Chapter 10

Pests and Diseases

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Introduction

Many species of arthropod pests (insects and mites) and diseases can infest plants grown within growth chambers and interfere with the plant processes under investigation or with general plant health. Also, the use of many of the pest control procedures introduces a variable that does, or may unknowingly, interact to influence growth rates or alter particular physiological or biochemical process within the plants being studied. Therefore, a major effort in growth chamber research should be directed toward avoiding contamination so that if pests invade the plants, the experiment does not have to be repeated.

The common arthropod pests are the principal problem because they generally are very small and often occur in places on a plant that may escape notice. Infestations can quickly escalate because of the short life cycles and high reproductive rates of the pests. They often go undetected until their numbers become large and damaging. Most growth chamber environments are optimal for arthropod pest development. Arthropods are usually able to survive in the same environments as their host plants. Control of an infestation can be difficult and complicated and may greatly interfere with an experiment.

Plant diseases are generally much less of a problem than arthropod pests, but once diseases are started, eradication becomes difficult.

This chapter provides information on the identification, types of damage, biology and life histories, and management strategies for pests and diseases commonly found on plants in growth chambers.

General Pest Management Considerations

Prevention is the most effective control measure for all pests in growth chambers. The chamber should be thoroughly cleaned before use. Insect pests often have a broad host plant range and can infest any new plant material brought into a chamber. To totally rid a chamber of pests, it may be necessary to deprive them of food by removing all plant material for several weeks while maintaining warm temperatures. More practically, emptying a chamber completely for 2-3 days and wiping the walls, floor, and shelves with a Chlorox solution, diluted 10X with water, will provide effective control of most pests. The surfaces should be wiped off with clean water after using the chlorine water to minimize the chance of toxicity from residual chlorine. Plants should be started from seed or from sterile cultured plantlets within the chamber whenever possible. Only pest-free soil or growing media should be used. If plant material is brought into a chamber, it should be carefully inspected for pests before introduction, but it is nearly impossible to avoid pests if plants are brought from greenhouses and outside areas. Plants can be quarantined and observed for pests before introduction into a chamber.

Before the start of growth chamber work, determine likely pests and develop a plan for their control. Although plant material may be initially uninfested, pests may be introduced through clothing or on air currents. Thus, plants should be carefully and regularly inspected for pests. Yellow sticky cards placed just above the plant canopy can be used to detect flying insects such as adult fungus gnats, leafminers, thrips, winged aphids, and whiteflies.

If possible, infested plants should be removed immediately to prevent the spread of an infestation. Selective removal of infested leaves or other plant parts may be adequate and less disruptive.

The duration of an experiment can greatly influence the severity of pest problems. In general, the longer plant materials are continually in a chamber, the more likely it is that pest problems will occur. Experiments concluded within one month are likely to have few problems, provided that few pests are initially present. If pests are found during an experiment, treatment may not be warranted if the remaining time and experimental conditions are insufficient to require control measures.

Control measures may sometimes be more harmful and disruptive than the pest damage. Insecticide applications should rarely be done within a chamber because they may damage the chamber or pose issues of legality and safety to workers and plants. It is best to remove plants to an uninfested greenhouse area for chemical treatment. Plant removal, however, may be very disruptive to an experiment. Also, certain pesticides may have serious acute and/or chronic effects on certain species or cultivars of plants; the effects may be more serious than pest damage.

Biological control with natural enemies of the pests (predators, parasitoids, and arthropod pathogens) is sometimes an option if environmental conditions and duration are sufficient. This option is safe to plants and workers, legal, and not harmful to chambers. In general, natural enemies should be introduced in sufficient numbers while pest numbers are very low. Multiple introductions may be necessary. Control is not instantaneous; some pest damage may occur before control is achieved. Advice on the availability and use of natural enemies can be obtained from cooperative extension services or commercial insectaries.

Certain species or cultivars of plants may be more susceptible to pests than others. The use of resistant or tolerant plants may be worthy of consideration in some cases.

The following paragraphs discuss the identification, damage, biology, and management guidelines for the common pests that may occur in growth chambers. Insects and mites will be discussed first, followed by discussion of diseases, nematodes, and algae.

Arthropods

Aphids

Identification. Aphids, also sometimes called plant lice, are small (1-3 mm), soft-bodied insects in the Order Homoptera, Family Aphidae. Extensive information on aphid biology and species identification can be found in Blackman and Eastop (1985) and Minks and Harrewijn (1987). These insects can be readily identified as aphids by the presence of a pair of tube-like structures, called siphunculi, on the posterior dorso-lateral surface of their abdomen. A number of aphid species can be present, differing in size, coloration, and food preferences. Wings may or may not be present. The most commonly encountered species is the green peach aphid, *Myzus persicae* (Sulzer), although the melon aphid, *Aphis gossypii* (Glover), is also common. The green peach aphid can infest a wide variety of crops. The color of the green peach aphid can vary from light green to rose. Melon aphids have a somewhat narrower host range that includes chrysanthemums and hibiscus. Their color may vary from light to very dark green. The chrysanthemum aphid, *Macrosiphoniella sanborni* (Gillette), is only found on chrysanthemum, and its color varies from dark red-brown to blackish-brown. Color alone, however, is not a reliable characteristic to use for aphid species identification because of variation. Correct identification can be important for efficient aphid control. For example, pyrethroid insecticides may be very effective against some aphid species (e.g., chrysanthemum and melon aphids) but not against others (e.g., green peach aphid) (Warkentin, 1988).

Damage. Aphids feed by inserting their piercing-sucking mouthparts through plant tissue directly into the phloem and removing plant sap. They may feed on stems, flower buds, and lower surfaces of leaves. Their feeding can lead to plant stunting and deformities. Large numbers of aphids can remove enough nutrients from a plant to reduce its vigor. Their excrement consists of a sweet, sticky secretion called "honeydew." This secretion can cause leaves to become shiny and sticky and can also serve as a growth substrate for a grey fungus known as sooty mold. Honeydew and sooty mold can affect leaf photosynthesis. Finally, aphids are responsible for the transmission of about 60% of all plant viruses of agricultural crops worldwide (Schwartz, 1985).

Biology. Under most growth chamber conditions, aphids reproduce parthenogenetically, i.e., all the insects present are females, and each female gives birth to more females without the need to mate. Aphids can be viviparous, meaning females give birth to living nymphs rather than laying eggs. In fact, in some species, an unborn aphid already contains a complement of developing nymphs, a phenomenon known as "paedogenesis." The individual aphids produced are genetic clones of their parents. Aphids produce eggs only under short-day conditions in the fall, and their ability to reproduce without mating or egg production causes their populations to increase almost explosively, especially because individuals can mature and begin to reproduce in as few as 7 days. As an aphid colony increases in age and size on individual plants, the proportion of winged forms increases.

The attraction of aphids to yellow aids them in finding a suitable plant. Some aphid species discriminate between plant species or varieties based on colors of the plant that they perceive. Also, aphids have a marked propensity to migrate to new host plants and will actively search for soft, fresh plant tissue upon which to feed.

Aphids have a well-known capability to develop insecticide resistance. Strains of some species have documented resistance to carbamate, organophosphate, and pyrethroid insecticides.

Management. Aphid control is much more successful when an infestation is detected and controlled early. Therefore, a regular scouting and monitoring program should be implemented. Inspection of yellow sticky cards may detect winged aphids. It is more important, however, to inspect plants at least weekly to allow for early detection and monitoring. Aphids can also be detected by noting the presence of the white cast skins that they leave behind as they molt between stages. Aphids can be spread on clothing, so plants located near walkways and doors should be examined. Stems and lower surfaces of all leaves on a plant should be examined.

Insecticides that have systemic or translaminar properties tend to be more effective than contact insecticides for green peach aphid control, provided that a sufficient amount of insecticide reaches the aphid feeding sites. Contact insecticides, however, may be very effective against other aphid species. Insecticide resistance can vary from place to place, and aphid strains with various levels of resistance to various chemicals may be introduced via incoming plant material. Therefore, it can be difficult to generalize about the efficacy of a particular insecticide.

Aphids have many natural enemies, including ladybird beetles, lacewings, flower flies (syrphids), parasitic wasps, predaceous midges (*Aphidoletes aphidomyza*), and insect-pathogenic fungi (Hall, 1985). Many of these are available from commercial insectaries.

Caterpillars

Identification/Damage. Caterpillars, or "worms," are the immature forms (larvae) of butterflies and moths (Order Lepidoptera). They are only occasionally pests in growth chambers. Some of these insects become very large, although others, when young, are barely discernible without magnification. Eggs or young larvae can be easily overlooked and introduced on plant material. Included within this diverse group are armyworms, cutworms, leaftiers, leafrollers, and loopers. These insects are damaging only as larvae; the adults either do not feed or feed only on nectar. The larvae have chewing mouthparts with which they can consume large amounts of foliage, tender stems, or even flowers. Their feeding can rapidly cause severe damage to a plant. The feeding preference of some species, such as the beet armyworm, for tender meristematic tissue can produce continued "pinching" of certain crops.

Biology. Some of these pests (e.g., beet armyworms) do not successfully overwinter in temperate regions, but can be year-round pests of indoor and outdoor crops in warmer climates.

Because there is exceptional diversity among caterpillar species, it is difficult to generalize about their life cycles. Some species lay eggs on the plants; others lay eggs on the soil. Some hide in the soil during daylight and emerge to feed only at night; others remain on the plants at all times; still others fold leaves around themselves and remain protected. Some species pupate in soil; others pupate on the plant. The list of biological differences is extensive.

Management. Plants should be inspected carefully and regularly for signs of leaf feeding. Eggs or small larvae may be present on plant material when first introduced into the chamber. Some caterpillars can be controlled by a disease organism, *Bacillus thuringiensis* (Bt) var. *kurstaki*. This bacterium, harmless to mammals as well as to insects other than caterpillars, is sold commercially under several trade names. Bt is an excellent first choice for controlling caterpillars because it is harmless to mammals, compatible with beneficial insects, and does not harm the environment.

Fungus Gnats

Identification. Fungus gnat (*Bradysia* sp.) adults are small, slender, black or dark brown flies (Order Diptera, Family Sciaridae) about 1/8 inch long (3.2 mm). The two wings are delicate and clear. The many-segmented antennae are longer than the head. Legs are long and gangly. Adults are weak flyers and may be found flying or running over soil surfaces or leaves.

The larvae, which is the stage that can damage a plant, are legless and worm-like, with a white body and a distinct black head capsule. They are about 1/4 inch (6.4 mm) long during their final larval stage. They pupate within silken cells near the soil surface.

Fungus gnats may be confused with another small, dark-bodied fly called the shore fly, *Scatella stagnalis* (Family Ephidridae). Considered harmless, shore flies usually do not affect crops in any way, although it may be possible for them to transmit certain plant pathogens (Goldberg and Stanghellini, 1990). The larvae of shore flies feed on algae growing on the soil surface or other substrates and are favored by the same wet conditions that are attractive to fungus gnats. With both insects, large numbers of adults may be a nuisance.

Shore flies have more robust bodies and the antennae are very short. Their most distinguishing characteristic, however, is the presence of five light-colored spots on each of their greyish wings. Shore flies are also stronger, faster fliers than fungus gnats. In the larval stage, shore flies may be distinguished by the opaqueness of the body and the absence of a head capsule. Shore flies feed by means of a pair of small mouth hooks. They display a characteristic forked air tube at the posterior end of the body.

Damage. With the increasing use of artificial soil mixes high in organic matter, fungus gnats have become a serious pest problem. These flies are attracted to damp locations where fungi are apt to flourish. Fungi are a major part of their diet. Unfortunately, the larvae may not limit their feeding to fungi. Larvae can attack the roots of growing plants, resulting in retarded plant development. They may be especially destructive to seedlings and young plants that are becoming established. Under water deficiency stress, foliage may wilt. Leaf yellowing and leaf drop may result. Plant parts (such as stems) below the soil surface may also be invaded. Tunneling of the larvae may cause collapse of the stem. The larvae also may introduce bacterial or fungal pathogens as secondary invaders. Formation of callus can be impeded or prevented, resulting in slow or poor root initiation.

Biology. Mated females deposit 75 to 200 eggs, singly or in clusters. The creamy white eggs are laid in cracks and crevices of the soil surface, and all subsequent immature stages can be found within the top 1 inch of the soil surface. Eggs mature in 3 to 6 days, giving rise to white, transparent or slightly translucent, legless larvae. Larvae feed and develop for about 2 weeks at 22°C. Pupation occurs in the soil. After about 4 to 7 days, adults emerge from the puparium. They live about one week. The life cycle is very dependent on temperature and moisture, with increased developmental time at decreasing temperatures. Overlapping life stages are common (Wilkinson and Daugherty, 1970a,b).

Management. Good sanitation practices, such as thorough chamber cleanup between and during periods of use, elimination of algae on chamber surfaces, and the use of sterilized or otherwise insect-free growing media, will do much to minimize fungus gnat and shore fly problems. Care should be taken to eliminate standing water on floors and benches. Badly infested containers of plants should be removed. Plant debris should not be allowed to build up.

Adult fungus gnats and shore flies can be detected and monitored through time with yellow sticky cards. Weekly inspections of yellow sticky cards can reveal the onset of an infestation, and continued recording of the number of adults per card per week can aid in evaluating the efficacy of control efforts.

If an infestation is detected, the best long-term control will probably occur if the larval stages are targeted. Insecticidal drenches or soil surface sprays can be effective. Certain insecticides may not affect eggs or pupae, and repeated applications may be necessary before control is achieved. Also, if chemical applications are directed only against the larval stages, it may take some time before control of the larval stages reduces numbers of adults. Natural enemies for fungus gnats include entomopathogenic nematodes (*Steinernema carpocapsae, S. feltiae*) (Lindquist and Pietkowski, 1993), predaceous mites (*Hypoaspis miles*) (Chambers et al., 1993), and the bacterium *Bacillus thuringiensis var. israelinsis* (Gnatrol®) (Osborne et al., 1985). These natural enemies are all available from commercial insectaries and can be effective.

Leafminers

Identification/Damage/Biology. Although a number of species of leafminers can attack crops, the most serious and most common are flies (Order Diptera) of the family Agromyzidae, and the most common and severe pest species is *Liriomyza trifolii* (Burgess). Parrella (1987) extensively reviews the biology of *Liriomyza* sp. These tiny (2 mm) flies are yellow and black, resemble small fruit flies, and are strong fliers. Females make small punctures on upper leaf surfaces with their ovipositors. Females and males feed on exuding plant juices from most of these punctures, but females lay eggs singly beneath the epidermis in some of them. The punctures turn white with time and give leaves a speckled appearance. On hatching, the larvae begin to feed on surrounding cells, using their sickle-like mouth hooks. As the cells are ruptured, the larvae move forward to consume more cells, continuing in this fashion and leaving behind winding trails (the "mines") within a leaf. The mines increase in length and width as the insects grow. At high population levels, the larval mines can reduce the photosynthetic capabilities of a leaf. The duration of the life cycle depends on temperature and plant species, but may be generalized as follows. Eggs hatch in as few as 4 or 5 days. The larvae feed within the leaf for 4 to 6 days, molting twice. Third instar larvae usually chew a small slit in the lower leaf surface and drop to the soil or onto lower leaves to pupate. The pupal stage can last from 35 days at 14°C to 9 days at 27°C. Egg to adult development can require 50 days at 14°C, and only 13 days at 30°C.

Management. The best initial defense against these pests is to avoid the use of infested plant material. Plant material should be inspected for leaf stipples and active mines, and perhaps held for several days to see if mines develop from leaf stipples. Yellow sticky cards can be used to detect adult activity and to monitor population levels. Leaves that display stipples or active mines can be removed. If necessary, chemical control aimed at the larval stage should be done outside the growth chamber. Biological control of leafminers has been successful on certain greenhouse crops (Heinz and Parrella, 1990).

Twospotted Spider Mites

Identification. The twospotted spider mite, *Tetranychus urticae* (Koch), is the most common species of the spider mite family, Tetranychidae, to infest growth chamber plants. Spider mites sometimes are referred to as "red spiders," although they are not spiders (Class Arachnida) and not necessarily red. They are minute arthropods in the subclass Acari, with the largest life stage (adult female) less than a millimeter in size. The body of the adult female and most immature stages is oval-shaped and usually appears light yellow to green with two large lateral dark green spots. All motile life stages have eight legs except for the larval stage, which has six. Eggs are tiny, spherical, whitish to yellowish, and are deposited among the webbing of a colony. Extensive information on spider mites can be found in Helle and Sabelis (1985).

Damage. Spider mites attack an exceptionally wide range of plant species. These mites can cause severe chlorosis in infested plants because they feed by "stabbing" cells with their piercing mouthparts and ingesting the cell contents that exude. Spider mites remove chlorophyll from plant cells and reduce photosynthesis. Removal of chlorophyll produces the characteristic stippling or mottling of foliage and sometimes causes leaf drop. When populations are low, the mites primarily infest the lower surface of leaves, but may cover all leaf surfaces as populations increase. In severe infestations, the plants may be covered with the mites' characteristic webbing, which is produced constantly by every motile life stage. Masses of adult females may be found at plant tips or hanging on strands of webbing as they deplete their food supply and begin to disperse. Water-stressed plants are particularly susceptible to spider mites.

Biology. Survival, developmental time, and reproduction are greatly influenced by environmental factors such as temperature, humidity, and host plant species. Of these, temperature is most important. Spider mite colonies are formed on lower surfaces of leaves where females lay eggs (up to 12 per day) within the fine webbing that the mites constantly produce. One female is capable of laying more than 100 eggs during her lifetime. The eggs hatch in as few as 3 days, depending on temperature, and the newly hatched mites (called larvae) immediately begin to feed. After as few as 5 days, the mites pass through two nymphal stages and become adults. Females will begin laying eggs from 1 to 3 days after emerging as adults, and mating is not required. Egg to adult development may take as few as 7 days at 27°C, and about 20 days at 18°C. At warm temperatures, the mites' capability for rapid population increase becomes apparent. Spider mites do best under hot, dry conditions, and develop more quickly on water-stressed plants.

Pesticide resistance can be a common problem in spider mite control. Unfortunately, many strains of mites exist, and many of these strains are resistant to one or more acaricides (miticides). Currently several acaricides are effective, but unless these chemicals are used carefully and sparingly, it is merely a matter of time before resistant strains evolve.

Management. Plants to be placed in growth chambers should be inspected carefully for the first signs of leaf stippling caused by spider mites. The lower surfaces of leaves also should be inspected for mites. Once in the chamber, particular and frequent attention should be given to areas of the growth chamber where mites are most likely to be spread on clothing, such as near entrances. Attention should also be focused on plant species or varieties that are particularly susceptible to mite infestations. Efficient and regular scouting can lead to early detection of an infestation. Control measures may then need only be applied to the infested area. Plants on which an infestation is detected can be marked and re-inspected with a hand lens several days after a spray to evaluate the degree of control achieved. Some miticides are not effective against mite eggs; thus a repeat application may be needed after 5 to 7 days. Thorough coverage of upper and lower surfaces of all leaves is critical for effective mite control.

Biological control of spider mites with predaceous mites (e.g., *Phytoseiulus persimilis* Athias-Henriot) may be feasible on many plant species in a growth chamber, provided that environmental conditions are compatible with the predaceous mites and that they are introduced in sufficient numbers at the first sign of spider mite damage. Several predaceous mite species are known to feed voraciously on spider mites and their eggs, and these predaceous species are commercially available and commonly used to control spider mites on greenhouse-grown vegetable crops in Canada and Europe.

Mealybugs

Identification. Mealybugs are related to aphids and whiteflies and are in the Order Homoptera, Family Pseudococcidae. Eggs are laid in a loose cottony mass called an ovisac. First instar crawlers are pinkish-orange and similar in size and shape to whitefly pupae. Older immatures and female adults are small (1 to 8 mm long), elongate-oval, soft-bodied insects that are covered with a layer of white, cottony wax. Males are rarely seen; they are winged and resemble adult whiteflies. Most mealybug species produce short, spine-like filaments along the margins of their bodies, and on some species the posterior filaments can be quite long. Some mealybug pests of greenhouse crops are the citrus mealybug, obscure mealybug, and long-tailed mealybug (Stimmel, 1987; Copland et al., 1985).

Damage. Mealybugs can be found infesting all parts of a plant, including roots. They often form colonies in leaf and stem axils and on undersides of leaves. These soft-bodied insects feed with stylet-like mouth parts, inserting them into plant tissue and sucking plant juices. Mealybug infestations can cause leaf distortion, particularly on new growth. Some species inject a toxin as they feed, which can produce necrotic areas, general yellowing, or leaf drop. Even a moderate infestation can reduce the vigor of a plant. Honeydew production can support the growth of sooty mold. Ants can be attracted to the honeydew; the presence of ants may signal a mealybug infestation.

Biology. Life cycles vary tremendously among different species, but may be generalized as follows: Females produce from 300 to 600 eggs, usually in the ovisac. Some species give birth to live young. The eggs mature in the ovisac for approximately 2 weeks, then hatch into first instar crawlers. The crawlers are the life stage most susceptible to insecticides. Crawlers and all subsequent life stages of mealybugs are mobile, although they are slow-moving. This pest, therefore, moves easily among leaves or plants and can spread an infestation over many plants. Mealybugs have a 30- to 70-day life cycle.

Management. Mealybugs easily go undetected, particularly at the onset of an infestation when their numbers are low. Their cryptic habitats make them difficult to detect, and provide protection from sprays. The waxy secretions of the ovisac, older immatures, and adults cover their bodies and confer further protection from insecticides. Early detection is very important for effective control. Infested plants should be isolated if possible to prevent spreading the problem to uninfested plants. It may be wise to discard an infested plant rather than spend time and effort attempting control while risking spread of the infestation.

If contact sprays of synthetic organic insecticides are used, they should be applied against the crawler stage of scales and mealybugs. Repeated applications are therefore necessary to contact the susceptible stages as they are produced. Spray intervals depend on the residual effectiveness of the insecticide used, which may vary from 1 to 3 weeks. The inclusion of a spreader-sticker can aid in coverage, penetration, and residual activity, although the risk of phytotoxicity may be increased. Good coverage is important for contact insecticides. Insecticidal oils and soaps can be very effective, killing more life stages of these pests than many contact insecticides, but there is no residual control, and thorough coverage is critical. Systemic insecticides may kill actively feeding stages, assuming adequate amounts of insecticide are translocated to the feeding site. Systemics will not kill the egg stage, however. An additional application may be necessary after 3 to 4 weeks if the residual activity of the systemic is inadequate. Fumigant insecticide formulations can be effective against mealybugs and should be applied at 10- to 14-day intervals.

Biological control of certain mealybug pests is possible with commercially available parasitoids and predators (Copland et al., 1985; Steiner and Elliot, 1987). Information regarding the use of these natural enemies and integrated control of these pests can be obtained from commercial insectaries and cooperative extension services.

Thrips

Identification. Thrips (Order Thysanoptera) are tiny insects; adults are 1 to 2 mm in length, with narrow bodies and fringed wings. Body color can vary from straw-yellow to dark brown or black. Accurate identification of thrips to species may be impossible without the use of a compound microscope. Several species of thrips can infest plants in growth chambers, but the most severe pests include *Thrips tabaci* (Hussey, 1985) and in recent years the western flower thrips (WFT), *Frankliniella occidentalis* Pergande (Robb, 1990). This discussion will center on this latter pest, and serve in general for other thrips species.

Damage. Western flower thrips feed by rasping plant cells and feeding on exuding juices. The collapse of plant cells caused by thrips feeding can result in deformed plant growth, flower deformation, or scarred areas and flecking on expanded leaves. Thrip damage on the surface of expanded leaves or petals is usually recognized as small patches that have been scarred and display tiny greenish-black fecal specks left by the thrips. Thrips also feed on pollen, which could be problematic for plant breeding experiments. One of the most serious threats of a WFT infestation is their ability to vector Tomato Spotted Wilt Virus (TSWV) and Impatiens Necrotic Spot Virus (INSV) to a wide variety of plants. One WFT adult can infect a plant after feeding for only 30 minutes. Both the virus and the thrips have a wide range of plant hosts, including weeds.

Biology. Control of WFT is extremely difficult because of several biological characteristics of this species. Biological information can be found in Robb (1990). Eggs are inserted into leaf or petal tissue and are thus protected from insecticides. The egg stage lasts from 2-1/2 to 4 days. The eggs hatch into larvae, which usually remain protected in flower buds or terminal foliage. The insect passes through two larval stages, both of which may feed in these protected areas. The first larval stage lasts 1 to 2 days; the second, 2 to 4 days. Toward the end of the second larval stage, the insect stops feeding and usually moves down into the soil or leaf litter to pupate. The insect passes through two "pupal" stages (prepupal and pupal), during which no feeding and little movement occurs. The prepupal stage lasts 1 to 2 days, and the pupal stage lasts 1 to 3 days. While in the pupal stage in the soil, the insect misses exposure to insecticides directed at the foliage. The adults, which can survive from 13 to 75 days and lay 40 to 250 eggs (depending on temperature and plant species), are also found feeding primarily in protected areas of the plant such as flowers and terminals. The pest's rapid developmental time (egg to adult in 7-1/2 to 13 days at fluctuating temperatures), and reproductive rate in these protected areas, can allow an undetected infestation to become a major problem quickly. They fly readily (although they are not strong fliers) and can be carried on wind currents or clothing to growth chambers near an infestation. Effective chemical control is further complicated by the problem of insecticide resistance. Resistance to certain organophosphate, carbamate, and synthetic pyrethroid insecticides has been documented in certain populations of western flower thrips (Hargreaves and Cooper, 1980; Immaraju et al., 1992).

Management. The use of plant material from a thrips-infested area should be avoided because thrips problems often originate from infested plant material. Thrips can also infest plants in a growth chamber through wind currents or on clothing. Early detection of a thrips infestation is critical because the symptoms of their feeding are often not noticed until after damage has occurred and because an infestation is easier to control when it is small. Yellow sticky cards provide an easy way to detect the onset of an infestation. These should be placed just above the plant canopy and near doors for thrips detection. Blue sticky cards may catch more thrips than yellow ones (Brodsgaard, 1989). However, because other kinds of insect pests are also attracted to yellow but not blue cards, it may be more efficient to use yellow cards for general pest monitoring. Flowers can also be checked for thrips by tapping a blossom over a sheet of paper, although it is more efficient to use sticky cards for monitoring. Infested plants should be removed if possible immediately upon detection of thrips, to reduce the population. Infested plants can be treated with insecticides elsewhere. Biological control of WFT is under investigation (Steiner and Tellier, 1990; Gilkeson et al., 1990). The predaceous mite *Amblyseius cucumeris* and anthocorid bugs, *Orius* sp., are available commercially. Other parasitic and predaceous insects as well as fungal pathogens of thrips are under investigation.

Whiteflies

Identification. Whiteflies (Order Homoptera, Family Aleyrodidae) are small (1-2 mm), white, fly-like insects in the adult stage. Extensive information on whiteflies can be found in Gerling (1990). Immature whiteflies, referred to as scales or nymphs, are flattened and oval and appressed to lower surfaces of leaves. Eggs are tiny, spindle-shaped objects, often arranged in a semicircular pattern on lower surfaces of leaves. Eggs are creamy white when first laid and turn grey with time. Two species of whiteflies commonly infest horticultural plants: greenhouse whitefly (GHWF) (*Trialeurodes vaporariorum* Westwood) and sweetpotato whitefly (SPWF) [*Bemisia tabaci* (Genn.)(B-strain)] (Byrne et al., 1990). A hand lens or other magnifying device should be used to differentiate between these two whitefly species. The "pupal" stage (largest immature stage) of the two whitefly species must be used to reliably differentiate them. The "skin," or "pupal case," left behind after the adult emerges can also be used for identification. No other life stage, except perhaps the adult, can be used for reliable identification.

The pupal stage of both species is commonly found on the undersides of leaves. The pupal case of GHWF has parallel sides perpendicular to the leaf surface, giving the pupa a disk-shaped, or cake-shaped appearance. In side view, SPWF appears more rounded, or dome-shaped, with no parallel sides. In top view, GHWF has a tiny fringe of setae around the periphery (or "rim") of the pupa; SPWF pupa has no fringe or setae around the edge.

The adult of GHWF is larger than the SPWF adult and holds its wings fairly flat over its abdomen in a plane approximately parallel with the leaf surface. The SPWF adult is slightly more yellow in color and holds its wings roof-like against its abdomen, with its wings at approximately a 45° angle to the leaf surface. Wings are held tightly against the body. Although the appearance of the adults can be used to differentiate between these two species with fair accuracy, the pupal stage must be used for confirmation. The characters of the pupal stage mentioned above are not difficult to see if a hand lens of at least 10X magnification is used.

Damage. Whiteflies are considered pests of commercial ornamental crops primarily because their presence detracts from the aesthetic value of a plant. Their stylet-like mouthparts, however, are used to siphon plant fluids, and feeding by severe infestations can cause leaves to become chlorotic and greatly reduce vigor. "Honeydew" excretions cause leaves to become sticky and shiny and serve as a substrate for the growth of grayish-black sooty mold, which can interfere with photosynthesis. Both whitefly pests can infest a broad range of plant species, and SPWF has the ability to vector a variety of plant viruses (Cohen 1990).

Biology. The life cycles of GHWF and SPWF are similar. All whitefly life stages are found almost exclusively on the lower surface of leaves. Sanderson and Ferrentino (1990) studied the biology of GHWF and SPWF at temperatures fluctuating between 18 and 24 °C on poinsettia. The eggs hatch in about 10 days for GHWF and 12 days for SPWF. The tiny first nymphal stage (crawler) hatches from the egg, crawls a short distance (a few millimeters), and settles down to feed. Upon molting to the second nymphal stage, it loses functional legs and does not move from this spot until emerging as an adult. It passes through two more nymphal stages before adult emergence. The "pupal" stage, in which the red eye spots of the developing adult are visible through the pupal case, lasts 5 days for both species. On poinsettia, at temperatures between 18 and 24 °C, an average of 32 and 39 days is required to develop from egg to adult for GHWF and SPWF, respectively. About 14 to 16 days of this developmental time are spent in life stages that are tolerant of most insecticides (i.e., eggs and pupae). A female can begin to lay eggs from 1 to 4 days after emerging as an adult. Mating is not necessary for egg production. A female may lay up to 200 eggs and live up to 1 month, depending on the whitefly species and environmental conditions such as temperature and host plant species. Infestations may build rapidly if not detected early, and overlapping life stages are common.

Management. Examine plant material for the presence of immature and adult whiteflies before placement in a growth chamber. Do not assume that plants are uninfested if adult whiteflies are not seen; eggs and other immature stages may be present. Inspect the undersides of leaves for the presence of any life stage. Plant inspections and yellow sticky cards may be used to detect infestations. Susceptibility to whitefly infestations can vary among plant species or cultivars. When possible, use nonpreferred cultivars. Infested plants or leaves should be removed before large numbers of adults begin to emerge and lay eggs. Insecticide applications should target the first, second, and third nymphal stages because these are susceptible to insecticides. If an infestation contains all life stages, repeated insecticide applications may be necessary to kill individuals in insecticide-tolerant stages after they progress to an insecticide-susceptible stage. Thorough coverage of all lower leaf surfaces is critical for chemical control. Choice of chemicals is also important; resistance to certain organophosphate, carbamate, and pyrethroid insecticides has been documented in populations of both whitefly species (Sanderson and Roush, 1992; Prabhaker et al., 1992).

Biological control of GHWF with the commercially available parasitic wasps *Encarsia formosa* and *Eretmocerus* nr. *californicus* may be feasible on many plant species in a growth chamber, provided that environmental conditions, including plant species, are compatible with the wasps and that they are introduced in sufficient numbers at the first sign of a whitefly infestation. The tiny, commercially available predaceous beetle *Delphastus pusillus* also may be effective. Fungal pathogens are becoming available as sprays for whitefly control (Fransen, 1990). Advice on the use of natural enemies is available from cooperative extension services or commercial insectaries.

Diseases

Diseases can cause serious damage to plants grown in growth chambers. Careful management of the environment is part of an effective control program because certain diseases may be more prevalent under specific conditions. Once a disease problem has developed, control or eradication becomes difficult. Therefore, a successful preventative program must be an integral part of the general cultural program. The researcher must anticipate any potentially damaging disease problems for the plants being grown. This section provides a discussion of control procedures, along with a description of optimum conditions for specific diseases that may occur in growth chambers.

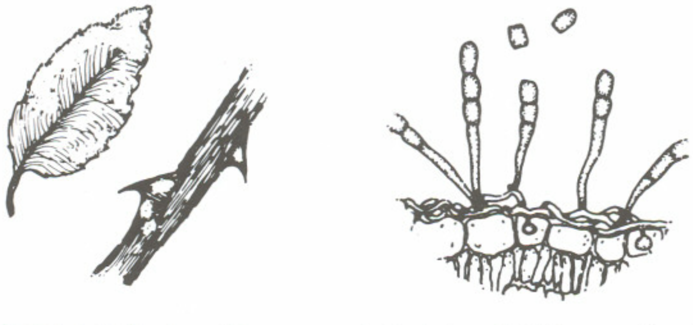

Figure 1. Left: Powdery mildews on rose leaf and stem. Right: Cross section of rose leaf showing chain spores produced on the lesions. (A. W. Dimock collection, Cornell University.)

Powdery Mildew

Powdery mildew (*Sphaerotheca* and *Erysiphe* spp.) is easily recognized by its characteristic white, powdery growth on surfaces of leaves, stems, and sometimes petals (Fig. 1). The spores of the fungus are borne on short erect branches that are generally visible with a hand lens (12X to 15X). Mature spores are easily detached from the branches and carried by air currents to surrounding plants where new infections may be initiated. Infection is commonly found on older foliage; however, young foliage is more susceptible on roses (Cornell Recommendations for Commercial Floriculture Crops, 1985).

The maximum temperature for spore germination is about 22°C (72°F), and germination and infection may occur in relative humidities of 23 to 99% (Mastalerz and Langhans, 1969). Spore production and germination seem to be correlated with high relative humidity and low temperatures, whereas spore maturation is correlated with low relative humidity and high temperatures. Air movement is important after spore maturation in the dispersal of spores. Nighttime conditions of low temperature (15°C, 59°F) and high humidity (90-99% RH), which encourage spore production, germination, and infection, alternating with daytime conditions of high temperatures (27°C, 81°F) and low humidity (40-70% RH), which encourage spore maturation, release, and spread, provide the optimum diurnal cycle for powdery mildew. Approximately 3 to 6 days of optimum conditions are required for epidemic development. These conditions encourage powdery mildew epidemics to develop in growth chambers if a susceptible plant is being used and the pathogen is present. Unlike the spores of nearly all other fungi, powdery mildew spores can germinate and initiate infections at humidity levels far below those commonly encountered in the field or greenhouse; however, development may be more rapid and luxurious at higher humidities. Such conditions are commonly present in growth chambers. As a deterrent to mildew, heating and aeration should be adjusted to avoid high-humidity conditions. Plants should be observed closely during the experiment for signs of powdery mildew development. Bicarbonate formulations are now registered by the EPA and will soon be available commercially as eradicant and protective spray treatments.

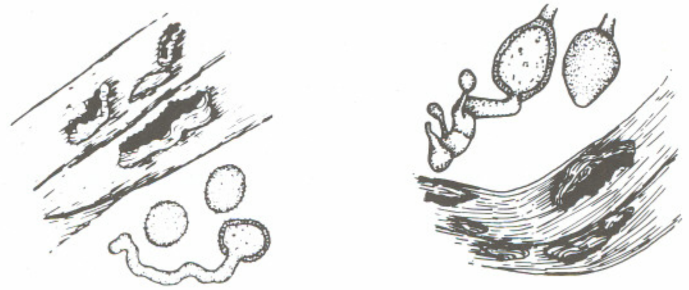

Figure 2. Rust on infected leaf with the production of two spore types in lesions. Left: Uredospores. Right: Teliospores. (A.W. Dimock collection, Cornell University.)

Rust

The symptoms of rust (*Puccinia, Uromyces,* and *Phragmidium* spp.) are small blisters that appear on the underside of leaves and on stems (Fig. 2). The first observable symptoms on the upper leaf surfaces appear as chlorotic spots. The epidermis over the blisters or pustules on the lower leaf surface ruptures, exposing dark brown or orange dusty spore masses. Pustules rarely appear on upper leaf surfaces. The chlorotic spotting that does appear on the upper surface of leaves is due to death of tissue immediately over pustules on the lower surface.

The fungus spores are transported by air currents, or the pathogen may be carried on plants. The disease is most severe under cooler temperature conditions (20°C, 68°F). Infection occurs most readily in a temperature range of 10 to 20°C (50 to 68°F) (Langhans, 1962). High temperatures above 25°C (77°F) restrict the development of rust by reducing germination of spores, eradicating established infections, and killing spores in existing pustules (Langhans, 1964; Horst and Nelson, 1975). Condensation or splashed water on the foliage is essential for spore germination and infection. For example, spores of the geranium rust fungus require liquid water, and germination occurs within 3 hours at the optimum temperature of 16°C (60°F). The disease can be prevented by keeping the foliage dry. Cuttings or plants to be placed in chambers should be examined carefully for evidence of infection. If such evidence is found, these plants should not be placed in the chamber. Hot water treatment may eliminate the rust fungus from infected plants. Rust on infected geraniums did not develop on plants after they were dipped for 90 seconds in water at 50-52°C (120-124°F) or were held for 24 to 48 hours in a water-saturated atmosphere at 38°C (100°F). Any plant showing rust symptoms after the initiation of the experiment should be removed immediately from the chamber.

Damping-off

Damping-off of seedlings or small plants may be caused by one or more pathogens, usually *Rhizoctonia* or *Pythium,* which may occur separately or simultaneously (Mastalerz, 1976). *Fusarium* and *Phytophthora* may also be involved in this complex. Preemergence or postemergence infection may be a part of the disease syndrome called "damping-off." Preemergence infection is usually caused by *Pythium* or *Phytophthora* and results in seed decay before germination or rot of seedlings before emergence. Postemergence

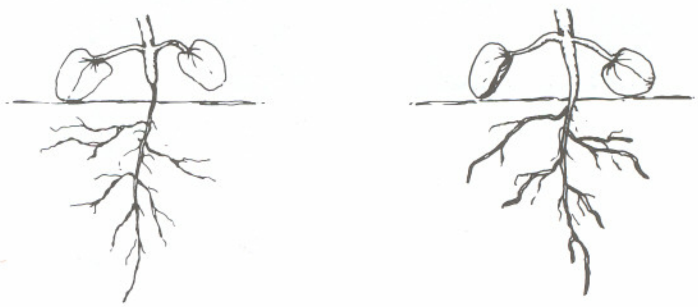

Figure 3. Damping-off symptoms on seedlings. Left: Postemergence damping-off with lesion at soil line caused by Rhizoctonia. Right: Lesions on root tips produced by *Phytium.* (A.W. Dimock collection, Cornell University.)

infection is commonly caused by *Rhizoctonia* and results in a rot at the soil line after emergence that topples the seedling (Fig. 3).

Damping-off pathogens survive in the soil in plant debris saprophytically and as resting bodies—that is, spores and sclerotia. These pathogens are adapted to a wide range of host plants and environmental conditions. *Rhizoctonia* and *Fusarium* generally are favored by warm, moist soils (soil temperatures greater than 20°C (68°F), whereas *Pythium* is generally favored by cool, wet soil conditions (soil temperatures less than 20°C). These pathogens do not have an airborne stage and spread by mechanical transfer of soil particles infested with mycelia, sclerotia, or resting spores. Therefore, infected plant debris left in growth chambers and dirty flats, tools, trays, and baskets can contaminate new plants. "New" peat used in soil mixes may also carry these fungi (Kim et al., 1975). If the planting medium is steamed or chemically treated and care is exercised to prevent recontamination, damping-off should not occur.

Biocontrol of fungi that cause damping-off has been achieved by adding species of *Trichoderma* to potting soils. Commercial preparations of antagonistic fungi (such as *Trichoderma*) are now available for biocontrol use. Seed flats with infected seedlings and individual infected seedlings should be removed from the growth chamber to prevent spread of the pathogens.

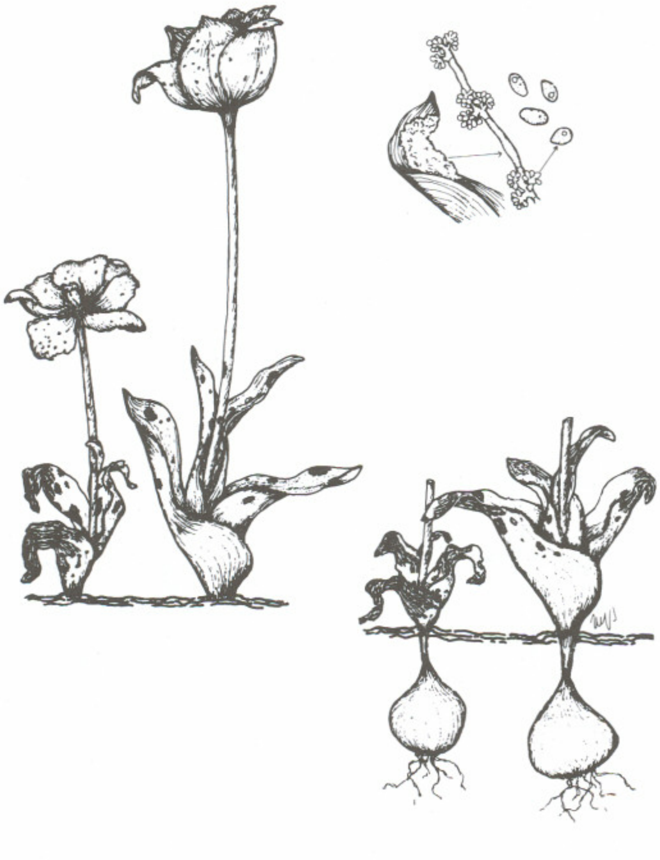

Figure 4. Botrytis blights on tulip leaves. Upper right: Spores produced on the lesions. (A.W. Dimock collection, Cornell University.)

Botrytis Blight

Botrytis blight (*Botrytis spp.*) is a serious disease of plants and is readily recognized by the brown rotting and blighting of affected tissues commonly followed by the growth of a grey mold fungus on the infected tissues. This fungus attacks a wide variety of plants and is usually identified by the fuzzy grey spore masses that grow over the surfaces of rotted tissues (Fig. 4). Sporulation does not develop under dry conditions. Spores are readily dislodged and may be carried by air currents to other plants.

The spores germinate and produce new infections only when they are in contact with water. This moisture may be from splashed water, condensation, or exudation. Active, healthy tissues are seldom invaded. There may be some exceptions, but usually only tender tissues (seedlings or petals), weakened tissues (stubs left after cutting), injured tissues (bases of unrooted cuttings), or old or dead tissues are attacked. This disease is a cool temperature disease. The optimum temperature for development of Botrytis blight is 15°C (59°F). The fungus can survive unfavorable conditions by forming sclerotia in plant debris.

Constant sanitation is extremely critical in reducing Botrytis blight. The removal of dead and dying plants and debris that accumulate in the chambers reduces sporulation of the fungus and thus reduces the spore load in the air. Because Botrytis requires free moisture for spore germination, low humidity reduces the amount of disease development. If high humidities are required for the experiment, good *Botrytis* control can be obtained by maintaining temperatures above 20°C (68°F). Good cultural conditions for plant growth also aid in Botrytis blight control.

Nematodes

Foliar nematodes (*Aphelenchoides* spp.) may be particularly serious and damaging to plants. These worms emerge from the soil or from previously infested leaves and swim up the stem in a film of water. They enter leaves through stomata. Invasion is possible only when plants are wet from sprinkling or syringing. Leafspots are first discernable on the lower leaf surface as yellowing or brownish areas that eventually turn black, resulting in necrotic spots and defoliation. Although lesions are small at first, favorable temperature and moisture conditions may cause spread until much of the leaf is destroyed. Infection may begin on lower leaves and progress upward.

A simple means of control is to water soil in a manner that avoids wetting the foliage, since a film of water is required for foliar nematodes to move. In addition, cutting for vegetative propagation should be taken only from the terminal tip of healthy plants. Unlike other nematodes, foliar nematodes do not persist in soil in the absence of living host tissue. Soil nematodes are rarely a problem in growth chamber research because soil mixes are rarely contaminated with soil nematodes. If field soil is used, however, nematodes can be a problem, but they will likely be confined and contained to the specific containers filled with the soil.

Algae

Very little has been written about the problems caused by algae in growth chambers. The blue-green algae require moisture and light for survival. Both conditions are generally available in growth chambers, and the more water is splashed on the chamber floors and walls, the more troublesome the algae. The problems will be exaggerated if nutrient or fertilizer solutions are splashed on floors and walls. Floors on which algae are allowed to grow are treacherous to walk on, and serious accidents or falls may occur. Algal growth on the chamber walls reduces reflected light. Algae may also clog the hydroponic and cooling systems.

To reduce algal growth, the floors and walls of the chamber should be kept as dry as possible. Window cleaning squeegees should be used to remove water from floors after watering. Floors and walls should be cleaned periodically to remove algal growth. If plants are in the chamber, only water should be used for cleaning. If the chamber is empty, a solution of Chlorox, diluted 10X with water, is recommended for wiping or scrubbing the surfaces. This should be followed with a flushing of the surfaces with plain water to remove the chlorine solution, and the chamber should be left empty for at least 12 hours to vaporize any residual chlorine.

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