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Control of whitefly in protected ornamental crops

This factsheet covers the identification, biology and control of whitefly, both native and quarantine species, that are important pests of protected ornamental crops in the UK.

Figure 1. Glasshouse whitefly adult holds its wings flat when at rest

Figure 2. Tobacco whitefly adult holds its wings in a tent-like shape and slightly apart, showing its yellow body colour

Action points

Identification

- Learn to distinguish between the two species of whitefly that are most common on protected ornamental crops in the UK. The native glasshouse whitefly, which is not subject to statutory Plant Health and Seeds Inspectorate (PHSI) controls, is the more common species. The quarantine pest, tobacco whitefly, is subject to PHSI eradication or control measures and is a notifiable pest. Differentiation of the two species is important when importing plants from outside Europe, particularly in the case of propagators.
- Report suspect tobacco whitefly to your local PHSI officer immediately. If this species is confirmed, a Statutory Notice will be issued that specifies the eradication programme. In certain circumstances, this may include crop destruction.

Monitoring

- Closely monitor all imported plants, cuttings and stock plants for the presence of whitefly.
- Look for the mobile adult whitefly around shoot tips or new growth, especially on susceptible species such as *Ceanothus*, *Fuchsia*, *Melianthus*, *Philadelphus* and poinsettia. The eggs, larvae (scales) and pupae are all immobile and are found on leaf undersides.
- Recognise the symptoms of whitefly attack. Whitefly honeydew on the leaves can allow sooty moulds to grow. Severely infested plants often have reduced vigour.
- In addition to checking plants, use yellow sticky traps to monitor for whitefly adults.

Cultural and biological control

- Ensure weeds are regularly removed from the floor, on and under benches inside glasshouses and polythene tunnels and around the outskirts of structures.
- Do not propagate from whitefly-infested stock plants.
- Use appropriate biological control agents in an integrated pest management (IPM) programme, introduced in a planned schedule, to be amended according to the results of monitoring.
- Commence regular releases of biological control agents before the pest is seen in the crop.

Chemical control

- If a biopesticide or insecticide is needed, choose the active substance carefully, taking into account potential insecticide resistance and any side effects on biological control agents if using IPM.
- If more than one application is required, alternate effective products with different modes of action.
- When spraying, use a pressure sufficient to 'move' the leaves, to ensure good coverage of the leaf undersides. The location of whitefly eggs and scales on the underside of leaves, and their waxy coating, can make good control using foliar sprays very difficult.

Introduction

Whiteflies are small, white, moth-like insects that are related to aphids and scale insects. The main whitefly species found on ornamental crops in the UK are the glasshouse, tobacco, cabbage and honeysuckle whiteflies. They feed on the plant sap, causing a reduction in plant vigour in severe infestations. The whitefly waste product, honeydew, builds up on the leaves and allows sooty moulds to grow, which can make ornamental plants unmarketable.

In addition to the problem of sooty moulds, the presence of whitefly on plants can also lead to crop rejection, particularly if the species is tobacco whitefly, as this is not native or established in the UK and is currently a notifiable quarantine pest. Tobacco whitefly can also potentially cause severe crop damage and even complete crop losses due to its ability to transmit a range of viruses, although these viruses are more important in protected edible crops and have not yet caused problems in the UK. However, there is a potential risk of tobacco whitefly imported on ornamental plants migrating to nearby protected edible crops and causing virus problems.

PHSI (part of the Animal and Plant Health Agency, APHA) must be informed of any suspect tobacco whitefly outbreaks arising from imported plants, cuttings or produce. Any confirmed outbreaks will be required to be eradicated under the supervision of PHSI.

It can be very difficult to spot whiteflies on bought-in cuttings or on young plants, particularly on large batches of plants, as the pest often occurs at very low levels. Therefore, whiteflies can easily be spread before their presence is noticed. Regular monitoring of both plants and yellow sticky traps is therefore essential, checking for any localised infestations or 'hot spots' in favourable areas, for example close to heating pipes, or on susceptible plant species.

If plants are close together or have a dense foliage canopy, whiteflies are a difficult target for foliar-applied insecticides, especially as the eggs and scales occur on the lower leaf surfaces. Insecticides with systemic or translaminar action can help to reach the target pests but, as whiteflies can rapidly develop insecticide resistance, many of the older plant protection products are now largely ineffective against this pest.

Whitefly species

Glasshouse whitefly (*Trialeurodes vaporariorum*)

The adults of this species are around 1mm in length, hold their wings flatter than tobacco whitefly and appear less yellow, as the wings are not held apart when at rest so the yellow body is not exposed (figure 1). The larvae and pupae (scales) are oval, transparent or white and fixed to the leaf surface. The pupae (developing during the fourth larval stage) are thicker than the younger scales and have a conspicuous fringe of waxy hairs around the edge as well as long waxy rods on the top (visible with a hand lens). This whitefly can colonise many plant species under protection and can sometimes be found outdoors in the summer, for example on hardy nursery stock moved outside from under protection. However, whitefly development rate is much slower outdoors than under protection and the glasshouse whitefly is not usually a problem pest outdoors.

Tobacco whitefly (*Bemisia tabaci*)

The UK still has Protected Zone status within the EU for tobacco whitefly, therefore any infestations of this quarantine pest on imported plant material are notifiable and subject to a policy of eradication. Adults of this species are similar in size to the glasshouse whitefly but hold their wings at an angle to the body, giving a tent-like appearance, and slightly apart so that the yellow body is visible (figure 2). They tend to fly less actively than the glasshouse whitefly. The largest scales (pupae) are yellower and flatter than those of the glasshouse whitefly, do not have a fringe of hairs around the edge and are slightly pointed at the rear end. Historically, poinsettia has been the main host plant on which interceptions or outbreaks of tobacco whitefly have occurred in the UK but more recently the most commonly intercepted infested plant species have been *Hibiscus*, *Mandevilla (Dipladenia)* and *Nerium Oleander*. Other protected ornamental plant hosts include *Ajuga*, *Begonia*, *Ficus*, *Gerbera* and *Solidago*. The pest can also be imported on herbs including rosemary and thyme.

Cabbage whitefly (*Aleyrodes proletella*)

This species is not usually a pest of protected ornamentals, although ornamental cabbage can be infested. However, adults can migrate from nearby oilseed rape or other brassica crops into glasshouses or polythene tunnels through the vents

or doors and may be caught on yellow sticky traps and seen on plants. The adults are larger (about 1.5mm in length) than those of the glasshouse whitefly and are easily recognised by the two grey patches on each of the wings (figure 3).

Honeysuckle whitefly (*Aleyrodes lonicerae*)

This species infests honeysuckle and snowberry, and numbers can increase to damaging levels under protection. Adults are off-white and have a distinctive single grey patch at the base of each wing (figure 4).

Figure 3. The cabbage whitefly adult has two grey patches on each of the wings

Figure 4. The honeysuckle whitefly adult has a single grey patch at the base of each wing

In this factsheet only the glasshouse whitefly and tobacco whitefly will be considered in detail. This is because both these species are polyphagous (they can colonise a very wide range of ornamentals) and therefore represent the greatest economic threat.

Host plants

Host plants for both glasshouse and tobacco whitefly include many economically important ornamental plants such as *Abutilon*, *Begonia*, *Dahlia*, *Fuchsia*, *Gerbera*, *Hibiscus*, *Lantana*, *Nicotiana*, regal pelargonium, poinsettia and *Verbena*.

Within a plant species, certain varieties may be more attractive to whitefly and can be regarded as indicator plants. Good examples of this are *Fuchsia triphylla* varieties, such as 'Firecracker' and 'Thalia', and *Fuchsia x brownii* 'Dropmore Scarlet', which glasshouse whitefly colonise very readily.

Glasshouse whitefly can also be a pest of protected nursery stock, including *Abelia*, *Arbutus*, *Caryopteris*, *Catalpa*, *Ceanothus*, *Clematis*, *Escallonica*, *Fuchsia* (hardy), *Lavatera*, *Melianthus*, *Passiflora*, *Philadelphus*, *Solanum* and *Veronica*, and of cut flowers for example *Alstroemeria* and *Chrysanthemum*.

Damage symptoms

Plants infested with low numbers of whiteflies may show little or no symptoms and it is at this low population density that monitoring is most difficult. As numbers increase, adults can be readily seen when plants are disturbed during production such as when pest monitoring, watering, spacing or pinching.

Damage symptoms include:

- Leaf yellowing
- Reduced vigour
- Loss of plant quality
- Sticky deposits (honeydew) on leaves
- Black sooty mould growth on the upper and/or lower leaf surface (figure 5)
- Virus symptoms (often symptomless in ornamental crops).

Figure 5. Honeydew and sooty mould growth on the underside of a leaf caused by whitefly infestation

Sources of infestation

Stock plants

Stock plants can be a major source of whitefly, so infested plants should not be used for cutting production. Large numbers of stock plants are difficult to monitor adequately and keep free of whitefly. Dense leaf canopies on stock plants can mean that achieving good spray coverage when using foliar applied insecticides is difficult, particularly on the undersides of leaves where whitefly mainly occur. Partial control may lead to infested cuttings being produced, thus perpetuating the problem, or lead to problems with adult whitefly flying from stock plants to adjacent susceptible crops. Where possible IPM should be adopted, releasing biological control agents even where the pest seems to be absent, as this can avoid problems occurring later.

Cuttings and young plants

Plants raised from seed are less likely to be infested by whitefly than those raised from cuttings. Whitefly eggs and young scales are small and can be easily overlooked on cutting material, while the conditions for rooting cuttings on heated propagation benches are ideal for whitefly development. Bought-in cuttings and young plants may have been propagated or grown overseas and these are more at risk of being infested with tobacco whitefly. Plants from EU countries will have plant passports confirming freedom from pests. Plants from countries outside the EU will have been inspected by PHSI in order to intercept any plants infested with quarantine pests.

Weeds

Weeds such as chickweed, dandelion and sow thistle are often overlooked, but they can be the initial host source of whitefly and a range of other pests at the start of the season and they can support surprisingly high populations. Good nursery hygiene including regular removal of weeds from the floor, on and under benches and around the outskirts of the glasshouse or polythene tunnel is therefore an essential part of a good whitefly prevention and control programme.

Previous or adjacent crops

Adult whitefly can fly into new, clean crops if these follow, or are grown adjacent to, infested crops or weeds. Prompt disposal of any unsold plants from previous crops and the use of yellow sticky traps to 'trap out' remaining or invading adults will help to reduce this risk.

Whitefly life cycle

There are four life stages in the development of whitefly, these are:

1. Eggs.
2. Larvae or scales.
3. Pupae (these develop during the fourth larval stage).
4. Adults.

Eggs

Eggs are laid by the female whitefly on the leaf undersides. Glasshouse whitefly eggs are an elongated oval shape, about 0.25mm in length, pointed at the tip and flattened at the base, by which they are stuck onto the leaf. Glasshouse whitefly eggs are white when first laid and turn black just before hatching (figure 6) into 'crawlers' or first stage larvae. Tobacco whitefly eggs are slightly smaller, about 0.18mm, and are yellowish-green in colour when first laid before turning light brown prior to hatching.

Eggs are normally laid on the youngest leaves towards the shoot tips. The glasshouse whitefly often lays them in a semicircle, but on hairy leaves the eggs are usually scattered randomly. The tobacco whitefly usually lays eggs randomly in groups and only lays them in semicircles on smooth-leaved plants such as *Ficus*.

Figure 6. Glasshouse whitefly eggs on leaf undersides are white when first laid and turn black just before hatching

Larvae or scales

First instar larvae or 'crawlers' hatch from the eggs and move around the leaf underside until they find a favourable spot, where they settle and attach themselves with their stylets (mouthparts). From this phase onwards they remain immobile, feeding on plant sap, and pass through four larval stages before becoming pupae, which develop during the fourth larval stage. Scales of glasshouse whitefly are translucent or pale cream in colour, while scales of tobacco whitefly are more yellow, particularly the older stages.

Pupae

Older scales and pupae are found more often on lower leaves. Pupae of glasshouse whitefly are creamy white in colour, oval in shape and have a fringe of short waxy hairs around the edge and longer waxy rods sticking up from the top that are easily seen (figure 7, left). When viewed from the side, glasshouse whitefly pupae have a visible depth, like a miniature mattress. In contrast, pupae of tobacco whitefly have few or no hairs, are flatter, yellow in colour and are pointed at the rear end (figure 7, right). The adult emerges from the pupa through a T–shaped slit in the upper surface. A hand lens is essential in order to check whether the adult has emerged, otherwise the empty pupa can be mistaken for a living whitefly scale. Such an error can lead to false conclusions about the effectiveness of control measures against whitefly scales.

Figure 7. White pupa of glasshouse whitefly fringed with waxy hairs (left) and yellow tobacco whitefly pupa with pointed rear end (right)

Adults

Adult whitefly are often found on the new soft tip growth of plants or on young leaves rather than on older leaves. They feed on plant sap in the same way as the scales but because the adults are mobile they may transmit viruses from plant to plant as they feed. However, whitefly-transmitted viruses are not usually a problem in the UK in ornamental crops.

Factors influencing development

Glasshouse whitefly

The speed of development of the glasshouse whitefly is dependent mainly on temperature, but the host plant species also affects both the development and survival rates. The temperature range required for development is between 8°C and 35°C. However, the optimum temperature range for faster development and increased survival is about 20–25°C, as mortality rates are high above 30°C. At 25°C on *Gerbera*, development time from egg to adult is 22 days. Optimum humidity is 75–80%.

The species and variety of the host plant can influence the number of eggs laid, the duration of the life cycle and, especially, survival through to the adult stage. Although the glasshouse whitefly can infest many species of plants, it only increases rapidly and causes problems on favoured hosts, such as *Fuchsia* and poinsettia.

There is no overwintering or resting stage and so glasshouse whitefly usually only survive the winter on weeds or cultivated plants under protection. The egg stage is the most tolerant of low temperatures and can survive a few days on winter-hardy leaves at temperatures as low as -6°C. Scales and pupae can survive short cold periods outdoors in mild winters or in more favourable regions such as the south-west or the Channel Islands.

Tobacco whitefly

As with the glasshouse whitefly, the main factor affecting development is temperature. As tobacco whitefly is not native to the UK (it occurs naturally in tropical and subtropical countries), its optimum temperature for development is higher (30°C) than for the glasshouse whitefly. At 25–28°C on poinsettia, development time from egg to adult is 23–32 days. Development rate is very slow below 16°C and the scales die below 9°C. Tobacco whitefly can survive the winter in glasshouses, but is killed at temperatures below freezing, and is therefore unlikely to survive outdoors in the UK.

Monitoring

Monitoring is essential for the effective control of whitefly as it is far better to prevent population explosions than to leave it until curative action is needed and risk losing saleable crop through pest presence or damage.

Yellow (but not blue) sticky traps attract adult whitefly and are useful for monitoring. They should be placed so that the bottom of the trap is just above the crop, or if using parasitoids such as *Encarsia*, place the traps 30cm higher to reduce the risk of adult *Encarsia* getting caught. There is no hard-and-fast rule for optimum trap density. One trap per 50–100m² of floor or bench space is often a practical density – it is better to have fewer traps that are inspected regularly than many that are never looked at.

Various brands and types of sticky trap are available. The easiest type to use has tear–off paper strips so that only part of the trap is exposed each week. In this way, each trap lasts for longer and so the labour and cost of replacing them across the nursery is much reduced. Traps should be labelled with the date it was put in position and numbered so that their location within the glasshouse or polythene tunnel is known and can be referred back to.

Traps are only of real value if they are checked regularly (ideally every week) and the number of insects trapped recorded, preferably on a customised form or spreadsheet. In this way, both the distribution and the density of populations can be monitored over time and records are available for comparison from year to year.

When whitefly first land on the trap they are clearly white and can be recognised easily (figure 8). Once they have been on the trap for a few days, they absorb the glue from the trap and become a dull brown. At this stage it is much harder to distinguish whitefly from other insects on the traps. This underlines how vital it is to carry out weekly checking of traps and maintain accurate records, especially on propagation nurseries.

Figure 8. Adult glasshouse whitefly caught on a yellow sticky trap

Whitefly distribution in the crop can be patchy, particularly in the early stages of an infestation. In addition, whitefly eggs, scales and pupae can only be found by careful examination of the plants, especially the leaf undersides. A good x10 or preferably x20 hand lens is essential for this task and staff should be trained in how to monitor for, and recognise, the different whitefly life stages as well as those of any biological control agents being introduced.

Control strategies

Integrated Pest Management (IPM)

The Sustainable Use Directive requires that in all EU member states, IPM should be used by all professional users of plant protection products from 1 January 2014, as long as practical and effective methods are available. This requirement, together with increasing problems with insecticide resistance in both glasshouse and tobacco whitefly populations, means that control strategies should ideally be based on an IPM programme, including cultural and biological control measures together with regular monitoring, applying plant protection products only if needed.

The control strategies summarised below are relevant for both the glasshouse whitefly and tobacco whitefly. However, if the notifiable quarantine pest tobacco whitefly is confirmed, the infestation must be eradicated. PHSI will issue a Statutory Notice outlining specific measures to eradicate the pest and prevent it from spreading to other nurseries. This will be designed in consultation with the grower and will include any required cultural, biological and/or chemical control methods, as appropriate for the nursery concerned.

Cultural control

Prevention of any whitefly problems is better than attempting to eradicate established populations, the aim being to start with a glasshouse or polythene tunnel free from whitefly. Cultural control methods play an important role in whitefly management and appropriate methods include:

- Not taking cuttings from infested stock plants.
- Adopting a thorough clean-up programme to minimise whitefly carry-over to following crops, if a previous crop has been infested.
- Promptly disposing of any crop debris, heavily infested unmarketable plants and any weeds. Infested material should be placed into sealed bags or covered containers, sited as far away from the glasshouse or polythene tunnel as possible.
- Checking regularly for the presence of weeds in production areas – on floors and on and under benches, including in any empty structures. Any gaps in floor coverings (for example around stanchions) should be sealed to prevent weed germination and growth. Weed control should be maintained around the outskirts of glasshouses and polythene tunnels.
- Sweeping, pressure washing and disinfecting benches and concrete floors between crops.
- Trapping via the use of sticky traps. Conventional yellow sticky traps or long yellow roller traps can be useful to trap whitefly adults in empty structures or between infested crops and new batches of plants. However, they can also catch flying biological control agents such as whitefly parasitoids so they should be positioned and their use timed with care. Large numbers of conventional traps or roller traps should not be used in crops where parasitoids are being used.

Further information on nursery hygiene for ornamental crops is given in AHDB Horticulture Factsheet 10/07.

Biological control

Several biological control agents are available for the control of whitefly and those used on protected ornamentals are summarised in table 1. The choice of biological control agents, combinations, timings and rates of release or application within an IPM programme should be planned carefully. If necessary, seek advice from the biological control supplier or an IPM consultant.

Whitefly parasitoids

Encarsia formosa

The parasitic wasp, *Encarsia formosa*, is the most widely used biological control agent for whitefly control in the UK. It is more effective against glasshouse whitefly than tobacco whitefly. *Encarsia* is sold as parasitised (black) glasshouse whitefly scales stuck to cards that are hung on to plants. The black scales contain *Encarsia* pupae that develop into very small (0.6mm long) adult parasitic wasps that emerge from the scales through a round exit hole cut in the top of the scales shortly after release. Adult *Encarsia* are predominantly females that have a black head and thorax (front end of body) and a yellow abdomen (figure 9). The females fly and search for healthy whitefly scales in which to lay eggs. The third and fourth stage whitefly larval scales are preferred for egg laying. Parasitised glasshouse whitefly pupae turn black (figure 10) whereas parasitised tobacco whitefly pupae appear translucent light brown and black because the developing *Encarsia* adult is visible inside. In addition to parasitising whitefly scales, *Encarsia* can also act as a predator by 'host feeding' on young larval scales of both glasshouse whitefly and tobacco whitefly. This is very useful in ornamentals where high numbers of scales on leaves are undesirable.

Figure 9. *Encarsia formosa* females have a black head and thorax and yellow abdomen

Table 1. Biological control agents currently marketed in the UK for the control of glasshouse and tobacco whitefly on ornamentals

Biological control agent	Type	Comments
Amblydromalus (Typhlodromalus) limonicus	Predatory mite	Feeds on both glasshouse and tobacco whitefly eggs and young scales (also on thrips larvae). Licensed for release only in fully enclosed glasshouses, not polythene tunnels.
Amblyseius (Typhlodromips) montdorensis	Predatory mite	Feeds on both glasshouse and tobacco whitefly eggs and young scales (also on thrips larvae). Licensed for release only in fully enclosed glasshouses, not polythene tunnels.
Amblyseius swirskii	Predatory mite	Feeds on both glasshouse and tobacco whitefly eggs and young scales (also on thrips larvae). Licensed for release only in fully enclosed glasshouses, not polythene tunnels.
Delphastus catalinae	Predatory beetle	Feeds on whitefly eggs and larvae. Licensed for release only in fully enclosed glasshouses, not polythene tunnels. Used as a 'hot spot' treatment where whitefly density is high.
Encarsia formosa	Parasitic wasp (parasitoid)	More effective against glasshouse whitefly than tobacco whitefly. Parasitises the scales and also 'host feeds' where it acts as a predator.
Eretmocerus eremicus	Parasitic wasp (parasitoid)	Parasitises and host feeds on both glasshouse and tobacco whitefly. More effective against tobacco whitefly than *E. formosa*. Licensed for release only in fully enclosed glasshouses, not polythene tunnels.

Figure 10. Glasshouse whitefly pupae turn from white to black when parasitised by *Encarsia*

For best control of whitefly, weekly releases of *Encarsia* should start preventively, before the pest is seen in the crop. If release programmes start too late, once whitefly have already started to increase in number, it is then more difficult for *Encarsia* to gain control. On crops that are very susceptible to whitefly, preventive use of predatory mites that eat whitefly eggs and young scales should also be considered for use in the IPM programme to supplement biological control by parasitoids (see the following section on predatory mites).

The optimum temperature for *Encarsia* is 20–25°C. However, *Encarsia* can be used as long as temperatures are 18°C or above for a few hours each day, as the adults do not fly below this temperature. This limits the use of *Encarsia* early in the season on unheated crops such as protected hardy nursery stock. As adult *Encarsia* activity is more limited below 20°C, higher release rates should be used placing the cards closer together to compensate for reduced flight activity. The preventive release rate should be increased once whiteflies are seen in the crop.

Regular monitoring of plants and sticky traps is essential in order to manage an effective control programme. If numbers of whitefly increase and the proportion of black scales is low, a compatible biopesticide or plant protection product can be used to reduce the numbers of whitefly to a level where biological control can be maintained. Careful management of the IPM programme is needed and advice should be sought from an IPM consultant or the biological control supplier if required.

Eretmocerus emericus

Another parasitic wasp available for whitefly control is *Eretmocerus emericus,* but this species may only be released in the UK inside fully enclosed glasshouses, not polythene tunnels. Like *Encarsia*, this species will parasitise both glasshouse and tobacco whitefly but performs slightly better on tobacco whitefly. *Eretmocerus* undertakes more host-feeding than *Encarsia* on both whitefly species. Second-stage whitefly larval scales are preferred for egg laying. *Eretmocerus* is supplied as parasitised scales on cards like *Encarsia,* in blister packs or in a bran carrier for distribution, depending on the supplier. The *E. emericus*-parasitised scales of both glasshouse and tobacco whitefly are yellow, which makes it difficult to assess the level of parasitism achieved in tobacco whitefly pupae that are also yellow when unparasitised. The adult female *E. emericus* are pale yellow (figure 11) and the males are yellowish-brown.

Figure 11. *Eretmocerus emericus,* females are yellow

As with *Encarsia*, weekly releases should start preventively for optimum control. If there is a risk of tobacco whitefly, such as on imported poinsettia plants, *E. eremicus* should be used rather than *Encarsia*. Alternatively, a mix of the two parasitoid species can be used and a commercial mix is available. The optimum temperature for *E. emericus* activity is 20°C and this species can tolerate higher temperatures (above 30°C) than *Encarsia*.

Predatory mites

Three predatory mite species are commercially available for the control of both whitefly and thrips: *Amblydromalus* (*Typhlodromalus*) *limonicus*, *Amblyseius* (*Typhlodromips*) *montdorensis* and *Amblyseius swirskii* (figure 12). None of these species are native to the UK so all are only permitted to be released into fully enclosed glasshouses, not polythene tunnels. The three species are all oval, beige mites, about 0.4mm in length, which feed on pollen, whitefly eggs and young scale and on thrips larvae.

All the predatory mite species are available in bottles with a carrier for sprinkling onto plants, *A. montdorensis* and *A. swirskii* are also available in release sachets for hanging onto plants. As these predators do not fly, it is important that the plants are touching when releases are made, to allow them to walk from plant to plant. If plants are not touching, a release system should be used to ensure the mites are distributed onto all the plants, such as the 'Airbug' automatic applicator, supplied by Koppert Biological Systems.

For optimum control, releases of these predators should start before whitefly are seen and should be used together with whitefly parasitoids in an IPM programme. Experience in both the UK and the Netherlands has shown that this combination can give good control of whitefly on protected ornamentals, including poinsettia. The choice of predator species is dependent upon temperature. *A. limonicus* is active at temperatures as low as 13°C, *A. montdorensis* needs night and day temperatures above 15°C and 20°C respectively and *A. swirskii* needs warm day temperatures regularly above 20–22°C.

Figure 12. The predatory mite *Amblyseius swirskii*, note whitefly eggs in the foreground

Predatory beetle

Delphastus catalinae is a small predatory beetle, about 1.5mm in length that feeds on both glasshouse and tobacco whitefly eggs and scales. The beetles have a black body and the females have a brown head. *Delphastus* is not native to the UK so may only be released into fully enclosed glasshouses, not polythene tunnels. Release should only be made to 'hot spots' with high whitefly densities, as the beetles need to eat large numbers of whitefly eggs and scales in order to reproduce. The optimum temperature range is 22–30°C and the minimum temperature is 20°C.

As *Delphastus* are expensive, they tend to be used only in situations where insecticides are undesirable, for example, in butterfly houses. In most protected ornamentals it will be more cost-effective to use a spot spray of an IPM-compatible biopesticide or plant protection product.

Entomopathogenic nematodes

Research at Fera has shown that the entomopathogenic nematodes *Steinernema carpocapsae* and *S. feltiae* can give some control of tobacco whitefly. Both nematode species were most effective when applied as foliar sprays to second and third stage whitefly scales under controlled conditions. Nematodes are not currently recommended for whitefly control by suppliers but they could have potential for use in an IPM programme.

Fungal biopesticides

Entomopathogenic fungi

Lecanicillium muscarium ('Mycotal')

Mycotal is the whitefly strain of the entomopathogenic fungus *Lecanicillium muscarium*, formerly known as *Verticillium lecanii*, supplied as spores in a wettable powder. The product should be applied as a high volume spray at the first sign of whitefly and repeated three times at five to seven day intervals. It is important to achieve good coverage of growing points and leaf undersides as the fungus needs to come into contact with the whitefly to be effective. The fungus requires a temperature range of 18–28°C and high relative humidity (over 80%) for several days after application to grow and infect whiteflies. Infected whitefly become covered with white fluffy cotton-like threads of the fungus seven to 10 days after application (figure 13). Mycotal can be used at slightly lower humidity (70%) if applied with the adjuvant 'Addit', which improves spore survival and germination and thus efficacy

against whitefly. The fungus mainly infects whitefly scale but when the relative humidity is very high it will also infect pupae and adults and recent research by Fera has also shown that it can infect tobacco whitefly eggs. Mycotal will also give some control of thrips and two-spotted spider mite.

Mycotal works best in humid propagation houses, rooting benches and under blackouts. If used in glasshouses or polythene tunnels, the product should be applied in the evening, during warm, humid weather conditions. Humidity can be manipulated in glasshouses to enhance efficacy, such as by closing vents after application. A fungicide should not be used within three days of any Mycotal application. Fungicides containing chlorothalonil, maneb or prochloraz should not be used on any crop where Mycotal is being used.

Figure 13. Whitefly scales infected with Mycotal

Beauveria bassiana ('BotaniGard' WP and 'Naturalis-L')

BotaniGard WP and Naturalis-L are products based on different strains of another entomopathogenic fungus, *Beauveria bassiana*.

BotaniGard WP infects whiteflies but will also give some incidental control of thrips. The fungus infects the first to fourth larval scale stages. For optimum control of all life stages, the supplier recommends tank mixing BotaniGard WP with maltodextrin (Majestik), as Majestik will kill whitefly adults and eggs. As with other entomopathogenic fungi, achieving good spray coverage, particularly on the leaf undersides, is critical for effective pest control. BotaniGard WP requires a temperature range of 15–35°C, with optimum temperatures being 20–30°C. Relative humidity should be above 70%. For optimum efficacy, the product should be applied in the late evening or under shade screens when relative humidity is high and UV levels are low. Details of safe integration of fungicides are available from the supplier.

Naturalis-L infects both whiteflies and thrips, and has also been observed to infect two-spotted spider mite in conditions of high humidity. The fungus will infect all stages of whitefly and recent Fera research has confirmed infection of tobacco whitefly eggs as well as scale. Like the other fungal biopesticides, good application coverage of growing points and leaf undersides is required in order for the fungus to reach the target whiteflies. Naturalis-L needs a temperature range of 20–30°C and relative humidity above 60%. The product should be applied at the first sign of whiteflies and repeated up to five times at no less than five day intervals. The effects of fungicides on Naturalis-L have not yet been fully tested so it is recommended that a fungicide should not be applied for at least 48 hours after any Naturalis-L application.

Plant protection products including botanical biopesticides

As stated previously in this factsheet, due to the requirements of the Sustainable Use Directive, problems with insecticide resistance and potential phytotoxicity, IPM programmes with minimal use of plant protection products should ideally be adopted, rather than relying on programmes based solely on the use of plant protection products. Currently approved plant protection products and other biopesticides available in the UK that may give some control of whitefly are presented in table 2 (separate sheets).

Integrating plant protection products with biological control agents in an IPM programme

Within an IPM programme, if crop monitoring indicates that whitefly numbers are increasing, or if the proportion of parasitised scales is too low, then corrective action will be needed. The release rate of biological control agents can be increased, and/or foliar sprays of a plant protection product safest to the biological control agents being used can be made (see table 2). Experience is needed when deciding whether or not to spray and which product to use; if necessary seek the advice of an IPM consultant or the biological control supplier. Full details of the side effects of plant protection products on biological control agents can be found on the following websites: biobest.be and koppert.com.

Resistance management

Both glasshouse and tobacco whitefly populations have developed resistance to many plant protection products in the UK and overseas. When importing plant material there is always the risk of bringing in new resistant strains of both species of whitefly. The 'Mediterranean species' (formerly known as the 'Q biotype') of tobacco whitefly is currently the main strain encountered in the UK on infested plant material. Populations of this tobacco whitefly strain are more likely to have developed resistance to neonicotinoid insecticides than the 'Middle East-Asia Minor 1 species' (formerly known as the 'B biotype').

It is very important to follow all resistant management guidelines on the product label or the Extension of Authorisation for Minor Use (EAMU). These include alternating insecticides in different mode of action groups, as using a single product or those within the same chemical group (for example the neonicotinoids) or mode of action group (such as group 4A) is likely to result in the survival of resistant individuals. All insecticides are classified by mode of action, with each

being allocated a group number (table 2). Other resistance management guidelines include not exceeding the maximum number of applications per crop or per year, using the recommended product rate and using an effective application method (see the following section on application methods).

Regular plant monitoring should be undertaken to record the numbers of whiteflies before and after application in order to detect any signs of potential resistance. If the insecticide used has not been fully effective despite good application, further treatments with the same insecticide, or with one in the same mode of action group, should not be made. Resistance is unlikely to develop to physically acting plant protection products (table 2). Further information on resistance management is given in the AHDB Horticulture Factsheet 01/13.

Application methods

Plant protection products for whitefly control include those applied via substrate incorporation or via foliar sprays (Table 2).

Substrate incorporation

Granular products currently approved for substrate incorporation with container-grown ornamentals (table 2) may only be used with peat-based growing media. Thorough incorporation of the granules during the final mixing stages using suitable machinery to ensure even distribution is essential. Follow the application guidelines on the product labels and in supplier technical leaflets.

Foliar application

When applying foliar sprays, good coverage is required over all parts of the plant including leaf undersides; this is particularly important for contact-acting products. Appropriate nozzle types, pressures and spray volumes should be used in order to achieve the necessary spray coverage; nozzle selection and the pressure used will affect the spray volume applied. A medium or fine spray is appropriate for pest control in ornamental crop production (table 3).

Good spray penetration is less likely to be achieved on closely spaced plants with a dense canopy foliage. Spray coverage can be checked using water-sensitive paper to detect the density and uniformity of spray deposits (figure 14). For further guidance see AHDB Horticulture Factsheet 06/15.

Figure 14. Spray deposition pattern on water sensitive paper

Crop safety

Label information should be checked for plant species that may be damaged by the application of any plant protection product. Any use of a plant protection product via an EAMU is undertaken at the grower's own risk. If crop safety information is not available, test the product on a small number of plants first to determine crop safety prior to widespread commercial use. Always use the recommended rate and water volume when applying foliar sprays and avoid spraying during hot, sunny weather conditions. Keep a record of the environmental conditions at the time of spraying and of any resultant phytotoxicity so that similar damage can be avoided in the future.

Table 3. Spray quality suitable for use in protected ornamental production

Spray quality	Justification
Medium	Should be used where no other advice is available or where spray quality is not specified on the product label. Gives the best mix of effective droplet sizes, resulting in good retention on difficult leaf surfaces whilst controlling drift.
Fine	Gives good retention on the target and is useful for contact-acting products or where good coverage is specified on the product label. A fine spray must not be used if the plant protection product is labelled 'Toxic', 'Very toxic', 'Corrosive' or 'Risk of serious damage to the eyes', or if drift would be damaging or would cause public concern, such as where spraying close to susceptible crops, gardens, near to sensitive areas such as houses, schools, hospitals, Sites of Special Scientific Interest (SSSI) or watercourses.

Table 2. **Currently approved plant protection products for whitefly control in protected ornamental plant production (October 2015)**

Product name (examples)	Active ingredient and IRAC code	Insecticide group	Approval status for protected ornamentals	Application method	Compatibility with biological control agents used for whitefly control*	Comments
Biopesticides – botanical						
Eradicoat, Majestik	Maltodextrin	Physically acting products, but are approved	On-label (for spider mite control, but some control of whitefly)	Foliar spray	Safe to biological control agents once spray deposit is dry.	Contact action. Effective against adults and eggs.
Biopesticides – fungal						
BotaniGard WP	*Beauveria bassiana*	Entomopathogenic fungus	On-label	Foliar spray	Consult supplier for details.	Needs 20–30°C and over 70% relative humidity for optimum control. Effective against scale stages. Recommended to be tank mixed with Majestik for optimum control of all life stages. Currently only approved for use in fully enclosed structures.
Mycotal	*Lecanicillium muscarium*	Entomopathogenic fungus	On-label	Foliar spray	Safe to *Encarsia, Eretmocerus* and *A. swirskii*.	Needs 18–28°C and (if applied with Addit) 70% relative humidity for several days after application. Mainly effective against scale stages, but will also control other stages in very high relative humidity.
Naturalis-L	*Beauveria bassiana*	Entomopathogenic fungus	On-label	Foliar spray	May have some adverse effects on *Encarsia*.	Needs 20–30°C and over 60% relative humidity for optimum control of all whitefly life stages.

Table 2. Currently approved plant protection products for whitefly control in protected ornamental plant production (October 2015) continued

Product name (examples)	Active ingredient and IRAC code	Insecticide group	Approval status for protected ornamentals	Application method	Compatibility with biological control agents used for whitefly control*	Comments
Insecticides – neonicotinoids						
Agrovista Reggae, Calypso	Thiacloprid (IRAC code 4A)	Neonicotinoid	EAMU (0474/2008) and EAMU (2151/2014) for control of tobacco whitefly	Foliar spray	Safe to *A. swirskii*. Conflicting information on whitefly parasitoids, but will have harmful effects on adults.	Contact, translaminar and systemic action. Maximum of two neonicotinoid applications per crop. Not subject to the EC neonicotinoid restrictions.**
Exemptor	Thiacloprid (IRAC code 4A)	Neonicotinoid	On-label	Substrate incorporation	No information on *A. swirskii*. Conflicting information on whitefly parasitoids but will have harmful effects on *Encarsia* adults.	Systemic action, gives up to 10 weeks control. Maximum of two neonicotinoid applications per crop. Not subject to the EC neonicotinoid restrictions.**
Gazelle	Acetamiprid (IRAC code 4A)	Neonicotinoid	On-label	Foliar spray	Harmful to *Encarsia* adults for up to 12 weeks, moderately harmful to *Eretmocerus*, harmful to *A. swirskii* for up to three weeks.	Contact, systemic and translaminar action. Maximum of two neonicotinoid applications per crop. Tobacco whitefly may be resistant. Not subject to EC neonicotinoid restrictions.**
Imidasect 5GR	Imidacloprid (IRAC code 4A)	Neonicotinoid	On-label	Substrate incorporation	Safe to *A. swirskii*. Conflicting information on whitefly parasitoids.	Systemic action, gives up to 12 weeks control. Use on container-grown ornamentals only. Do not use in substrate that has been treated with another imidacloprid product within 12 months. So far only one UK case of confirmed resistance in glasshouse whitefly. Subject to EC neonicotinoid restrictions.**

Table 2. Currently approved plant protection products for whitefly control in protected ornamental plant production (October 2015) continued

Product name (examples)	Active ingredient and IRAC code	Insecticide group	Approval status for protected ornamentals	Application method	Compatibility with biological control agents used for whitefly control*	Comments
Insecticides – physically acting						
Agri-50E	Dodecylphenol ethoxylate	Physically acting product, exempt from plant protection product regulations	On-label	Foliar spray	Label claims compatibility with natural enemies used in IPM.	Contact action. Buffer water in hard water areas.
Savona	Potassium salts of fatty acids	Physically acting product, but is approved	Revoked February 2015 and no longer marketed. Use up date of 28/02/2017 for use covering ornamental trees and shrubs	Foliar spray	Safe to biological control agents once spray deposit is dry.	Contact action. Use soft water.
SB Plant Invigorator	Foliar lattice, linear sulphanate, iron chelate, nitrogen, natural products	Physically acting product, exempt from plant protection product regulations	On-label	Foliar spray	Label claims safety to parasitic wasps inside whitefly scales, but multiple applications affect predatory mites.	Contact action.
Insecticides – pyrethroids						
Bandu, Decis	Deltamethrin (IRAC code 3)	Pyrethroid	On-label	Foliar spray	Harmful to most biological control agents for up to 12 weeks, incompatible with IPM.	Contact action. Glasshouse whitefly likely to be resistant, tobacco whitefly may be resistant.
Clayton Cajole	Esfenvalerate (IRAC code 3)	Pyrethroid	On-label	Foliar spray	Harmful to *Encarsia* and *Eretmocerus* for up to 12 weeks, harmful to *A. swirskii* for up to five weeks, incompatible with IPM.	Contact action. Glasshouse whitefly likely to be resistant, tobacco whitefly may be resistant. Maximum of two applications per crop.
Pyrethrum 5 EC, Spruzit	Pyrethrins (IRAC code 3)	Pyrethrins	On-label	Foliar spray	No information on *A. swirskii*. Harmful to whitefly parasitoids for up to two weeks.	Contact action. Glasshouse whitefly likely to be resistant, tobacco whitefly may be resistant.

Table 2. Currently approved plant protection products for whitefly control in protected ornamental plant production (October 2015) continued

Product name (examples)	Active ingredient and IRAC code	Insecticide group	Approval status for protected ornamentals	Application method	Compatibility with biological control agents used for whitefly control*	Comments
Insecticides – various other chemical groups						
Acaramik, Dynamec	Abamectin (IRAC code 6)	Avermectin	On-label control of other pests (no recommendation for whitefly control)	Foliar spray	Harmful to *Encarsia* and *Eretmocerus* adults for up to three weeks and harmful to *A. swirskii* for up to two weeks.	Contact and translaminar action. Has been shown to kill tobacco whitefly eggs.
Chess WG	Pymetrozine (IRAC code 9B)	Azomethine	On-label control of aphids. EAMU (2016/2013) for control of aphids and whitefly	Foliar spray	Safe to *A. swirskii*, slightly harmful to *Encarsia* and *Eretmocerus*.	Contact, translaminar and systemic feeding inhibitor. Low levels of reduced susceptibility reported in glasshouse whitefly and resistance possible in tobacco whitefly, with cross-resistance to neonicotinoids.
Mainman	Flonicamid (IRAC code 9C)	Pyridincarboxamid	EAMU (0045/2013) for control of tobacco whitefly	Foliar spray	Safe to *Encarsia* adults and *A. swirskii*. No information on *Eretmocerus*.	Systemic feeding inhibitor. Maximum of three applications per year.
Movento	Spirotetramat (IRAC code 23)	Ketoenole – tetramic acid	EAMU (1987/2011)	Foliar spray	Safe to *Encarsia* and *Eretmocerus*, moderately harmful to *A. swirskii*.	Two-way systemic action. Maximum of two applications per year.
Oberon	Spiromesifen (IRAC code 23)	Ketoenole – tetronic acid	EAMU (1718/2004) for control of whitefly and spider mites	Foliar spray	Safe to *Eretmocerus*, no information on *Encarsia,* moderately harmful to *A. swirskii*.	Contact action. Container-grown crops only. Maximum of two applications per year. Resistance in glasshouse whitefly possible.

This table has been collated using information from the Health and Safety Executive (HSE) website (pesticides.gov.uk) and from product labels and supplier technical leaflets. Important – regular changes occur in the approval status of plant protection products, arising from changes in the legislation or for other reasons. For the most up to date information, please check the HSE website or with a professional supplier or BASIS-qualified consultant, as information could have changed since the publication of this factsheet.

EAMU – Extension of Authorisation for Minor Use.

Growers must hold a paper or electronic copy of an EAMU before using any product under the EAMU arrangements. Any use of a plant protection product with an EAMU is at grower's own risk.

Always follow label or EAMU recommendations, including rate of use, maximum number of applications per crop or year and where crop safety information is not available, test the product on a small number of plants to determine crop safety prior to widespread commercial use.

If in doubt about which products are permissible on ornamentals or how to use them correctly, seek advice from a BASIS-qualified consultant with expertise in ornamental plant production.

**Full details of compatibility of plant protection products with biological control agents are available from biological control suppliers or IPM consultants. See the following websites: biobest.be and koppert.com. 'Safe': kills<25% of the biological control agents; 'slightly harmful': kills 25–50%; 'moderately harmful': kills 50–75%; 'harmful': kills >75%.*

***With effect from 1 December 2013, professional use of three neonicotinoid insecticides (clothianidin, imidacloprid and thiamethoxam) is no longer permitted on crops considered attractive to bees. For whitefly control, imidacloprid products can only be used on ornamental plants in a glasshouse (not a polythene tunnel) and plants treated with imidacloprid cannot be placed outside until after they have finished flowering. Plants that do not flower can be moved outside following treatment in a glasshouse. Acetamiprid and thiacloprid are also neonicotinoid insecticides but are not currently restricted under these regulations.*

Further information

AHDB Horticulture factsheets and publications

Factsheet 06/15. 'Improving the efficacy of plant protection applications to ornamental crops via handheld sprayers'.

Factsheet 01/13. 'Practical measures to prevent and manage insecticide, fungicide and herbicide resistance for horticultural crops'.

Factsheet 10/07. 'Guidelines on nursery hygiene for outdoor and protected ornamental crops'.

AHDB Horticulture grower summaries and reports

CP 124: 'Managing ornamental plants sustainably (MOPS) – Developing integrated plant protection strategies'.

PO 003: 'Development of safe and effective programmes for the early control of tobacco whitefly on poinsettia crops'.

Other publications

Bemisia tabaci – the tobacco whitefly (also known as the silverleaf or sweet potato whitefly). (fera.co.uk/plantClinic/documents/factsheets/bemisia.pdf).

Insecticide Resistance Action Committee (IRAC): Mode of action classification scheme (irac-online.org/documents/moa-classification).

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