Managing silverleaf whitefly in production nurseries

Background and general biology

In general, adult whiteflies are small (about 1 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.

Fig. 1. SLW on underside of rose leaves

The two main species of whiteflies which are pests of production nurseries in Australia are silverleaf whitefly (SLW - *Bemisia tabaci* biotype B) and greenhouse whitefly (GHW - *Trialeurodes vaporariorum*). This fact sheet will focus on SLW, although reference will also be made to GHW as required. 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 three biotypes recognised in Australia, biotype B and two Australian native biotypes, which may represent separate species that are morphologically identical. 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. Q biotype was reported in Australia (Qld and NSW) in 2008; however, the report was not confirmed and this biotype is now considered absent from Australia [1]. In other countries, Q biotype has developed almost complete resistance to insecticides and has become very difficult to manage.

Eggs are laid on the underside of young leaves either singly or in groups. After about 10 days (depending on temperature) first instar nymphs (‘crawlers’) hatch and move a short distance from their eggs. Subsequent nymphal instars are oval and flattened, becoming thicker as they develop. Fourth instar nymphs develop into pupae, from which adults emerge. Silverleaf whitefly develops from egg to adult in 18 to 31 days at 30°C and 20°C, respectively, or sometimes longer on some host plants. Females can lay between 50 to 400 eggs over their lifetime, starting just 24 hours after becoming an adult, depending on the temperature and host plant. About two-thirds of SLW populations are female. As a result, populations can build up relatively quickly under ideal conditions.

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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 which results 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. However, populations are not normally high enough to cause abnormalities. Instead, damage usually results from honeydew and black sooty mould. Presence of SLW may also result in restricted market access to certain states, such as WA.

SLW as a virus vector

Globally, there are hundreds of whitefly-transmitted viruses for which SLW is a vector. In Australia there are only two major viruses vectored by SLW, *Tomato yellow leaf curl virus* (TYLCV) and *Tomato torrado virus* (ToTV). ToTV is a new group of plant virus which has only been found in glasshouse-grown tomato crops in North Adelaide Plain and at Lara in Victoria [2, 3]. Early symptoms of ToTV include necrotic or dead spots, surrounded by a light green or yellow area at the base of leaflets. Damaged areas may then fall out, leaving a 'shot hole' in leaflets. Necrosis and mottling extend to the entire leaves and, in susceptible varieties, entire leaves become necrotic, wither and die (Fig. 2). Fruits may develop necrotic line patterns which often develop into cracks. ToTV is also spread by GHW.

Fig. 2. Symptoms of *Tomato torrado virus* on tomatoes, including dead areas near petioles and yellow areas around bases of leaflets. Photos by Cherie Gambley.

TYLCV was first found in south east Queensland in 2006 and now is known 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 and chilli pepper, petunia, lisianthus, poinsettia, other *Euphorbia* species and weed species (e.g. black nightshade and thorn apple) [4, 5]. Many weed species remain non-symptomatic but allow SLW feeding on them to acquire and transmit the virus to other hosts [6]. Growth of tomatoes infected with TYLCV is relatively slow and plants become stunted. Leaflets become rolled upwards and inwards and develop interveinal chlorosis (Fig. 3). Leaves often become bent downwards and are unusually stiff. The yield and fruit quality of infected plants is also much reduced. The margins of leaves have a yellow fringe and will set very few fruit after infection.

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 [7]. ToTV is acquired in a similar manner but is only retained in whitefly for a few days [3].

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. Resistant varieties of plants are available for both ToTV and TYLCV.

Fig. 3. Symptoms of *Tomato yellow leaf curl virus* on tomato, including leaf curling and interveinal chlorosis. Photos by John Thomas and Denis Persley.

Host range and varietal resistance

SLW have can reproduce and/or feed to varying degrees on more than 600 plant species, with new hosts being recorded over time [8, 9]. 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 [10], 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 [10, 11]. 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. 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 SLW infestations. This information can be used to help make decisions to manage SLW 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 at the farm and environmental conditions. The exact management strategy therefore has to be tailored to each farm. However, the following actions should generally assist in the management of SLW.

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 [13]. However, highly residual products will increase the likelihood of the development of resistance, particularly if applied regularly. SLW is notorious for developing resistance to chemicals that are overused. Therefore, it is recommended to not to 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 (various MOAs) [14]. Do not continue to apply insecticides that are not effective in controlling SLW; this will increase insecticide resistance.

Chemical control of SLW should not be relied upon solely. Cultural and biological controls should be employed to prevent or at least minimise whitefly infestations, with insecticides used in a targeted, strategic manner to clean up any high level infestations. To assist growers in management decisions, all insecticides which are registered or that have permits for use on ornamental plants are summarised in Table 1. Registrations and permits on horticultural crops that are part of the nursery sector, but without a general ornamental label, are summarised in Table 2. Included in these tables are notes on their effect on beneficials and prevalence of insecticide resistance. Tables are current as of September 2012. Check the APVMA website registrations[i] and permits[ii] for changes to labels.

Cultural control

The prevention of whitefly infestations and their spread are very important for successful management, as large populations can build up quickly and can be difficult to control. 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 hosts of SLW [12]. Good weed management will also help reduce a variety of other pest problems including aphids, thrips and mealy bugs.
2. Distinguish GHW from SLW (Fig. 4). Management of SLW is more difficult because it is much more likely to become resistant to insecticides. Furthermore, 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 SLW. Use resistant varieties whenever possible.
4. Prune and thin plants with light to moderate infestations to reduce pest load, increase airflow and access by insecticides.

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

5. Remove and destroy heavily infested stock. Retaining unsaleable stock provides a 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 farm, particularly as the plant material starts to wilt and die.
6. Screens (mesh size of < 0.19 mm / 400 microns) 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 [15]. 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 SLW for a season 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 farm.
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).

Fig. 4. 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.

Fig. 5. 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).

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 of your farm. If necessary, apply an insecticide or oil spray to kill adult flies before destroying the crops.
13. Reduce weeds around your farm, as they can harbour viruses and may remain non-symptomatic.
14. Plant virus-resistant plants in areas where the virus is likely to be a problem.

Monitoring whitefly

Plants should be inspected on a weekly basis for the presence of whitefly and data recorded. Increase the frequency of monitoring during warmer weather and on host plants which are known to be more susceptible to SLW. 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 leaves of plants that look stunted or are chlorotic on both leaf surfaces 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, 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 farm. 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 on the farm and thus help in allocating search effort. It is also important to note that whiteflies are more difficult to detect on pale yellow or 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 SLW. 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 SLW and produce highly visible damage. SLW that enter the nursery will be more likely to land and stay on these plants. Two good indicators are squash and melon seedlings, as their leaves turn silver with low numbers of SLW [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 farm may lend themselves to a 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 farm.

Biological control

In Australia there are five commercially available whitefly biological control agents, four of which are effective against SLW. 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 [15]. Probably the most effective of those available is *Eretmocerus hayati*, a small parasitoid wasp. *Encarsia formosa* is another small parasitoid wasp which is effective against both SLW and GHW. *Typhlodromips montdorensis* is a small predatory mite which is a significant predator of whiteflies and thrips, but also feeds on broad mites, rust mites (family Eriophyidae) and spider mite eggs. *Mallada signata*, the green lacewing, feeds on a range of pests including scales, whiteflies and many other herbivores. *Eretmocerus warrae* is a small parasitoid wasp but is only effective against GHW, not SLW. There are also a number of native or naturalised predators and parasitoids that may provide control of SLW under the right conditions (e.g. when pesticides that cause significant mortality to predators are not used).

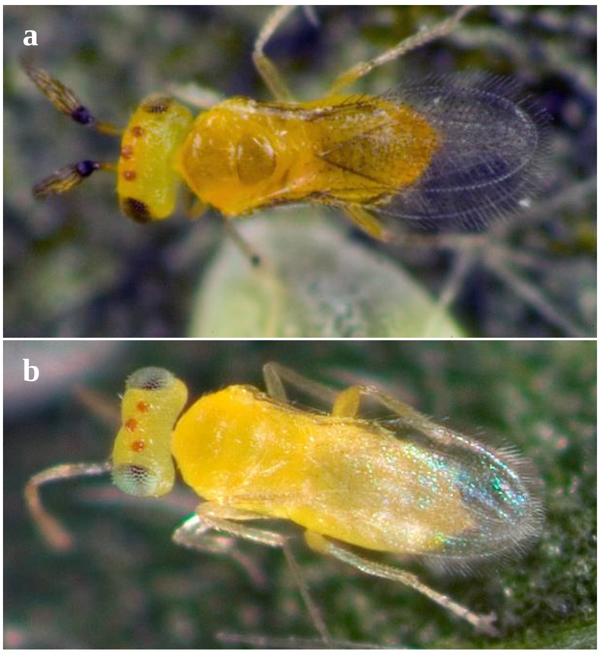

Fig. 6. Male (a) and female (a) *Eretmocerus hayati* are about 0.5 mm in length. Photos by Paul de Barro.

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 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.

Eretmocerus hayati (hayati)

The most effective parasitoid of silverleaf whitefly in Australia is hayati [17]. This small wasp (Fig. 6) was introduced into Australia from Pakistan in 2004 and has spread to Narrabri and the Sydney Basin [18]. 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 [19, 20], i.e. each female can potentially kill over 200 SLW nymphs. In addition, adults host feed on hosts which are not parasitised further increasing mortality to SLW. Their development takes about 12 to 32 days at 30°C and 20°C, respectively. In areas where *Er. hayati* is present, as much as 85% of parasitism is contributed to the parasitoid, with only 24% of samples having no parasitism. Prior to the release of *Er. hayati*, only 25% of samples had any parasitism [17]. As such, hayati should be used first under conditions which are conducive to its survival.

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 currently in the process of making this wasp commercially available.

Encarsia formosa (encarsia)

Fig. 7. *Encarsia formosa* adult wasp.

Encarsia is a black and orange parasitoid wasp which is very small (about half a millimetre) (Fig. 7). 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 [21]. 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 about 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 [22,23]. The wasp also feeds on young nymphs, sometimes causing significant mortality.

Encarsia is favoured in 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 [23]. Encarsia is made commercially available in Australia by Biological Services.

Transeus montdorensis (montdorensis) = *Typhlodromips montdorensis*

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. It is a pale, teardrop-shaped mite which is about 1mm in length (Fig. 8); 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, but eggs and immatures are not. 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 [24].

Fig. 8. The predatory mite, *Transeus montdorensis*, is an opaque white or yellow mite a little less than 1 mm. Photo by Marilyn Steiner.

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 made commercially available in Australia by 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

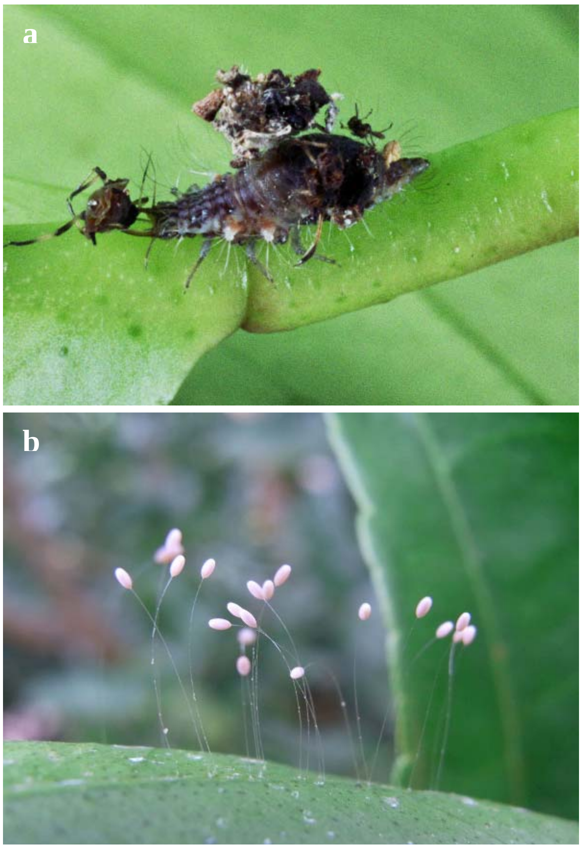

Fig. 9. Larvae of the green lacewing (a) grow to about 8 mm. Eggs are laid in clusters (b), each on a thin stalk. Photos by Dan Papacek.

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 [25]. 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 made commercially available by Bugs for Bugs.

Other naturalised beneficials

While the most effective parasitoid of silverleaf whitefly in Australia is *Eretmocerus hayati* [20], there are a variety of other native SLW parasitoids present in Australia, including two additional *Eretmocerus* species and 11 *Encarsia* species [26]. In general, *Eretmocerus* species that parasitise SLW tend to be more effective than *Encarsia* spp, including *E. formosa*. However this is modified by the host plant on which SLW is present. To encourage natural parasitism of whiteflies on your farm, limit broad spectrum, systemic and highly residual insecticide applications as all of these parasitoids are very sensitive to such products.

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.

This document was prepared by Andrew Manners and Lara Senior (Agri-science Queensland, Department of Agriculture, Fisheries and Forestry, Redlands Research Facility, PO Box 327, Cleveland, Qld 4163) as part of NY11001 Plant health biosecurity, risk management and capacity building for the nursery industry. Thanks go to Janelle Dahler, Zara Hall, Cherie Gambley (All QDAFF), Lynita Howie (CSIRO) and John McDonald (NGIQ) for help in the preparation of the document and Zara Hall and Grant Herron (NSW DPI) for comments on the levels of pesticide resistance in Australia presented in Table 1 and 2.

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Table 1. Pesticides currently registered or with minor use permit in Australia for ornamental use whiteflies, including SLW, GHW and other species. Results presented were from queries of Infopest, 2012 and the APVMA pubcris and permit searches. Notes on their use, toxicity to beneficial organisms and the level of resistance (which has been combined according to mode of action group). 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]	Notes on insecticide resistance
1B	Dimethoate	Dimethoate	PER13156 for ornamentals and flowers.	No specified limit.	C, S	Apply at 10-14 day intervals as needed.	H – 4 weeks residual	Widespread, high levels of resistance on Australian cotton [14]
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	Widespread, high levels of resistance on Australian cotton [14]. Repeat sprays of bifenthrin more likely to result in resistance and failure to control SLW populations [27].
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	Widespread low to moderate levels of resistance to imidacloprid on Australian cotton [14].
4A	Imidacloprid	Confidor	Ornamentals, plus various permits available for nursery stock in certain jurisdiction (e.g. PER 11936, 13124, 11560	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.	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*.	Low to high levels of resistance detected from melons, rockmelon and honeydew in localised areas [28]. Resistance also detected in cotton in Australia and overseas [27].
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	Not in Australia, but is reported in other countries [29]. Cross resistance to imida-cloprid and neonicotinoids reported [30].

Mode of action group	Active ingredient	Example product name	Registration information	Limits on applications per season	Action[1]	Other information	Toxicity to beneficials[2]	Notes on insecticide resistance
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	Very low widespread levels of resistance present [27, 28].
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	Not reported in Australia.
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	Not reported in Australia.
NA	Fatty acids – potassium salt	Bugguard, Natrasoap	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.	Not reported in Australia.
NA	Paraffinic oil	SACOA BioPest	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. 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 No residual	Not reported in Australia.
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	Not reported in Australia.

Table 2. 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, 2012 and the APVMA pubcris[i] and permit[ii] searches. Notes on their use, toxicity to beneficial organisms and the level of resistance (which has been combined according to mode of action group) are also included. 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	Notes on insecticide resistance
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	Widespread, high levels of resistance on Australian cotton [14].
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	Widespread, high levels of resistance on Australian cotton [14].
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	Widespread low to moderate levels of resistance to imidacloprid on Australian cotton [14].
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	Not reported in Australia.
22A	Azadirachtin	Azamax	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	Must be applied by boom spray or knapsack.	L-M – 1 week residual	Not reported in Australia.
23	Spirotetramat	Movento	Beans, peas, brassica vegetables, brassica leaf vegetables, cucurbits, eggplant, Peppers and potatoes.	2-3 applications per crop, dependent on plant species.	I, T, S	Refer to label for each plant species.	Unknown, probably L-M – residual unknown	Not reported in Australia [27].

[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* [23], http://www.koppert.com/, http://www.biologicalservices.com.au/, http://www.bugsforbugs.com.au/ and http://www.ipm.ucdavis.edu/

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