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Mandeep Rathee
Ph.D. Student, Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India

Naveen Vikram Singh
Ph.D. Student, Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India

Pradeep Kumar Dalal
Ph.D. Student, Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India

Swati Mehra
Assistant Scientist, Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India

Correspondence
Mandeep Rathee
Ph.D. Student, Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India

Integrated pest management under protected cultivation: A review

Mandeep Rathee, Naveen Vikram Singh, Pradeep Kumar Dalal and Swati Mehra

Abstract
Insect pests are the prime threats to production and productivity of greenhouse crops worldwide. Presence of warm, humid conditions and abundant food under protected structures provide a stable environment and habitat for pest development. Often, the natural enemies that keep pests under control outside are lacking under protected environment. For these reasons, pest situations often become alarming in the indoor environment than outdoors. The damage inflicted by arthropod pests on greenhouse crops varies from pest to pest and season to season. The level of damage that can be tolerated is greatly dependent on the type of crop as well. Integrated pest management (IPM) is a systematic approach to manage insect-pests that combines a range of techniques and strategies to either reduce pest populations or decrease their economic impact. It is a site-specific strategy for managing pests that relies on correct pest identification and understanding the pest biology. With a long-term perspective it is easier to visualize that an investment in IPM can surely pay for itself in a higher-quality crop and a cleaner environment in greenhouse crop production.

Keywords: environment, IPM, protected cultivation, sucking insect

Introduction

Protected cultivation of high value vegetables and cut-flowers has shown tremendous potential during the last decade or so. In terms of area of fruit and vegetable crops under protected cultivation, China ranks first (27,60,000 ha), while India stands at seventh (25,000 ha) worldwide [18]. With the progress of liberalized economy and the advent of newer technologies in agriculture, protected cultivation has boosted in the field of agriculture worldwide. These technologies are not only creating avenues at higher level but also to the growers with the smaller landholdings as the higher productivity levels retain economic relevance to agriculture. The technology involves the cultivation of horticultural crops in a controlled environment wherein the factors like the temperature, humidity, light, soil, water, fertilizers, etc. are manipulated to attain maximum produce as well as allow a regular supply of them even during off-season. By adopting protected cultivation technology, the growers can look forward to a better and additional remuneration for high quality produce.

But as a matter of fact, greenhouse vegetable crops grown all over the world are vulnerable to various diseases and pest attacks as the protected crops provide stable and favorable microclimates for development of pest populations, which often limit the success of this crop production system [28]. The losses caused due to pests in greenhouses crops like tomato, okra, capsicum, gerbera, carnation, cucumber, lettuce, beans, etc. are tremendous. Crop losses are mainly due to arthropod pests like mites, whiteflies, thrips, leaf-miners, aphids and diseases caused by virus, fungi, bacteria, nematodes etc. Among these various, insects are of much importance and need to be managed properly so as to prevent the crop losses and increase yields. The increasing need for higher crop yields both in the field and in greenhouses brings with it problems linked to large monocultures and pest attacks. Chemical pest control has to be reduced owing to its unwanted effects on non-targeted organisms [3] and pest resistance [15]. Thus, alternative and sustainable long-lasting pest control methods are urgently needed to enhance the activity of beneficial organisms [32]. In this write up greenhouse insect pests of various crops have been discussed along with their management.

Integrated pest management

Since the first definition of integrated control by [29], more than 65 definitions of IPC and IPM have been proposed. IPM refers to an ecological approach in PM in which all the available necessary techniques are consolidated in a unified program, so that pest populations can be managed in such a way that economic damage is avoided and adverse side effects are minimized [19]. According to modern concept IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society and the environment [12].

Protected cultivation

Protected cultivation is the concept of growing potential crops in the modified natural environment for ensuring optimum growth of the crop plants without any or least stress [25]. In other words, protected cultivation can also be defined as controlled environment agriculture (CEA) which is highly productive, conservative of water and land and also protective of the environment [10].

Types of protective structures

Greenhouse for vegetable production encompasses: glasshouse, polyhouse, insect-proof net house, low tunnel polyhouse, zero energy polyhouse. Protected structures are of different kinds, viz. open-ventilated, closed polyhouse with fan and cooling-pad system, shade net house, etc. Greenhouse structures are of different kinds based on shape (lean to type, evan span type, ridge and furrow type etc.), utility (temperature and humidity controlled), construction (wooden, pipe or truss framed), covering material (glass, fiber glass, plastic-film). Plastic film covering materials are of different types such as acrylic, polycarbonate, fiber glass reinforced polyester, polyethylene film [17] and polyvinyl chloride film. Most greenhouse crops grow best in light whose wavelengths range from 400 to 700 nm and hence the glazing materials should be highly transparent [25].

Table 1: Insect-pests scenario under protected environment in India [25]

Insect		Host
Common Name	**Scientific Name**	
Aphids	*Aphis gossypii*	Capsicum
	Macrosiphoniella sanborni	Chrysanthemum
	Myzus escalonicus	Strawberry
	Myzus persicae	Capsicum Gerbera
	Toxoptera aurantii	Orchid
Caterpillars	*Helicoverpa armigera*	Capsicum, tomato, carnation
	Spodoptera litura	Rose, tomato, capsicum, cucumber
Leaf-miners	*Liriomyza trifolii*	Tomato, cucumber, chrysanthemum, gerbera
Mites	*Aceria lycopersici*	Tomato
	Polyphagotarsonemus latus	Capsicum
	Stenotarsonemus fragariae	Strawberry
	Tetranychus cinnabarinus	Carnation
Thrips	*Scritothrips dorsalis*	Rose
	Thrips palmi	Gerbera
Whiteflies	*Bemisia tabaci*	Gerbera, capsicum
	Trialeurodes vaporariorum	Tomato, cucumber, capsicum, beans, gerbera

Integrated Pest Management strategies for protected cultivation

I. Preventive measures
II. Scouting and early detection
III. Curative measures

I. Preventive Strategies

A) Exclusion

1) Use of physical barriers

Exclusion means keeping insects from entering the greenhouse by use of physical barriers such as insect proof screens. Insect exclusion is considered a first step in developing an integrated approach to greenhouse pest management. The pests not only damage the crop by direct feeding but may also transmit phytopathogenic organisms. Moreover, crop protection from insects is regarded from many growers in the Mediterranean basin as more important than protecting them from excessive heat. The exclusion is obtained by installing fine-mesh screens which act as mechanical barriers on the greenhouse openings [2]. Some of exclusive mechanisms are discussed below:

a) Use of insect-proof nets

This includes common greenhouse pests such as thrips, aphids, leaf-miners and whiteflies, but also some less common pests such as fruit borers. Screen mesh of holes less than 200 micrometers is required for complete exclusion. Insect-proof screens 10 x 20 micron and 10 x 22 micron give adequate exclusion of whiteflies *Trialeurodes vaporariorum* and *Bemisia tabaci* without impeding natural enemies (*Diglyphus isea* and *Eretmocerus erimicus*) movement [7].

b) Provision of double door

Limited access to screened areas is beneficial since insects may come in the protected structure on clothing or be swept in with the wind. Building a screened foyer to create a double-door entry partially solve the problem of wind-carried insects. Special efforts must be put in for repairing holes or tears immediately, and cleaning the screens to maintain airflow.

c) Use of reflective or metalized mulches

These are used primarily for the repelling effects on certain insects. Metalized mulch was effective in reducing silverleaf whitefly entrance by 90 per cent. The combination of screening and metalized mulch should be used together and will provide the greatest total reduction of whitefly entry [8]. Complete mulching of the greenhouse floor preventing weeds and acting as a mechanical barrier to certain insect (leaf-miners, thrips and other lepidopteran pests) life stages preventing them from moving into the soil for pupation.

d) Ultra-violet radiation absorbing sheets

Altering the visual behaviour of insects has been used successfully as a tool in IPM programmes directed to protect crops from insects and insect-borne viral diseases. The first evidence that UV-absorbing films may reduce insect invasion of greenhouses came from Japan. Insects perceive light signals through their compound eyes. The anatomy and physiology of the compound eye is adapted to sense UV wavelengths alone or a mixture of UV and visible radiation. The UV part of the solar spectrum plays an important role in the ecological behavior of insects, including orientation, navigation, feeding and interaction between the sexes. Spectrally modified sheets are produced commercially by the introduction of a UV-absorbing additive into the raw material which blocks the transmission of most wavelengths in the UV range below 370-380 nm without interfering with the transmission of photosynthetically active radiation (400-700 nm).

The manipulation of the UV vision of insects by using UV-blocking greenhouse cladding materials has been shown to be effective in preventing the immigration of a wide range of insect-pests (whiteflies, aphids, thrips and leaf-miners) from the external environment into the protected crop. It was found that populations of aphid (*Aphs gossypii*), greenhouse whitefly (*T. vaporariorum)*, thrips (*Frankliniella occidentales* and *Scirtothrips dorsalis*) and leaf-miner (*Liriomyza* sp.) were lower on tomatoes grown in a plastic-house made of polyethylene treated to exclude UV wavelengths than on crops grown in an ordinary plastic house. The number of whiteflies, aphids and thrips trapped on sticky yellow cards under a UV-absorbing film were 10 - 100 times lower than the number trapped under regular films. The use of UV-A films also helped in reducing the number of insecticide applications by 50-80 per cent for the management of *Spodoptera lituralis*. UV-absorbing plastic roofs showed the most pronounced deterrent effect for thrips [20]. UV blocking PE films found very effective in reducing the no. of injured fruit in tomato and produces higher yield in comparison to other covering material [22].

Mesh size depends upon the targeted insect (Table 2). Mesh with holes less than 200 micrometers is required for complete exclusion of thrips; however, screening with holes as large as 600 mm is sufficient for excluding leaf-miners [28].

Table 2: Screen mesh sizes needed to exclude major greenhouse pest species

Insect-Pest	Hole size (micron)	Mesh (number of threads per linear inch)
Leaf-miner (*L. trifoli)*	610	34
Cotton whitefly (*B. tabaci*)	462	42
Aphid (*M. persicae)*	340	52
Greenhouse whitefly (*T. vaporariorum*)	290	58
Thrips (*Thrips* spp.)	192	76

B) Sanitation and cultural practices

1) Sanitation

Sanitation involves the removal of both infested materials and potential sources of infestation, followed by disinfection of surfaces and includes various approaches like, clean planting material, ventilation, clean or sterile soils tools, flats and other equipments. Maintain a clean, closely mowed area around the greenhouse to reduce invasion by pests that develop in weeds outdoors, dispose of trash, boards and old plant debris in the area, removal of weeds and any plant debris and clean the greenhouse thoroughly after each production cycle.

2) Cultural Practices

a) Pre-season cleanup

Before introducing a new crop into the greenhouse, it is extremely important to pests from the previous crop. Remove all plant debris and weeds from the greenhouse. Many pests also occur on other crops or broadleaf weeds. For this reason, it is important to avoid growing other crops next to the greenhouse and to prevent heavy growths of broadleaf weeds around the outside edges of the greenhouse. Under protected environment monoculture is suggested, however, if one has to go for polyculture then avoid staggered planting. A fallow period of two to four weeks reduces the pest load considerably. To determine the presence of thrips, whiteflies, leaf-miners, or other insects, set up yellow sticky cards and indicator plants after watering. Observe for any insects that are trapped on the cards after two days and continue till the activity is ceased and only thereafter the decision regarding plantation of new crop be made.

b) Inspection upon arrival

One of the most important points in protected cultivation is to begin with insect-free planting material. When new plants arrive at the greenhouse, examine them closely for signs of pest infestation. If necessary, remove lower or damaged leaves to avoid spread of pests. Make the decision whether treatment is needed from the first sign of symptoms of insects or mites. It is much easier to manage a pest infestation by treating a group of small plants (in seedling stage) rather than larger plants where the dense canopy prevents thorough coverage.

c) Balanced use of fertilizer

Fertilization schedules based on balanced use of nutrients should be followed. Nitrogen should be applied only as needed for optimal growth. Periodic heavy applications set up nitrogen surpluses that cause excessive growth, which favour the population growth of aphids, and other pests. Application of potassium at desired levels has been found to reduce the incidence of insect-pests.

d) Pinching and Pruning

Pinching-off damaged plant parts, flowers, and spotted leaves (and those with insect larvae or egg deposits) can be a very effective way of reducing the spread of pests in the greenhouse. The plant debris should be placed immediately in a covered container before being disposed-off. This practice can be helpful in reducing the pest population of all the targeted pests. Pruning lower leaves after harvesting lower fruit clusters is helpful measure in removing large numbers of developing leaf-miners and whiteflies.

e) Trap crop/Indicator plants

For early detection and trapping of the target pests, some of the preferred hosts of the target pests can be used. Planting border rows of *Portulaca oleracea* in rose can be used as a trap crop for tobacco caterpillar under protected environment.

f) Plant Quarantine

Professionals or labours working in the greenhouse are one of the mechanisms for dispersal of insects and mite pests. One should try to avoid moving plants with mites or thrips and they should not be touched or moved immediately before handling clean and healthy plants.

II. Scouting and early detection

Scouting and early detection are critical to manage the insect infestation successfully. Monitoring or scouting is the regular, systematic inspection of the plants and exteriors to identify and assess pest problems. It includes visual inspection of foliage and flowers; and the use of sticky or light traps. Many insect infestations begin in isolated spots within the greenhouse. Timely crop monitoring identifies situations where pests are absent or are at levels well below economic injury, thus preventing unnecessary control applications and expenditures therby.

Scouting

Scouting procedures for most greenhouse-grown crops are based on visual observations and are used to provide estimates of the pest population in protected environment. The common pests that attack greenhouse crops do not distribute themselves evenly throughout the crop. Therefore, it is imperative to scout the entire greenhouse in a consistent, uniform pattern. Inspect the entire plant, including the soil surface, for the presence of arthropod pests. Look at the plant systematically each time. Begin at the bottom and work up. Look at the older leaves, the young, tender leaves, and the flush growth. When the crop is young, it is important to check all the leaves on the plant. Because a majority of arthropod pests associated prefers the underside of a leaf, it is important to turn the leaves over to check for pests. The detailed account of observations to be recorded is presented below.

Scout the crop on a regular basis and at least 1-2 per cent of the total plants should be inspected at weekly interval. A thorough greenhouse inspection reveals the location and severity of any current pest problems. One should use a field data sheet to record the identification, location, and severity of all pests present, and record the effectiveness of any treatments [22].

Monitoring

It is a relative method of insect population estimation where no direct observations on the plants for the presence of insect-pests are needed. However, the pest population is estimated with the help of attractant traps. For whiteflies, aphids, thrips and leaf-miner adults, yellow sticky cards (4″x12″ or 8″x12″) are an excellent supplement to pest observation in the protected environment. Additionally, for thrips blue coloured sticky traps can also be used. The traps are placed in a grid pattern and 1-2 yellow sticky cards per 100 square meter of floor area are used. If the target is mass trapping, then number of traps can be increased to five or more. Hang the yellow sticky cards/ traps in the crop with the help of strings about 4″ to 6″ above the plant canopy. As the crop grows, cards can be moved up. Designate the location of each sticky card on a map of the greenhouse. Check the sticky cards every scouting visit (twice a week if possible) and record the total number of whiteflies, thrips, winged aphids and leaf-miners from each card on the field data sheet. Change the cards when more than 60-70 per cent of the area is covered by trapped insect.

III. Curative measures

A) Biological Control

Biological control is the action of parasites, predators or pathogens in maintaining another organism population density at a lower average that would occur in their absence. In entomology, it has been used to describe the use of live insect predator and parasitoids, entomopathogenic nematodes or microbial pathogens to suppress populations of different pest insects. The organism that suppresses the insect pest is referred to as the biological control agent (BCA) [15]. BCAs are of utmost importance in case of protected cultivation and widely used against a number of pests. Biological control in the greenhouse environment is a viable alternative to pesticide use from both environmental and economic perspectives [26]. The important BCAs used against greenhouse pests are listed below in Table 3 [20].

Table 3: Major BCAs of key pests of green houses

Pest	Predator	Parasitoid	Entomopathogens
Mites	*Phytoseiulis persimilis Neoseiulis cucumeris Orius laevigatus*	-	-
Whitefly	*Orius laevigatus Chrysoperla spp*	*Eretmocerus mundus Encarsia formosa*	*Verticillium lecanii Beauveria bassiana*
Thrips	*Orius laevigatus Neoseiulis cucumeris*	-	-
Leafminer	-	*Diglyphus isaea Dacnusa siberica*	*Bacillus thuringiensis*
Aphids	*Orius laevigatus Chrysoperla spp. Apidoletes aphidomyza*	*Aphidus colemani Aphidus matricarae*	-
Caterpillars (*Spodoptera sp.*)	*Chrysoperla carnea*	*Trichogramma spp.*	*Bacillus thuringiensis, Sl*NPV, *Ha*NPV

Commercially available biological control agents for common greenhouse insect pests [31]

Biocontrol agents of whitefly

Parasitoids

Encarsia formosa

- It is the most widely used parasitoid for greenhouse whiteflies
- Most effective at higher temperatures (>70° F)
- May be ineffective on plants with honeydew (clear, sticky liquid)
- Make releases when greenhouse whitefly populations are low
- Adult females will host feed on nymphs
- Release parasitoids every 1 to 2 weeks
- Release 2 wasps per 15 square feet every 1-2 weeks for preventation

Eretmocerus eremicus

- Parasitizes sweet potato and greenhouse whitefly
- Females prefer laying eggs into 2nd or 3rd nymphal instars
- Tolerates higher temperatures and does more host-feeding than *Encarsia formosa*

Predators

Predatory mite *Amblyseius swirskii*:

- Feeds on the eggs and nymphs of whiteflies and larvae of western flower thrips
- May also feed on pollen in the absence of prey

Predatory Beetle, *Delphastus catalinae*
- Most effective when whitefly populations are high
- Can feed on >150 whitefly eggs per day
- Will not attack parasitized whitefly
- May be sensitive to pesticide residues

Predatory Mirid Bug, *Dicyphus hesperus*
- Feeds on greenhouse whitefly
- Reared on mullein banker plants: requires a minimum of 8 weeks to establish a sufficient population

Biocontrol Agents of Aphids
Parasitoids
Aphelinus abdominalis
- Parasitizes a wide-range of aphid species
- Can tolerate higher temperatures than most *Aphidius* species
- Slower to establish than *Aphidius* species
- Release 2 to 4 adult wasps per 10 square feet weekly or until 80-90% of the aphids are parasitized

Aphidius colemani
- Parasitizes smaller aphids such as green peach and melon aphid
- Can be reared using banker plants (oat or wheat) infested with bird cherry oat aphid (use a minimum of 4 banker plants per acre)
- May be sold as a mixture with *Aphidius ervi*
- Release 400 to 2,000 adults per acre

Predators
Predatory Gall Midge, *Aphidoletes aphidimyza*
- Larval stages prey on all aphid species encountered in greenhouses
- Most effective at temperatures between 68 and 80°F and a relative humidity between 70 and 80%
- Primarily active at night
- Mainly used against high aphid populations

Ladybird Beetle, *Adalia bipunctata*
- Both larvae and adult feed on many different aphid species
- Used when aphid populations are high
- Adults typically attempt to leave the greenhouse after release. Therefore, make releases in the evening
- Release adults every 2 to 3 weeks

Green Lacewing, *Chrysoperla carnea*
- Feeds on greenhouse whitefly
- Reared on mullein banker plants: requires a minimum of 8 weeks to establish a sufficient population

Biocontrol Agents of Western flower thrips
Predators
Predatory mite *Amblyseius swirskii*
- Feeds on both 1st and 2nd instar larvae
- Tolerates higher temperatures than *Neoseiulus cucumeris*
- Will also feed on the eggs and nymphs of whiteflies
- Feeds on pollen in the absence of prey
- More expensive than *N. cucumeris*

Predatory mite, *Neoseiulus (=Amblyseius) cucumeris*
- Most widely used predatory mite for western flower thrips
- Feeds on the 1st instar larvae
- Make releases early in the crop production cycle

Minute pirate bug, *Orius* spp
- Feed on larvae and adults of western flower thrips
- May also feed on aphids and whiteflies
- Can be used with ornamental pepper plants serving as banker plants (example: 'Purple Flash,' 100 per acre)
- More expensive than using *Neoseiulus cucumeris*
- Most effective when temperatures are >60° F and day length is >12 hours
- Release 1 per square foot

Soil dwelling predatory mite, *Stratiolaelaps scimitus*
- Adults may kill up to 30 prey, including western flower thrips pupae or fungus gnat larvae, per day. Release 1,000 to 2,000 per square foot

Case Studies involving biocontrol agents and botanicals

Efficiency of predator *Chrysoperla carnea* second instar larvae were estimated against *Aphis gossypii*, *Myzus persicae*, *Bemisia tabaci* at three different rates (3, 5 and 7 larvae / plant) on cantaloupe (*Cucumis melo* L.) under greenhouse conditions. The promising and best results were obtained after 21 days by releasing larvae @ 5 larvae/plant, reducing population of aphids and whitefly by 73.9 and 83.07 per cent, respectively [34]. Efficacy of the parasitoid *Eretmocerus ermicus* (Hymenoptera: Aphelinidae) and the predatory mite, *Amblyseius swirski* (Acarina: Phytoseiidae) in comparison with conventional insecticides against whiteflies and thrips on herbs at Koka, Ethiopia was studied during 2009-10 [1]. Thrips population in both green houses was low in the first three to four months (November to January/February). After January/February, thrips population in the biological control green house (BCGH) was lower than the conventional insecticide green house (CIGH). On the hand, white fly population was higher in BCGH than the CIGH throughout the experimental period. The predatory mite as measured by the proportion of plants having the predator was low initially (November through January) which later increased with time. On the other hand, the parasitoid was almost nil throughout the experimental period. Overall lower thrips number in BCGH than in CIGH and the presence of *A. swirski* in good number later in the season suggest the need and importance of considering *A. swirski* as an integral component of thrips management in herbs. Its use, however, entails use of effective biocontrol agents or Integrated Pest Management compatible products against the concurrently occurring white flies. *Eretmocerus ermicus* establishment was very poor and hence its influence on the pests.

Aphelinid parasitoids (*Eretmocerus* sp., *Encarsia formosa*) and predators, *Aphidoletes aphidimyza* were able to control pest on tomato, cucumber and ornamental crops grown in greenhouses. Parasitism of the whiteflies, *Trialeurodes vaporariorum* and *Bemisia tabaci* was as high as 85 to 96 per cent. Natural enemies released also effectively suppressed aphid populations in tomato and cabbage crops. Egg parasitism of the cabbage butterfly, *Pieris rapae*, and tomato fruit borer, *Helicoverpa armigera*, by *Trichogramma* sp. was 78 to 95 per cent on an average [28].

Efficacy of *Aphidius colemani* Viereck (Hymenoptera: Braconidae) for suppression of *A. gossypii* in greenhouse-grown chrysanthemum, *Dendranthema grandiflora* was compared with a pesticide standard, imidacloprid (Marathon 1% G) and an untreated check. No significant differences were found between aphid populations in the two treatments.

A. colemani and imidacloprid kept aphid numbers very low, in contrast to the untreated plants. Parasitism levels in *A. colemani* plots ranged from 48.93 to 83.38 per cent [30].

Three hymenopteran parasitoids were recorded from *Myzus persicae*, including one Aphelinidae, *Aphelinus asychis* Walker, and two Braconidae, *Aphidius matricariae* Haliday, and *Aphidius ervi* (Haliday) in a bell pepper crop grown in a polyhouse at Palampur, Himachal Pradesh, India during 2011-2012. The parasitoid *A. asychis* (black mummies) was detected in the first week of December, whereas the braconid parasitoids (goldenbrown mummies) were first recorded in the last week of December and second week of January, respectively. Of these, *A. matricariae* was recorded first and *A. ervi* appeared later on. Parasitism rates varied from 2.4-38.6 per cent (mean = 20.5%) for *A. asychis* [6].

Botanicals (Neem oil, Pongamia oil, NSKE, Sweet flag rhizome, Vitex negundo leaves) and mycopathogens (*Verticillium lecanii, Metarrhizium anisopliae*) were evaluated for the management of mites and thrips under polyhouse condition in Dharwad during 2006-07. At 10 DAS, neem oil maintained its superiority in recording lowest mite population (6.97 mites / leaflet). *V. negundo* (7.18 mites /leaflet) and *V. lecanii* (8.00 mites /leaflet) were the next best treatments in reducing the mite population. At 10 DAS, pongamia oil was the most superior treatment (3.50 thrips /leaflet) followed by neem oil (4.20 thrips /leaflet) and NSKE (4.68 thrips /leaflet) in controlling thrips [13]. Evaluation of phytoseiid predators for control of western flower thrips (WFT), *Frankliniella occidentalis* (Pergande) on greenhouse cucumber revealed that predatory mite species, *Typhlodromalus limonicus* (Garman & McGregor), *Typhlodromips swir*skii (Athias-Henriot) and *Euseius ovalis* (Evans) reached much higher population levels resulting in a significantly better control of thrips. *T. limonicus* was clearly the best predator of WFT [16]. A polyhouse experiment conducted to find out the efficacy of botanicals and entomopathogens against *Scirtothrips dorsalis* Hood on different stages of rose (bud, half opened and full opened flower) revealed that among different stages of rose, half opened flower was found superior to control *S. dorsalis*. Among different botanicals NSKE (2%) was recorded 74.37 per cent mortality to thrips. Among different entomopathogens, *Heterorhabditis indica* (2000 IJs/ml) was found next best to botanicals by recording 72.08 per cent mortality of thrips [9].

B) Chemical control

Control of insects with chemicals is known is chemical control. The term pesticide is used to those chemicals which kill pests and these pests may include insects, animals, mites, diseases or even weeds. Chemicals which kill insects are called as insecticides. Insecticide may be defined as a substance or mixture of substances intended to kill, repel or otherwise prevent the insects.

Importance of chemical control

Insecticides are the most powerful tools available for use in pest management. They are highly effective, rapid in curative action, adoptable to most situations, flexible in meeting changing agronomic and ecological conditions and economical. Insecticides are the only tool for pest management that is reliable for emergency action when insect pest populations approach or exceed the economic threshold. A major technique such as the use of pesticides can be the very heart and core of integrated systems. Chemical pesticides will continue to be essential in the pest management programmes. Some of the important chemical insecticides used against greenhouse insect pests are listed below in Table 4.

Table 4: Some of the important chemical formulations used against greenhouse insect pests

Target pests	Chemicals	References
Mites	Diafenthiuron, Fenpyroximate, Abamectin @ 0.5ml/L	[27]
Thrips, Whiteflies, Aphids	Imidacloprid @ 0.4g/L, Acephate @ 1g/L or Acetamiprid @ 0.2g/L, Abamectin @ 0.5 ml/L, Phosphomidan 0.2 mL	[11], [14], [24]
Leafminer	Spinosad @ 0.3ml/L, Abamectin @ 0.5ml/L	[26]
Caterpillars	Spinosad, Chlorantraniliprole @ 0.3ml/L, Flubendiamide @ 0.1ml/L	[26]

Case studies including chemicals and botanicals

Neem Azal-T/S (azadirachtin), Success (spinosad) and abamectin were tested against different life stages of sweet potato whitefly, *Bemisia tabaci*, in an air conditioned tropical net greenhouse. Neem Azal-T/S and abamectin deterred the settling of adults on tomato, *Lycopersicon esculentum* and consequently reduced egg deposition. No such effect was detected for Success. All three pesticides influenced egg hatch. Effects of Neem Azal-T/ S were significantly altered if applied to different-aged eggs (1, 3 and 5 day old). In contrast, abamectin-treated eggs failed to hatch at any given age class. All three products caused heavy mortality of the three nymphal stages of *B. tabaci*, with the first instars being most susceptible, abamectin-treated nymphs died within 24 h post application. In contrast, 100% nymphal mortality with Neem Azal-T/S and Success was reached 6-9 day post application. Abamectin caused 100% immature mortality at all residue ages (1, 5, 10 and 15 day) in the laboratory and greenhouse as well [14]. The combination of agricultural spray oil + azadirachtin proved most effective in reducing the mite (*Tetranychus urticae*) population as compared to control in cucurbits throughout the treatment period followed by agricultural spray oil and azadirachtin alone [23].

Effective control of two-spotted spider mite, *T. urticae* on greenhouse cucumber was obtained by combined spraying of agricultural spray oil and azadirachtin (0.5%) [5]. In chrysanthemum, combined treatment of phosphamidon and cypermethrin was the most effective for the key pests, *viz.* aphid, *Macrosiphoniella* and *Spodoptera* caterpillar. Efficacy of caterpillar management by spinosad 11.6% SC increased after three days of application (94.44%). In aphid control, the agricultural spray oil @ 0.50% showed very effective result [24].

The studies on efficacy of some insecticides and botanicals against sucking pests on capsicum under net house resulted in significantly low aphid counts/plant (0.76-1.05) in treatments Asataf (Acephate) 75 SP @ 0.10% and Neem Soap (*Azadirachta indica)* @ 1.0%. Significantly low chilli thrips counts /top canopy/plant (0.03-0.06) were recorded in treatments confidor 17.8 SL (Imidacloprid) @ 0.05% followed by Asataf (Acephate) 75 SP @ 0.10% and significantly lower mean yellow mite rating (2.42-2.45) was recorded in treatment Decis 2.8 EC @ 0.05 % [11].

Conclusion

Based on the insight of available literature it is concluded that for successful management of greenhouse pests can be done by using integrated approach. It is important for greenhouse producers in India to implement as many IPM exclusion strategies as possible to manage insect-pests. Once these pests enter the greenhouse, growers have very few options to manage them. Therefore, excluding the pests from entering the greenhouse is of utmost importance.Integrated approaches involving bio control agents, botanicals and microbial pathogen with limited and ecologically safe insecticides to non-target organisms must be developed and adopted at large scale. Many of the serious insect pests of greenhouse crops, including aphids, silverleaf whitefly, mite and thrips, require special control efforts due to their potential to act as vector plant viruses.

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