Managing western flower thrips in production nurseries

Background and general biology

Fig. 1. First and second instar WFT larvae on a cucumber, about 0.5-1 mm in length.

Western flower thrips (WFT – *Frankliniella occidentalis* Fig. 1) is an economically important insect pest for many vegetable, ornamental and flower crops, including, tomatoes, capsicums, beans, lettuce, eggplant, cucumbers, grapes, apples, plums, strawberries, chrysanthemums, gerberas, anthuriums, lisianthus, dahlias, roses and other crops. Injury to flower buds and growing points causes scarring, wilt and discoloration, presenting as distortion as the foliage (Fig. 2), flowers and fruit grow and develop. Damage may cause halo-spotted dark marks on foliage, surrounded by white tissue. It also serves as a vector for tospoviruses such as *Tomato Spotted Wilt Virus* (TSWV), a virus which causes economic losses in a broad range of potted ornamental crops, cut flower crops and vegetables. While native to North America, WFT was first found in Australia in 1993 and has since spread to all production areas of Australia.

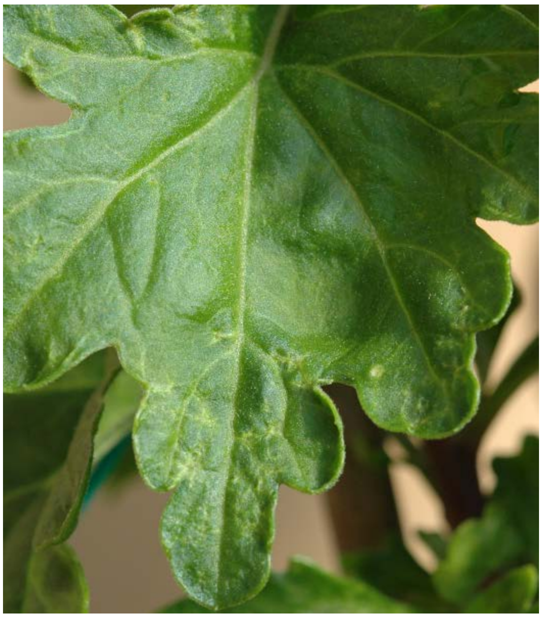

Fig. 2. Thrips damage on chrysanthemum leaves.

It is widely recognised that WFT control is difficult due to its high reproductive rate, its tendency to inhabit protected areas of the plant (e.g. the growing tip and flower buds) and its resistance to many insecticides. Therefore, chemical treatments are not sustainable in the long term and should only be used when all other measures have taken.

WFT are slender, sausage-shaped insects. Larvae are very small, ranging from 0.5-1 mm (Fig. 1), opaque and wingless. Pupae are largely immobile, non-feeding and are generally around 1 mm. Adults are pale yellow to dark brown, ranging between 1.5-2 mm, with males being slightly smaller and of a more slender build than females.

Female WFT lay eggs into flowers and foliage and hatch in about 2-4 days at optimal temperatures of 25-30°C [1]. There are two larval instars which take about 8-10 days, depending upon the temperature and host plant. Late 2nd instar larvae either pupate on plants, generally in small crevices, or in the soil. The proportion of thrips that pupate in the soil or on plants is directly influenced by humidity; 80% RH or less causes

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thrips to drop from plants and pupate in the soil [2]. Furthermore, WFT pupae can not survive lower than 80% RH [2]. Pupation behaviour is probably also influenced by availability of suitable pupation sites on plants which may act to buffer against low humidity environments, e.g. flower buds and growing tips may create a microclimate suitable for survival of pupae. Rates of soil pupation have sometimes been reported as being very high, e.g. about 50-90% on chrysanthemums [3], roses [4], beans [5] and cucumbers [6]. However, sometimes very low rates of pupation (i.e. <10%) have been reported on cut flowers [7] and lettuce [2]. If soil pupation rates are high, releasing soil predators could be beneficial, however, if low, the benefit may be limited.

Females may live for up to 4-5 weeks at 28°C [8] and may lay more than 200 eggs [1]. In addition, populations are often about 70% female [9], allowing for very rapid population increases. Flight activity, in terms of thrips taking flight, of WFT in the UK peaked just before midday [10]. While this behaviour could be modified under typical Australian conditions, activity seems to increase during daylight hours and with temperature; WFT do not take-off at 15°C, take-off increases from 20-30°C, with 30°C showing maximum rates of take-off. Rates of take off do not increase between 30-40°C and death occurs around 45°C [10].

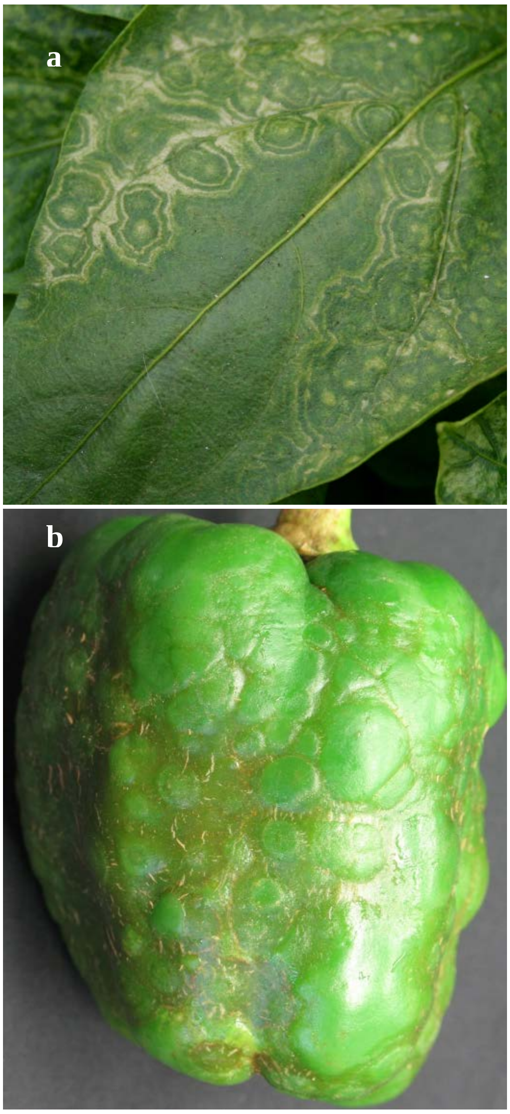

Fig. 3. Symptoms of TSWV on capsicum leaves (a) and fruit (b). Photos by Cherie Gambly and Denis Persley.

Thrips and tospoviruses

Many thrips species in Australia vector tospoviruses, including WFT, onion thrips (*Thrips tabaci*), tomato thrips (*F. shultzei*) and melon thrips (*Thrips palmi*). Once infected, plants can not be cured. Therefore, preventative measures must be put in place to reduce the risk associated with virus outbreaks. The major tospoviruses found in Australia are TSWV, *Capsicum chlorosis virus* (CaCV) and *Iris yellow spot virus* (IYSV) [11]. Symptoms can vary considerably (Figs. 3-4) and information on symptoms, biology, and host range are available online [11].

Only larval thrips acquire tospoviruses from feeding on infected plants for as little as 30 minutes. The virus multiplies in the thrips and can be transmitted to other plants when adult thrips feed on another plant for as little as 5 to 10 minutes. Tospoviruses are not spread by seed but will be transmitted when cuttings and bulbs are taken from infected plants [11].

Host range and varietal resistance

While WFT can cause direct damage to a wide range of crops, as listed above, some plants are better hosts than others. For example, survival of larval thrips on thrips-resistant (TR) capsicum (variety 'CPRO-1') was about 20% of that of larvae on susceptible (TS) capsicums, thrips actively moved away from TR plants in search of TS plants and females laid fewer eggs or TR plants [12]. Unfortunately, WFT appears to have a high reproductive capacity on a wide range of hosts [1]. Since the whole range of plant species produced in the nursery sector has not been tested, it is likely that some varieties will be more susceptible to WFT than others. In addition, predators may be more or less effective on different host plants. For example, *Orius albidipennis* (not commercially available in Australia) reduced thrips populations on sweet pepper and eggplant, but not on cucumber [13]. Therefore it is important to take records of plant species and varieties which are more or less susceptible as this information can be used to help make decisions to manage WFT more successfully.

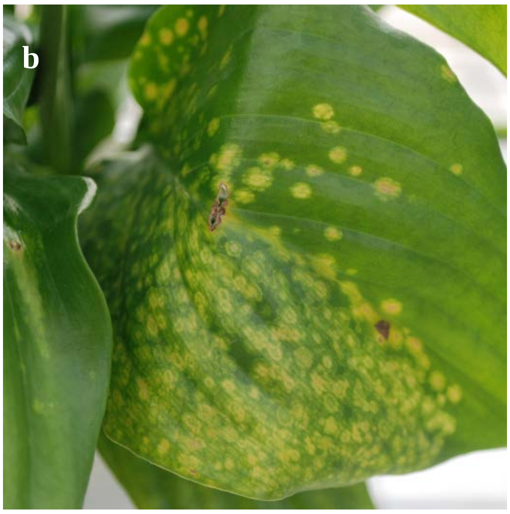

Fig. 4. Symptoms of *Impatiens necrotic spot virus* (INSV) on (a) begonia and (b) sphathphylum. This virus, vectored by WFT, was eradicated from NSW in 2010 (Len Tesoriero, NSW Primary Industries, personal communication) but would cause significant economic loss to many nursery and vegetable crops if it were to become established in Australia.

Managing WFT

Host plants that are flowering or have flower buds are more attractive than plants without buds or flowers [7, 14]; i.e. WFT are more likely to land and reproduce on flowering host plants. Therefore, careful attention should be given to plants just prior to flowering so as to prevent WFT populations from increasing. Continue preventative actions throughout flowering periods, particularly in warmer conditions. Since populations can build up rapidly, monitor plants regularly, particularly those varieties that are more susceptible, as indicated by records at your farm. Do not rely on insecticides to control WFT.

Chemical control and insecticide resistance

WFT is notorious for developing resistance to chemicals that are overused. The majority of WFT are found in protected regions of their host plants (growing tips and flower buds). Therefore, contact pesticides may not provide adequate control. Low-risk translaminar products (chemicals that penetrate through plant tissue a short distance, but do not travel through the entire plant) are more likely to be effective. However, highly residual products will increase the likelihood of the development of resistance, particularly if applied regularly. Widespread, low to high level resistance exists in Australia for a wide range of products, e.g. OPs, pyrethroids, spinosyns and avermectin products. Research shows that three consecutive sprays 3-5 days or 6-12 days intervals depending on temperature. Then switch to a product with a different mode of action after 2-3 weeks. Refer to the NSW DPI insecticide resistance management plan for more details[i]. Read the label carefully and follow instructions to ensure insecticides are used correctly and for maximum efficacy. Do not continue to apply insecticides that are not effective in controlling WFT; this will increase insecticide resistance.

Chemical control of WFT should not be relied upon solely. Cultural and biological controls should be employed to prevent and minimise WFT infestations, with insecticides used in a targeted, strategic manner to clean up any high level infestations. To assist growers in

[i] http://www.dpi.nsw.gov.au/agriculture/horticulture/pests-diseases-hort/multiple/thrips/wft-resistance

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[ii] and permits[iii] for changes to labels.

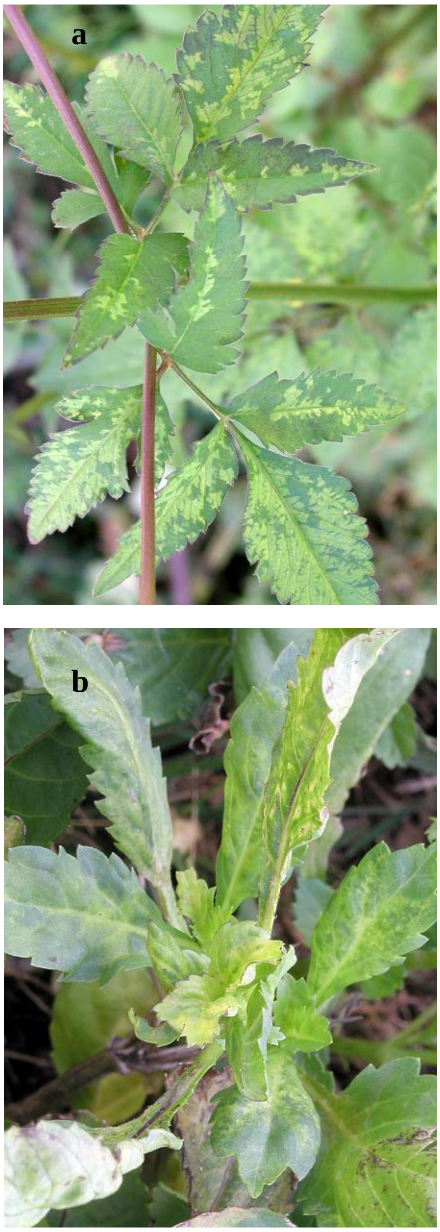

Fig. 5. Symptoms of TSWV on cobbler's peg (a) and snake weed (b)which can be common weed hosts. Photos by Denis Persley.

Cultural control – modify for WFT

The prevention of WFT 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 WFT successfully to reduce economic impacts, particularly if the host is susceptible to tospoviruses.

1. Manage sources of infestation: control broad-leaf weeds and reduce other alternative hosts in the production area and surrounds. The use of weed matting, plastic or gravel on the floor can help nursery situations. Good weed management will also help reduce a variety of other pest problems including aphids, whiteflies and mealybugs.
2. Check incoming stock, new seedlings and other new planting material to ensure it is clean and to break the lifecycle of WFT. Use resistant varieties whenever possible.
3. Prune and thin plants with light to moderate infestations to reduce pest load, increase airflow and access by insecticides.
4. 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.
5. Screens placed over greenhouse vents and doors can be used to help prevent entry by thrips. 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.
6. If infestations persist for long periods in a particular area or glasshouse, grow plants that are not hosts of WFT for a season to break the life cycle.
7. 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.
8. Identify the species of thrips infesting your crop. Some thrips are more resistant to

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

insecticides and some thrips are predators of pestiferous thrips, e.g. *Haplothrips*. With practice, a keen interest in learning and the use of a quality stereo microscope it is possible make preliminary identifications of thrips (Fig. 6). Free online resources can help as they have many pictures which will aid in the identification process [iv]. However, when in doubt, contact your local department of agriculture or Grow Help Australia [v].

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. 6. Adult WFT showing important taxonomic characters including two pairs of large setae on the front and back of the pronotum (circled) and large pair of setae between red ocelli relatively wide. This provides only a preliminary identification for WFT.

Additional and important steps to manage whitefly transmitted viruses

11. Do not transport plants from areas with thrips and viruses to areas without the virus.
12. Dispose of throw-outs promptly, ensuring that thrips will not migrate from the plants to other parts of your farm.
13. Reduce weeds around your farm, as they can harbour viruses and may remain unnoticed or non-symptomatic.
14. Use resistant plants where possible but do not rely solely resistant plants; maintain high levels of cultural control practices mentioned above.

Monitoring for thrips

Plants should be inspected on a weekly basis for the presence of thrips and data recorded. Increase the frequency of monitoring during warmer weather and on host plants which are known to be more susceptible to WFT, particularly during periods with strong, warm winds. Frequent monitoring will enable infestations to be spotted while they are still light, and thus easier and cheaper to manage. Methods of monitoring include:

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, chlorotic or have silvering on both leaf surfaces using a x10 hand lens. Thrips tend to inhabit crevices near leaf veins and growing tips. 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 thrips,

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[iv] http://www.hin.com.au/Resources/Western-Flower-Thrip-Identification
http://keys.lucidcentral.org/keys/v3/thrips_of_california/identify-thrips/identify-thrips.html
http://anic.ento.csiro.au/thrips/identifying_thrips/index.html (click on families to identify thrips to family, then use the key for that family. The visual glossary is also very helpful).

[v] http://www.daff.qld.gov.au/4790_12360.htm

herbivorous and predatory mites, aphids, whiteflies, lady beetles, small caterpillars and a variety of other insects. However, thrips may fly off the beating tray quickly, so beat a few metres worth of plants and then examine the tray. 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. Additional information (e.g. symptoms, extent of damage) may also be useful and will help assess efficacy of management actions. Accurate records can help determine long-term patterns of host use on the farm and thus help in allocating search effort. Remember that damage to growing tips requires some time to grow out. Thus symptoms may still occur for sometime after thrips have been eradicated, depending upon the growth rate of the plant.

2. Yellow sticky traps are useful tools for monitoring thrips adults. Adults are most attracted to young foliage and flowers, 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 thrips. Inspect sticky traps at least weekly and change traps every 2 to 4 weeks.

Fig. 7. Yellow sticky trap placed under the foliage of plants to trap WFT adults and immatures.

3. If you are considering using soil biocontrol agents, first determine if there are significant numbers of thrips in the soil. This can be done by placing yellow sticky traps under the canopy of a crop, sticky side up. Pupating larvae drop from plants, landing on the trap, and can then be examined under a microscope. Alternatively, place a wire mesh over the pot and place sticky traps, sticky side down, over the mesh (this prevents dirt and other material from becoming stuck on the sticky trap). Adults emerging from the soil will be caught in the sticky trap which can then be examined (Fig. 7). If there is significant soil activity, as indicated by adults emerging from the soil, larvae dropping from the plant or both), soil predators are likely to be beneficial. If few WFT are in the soil, soil predators are unlikely to be beneficial.

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. 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

As mentioned above, there are two types of thrips predators available commercially, foliage and soil predators. Foliage predators generally consume larvae, although *Orius armatus* can also consume adults. Soil predators only consume pupae that pupate in the soil. When using a predator for the first time, it is recommended to talk to your biocontrol agent provider for information that may be important to your exact situation which may enhance its successful use.

Foliage predators

Research in cut flowers indicates that foliage predators are more effective in controlling numbers of WFT than soil predators. Reductions of 30-99% WFT were recorded, depending on the life stage of thrips and area of host plant (see online factsheet currently available [7]).

Orius armatus (*Orius*)

Orius armatus (Fig. 8) is an Australian native pirate bug which is similar to other *Orius* spp. overseas, however little research into its biology has been completed. *Orius* is the only commercially available thrips predator that consumes significant numbers of adult thrips. Besides adult thrips, *Orius* will consume thrips larvae, aphids, spider mites, butterfly and moth eggs and pollen. *Orius* develops from egg to adult in about 12-18 days at 30-25°C. Adults live for 3-4 weeks. At 20°C, *Orius* consumes about 2 thrips per day, but will kill more thrips at high pest densities and temperatures. Adults are able to fly and readily disperse to new areas to find prey. *Orius* is light sensitive and less likely to be active during cool, dark periods of the day.

Fig. 8. *Orius armatus* nymph on the bud of a chrysanthemum.

All but the most low toxic insecticides and fungicides will cause significant mortality to *Orius*, e.g. bifenazate and BT sprays are relatively safe but many other products are not. *Orius* is made commercially available by Manchil IPM Services.

Neoseiulus cucumeris (cucumeris) = *Amblyseius cucumeris*

Fig. 9. *Neoseiulus cucumeris* next to a larval thrips. Photo by Biological Services.

Cucumeris is a small (a little less than 1 mm), tear-drop shaped, opaque predatory mite which looks similar to montdorensis (below) and is of the same family as the widely used spider mite predator, *Phytoseiulus persimilis*. Cucumeris feeds on a variety of prey including thrips larvae, broad mites, pollen and a variety of other small insect and mite prey, including spider mites [15]. Development of cucumeris takes about 8-11 days at 25-20°C and subsequent adults live for about 3 weeks. No development occurs less than 13°C and above 32°C. They prefer conditions greater than about 65% RH. Females lay about 30 eggs over their adult life [16] and may eat up to 4 thrips larvae per day [15]. Cucumeris can be used in most greenhouse and nursery crops and will persist without prey when pollen is available. While cucumeris has been used successfully for thrips control in cucumbers, capsicums, eggplants, gerberas, roses, chrysanthemums and other potted plants, they are not effective on tomatoes or geraniums due to leaf structure and toxic plant exudates.

Cucumeris is sensitive to persistent insecticides, particularly pyrethroids and organophosphates. Direct contact with more low-risk pesticides may still have significant negative impacts on cucumeris survival, e.g. abamectin and spinosad [17]. Cucumeris is made commercially available through Biological Services and Manchil IPM Services.

Transeus montdorensis (montdorensis) = *Typhlodromips montdorensis*

Montdorensis (Fig. 9) 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 1 mm 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 a short period, 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 [18].

Fig. 9. 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 insecticides, 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

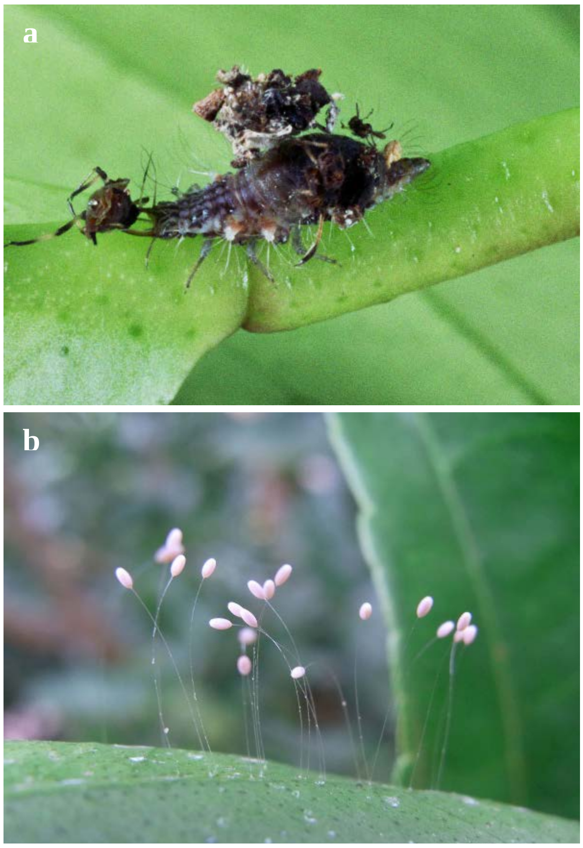

Fig. 10. Larvae of the green lacewing (a) grow to about 8 mm. Eggs are laid in clusters (b), each on a thin stalk. Photos by Dan Papacek.

mites, various scales, mealy bugs, moth eggs and small caterpillars as well as whitefly species. Pollen and nectar can also be ingested. Larvae (Fig. 10a), but not adults, are predacious. Adults have a green body and hold their transparent wings tent-like 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. 10b). 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 [19]. 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 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.

Soil predators

Soil predators can be used to provide good control of WFT in certain situations, i.e. when a significant portion of WFT pupate in the soil. However, research has shown that this is not always the case [7]. There are a number of simple ways to determine if WFT are pupating in the soil under particular crops described above in the monitoring section.

Geolaelaps aculeifer (*Hypoaspis* A or killer mite) = *Hypoaspis aculeifer* *Stratiolaelaps scimitus* (*Hypoaspis* M) = *Hypoaspis miles*

Fig. 11. Both *Stratiolaelaps scimitus* and *Geolaelaps aculeifer* are very similar in appearance. Above is an adult *S. scimitus*. Photo by Biological Services.

Geolaelaps aculeifer is a relatively large, brown to orange coloured, soil-dwelling predatory mite (about 1 mm in length). Nymphs and adults feed on thrips pupae that pupate in the soil and on a variety of other soil organisms, including nematodes, springtails, fungus gnat larvae, root aphids and mites, preferring moist habitats high in organic material. The killer mite takes about 12 days to complete development at 27°C, but up to 40 days at 16°C and can survive for long periods scavenging on soil arthropods without specific pest prey. Temperatures above about 30°C are detrimental and activity below 10°C is very low. Soil conditions do not always reflect outside air temperatures and this should be taken into account when deciding to use soil predators. Direct sun on the container of plants may increase the temperature for media within pots compared to air temperature. By contrast, soil in the shade may be substantially cooler than air temperature. Females lay about 3-4 eggs per day under good conditions.

Strateolaelaps scimitus feeds on a similar range of prey as *G. aculeifer*, thrips pupae in the soil, fungus gnat larvae, nematodes and other small soil arthropods. Females lay about 2-3 eggs and consume 1-5 prey items per day. Development from egg to adult ranges from 10-18 days at 25°C and 20°C, and 30 or more days at 15°C.

In laboratory studies, *G. aculeifer* was more voracious than *S. scimitus* (*Hypoaspis* M). Consult Biological Services for which species best suits your growing needs prior to first use. While soil predators may have some protection from foliar sprays of insecticides, run-off from high impact pesticides can still have a negative effect on predators, particularly if they have long residual activity. Biological Services is the only provider of *G. aculeifer* and *S. miles* in Australia and they are called *Hypoaspis* A and M, respectively, on their webpage.

Dalotia coriaria = Atheta coriaria

Adults and larvae of the rove beetle, *Dalotia coriaria*, feed on a range of small insects and mites, feeding heavily on thrips pupae, fungus gnats and shoreflies eggs and first instar larvae [20]. Adults are slender, fast moving glossy blackish-brown beetles that are 3-4 mm long. Optimum temperature for *D. coriaria* is 27°C, at which temperature development is completed in 13 days. Adults have wings and may fly to find food. Adults live about 21 days and lay about up to 8 eggs per day. Biological services is the only provider of *D. coriaria* in Australia.

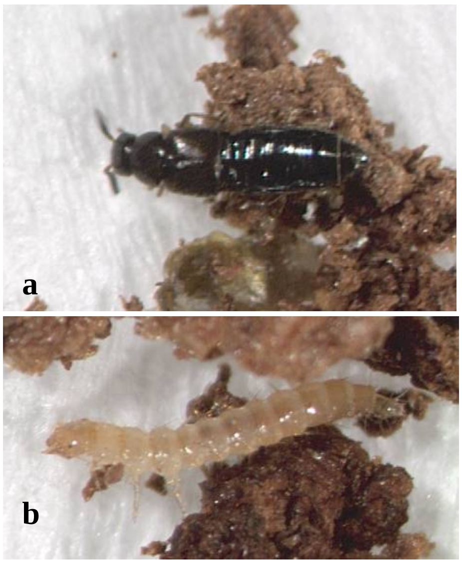

Fig. 11. *Dalotia coriaria* adult (a) and larva (b). They are about 3-4 mm in length.

Insect-eating nematodes (e.g. *Steinernema feltiae*)

Insect-eating (entomopathogenic) nematodes are tiny, very slender, worm-like, soil-dwelling organisms that are a little less than 1 mm in length. The nematodes have limited dispersal capacity and thus must be drenched into the growing media at high rates. Once they come in contact with a host, they enter it and release a bacteria which breaks down the tissue into food. Thousands of nematodes can breed within a certain hosts, largely dependent on its size, e.g. up to 100 000 nematodes can develop from a single scarab beetle larva. Once the food is completely consumed the host basically disintegrates, releasing the nematodes into the soil to infect new hosts.

Internationally, research has shown significant WFT mortality associated with soil predators. The exact species, culture (for nematodes) and combination of predators applied played a critical role in the level of WFT mortality, which was often 40-80% [21-23]. This indicates that different ‘strains’ or formulations of each species of nematode have differential virulence to WFT. It is not known which nematode commercially available in Australia is most effective at reducing numbers of WFT pupae, however *Steinernema feltiae* often performs well overseas.

There are two producers of insect-eating nematodes in Australia, Ecogrow and Becker Underwood.

This document was prepared by Andrew Manners (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 Cherie Gambley for advice related to viruses vectored by WFT and Grant Herron for information regarding pesticide resistance of WFT.

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Table 1. Pesticides currently registered or with minor use permit in Australia for ornamental use against thrips, WFT 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 and efficacy against WFT
1B	Acephate	Lancer	PER 12378 for non-bearing ornamental crops, tomatoes and peppers	Do not reapply if the first application does not exert control	C, S	None	H – 8-12 weeks residual	Low level resistance detected [24].
1B	Diazinon	Diazinon	For all thrips species on nursery plants in NSW and Vic, sometimes also in ACT and WA. Also registered against certain thrips on beans, cucurbits, onions, garlic, tomatoes and bananas.	No limits on label	C, I, V		M-H – about 3 weeks residual	Not known in Australia but low to high resistance has been detected overseas [25].
1B	Dimethoate	Dimethoate	PER 13156 on nursery plants and flowers against all thrips species	No limits on permit.	C, S, I	Registration has been suspended. See the APVMA for further information.	H – 8-12 weeks residual	No resistance detected [24]. Not effective in Australian pepper field trials [26].
1B	Fenamiphos	Fenamiphos, Nemacur	For all thrips species in ornamental plants, some labels not registered in Tas.	No limits on label	C, S, I		Unknown, probably high toxicity with a relatively long residual	Not reported.
1B	Maldison	Maldison	Most products are registered for ornamental use against all thrips species, in all states except Queensland.	No limits on label.	C, S, I		H – at least 3 weeks residual.	Not reported.
1B	Methamidophos	Nitofol	For use on ornamentals against WFT only and all thrips species on gladioli.	No limits on label.	C, S, I	Very toxic to human health.	H – at least 3 weeks residual.	Sporadic low to medium resistance when over used [27].
1B	Methidathion	Supracide	For use on ornamentals, trees, shrubs in nurseries, parks, gardens and forestry situations against all thrips species. PER 10265 on ornamentals (non-bearing) against WFT only.	No limits on label/permit.	C, I		H – 6-8 weeks residual	Sporadic low to high level resistance [27]. Some trials have shown limited efficacy in Australian pepper field trials [26].
2B	Fipronil	Regent	PER 9929 only allows for use as a quarantine treatment of ornamental nursery stock. All thrips species allowed.	For quarantine treatments only.	C, S, I	Do not handle plants for 48 hours following application.	H – at least 1 week residual	Low level resistance [24].
3A	Pyrethrins and piperonyl butoxide	S-Py, Py-Bo	For all ornamentals against all thrips species.	No limit on label.	C		H – at least 4 weeks residual	Widespread high level resistance to pyrethroids; not recommended against WFT [24, 28].
4A	Acetamiprid	Crown 58558	Registered against plague thrips and greenhouse thrips on ornamental plants.	No limits on label.	C, I, S, T	Do not use against WFT. Identify thrips species before use.	H – 6-7 weeks residual	No resistance detected [24].
4A	Imidacloprid	Confidor, Spectrum	Only registered against greenhouse thrips on ornamental plants as a foliar spray only. Not all products are registered for greenhouse thrips on ornamental crops.	No limits on label.	C, I, S		H – 2-4 weeks residual as a foliar spray; L toxicity as a soil drench.	Not reported but has been shown to be ineffective in Australian pepper field trials [26].

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 and efficacy against WFT
5	Spinetoram	Success neo	For all ornamentals against WFT only.	Make 3 consecutive sprays 3-5 days apart (6-12 days apart less than 20°C) then switch to a different product from another chemical group.	C, I		Unknown – probably moderate toxicity with low residual.	Not reported in Australia but strong spinosad cross resistance highly likely [29].
5	Spinosad	Success2	Ornamental registration against WFT.	No more than 3 consecutive applications.	C, I	Make 3 consecutive applications at various intervals dependent on temperature. See lable for details.	M – 1 week residual.	High level resistance [24].
6	Abamectin	Vantal 18 EW	For ornamental use, including roses, chrysanthemums, carnations and indoor foliage plants against WFT, also many vegetables registered. Can only be used against melon thrips for interstate quarantine requirements	No more than 2 times per season.	T, I	Test for phytotoxicity on plants that have not been sprayed with this product previously. Do not use on ferns or Shasta.	M – 1-2 week residual.	Low level resistance [24]. Not effective in Australian pepper field trials [26].
NA	Fatty acids – K salts	Natrasoap, bugguard	For all thrips species in ornamental plants, indoor and outdoor.	No limits on permit.	C	Do not apply during hot part of the day. May not be suitable for delicate ferns, mosses, flowers and plants under stress.	M-H – no residual.	Not reported but, not effective in Australian pepper field trials [26].

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 thrips, including WFT 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 and efficacy against WFT
1B	Omethoate	Folimat	For use on carnations, chrysanthemums, pelargoniums, roses, callistemons, *Eucalyptus* spp., *Grevillea* spp., paperbarks, wattles and onions against all thrips species.	No limits on label.	C, S, I		H – 8-12 weeks residual.	Not reported
1B	Phorate	Thimet, Umet, Zeemet	For all thrips species on carnations, chrysanthemums, dahlias, lily bulbs, azaleas, roses and other woody ornamentals, cabbage, broccoli, cauliflower, Brussel sprouts, carrots, onions and potatoes in all states. Tomatoes in NSW, Qld, WA, SA, Vic and Tas only.	No limits on label. Soil drench only.	S		Unknown, probably high toxicity with long residual.	Not reported

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

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 and efficacy against WFT
1B	Chlorpyrifos	David Grays Chlorpyrifos	Registered against certain thrips species on bananas and citrus.	No limit on label	C, I, V		High – 6-8 week residual	Low level resistance [24]. Not effective in Australian pepper field trials [26].
1B	Disulfoton	Disulfoton	For all thrips species but only on bulbs and gladioli.		S		Unknown, probably high toxicity with long residual, perhaps 6-8 weeks.	Not reported
3A	Beta-cyfluthrin	Prolong,	Registered for all thrips species on azaleas, hibiscus, pelargoniums and roses.	No limits on label	C, I	NA	Unknown – probably high toxicity with at least 4 weeks residual	Widespread high level resistance to pyrethroids; not recommended against WFT [24, 28].
3A	Bifenthrin	Bifenthrin, Fivestar	Most products registered against *Thrips imagines*, *T. simplex* and *T. hawaiiensis* on roses, carnations and other ornamental plants. Some products registered against other thrips species, e.g. *T. florum*.	No limits on label	C, I	Not registered for WFT.	High – 8-12 week residual	
3A	Tau-Fluvalinate	Mavrik	Against plague thrips only, on apples, cherries, nectarines, peaches, plums and grapes in Qld, NSW, Vic, SA and WA only.	Apply a maximum of two consecutive sprays	C, I		High – probably at least 4 weeks residual.	
4A/28	Thiamethoxam and Chlorantraniliprole	Durivo	No ornamental registration, but may be applied against WFT on 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 moderate toxicity and residual.	No resistance detected for thiamethoxam [24].
23	Spirotetramat	Movento	Registered against WFT and tomato thrips (*F. schultzei*) on green beans; WFT only on eggplant, eggplant, Peppers and tomatoes; onion thrips on onions; Kelly's citrus thrips on citrus.	2-3 applications per crop, dependent on plant species.	I, T, S	Refer to label for each plant species. Not effective against adults in Australian pepper field trials [26].	Unknown – probably moderate toxicity with low residual activity.	Not found, despite test [26].
NA	Paraffinic oil	Bioclear, Trump	Registered for asparagus, beet, cucurbits, radish, squash, azalea, begonia, camellia, chrysanthemum, crown of thorns, diffenbachia, easter lilly, fern, gardenia, hibiscus foliage, jade plant, palm, philodendron, poinsettia reiger begonia and zinnias in all states. Beans, tomatoes, corn and peppers are also registered in all states except Qld. All registrations are against all thrips species.	No limits but only once per week.	C	Do not apply to plants in direct sunlight behind glass. Do not use on coconut palms and maidenhair ferns or chrysanthemum blooms. Test on a small number of plants for phytotoxicity prior to using in a widespread manner.	Unknown – probably moderate toxicity with no residual effect.	Not reported.
NA	Petroleum oils	Biocover	Registered for asparagus, beet, cucurbits, radish, squash, azalea, begonia, camellia, chrysanthemum, crown of thorns, diffenbachia, easter lilly, fern, gardenia, hibiscus foliage, jade plant, palm, philodendron, poinsettia reiger begonia and zinnias in all states. Beans, tomatoes, corn and peppers are also registered in all states except Qld. All registrations are against all thrips species.	No limits but only once per week.	C	Do not apply to plants in direct sunlight behind glass. Do not use on coconut palms and maidenhair ferns or chrysanthemum blooms. Test on a small number of plants for phytotoxicity prior to using in a widespread manner.	M – no residual.	Not reported

[1] Action: C = contact; S = systemic; I = ingestion; T = translaminar; V = vapour.
[2] In the context of the table, beneficials refers to *T. montdorensis*, *N. cucumeris* and *O. armatus*. Summarised primarily from *The Good Bug Book* [16], http://www.koppert.com/, http://www.biologicalservices.com.au/, http://www.bugsforbugs.com.au/ and http://www.ipm.ucdavis.edu/