In a greenhouse, *B. bassiana* (BotaniGard 22WP) was effectively delivered by *Bombus impatiens* without affecting their mortality (Shipp et al. 2012). Although survival of the minute pirate bug, *Orius insidiosus* was negatively impacted by *B. bassiana*, the level of parasitism by multiple parasitoids (against *T. vaporariorum* and *M. persicae*) and predation by *O. insidiosus* or the predatory mite *Amblyseius swirskii* (against *F. occidenatalis*) were not affected. Honey bee-vectored *B. bassiana* caused significant levels of infection in tarnished plant bug, *Lygus lineolaris*, in caged canola (Al Mazra'awi et al. 2006). Based on these studies, beevectoring can be a very effective tool especially in an enclosed greenhouse environment and could save on pesticides and their application costs.

21.12 Non-conventional Chemicals and Induced Resistance

In addition to the conventional pest and disease management practices, treating plants with certain minerals and chemicals can be a prophylactic strategy to induce systemic resistance and improve plant performance under biotic and abiotic stress factors. Abscisic acid, jasmonic acid, silicates, salicylate-based compounds, chitosan, beneficial bacteria, mycorrhizae and other treatments have a positive impact on crop growth, yield, and disease and pest resisting abilities (Archbold et al. 1997; Reddy et al. 2000; Dihazi et al. 2003; Holopainen et al. 2009; Meyer and Kirkpatrick 2011; Pieterse et al. 2014). Application of such materials is a good preventive and curative strategy in IPDM.

Methyl jasmonate, salicylic acid, methyl salicylate, and benzothiadiazole are some of the elicitors or compounds that stimulate plant defenses through the production of phenolic compounds (Holopainen et al. 2009). A significant reduction in crown rot caused by *Phytophthora cactorum* and *P. fragariae* var. *fragariae* was observed when strawberry plants were treated with putative disease resistance elicitors, acibenzolar-*S*-methyl and chitosan, a polysaccharide compound (Eikemo et al. 2003). Treating strawberry plants with chitosan, 5 or 10 days before harvest, significantly reduced postharvest *B. cinerea* incidence in storage (Reddy et al. 2000). Chitosan also improved strawberry quality in terms of fruit firmness and slower ripening. Similarly, natural volatile compounds like hexanal, methyl salicylate, and methyl benzoate inhibited *B. cinerea* in postharvest storage of strawberry, blackberry, and grape (Archbold et al. 1997). A laboratory study in Italy demonstrated that treating harvested strawberries with chitosan, benzothiadiazole, and a commercial formulation of calcium and organic acids up-regulated several defense genes (Landi et al. 2014). In table grapes, preharvest application of chitosan alone or in combination with postharvest irradiation with UV light improved protection from *B. cinerea* (Romanazzi et al. 2006). Carlen et al. (2004) reported the results of multiple greenhouse and field studies in Europe where commercial formulations of the synthetic elicitor, acibenzolar-S-methyl and the extract of giant knotweed, *Reynoutria sachalinensis* provided a good control of *P. aphanis* on strawberry. The extract of *R. sachalinensis* was as effective as fungicide treatments in controlling *B. cinerea*. Soil amendment with silicon, considered as a beneficial nutrient, resulted in a significant reduction of *P. aphanis* in high tunnel strawberry in Canada (Ouellette et al. 2017). Foliar application of silicon, on the other hand, had conflicting effects in reducing *P. aphanis* (Wang and Galletta 1998; Palmer et al. 2006). Silicon is thought to interfere with biotrophic or parasitic pathogens such as *P. aphanis* in finding target sites in the host plant (Vivancos et al. 2015).

21.13 General Guidelines for IPDM

General guidelines that prevent and control pests and diseases are listed below (Fig. 21.1):

- Choose cultivars that are resistant to pests and diseases especially in areas are prone to these problems.
- Obtain healthy and certified transplants, free of pests and diseases, from reputed nurseries.
- Inoculate transplants with beneficial microbes for a healthy start and to induce systemic resistance against potential pests and diseases. Continue periodical inoculation to maintain crop health.
- Use clean substrate or consider non-chemical fumigation alternatives to disinfest if substrate has to be used multiple times.
- Secure the greenhouse with proper screening, positive pressure ventilation, footbaths/sticky mats, double-doors, restricted accesses, and other measures that minimize the entry of pests.
- Maintain optimal temperature, relative humidity, ventilation, plant density that are ideal for healthy crop growth without promoting pest and disease populations.
- Regularly monitor crop health, pest and disease levels, and employ appropriate control measures as warranted by treatment thresholds.
- Maintain proper sanitation by removing dead, diseased, or infested plant material.

- Adopt ideal fertility and irrigation management practices as healthy plants can withstand pest and disease pressure and reduce the need for corrective treatments.
- Release predators and parasitoids to promote biological control.
- Make use of yellow sticky cards, pheromones, attractants, vacuums and other such mechanical or physical control options.
- Take advantage of botanical and microbial pesticides, biostimulants, and materials that induce systemic resistance and use chemical control options only when necessary.
- Use pollinators for delivering beneficial microbes that control pests and diseases.
- When chemical pesticides and fungicides are applied, be judicious in their use and rotate among different mode of action groups to reduce the risk of resistance development.

Fig. 21.1 Preventive, curative, maintenance, and regulatory approaches in IPDM

- Enforce regulatory control to prevent the spread of pests and diseases from nurseries and between greenhouse operations, to ensure application of recommended rates and amounts of pesticides, and to encourage IPDM practices.
- Implement good outreach efforts to disseminate information to the growers and pest management experts, and encourage grower collaboration and exchange of ideas for area-wide management of pests and diseases.
- Increase public awareness of invasive pests and diseases to prevent their accidental introduction, and of IPDM practices to promote their preference and thus sustainable management practices.

21.14 Conclusion

IPDM, by adopting a variety of management techniques, maintains high productivity while ensuring environmental sustainability and affordability. Sustainable practices such as IPDM may also improve the quality of the fruits as seen in the Asami et al. (2003) study where marionberry and strawberry had significantly higher antioxidant (total phenolic and ascorbic acid) content compared to conventionally produced berries. Such antioxidants are also important in plant defense against pests and diseases. As new crop protection technologies emerge, they need to be continuously evaluated and adopted as appropriate for pest and disease management in greenhouse berries. Outreach of IPDM practices, new research developments, and emerging threats, and regulatory changes is also important to enable growers for taking appropriate actions. While some pest management techniques might be guarded as proprietary information by some growers, exchanging best management practices and new ideas among the grower community helps address area wide issues. Increasing consumer awareness about IPDM practices and their contribution to healthy and sustainable food systems also promotes the adoption of IPDM.

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