# Integrated pest management plan for whiteflies in production nurseries.

## Background and general biology

There are four main species of whiteflies which are considered pests of production nurseries in Australia. These are silverleaf whitefly (SLW - *Bemisia tabaci* biotype B), greenhouse whitefly (GHW - *Trialeurodes vaporariorum*), ash whitefly (*Siphoninus phillyreae*) and spiralling whitefly (*Aleurodicus dispersus*). Since the nursery production industry is very diverse, other species of whiteflies may be pests of particular host plants, particularly native plants that are associated with a native whitefly species. This pest management plan will summarise aspects of their biology and how to come to a preliminary identification of each major species; there is also a fact sheet focused specifically on management of SLW on the NGIA website [i].

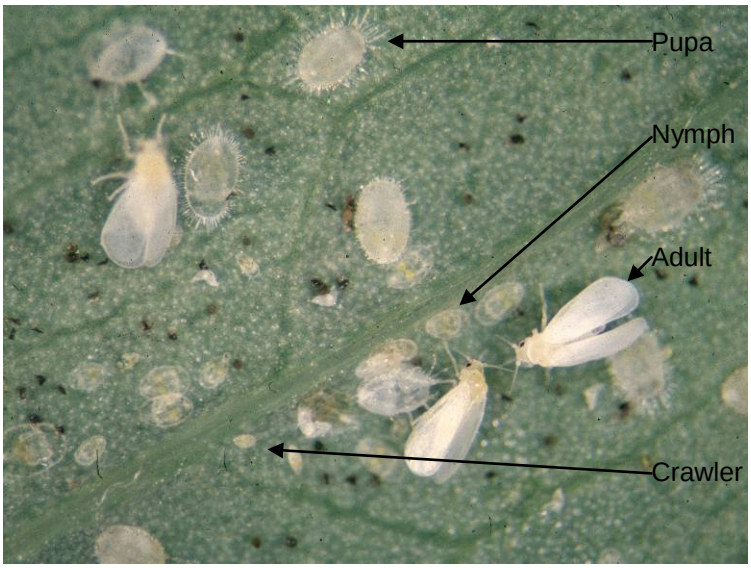



Fig. 1. Greenhouse whitefly. Photo by Whitney Cranshaw, Colorado State University, www.Bugwood.org

In general, adult whiteflies are small (about 1-2 mm in length), white-winged insects. The immature stages are largely immobile, becoming attached to the surface of the leaf soon after hatching. All life stages are found on the undersides of the leaves (Fig. 1) and can be associated with significant economic loss and/or increased costs in production. Whiteflies are sap-sucking insects which can reduce plant growth rates and cause leaf chlorosis, senescence or death, depending on the level of infestation. As they feed, whiteflies excrete honeydew on which black sooty mould grows resulting in reduced photosynthesis and blemishes that may render plants unmarketable. The saliva can produce toxic effects resulting in abnormal growth in some plants, such as poinsettia, and SLW can a silvering effect on the leaves of cucurbits. However, populations are not normally high enough to cause abnormalities. Instead, damage usually results from honeydew, black sooty mould and viruses vectored by whiteflies.

[i] www.ngia.com.au – search for 'pest fact sheets' using the internal website search engine.

Eggs are very small and laid on the underside of young leaves either singly or in groups. First instar nymphs (known as 'crawlers') hatch and move a short distance from their eggs. Subsequent nymphal instars are circular to oval in shape, relatively flat and are not able to move. Fourth instar nymphs develop into pupae, from which adults emerge (Fig. 1).

## Silverleaf whitefly

In Australia, SLW is found throughout Queensland, New South Wales, northern Western Australia and the Northern Territory. It has also been recorded in glasshouses in South Australia, Victoria and southern WA (i.e. Perth). There are currently at least three biotypes recognised in Australia, biotype B and two Australian native biotypes, which probably represent separate species that are morphologically identical [14]. In any case, only biotype B is considered a pest as it has a much wider host range and a much higher tendency to become resistant to insecticides. Other biotypes are present in other parts of the world and more continue to be identified. Females can start laying eggs just 24 hours after becoming an adult, depending on the temperature and host plant. About two-thirds of SLW populations are female. For other aspects of their biology refer to Table 1. Presence of SLW may also result in restricted market access to certain states, such as WA.

**Table 1.** Comparison of various aspects of the biology of the four main whitefly species affecting the nursery production industry.

| **Biological parameter** | **Silverleaf whitefly** [26, 36, ii] | **Greenhouse whitefly** [6, 36, iii] | **Ash whitefly** [19] | **Spiralling whitefly** [1, 35] |
|---|---|---|---|---|
| Main distribution [a] | Qld, NSW, NT | All states and territories, except NT. | SA, NSW, Vic | NT, Qld |
| Development time | 18 to 31 days at 30°C and 20°C | About 20-60 days. 22 days at 23°C | 25 days at 30°C 100 days at 15°C | 23 – 41 days. 30 days at 29°C |
| Lifetime egg production | 50 to 400 | 10-500 | 40-300 | 10-50 |
| Ideal temperature range | 25-30°C | 18-23°C | 20-25°C | 25-30°C |
| Important viruses transmitted | *Tomato yellow leaf curl virus*; *Tomato torrado virus* (ToTV) | *Beet pseudo-yellows virus*; ToTV | Viruses it can vector are not recorded in Australia | Not known to vector viruses |
| Biocontrol agents | *Eretmocerus hayati*; montdorensis | *E. warrae*; *Encarsia Formosa*; montdorensis | Specific predator not present in Australia [b, c] | *En. dispersa* [c, d] |

[a] Isolated populations may exist in other states, perhaps associated with protected cropping. The main distribution indicates where climatic conditions exist that populations can thrive.
[b] There are no devoted predators for ash whitefly.
[c] Montdorensis may provide control for ash and spiralling whitefly, but should be tested in consultation with its supplier, Bugs For Bugs.
[d] This wasp is not available commercially but has established in northern Australia.

[ii] http://www.ipm.ucdavis.edu/PMG/r280301611.html; http://hortipm.tamu.edu/publications/SPWF.html
[iii] http://www.entomology.umn.edu/cues/inter/inmine/Whiteff.html

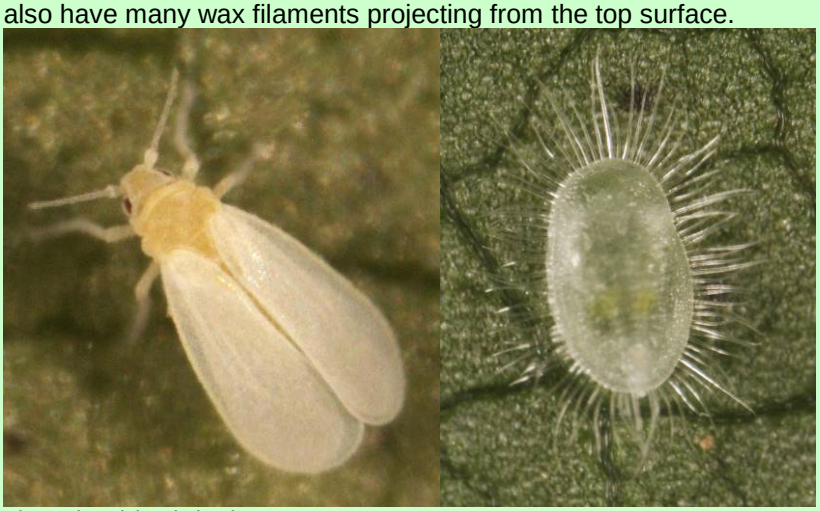
SLW can reproduce and/or feed on more than 600 plant species, with new hosts being recorded [22, 28]. A great many ornamentals are affected, including poinsettia, hibiscus, chrysanthemum, begonia, nicotiana, fuchsia and aster. Infestations of whitefly are also found on a wide range of broadleaf weeds such as sowthistle, turnip weed, mallow and wireweed.

Despite the wide host range, there is a wide variability in host plant suitability, both between plant species and between cultivars. For instance, mortality is higher, development time longer and fecundity lower on capsicum than on eggplant [32], indicating that fewer SLW will develop on capsicum than eggplant for a given time period. Factors such as leaf colour, leaf hair density and nutritional state of the plant can all influence host plant selection by SLW [8, 32]. Varieties tolerant to whitefly feeding and growth have been developed for some vegetable crops, but little new information has become available that is specific to nursery stock [12]. Many varieties of hibiscus and virtually all poinsettia, duranta (Sheena's Gold and Aussie 2000), various herbs and fruit and vegetable seedlings such as tomato, melon, squash, eggplant, cabbage, broccoli and beans are all very good hosts for SLW. Other ornamental hosts include *Mussaenda* (Bangkok rose), *Alamanda* (Jamaica Sunset), Chilean jasmine, Mandevila Alice du Pont, *Verbena*, *Lisianthus* and gerbera. On some of these hosts, SLW will persist at low levels providing a source from which other more susceptible host plants can become infested.

**Fig. 2. Distinguishing SLW and GHW**

**SLW adults** (left) hold their wings tent-like over their body, partially exposing the end of their abdomen and tend to be relatively narrow, compared to GHW.
**SLW pupae** (right) are relatively flat and do not have marginal fringe filaments and few hairs projecting from the upper surface (less than 9). They tend to be more of an irregular, shield-like, oval shape. Wherever possible, use pupae to distinguish SLW from GHW as it is more likely to lead to correct identification.

**GHW adults** hold their wings in a more flat position, almost parallel to the leaf surface, completely covering the end of their abdomen.
**GHW pupae** have vertical, perpendicular sides and a fringe of filaments along the margin. They tend to be more oval shaped and also have many wax filaments projecting from the top surface.



Photos by Richard Lloyd, DAFF.

## Greenhouse whitefly

Greenhouse whitefly is extremely polyphagous and has a similar host range as SLW. Adults land on plants at random, examine the plant to determine if it is a suitable host and either stay or move [33]. On good hosts, e.g. eggplant, most individuals will remain on the plant, whereas on bad hosts, e.g. sweet capsicum, most individuals leave the plant. Varietal resistance has also been found on particular varieties of bean, where the lifetime number of eggs laid on GHW resistant and susceptible varieties was between about 70 and 240, respectively [6]. Similarly, different host plant species are more or less susceptible to GHW and this effects the longevity and mortality of individuals on each host plant species [33].

**Fig. 3.** Adult and immature ash whitefly. Photo by Lyle J. Buss, University of Florida.

Adult SLW and GHW are similar in appearance (Fig. 2) but it can be very important to differentiate infestations of each species. SLW and GHW differ in their resistance to chemicals, transmit different viruses and have different biological control agents suited to manage each species. With practice and a good hand lens or microscope, one can easily distinguish pupae of SLW and GHW (Fig. 2).

**Fig. 4.** Typical 'spiral' produced by spiralling whitefly.

## Ash whitefly

Ash whitefly is adapted to temperate and Mediterranean climates. In Australia, it is mainly a pest of the southern states, but has also been recorded in Queensland. Adults are similar in size and appearance to SLW and GHW but with a light dusting of white wax. Pupae are light beige in colour, often have two tufts of white wax and have distinctive glassy wax droplets on the end of small hair-like structures (Fig. 3). Ash whitefly has a moderate host range and prefers such species as deciduous ash, pomegranate, apple and pear. When these hosts drop their leaves, adults move to their winter hosts, including citrus and other non-deciduous trees. Other hosts include crepe myrtle, star magnolia, ash, lilac, hawthorn, and various pome and stone fruit [4]. Damage from ash whitefly is similar to that caused by SLW and GHW, however, it is not known to transmit viruses. Overseas, the parasitoid wasp, *Encarsia inaron*, manages ash whitefly below economic thresholds, but it is not known to be present in Australia.

## Spiralling whitefly

Spiralling whitefly is adapted to tropical regions and has a wide host range including capsicums, citrus, coconut, *Euphorbia* spp., *Hibiscus*, tomato, mango, avocado, *Prunus* spp.,

egg fruit, and many other ornamental plants. In Australia, it is present in Queensland, as far south as Gladstone, and the Northern Territory. Females lay eggs on silken spirals (Fig. 4), hence their name, and high infestations are associated with a heavy wax coating on leaves. While heavy infestations can cause premature leaf senescence, most damage is caused from growth of black sooty mould and reduced photosynthesis. In Australia, an introduced biological control agent (*En. dispersa*) successfully manages populations of spiralling whitefly. Use of insecticide is not recommended against this species as it normally causes substantial mortality to biocontrol agents. Furthermore, the long-term use of insecticides to manage spiralling whitefly overseas has had limited success.

**Fig. 5.** Symptoms of *Tomato torrado virus* on tomatoes including dead areas near petioles and yellow areas around the base of leaflets. Photos by Cherie Gambley

## Whiteflies as a virus vector

Globally, there are hundreds of whitefly-transmitted viruses. In Australia, there are a number of major viruses vectored by SLW and GHW. Spiralling whitefly and ash whitefly are not known to vector viruses in Australia but may do so overseas. Managing viruses vectored by whiteflies is more challenging than managing whiteflies without the virus because the economic threshold for the virus is much lower than that of the whiteflies. As such, management actions suggested below should be followed more rigorously.

***Tomato torrado virus* (ToTV):** ToTV is from a new group of plant viruses which has only been found in glasshouse-grown tomato crops in North Adelaide Plain and at Lara in Victoria [15, 24]. Early symptoms of ToTV include necrotic or dead spots, surrounded by a light green or yellow areas at the base of leaflets. Damaged areas may then fall out, leaving a 'shot hole' appearance in the leaflets. Necrosis and mottling extend to the entire leaves and, in susceptible varieties, entire leaves become necrotic, wither and die (Fig. 5). Fruits may develop necrotic line patterns which often develop into cracks. ToTV is spread by GHW and SLW and can infect tomato, capsicum and eggplant as well as a number of weed species including plants from the genera *Amaranthus*, *Atriplex*, *Chenopodium*, *Malva*, *Polygonum*, *Nicotiana* and *Solanum*.

Nymphal whiteflies acquire the virus by feeding on infected plants for short periods of time. When individuals turn into adults they then have the capacity to fly and infect healthy plants. ToTV is probably only retained in whiteflies for a few days [24].

***Tomato yellow leaf curl virus* (TYLCV):** TYLCV was first found in south east Queensland in 2006 and can now be found as far north as Mareeba on the Atherton Tableland. It causes severe economic losses in tomatoes and can also infect various other crops to a lesser extent, e.g. common bean, sweet capsicum, chilli, petunia, lisianthus, poinsettia, other *Euphorbia* species and weed species (e.g. blackberry nightshade and thorn apple) [3, 31]. Many weed species remain non-symptomatic but allow SLW feeding on them to acquire and transmit the virus to other hosts [23]. Growth of tomatoes infected with TYLCV is relatively slow and plants become stunted. Leaflets become rolled upwards and inwards and develop interveinal chlorosis (Fig. 6). Leaves often become bent downwards and are unusually stiff. The margins of leaves have a yellow fringe and will set very few fruit after infection. Fruit quality of infected plants is also much reduced.

Nymphal whiteflies acquire viruses from feeding on infected plants for as little as 15 minutes, but virus acquisition reaches a maximum after 12-24 hours. However, nymphs cannot spread the virus until they become adults and have the capacity to fly to uninfected plants. After a whitefly acquires TYCLV it takes about 24 hours to move through the whitefly and become able to infect other plants for about 20 days [9].

**Fig. 6.** Symptoms of *Tomato yellow leaf curl virus* on tomato, including leaf curling and interveinal chlorosis. Photos by John Thomas and Denis Persley.

***Tomato leaf curl virus* (TLCV):** TCLV has similar symptoms and biology as TYLCV, including leaflets being rolled upwards and inwards, leaves are often stiff, thicker than normal and are often bent downwards. Young leaves are slightly chlorotic. If fruit are produced they are normally small, dry and unsaleable. Both TLCV and TYLCV can be confused with several other tomato disorders. It is found in north Queensland and the Northern Territory and is only transmitted by SLW. Tomato is normally the only host that is affected in the field, but many plants can be experimentally infected with TLCV, e.g. tobacco, French bean and potato [iv]. TLCV is generally less severe than TYLCV.

***Beet pseudoyellows virus* (BPYV):** BPYV is a crinivirus which causes cucumber yellows disease. Symptoms generally only develop on older leaves and include chlorosis between the veins and leaf margins curl down. Necrotic or dead areas may also develop between veins. Since young leaves rarely express symptoms, infected seedlings may go unnoticed. This virus is often confused with nutritional or environmental disorders which can delay appropriate management actions to reduce economic loss from this virus; laboratory testing is often required to confirm a diagnosis.

[iv] http://www.daff.qld.gov.au/plants/health-pests-diseases/a-z-significant/tomato-leaf-curl-virus

BPYV is acquired by GHW when insects feed on infected plants for as little as one hour. It can be transmitted to a healthy plant when the insect feeds for as little as several minutes and is retained by the insects for several days. The virus is not seed-borne and is not spread by contact. BPYV has a relatively wide host range including lettuce, beet, endive and common weeds including prickly lettuce (*Lactuca serriola*), nettleleaf goosefoot (*Chenopodium murale*), dandelion (*Taraxacum officinale*) and shepherd's purse (*Capsella bursa-pastoris*) [24].

**Fig. 7.** Symptoms of *Beet psuedoyellows virus* on cucumber. Photos by Cherie Gambly and Denis Persley.

## Host range and varietal resistance

Since new varieties of ornamental plants become available on a regular basis, it is important to keep records of those host plants and varieties that are more or less susceptible to whitefly infestations. This information can be used to help make decisions to manage whiteflies more successfully.

## Managing whitefly

The appropriate management technique will depend on a number of factors, such as the extent of the infestation, the presence of other pests and predators in the crop, presence of viruses, host plants present and environmental conditions. The exact management strategy therefore has to be tailored to each situation or nursery crop. However, the following actions should generally assist in the management of whiteflies.

## Chemical control and insecticide resistance

As whiteflies are found on the undersides of leaves, care must be taken to ensure thorough coverage. A systemic insecticide such as imidacloprid, applied as a soil drench, can provide effective longer-term control and is not as toxic to predators as a foliar application [5]. However, highly residual products will increase the likelihood of the development of resistance, particularly if applied on a regular basis. Chemical control of whiteflies should not be relied upon solely. Cultural and biological controls should be employed to prevent and minimise whitefly infestations. Insecticides should be used in a targeted, strategic manner to clean up any high level infestations.

SLW is notorious for developing resistance to chemicals that are overused. Therefore, it is recommended to not apply chemicals of the same mode of action group (MOA)

consecutively and to follow label instructions on pesticide resistance management. Read the label carefully and follow instructions to ensure insecticides are used correctly and for maximum efficacy. To complicate matters further, cross resistance between pyrethroids (MOA 3), most organophosphates (MOA 1B), carbamates (MOA 1A) and some insect growth regulators can occur for SLW [20]. Do not continue to apply insecticides that are not effective in controlling SLW; this will increase insecticide resistance. For more detail on the level of pesticide resistance for SLW refer to the SLW factsheet on the NGIA website.

Although specific levels of GHW pesticide resistance are not known in Australia, resistance could easily occur as indicated by reports overseas. Research indicates that GHW is capable of developing resistance at a reasonably rapid rate, particularly if the same product is used multiple times without rotating [25]. In fact, rotating between three products of different modes of action reduced levels of resistance by about 50 times compared to insects that had continuous applications of one product [25].

Limited information is available on insecticide resistance for ash whitefly and spiralling whitefly. However, there are unconfirmed reports of ash whitefly resistance to imidacloprid when injected in established street trees in southern states of Australia [v].

To assist growers in management decisions, all insecticides which are registered or that have permits for use on ornamental plants are summarised in Table 2. Registrations and permits on horticultural crops that are part of the nursery sector, but without a general ornamental label, are summarised in Table 3. These tables are summarise notes on their effect on beneficials and major restrictions for their use. Tables are current as of September 2013. Check the APVMA website registrations[vi] and permits[vii] or Infopest[viii] for changes to labels.

## Cultural control

The prevention and spread of whitefly infestations is very important for successful management, as large populations can build up quickly and can be difficult to control (Fig. 8). It is extremely important to prevent and manage whitefly successfully to reduce economic impacts caused by whitefly-vectored viruses.

1. Manage sources of infestation: control broad-leaf weeds and reduce other alternative hosts in the production area and surrounds, particularly weedy species from the families Euphorbiaceae, Asteraceae and some Malvaceae. The use of weed matting, plastic or gravel on the floor can help nursery situations. Short, managed grasses or turf can be used to exclude broad leaf weeds and are not host plants [12]. Good weed management will also help reduce a variety of other pest problems including aphids, thrips, mites and mealy bugs.
2. Determine what species is in the crop, in particular distinguish GHW from SLW (Fig. 2). SLW has higher levels of pesticide resistance, different limits on insecticidal applications are in place for GHW and SLW and certain biocontrol agent species are only effective against particular species of whitefly.
3. Check incoming stock, new seedlings and other new planting material to ensure it is clean and to break the lifecycle of whiteflies. Use resistant varieties whenever possible.
4. Prune and thin plants with light to moderate infestations to reduce pest load, increase airflow and penetration by insecticides.

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v http://www.elmsavers.com.au/wp-content/uploads/downloads/factsheet/ash-whitefly.pdf
vi http://services.apvma.gov.au/PubcrisWebClient/welcome.do
vii http://www.apvma.gov.au/permits/search.php
viii www.infopest.com.au

5. Remove and destroy heavily infested stock. Retaining unsaleable stock provides a

**Fig. 8.** Whitefly infestations can build up quickly. If populations are frequently first discovered from a cloud of whitefly flying out of infested plants then your monitoring technique needs improvement (see below). Photo by Cherie Gambley (DAFF).

source of further infestation. Infested material should be bagged and deep buried or placed in a black bag in the sun for several hours to kill pests. Leaving unbagged, infested plants or cuttings in the bin encourages pests to reinfest the nursery, particularly as the plant material starts to wilt and die.

6. Screens (mesh size of about 0.2 mm) placed over greenhouse vents and doors can be used to help prevent entry by whiteflies. Specialised products are now available that prevent entry of SLW but allow entry of beneficial insects that parasitise SLW [29]. Furthermore, glasshouses can be modified in such a way as to provide area freedom from SLW. However, placement of such screens can increase the humidity in the structure, causing ventilation problems. It is recommended to use a protected cropping consultant/designer before retrofitting or building an insect-proof tunnel or glasshouse.
7. If infestations persist for long periods in a particular area or glasshouse, grow plants that are not hosts of the whitefly for a significant period of time to break the life cycle.
8. Practice good crop hygiene to avoid contamination between greenhouses or production sites. Mark areas that are known to have infestations with visible signs so that workers can avoid moving through that area. Disturbed vegetation causes adults to disperse, thus spreading the infestation to other areas of the nursery.
9. Most importantly, identify infestations early through regular monitoring.
10. Avoid broad spectrum, residual chemicals that will cause high mortality of naturalised parasitoids and predators (see section on biological control below).

### Additional and important steps to manage whitefly transmitted viruses

11. Do not transport plants from areas with whiteflies and viruses to areas without the virus.
12. Dispose of throw-outs promptly, ensuring that whiteflies will not migrate from the plants to other parts on your nursery. If necessary, apply an insecticide or oil spray to kill adult flies before destroying the crops.
13. Reduce weeds around your nursery, as they can harbour viruses and may remain non-symptomatic.
14. Grow virus-resistant plants in areas and seasons for which the virus is likely to be a problem.

## Monitoring whitefly

Plants should be inspected at least on a weekly basis for the presence of whitefly and data recorded, preferably electronically. Increase the frequency of monitoring during warmer weather and on host plants which are known to be more susceptible to whitefly. Frequent monitoring will enable infestations to be spotted while they are still light, and thus easier and cheaper to manage. Methods of monitoring include:

> Adult whiteflies tend to fly off the plant when disturbed. Thus as you beat plants, make sure to notice any small white insects flying around the plants. Inspect the area more closely when observed.

1. Visual inspection and plant beating can be completed simultaneously. Inspect a small percentage of each plant type by hand (generally 1 to 10%, depending upon the number of plants and their susceptibility). Examine both leaf surfaces of plants that look stunted or are chlorotic using a x10 hand lens. Older nymphs tend to be found on older leaves, eggs and young nymphs tend to be found on young growth. Move through the crop and gently but firmly hit foliage against a beating tray (which can be a folder, bucket or plastic plate). The beating tray should be a single colour; white or black is preferable as this will make moving organisms more visible. Beating plants is a relatively efficient way of monitoring for insects and mites that can be knocked from plants, including whitefly adults, herbivorous and predatory mites, aphids, thrips, lady beetles, small caterpillars and a variety of other insects. However, adult whitefly may fly off the beating tray quickly, so take note of insects flying from the plant and tray and investigate more closely. Once something is found, a 10-15x hand lens can be used to inspect the catch. Record the number of plants inspected and the number with any given pest in each area of your nursery. More detailed information (e.g. a rough indication of the level of infestation) may also be useful, particularly for determining how effective management actions have been. Accurate records can help determine long-term patterns of host use in the nursery and areas or host plants that are prone to whitefly infestations. Greater search effort can then be given to these areas. It is also important to note that whiteflies are more difficult to detect on pale yellow/green leaves.
2. Yellow sticky traps are useful tools for monitoring whitefly adults. Adults are most attracted to young foliage, so traps should be positioned just above the plant tops. Traps should also be placed near doors, vents and any susceptible crops or areas. At least one trap per 100 $m^2$ is recommended for greenhouse crops, more in varieties that are known to be susceptible to whiteflies. Inspect sticky traps at least weekly and change traps every 2 to 4 weeks [12, 16].
3. Indicator plants can be placed around your nursery as part of an early warning system. Such plants are very susceptible to whitefly and produce highly visible damage. Whiteflies that enter the nursery will be more likely to land and stay on these plants. Two good indicators for SLW are squash and melon seedlings, as their leaves turn silver with only a small number of individuals [12].

Keeping long-term records can help to identify areas and varieties that are more susceptible to infestations. It is also important to continue monitoring following application of insecticides or release of biological controls to determine the effectiveness of treatments. These records can assist with making management decisions in the future. For example, wind patterns at your nursery may lend themselves to greater numbers of sentinel plants being placed upwind, or during warmer periods of the year. Insect monitoring data sheets are available in the BioSecure *HACCP* protocols available on the NGIA website (www.ngia.com.au). Alternatively, simple spreadsheets can be created and modified to suit your nursery. It is recommended to keep your data stored electronically; searching and sorting the data is far more efficient. Patterns are then more likely to be observed which can lead to more efficient management strategies.

## Biological control

In Australia there are five commercially available biological control agents for whitefly species. Overseas, a variety of biopesticides (using bacteria, fungi or viruses to kill insect pests) are available but these are not yet registered in Australia, e.g. BotaniGard [29]. Different parasitoids are more suited to particular species of whitefly. Best practice guidelines for release of each agent are found on the website of the relevant biocontrol agent producer. Many factors can influence the success of predators and parasitoids including climate, host plant and the exact species of pest for which control is sought. As such, biocontrol agent producers are in the best position to give advice on what is most likely to be effective in your situation.

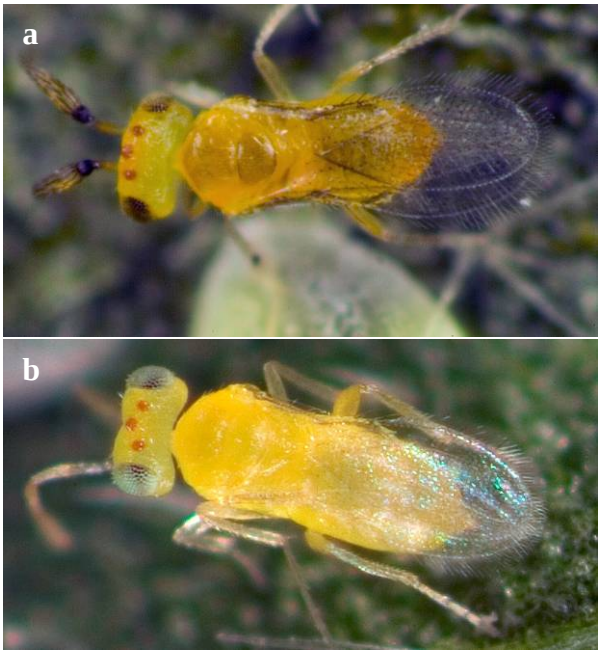


**Fig. 9.** Male (a) and female (a) *Eretmocerus hayati* are about 0.5 mm in length. Photos by Paul de Barro.

### *Eretmocerus hayati* (hayati)

The most effective parasitoid of silverleaf whitefly in Australia is hayati [11]. This small wasp (Fig. 9) was introduced into Australia from Pakistan in 2004 and has spread from Bowen to Narrabri and the Sydney Basin [7]. Hayati is only known to parasitise SLW, and is much more effective than *Encarsia formosa* against SLW. It is extremely mobile, travelling up to 1 km per day and often arrives in a crop 1-3 days after SLW, in ideal conditions. Hayati reproduces very quickly, laying between 80 and 200 eggs over about 10-20 days depending on the host plant [17, 34], i.e. each female can potentially kill over 200 SLW nymphs. In addition, adults feed on nymphs which are not parasitised further increasing mortality to SLW. Their development takes about 12 to 32 days at 30°C and 20°C, respectively. Research has shown that, in areas where *Er. hayati* is present, as much as 85% of parasitism is contributed to this parasitoid. Prior to the release of hayati, only 25% of samples had any parasitism [11]. As such, hayati should be used first under conditions which are conducive to its survival.

Pesticides can have direct or indirect negative effects on predator populations. Direct negative effects occur when they come in contact with the product and its residue. Sub-lethal rates can also reduce the number of eggs laid, pests attacked and survival rates. Indirect effects can occur from reductions in pest populations, e.g. if a healthy predator population is present and a pesticide reduces the pest population by 80%, it is likely that very few predators will remain for any substantial period of time. New releases will be required to re-establish the predator population.

Hayati is very sensitive to persistent insecticides and fungicides. Avoid insecticides that are toxic to beneficials to increase the success of using hayati (Table 1 and 2). Bugs for Bugs is the only supplier of this parasitoid in Australia.

### *Encarsia formosa* (Encarsia)

Encarsia is a black and yellow parasitoid wasp which is very small (about half a millimetre) (Fig. 10). Female wasps parasitise both SLW and GHW, laying eggs into all stages of immature SLW, although they prefer the third or fourth instar. Once parasitised, Encarsia larvae eat and kill the whitefly from the inside, causing it to turn brown or black after about a

week (GHW turn black, SLW turn brown). Encarsia completes its development in 14 to 28 days at 32°C and 21°C, respectively [27]. Their population is 98% female; therefore, almost all individuals can parasitise whiteflies. Each female may lay between 50-150 eggs in GHW over about 10 days of their adult life; however they may live up to 40 days under optimal conditions. Parasitism rate is highly influenced by the host plant on which the whitefly is feeding, with hairy, glandular plants or plants with large deposits of honeydew being less preferred than smooth hosts [13,21]. The wasp also feeds on young nymphs, sometimes causing significant mortality.

**Fig. 10.** *Encarsia formosa* adult wasp.

Encarsia is favoured by moderate temperatures, between 20 and 30°C, with 50-70% relative humidity and high light levels. Lower temperatures increase their development time, causing them to reproduce slower than their whitefly hosts. Higher temperatures cause mortality if prolonged for significant periods. The optimum temperature range for whitefly control with *E. formosa* is 27 to 30°C; a minimum average daily and nightly temperature of 23°C and 15°C, respectively is required for good control. Encarsia works most effectively with greater than 10 hours of daylight. Supplementary lighting will be beneficial under shorter day length conditions. Similar to many other whitefly parasites, Encarsia leave a circular exit hole and black faeces in the pupal host remains. Adult whiteflies emerging from pupal cases leave a ragged or T-shaped emergence hole and are free of black faeces. Therefore, evidence of parasitism rates can be observed from pupal skins. As a general rule of thumb, parasitism above about 80% does not require further releases and probably will not require any insecticide applications. Encarsia is more effective at controlling GHW than SLW, therefore higher rates of release are required to manage SLW.

Encarsia is very sensitive to persistent insecticides, which cause significant mortality, and may also be negatively influenced by some fungicides and miticides [21]. Encarsia is commercially available in Australia by Biological Services.

### *Eretmocerus warrae* (warrae)

Warrae is very similar in appearance to hayati, being yellow and less than 1mm in length (Fig. 11). It is believed that warrae is native to Australia and New Zealand and the full range of whitefly species that they parasitise is not known. However, warrae seem to parasitise GHW at high levels but do not control SLW. Only a little is known about the biology of warrae, though it is

**Fig. 11.** Eretmocerus warrae, a small parasitoid of GHW (above) and GHW parasitised by Encarsia (below left) and Er. warrae (below right). Photos by Biological Services.

currently being studied at the University of Adelaide. Most wasps are female and they can lay up to about 150 eggs over their 1-2 week lifetime [ix]. GHW parasitised by warrae turn yellow/brown, not black, as when parasitised by Encarsia. Just prior to the emergence of warrae, its head (with three red dots) can be observed with careful examination using a hand lens. Like most other whitefly parasitoids, warrae exits via a circular hole in the back of its host. Eggs are laid into young whitefly nymphs, older nymphs are sometimes fed upon and contributes to control of GHW. Development of warrae from egg to adult takes 14-28 days, depending on temperature.

Little is known of the effect of temperature on warrae. However, it is thought that it will be useful for the control of GHW between 15-35°C, and will survive temperatures around 10°C and 38°C. Thus, warrae is better able to survive extreme conditions compared to Encarsia.

### *Transeus montdorensis* (montdorensis) = *Typhlodromips montdorensis*

**Fig. 11.** The predatory mite, *Transeus montdorensis*, is an opaque white or yellow mite a little less than 1 mm. Photo by Marilyn Steiner.

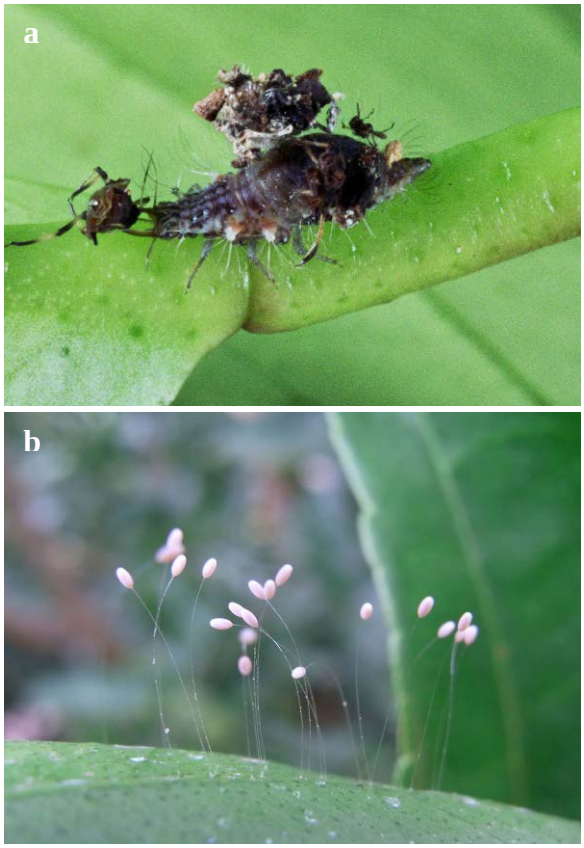


**Fig. 9.** Larvae of the green lacewing (a) grow to about 8 mm. Eggs are laid in clusters (b), each on a thin stalk. Photos by Dan Papacek.

Montdorensis is a native Australian predatory mite in the same family as the widely used spider mite predator, *Phytoseiulus persimilis*. Montdorensis feeds on whiteflies, thrips larvae, broad mites, a variety of other small insects and mites, pollen and honeydew. Commercial releases against SLW indicate that montdorensis has the potential to reduce populations considerably. It is a pale, teardrop-shaped mite which is about 1mm in length (Fig. 11); the exact colour of the mite changes depending on prey that has been eaten. Development of montdorensis takes about 1 week at 25°C and females can lay 2 to 4 eggs per day, about 50 eggs over a 4-week lifespan. Populations of the mite are generally about 2:1 female:male. Montdorensis prefers warmer temperatures, 20-30°C being optimal. Adults are able to tolerate up to 45°C for at least short periods at high humidity, but eggs and immatures will not; releasing this species at these temperatures is not recommended. At temperatures below 11°C montdorensis becomes inactive, but as long as daytime temperatures are warm it will remain active throughout the year. Eggs require a relative humidity of greater than 70%, otherwise significant numbers fail to develop [30].

[ix] http://www.biologicalservices.com.au/eretmocerus-w.html

Montdorensis is sensitive to persistent pesticides, particularly synthetic pyrethroids and some organophosphates; in general, IPM-friendly products have a relatively minor negative effect on this predatory mite. Montdorensis is commercially available in Australia from Bugs for Bugs.

### *Mallada signata*, green lacewing

The green lacewing has a relatively wide host range, feeding on aphids, spider mites, various scales, mealy bugs, moth eggs and small caterpillars as well as whitefly species. Pollen and nectar can also be ingested. Larvae (Fig. 9a), but not adults are predacious. Adults have a green body and hold their transparent wings tentlike over their body and feed on pollen and nectar. Females live for 3-4 weeks and lay up to 600 eggs. Almost all lacewing species are predators and often lay their eggs on thin white stalks with a bulbous white egg at the end; most species lay multiple eggs in the same area, most often in a straight or roughly straight line or in a horseshoe arrangement (Fig. 9b). Green lacewing larvae grow to nearly 1 cm in length before pupating and typically place the remains of their prey on top of spines protruding from their back. In fact, research suggests that green lacewing larvae with trash-packages are more active and forage more efficiently, while those without trash-packages are more likely to become inactive [2]. After about 12 days, larvae pupate and emerge as adults about 9 days later. Females must be about 7 days old before laying their first egg.

It is well adapted to relatively warm conditions and very sensitive to persistent and or broad spectrum chemical applications, although reduced risk pesticides have a relatively minor negative effect on this insect. Green lacewing is commercially available from Bugs for Bugs.

### Other naturalised beneficials

There are many whitefly parasitoids which will colonise a growing area that are not commercially available [7, 10]. To encourage natural parasitism of whiteflies in your nursery, limit broad spectrum, systemic and highly residual insecticide applications as all of these parasitoids are very sensitive to such products. This is particularly important in relation to management of spiralling whitefly. Spiralling whitefly is parasitised heavily by *En. dispersa*, a wasp which was released in the Torres Strait [18] and colonised north Queensland naturally [x]. Since its arrival it has spread and often will control spiralling whitefly in commercial growing situations. A range of naturally-occurring predators may also help to keep whitefly populations in check. These include big-eyed bugs, various species of lacewing larvae and lady beetles.

### Recommendations: putting it all together

The following recommendations can be used as a guide, but may require changes to suit your exact situation. Since many pestiferous whiteflies may develop pesticide resistance, this pest management plan focuses on the control of whiteflies using beneficial insects. Chemical control of whiteflies is only recommended when numbers are too high for biological control to be effective. A low residual product is then recommended so that predators and parasitoids can be introduced soon after the insecticide application. Action thresholds indicated here are somewhat broad, focusing on actions that should be taken when whitefly populations are absent, low, moderate and high. The exact number of whitefly per leaf which characterises low, moderate, and high is not defined here as each host plant will have differing levels of susceptibility. Furthermore, regional differences and the species of whitefly infesting the crop will also modify threshold levels. Regular monitoring, record keeping and evaluation of the efficacy of each treatment and the amount of damage incurred (if any) under different scenarios will help growers determine what constitutes low, moderate and high. As such, it is

[x] http://www.daff.qld.gov.au/plants/health-pests-diseases/a-z-significant/spiralling-whitefly

recommended to modify the below guidelines as necessary to gain successful management of whiteflies. Talk to your local IDO to inform them of your progress regarding whitefly management using this pest management plan.

The below guidelines assume that you have identified the species of whitefly present. Incorrect identification of the whitefly may cause biological control to fail if you release the wrong species of parasitoid wasp. Also ensure that the environmental conditions are suitable for the specie to successfully control whitefly; extreme cool or hot temperatures will preclude the option of releasing biological control agents successfully. If in doubt, talk to your biological control agent producer before ordering a predator or parasitoid.

| Whiteflies absent | Low populations | Moderate populations | High populations |
|---|---|---|---|
| Continue monitoring. If a particular species of whitefly consistently attacks the plant during a particular time of year, release at preventative rates. | Release at normal rate weekly until 80% of whitefly are parasitised or otherwise consumed. If hot spots occur within otherwise low levels of whitefly, add high rates to the hotspot. | Release at high rates weekly until 80% of whitefly are parasitised or otherwise consumed. If the plant species is highly susceptible to damage, application of a low risk insecticide may be warranted prior to release. | Apply a low risk insecticide (e.g. products with the active ingredients pymetrozine, buprofezin, detergent base product, botanical or petroleum oil) to knock down whitefly numbers to a manageable level. Be aware of how long the product will be active against the biocontrol agent. Release when safe and numbers are low. |

While we recommend release of beneficial insects as the best practice method to manage whiteflies, there are a number of scenarios which will preclude their release. These include recent application of highly toxic and residual pesticides which would kill beneficial insects or adverse climatic conditions (i.e. either too hot or too cold). Practical constraints may also influence release of beneficial insects, e.g. if there are only a very small number of plants for which whitefly need to be managed it may not be economically feasible to use biological control. In these scenarios, pesticides should be used before whiteflies reach large numbers and rotated using as many different mode of action groups as possible. The following rotation could be used until such a time as biological control is a feasible option:

1. Pymetrozine (MOA 9B)
2. Buprofezin (MOA 16)
3. Diafenthiuron (MOA 12A)
4. Detergent and or oil based product
5. Pyroproxyfen (MOA 7C)
6. Other active ingredients that could be an option depending on the exact crop are azadirachtin and spirotetramat.

It is not recommended to use organophosphate (MOA 1B), synthetic pyrethroids (MOA 3A) or neonicotinoids (MOA 4A) unless all other options have been unsuccessful. If using one of these products it can be a considerable period before biological control can be feasible. During this period, the above low-risk products can be used until such a time when biological control can be considered. If in doubt, talk to your biological control agent producer.

This document was prepared by Andrew Manners (Agri-science Queensland, Department of Agriculture, Fisheries and Forestry, Ecosciences Precinct, PO Box 267, Brisbane, Qld 4001) as part of NY11001 Plant health biosecurity, risk management and capacity building for the nursery industry. Thanks go to John Duff, James Altmann (Biological Services) and Anthony Kachenko for comments which improved this document.

## References


1. Aishwariya, K.K., M. Manjunatha, and M.I. Naik, 2007. Biology and host range of spiralling whitefly. *Karnataka Journal of Agricultural Sciences* **20**: 149-152.
2. Anderson, K.L., J.E. Seymour, and R. Rowe, 2003. Influence of a dorsal trash-package on interactions between larvae of *Mallada signata* (Schneider) (Neuroptera : Chrysopidae). *Australian Journal of Entomology* **42**: 363-366.
3. Antonio Diaz-Pendon, J., M. Carmen Canizares, E. Moriones, E.R. Bejarano, H. Czosnek, and J. Navas-Castillo, 2010. Tomato yellow leaf curl viruses: menage a trois between the virus complex, the plant and the whitefly vector. *Molecular Plant Pathology* **11**: 441-450.
4. Bellows, T.S., T.D. Paine, K.Y. Arakawa, C. Meisenbacher, P. Leddy, and J. Kabashima, 1990. Biological control sought for ash whitefly. *California Agriculture* **44**: 1-4.
5. Bethke, J.A. and R.A. Redak, 1997. Effect of imidacloprid on the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring (Homoptera: Aleyrodidae), and whitefly parasitism. *Annals of Applied Biology* **130**: 397-407.
6. Campos, O.R., W.B. Crocomo, and A.M. Labinas, 2003. Comparative biology of the whitefly *Trialeurodes vaporariorum* (West.) (Hemiptera - Homoptera: Aleyrodidae) on soybean and bean cultivars. *Neotropical Entomology* **32**: 133-138.
7. Childs, I.J., R.V. Gunning, and S. Mansfield, 2011. Parasitoids of economically important whiteflies associated with greenhouse vegetable crops in western Sydney. *Australian Journal of Entomology* **50**: 296-299.
8. Chu, C.C., T.J. Henneberry, and A.C. Cohen, 1995. *Bemisia argentifolii* (Homoptera, Aleyrodidae) - host preference and factors affecting oviposition and feeding site preference. *Environmental Entomology* **24**: 354-360.
9. de Barro, P.J., 1995. *Bemisia tabaci biotype B: a review of its biology, distribution and control*. Canberra, Australia: CSIRO Publishing.
10. De Barro, P.J., 1999 Pre-emptive research into the biology and biological control of silverleaf whitefly, *Bemisia tabaci* biotype B. Horticultural Research & Development Corporation
11. De Barro, P.J. and M.T. Coombs, 2009. Post-release evaluation of *Eretmocerus hayati* Zolnerowich and Rose in Australia. *Bulletin of Entomological Research* **99**: 193-206.
12. De Barro, P.J. and A. Frodsham, 1997. Silverleaf whitefly: management of a new nursery pest, In *The Nursery Paper*.#009.
13. De Barro, P.J., P.J. Hart, and R. Morton, 2000. The biology of two *Eretmocerus* spp. (Haldeman) and three *Encarsia* spp. Forster and their potential as biological control agents of *Bemisia tabaci* biotype B in Australia. *Entomologia Experimentalis Et Applicata* **94**: 93-102.
14. Dinsdale, A., L. Cook, C. Riginos, Y.M. Buckley, and P. De Barro, 2010. Refined global analysis of *Bemisia tabaci* (Hemiptera: Sternorrhyncha: Aleyrodoidea: Aleyrodidae) mitochondrial cytochrome oxidase 1 to identify species level genetic boundaries. *Annals of the Entomological Society of America* **103**: 196-208.
15. Gambley, C.F., J.E. Thomas, D.M. Persley, and B.H. Hall, 2010. First report of *Tomato torrado virus* on tomato from Australia. *Plant Disease* **94**: 486.
16. Jelinek, S. 2010, *Whitefly management in greenhouse vegetable crops* <www.dpi.nsw.gov.au/primefacts> Web Page,
17. Kuang, W., N. Yang, F. Wan, and Z. Yuan, 2011. Effects of temperatures and *Bemisia tabaci* (Gennadius) reared on different host plants on development and reproduction of parasitoid, *Eretmocerus hayati* (Zolnerowich and Rose). *Chinese Journal of Biological Control* **27**: 152-156.
18. Lambkin, T.A. and M.P. Zalucki, 2010. Long-term efficacy of *Encarsia dispersa* Polaszek (Hymenoptera: Aphelinidae) for the biological control of *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae) in tropical monsoon Australia. *Australian Journal of Entomology* **49**: 190-198.
19. Leddy, P.M., T.D. Paine, and T.S. Bellows, 1995. Biology of *Siphoninus phillyreae* (Haliday) (Hollloptera: Aleyrodidae) and its relationship to temperature. *Environmental Entomology* **24**: 380-386.
20. Leven, T., R. Mensah, R. Sequeria, L.J. Wilson, and M. Dillon, 2012. Key insects and mite pests of Australian cotton, In *Cotton Pest Management Guide 2012-13*, S. Maas, Editor. Cotton CRC, available from <http://www.cottoncrc.org.au/industry/Publications/Pests_and_Beneficials>.
21. Llewellyn, R.E., 2002. *The Good Bug Book, 2nd Ed*. Richmond, NSW: Integrated Pest Management Pty Ltd.
22. Oliveira, M.R.V., T.J. Henneberry, and P. Anderson, 2001. History, current status, and collaborative research projects for *Bemisia tabaci*. *Crop Protection* **20**: 709-723.
23. Papayiannis, L.C., 2011. Identification of weed hosts of *Tomato yellow leaf curl virus* in Cyprus. *Plant Disease* **95**: 120-125.
24. Persley, D. and C. Gambley. 2011, *Whitefly-Transmitted Viruses in Vegetable Crops* <http://www.daff.qld.gov.au/documents/PlantIndustries_FruitAndVegetables/Whitefly-viruses-veg-crops.pdf> Web Page, Queensland Department of Employment, Economic Development and Innovation
25. Prabhaker, N., N.C. Toscano, and T.J. Henneberry, 1998. Evaluation of insecticide rotations and mixtures as resistance management strategies for *Bemisia argentifolii* (Homoptera : Aleyrodidae). *Journal of Economic Entomology* **91**: 820-826.
26. Qiu, B.-L., F. Dang, S.-J. Li, M.Z. Ahmed, F.-L. Jin, S.-X. Ren, and A.G.S. Cuthbertson, 2011. Comparison of biological parameters between the invasive B biotype and a new defined Cv biotype of *Bemisia tabaci* (Hemiptera: Aleyradidae) in China. *Journal of Pest Science* **84**: 419-427.
27. Qiu, Y.T., J.C. Van Lenteren, Y.C. Drost, and C. Posthuma-Doodeman, 2004. Life-history parameters of *Encarsia formosa*, *Eretmocerus eremicus* and *E. mundus*, aphelinid parasitoids of *Bemisia argentifolii* (Hemiptera : Aleyrodidae). *European Journal of Entomology* **101**: 83-94.
28. Simmons, A.M., H.F. Harrison, and K.S. Ling, 2008. Forty-nine new host plant species for *Bemisia tabaci* (Hemiptera: Aleyrodidae). *Entomological Science* **11**: 385-390.
29. Stansly, P.A. and E.T. Natwick, 2010. Integrated systems for managing *Bemisia tabaci* in protected and open field agriculture, In *Bemisia: Bionomics and Management of a Global Pest*, P.A. Stansly and S.E. Naranjo, Editors. Springer: New York. 467-502.
30. Steiner, M.Y., S. Goodwin, T.M. Wellham, I.M. Barchia, and L.J. Spohr, 2003. Biological studies of the Australian predatory mite *Typhlodromips montdorensis* (Schicha) (Acari : Phytoseiidae), a potential biocontrol agent for western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera : Thripidae). *Australian Journal of Entomology* **42**: 124-130.
31. Teosoriero, L. and S. Azzopardi. 2006, *Tomato Yellow Leaf Curl Virus* <www.dpi.nsw.gov.au/primefacts> Web Page,
32. Van Lenteren, J.C. and L.P.J.J. Noldus, 1990. Whitefly-plant relationships: behavioural and ecological aspects, In *Whiteflies: their bionomics, pest status and management.*, D. Gerling, Editor. Intercept Ltd: UK. 47-89.
33. van Lenteren, J.C., H.J.W. van Roermund, and S. Sutterlin, 1996. Biological control of greenhouse whitefly (*Trialeurodes vaporariorum*) with the parasitoid *Encarsia formosa*: How does it work? *Biological Control* **6**: 1-10.
34. Villanueva-Jimenez, J., N. Schellhorn, and P.J. de Barro, 2012. Comparison between two species of *Eretmocerus* (Hymenoptera:Aphelinidae): reproductive performance is one explanation for more effective control in the field. *Biological Control* **63**: 333-338.
35. Wen, H., T. Hsu, and C. Chen, 1994. Effects of temperature on the development, adult longevity, activity and oviposition of the spiralling whitefly, *Aleurodicus dispersus* Russell (Homoptera: Aleyrodidae). *Chinese Journal of Entomology* **14**: 163-172.
36. Xie, M., F.H. Wan, Y.H. Chen, and G. Wu, 2011. Effects of temperature on the growth and reproduction characteristics of *Bemisia tabaci* B-biotype and *Trialeurodes vaporariorum*. *Journal of Applied Entomology* **135**: 252-257.

**Table 2.** Pesticides currently registered or with minor use permit in Australia for ornamental use against whiteflies, including SLW, GHW and other species. Results presented were from queries of Infopest and the APVMA pubcris and permit searches. Notes are also included on their use and toxicity to beneficial organisms. Always check full product labels and/or permits to determine suitability of use.

| Mode of action group | Active ingredient | Example product name | Registration information | Limits on applications per season | Action[1] | Other information | Toxicity to beneficials[2] |
|---|---|---|---|---|---|---|---|
| 1B | Dichlorvos | Insectigas-D | PER14076 In greenhouses only for non-food crops. | No specified limit. | C, S | Only use on plants that are known to tolerate dichlorvos. Do not treat stressed plants. | Not known, probably H with long residual. |
| 3A | Bifenthrin | Bifenthrin, Talstar | Ornamentals, including roses and carnations. | No specified limit | C, I | Do not apply as fog or mist | H – 8-12 weeks residual |
| 3A | Garlic, chilli, pyrethrins and piperonyl butoxide | Beat-a-bug Insect spray | Ornamentals against all whiteflies | No specified limit | C, I | Ensure thorough coverage. | M-H – 2 weeks residual |
| 3A | Piperonyl butoxide | Synergy | Cucurbits and tomato only | No specified limit, but rotate mode of action. | C, I | Must be mixed with registered or permitted rate of Talstar 100EC | H – 8-12 weeks residual |
| 3A | Pyrethrins | PY-Omni, Pyzap, PY-Bo | Ornamental registration against all whitefly species. | No specified limit. | C, I | Ensure thorough coverage | H – 1-3 weeks residual |
| 4A | Acetamiprid | Crown | Ornamental registration for SLW and GHW. | No specified limit. | C, I, S, T | Spray to point of run-off on both leaf surfaces. | H – 8-12 weeks residual |
| 4A | Imidacloprid | Confidor | Ornamentals, plus various permits available for nursery stock in certain jurisdiction, e.g. PER 13124, PER13953, all against SLW only. | Do not apply in consecutive sprays within and between seasons with any other product of the same group. In confined environments: no more than 1 spray per crop for annuals, or 3 sprays in any 12 month period for perennials. | C, I, S | Applications should target nymphal stages. Ensure thorough coverage on both leaf surfaces. Refer to each label/permit. | H – 2-12 weeks residual depending on predator |
| 7C | Pyriproxyfen | Admiral | PER12659 Non food nursery stock including seedlings and plugs, potted colour trees and shrubs, foliage plants, palms, grasses and fruit trees (non-bearing) against all whitefly species. | None specified on PER 12659, however, PER 10764 limits to 2 applications per crop which should be followed to avoid resistance. | C, T | Controls juvenile stages only. Apply 7 – 10 days after initial appearance of adult whitefly or when nymphal whiteflies are present above economic threshold. Rotate with different MOA groups. | L-M on adult wasps; H with 4 week residual on wasp pupae; unknown on *T. montdorensis*. |
| 9B | Pymetrozine | Chess | PER11973 Non-food nursery stock including seedling & plugs, potted colour, trees and shrubs, foliage plants, palms, grasses & fruit trees against all whitefly species | 2 per cropping season. Do not apply consecutive applications and allow a minimum 7 days between | C, S | Spray at first sign of infestation to the point of runoff. Do not apply more than 2 applications per cropping season and do not apply consecutive applications with the same MOA group. Allow a minimum of 7 days between applications. | L – 1 week residual |
| 12A | Diafenthiuron | Pegasus | PER11971 for non-food nursery stock and fruit trees against whiteflies. | 2 per annual production cycle | C, I | Do not use when greater than 20% of leaves are infested. Aim at early nymphs. Do not apply sequentially, rotate chemical groups. | Unknown, probably L-M, with 1-3 week residual |
| 16 | Buprofezin | Applaud | PER11553 for non-food nursery stock and fruit trees against SLW and GHW. All states except Vic, but permit not required in Vic. | 2 per annual production cycle, regardless of target pests | C, V | IGR – apply when nymph stages are prevalent in population, particularly crawlers. Apply 7-10 days after adults first appear in crop. Is not very active against adults. Do not use two consecutive sprays of this product. | L – 0-1 week residual |

| Mode of action group | Active ingredient | Example product name | Registration information | Limits on applications per season | Action[1] | Other information | Toxicity to beneficials[2] |
|---|---|---|---|---|---|---|---|
| 22A | Azadirachtin | Azamax, Eco-neem | All whitefly species on ornamental plants. PER 11221. Registration for eucalypt nursery plants, exotic pine and hoop pine against all whitefly species. Qld only. | Maximum of 7 applications per year between October and April. | C, I | Apply every 7 days once first appear in crop. Apply to a small area to test for phytotoxicity. Must be applied by boom spray or knapsack. | L-M – 1 week residual |
| NA | Botanical oil | Eco-oil | GHW only, on ornamentals. Some vegetables have permit (10311) for SLW. | No specified limit | C | Do not apply in temperatures exceeding 35°C. Sensitive flower heads may show oil spotting. Do not apply to heat or moisture stressed plants. | L-M – No residual |
| NA | Fatty acids – potassium salt | Bugguard, Natrasoap | Registered against all whitefly species vegetables, fruit trees, pot plants and ornamentals. | No specified limit. | C | Complete coverage is necessary on both leaf surfaces, apply morning or evening when temperatures are cooler, addition of a petroleum oil may assist control. Use lower rates when using IPM. Not suitable for delicate ferns, mosses, flowers and plants under stress. | L – no residual against *T. montdorensis*, L-H – 1 week residual for wasps, depending on species. |
| NA | Paraffinic oil | SACOA BioPest | All whitely species on flowers and foliage plant including roses and other flowering shrubs, foliage ornamentals and bedding plants, ornamental trees and a large number of fruit and vegetable species.<br><br>Registration for ornamentals limited to NSW, ACT, VIC, SA, WA, Tas only, but various other crops have registration in different combinations of states. A variety of ornamental species have registration in all states, including chrysanthemum, begonia, dracaena, ferns, gardenias, palms, philodendron, azalea, poinsettia and a number of others. | Spray no more than 4 times during growing season with 2 weeks minimum application interval. | C | Do not spray when there is obvious moisture in the leaves or the plant is under stress or in direct sunlight under glass. Avoid spraying open blooms. Oil removes the glaucous (blue) bloom from some evergreens. Do not apply to glasshouse roses. Do not apply when buds are fully opened and or shoot elongation is occurring. Test a small number of plants for phytotoxicity before spraying over a widespread area. | L-M<br>No residual |
| NA | Petroleum oils | Biocover | Ornamental flowers, foliage plants and trees and shrubs in NSW, Vic, SA, WA and Tas against all whiteflies. No general registration in all states. For all states, a large number of ornamental, fruit and vegetable species are mentioned specifically including chrysanthemum, dracaena, ferns, gardenia, palms, philodendron, azalea, begonia, camellia, hibiscus, poinsettia | No more than 4 applications per growing season with a two week minimum application interval | C | Some plants may show phytotoxicity, particularly when flowering. Do not spray when plants are wilting or otherwise under stress. Do not apply to plants in direct sunlight behind glass. | L-M – No residual |

[1] Action: C = contact; S = systemic; I = ingestion; T = translaminar; V = vapour

[2] In the context of the table, beneficials refers to *E. formosa,Eretmocerus* spp. and *T. montdorensis*. Summarised primarily from *The Good Bug Book* [21], http://www.koppert.com/, http://www.biologicalservices.com.au/, http://www.bugsforbugs.com.au/ and http://www.ipm.ucdavis.edu/

**Table 3.** Pesticides that have limited use for the nursery industry because they do not have an "ornamental" permit or registration in Australia for use against whiteflies, including SLW, GHW and other species. Results presented were from queries of Infopest and the APVMA pubcris[xi] and permit[xii] searches. Notes are also included on their use and toxicity to beneficial organisms. Always check full product labels and/or permits to determine suitability of use.

| Mode of action group | Active ingredient | Example product name | Registration information | Limits on applications per season | Action[1] | Other information | Toxicity to beneficials |
|---|---|---|---|---|---|---|---|
| 1B | Acephate | Eraser, Lancer | Registration of whiteflies on tobacco only. No ornamental registration. Qld and WA only. | No specified limit. | C, S | | H – 8-12 week residual |
| 1B | Chlorpyrifos | Chlorpyrifos | Cucurbits only. | No specified limit. | C, I, V | | H – 3-12 week residual |
| 1B | Omethoate | Folimat | Registered for carnations, chyrsanthemums, pelargoniums, roses, callistemons, Eucalyptus spp., Grevillea spp., paperbarks and wattles, no general ornamental registration | Repeat spray at beginning of renewed pest activity. | C, S, I | | H – 8-12 week residual |
| 3A | Beta-cyfluthrin | Tempo, Prolong | Whitefly registration for azaleas, hibiscus, pelargoniums and roses only; no ornamental registration. | No specified limit. | C, I | Ensure thorough coverage. | Unknown, probably H - > 2 week residual |
| 4A | Thiamethoxam | Actara | Tomatoes only for SLW and GHW | No specified limit | C, S | Apply as potting media drench, refer to label for instructions | Unknown, probably M-H – 2-3 week residual |
| 4A/28 | Thiamethoxam and Chlorantraniliprole | Durivo | No ornamental registration, but may be applied to the seedlings of a variety of brassica, fruiting vegetables and leafy vegetables. | 1 per crop | C, I, S | Final volume must be sufficient to wash product into the seedling root ball but not cause runoff or leaching from seedling cells. | Unknown, probably M-H – 2-3 week residual |
| 23 | Spirotetramat | Movento | Non-food nursery (PER12543), beans, peas, brassica vegetables, brassica leafy vegetables, cucurbits, eggplant, peppers, tomatoes, potatoes and sweet potatoes against SLW only. | 2-3 applications per crop, dependent on plant species. | I, T, S | Refer to label for each plant species; PER12543 allows for no more than 3 applications in a 12 month period per crop. | Unknown, probably L-M – residual unknown |

[1] Action: C = contact; S = systemic; I = ingestion; T = translaminar; V = vapour.
[2] In the context of the table, beneficials refers to *E. formosa,Eretmocerus* spp. and *T. montdorensis*. Summarised primarily from *The Good Bug Book* [21], http://www.koppert.com/, http://www.biologicalservices.com.au/, http://www.bugsforbugs.com.au/ and http://www.ipm.ucdavis.edu/

[xi] http://services.apvma.gov.au/PubcrisWebClient/welcome.do
[xii] http://www.apvma.gov.au/permits/search.php