

Chapter

Management of Strawberry Insect and Mite Pests in Greenhouse and Field Crops

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Abstract

Strawberry is an important small fruit crop grown throughout the world due to its rich sources of vitamins and abundance of antioxidants. The US is the world's leading producer of strawberries followed by Mexico. The main strawberry producing states are California followed by Florida, which produce >90% of the strawberries grown in the US. Strawberry production is often threatened by a host of arthropod pests that include insect and mite species. In order for the US to maintain its lead in strawberry production it is vital to develop effective management tools for key insect pests, diseases, and weeds. Some of the major arthropod pests that affect strawberry production include twospotted spider mites, *Tetranychus urticae* Koch, thrips, *Frankliniella* and *Scirtothrips* spp., armyworms, root-boring pests, and many different hemipterans that cause injury to the strawberry leaf and fruit including the tarnished plant bug, *Lygus Hesperus*, and the seed bug *Neopamera bilobata* Say. This chapter will summarize some of the key pests that can severely impact strawberry production. We have included some integrated management guidelines to curtail pest's activities during a production season.

Keywords: arthropods, biological control, integrated pest management, monitoring, strawberry

1. Introduction

Strawberry is an important crop in the United States with production in 2017 valued at \$3.5 billion USD [1]. Fresh market strawberries dominate this production with a \$3.3 billion USD value. California is the largest producer of strawberries in the United States with 15,459 hectares planted to strawberries in 2017. Florida is the second largest producer with 4330 hectares. The remaining 2000 hectares is spread among Michigan, New York, North Carolina, Ohio, Oregon, Pennsylvania, Washington, and Wisconsin. Pest management is a crucial part of strawberry production especially when even cosmetic injury can make fresh fruit unmarketable.

There are a number of insect and mite pests that can have detrimental effects on strawberry production. Some pests, such as the twospotted spider mite, *Tetranychus urticae* Koch, are major pests wherever strawberry plants are grown. Others are major pests in certain regions or under specific production systems. Becoming familiar with the mites and insects that are likely to cause economic damage in production systems is an important first step in an integrated pest management (IPM) program [2].

Monitoring is a critical component of a successful IPM program [2]. Scouting is the most common monitoring technique used in strawberry production in the United States [3]. Scouting involves examining a sample of strawberry plants from the field or greenhouse for the presence and abundance of pest mites and insects. A sampling plan should be designed to get a good representation of what is happening in the field or greenhouse. There are also monitoring traps available for certain pest insects. Yellow sticky traps, for example, are often used to monitor for aphids and whiteflies in field and greenhouse situations. The information gained from monitoring is used to determine if a treatment action, such as an insecticide application, is warranted.

Action thresholds are needed to determine when a treatment is warranted [2]. An action threshold is the point where the cost of control is less than the economic damage that will result if the pest is left untreated. These vary depending on the pest, region, production system, etc. Numbers of natural enemies present in the field or greenhouse should also be considered when deciding if a treatment action is necessary. The action threshold for releasing biological control agents, such as predatory mites, will be different than the action threshold for an insecticide or miticide application.

Strawberries can be produced in the open field and in greenhouse settings. In the United States, there are two major field production systems for strawberry production [3]. In warmer, southern areas, such as Florida and southern California, strawberries are grown as an annual crop on raised beds covered with plastic mulch. The production season is lengthy (October through March in Florida with berries harvested December through March). In contrast, strawberries are grown as a perennial crop in northern areas of the United States. Matted rows are used and the harvest season is short, occurring during the summer months. Recently, researchers and growers have been experimenting with using high and low tunnel systems. These systems use tunnels to extend the growing season in colder areas. The pest complex in each system (tunnel, greenhouse and field) overlaps but is usually different.

This chapter will discuss the pest complex of each production system. Descriptions of pests, the injury they cause, and management strategies will be presented. Management strategies will include monitoring methods, action thresholds, and treatment options.

2. Pest complexes of strawberry production systems in the United States

2.1 Greenhouse production

A well-constructed and maintained greenhouse can prevent larger insects, like moths, from accessing the plants inside. For this reason, the major pests of greenhouse grown strawberries are the twospotted spider mite, aphids, whiteflies, and thrips. Other strawberry pests can, however, be introduced into the greenhouse on infested transplants and equipment.

2.2 Annual field production

Key pests in annual strawberry production throughout its range include the twospotted spider mite and spotted wing drosophila (SWD), *Drosophila suzukii* Matsumura. Other potential pests include cyclamen mites, aphids, whiteflies, spittlebugs, flower thrips, chili thrips, armyworms and related Noctuid caterpillars, strawberry leafrollers, tarnished plant bugs, strawberry seed bugs, and sap beetles.

2.3 Perennial field production

The two key pests (twospotted spider mite and spotted wing drosophila) in annual strawberry production are also key pests in perennial production systems. There are also several beetles that can be major pests in perennial strawberries, which are not present in annual systems. Other potential pests, in addition to those listed under annual field production, include potato leafhoppers and cutworms.

2.4 High and low tunnel systems

The pest complex in a high or low tunnel system will be similar to the pest complex in field grown strawberries in the same region. The warmer temperatures in the tunnels may lead to increased pest outbreaks in tunnels compared with field strawberries.

3. Leaf pests

Leaf pests can be divided into two main groups, sucking pests and chewing pests. Sucking pests include twospotted spider mites, cyclamen mites, chili thrips, aphids, whiteflies, potato leaf hoppers, and spittlebugs. Chewing pests include armyworms, cutworms, and strawberry leafrollers. Injury to leaves reduces the plants ability to photosynthesize (make food), which can reduce the quality and quantity of fruit produced. In perennial production, this injury can affect the yield the following season, also [3].

3.1 Twospotted spider mite

Twospotted spider mites, *Tetranychus urticae* Koch (**Figure 1**) are oval shaped and tiny. The adults are 0.5 mm in length, which is about the size of a period in 12-point font. They are usually light greenish-yellow in color with two large, dark spots on their abdomens. However, brown, red, orange, and darker green forms also occur. The eggs are spherical and clear to tan in color. The eggs and all stages of mites are usually found on the undersides of leaves. The twospotted spider mite life cycle progresses through five stages: egg, six-legged larvae, protonymph, deutonymph, and adult. Each of the three intermediate stages feeds and grows for



Figure 1. Twospotted spider mites and eggs on the underside of a strawberry leaf as seen under a microscope (photo credit: L. Buss, UF).

only a short time before entering a resting state prior to molting to the next stage [4]. Females are larger and rounder than males. Development from egg to mature adult takes an average of 19 days, although this time can be as short as 5 days [4]. Optimal conditions for development are high temperatures (up to 38°C) and low humidity [5, 6].

During feeding, twospotted spider mites puncture leaf cells and suck out their contents [3]. The feeding injury causes affected leaves to have a stippled appearance (**Figure 2a** and **b**). Spider mites do produce webbing, which is where their common name originates from (**Figure 2c**). The webbing provides protection from predators and may also help maintain favorable temperature and humidity conditions for the mites. Webbing is only visible when populations are high and, therefore, economic damage to the crop is already occurring.

Monitoring can be accomplished by checking and counting twospotted spider mites on the underside of strawberry leaves with a 10x hand lens [3]. Alternatively, strawberry leaves can be collected from the field and examined later. Leaf samples should be processed within 3 days of collection if possible. In annual production, sampling for twospotted spider mites should begin after the transplants have become established. In perennial culture, sampling should start once the new leaves fully open in the Spring. Sample 13–25 fully mature leaves per hectare. Counting the number of spider mites on each leaf will give more accurate results, but it can be time consuming. An alternative is simply to note how many leaves have spider mites present on them. A presence/absence system is used

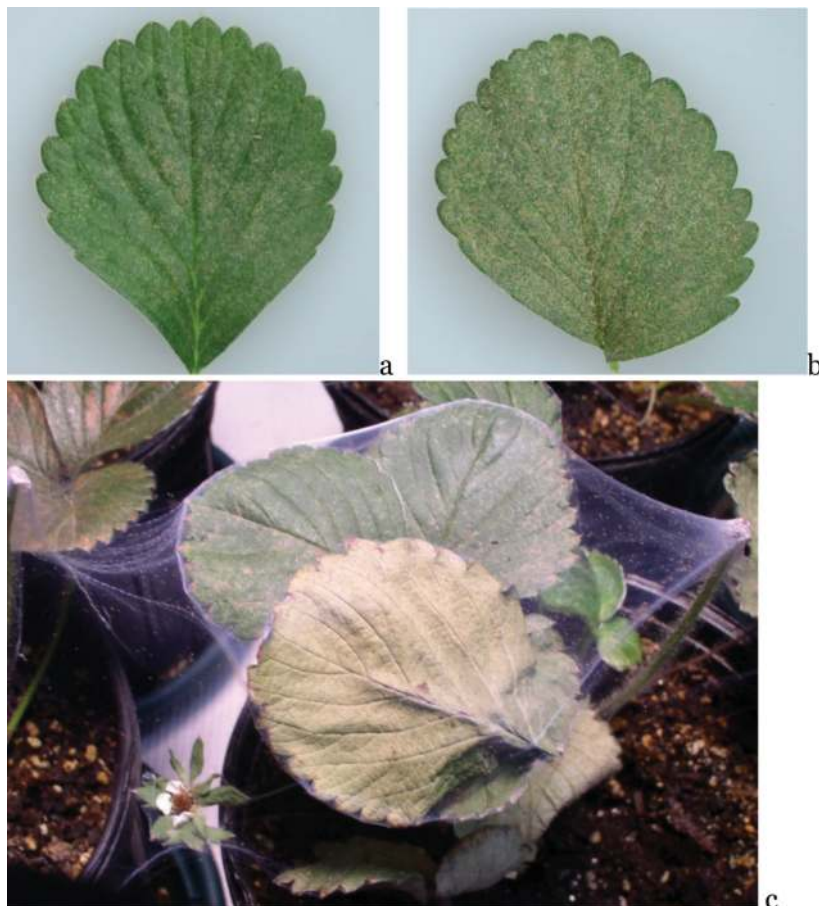


Figure 2. Examples of (a) and (b) stippling injury to strawberry leaves and (c) spider mite webbing (photo credits: (a) and (b) T.W. Nyoike, UF; and (c) E.M. Rhodes, UF).

sometimes on large fields but this assessment method has some limitations and a history of mite population in the field is sometimes needed to improve its accuracy. A common threshold for this type of monitoring is 5% of leaves infested. In California, the treatment threshold is an average of 5 mites per leaf before the harvest period begins, which increases to an average of 15–20 mites per leaf once the harvest period begins [7]. An average of 10 spider mites per leaf is a common threshold used in Florida production [8].

There are a number of miticides available for twospotted spider mite management. Thorough spray coverage is essential for effective applications [3]. Rotating modes of action is also very important as spider mites can quickly develop resistance to miticides due to their short life cycle.

There are several commercially available predatory mite species that can be used in a twospotted spider mite management program [3]. They are especially effective in greenhouse settings. *Neoseiulus californicus* (McGregor) and *Phytoseiulus persimilis* Athias-Henriot are two commonly used species [9, 10]. *Neoseiulus californicus* mites (**Figure 3**) are orange to peach in color and slightly larger than twospotted spider mites. Their eggs are milky white and ovoid in shape. They prefer spider mites as prey and can subsist on other food sources, such as small insects and pollen, when twospotted spider mite numbers are low. For this reason, preventative releases of small numbers of *N. californicus* early in the season can reduce the severity of mite outbreaks and even eliminate them all together in some cases. In contrast, *P. persimilis* mites (**Figure 4**) specialize on spider mites, so their population declines rapidly once the spider mite population has declined to low levels. This can necessitate multiple releases in a season. Adults are pink in color with spider-like legs. Eggs are similar in shape to *N. californicus* eggs and have a pinkish to orangish tint. Preventative and curative rates are listed on supplier websites. If spider mite numbers are high, it is advisable to knock down the population with a miticide before predatory mites are released. Predatory mites should be released 7–10 days after the miticide application.

3.2 Cyclamen mite

Cyclamen mites, *Phytonemus pallidus* (Banks), are half the size of spider mites, ~0.25 mm, and invisible to the naked eye [3, 7]. Adults are shiny and pinkish to orangish in color while immatures are opaque white. Eggs are ovoid and translucent. They feed on developing tissues and are most commonly found on unfolded



Figure 3. *N. californicus* mite and eggs on a strawberry leaf (photo credit: E.M. Rhodes, UF).

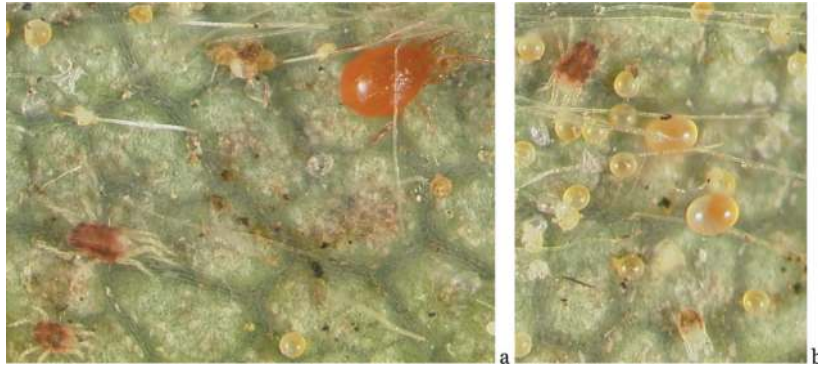


Figure 4. *P. persimilis* (a) adult and (b) eggs with twospotted spider mites and eggs on a strawberry leaf (photo credit: E. M. Rhodes, UF).

leaves near the midvein and in flower buds. Infested leaves are small and wrinkled. High infestations can cause a compact mass of these leaves in the center of plants. Injury to leaves causes them to turn brown, wither, and die. Any fruit produced is stunted and russety.

Cyclamen mites can persist in perennial production systems, making them a greater threat to these systems [3]. They often come into a field on infested transplants and can also be transported by insects, birds, and even people via contaminated clothes or equipment. The threshold is low, 1 mite per 10 leaves in California [7]. Miticides must be applied in large volumes of water, 2839–4732 liters per hectare, to ensure soaking of the developing tissues in the crown.

3.3 Chili thrips

Chili thrips, *Scirtothrips dorsalis* Hood, is a more recently introduced pest that was first reported in the US from Florida in 2004 and Texas in 2008 [11]. It has become a serious pest of multiple crops and has the potential to spread throughout the southern United States and in western states such as California [11]. Chili thrips adults (**Figure 5**) are tiny, only 1.2 mm in length [12, 13]. They are pale yellow in color except for their dark wings, which are bristle-like, and dark spots along the top of the abdomen that form an incomplete stripe. Immatures are pale yellow in color and lack wings.

Adults and immatures feed on young strawberry leaves causing darkening of the leaf veins near the leaf base [12, 13]. As the infestation progresses, the darkening



Figure 5. *Chili thrips* adult (photo credit: B. Panthi, UF).

becomes streaks on the leaves that can cover the entire leaf surface and lead to leaf deformation. Heavy infestations can cause stunting of entire plants. Infestations early in the season when strawberry plants are small and have only a few leaves cause the most damage.

Scouting for Chili thrips is best accomplished by looking for the injury they cause [12]. Leaves with the characteristic injury described above can be gently tapped over a white sheet of paper. This will dislodge any Chili thrips present, which will resemble tiny, yellow dashes crawling on the piece of paper. Thresholds have not yet been developed.

The predatory mite *Amblyseius swirskii* (Athias-Henriot) has shown some efficacy against thrips species in vegetable systems [14]. These predators feed primarily on eggs and immatures of thrips. This predatory mite is commercially available and has the potential to be used in other crops like strawberry. Insecticides should be avoided when possible because they cause disruption in the predator complex and cause thrips population to flare up. Insecticides should only be applied if the infestation is severe, particularly if thrips numbers are high early in the season.

3.4 Aphids

There are four species of aphids (**Figure 6**) commonly found in strawberries: the green peach aphid, *Myzus persicae* (Sulzer), the melon aphid, *Aphis gossypii* Glover, the potato aphid, *Macrosiphum euphorbiae* (Thomas), and the strawberry aphid, *Chaetosiphon fragaefolii* (Cockerell) [3, 7]. The strawberry aphid can severely affect yield because it transmits a host of virus including the strawberry mild yellow edge virus, strawberry crinkle virus and the strawberry mottle virus [7, 15]. In general, aphids are small (2.54 cm), globular, pear-shaped, soft-bodied insects found on the underside of leaves. Aphids are often various shades of green or yellow but can be black or even pink. There are winged and wingless forms. Aphids can be distinguished from similar insects by the two cornicles (tube-like structures) protruding from the end of the abdomen.

Winged females enter fields from nearby infested crops or weedy areas [3, 7]. They can also enter greenhouses. Female aphids can produce daughters without mating, so populations can build up very quickly. Aphids use their sucking mouthparts to feed on plant juices and excrete excess sugar as a sticky, sugary honeydew. Sooty mold fungus will grow on the honeydew and can contaminate fruit. Aphids efficiently transmit plant viruses. In strawberry production, these viruses are mainly a concern in nursery production. Viruses can also persist from one season to another in perennial production, but this is a rare occurrence.



Figure 6.
Aphids on a grape leaf (photo credit: B. Achhami, UF).

Aphids rarely reach damaging levels in field grown strawberries [3]. Monitoring for aphids involves examining leaves in the field or collecting the leaves and examining them elsewhere. In Southern California, where they can be as issue, the threshold is 30% infested leaves from a sample of 100 leaves per hectare [7]. Yellow sticky traps can be used to monitor winged aphid populations and are especially useful in greenhouses.

Aphids have many natural enemies and it is important to take parasitism into consideration when deciding if a spray is necessary. Parasitized aphids, often called mummies, are swollen, brown, and sometimes have a hole chewed in the abdomen if the adult parasitoid wasp has emerged [3, 7]. The adult parasitoids are tiny wasps that lay eggs in aphids. The larvae develop inside the aphids, feeding on the aphid from the inside out and killing it in the process. The larva pupates in the aphid mummy and the adult wasp chews a hole in the aphid to emerge and begin the cycle again. Several aphid parasitoids are available commercially and are particularly effective in greenhouses. Green lacewing larvae, *Chrysoperla rufilabris* (Burmeister) and other generalist predators will also prey on aphids.

3.5 Whiteflies

There are many species of whiteflies (**Figure 7**) that can be found in strawberry [3, 7]. These include the bandedwing whitefly, *Trialeurodes abutilonia* (Hold.), greenhouse whitefly, *T. vaporariorum* (West.), iris whitefly, *Aleyrodes spiroeoides* Quaintance, silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, and the strawberry whitefly, *T. packardi* (Morrill). Whitefly adults are yellowish in color with white wings. Immatures, called nymphs, resemble scale insects. The first immature stage is a crawler that moves a short distance from the eggs before becoming sedentary and forming its protective scale. The final nymphal stage is nonfeeding and often called a pupal stage. All stages are found on the underside of leaves. Adults and nymphs suck plant juices and produce honeydew like aphids. Whiteflies can also vector some viruses.

Whiteflies are typically not an important pest in strawberry but can be more of a nuisance pest [3]. They are of concern in greenhouse strawberry production and in field production in California [7]. In California, the greenhouse whitefly vectors pallidosis-related decline of strawberry [7].

Adult whiteflies can be monitored using yellow sticky traps [7]. One trap per 25 hectares should be hung from a stake just above the crop canopy and checked weekly. It is important to monitor nymphs at the same time. This is done by checking 20 mature leaves from each field quarter. There is no treatment threshold.



Figure 7.
Whiteflies on a squash leaf (photo credit: D. frank, UF).

In California, it is recommended to treat when the population appears to be increasing at a rapid rate and parasitism levels are low [7].

Whitefly nymphs are parasitized by tiny wasps, like aphids, and parasitized nymphs are black in color [3, 7]. Some whitefly parasitoids including *Encarsia formosa* and *Eretmocerus* spp. are available commercially and generalist predators, *Delphastus* spp. feed on them as well. Thorough coverage is essential when applying insecticides.

3.6 Potato leafhopper

Potato leafhoppers, *Empoasca fabae* Harris, are bright green leafhoppers [3, 16]. Nymphs are lighter green in color and wingless. The nymphs will move sideways when disturbed, which distinguishes them from other leafhoppers. Potato leafhoppers are larger than whiteflies and aphids, with adults being about 8.5 mm long. They overwinter in southern states with mild winters and migrate north as the weather warms up. They reach as far north as Canada. They generally reach North Carolina by early summer and continue north from there [16]. They feed and reproduce throughout the summer and fall until they are killed off by the first frost. Like the other sucking pests, potato leafhoppers are found on the underside of leaves.

Potato leafhoppers feed by sucking out plant juices. They prefer to feed on new growth. Unlike other sucking pests, potato leaf hoppers inject toxins into the plant tissue with their saliva [3, 16]. These toxins cause stunting, curling, and browning of leaves. This is often called “hopperburn” and resembles herbicide burn. In perennial strawberries, high amounts of hopperburn can cause reduced growth and yield in the next season. There are no established thresholds, but insecticides should be applied before hopperburn becomes widespread.

3.7 Other sucking pests

Many other mites and sucking insects are encountered in strawberry plantings. Most are encountered occasionally in small numbers. However, there is the potential for some to become pests. Spittlebugs, mealybugs, and stink bugs are examples of these.

Spittlebugs, Cercopidae, are immature froghoppers. Adult froghoppers resemble leafhoppers but are usually larger and flatter than leafhoppers [17]. The nymphs secrete a frothy foam for protection (**Figure 8**) that resembles spittle, hence their common name. The species *Philaenus spumaris* (L.) can be a pest in strawberries, primarily because the foam can be annoying to pickers [3].

Mealybugs, Pseudococcidae, are covered in waxy or mealy secretions for protection [17]. Adults are small and oval in shape with well-developed legs. Currently, there are no major mealybug pests of strawberries, but several species are serious pests of other crops and ornamentals. However, mealybugs are sometimes seen in strawberries, so it is important to be aware of them [3].

Stink bugs, Pentatomidae, are a family of true bugs that are shield shaped and secrete foul-smelling chemicals when disturbed [17]. Many species are various shades of green or brown. Other species, like the harlequin bug, *Murgantia histrionica* (Hahn), sport very bright colors. Some stink bug species, like the harlequin bug and southern green stink bug, *Nezara viridula* (L.), are major pest species [17]. Some of these pest species can be found in strawberries but rarely build up to damaging numbers. Other species of stink bug are predatory, like the well-known spined soldier bug, *Podisus maculiventris* (Say), and feed on other insects [17]. It is



Figure 8.

Spittlebug protective frothy foam. The spittle bug nymphs are underneath the foam and cannot be seen (photo credit: E.M. Rhodes, UF).

important to properly identify any stink bug causing concern in strawberries to make sure it is not a beneficial predatory species.

3.8 Caterpillars

Armyworms, cutworms, the strawberry leafroller, and saltmarsh caterpillars all feed on strawberry leaves and sometimes chew holes in fruit [3]. Cutworms will also feed on strawberry flowers. While armyworms, cutworms, and strawberry leafrollers are considered major strawberry pests, saltmarsh caterpillars rarely reach damaging levels.

Armyworms, Noctuidae, are the caterpillars of brown, night flying moths [3, 7, 8, 17]. Eggs are laid in clusters and covered with scales from the female moth that laid them. Early instar larvae are light green with black head capsules and cluster together. The larvae become darker and develop white, vertical stripes that travel the length of the body as they mature (**Figure 9**). Armyworm larvae feed on the undersides of leaves. Early instar larvae leave the top layers of the leaf tissue intact while larger, later instar larvae consume all the leaf tissue and can quickly skeletonize leaves. Leaf injury can lead to a decrease in the quality and quantity of fruit produced. Armyworms can also cause direct injury by feeding on fruit. The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) and southern armyworm, *Spodoptera eridania* (Stoll) are the species most commonly found on strawberries in Florida [8], whereas the beet armyworm, *Spodoptera exigua* (Hübner), is the main armyworm found in strawberries in California [7]. In California, beet armyworm adults are monitored using pheromone traps put out just prior to transplanting. If trap catches are high, the young strawberry plants should be examined for egg masses. It is important to time insecticide applications after egg hatch when larvae are early instars.

Cutworms are also the caterpillars of Noctuid moths [3, 17]. They can be a major pest in perennial strawberry systems. The caterpillars are smooth, like armyworms, and mottled brown or gray in color. The black cutworm, *Agrotis ipsilon* (Hufnagel), is the most common species causing damage in California [7]. Cutworms chew holes in leaves and cut stems. It is this stem cutting that gives them their common name. They will sometimes feed on flowers, which cause fruit to be deformed and unmarketable. Injury often occurs along field margins, so monitoring should focus



Figure 9.
Later instar fall armyworm on velvet bean plant (photo credit: C. Scott, UF).

on these areas [3, 7]. As with armyworms, young plants are especially vulnerable. There are no established thresholds.

The strawberry leaf roller, *Ancylis comptana* (Frölich) is an occasional pest of strawberries in the United States [3, 18] The adults are small, reddish-brown moths (**Figure 10a**). Early instar caterpillars are pale green with brown heads (**Figure 10b**) while later instar larvae are gray-brown with yellowish-brown heads. Early instar larvae feed on the underside of strawberry leaves near veins. They produce a silky covering for protection. They grow and eventually move to the top of the leaf and fold or roll leaf edges together. The rolled leaves protect them from predators and environmental factors. The caterpillars pupate in the leaf roll. Strawberries can tolerate 10–20% of their leaves being infested with leafrollers, so management is often unnecessary [3, 18]. Removal and destruction of infested leaves can prevent infestations from building up. If a spray is necessary, thorough coverage is essential.

Salt marsh caterpillars (**Figure 11**), *Estigmene acrea* (Drury), are the caterpillars of a species of tiger moth [17]. The adult moths are white with black spots with a pinkish to orangish abdomen that also has black spots. Female hind wings are white while male hind wings are yellowish to orangish in color. The caterpillars are



Figure 10.
Strawberry leaf roller (a) adult and (b) caterpillar (photo credit J. Renkema, UF).



Figure 11.
Later instar salt marsh caterpillar (photo credit: M. Lopez, UF).

covered in hairs that can be white, various shades of yellow and orange, and black. The early instars cluster together to feed and then disperse as they grow. Mature caterpillars can be 5 cm long and look even larger because of their hairs. Salt marsh caterpillars prefer grasses and rarely occur in large enough numbers in strawberry plantings to be of concern.

3.9 Other chewing pests

It is possible for other caterpillars to be seen feeding on strawberry. The lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller), a serious pest of corn, is occasionally seen in strawberries, for example [3]. Various species of crickets and grasshoppers will feed on strawberry leaves, though they rarely occur in large numbers or cause enough injury to be of concern. The same is true of some species of earwigs.

4. Root pests

Root pests are only a concern in perennial strawberry production systems [3]. The strawberry root worm, strawberry root weevil, black vine weevil, and white grubs all attack roots. These are all beetles and it is the immatures, or grubs, that feed on the roots. Injury to roots reduces the plants ability to draw water and nutrients from the soil, which can lead to reduced plant vigor, yield, and even plant death. The injury can also provide an entry point for diseases. Adults feed on leaves and can, occasionally, reach damaging levels.

4.1 Weevils

The most damaging of the root pests are the weevils. Weevils are easily distinguished from other beetles by the snout-like structure that protrudes from the front of their heads [17]. Strawberry root weevils, *Otiorhynchus ovatus* (L.), adults are approximately 6.4 mm long and brown to black in color [3, 7]. Black vine weevils,

O. sulcatus Fabricius, are black flecked with yellow and larger at approximately 1.27 cm long [3, 7]. Adults of both species emerge in late spring and early summer and feed on leaves at night while sheltering near the base of plants during the daytime [3, 7]. They feed on the leaf margins, producing distinctive hook-shaped notches. Adults lay eggs in the fall and larvae feed on roots before burrowing deeper into the soil to overwinter. The larvae are legless, crescent shaped, creamy white to light pink grubs similar in size to the adults. As temperatures warm up in the spring, larvae again feed on roots before burrowing into plant crowns to pupate. Infested plants are dull and reddish, wilted, stunted, and extremely susceptible to stress. Injury in a field often occurs in a circular pattern. Adults emerge from these pupae to begin the cycle again.

Managing these weevil pests is difficult. Sanitizing farm equipment is important to avoid moving beetles from infested fields into fields that are not infested. Heavily infested fields should be plowed to prevent the spread of the weevil and repeated disking will continue to expose grubs to predation and weather. Soil fumigation after plowing is also effective. Two grubs per plant can cause economic damage, which makes for a low threshold [3, 7]. There are insecticides available to reduce the population of adults before they lay eggs, but efficacy is limited. Using nematodes that parasitize grubs in combination with insecticides to manage adults has shown some success. *Steinernema feltiae* (Filipjev) and *Heterorhabditis bacteriophora* (Poinar) are both commercially available and can be used in combination. Soil should be moist when nematodes are released.

4.2 Strawberry rootworm

The strawberry rootworm, *Paria fragaria* Wilcox, is the smallest of these beetle pests [3, 19]. Both adults and grubs are only 3.2 mm long. Adults are shiny and vary from brown in color with four black splotches to completely black. They chew holes in leaves and can skeletonize leaves when infestations are severe. Adults overwinter in sheltered places such as ground litter and become active as temperatures warm in the Spring. In the northern United States, high numbers can occur in May and June, though this is uncommon [19]. These adults lay eggs in the soil that hatch into grubs, which are milky white in color and have six legs. Larvae feed on roots, which can cause plants to be stunted, and then pupate in the soil. Adults emerge from these pupae in July and August. This second generation of adults will overwinter and begin the cycle again. Insecticide applications should be timed when adults are feeding [3, 19].

4.3 White grubs

White grubs, which are the larvae of Scarab beetles such as the June Beetle, Japanese Beetle, and Rose Chafer, can also be an issue in perennial strawberries [3, 20]. The grubs are C-shaped, milky white in color, have six legs, and vary in size depending on species. White grubs can grow as large as 2.5–3.8 cm long. They are a major pest of sod and can move into strawberry fields from adjacent grassy areas [3, 20]. June beetles lay their eggs in early summer. The larvae feed on roots and burrow deeper in the soil to overwinter. Larvae repeat this pattern for the next two seasons, pupating in the soil at the end of the 3rd summer. Most white grub adults have a similar 3-year life cycle [3, 20]. However, a few, like the Japanese beetle, have a 1-year life cycle. Fields planted to sod should be left fallow or planted to non-susceptible hosts, such as squash and its relatives, for several seasons before strawberries are planted there [3, 20]. Prevention is key because grubs are difficult to control once they infest a field.

5. Flower pests

Strawberry bud weevils feed on and lay their eggs in strawberry buds and can cause significant yield losses. Flower thrips feed in open flowers. Tarnished plant bugs feed on both flowers and fruit. Injury to flowers can result in deformed fruit that is unmarketable. Severely injured buds and flowers may not develop into fruit. Both situations cause yield loss.

5.1 Strawberry bud weevil

The strawberry bud weevil, *Anthonomus signatus* (Say), also known as the strawberry clipper, is a highly destructive pest in perennial strawberries [3, 21]. Adult weevils are only 1/10"–1/8" long and are copper colored with two large, black spots on the back of their wing covers. Adults become active in the Spring when temperatures reach about 60°F. Adult females chew a hole in a developing flower bud and use their long snout to feed on the pollen. They then lay a single egg in the bud and girdle or clip the pedicel, which is the stem that attaches the bud to the plant, right at the base of the bud. The buds turn brown and eventually fall to the ground. The small, opaque white, legless grub develops and then pupates in the bud. Adults emerge in June, feed on flower pollen, and then seek overwintering sites, where they stay until the following Spring. Preferred overwintering sites include mulches, brush, woods, and woodlots.

Girdled buds do not become fruit, so strawberry bud weevils can cause substantial yield loss if populations are high. Monitoring should begin once strawberry flower buds appear in the spring [3, 21]. In smaller fields, sample two feet of row from 5–10 areas of the field counting the number of cut buds in each section. For larger fields, sample five 10-foot sections of row. The threshold is one cut bud per foot of row. Two applications of insecticides should be made if the threshold is met or exceeded, one right away and the 2nd 10 days after the first.

Reducing overwintering sites for adult weevils is an important part of managing this pest [3, 21]. This includes plowing under old beds as soon after the end of harvest as possible and removing dead leaves and mulch from the field. Rotating a strawberry field to another crop after 3 years is also important in reducing the incidence of strawberry bud weevil injury and damage.

5.2 Flower thrips

A mix of thrips species can be found in strawberry flowers. The western flower thrips (**Figure 12**), *Frankliniella occidentalis* (Pergande), feeds on strawberry flowers along with other species, primarily in the genera *Frankliniella* and *Thrips* [3, 7, 8]. They are similar in size and appearance to chili thrips. They vary in color from light yellow to dark brown, depending on species, and lack the abdominal spots present on chili thrips. Adults are blown into strawberry fields from other hosts on wind currents. Some species lay eggs in the strawberry flowers while others simply feed on the flowers. Immature thrips are smaller than adults and lack wings. Populations of flower thrips usually migrate into strawberries when flowering resources are unavailable on other host crops or weeds. In the US, the most abundant flower thrips species in the strawberry growing region is the western flower thrips, *Frankliniella occidentalis* (Pergande) [3, 7]. Florida has a unique flower thrips species, *Frankliniella bispinosa* Morgan that is common to that region [8]. Regardless, flower thrips rarely cause economic damage in strawberry. Predatory bugs



Figure 12.
Western flower thrips female (left) and male (right) (photo credit: E.M. Rhodes, UF).

(*Orius* spp. and *Geocoris* spp.), that are common in the strawberry system, regulate thrips populations.

Thrips possess a single mandible that they use to puncture plant tissue. The rest of the mouthparts are formed into a tube-like structure they use to suck up the contents of punctured tissues. Flower thrips feed on the ovaries in most flowers, which is the part that develops into fruit. In the case of strawberries, flower thrips feed on the expanding receptacle [3, 7]. Feeding injury can cause russetting or bronzing of strawberry fruit around the fruit cap. Dulling of the fruit and fruit cracking has also been attributed to thrips feeding injury.

Monitoring for flower thrips is done by gently tapping flowers over a white piece of paper [3, 7, 8]. The thrips will resemble tiny yellow and brown dashes crawling around on the paper. Strawberries can tolerate high numbers of flower thrips, so the treatment threshold is 10 thrips per flower [3, 7]. Minute pirate bugs, *Orius* spp., feed on flower thrips and are commercially available although release rates in strawberries have not been determined.

6. Fruit pests

SWD larvae, tarnished plant bugs, strawberry seed bugs, and sap beetles feed directly on strawberry fruit. SWD, tarnished plant bugs, and seed bugs can cause significant yield losses because they feed on developing and ripe fruit. Sap beetles, in contrast, prefer overripe fruit, but will chew holes in ripe fruit, which can reduce yield.

6.1 Spotted wing drosophila

The spotted wing drosophila, *Drosophila suzukii* Matsumura, is a more recently introduced pest of strawberries and other thin-skinned fruits. It was first found in Santa Cruz County, California in 2008 and has since spread across the United States [22, 23] Males can be distinguished from other drosophilid species by a spot present

on each wing (**Figure 13a**) and two pairs of combs on each foreleg that have four to six teeth each (**Figure 13b**) [22]. Newly emerged males lack the wing spots but can be identified by the combs. Unlike most other drosophilid species, female *D. suzukii* possess a heavily sclerotized serrated ovipositor (**Figure 13c** and **d**) that allows them to lay their eggs in ripening and ripe fruit [22].

Spotted wing drosophila larvae develop in the fruit, consuming the fruit as they do so, which renders the fruit unmarketable [22, 23]. As the larvae feed, areas where they are feeding will turn brown and become soft. Sunken areas that leak juice will appear on the surface of fruit. A single larva found in a shipment of fruit can cause the entire shipment to be rejected. The injury can also make the fruit susceptible to attack by other drosophilid species and diseases.

Adult spotted wing drosophila can be monitored with traps [24]. There are several commercially available traps and baits but a bait specific to spotted wing drosophila has not yet been developed. Soapy water is used as the drowning solution in these traps. Homemade traps can provide a more cost-effective option. Any plastic container with a lid that is around the size of a peanut butter jar can be used in trap construction. Punch two or three rows of holes around the middle of the plastic container leaving a 1" unpunched area so the trap contents can easily be poured out. The holes should be large enough to allow spotted wing drosophila to enter but not so large that bees and other pollinators can enter. String or a long twist tie can be used to create a hanger for the trap by tying it through holes on either side of the trap. An example of a home-made trap is shown in **Figure 14**. The most effective homemade bait is a mixture of yeast, sugar, and water. Mix 2 tsp. sugar and ¼ tsp. active dry yeast in 2/3 cup water per trap. In this case, the bait also serves as the drowning solution. Traps should be checked weekly. The contents can be



Figure 13. Spotted wing drosophila (a) male, (b) enlarged view of male foreleg showing the two combs, (c) female, and (d) enlarged picture of female ovipositor (photo credits: L.E. Iglesias, UF).



Figure 14.
Home-made spotted wing drosophila trap baited with yeast, sugar, and water mix (photo credit: L. Iglesias, UF).

emptied into another container or dumped through a filter screen. As females often arrive earlier than males, examining the flies on the screen with a hand lens even if no flies with wing spots are present is very important. There is no threshold for spotted wing drosophila and most growers begin a spray program once flies are found in traps.

The only way to sample for larvae is by collecting fruit and placing them in the freezer. Larvae will migrate to the surface of fruit as they freeze [24]. Because strawberry fruit are large, juicy, and contain a lot of flesh relative to other berries, dissection and extraction (salt and sugar) techniques that work well with other berries are difficult to perform and do not work well. The presence of a larvae indicates the need for insecticide application.

6.2 Tarnished plant bugs

Two lygus bugs are known as tarnished plant bugs, *Lygus lineolaris* (palisot de Beauvois) and *L. hesperus* Knight in the eastern and western United States, respectively [3, 7, 25]. They overwinter as adults and females begin laying eggs in the spring. Early instar tarnished plant bugs are small, bright green, and resemble aphids. They can be distinguished from aphids because they move much faster than aphids and lack cornicles on their abdomens. Nymphs develop brown markings as they mature. Adults are ¼" long and bronze/yellow or mottled brown in color. Adults resemble big-eyed bugs, *Geocoris* spp., which are beneficial predatory insects. As their name suggests, big eyed bugs have much larger eyes than tarnished plant bugs.

Both nymphs and adults feed on developing flowers and fruit [3, 7, 25]. They feed on the seeds, which stops the area around the seeds from developing, which, in turn, causes fruit to be misshapen or "cat-faced." "Cat-faced" fruit are deformed, small, and their ends are seedy. Tarnished plant bugs are a serious pest in perennial strawberries and can cause 90% yield loss if not controlled. The overwintering adults and first generation of nymphs are the most destructive to perennial

strawberries because they feed during the bloom period. It is important to note that poor pollination can also cause misshapen fruit. However, fruit misshapen from poor pollination will have seeds that vary in size while those injured by tarnished plant bugs will have seeds that are uniform in size [25].

Monitoring for tarnished plant bug should begin right before the start of bloom. Thirty flower clusters should be sampled evenly across the field by gently tapping them over a white piece of paper or another white surface. Nymphs will fall onto the white paper. The threshold is 0.25 nymphs before 10% bloom or more than 4 clusters infested [3, 7, 25]. The threshold rises to 0.5 nymphs per flower from mid to late bloom. There are also devices available to vacuum tarnished plant bugs off strawberry and other plants. The threshold for vacuuming is one bug per 10 plants [7].

Controlling weeds is an important part of managing tarnished plant bugs because tarnished plant bugs feed on many different weeds [3, 7, 25]. In California, the parasitoid wasp *Anaphes iole* Girault, which is an egg parasitoid, is available commercially [7]. Bug-vacs can be used to manage mild to moderate infestations but may also remove predatory insects and spiders from the plants [7].

6.3 Seed bugs

The strawberry seed bug (**Figure 15**), *Neopamera bilobata* (Say), has recently become a pest of annual strawberry production systems in Florida. Adults are similar in appearance to tarnished plant bugs but are smaller and more elongated in shape. Immatures closely resemble ants, especially at a distance. Ants have elbowed antenna and a narrow “waist” (narrow constriction between thorax and abdomen) while seed bug nymphs have straight antennae and the abdomen more broadly connected to the thorax. Adults and nymphs feed on developing fruit, which is suspected to cause injury to the fruit that can make it unmarketable. Research into economic impacts, thresholds, and treatment options is in the early stages.

6.4 Sap beetles

The strawberry sap beetle, *Stelidota geminate* (Say), is one of many sap beetles, family Nitidulidae, that are found in strawberry plantings. Along with the strawberry sap beetle, the dusky sap beetle, *Carpophilus lugubris* Murray, and the fourspotted sap beetle, *Glischrochilus quadrisignatus* (Say), are the most common



Figure 15.
The strawberry seedbug (photo credit: O. Dosunmu).

species found in North Carolina [26]. In contrast, *C. fumatus* Boheman, *Lobiopa insularis* (Castelnau), and *Epuraea luteola* Erichson are the most common species found in Florida strawberries [27]. In general, sap beetles are small, 1/8"–1/4" in length, and orange to dark brown in color. Several abdominal segments protrude beyond the elytra and they have clubbed antennae.

Adults fly into strawberry fields from wooded areas or other protected sites after overwintering [26]. In Florida, they do not overwinter and can come into fields at anytime but are more common in February through the end of harvest in March or April [27]. Females lay their eggs on or near overripe and rotting fruit. The larvae feed on and develop inside the fruit and then pupate in the soil nearby. The adults feed on ripe fruit, chewing small holes in the fruit that can make fruit unmarketable and introduce disease organisms.

The best way to manage sap beetles is to practice good field sanitation [26, 27]. Frequent harvests that include the removal and disposal of overripe and other unmarketable fruits usually prevent sap beetles from becoming a problem.

7. Conclusions


This chapter has reviewed the most common strawberry pests in the United States at the time this chapter was written. Pest complexes in other regions of the world will differ. It is probably inevitable that other exotic species will slip through our borders and become pests like the spotted wing drosophila and chili thrips have done. Climate change and changes in agricultural practices, such as the use of high and low tunnel systems, may change the pest complex in different areas of the United States. It is important to be aware of these things when developing an IPM program.

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