Fruit Fly Management

for fruit and vegetable growers

Contents

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01.

FRUIT FLIES CAN INFEST MANY FRUIT AND FRUITING VEGETABLE CROPS. WHILE COVER SPRAY OPTIONS ARE DECREASING, THERE ARE MANY OTHER TOOLS GROWERS CAN USE. THIS PUBLICATION DESCRIBES THE OPTIONS AVAILABLE AND SUGGESTS BEST PRACTICE BASED ON CURRENT KNOWLEDGE.

Introduction

Fruit flies are a major pest, not only because they damage production but also because of their impact on domestic and international trade.

Fruit fly management and control have two quite separate objectives.

1. Fruit fly **management** is all about producing a marketable crop
2. **Control** is focussed on applying a phytosanitary measure to meet the biosecurity requirements of trading partners

A range of management tools can be used to produce a pest free crop. These include exploitation of fruit fly biology and behaviour, chemical controls, food-based and parapheromone lures, sterile insect technique and physical barriers. Integrated pest management (IPM) for fruit flies involves combining two or more of these strategies, improving overall effectiveness.

In contrast, accessing markets that have biosecurity barriers to trade requires a much higher level of certainty. Either probit 9 (ensuring 99.9968% mortality) or probit 8.7 (ensuring 99.99% mortality) are likely to be used as a standard, ensuring that the risk that pests are present is virtually zero. Accessing fruit fly sensitive markets often requires a postharvest kill step, or proof of pest freedom, to ensure there is minimal risk to the importing region.

Postharvest control strategies to achieve market access requirements include cold, heat, irradiation, fumigation and combinations of these treatments. Application is independent from actual infestation levels, the probability of establishment in the market, or other factors likely to limit risk to the importer.

This publication is focused purely on objective 1 – **producing a marketable crop.**

Without this, there is little purpose to progressing towards objective two!

In this booklet we have aimed to combine published literature, experimental data, the knowledge of experienced fruit fly management practitioners and commercial practices to provide a practical manual for fruit fly management.

The guide is split into sections on:

- Fruit fly species
- Lifecycle and movement in the landscape
- Monitoring and trapping
- Protein baits
- Male annihilation
- Cover sprays
- Sterile insect technique
- Parasitoids and other biological controls
- Protected cropping, from glass to netting
- Field hygiene
- Area Wide Management (AWM) and IPM

Insecticides were once the major fruit fly management tool of choice. However, with increasing concern about pesticide residues in food and the environment, and dwindling access to insecticides, it is essential that growers understand their fruit fly foe. Whereas once we may have sprayed first and asked questions later, we now understand the value of combining different control strategies to manage fruit fly pests.

The integrated fruit fly management toolkit therefore includes a range of different control strategies. These can include cover sprays (applied according to the label) where pest pressure is high.

To use these strategies effectively, growers need to know where fruit flies are, how they behave, and the best ways to manage these incredibly damaging pests. This will ensure that fruit and fruit vegetables are not only fruit fly free but grown with care for human health and environmental sustainability.

02.

THERE ARE MANY DIFFERENT FRUIT FLY SPECIES IN AUSTRALIA. IDENTIFYING WHICH ONES CREATE A PROBLEM IN THE CROP IS AN IMPORTANT STEP IN MANAGING THESE PESTS.

Fruit fly species

Australia has more than 300 species of fruit fly. Fortunately, only a few are pests of commercial fruit and vegetable crops, with Queensland fruit fly (Qfly) and Mediterranean fruit fly (Medfly) the key species of concern. These two are responsible for the vast majority of production losses, as well as acting as barriers to trade. Little is known of many other species, including means and effectiveness of current control strategies.

QUEENSLAND FRUIT FLY
(Bactrocera tryoni)

Queensland fruit fly (Qfly) is the species most people think about when discussing fruit fly control. Qfly can infest nearly all fruit and fruiting vegetables, from apples to peaches and chillies to zucchini.

Qfly is found through the Northern Territory and eastern Australia, stretching from Cape York to Melbourne and including both coastal and inland areas. With the exception of Papua New Guinea and some northern Islands, Qfly is found nowhere else in the world.

Until relatively recently, Victoria and large areas of the New South Wales Riverina were considered free of Qfly. However, mild winters and increased host availability have increased its range.

Qfly is brown with clear wings, yellow 'shoulder pads' and other markings, including a yellow triangle at the base of the thorax (middle segment).


Female (left) and male (right) Queensland fruit fly (Qfly) (Images: J Ekman)

MEDITERRANEAN FRUIT FLY
(Ceratitis capitata)

Mediterranean fruit fly (Medfly) is a native of Africa but has spread widely throughout Europe, Central and South America and the Middle East. It is present in south-west Western Australia (WA), and north along the coast as far as Carnarvon. Although also introduced to eastern Australia, it has not been found in NSW since 1941. This is thought to be due to competition from Qfly.

Like Qfly, Medfly can infest a very wide range of fruit and fruiting vegetables. Medfly is somewhat smaller than Qfly, with adults around 3-5mm long. It is quite colourful, with black and silver patches on its thorax (middle), a striped brown abdomen and brown-gold patches on its wings.

Male Mediterranean fruit fly (Medfly) (Image: M Mudie)

Female Mediterranean fruit fly (Medfly) (Image: G Ohm)

CUCUMBER FLY
(Zeugodacus cucumis)

An Australian native, cucumber fly is a significant pest of cucurbit crops. Preferred hosts include zucchini, squash, and cucumbers. However, it readily infests melons and other cucurbits. Tomatoes, guava, passionfruit and pawpaw may also be attacked, with populations persisting in native cucurbits.

As cucumber fly does not respond to the lures used for other fly species, its distribution is poorly understood. Outbreaks have been most frequent in tropical areas of Queensland and the Northern Territory (NT), extending to Kununurra in WA. Cucumber fly is also occasionally detected in coastal areas of northern New South Wales (NSW).

Cucumber fly is lighter brown and more slender than Qfly, with a longer ovipositor. It also has a distinctive yellow keel in the centre of its back (thorax), so the two species are relatively easy to distinguish.

Male cucumber fly (Image: M Tattersall)

Queensland fruit fly (left) and lesser Queensland fruit fly (right). Lesser Queensland fruit fly lacks one set of yellow 'shoulder pads'. (Image: UNSW Fruit Fly Lab)

LESSER QUEENSLAND FRUIT FLY
(Bactrocera neohumeralis)

Lesser Qfly infests a similar range of crops to Qfly. It is thought to occur in large numbers, especially in coastal, northern areas of Queensland, where populations may be similar to that of Qfly.

It is difficult even for practised entomologists to distinguish Lesser Qfly from Qfly, as they look very similar. Lesser Qfly is slightly darker than Qfly, and lacks one set of yellow 'shoulder pads'. However the main difference between the two is that Lesser Qfly mates during the day, whereas Qfly mates at dusk. Also, Lesser Qfly has not extended its range south into cooler climates, but is normally found only in tropical areas.

Lesser Qfly is listed as a pest of quarantine concern by a number of trading partners.

Lesser Queensland fruit fly (Image: L Grenfell)

B. bryoniae (Image: A Pearson)

02. FRUIT FLY SPECIES

JARVIS' FRUIT FLY
(Bactrocera jarvisi)

Like cucumber fly, *B. jarvisi* is increasingly being recognised as a major pest, able to attack a wide range of commercial crops. It is very common in north-west Queensland, where populations may be greater than Qfly. It is found from Broome through to the Northern Territory and down the east coast, possibly even extending to Sydney.

Although Jarvis' fly looks similar to Qfly, it responds strongly to the lure zingerone, whereas Qfly responds similarly to cue-lure/raspberry ketone. It can also be distinguished by the distinct, wide cream band on its abdomen, with dark stripe either side and a dark keel down to the tip of its abdomen. It also has more even colour on its thorax and a longer ovipositor than Qfly.

Female *B. jarvisi.*
(Image: G Cocks)

Island fly (Image: R Richter)

MINOR SPECIES

The **Northern Territory fruit fly** (*Bactrocera aquilonis*) is genetically indistinguishable from Qfly and hybridises readily, resulting in viable offspring. It is therefore considered by some researchers and regulators to be the same species. Despite this, there are some slight differences in appearance and behaviour between the two. For example, *B. aquilonis* is somewhat lighter in colour than Qfly, and favours hosts including bitter melon (*Momordica charantia*) and guava. It is found throughout the northern parts of WA and the NT.

Bactrocera bryoniae is commonly found in coastal areas of north-eastern Australia, with occasional detections in northern NSW and down as far as Sydney. It has a limited host range and is mainly found in native fruits. It has caused damage to crops in Papua New Guinea but has rarely been isolated from commercial crops (for example, chillies) in Australia. Like Qfly, *B. bryoniae* is attracted to cue-lure, so may be detected during monitoring programs.

Bactrocera bryoniae tends to be darker than Qfly, with an evenly coloured thorax and often has a distinct 'T' marking on the abdomen.

The **Banana fruit fly** (*Bactrocera musae*), is common along the eastern coast of Queensland as far south as Townsville. It can lay eggs into bananas which are not fully ripe, however the eggs fail to develop if the bananas are immature. Commercial bananas harvested unripe are therefore not considered hosts of *B. musae*. Harvesting Cavendish bananas when hard green is recognised as a suitable phytosanitary measure by trading partners.

While native and unmanaged bananas are favoured hosts, *B. musae* also occasionally infests papaya and guava. Males can be monitored using traps baited with methyl eugenol. Banana fly resembles Qfly, but with a lighter coloured abdomen and darker thorax.

Although not known to infest commercial fruit, **Newman fly** (*Dacus newmani*), is attracted by both cue-lure and raspberry ketone. As a result, it may be detected during surveillance, especially in inland areas. It is sometimes called the drought fruit fly because large numbers may be trapped during dry periods. It does not occur in coastal or urban environments and has never been isolated from infested fruit (native or introduced). Instead, it has been speculated that larvae feed on the woody fruit of *Marsdenia viridiflora* and *Marsdenia australis*, native climbers with milky sap. Despite regular trapping of male Newman flies, little is known of this species.

Island fly (*Dirioxia pornia)* is also sometimes found in cue-lure baited traps, as well as in protein and food-based lures. Island fly only lays eggs into overripe or rotting fruit, so is not a pest of quarantine concern. While it is quite different in appearance to Qfly, having dark wings and a black and white abdomen, it is important that it is not misidentified during surveillance programs.

03.

UNDERSTANDING THE LIFECYCLE AND BEHAVIOUR OF FRUIT FLIES PROVIDES MANY CLUES AS TO THE BEST WAY TO PREVENT THEM INFESTING CROPS.

The life of fruit flies

From a freshly laid egg to an adult fly capable of laying several hundred more eggs, a fruit fly generation can be completed in less than a month. Understanding this lifecycle, and how it interacts with environmental conditions, can help identify management strategies to control these pests.

The information in this section is based primarily on Qfly. Other species are similar, but specific details will vary.

Female Qfly laying eggs (Image: J Ekman)

THE FRUIT FLY LIFECYCLE

Laying eggs

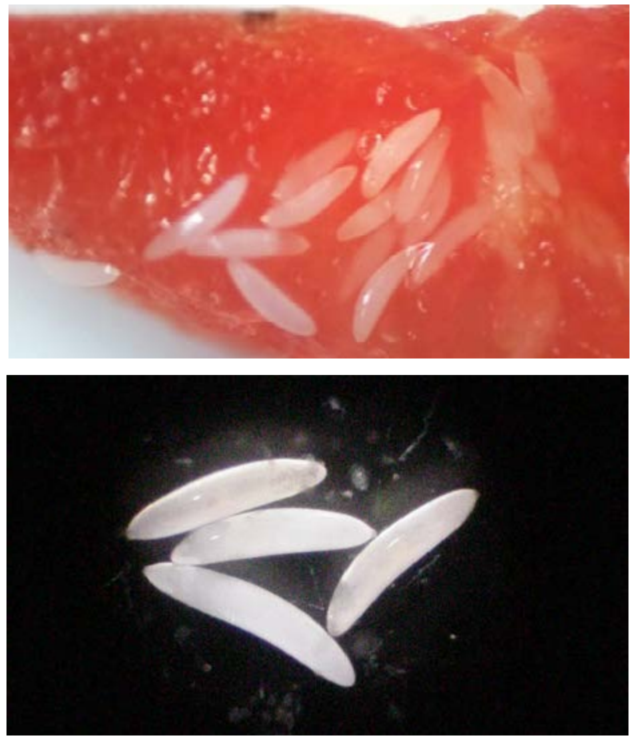
A mature female Qfly can potentially lay up to 100 eggs per day, remaining fertile for many weeks. With two ovaries, each containing 35 to 45 ovarioles (egg production sites), she is a more prolific egg producer than many other fruit fly species.

All female fruit flies are equipped with a sharp ovipositor, which they use to deposit eggs just under the skin of the host fruit. Unlike some exotic fruit flies, the ovipositors of Medfly, Qfly and other Australian species are not that strong, so the females often lay into natural openings like a split, wound or the fruit lenticels (breathing holes).

Female Qfly are unable to lay into hard green fruit such as unripe avocadoes and bananas. Even if they do succeed in laying an egg into a natural opening, larvae fail to develop. They also find it difficult (although not impossible) to lay eggs directly into smooth, firm fruit with no natural openings, such as cherry tomatoes. In this case, their ovipositor tends to slide off the surface rather than piercing the skin.

Eggs

On average it takes a female Qfly around three minutes to lay a batch of between 6 and 20 eggs into the host fruit. Fruit fly eggs are white, slender and around 1mm long, so barely visible with the naked eye. “Sting” marks, where flies have laid eggs, are easy to see on light coloured fruit such as apples and loquats. However, they are more difficult to detect on strongly coloured fruit such as plums and cherries.



Eggs laid into a red capsicum (top) and under the microscope (Images: J Ekman and NSW DPI)

Qfly eggs hatch after 1-2 days, with larvae initially less than 2mm long and pure white (left), Bacteria introduced on the surface of Qfly eggs, together with those naturally present in the environment, break down the fruit flesh into a slurry that larvae can scoop up and digest (centre and right) (Images: NSW DPI and J Ekman)

Sting marks are easy to see on an apple, but harder to detect on coloured fruit, as seen on these artificially infested cherries. Sting marks appear as tiny, sunken holes (Images: J Ekman)

Larvae

Fruit fly development rates are strongly temperature dependent. For example, Qfly eggs hatch after 1-2 days at 26°C.

New larvae are just over 1mm long. Bacteria carried on the egg surface, together with those present in the surrounding environment, break down the fruit flesh into a semi liquid. The larvae feed by scooping up this pulp, while regurgitating liquid containing more bacteria into the surrounding flesh. This is why they cause so much damage.

Their nutritionally rich diet allows the larvae to grow incredibly quickly, maturing after only six days at 26°C. By this time they have reached 5-9mm long and their black feeding hooks can be easily seen. Mature larvae are a creamy colour, with their gut coloured by the food they are eating.

Larvae feed underneath the fruit skin, so damage may not be easily seen from the outside. Sunken, discoloured or soft areas can indicate where the underlying flesh has been broken down, leaving the skin intact. Breaking the fruit open reveals soft, cavity riddled flesh but without obvious fungal infection.

In orchard crops such as stone fruit and pome fruit, the larvae burrow their way into the sweet centre of the fruit, which can become brown and liquefied. When the fruit is broken open the larvae will immediately attempt to wriggle back into the flesh.

Larvae develop through three distinct instars, or life stages. These are identifiable by the size, colour and shape of the feeding hook as well as larval size.

The final, third instar is the only one able to move by hopping. To hop, the larva curls in on itself, then releases like a spring.

As larvae mature they become cream coloured, with their black feeding hook increasingly visible, and the food they are eating colouring their gut. Images of cherries and capsicum (right) (Images: NSW DPI and J Ekman)

Apple infested with Qfly, seen from the outside (left) and inside (right) (Images: B Koll).

Fly feeding on sugar syrup on a leaf (left) and males gathered together in a citrus tree at dusk (right) (Images: J Ekman)

PUPAE

Once the larva is mature it hops from the fruit and buries itself in the soil. The outside coat hardens and it forms into a pupa. Pupae look like large grains of brown rice.

It takes around 10 to 18 days for the larva to re-assemble its body inside its pupal case, developing into a fly. When it is ready to emerge, the young fly breaks the top off the pupal case and scrambles up to the soil surface. In the image at right, some of the flies have emerged, leaving behind the empty pupal cases.

ADULT FLIES

Once the adult fly emerges and expands its new wings, the first thing it needs is a drink of water. In warm conditions flies die within 48 hours if no water is available.

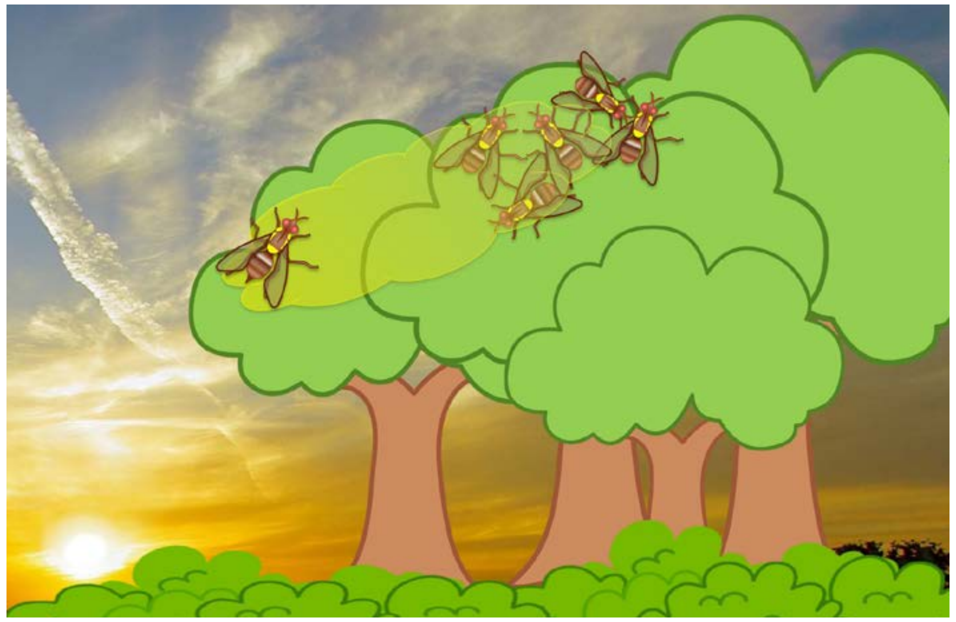
As flies cannot feed on solids, they need either liquid food or food they can dissolve in regurgitated gut liquid. It is unclear what fruit flies feed on in nature, but it is believed food sources include nectar, juice from damaged fruit and exudates on leaves.

Pupal cases; some pupae are intact, but in others the cap has come off and the fly has already emerged (Image: J Ekman)

Both male and female flies need to feed on protein to become sexually mature. This is especially important for the female in order to produce viable eggs.

The more protein the female can find, the more eggs she is able to lay. Natural sources of protein include bird droppings, yeast on decaying fruit and bacteria on leaves.

Under warm (over 22°C) conditions and with adequate water and protein, Qflies become sexually mature within



At dusk, male Qflies gather together at 'lekking points' in trees and emit a pheromone to attract female flies.

10–14 days after emergence. Development is slower in cool conditions. However, Qfly has been shown to adapt quickly to the lower temperatures experienced at their southern limits.

Once mature, fruit flies search for a mate. Qfly mates only at dusk, for a period of around 30 minutes. Temperatures need to be at least 16°C for mating to occur, so breeding is rare unless daily maximums exceed 20°C. Male flies gather in groups in trees (lekking sites) at dusk, emitting a cloud of pheromone to attract female flies. Males are more likely to find a mate if they have fed on the parapheromone cue-lure, as well as if they are able to "sing" (a clicking noise to us).

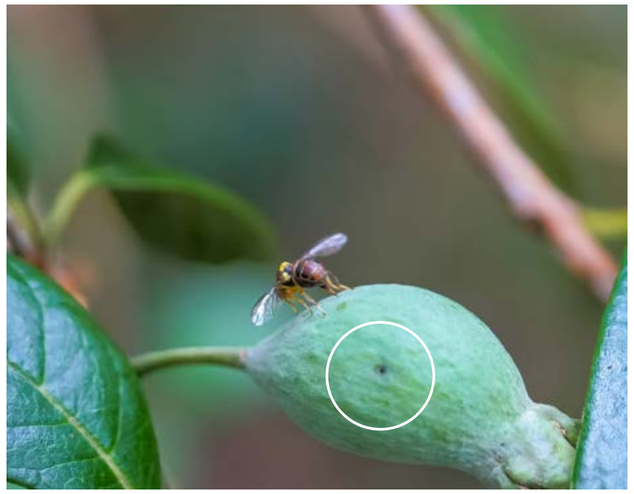
Females usually mate once but can mate twice or more. Sperm from each partner can be stored and used as needed to fertilise eggs. This means even if the female mates only once, she can continue to lay fertile eggs for several weeks.

It is easy to tell male and female flies apart. Female flies have a sharp ovipositor, which is used to pierce fruit skin and lay eggs. This protrudes behind them. Males simply have a rounded abdomen.

Once the female fly has mated, she searches for a suitable host to lay her eggs. It is believed she mainly uses visual cues – fruit flies are most attracted to yellow – but smell is also important. Her preferred hosts are soft fruit such as peaches, loquats and feijoas. However, potential hosts also include lemons, grapes, passionfruit, chillies, tomatoes and even avocados if they have started to soften. Fruit usually has to be ripening, but flies will lay eggs in unripe fruit if no other hosts are available.

Female fruit flies usually lay into intact fruit; fruit that is rotting or on the ground is not preferred. However, infested fruit that has started to decay sometimes detaches from the plant. Orchards with a lot of fallen fruit can prove to be population centres for fruit flies.

Female Qfly on a backyard loquat tree, searching for a good place to lay eggs (image: J Ekman)



Female Qfly laying into a feijoa, with another sting mark clearly visible (Image: Crbellette)

Low temperatures restrict development, mating and egg lay. Qfly rarely mates below 16°C and is unlikely to fly below 15°C. Adults become completely inactive below temperatures ranging from 3°C to 7°C. This minimum threshold varies because of the ability of Qfly to adapt to cold conditions. Flies previously exposed to cold are more likely to remain active as temperatures drop.

By reducing metabolic activity, low temperatures can increase lifespan. Fruit flies overwinter as adults, not as pupae or larvae. At temperatures below 13.5°C, female Qflies re-absorb some or all of their eggs, helping them to survive the winter. However, they then need to mate again once temperatures rise in spring. This requirement can provide a "winter window" for some crops.

It has been reported that 50% of flies emerging during late autumn are still alive after 100 days, with 10% surviving 160 days. However, this depends on minimum temperatures. Average daily temperatures below 2.6°C reduce survival, while at least 50% of Qfly are killed if temperatures fall below -3°C for 7 hours.

Some researchers have suggested that Qfly undergoes a period of diapause (reproductive dormancy) as an evolutionary adaptation to seasonal fruiting in tropical forests. As a result, populations fall during winter, even if temperatures remain warm and hosts are available.

03. THE LIFE OF FRUIT FLIES

Queensland fruit fly

Bactrocera tryoni

THE EFFECT OF TEMPERATURE

As insects are 'cold blooded', their development rate is almost entirely determined by temperature. Development can slow or stop at low temperatures, but speeds back up once conditions warm.

In the case of Qfly, a full lifecycle has been predicted to require approximately 380 degree-days above 12°C. So at an average of 22°C a lifecycle takes 38 days, whereas at average 28°C a full lifecycle may be completed in only 24 days.

This has significant implications for management strategies. For example, if temperatures at dusk are too low for mating, this will restrict the ability of unmated females to lay viable eggs. Low temperatures later in the season extend the time that adult flies are emerging from the soil, so protein baits may need to be applied over a longer period. Conversely, at warm temperatures (up to around 36°C) populations can increase extremely rapidly, making it essential to respond quickly to outbreaks.

Fruit fly species vary in their temperature tolerance. Unlike Qfly, Medfly can continue to reproduce at 16°C. However, it is considered less tolerant of high temperatures, with four hours over 39°C causing high mortality.

Cucumber fly is the opposite. It matures fastest at 30°C, with development time decreasing from 44 days to only 12 days with an increase in average temperature from 15 to 30°C.

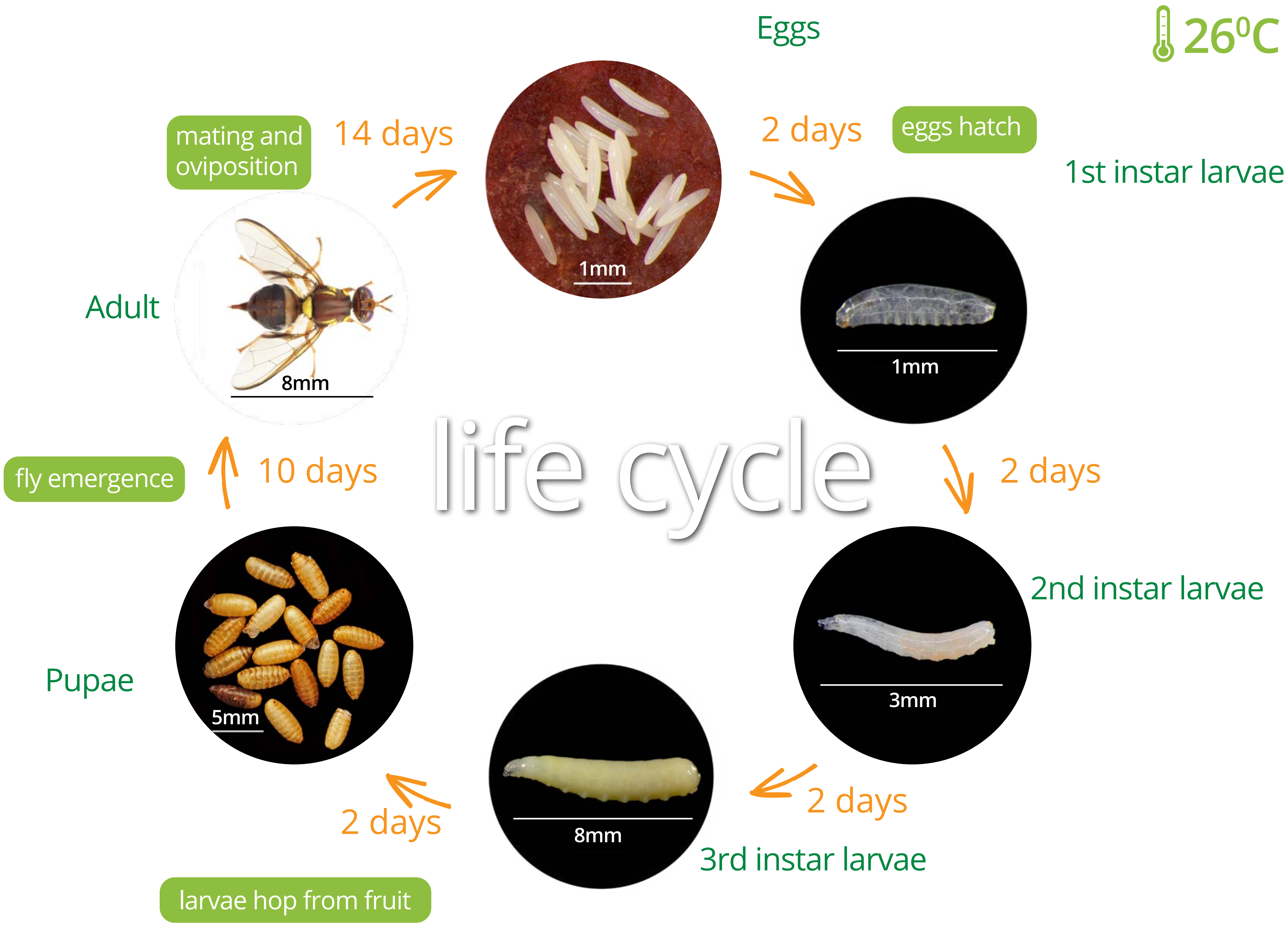
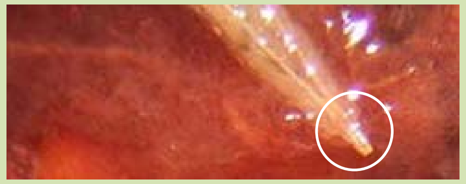


Table 1. Key Differences Between Fruit Flies and Vinegar Flies:

	Qfly	**Vinegar fly**
	Generally intact fruit	**Rotting fruit or vegetable**
Egg	Slender with smooth ends and slightly curved shape 	White, oval with two slightly clubbed, hairlike appendages 
Larvae number in fruit	Usually 2 to 10 per fruit 	Usually >30 per fruit, rarely <10 per fruit. 
Larvae appearance	White to cream, black feeding hook visible in mature larvae, smooth bodied, 2–9mm long.	White with black feeding hook, slightly notched along body, 1–5mm long.
Larvae shape	Wedge shaped, wider at tail than head. 	Slender throughout. 
Larvae spiracles	Very slight bumps for breathing holes in tail end. 	Distinct, long breathing tubes coming out of tail end. 
Host material	Soft, spongy, starting to rot. May be fully eaten out with only skin left.	Liquified and rotting.
Pupae appearance	Like a large grain of brown rice, variable colour. 	Like a small, slender grain of brown rice, with two small prongs at one end. 
Adult fly	Wings held out from body, 8mm long, brown and yellow, female with distinct ovipositor. 	Wings flat along back, 2.5mm long, yellow-brown and black, female with slightly pointed abdomen. 

FRUIT FLY OR VINEGAR FLY?

In general, if larvae are found in fruit already rotting on the ground, it is likely it has been infested by *Drosophila melanogaster* – vinegar fly. True fruit flies (like Qfly and Medfly) lay eggs in intact fruit. As vinegar fly only attacks damaged fruit it is not an economic pest.

Larvae of other flies are also occasionally found in damaged fruit. These include Island fly, metallic-green tomato fly (*Lamprolonchaea brouniana*) and *Atherigona* spp. Like vinegar fly, these species lay eggs in damaged or rotting fruit, so are not economic pests. Atherigona larvae are easily distinguished as they have distinct black spiracles (breathing holes) at their rear end. However, many larvae are difficult to tell apart without the help of an experienced entomologist. Moreover, there may be more than one species present in a piece of rotting fruit.

Metallic-green tomato fly larvae look very like fruit fly larvae, but are smaller (less than 3mm long) and darker (Image: D Crawford)

Atherigona larvae also look similar to fruit fly but are bright white with black spiracles (Image: J Ekman)

FRUIT FLY BEHAVIOUR

Natural habitat

The natural habitat of fruit flies is the forest, particularly the forest edges. Trees are sources of food, moisture and shelter. Bacteria and bird droppings on leaves and branches are also important foods for fruit flies. Irrigated orchards and urban gardens can therefore provide comfortable environments for fruit flies, with ready access to both food and water.

Pastured areas, as well as ground crops such as strawberries, capsicums and tomatoes, do not provide roosting spots or food. Flies are likely to only enter to lay eggs before they return to the safety of the surrounding trees. In large blocks, fruit near the crop edge is the most likely to become infested, especially if trees, shrubs or other shelter is nearby.

As the main reason for being in the crop is to lay eggs, female flies are more likely to enter than males.

Flight distance

Fruit flies are not strong fliers. They spend far more time walking around the tree canopy than flying. When they do fly, it tends to be relatively short distances (5–50cm) from branch to branch, or approximately 2m from the ground in between trees. However, flight is an essential skill. Without it, fruit flies are unable to find a mate or host fruit to lay eggs.

Flight-ability is affected by factors such as temperature, humidity and nutrition. As previously noted, they are unable to fly at temperatures below around 15°C. Flight is also restricted by high winds or low humidity.

As long as food and host fruit are available, 90% of flies will range only 600m from where they emerged. Medflies are similar, with 90% of flies travelling less than 700m during their lifetime. Both species rarely travel more than 1km.

One of the reasons flies rarely disperse widely is because it makes it difficult for them to find mates. For example, Qflies mate for only around 30 minutes at dusk. During this short time groups of males gather, producing a plume of scented pheromone which attracts female flies. A single male cannot produce enough pheromone to attract distant females, so is unlikely to find a mate.

Flies can also disperse long distance through accidental "hitch-hiking" on vehicles, equipment or plant material. Reports of Qflies travelling tens of kilometres are likely to be human assisted journeys rather than ones taken by wing power alone! Outbreaks of fruit flies in remote areas are more likely due to infested fruit carried into the region than incursions by travelling flies.

Likes and dislikes

There are conflicting reports about what colours attract or repel fruit flies. Yellow is definitely attractive, which is why most monitoring traps are this colour. However, flies see in higher wavelengths than humans, so items that reflect a lot of ultraviolet (UV) might look quite different to flies than they do to us. It has been demonstrated that reflected UV light can attract fruit flies, especially at dusk.

It is also clear that fruit flies prefer to gather in dark spaces than brightly lit ones, probably due to their rainforest origins. Conversely, flies are not attracted to white. White plastic and/or netting may help deter fruit flies from entering greenhouse environments.

Fruit flies can be attracted by certain fruit volatiles, as well as by ammonia. There is now evidence that the aromas given off by live yeast can also attract female flies. Combining such aromas with fruit mimics provides a way to attract female fruit flies.

Given that fruit flies are also attracted to "tree shaped" objects, areas around creeks and dams are good habitats for flies. It has been suggested that creek-lines are the main route they use to move through the landscape, fruit flies rarely flying directly across open grassland or grain crops.

Damp, tree lined areas along watercourses are good habitats for fruit flies. (Image: J Ekman)

04.

MONITORING CAN HELP IDENTIFY WHERE FRUIT FLIES ARE COMING FROM, WHETHER POPULATIONS ARE INCREASING OR DECREASING, AND WHAT ACTIONS ARE NEEDED. TRAPS NEED TO BE PLACED IN HIGH-RISK AREAS AS WELL AS AROUND CROP PERIMETERS AND CHECKED REGULARLY. MANY DIFFERENT TYPES OF TRAPS ARE AVAILABLE, BUT SOME ARE MORE SUITED TO MONITORING THAN OTHERS.

Monitoring and trapping

The purpose of monitoring is to find out whether flies are present, and if numbers are increasing or decreasing.

Monitoring DOES NOT indicate how many flies are in the crop, whether females are present, or fruit is infested. Depending on the crop, even significant numbers of flies in traps does not mean the product is infested. Conversely, there may be flies in the crop but none in the traps if there are other strong smells or attractants nearby.

Monitoring DOES indicate whether control strategies are proving effective. It can also help focus extra control measures on fly hot spots, in or around the crop.

MONITORING GRIDS

The purpose of a monitoring grid

Monitoring grids for fruit flies are designed around the species targeted, growing region, crop/s grown, the organisation collecting the information and the potential impacts of a detection. Monitoring grids normally use traps containing lures for male flies due to their range and target pest accuracy.

Exotic pest surveillance grids provide evidence supporting the “non-presence” of fruit flies of biosecurity concern. They are an essential tool when accessing protocol markets where access is based on the absence of a pest from that state or region. Such grids operate under strict protocols and are often managed by Government (State and Federal) in agreement with fruit industry bodies.

Exotic pest surveillance grids are also used to provide early detection of any unwanted international arrivals. Fruit fly traps are located in major cities, around ports and along coast lines, helping to alert authorities to international pest incursions.

There are also State based grids. South Australia, Western Australia and Tasmania use surveillance grids to detect incursions of Qfly from established populations in the eastern mainland states. These grids, in combination with other production criteria, demonstrate to trade partners that there is no significant risk that exported fruit contains Qfly.

Other monitoring grids are in place where pests are known to exist and pose a risk to the crop. Information from the traps is used to determine appropriate management strategies, protecting both fruit quality and economic outcomes. Such grids may use the same guidelines as those for exotic pest surveillance, or be modified to suit the region, pest pressure and crop type.

Establishing a monitoring grid

The type of trap used, where traps are placed and how many are used vary according to the fruit fly species, crop type, season and surrounding environment. It is also important to consider the level of risk, based on whether the fruit fly species is exotic or an established pest.

For Qfly, grid spacings can vary according to proof of freedom or early detection requirements. Grids generally involve male Qfly traps spaced at 400m intervals within the crop. These can be supported by a larger network of traps at 1km, 2km and 5km intervals.

Traps should be in place before flowering, with monitoring continued for at least two weeks after the crop has been harvested, or longer if possible.

The effectiveness of monitoring grids depends on the other smells and attractions around the crop at the time. Female biased traps can support information from male fruit fly based monitoring grids. In some cases, there may be no Qfly found in monitoring traps, with infestation first detected through fruit inspection. All monitoring grids should be supported by regular fruit inspection during the growing season.

Wafer type lure (left), traditional dental wick (centre) and an enclosed wick lure (right) (Images: J Ekman and B Koll)

LURE TYPES

Parapheromone lures

Parapheromones resemble the natural pheromones produced by insects. Young male flies seek out parapheromones as they help improve their mating performance.

Parapheromone attractants used in traps are usually synthetic products used at a high concentrations, out-competing natural sources of related compounds.

The distance over which parapheromones can attract male flies is unclear. In the case of Qfly, cue-lure may have a zone of attraction extending in the order of 20m or as much as 200m. Trimedlure is thought to attract flies for up to 50m. Even within this zone only a percentage of male flies will be captured; no lure will capture 100% of male flies.

Parapheromones do not attract female flies or other insects, and are fairly species specific;

- **Cue-lure** attracts Queensland fruit fly (*Bactrocera tryoni*), along with lesser Qfly (*B. neohumeralis*), Newman fly (*B. newmani*) and *B. aquilonis.*
- **Trimedlure** attracts Mediterranean fruit fly (*Ceratitis capitata*).
- **Methyl eugenol** attracts Banana fruit fly (*B. musae*), wild tobacco fruit fly (*B. cacuminata*) and exotic species such as Oriental fruit fly (*B. dorsalis*).
- **Zingerone** attracts Jarvis fly (*B. jarvisi*).

Approximately 50% of fruit fly species do not respond to any of these male attractants. This makes monitoring problematic. For example, Cucumber fly (*B. cucumis*) is an increasingly important pest of cucurbits such as zucchini and squash. However, surveillance is difficult as it does not respond to any known parapheromone and is only weakly attracted to protein lures, with the best results from a cucumber volatile blend.

In their pure liquid state, parapheromones are relatively short lasting and difficult to handle. They are easier to use when absorbed into a rolled cotton wick, incorporated into a gel, or impregnated into a waxy “wafer” matrix. While the cost of wafer lures is slightly higher than older style ‘dental wick’ lures, they offer a more controlled release over time. This means they can potentially remain active for up to 16 weeks under field conditions.

Other types of lure

Some liquid lures, for example Wild May and Gepro, also attract male flies using compounds that resemble natural pheromones. The aim is to attract and drown male flies. As they are insecticide free they meet organic certification requirements.

It is important to note that if a parapheromone is being used to attract and kill male flies, monitoring using the same attractant becomes unreliable.

Other liquid lures are based on protein and/or fruit volatiles. Such food-based lures attract both female and male flies, but have a smaller zone of attraction than parapheromones. However, they can provide some information about fruit fly populations.

All liquid lures need to be topped up regularly and can become smelly and messy due to their content of dead flies. This makes it difficult to count the captured flies and even harder to confirm species. This limits their usefulness for monitoring purposes. Food-based traps also attract by-catch, such as blowflies and other non-pest insects.

Lures can also rely on visual and/or aroma cues, simulating a host fruit. These are primarily used as sticky traps. Like the liquid lures, such traps can catch non-target insects, as well as reptiles, birds and even small mammals. They cannot be legally used in some states and territories. Also, while flies stuck onto traps can generally be identified, they cannot be easily removed if further expert assessment is needed.

Ryset traps (left), and others, can be loaded with a liquid lure as part of an attract and kill management strategy (Images: B Koll)

Examples of male traps primarily designed for use with a dry parapheromone lure. Top row, left to right: Bugs for Bugs Pro trap; ISCA ball trap; Bugs for Bugs small trap. Bottom row, left to right: Biotrap; Searles trap. (Images: J Ekman and B Koll)

TRAP TYPES

There are numerous different types and styles of traps used for monitoring populations of male flies. They are usually bright, fruit colours (yellow or red) with clear sections that both encourage flies to enter and allow the contents to be easily inspected.

Fruit fly monitoring grids usually use a ‘dry’ parapheromone lure combined with insecticide. Fruit flies are lured inside the trap then killed by insecticide. Other kill methods include drowning or immobilisation on a sticky card. It is essential that the dead flies are retained inside the trap in such a way as they can be easily identified and recorded before the trap is emptied.

Conventional male traps

Male traps target young male flies that have reached sexual maturity and are ready to mate. They are highly attracted to parapheromones, which increase their chance of mating success. Male traps can provide early detection of fruit fly populations, which can then drive management decisions.

Male traps are available to suit everything from a backyard garden to a large commercial orchard.

Commercially available male Qfly attracting traps that use a wick, wafer or gel style of lure are made by Biotrap, Bugs for Bugs, Eco-Lure, ISCA and Searles.

Gepro and Wild May make a wet trap where male flies are attracted into the trap and drown (see p17).

While other trap styles are available these are not readily used for Qfly, or are primarily designed for experimental use.

Automated male traps

Regular trap inspection and counting of flies can be both laborious and expensive. This has led to the development of automated ‘smart’ traps. Smart traps aim to save time and improve the speed with which information from the field gets to decision makers. Improving the timeliness of control actions can promote the effectiveness of management strategies.

For example, smart traps can alert growers immediately when a fly arrives in a previously empty trap, or if trap catches start to increase. When operating correctly, such warnings have a clear advantage over weekly (or less frequent) trap checks. With only occasional maintenance required, smart traps potentially provide significant travel and labour savings, especially for remote areas.

Several systems are under development or available. All use a parapheromone lure to attract male flies past a camera or sensor, and a toxicant to kill them once inside. In some cases the system identifies the insect using artificial intelligence and sends an alert. In others, the system simply sends an image, with identification left to a human receiver.

Depending on the system used, smart traps are not purchased directly, but made available through subscription. Under this arrangement, growers may not be responsible for trap maintenance.

Another advantage of such systems is that data from different surveillance grids can easily be pooled. Growers can see the current average pest pressure for their region as well as a forecast of what is likely to happen over the next five days. This can help them target control activities at the times and locations when flies are most likely to be present.

Note that no automated systems have yet been accepted for protocol trapping grids. They also cannot provide the real-life crop observations and fruit inspection services that a person performing manual trap inspections can do whilst in the orchard.

Systems include SnapTrap, TrapView (under development) and RapidAIM.

Female biased traps

Despite many years of searching, there are no pheromone-based lures for female fruit flies. Female biased traps therefore use either a food-based lure rich in protein or simulate the appearance and aroma of a host fruit. Current research on new female lures is showing promising results using the aromas released as larvae break down host fruit.

Female biased traps aim to attract either unmated young females or mature females searching for host fruit to lay their eggs. They can provide useful support to male focused trapping grids (where there are no conflicting protocol requirements) as they provide a way to observe population trends where parapheromones are already used for control (for example the Male Annihilation Technique, section 6).

Unfortunately, female biased traps generally don’t have a large zone of attraction (possibly 5 to 10m) and can be outcompeted by naturally occurring food and fruit scents.

As the lures used are not specific to fruit flies they attract and kill other insects.

For example, decomposing protein also attracts ants, blowflies and vinegar flies. This makes it difficult to confirm identification, or even to count the number of fruit flies present.

Commercially available female biased traps include CeraTrap, Biotrap, ISCA Ball trap and the Fruition trap.

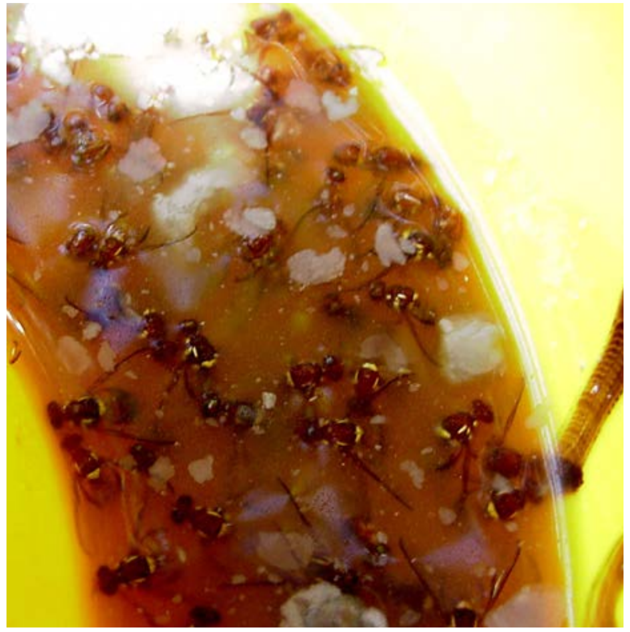
Two types of automated smart traps: The RapidAIM (left, J Eccles) and SnapTrap (right, B Koll). Above: Cera trap (Image: J Ekman)

Mass-trapping devices

Mass trapping devices aim to lure and kill a large percentage of the fruit fly population. Female biased traps can be used in a mass trapping program. They are generally based on either a protein rich food attractant or a mixture of visual/aroma cues that mimic host fruit.

As mass trapping devices typically have a relatively small zone of attraction, large numbers of the devices must be deployed through the crop. Recommended rates range from 15 to 80 traps/ha. Lower rates may be used for less susceptibile crops. For more vulnerable crops, it is common to deploy more than 50 traps/ha, with traps concentrated around the borders.

Even at high densities, there is limited data on effectiveness of mass trapping systems. For example, research in Italy found that 50 traps/ha reduced, but did not eliminate, larval damage to figs. This means systems can be expensive to set up and maintain. However, they may be used in areas where bait application is not possible.



Liquid lures can become smelly and messy if large numbers of flies are caught (Image: J Ekman)

Sticky traps

Some traps used for monitoring or mass trapping kill by trapping the insects on a sticky surface.

In general, sticky traps are indiscriminate. They can potentially trap beneficial insects and even small mammals, reptiles and birds. Sticky traps must always be positioned so as to minimise such bycatch. Alternatively, they may be designed to have small entry holes and/or a fruit fly specific lure to reduce accidental catches.

Deployment of sticky traps is highly regulated in some states and territories. Although use is still permitted in other areas, there is pressure to improve protection for wildlife by, for example, adopting the requirement for a protective cage to prevent animals contacting the sticky surface.

TRAP PLACEMENT

If using a 400 m standard grid as part of a market access protocol, it is important to place traps exactly where they are required. No additional traps can be deployed.

However, if monitoring is being conducted as a crop management tool, trap locations can be determined based on the environment and assessment of risk.

Installing traps in orchards

Traps have a limited zone of attraction. They therefore need to be placed where fruit flies are most likely to be. The natural habitat of fruit flies is the forest. Flies tend to feed and rest in trees, preferring those near moist areas such as creek lines or dam edges. They move along tree corridors, and mate within the canopy.

If the trap location is near trees, traps should be hung around 1.5m from the ground and inside the canopy. Fruit flies don't like going into hot traps, so traps should be shaded by some foliage. Moderate air flow is important. Having some air flow allows the attractant to circulate freely, but avoids the lure being blown away by strong winds.

Under cold conditions, flies are likely to be attracted to warm spots, such the northern side of trees. However, if conditions are hot and dry, then the flies are more likely to be found on the eastern or southern side of trees.

This Biotrap can be loaded with a food based gel or parapheromone lure and contains a sticky, removable sheet, providing a targeted, non-chemical kill method.

The Fruition trap is designed to attract female flies searching for host fruit using a combination of sticky yellow spheres and fruit volatile aroma (Image: AgNova Technologies). Right shows the 'Wildlife safe' covered version.

Table 2. Examples of traps used for monitoring Queensland fruit fly, available at the time of publication

	Male Qfly	Mass trapping and/or Female biased	Female Qfly
Kill method	Parapheromone lure attracts males prior to mating	Protein or food attracts hungry flies, especially young females searching for protein	Fruit scents attract female flies searching for host fruit to lay their eggs
CHEMICAL – Active ingredient kills by contact or ingestion	*Cuelure + insecticide in a protected wick* – Ecolure/Bugs for Bugs – BioTrap – Searles	*Protein gel + insecticide cube* – BioTrap	
STICKY TRAP – Fly trapped on sticky surface	*Cuelure in a protected wick + sticky card* – BioTrap	*Protein gel + sticky card* – BioTrap	*Fruit scent and protein gel + sticky card* – Fruition (Agnova/Vasili's)
LIQUID – Drowns the fly	*Liquid male Qfly attractant* – Wild May – GePro	*Liquid with yeast extract* – Cera trap – DIY recipe (could include beer, vegemite or liquid protein)	*Orange or fruit juice with cloudy ammonia* – DIY recipe

It may therefore be advantageous to place traps in a warm, north facing position during spring, especially in cooler climates. Traps can be moved further into the shelter of the canopy during summer, or placed more permanently on the south-east side of trees in hot climates.

Traps should also be placed in serviceable parts of the tree. They should not be in the way of tractors, machinery or other staff operations.

Traps baited with different types of lures should be placed at least 30m apart.

Installing traps in other crops

Crops with relatively flat architecture, such as berries or vegetables, do not provide the environment preferred by feeding or resting fruit flies. While females will readily enter these crops to lay eggs, traps attract male, not female flies. The best place for traps in these crops is therefore in the tree lines and windbreaks bordering the field.

In protected cropping, traps are best placed at entry points to greenhouses, such as at the tunnel ends, or in line with openings along gutters or vents. They may also be located both above and below benches where crops are produced on table systems.

Extra traps

Extra traps should be deployed in the areas where incursions are most likely to occur. These could include neighbouring orchards, bush and roadsides or tree lines facing the prevailing wind. Natural waterways growing plants such as blackberry, wild tobacco and feral fruit trees form natural highways for fruit flies, while backyard fruit trees in urban areas can host fruit flies year round. Abandoned or unmanaged fruit crops are a major risk, so monitoring these is particularly important.

Monitoring programs that include the participation of neighbours, especially home gardeners, can be highly beneficial. A typical home gardener might deploy one or two male and female biased traps to both monitor and help manage fruit flies.

CHECKING TRAPS

Traps should be numbered and listed on a farm map, so that anyone can check them. Traps need to be checked weekly during summer, or whenever populations are expected to be high. The more frequent the checks, the more timely the response to changes in populations. The operator needs to record the number of flies found using a record sheet and always remember to empty the trap afterwards!

If possible, the operator should also record whether any female flies are found inside the trap – finding a female fly inside a male trap can indicate that populations are relatively high, and that action needs to be taken immediately.

If the operator is changing the lure, it is important to wear disposable gloves and avoid contaminating the trap itself. Flies are less likely to enter the trap if parapheromone is already available on the outside surface.

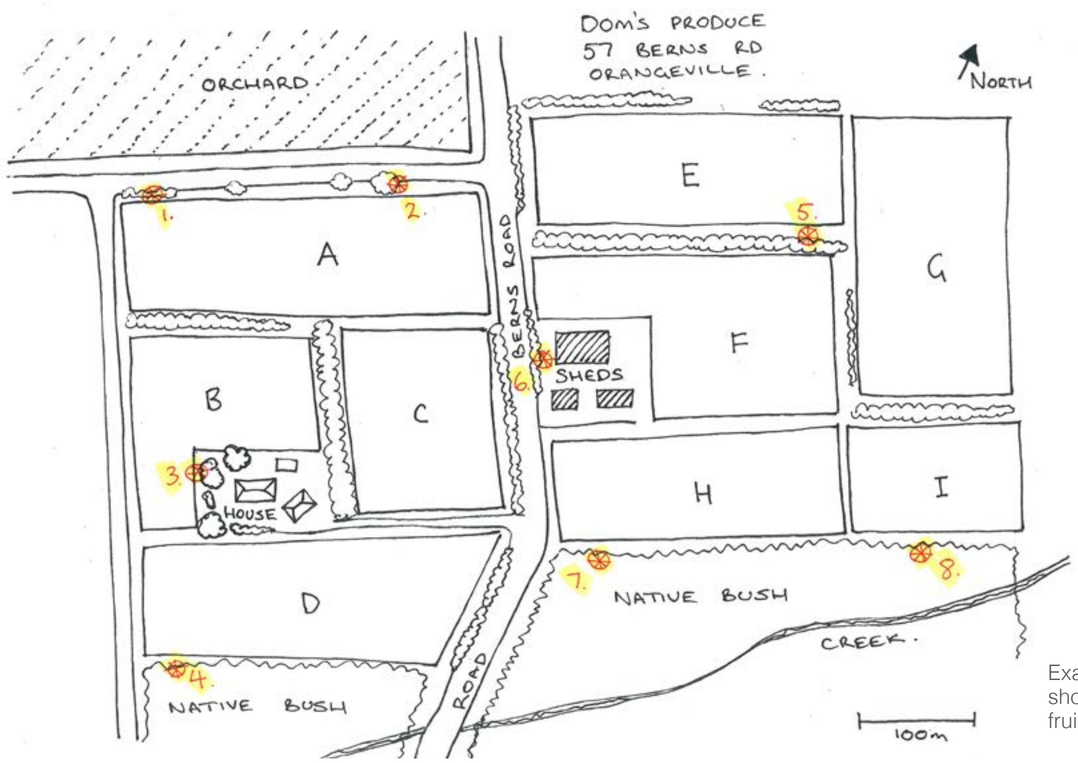
Checking and maintaining traps takes time. However, the more traps there are, the better the warning of incursions into the crop.

The purpose of monitoring is to detect incursions of fruit flies into the area and determine whether populations are increasing or decreasing. Trap catches do not necessarily reveal the likelihood of infestation in the crop. Checking the fruit itself is therefore an invaluable support activity.

Fruit fly monitoring

Date	Trap no.	Fruit flies	Other

Example of fruit fly record sheet



Example of a farm map showing placement of fruit fly traps

TIPS FOR SELECTING AND INSTALLING FRUIT FLY TRAPS

- ✓ Protocol monitoring grids for 'proof of absence' of Qfly don't permit extra traps. These grids specify the lures, trap types and trap numbers to be used, with trap examination by independent accredited inspectors
- ✓ Traps vary in colour and shape, factors that can influence their attractiveness to flies
- ✓ Traps using wet lures
  - Require frequent checking and topping up, especially in hot, dry weather
  - May need to be protected from rain and irrigation water
  - Make it difficult to identify and count flies, and can be unpleasant to inspect if the insects have started to rot
- ✓ Traps using dry parapheromones lures (wicks and wafers)
  - Are easier to inspect and collect fly samples from, so long as they are not contaminated by liquid or sticky glue
  - Have a defined expiry date and must be routinely replaced
  - Vary in their rate of parapheromone release and period of effectiveness in the field.
- ✓ Sticky traps
  - Do not rely on chemicals to capture fruit flies
  - Include cards with a printed scale to make identification using photos easier
  - Can capture non-target organisms including beneficial insects, reptiles, birds and even small mammals; some states mandate that sticky traps are protected from such accidental by-catch
  - If exposed, can be contaminated by soil or other organic materials under windy conditions
- ✓ Some lures are easily available, yet others are only available to commercial customers
- ✓ Some traps are heavier, sturdier and more reusable, while others are light weight and single use, with lower prices accordingly
- ✓ Organic producers can use any trap or lure depending on individual market requirements or recognition of permitted lures within their Organic Certification
  - In general, they are permitted for use so long as active ingredients do not contact the ground or the crop
- ✓ Traps with chemicals should be placed safely away from children and animals; always adhere to label directions

Traps should be placed at least 1.5m from the ground in a position protected from direct sun and wind. This trap is hung in a windbreak tree at the edge of the cropping area (left)

Unmanaged crops such as abandoned citrus orchards are a major potential source of fruit flies, so well worth monitoring with an extra trap (right)

ACTIONS FROM MONITORING

How trapping information is used will depend on the circumstances of the grower and risk of crop infestation. Typical actions taken could include:

Fruit fly trap catches	Actions needed
None found	• Check the traps are functioning correctly (for example, lures still attractive, insecticide active) • No control actions may be needed • If control actions are already in place no additional actions are needed • Control actions may be reduced while risk is low
Catches increasing	• Start control actions, such as hygiene, baiting, male annihilation and cover sprays (if none is currently underway) • Increase the variety, area and frequency of control actions if they are already underway • Maintain surveillance and potentially increase inspection rate
Catches decreasing	• Control actions may be working • Continue current program until drops in population are confirmed by longer term trends • Note that temporary drops in catches may be caused by factors that reduce flight (high or low temperatures, strong winds), crop development stage or natural population variability • Low trap catches may also be the result of cover sprays, use of male annihilation devices or other suppression activities.

Each crop and region is different, so management varies. Collecting data over time and keeping good records will help manage crops according to crop, region and microclimate.

In general, successive catches of male Qfly in traps within 1km proximity in a two-week period suggest that more action is needed.

High numbers of male flies, detection of females in traps, or finding larvae in fruit all suggest that a long-term control program is needed to break the breeding cycle of fruit flies in the cropping area. Such programs need to run for at least 12 weeks and usually involve a range of corrective actions. The cause of the infestation should be investigated further, with measures such as crop hygiene and removal of unwanted host fruit used to limit ongoing issues.

If high populations of fruit fly are present then susceptible crops must be checked during harvest and packing. Thorough inspection reduces the risk of sending infested fruit to market. It is illegal to knowingly market fruit fly affected produce. Additional postharvest treatments may be required to ensure produce is fruit fly free.

Check traps regularly, record the number and sex of any flies caught, then ensure you empty the trap before re-setting

BEST PRACTICE

- ✓ Monitoring programs usually involve a parapheromone lure specific to male flies of the target species
  - Cue-lure is attractive to Qfly, lesser Qfly and Newman fly
  - Trimedlure is used for Medfly
  - There are currently no commercial parapheromone lures for Cucumber fly or Jarvis' fly
- ✓ There are a wide range of conventional traps that can be used with parapheromone lures
- ✓ Automated 'smart' traps with parapheromone lures can potentially provide remote data in real time and minimise the need for physical visits
- ✓ Female biased traps based on food, aroma and/or visual cues are most likely to be valuable for monitoring if parapheromones are already used as part of a control strategy
- ✓ Sticky traps can kill non-target insects as well as reptiles, birds and small mammals; a protective cover that only allows small insects to enter can reduce unintended harm and is a legal requirement in some states and territories
- ✓ Mass trapping devices based on food, aroma and/or visual cues have a limited zone of attractiveness, so must be deployed through the crop in very large numbers to be effective
- ✓ Monitoring grids used to demonstrate pest freedom must be installed exactly in accordance with market access protocols
- ✓ Monitoring grids used for crop management can be based on a 400m grid within or around the cropping area, customised to suit the lay of the land, crop type and risk
  - Hang traps approximately 1.5m high within the tree foliage, protected from direct sunlight and strong wind
  - Install extra traps in high-risk areas, such as adjacent to orchards, near urban areas and along treed watercourses.
- ✓ Locate or move traps according to seasonal conditions
  - At cooler locations, locate traps in warm spots, such as the north-eastern side of trees
  - In hot production areas or during summer months, locate traps in shaded areas on the southern side of trees
- ✓ Traps need to be numbered and recorded on a farm map.
- ✓ Check traps weekly during the growing season as well as when populations are increasing or high and fortnightly at other times.
  - Record the number of flies, noting if any are female, and re-set the trap.
- ✓ Thresholds for control programs will vary according to the fly species detected, crop stage and farm circumstances
  - For protocol focused monitoring grids, control programs are triggered at pre-determined levels according to regulatory requirements for that crop
  - Higher or lower thresholds may be appropriate for farms not using such agreements

05. PROTEIN BAIT

05.

PROTEIN BAIT IS AN IMPORTANT PART OF ANY FRUIT FLY MANAGEMENT PLAN AS THEY PRIMARILY TARGET IMMATURE FEMALE FLIES. THEY SHOULD BE APPLIED WEEKLY ONCE FLIES START TO EMERGE.

Protein bait

Protein bait can attract both male and female flies. Bait is especially attractive to newly emerged females, which need to feed on protein to mature and develop their eggs. The ingredients used, and how and when baits are applied, greatly influences their effectiveness in the field.

Sprayable bait can contain:

Protein + Insecticide + Carbohydrate + Thickeners

TYPES OF BAIT

Fruit fly bait is made from protein lure and an insecticide. Protein needs to be partially broken down (hydrolysed) to make it attractive to the flies. Yeast autolysate and hydrolysate are the usual protein sources used. Bait is generally available as a lure only formulation, to which a registered insecticide is added at the time of mixing for field application. Examples of protein only lure include Fruit Fly Lure, Natflav, Cerabait, Flavex, Hym-Lure and DacGEL. Anamed has added parapheromone (trimedlure). Naturalure and Anamed WB SP0.1 (registration pending) are ready mixed protein baits with an organic insecticide (spinosad).

Commercial protein products are available as viscous liquids, pastes and powders. Liquids are the most common. The type of protein used in bait varies between manufacturers, and some may be more suited to specific crop situations or target different fruit fly species.

PROTEIN

Protein concentrate needs to be mixed with the required amount of water in a large tank. Typically, one to five litres of concentrate are combined with 100L of water. Dilution rates depend on the protein concentration in the bait and the application method used.

Carbohydrates (sugars) and ammonia compounds can be added, increasing attractiveness to fruit flies. However, sugars can also attract non-target insects such as ants and even bees. Thickeners can be added to keep the bait moist and attractive for longer.

Making the solution ahead of time can potentially reduce the risk of clogging during application, especially if a powdered protein or thickener (xanthum gum) is used.

Unless using a pre-mix, insecticide needs to be added to the protein solution immediately before use. All mixes should be continually mixed to ensure uniformity. Use all of the freshly made up solution, do not save or store it.

INSECTICIDES AND INSECTICIDE-CONTAINING PRE-MIXES

Both insecticides and lures are subject to APVMA (Australian Pesticides and Veterinary Medicines Authority) permits and registrations. These define the crop situations where each product can be used, with application methods listed on the label. Ensure that the lure and selected insecticide are compatible and consistent with market requirements.

Always follow the label directions and **never apply fruit fly bait to fruit.**

Female fly feeding on protein bait (Image: J Ekman)

Approved insecticides at time of publication are:

ACTIVE INGREDIENT	CROP / SITUATION LISTED ON LABEL
Malathion (also called Maldison)	Fruit trees, other trees Non-crop vegetation on the perimeter of blueberries, rubus, ribes and strawberries
Trichlorfon	Lower foliage of fruit and vegetables
Chlorpyrifos	Low strip or patch low on the tree for citrus, avocados and passionfruit, commercial use only
Abamectin	Base of plant application in blueberries, raspberries and blackberries Citrus tree skirt only

Naturalure and Anamed WB SP0.1 (registration pending at time of publication) are protein pre-mixes that use spinosad as the active ingredient to kill fruit fly. Anamed WB SP0.1 also contains the Medfly male attractant trimedlure, stabilisers and other ingredients.

ACTIVE INGREDIENT	CROP / SITUATION LISTED ON LABEL
Spinosad	Tree fruit, nut, vine, vegetable crops and ornamentals Non-crop vegetation and fruit fly resting sites

Chemicals have different modes of action and ways of targeting pests. Malathion, chlorpyrifos and trichlorfon are organophosphate insecticides that kill on contact.

Abamectin and spinosad mainly kill via ingestion. If a fly only eats a small amount, it may not eat a toxic dose. This means they are less effective against female flies that have already fed on protein. Timing bait applications is therefore essential.

The efficacy and longevity of bait varies depending on the active ingredient, additives, application method and environmental conditions. In general, organophosphate insecticides persist in the environment for significantly longer than abamectin and spinosad. Organophosphates usually remain active against flies for one week or more, whereas abamectin and spinosad may be degraded by UV light within days.

However, spinosad is more suitable for use in sensitive environments. Compared to organophosphates, it minimises harm to beneficial insects and potentially ensures compliance with markets or certifiers. Such factors should be considered when developing the farm chemical strategy.

Insecticides used in bait may be hazardous to humans, other mammals, other insects (bees and beneficials) and fish. Always minimise impact on off-target species.

APPLYING BAITS

All bait mixtures should be tested on crops first. To reduce the risk of phytotoxicity, try to apply bait to different foliage areas each time. Bait applied early in the morning is least likely to produce phytotoxic effects. Conversely, avoid application in very hot, dry weather.

Where to apply bait – trees

Bait has only a very small zone of attractiveness, so it needs to be applied where flies are most likely to be.

One of the key criteria for effectiveness is height. Bait is most likely to be effective if sprayed where flies are likely to roost, rather than the base of the trees or outer skirt. Qfly tends to roost high in trees, so baits should ideally be applied 1.5m to 2m above the ground. Cucumber fly tends to rest in lower vegetation, so bait can be placed 1m from the ground.

At the same time, it is essential to avoid contaminating harvestable fruit with insecticidal bait. Tree architecture therefore means it is not always possible to apply bait at the optimal height.

Mix bait thoroughly before use (Images: B Koll)

Be careful to avoid contacting fruit when applying bait (Image: Fruit Fly Murray Valley)

In orchards with fruit still on trees, it is usually recommended to treat every second row, applying a band or coarse spot spray to tree trunks and lower, non fruit-bearing foliage.

Where to apply bait – perimeters

In berry and vegetable crops it is not possible to spray within the crop itself. Bait must therefore be applied to the perimeter vegetation, whether this is trees, long grass or hedging. This is the best location anyway, as flies are most likely to feed, rest and search for mates in this habitat.

If growing in protected cropping, bait should be sprayed on plants around the perimeter of the cropping area. Check with your agronomist before using bait inside protected cropping structures.

Bait stations

Bait performs better when sprayed onto living vegetation compared to inert surfaces (such as posts, boards etc.). This is thought to be because bait stimulates bacteria on the plant leaves. Volatiles from these bacteria help attract hungry young female flies.

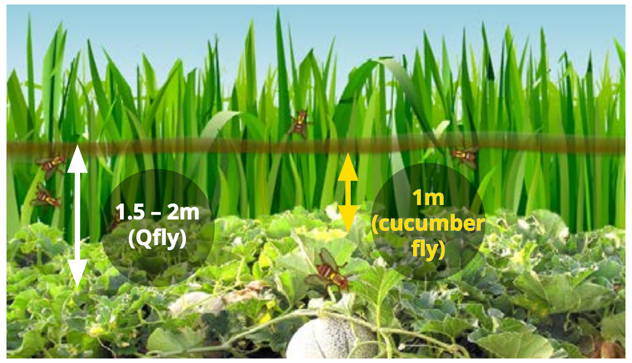
In some situations there may be no suitable vegetation available. If using artificial bait stations, their performance may be improved by including a soft wood or caneite target board, adding a rain-guard and potentially incorporating other features to make them more appealing as a natural shelter for fruit flies.

Bait application rates

Always follow label directions with regard to maximum application rates (volume/ha) and critical comments on placement.

If ONLY applying bait around the crop perimeter, application rate may vary depending on crop type, area baited and pest pressure.

Label directions on Naturalure include two dilution rates, adjusted to the same amount of active/ha. The more dilute rate of 1:6.5 can readily be applied through a spray unit. The more concentrated rate of 1:1.5 increases product efficacy, and is applied at a reduced amount of locations/ha.



Windbreak plants, such as sorghum or other tall grasses, are suitable for applying baits around field crops. Apply baits for Qfly 1.5-2m above the ground. Baits for cucumber fly are best at 1m above the ground, as that is where the flies are likely to be foraging.

It can be difficult to distribute bait containing gel at consistent rate/ha. A specialised application tool may be needed to apply dollops of material evenly.

How to apply bait

Protein bait is usually applied as large droplets. Different droplet sizes can be generated by adjusting the nozzles on vehicle-mounted pressurised spray applicators to produce a stream of the mixed bait. Calibrate equipment to deliver the required amount of bait per hectare.

When applying from a moving vehicle, a continuous stream of solution will result in large droplets on the leaves. If using a backpack sprayer, apply rough splats of bait to foliage and tree trunks. Never apply bait as a mist or cover spray.

Thickened formulations, such as the concentrated rate of Naturalure, do not pass easily through a spray applicator. These may need to be applied as a thick spot, or daubed on thickly with a brush or roller.

When to apply bait

Flies take approximately two weeks to mature after emerging from pupae. This is when females most actively search for the protein they need to mature their eggs. Once they have fed on protein they are less interested in finding more.

Bait therefore needs to be easily available to flies when they most need a protein meal. That means starting bait applications before young flies start to emerge.

The best time to spray bait is early in the morning, as this is when flies are actively searching for food. Applying bait in cool conditions also helps limit potential impact on bees.

Like bread from the bakery, bait is most attractive when it is fresh. Even though the insecticide in bait can remain active for several weeks, protein that has dried and aged is not nearly so attractive to flies. Bait should therefore be applied every 4 to 10 days, depending on crop, bait type and pest pressure. Some growers apply at a five day interval if it is likely that weather conditions will force them to miss an application.

Baits for Qfly and Medfly should ideally be applied on the lower leaves and trunks of orchard trees. It is essential to avoid contacting fruit, and check for phytotoxic effects before applying to new areas.

Bait needs to be in place before fruit become susceptible to attack. Baiting therefore needs to be conducted for several weeks leading up to harvest. It should continue after harvest if fruit is still present or flies continue to be caught in monitoring traps.

If it rains, or overhead irrigation is applied, it may be necessary to re-apply the bait.

PERMITS AND REGISTRATION

Check permits, registration and label information before use. Always follow label directions and check that products are safe to apply, suitable for your crop and respect neighbouring land uses. Ensure bait does not contact harvestable fruit.

Bait applicators need to be appropriately trained, wear suitable personal protective equipment and record all applications.

Protein bait application record

Date	Start time	Finish time	Location treated	Product	Rate	Equipment	Wind	Operator signature

Like any pesticide, always record applications of bait

BEST PRACTICE

- ✓ Bait is made by combining an attractive protein source with an effective insecticide
  - A range of different hydrolysed protein sources and registered, approved insecticides are available
  - Adding a carbohydrate source can increase attractiveness but risks affecting non-target insects
  - Gels make the bait stickier and allow re-wetting, making bait longer lasting in the environment
  - Always apply bait according to label directions and prioritise safety
- ✓ Pre-mixed, spinosad based baits offer a softer alternative to insecticide plus protein baits, so may be used in sensitive areas
  - Apply heavy droplets at the 1:1.5 dilution rate for best results
- ✓ As newly emerged female flies are most strongly attracted to protein, applications should begin when flies are just starting to appear
- ✓ Bait should be applied early in the morning as this is when flies are actively searching for food and also minimises risk of phytotoxicity
- ✓ Apply bait regularly when fly populations are high and re-apply if rain or irrigation washes bait off
- ✓ Spray bait on alternate rows in the orchard, avoiding contact with harvestable fruit
- ✓ Under protected cropping, as well as for berry crops and vegetables, bait should be sprayed on windbreak plants around the crop perimeter
  - Consult your agronomist before applying bait inside protected cropping structures
- ✓ If no suitable vegetation is available, wooden bait stations should be equipped with a rain guard and constructed so as to provide potential shelter as well as food to flies
- ✓ Bait should ideally be applied about 1.5m from the ground to target Qfly and Medfly, but 1m from the ground for Cucumber fly
- ✓ Bait must be applied by trained operators in accordance with label directions. Appropriate personal protective equipment must be worn and all applications recorded in a spray diary

06.

MAT USES A PARAPHEROMONE LURE PLUS INSECTICIDE TO LURE AND KILL A PERCENTAGE OF MALE FLIES, SUPPRESSING THE OVERALL POPULATION. AS MALES CAN MATE MANY TIMES, MAT NEEDS TO BE COMBINED WITH PROTEIN BAITING AND OTHER CONTROL STRATEGIES TO BE EFFECTIVE.

Male annihilation

The Male Annihilation Technique (MAT) involves the same lures and insecticides that are used for monitoring, just without the trap to retain dead flies.

Simple MAT block made from caneite soaked in a mixture of cue-lure and malathion (left), and DacLure CL block containing cue-lure plus fipronil insecticide (right) (Images: J Ekman)

TYPES OF MAT

MAT combines a parapheromone such as cue-lure with an insecticide, such as malathion or fipronil.

This mixture can be soaked into an absorbent material such as caneite blocks, compressed cardboard or wick with protective cover and simply hung out in the field. For example, the wick lure used in the Bugs for Bugs trap can also be used separately as an MAT device. This unit has the advantage that the plastic cap protects the wick from rain and UV, extending its useful life to approximately 3 months.

Similarly, the Magnet MED trap contains trimedlure inside a protective, laminated shell. The outside of the device is coated with insecticide, and remains able to kill Medfly for approximately 6 months.

SPLAT CL is a viscous emulsion containing cue-lure. After adding an insecticide, the material can be daubed directly onto branches and vegetation using a spatula, caulking gun, or other specialised equipment.

HOW TO USE MAT

Just as with traps, not every male will be attracted to a lure. Parapheromones are attractive to male flies because feeding on them increases their attractiveness to females. Just as with protein in baits, they will be less responsive once they have sampled cue-lure, or a similar natural product.

MAT is most likely to be effective with young males who are still maturing. They should be deployed early in the season, before fruit becomes susceptible to fruit fly attack.

Generally, MAT devices remain attractive and effective for three to six months, depending on environmental conditions. Also note that not all devices are registered in every state and territory. Follow label directions with regard to replacement intervals and check registration for your area.

06. MALE ANNIHILATION

Two types of MAT supplied by Bugs for Bugs (Image: J Hill)

Fruit fly feeding on SPLAT CL (Image: ISCA)

ORCHARD PLACEMENT

As previously noted, parapheromones have a limited zone of attraction. For example, cue-lure can attract Qfly from 20m and possibly further. However, within this distance not all flies will respond. MAT units therefore need to be spaced regularly around the orchard or crop edges. Also place them in other areas where flies are likely to gather, such as trees near watercourses.

Spacing every 20 to 30m (approximately 16 to 25 per hectare) will maximise impact. Where possible, MAT should be placed 1.5m high, amongst foliage and away from direct sun.

OTHER CONSIDERATIONS

The other issue with MAT is that males can mate many times. Even eliminating a large number of males from the population will not prevent female flies from mating and laying eggs.

Finally, if the same lure and kill system is being used for MAT and in traps, this can affect the outcomes of the monitoring program. Using MAT may reduce the number of male flies caught in traps, suggesting that the population is low or falling. However, there may actually be significant numbers of female flies present and laying eggs. Discuss this issue with your agronomist.

Wear appropriate PPE when handling MAT devices and dispose of as you would other waste chemicals.

MAT needs to be used in combination with other strategies, particularly protein baiting.

MAT will be ineffective if used alone.

Magnet MED trap for Medfly (Image: Suterra)

BEST PRACTICE

- ✓ MAT devices are most effective when installed;
  - No more than 20m apart around the perimeter of the growing area
  - At 20-30m intervals if placed through the growing area
  - Other places that flies may gather
- ✓ Units need to be removed and replaced every 3–6 months (in accordance with label directions) to ensure the insecticide remains effective.
- ✓ As MAT uses the same lures and insecticides that are used in monitoring traps, trap data should be interpreted cautiously if MAT is in place.
- ✓ MAT is ineffective used alone but can be combined with other control strategies as part of an Area Wide Management strategy.

07.

INSECTICIDAL COVER SPRAYS CAN PROVIDE A QUICK AND EFFECTIVE METHOD OF CONTROLLING FRUIT FLIES. HOWEVER, IT IS ESSENTIAL TO FOLLOW LABEL DIRECTIONS TO ENSURE RESIDUES ARE WITHIN ACCEPTED LIMITS AND IMPACT TO BENEFICIAL INSECTS IS MINIMISED.

Cover sprays

Cover sprays involve application of a registered, approved chemical to a cropping area so as to cover everything. They are typically applied to the point of runoff using air-blast or boom spray equipment.

Fruit and vegetable industries used to rely almost entirely on broad-spectrum cover sprays for fruit fly control. However, old chemical options such as fenthion (no longer registered in Australia and many other countries) and dimethoate (restricted use based on permits) are now less readily available for general fruit fly control.

Managing fruit fly is now more complex and integrated. Protecting beneficial insects, managing fruit fly resistance, work health and safety, and delivering fresh produce with minimal chemical residues are all important considerations.

There is a trend in pest control towards more specialised, 'softer' products that are safer for human health and the environment. Unfortunately, there is no fruit fly specific cover spray, hence the reliance on the area wide management techniques of hygiene, baiting and MAT, as well as investment in new technologies. These new techniques are increasingly important, as the current registered chemicals may soon be either deleted, or have further restrictions on use.

Current fruit fly cover sprays are broad-spectrum insecticides, so will affect non-target insects. Similarly, broad-spectrum insecticides used for other pests may also suppress fruit flies. An agronomist can provide a specific and personalised crop management program for your crop(s) including all of the available fruit fly management tools.

Cover sprays are both effective at the time of application and have residual action that continues afterwards. How long they remain effective depends on the longevity of the product in the environment and its mode of action.

REGISTERED PRODUCTS

Chemicals registered with the Australian Pesticides and Veterinary Medicines Authority (APVMA) which are approved for fruit fly control differ between fruit fly species as well as the situation in which they are used. For example, the total number of applications during the cropping cycle may be limited to reduce the risk of insecticide resistance.

Chemicals registered with the APVMA for cover spray treatment of fruit flies include:

Active ingredient	Crop / situations listed on labels when used as a cover spray
Malathion (also called maldison)	Apples, pears, citrus, grapevines, persimmons, blueberries, berries (rubus, ribes) and strawberries*, capsicum, tomato, cucumbers *not all formulations of malathion
Trichlorfon	Guava, stonefruit, pome fruit, blueberries, capsicums/chillies, tomatoes
Clothianidin	Pome fruit, persimmon, stonefruit, table grapes
Dimethoate	Avocados, blueberries/bilberries, capsicums, citrus (some exceptions), mangoes, tomatoes (processing only)
Etofenprox	Stonefruit (except cherries)
Acetamiprid variations	Acetamiprid | Novaluron – apples, pears, stonefruit (suppression only) Acetamiprid | Pyriproxyfen – avocados, citrus, mangoes (suppression only)

NOTES:
It is essential to apply insecticides in accordance with the label. Registrations can expire: check the APVMA website and consult your agronomist to ensure products are safe to use, suitable for your crop and respect neighbouring land uses. Labels from registered products are accessible on the APVMA website https://portal.apvma.gov.au/pubcris

Note that formulations and concentrations of active ingredients can vary within and between brands.

Restrictions on use exist to protect human health and the environment as well as to avoid resistance. Like all chemicals, cover spray applications must be in accordance with label directions, with applications recorded in the farm spray diary. Applicators must wear appropriate PPE and prioritise safety. Always consider critical comments and follow instructions for mixing and application. Observe withholding and re-entry periods and follow DO NOT statements and warnings.

Registration conditions vary between states and internationally. Even if a chemical is registered for your crop, your market or certifying agency may not accept its use. Additional restrictions may apply when using chemicals in protected cropping. Always check and work with your agronomist and chemical adviser to determine what options suit your crop/situation and production area.

Some cover spray applications may be compulsory in order to meet protocol trade agreement conditions. These may mandate a program of cover sprays to be used either alone or in conjunction with postharvest inspection. Cover spray applications to meet these requirements also need to conform with the label directions registered and approved in the state or territory in which they are being applied.

COVER SPRAY APPLICATION

Insecticide coverage can be improved using a fine spray, but it is essential to minimise drift into non-target areas. It is also important to be mindful of potential runoff of sprays into watercourses.

Current registered insecticides rely on contact, so rarely kill larvae that has already burrowed into the fruit. All fruit fly management programs should focus on preventing damage rather than trying to treat produce after the damage has occurred. While postharvest treatments can kill eggs and larvae, they don't remove them from the fruit. Consumers finding a dead larvae will be just as repelled as if they found a live one!

MINOR USE PERMITS

Some insecticides can be included in fruit fly control programs using minor-use permits for specific crops issued by the APVMA. These allow the use of chemicals where registration is pending, applications are unique or involve uncommon fruit types and for emergency management.

Examples include additional crops / situations for the insecticide cover sprays trichlorfon, spinatoram, alpha-cypermethrin and bifenthrin. The latter three minor use permits aim to increase rotation of chemicals within spray programs, reducing the risk of insecticide resistance.

BEES AND NON-TARGET INSECTS

Cover sprays are toxic to bees and non-target beneficial insects. Notifying beekeepers of planned spray activities and not applying insecticides in areas that bees are active, will help limit toxic effects on bee populations.

In some cases floral attractions (such as weeds in the inter-rows) may be removed to reduce the activity of non-target insects.

BEST PRACTICE

- ✓ Cover sprays can be used to control fruit fly when other measures are no longer managing the population
- ✓ Registrations vary between states and territories and can change – always check before application
- ✓ Only use products that are registered and approved for the specific pest species and situation and which will be acceptable to trading partners
- ✓ Always minimise spray drift into other areas and minimise impacts on non-target insects

08.

THE STERILE INSECT TECHNIQUE (SIT) HAS BEEN USED SUCCESSFULLY TO BOTH MANAGE AND ERADICATE INCURSIONS OF VARIOUS INSECT SPECIES. THE BEST RESULTS ARE ACHIEVED WHEN POPULATIONS OF THE PEST SPECIES ARE LOW.

Sterile insect technique

The sterile insect technique (SIT) relies on breeding and releasing very large numbers of sterile insects. Overflooding the wild population reduces mating between females and fertile males, decreasing the production of viable eggs. However, achieving success relies on thoroughly understanding the target species.

HOW SIT WORKS

SIT does not involve use of toxins and is highly specific to the targeted pest, so represents perhaps the most environmentally friendly method of managing invasive insect pests. It has been used successfully against screw-worm fly, tsetse fly and several species of moths and mosquitoes.

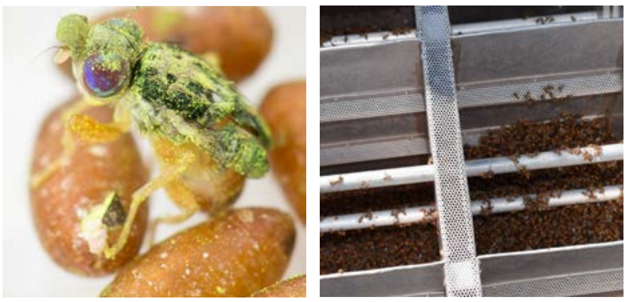
A number of fruit fly species, including both Medfly and Qfly, can also be managed using SIT. The general process is:

1. Initial collection of larvae from infested fruit
2. Rearing and confirmation of adult fly species (individually)
3. Population increased in the laboratory over many generations
4. Flies encouraged to lay eggs into artificial "fruit" (perforated plastic cups containing water and, sometimes, fruit)
5. Larvae grown on artificial media, mature and form pupae
6. Pupae sterilised by exposure to a sub-lethal dose of gamma or x-rays (Note that new genetic methods of sterilisation are being developed)
7. Pupae coated with a fluorescent dye; as the flies emerge they retain traces of dye, allowing them to be differentiated from wild flies
8. Pupae transported to area to be treated;
   a. Pupae placed in the field directly
   b. Flies emerge, provided with food and water, then released into the field

Process for producing sterile Qfly at the SITPlus facility in South Australia

Eggs are collected from flies by allowing them to lay into perforated plastic jars, usually baited with fruit or juice (left); Eggs are spread onto thin trays of semi-liquid diet, where they hatch into larvae and develop for 6-7 days (centre and right)

Once larvae mature they hop from the trays and are transferred into bags of vermiculite to pupate (left); Pupae are sieved, coated with fluorescent dye and packed into canisters for irradiation in an x-ray machine (centre and right)



As pupae hatch, fluorescent dye transfers to the emerging fly, allowing it to be identified as sterile (Medfly, left). The flies are allowed to mature for five days then released into the target area (right). (Medfly image: P Scanlon, all others courtesy T. Marais)

CRITICAL FACTORS FOR SUCCESS OF SIT

Currently, SIT can only be used to control Medfly and Qfly. While the overall process sounds straightforward in theory, many factors influence commercial success. These include:

- Sterile flies must be "fit", so able to fly strongly, survive in the environment and compete for mates
- Sterile flies must greatly outnumber wild flies; overflooding ratios of 100 steriles to every wild fly, or more, are likely to have the best impact
- Reproductive behaviour of sterile flies must be compatible with the local wild flies
- The treatment area should be relatively isolated, limiting new incursions
- Attempts at egg laying by sterile females must not damage commercial crops
- Sterile flies need to be clearly identifiable when trapped

Fitness in the environment can be particularly challenging. For example, flies kept for many generations in the laboratory may not make the same mating calls or produce the same pheromones as wild flies. Irradiation itself suppresses pupal respiration, changes symbiotic gut bacteria, and can reduce adult fly vigour if not accurately applied. Moreover, fruit fly strains that thrive in the protected environment of a mass-rearing facility can struggle under the high temperatures, low humidity and changeable weather experienced in cropping areas.

Many years of research into optimising fitness of irradiated Qflies means that we now have the tools to produce sterile flies that can survive and compete. Providing food, water and even pro-biotic bacteria to newly emerged sterile flies can help them survive and perform. For this reason, the relatively cheap and easy method of pupal release has tended to be replaced by rearing and release of adults. Such releases may be from static bins, a moving vehicle, or even a low flying plane, allowing flies to be distributed across the outbreak area.

However, even with good quality sterile flies, cost and logistics are barriers to use. Production is highly labour intensive and may be far from where the flies are needed. Very large numbers of sterile flies, distributed over large areas, are needed for success, even if the outbreak is small. This is particularly important as females can potentially mate more than once, storing sperm from both partners for later use. Although mating with both sterile and fertile males reduces overall fertility.

USE OF SIT IN AUSTRALIA

The sterile insect technique has been deployed to control outbreaks in the Qfly free areas of Western and South Australia, as well as in regions with area freedom. It likely contributed to the eventual eradication of those outbreaks.

SIT has also been used to control Qfly in towns within fruit and vegetable production regions. These are areas where other control strategies (such as chemicals) cannot be used, but which provide refuges for pest fly populations. Moreover, urban environments may provide relatively favorable conditions to sterile flies.

Use of SIT is also a tool to be considered in the event of an exotic fly outbreak – such as an incursion by oriental fruit fly.

Sterile Qflies are produced at the SITplus facility in Port Augusta, South Australia. A female lethal gene has been identified and inserted into Qfly using molecular techniques. However, the current ban on release of genetically modified organisms makes it unlikely these flies can be used. Sorting systems based on pupal colour are now under development, and there are plans to introduce these strains to the SITplus facility in 2025.

In Australia, SIT releases have been primarily in the context of biosecurity, eradicating fruit flies from areas otherwise fruit fly free. Biosecurity is a government responsibility, so most releases have been funded through State and Federal agencies. Without a sustainable funding framework, the cost for an individual grower to use SIT to manage fruit flies is likely to be prohibitive.

BEST PRACTICE

- ✓ The sterile insect technique (SIT) can be a useful tool in controlling outbreaks of Qfly and Medfly
- ✓ It is most effective when pest numbers are low and the area is isolated, allowing large "overflooding" of the wild population
- ✓ SIT needs to be used in conjunction with other fruit fly management tools, in order to keep the population suppressed
- ✓ A mass rearing facility in South Australia produces sterile Qfly, which may be released as adults or pupae
- ✓ The cost and technical difficulty of using SIT is high, making it unlikely to be viable strategy for individual growers. However regional support that combines government, local councils and industry to fund SIT may be an option in the future.

09.

BIOLOGICAL CONTROL AGENTS DO NOT NECESSARILY PREVENT FRUIT FLIES DAMAGING FRUIT. HOWEVER, THEY DO OFFER A LONG-TERM WAY TO REDUCE POPULATIONS IN AREAS THAT CANNOT BE MANAGED BY OTHER MEANS. THEY MAY ALSO HELP "CLEAN UP" INFESTED CROPS WHERE OTHER STRATEGIES ARE NOT VIABLE.

Biological controls

Natural enemies are a key management tool used to control pest species within integrated pest management programs. Fruit fly eggs and larvae are attacked by several local species of parasitoid wasps, while entomopathogenic fungi may help control life stages in the soil.

PARASITOID WASPS

Australian pest fruit flies, as well as Medfly, are attacked by at least 11 local species of parasitoid wasps. In the last few years, rates of around 30% parasitism have been reported from naturally infested fruit. It seems that natural parasitism has increased markedly with reductions on use of organophosphate cover sprays.

Current knowledge suggests eight species can parasitise Qfly, three species parasitise Medfly and two species parasitise minor species. While generally regarded as tropical to subtropical insects, the distribution of parasitoid wasps – like that of the flies they attack – has expanded south in recent years. At least one species is now present in Victoria.

Two wasp species were recently investigated in terms of the viability and effectiveness of mass releasing these parasitoids into infested areas;

Fopius arisanus was originally introduced from Hawaii in the 1950's. In Hawaii, parasitism rates of up to 70% have been reported for Oriental fruit flies. The wasp lays its egg inside fruit fly eggs, its tiny larva then developing inside the growing fruit fly larva. Eventually the fruit fly larva pupates, but it is an adult wasp, not a fruit fly, that emerges from the pupal case. The species is used as a biocontrol agent worldwide and is a relatively common parasitoid of Qfly.

Diachasmimorpha kraussi is an Australian native that has become established as a biological control agent in Israel and Hawaii. It has been found to parasitise 13 *Bactrocera* species plus Medfly and is widely distributed around Australia. The wasp lays its eggs directly into fruit fly larvae, preferring the second instar (life stage). As with *F. arisanus,* the wasp emerges from the fruit fly pupal case.

Mass rearing techniques have been developed for both species, with test releases of up to 10,000 *F. arisanus* and 6,000 *D. kraussi*. These releases were focused on introducing the wasps into new areas. Such introductions may also aid control in areas which are too cold during winter or hot in summer for the species to permanently establish.

Inundative releases, where very large numbers of parasitoid wasps are released, are most likely to be effective at reducing fruit fly populations when pest populations are low; ratios of 10 wasps per fruit fly have been suggested.

Female *Fopius arisanus* (Image: S. Bauer, USDA)

Female *Diachasmimorpha* spp. (Image: A Zamek).

An augmentarium, designed to allow parasitoid wasps inside infested vegetables to complete their lifecycle and return to the cropping area. The mesh is sized so as to prevent adult fruit flies from escaping but allow smaller parasitoid wasps to escape. Base measures approximately 1.5 x 2m (Image: M Klungness USDA)

Mass rearing facilities commonly breed parasitoid wasps by using irradiated fruit fly larvae; the larvae survive long enough for the wasp to emerge but cannot develop into an adult fruit fly.

In contrast, augmentoria offer a simple way to increase populations in the field. An augmentaria consists of a shaded structure with fine mesh panels. The mesh size is chosen so that parasitoid wasps can pass through, but relatively large adult fruit flies cannot. Infested fruit is placed inside, allowing any parasitoid wasps present to complete their lifecycle and return to the orchard.

The presence of diverse flowering plants and fruit can help adult parasitoid wasps survive in the field, while avoiding broad spectrum insecticides is essential if they are to establish.

While parasitoid wasps cannot prevent damage to fruit, they potentially provide a useful tool in areas which cannot be managed by other means, including urban areas, abandoned orchards and rainforest/bushland.

ENTOMOPATHOGENIC FUNGI AND NEMATODES

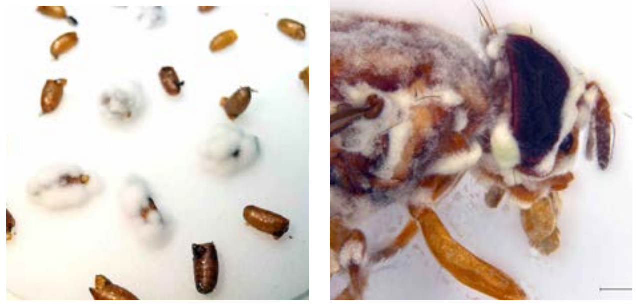
Once fruit fly larvae mature, they leave the host fruit and drop to the ground. Here they make shallow burrows into the soil or leaf litter, searching for a safe place to pupate. Entomopathogenic fungi and nematodes may provide a way to target this part of their lifecycle.

For example, certain species of green muscardine fungi (*Metarhizium* spp.) have been found to infect and kill up to 93% of mature larvae attempting to pupate. Adult flies exposed to the *Metarhizium* spores as they emerge from their pupae in the soil may also be affected. Laboratory trials have found high death rates (56 to 76%) within 9 days. As it takes approximately 10 to14 days for flies to become sexually mature, infected flies are unlikely to lay viable eggs.

Predatory nematodes from the families *Steinernema* spp. and *Heterorhabditis* spp. are natural soil dwellers that can infect third instar larvae as well as adults during emergence. Recent research has identified at least seven different nematode strains which can penetrate Qfly larvae and pupae and have potential as field controls.

Potentially, fungal spores and/or predatory nematodes could be applied as a soil drench at the end of the season. This would target the larvae that form the basis of the overwintering population, breaking the cycle.

In the past, biopesticides based on entomopathogenic fungi have struggled to achieve commercialisation. This has been due to technical difficulties as well as the scale of local investment and field trials required. However, the discovery of new, highly active strains and advances in mycology could make this a potential tool available to growers in the future.



Green muscardine fungus attacking Qfly pupae, and an infected adult fly (Images: A. McKinnon)

Entomopathogenic nematodes infecting Qfly larva (top left) and pupae (top right) and a larva killed by nematodes (below) (Images: Aryal et al, 2022.)

BEST PRACTICE

- ✓ Fruit flies are attacked by a range of parasitoid wasps, of which at least two species are suitable for mass rearing
- ✓ Parasitoid wasps infest up to 30% of fruit fly eggs and larvae but do not prevent damage to fruit
- ✓ Inundative releases could potentially introduce parasitoids to new areas and provide a measure of control in areas not readily managed by other means
- ✓ Biocontrol agents suitable for managing fruit fly, including isolates of green muscardine fungus and entomopathogenic nematodes, are not readily commercially available, but may be so in the future

10.

GREENHOUSE WALLS, NETTING AND EVEN PLANT COATINGS CAN PREVENT OR REDUCE FLIES ENTERING THE CROP AND INFESTING FRUIT. AS WELL AS BEING PHYSICAL BARRIERS, THESE DEFENCES CAN PREVENT FLIES FROM SEEING AND/OR SMELLING POTENTIAL HOSTS.

Physical protection

Physical protection can be expensive and is not suitable for all crops and field situations. However, it is a highly effective way to protect fruit and vegetables from fruit fly. It can also provide additional benefits in terms of productivity, quality, reduced irrigation requirements and control of other pests.

Enclosed greenhouses offer a major barrier to fruit flies, whether glass (left) or plastic (centre); Even though this (Cravo) greenhouse has a retractable roof, it still presents a significant barrier to entry of fruit flies.

PROTECTED CROPPING

Fruit flies do sometimes enter open-ended plastic tunnels and other forms of protected cropping. However, they rarely, if ever, enter enclosed, structured greenhouses.

Glass walls and plastic sheeting are clearly physical barriers to fruit flies. They usually present a flat, white exterior, obscuring the crop inside.

As natural forest-dwellers, fruit flies generally orient towards dark, tree shaped objects. They tend to avoid white or reflective areas. Greenhouses are therefore less attractive.

Although fruit flies could still enter through un-meshed roof vents or opened doors, they rarely do so. They are not strong flyers and are thought to usually keep low to the ground or dart from tree to tree, rather than flying high across open spaces. This suggests that they are only likely to enter roof vents if strongly attracted by fruit aroma or pheromone, or if blown there accidentally.

NET HOUSES

Net houses can be used to protect crops from weather, sunburn and pests ranging from wallabies to thrips.

The traditional advice when using netting to protect crops from fruit fly was that the crop had to be fully enclosed in insect proof netting, with ‘air-locks’ provided for entry and exit of people and equipment.

However, netting with much lower levels of security can still reduce rates of infestation.

Hail netting is not fruit fly proof, as holes are large enough for flies to crawl through. Despite this, experience has shown that installing hail netting on both top and sidewalls of orchards greatly reduces entry of flies. If the netting is white it may offer better security than if it is dark-coloured, although this has yet to be proven.

Flies use both visual and scent clues to find host fruit. Hail netting and windbreak materials hide the crop from flies, and may even reduce drifting of fruit aromas. If flies cannot see or smell the fruit, there is no reason for them to try to go inside.

Netting needs to be tensioned and secured so as to prevent wildlife becoming entangled. This is a legal requirement in some states.

Net houses, such as these ones for capsicums (left, J Ekman) and apples (right, C Pokorny) can greatly reduce the number of flies entering a crop. Even though flies can physically fit through or go under the mesh, the combination of a visual and a physical barrier reduces incursions.

FLOATING ROW COVERS

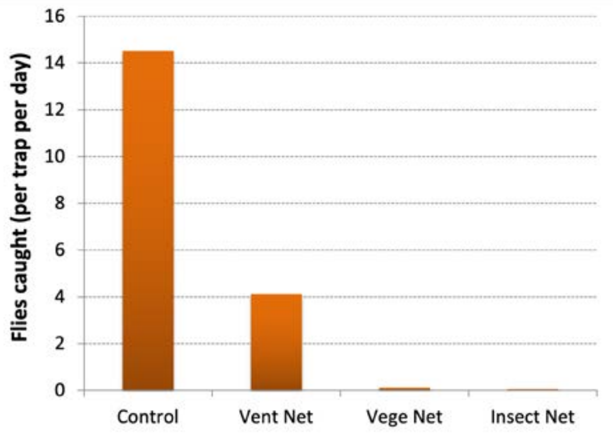
Unlike the permanent structures required to construct net houses, floating row covers involve simply draping netting over plants and securing the edges with soil.

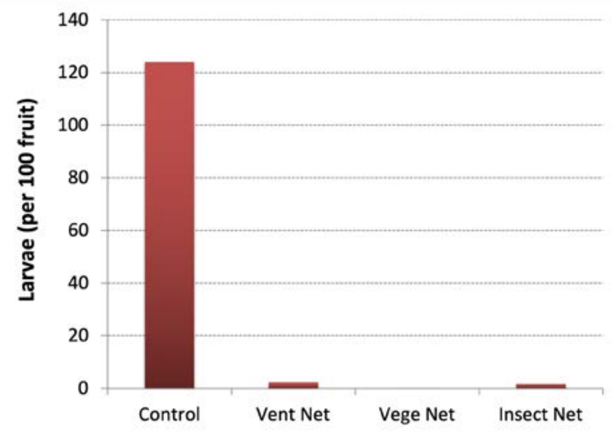
Various grades of netting can be used, ranging from coarse windbreak materials to extra fine nets designed to exclude all pests. The weight of materials can be an issue if they are not supported, but upright plants such as capsicums and eggplant can easily support lighter grade nets as they grow.

As with net houses, floating covers can give plants protection from wind, heavy rain and sunburn. They also reduce water requirements and exclude various pests. Light is diffused and evaporation is reduced, resulting in larger and healthier plants. For example, floating covers have been shown to increase marketable yield of capsicums, mainly through improved fruit set and reduced damage from wind and sun.

Like net houses, floating covers also provide a visual barrier to fruit flies. Even if a few flies do penetrate the netting, the number of infested fruit can be greatly reduced.

Lightweight materials such as VegeNet (NetPro) and Insect and Fruit fly netting (Haverford) are suitable for excluding fruit flies. These materials weigh 45g/m^2 and have mesh size approximately 1 x 3mm.





Number of flies caught (left) and number of larvae found per 100 fruit sampled (right) in a cayenne chilli crop where plants were left uncovered (control) or covered with VentNet (windbreak material), VegeNet (lightweight net) or Insect Net (fine net).

Trials conducted by the authors testing various netting types on capsicum crops found that:

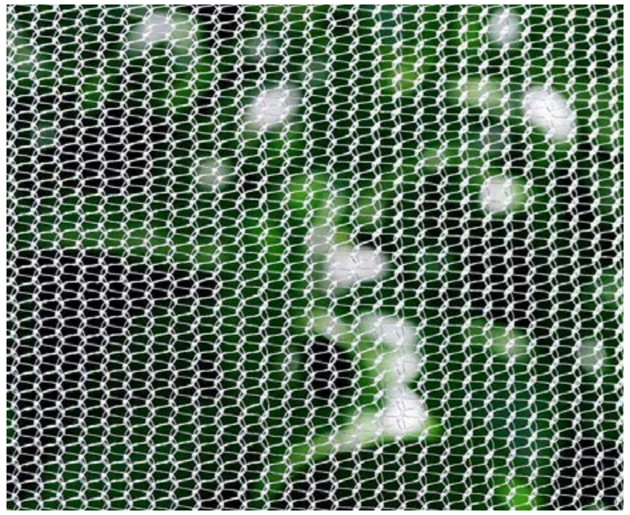
- VegeNet was an effective visual barrier and did not exclude natural predators from the crop. No infested fruit was found under this material while it remained intact.
- Insect net with mesh size 0.8mm was relatively transparent and excluded beneficial insects. As no insecticide was used, aphids heavily infested the covered plants.
- Although flies could get into crops covered with Vent-Net (windbreak) screening material relatively easily, very few fruit were infested.
- Placing netting over the crop while the plants are still small, even before fruit set, gave the best improvements in plant health.

Netting adds cost, both in materials and labour. Accessing the crop is more difficult, which is especially an issue if there are multiple harvests. While netting can be used for several years, cleaning the material between uses (to ensure disease is not spread) also creates challenges.

Single use frost protection (fleece) materials such as Daltex Groshield or Agryl can make effective insect barriers. While these materials are inexpensive, they tear easily if wind gets beneath the covers. These materials are therefore not suitable for application to upright plants such as capsicums, blueberries or orchard trees, but could potentially be used to protect low growing crops such as strawberries or melons.

Fleece draped over capsicums for a trial in Bundaberg (Image: J Ekman)

Protective netting draped over peaches (left, B Koll) and cherry trees (right, FiledIMAGE).



Male Qfly on the outside of VegeNet (NetPro), unable to easily reach the cue-lure baited trap inside (left, J Ekman) and close-up of Insect net (Haverford, right).

KAOLIN CLAY

Kaolin – aluminium silicate – comes from kaolinite, a natural mineral. It is allowed under organic systems and has a wide range of both industrial and agricultural uses.

Commercial sprayable kaolin products (for example Surround WP) are most commonly applied to tree crops such as apples and pears to prevent sunburn. The suspension is sprayed on using an agitated tank, coating the plants with fine, white powder. The crystalline structure of the clay reflects red light wavelengths and diffuses sunlight, so photosynthesis is actually increased. Kaolin lowers temperatures on the leaf surface and reduces water loss.

Spraying plants with kaolin disguises the fruit, making them harder to visually distinguish from the foliage. Additionally, the fine clay particles are believed to irritate flies landing on the material, discouraging them from settling.

Trials conducted by the authors using kaolin clay on capsicum crops found that it could reduce the number of larvae in fruit by 90% or more compared to untreated controls.

Kaolin is not without drawbacks. The material is relatively expensive, has to be applied several times to get a good coating and can block spray nozzles and tanks. Kaolin will likely need re-application if it rains or overhead irrigation is used.

After harvest, fruit needs to be thoroughly washed to remove the material. This will require water jets and brushes. While this is possible for apples and citrus, it is likely to be impossible to remove all kaolin residues from irregularly shaped products such as capsicums, or those with furry or russetted skins, such as peaches and pears. It is also not possible to use kaolin on soft products intolerant of washing, such as berries or grapes.

BEST PRACTICE

- ✓ Physical barriers are highly effective against fruit fly infestation
  - Fruit flies rarely enter enclosed glass or plastic houses
  - Fruit flies will enter plastic tunnels if the sides or ends are open
- ✓ Floating covers reduce the number of flies entering a crop and can also improve plant health
  - Net with 1 x 3mm diameter mesh is very suitable for excluding fruit flies
  - Nets that are not insect-proof can still be effective if they provide a visual barrier
  - Secure nets well around the edges
  - Clean nets between uses to avoid transferring disease to new crops
  - Disposable fleece materials could potentially be used on low growing plants
- ✓ Coating plants with kaolin may be a useful management tool, but cost and issues with removal must be considered

Kaolin on chilli plants (left) and satsuma mandarins (right). Even if some material washes off the plants, they still appear white from a distance. (images: J Ekman and ActiveMinerals Int.)

11

GOOD FIELD HYGIENE CAN BE AN INCREDIBLY EFFECTIVE STRATEGY FOR MANAGING FRUIT FLIES. REMOVING POTENTIAL SOURCES OF INFESTATION CAN STOP FRUIT FLY POPULATIONS BUILDING UP ON FARMS AND PREVENT INCURSIONS FROM NEIGHBOURING AREAS.

Hygiene

On-farm hygiene and biosecurity are good practice in terms of managing ALL pests and diseases, not just fruit flies. Fruit flies can move, which creates additional challenges. However, limiting incursions into a crop can both reduce fruit infestation and increase the effectiveness of other control measures.

ISOLATING THE CROP

As previously described, fruit flies are tree dwellers, at home in trees and vegetation. They are not strong flyers, usually travelling less than 1km, and frequently less than 600m during their lifetime.

Grassy fields and vacant paddocks offer no food, shelter or potential hosts. Traps located in cereal crops or pastures consistently fail to trap any flies. Fruit flies just do not go there.

Crops that are located well away from orchards, town areas, weedy creek lines and native rainforest are likely to be less susceptible to incursions by flies. While flies do move, a 200–400m wide cleared buffer around cropping areas still presents a significant barrier to infestation from the surrounding countryside.

Of course, it is not always possible to maintain such a large distance between fruit and vegetable crops and potential hosts and roosting sites. However, it is worthwhile considering how and where flies can move into the crop from other areas. For example, along weedy creek lines and rivers, such as those infested with blackberries.

This hydroponic tomato farm is located in an area endemic to fruit fly. However the farm is isolated, with more than 1km dry grassland in all directions. Combined with low pest pressure and the high walls of the greenhouse itself, fruit flies are effectively prevented from entering the crop.

REDUCING INCURSIONS

Removing feral fruit trees is key to managing fruit flies; a single feijoa tree can produce up to 30,000 flies in a season if left unmanaged.

Backyard trees and urban areas in general are common breeding grounds for fruit flies. Tree owners may be unwilling or unable to control fruit flies themselves.

In addition, urban areas provide overwintering refuges. This is particularly important in regions with cold climates, which are only marginal for fruit fly survival. Microclimates around houses and shops are often significantly warmer than the surrounding countryside. This can allow adult flies to survive freezing winter temperatures that would normally kill them. Once the weather warms enough for flies to fly, the females can mate and disperse to neighbouring crops to lay freshly fertilised eggs.

Reject fruit that can't be removed from the crop should be mulched to ensure it decays quickly. Images show before (left) and after mulching (right) (Images: B Koll)

Physical barriers, or bare zones, can help prevent incursions from such areas, as can programs that support home gardeners to carry out 'best practice' at home.

Fruit fly outbreaks have also been associated with holidaymakers and workers, who unknowingly bring infested fruit into production areas. Ensuring that staff and contractors do not bring suspect fruit on-site can also reduce the chance of an outbreak.

FARM HYGIENE

Standard recommendations for fruit fly management in orchards state that waste fruit needs to be removed to prevent further infestation.

Although flies do not usually lay eggs in fruit already rotting on the ground, infested fruit is more likely to drop naturally or be poor quality and therefore discarded.

Ideally, unmarketable fruit should be picked into waste buckets and disposed of away from the crop.

For crops such as strawberries and capsicums this is often not feasible, as picking and removing every fruit is extremely difficult. It is also very expensive. For example, whole orchards of cherries may be abandoned after rain-cracking, but the cost of harvesting this fruit makes this option uneconomic.

If removing unmarketable fruit is not possible, risk can be reduced by dropping it into the inter-row and mulching by driving through with a tractor. While not ideal, this can help the fruit rot or dry out before any resident fruit fly larvae have had a chance to mature.

If the entire crop is abandoned, protein baiting and chemical controls may be the best way to prevent a fruit fly population explosion that then affects neighbouring crops.

Short term crops that are fruit fly hosts, such as vegetables or strawberries, should be destroyed as soon as possible once the final harvest is complete. Herbicide application and/or mulching the plants are a good way to terminate a crop. If the crop is known to be infested, adding a chemical control (such as dimethoate, where permitted on the label) will ensure all larvae are killed.

Any infested fruit found should be destroyed to make sure the larvae do not survive. Either;

- Freeze the infested product
- Place inside (2) black plastic garbage bags and leave in the sun for at least two weeks
- Boil or microwave (home gardeners)
- Bury at least 50cm deep
- Add to an augmentorium as described in Section 9
- Feed to animals (ensuring they eat everything)

Once harvesting has finished, potential fruit fly host crops need to be destroyed as soon as possible. (Image: J Ekman)

Cucurbit fruit such as melons or pumpkins can persist for a long time in the field, even after the plants have died (left). This can allow large populations of Cucumber fly to build up (right), then potentially transfer to neighbouring crops. (Images: J Ekman)

BEST PRACTICE

- ✓ Remove unmanaged fruit trees growing within 600m of the crop or orchard
  - If unmanaged fruit trees cannot be removed, then treat with insecticide during fruiting, or pick fruit before maturity
- ✓ Instruct harvesting staff to remove unmarketable fruit from the cropping area
  - If removal is not feasible, risk can be reduced by crushing to speed decay and/or applying insecticide
- ✓ Terminate short term crops as soon as possible once the final harvest is complete.
- ✓ Destroy infested fruit by freezing, heating or deep burial, or add to an augmentorium

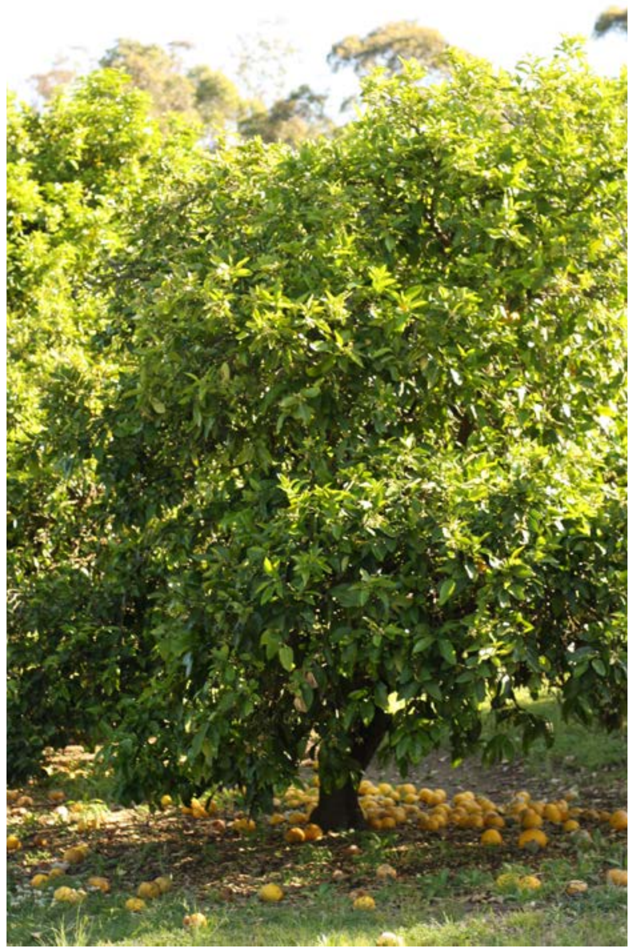
12 AREA WIDE MANAGEMENT AND IPM

12

FRUIT FLIES ARE NOW MORE WIDESPREAD AND DIFFICULT TO CONTROL THAN EVER BEFORE. HOWEVER, BY USING A RANGE OF MANAGEMENT TOOLS, AND IMPLEMENTING THESE ON AN AREA WIDE BASIS, WE CAN STILL PRODUCE SAFE, HEALTHY FRUIT FOR ALL TO ENJOY.

Area wide management and Integrated pest management

Fruit flies are our most damaging horticultural pests. They affect both our ability to grow fruit and fruiting vegetables and the capacity to ship to some domestic and overseas markets. Finding ways to manage fruit flies is therefore key to profitable farms as well as satisfied consumers.



Poorly managed or abandoned host crops can be major sources of infestation to adjoining properties. Encouraging all landowners to participate in AWM programs will help reduce fruit fly populations throughout the region. (Image: J Ekman)

While there are many different fruit fly species found around Australia, Queensland fruit fly (Qfly) has proven to be wthe most problematic. However, this was not always the case. Although Qfly susceptible produce was grown from the first days of European settlement in 1788, it was not until a hundred years later that outbreaks made it the enemy of commercial fruit growers.

It seems certain that commercial orcharding, provision of irrigation and urban development have allowed Qfly to expand its physical and biological range, a process that has continued up until today.

Initial attempts at control relied heavily on single step killing solutions. Pesticides used once included arsenic, nicotine and DDT, evolving in later years to organophosphates such as fenthion, malathion and dimethoate, neonicotinoids and the biologically derived spinosad.

However, we now recognise the downsides of relying on chemical controls. Destruction of non-target insects (including beneficials and pollinators), the rise of resistance, increasing regulation and consumer concern regarding pesticides in food mean that growers need to use more than one tool from their toolbox.

This guide details the main tools currently available as part of a multi-tool approach to fruit fly management. These tools include traps for both monitoring and lure-and-kill, protein baits, male annihilation (MAT), biological controls, sterile insect technique (SIT), physical exclusion and field hygiene.

Rather than simply “spray and pray”, growers can take a more intelligent approach based on fruit fly population monitoring and risk. Management can start with hygiene, protein baiting and MAT, arriving finally at cover sprays if pest pressure continues to mount. In effect, this is integrated pest management (IPM) for fruit flies.

One of the reasons fruit flies are so difficult to control is their mobility. Fruit flies are oblivious to property boundaries and state divides. The success of a systems approach therefore depends on growers working together wherever possible. If a grower using an integrated approach is surrounded by orchards where fruit fly is not controlled, they will soon pass through their options and arrive at chemical controls.

Area wide management (AWM), where fruit flies are suppressed across a larger area, is the best strategy of all to control these damaging pests.

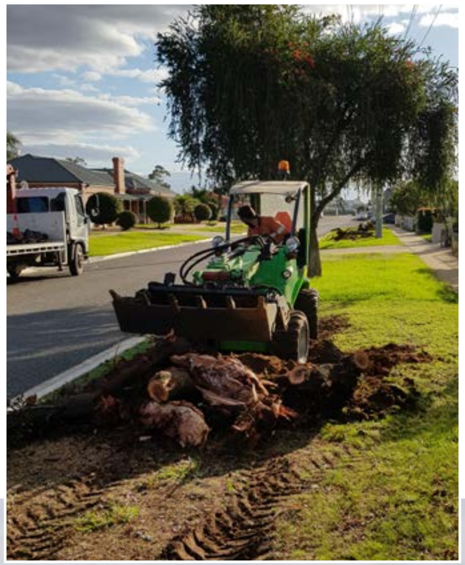
AWM relies on cooperation between all landholders. This includes farmers, home gardeners, businesses, council staff, government, regulatory agencies, and even consumers, who might bag a piece of infested fruit instead of throwing it on the compost heap. Members of the community can take ownership of their part of the regional fruit fly issue and take action to fix it.

Coordinating the support and participation of all those within a region is essential to successful AWM. Community based programs, such as ‘Keep Yarra Valley Fruit fly Free’, ‘Fruit Fly Murray Valley’, ‘Goulburn Murray Valley Fruit Fly Area Wide Management Program’ and NSW Local Land Services, can engage with the whole community in the local area to promote awareness of fruit fly management. These programs are educational, demonstrating how and when the various tools in the fruit fly management toolbox can be deployed. They are proven to reduce the impact of fruit fly populations on fruit production.

Fruit flies are now more widespread than ever before. Unmanaged host plants contribute to this issue. Removal of these trees, and regeneration of the land with non host species, is crucial for the long-term success of AWM.

Implementing a range of management tools on an area wide basis is the best way to ensure production of safe, healthy fruit for all to enjoy.

Home gardeners can play an important role in AWM by controlling infestations in their fruit trees, especially susceptible fruit such as loquats. (Image: J Ekman)



Removing unmanaged orchards, as well as unwanted urban fruit trees (inset), is essential in order to reduce pest pressure and achieve AWM goals (Images: R Abberfield).

13 References and further reading

Aryal S. et al. 2022. Virulence, penetration rate and reproductive potential of entomopathogenic nematodes from eastern Australia in Queensland fruit fly *Bactrocera tryoni*. Biological Control. 169:104871.

Balagawi S. et al. 2012. Spatial and temporal foraging patterns of Queensland fruit fly *Bactrocera tryoni* for protein and implications for management. Aust. J. Ent. 51:279-288.

Balagawi S. Jackson K. Clarke AR. 2013. Resting sites, edge effects and dispersion of a polyphagous *Bactrocera* fruit fly within crops of different architecture. J. App. Ent. 138:510-515.

Broughton S, DeLima CPF. 2002. Field evaluation of female attractants for monitoring *Ceratitis capitata* under a range of climatic conditions and population levels in Western Australia. J. Econ. Entomol. 95:507-512.

Cameron EC, Sved JA, Gilchrist AS. 2010. Pest fruit fly (Diptera:Tephritidae) in northwestern Australia: One species or two? Bull. Entomol. Res. 100:197-206.

Clarke AR et al. 2010. The ecology of *Bactrocera tryoni:* What do we know to assist pest management? Ann. App. Biol. 158:26-54.

Clarke AR et al. 2018. *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) overwintering: an overview. Austral. Entomol. 58:3-8.

Clarke AR et al. 2021. Opiine parasitoids (Hymenoptera:Braconidae) and biological control of fruit flies (Diptera:Tephritidae) in Australia: Past, present and future. Ann. Appl. Biol. 180:44-72

Clarke AR, Leach P, Measham PF. 2022. The fallacy of year-round breeding in polyphagous Tropical Fruit flies (Diptera: Tephritidae): Evidence for a seasonal reproductive arrestment in *Bactrocera* species. Insects. 13:882.

Cunningham P. 2022. Parasitoids for the management of fruit flies in Australia. HIA Final Report MT19003.

D'Aquino S et al. 2011. Effects of kaolin based particle film to control *Ceratitis capitata* infestations and postharvest decay in citrus and stone fruit. Crop Prot. 30:1079-1086.

DeFaveri S. 2016. Farm-wide fruit fly management systems for the east coast of Australia. HIA Final Report MT12050.

Dominiak BC, Daniels D, Mapson R. 2011. Review of the outbreak threshold for Queensland fruit fly (*Bactrocera tryoni*). Plant Prot. Quart. 26:141-147.

Dominiak BC, Daniels D. 2012. Review of the past and present distribution of Mediterranean fruit fly (*Ceratitis capitata*) and Queensland fruit fly (*Bactrocera tryoni*) in Australia. Aust. J. Ent. 51:104-115.

Dominiak BC, Ekman JH. 2013. The rise and demise of control options for fruit fly in Australia. Crop Prot. 51:57-67.

Dominiak BC, Mavi HS, Nicol HI. 2006. Effect of town microclimate on the Queensland fruit fly *Bactrocera tryoni*. Aust. J. Exp. Ag. 46:1239-1249.

Dominiak BC. 2012. Review of dispersal, survival and establishment of *Bactrocera tryoni* for quarantine purposes. Ann. Ent. Soc. Am. 105:434-446.

Dominiak BC, Worsley P. 2018. Review of cucumber fruit fly *Bactrocera cucumis* (French) (Diptera: Tephritidae: Dacinae) in Australia: Part 1, host range, surveillance and distribution. Crop Prot. 106:79-85.

Ekman JH. 2015. Fruit fly research gap analysis. HIA Final Report VG13040.

Henneken J, Farnier K, Cunningham JP. 2022. A synthetic blend of fruit and live yeast odours shows promise for trapping mated Queensland fruit fly, *Bactrocera tryoni*, in the field. J. Chem. Ecol. 48:817-826.

Mahat K, Clarke AR. 2021. Fruit fly parasitoids (Hymenoptera: Braconidae) in south-east Queensland, Australia. Aust. Entomol. 600:738-745.

Mazor M, Erez A. 2004. Processed kaolin protects fruits from Mediterranean fruit fly infestations. Crop Prot. 23:47-51.

Meats A, Edgerton JE. 2008. Short and long range dispersal of the Queensland fruit fly *Bactrocera tryoni* and its relevance to invasive potential, sterile insect technique and surveillance trapping. Aust. J. Exp. Ag. 48:1237-1245.

Meats A, Hartland CL. 1999. Upwind anemotaxis in response to cue-lure by the Queensland fruit fly *Bactrocera tryoni*. Phys. Ent. 24:90-97.

Meats A, Smallridge CJ. 2007. Short and long-range dispersal of medfly *Ceratitis capitata* and its invasive potential. J. Appl. Ent. 131:518-523.

Morimoto J. et al. 2014. Pest behaviour insights from quarantine surveillance of male Queensland fruit fly *Bactrocera tryoni*. Crop Prot. 62:55-63.

Morimoto J. et al. 2019. Commensal microbiota modulates larval foraging behaviour, development rate and pupal production in *Bactrocera tryoni*. BMC Microbiol. 19:286.

O'Loughlin GT, East RA, Meats A. 1984. Survival, development rates and generation times of the Queensland fruit fly, *Dacus tryoni*, in a marginally favourable climate: Experiments in Victoria. Aust. J. Zool. 32:353–361

Pinerao JC, Mau RFL, Vargas RI. 2011. A comparative assessment of the response of three fruit fly species to a spinosad-based bait: effect of ammonium acetate, female age and protein hunger. Bull. Ent. Res. 101:373-381.

Prince M et al. 2024. *Metarhizium* spp. isolates effective against Queensland fruit fly juvenile life stages in soil. PLoS ONE 19:e0297341.

Royer JE et al. 2014. Cucumber volatile blend, a promising female-biased lure for Bactrocera cucumis, a pest fruit fly that does not respond to male attractants. Aust. Ent. 53:347-352.

Schutze MK et al. 2016. 'Ladd traps' as a visual trap for male and female Queensland fruit fly *Bactrocera tryoni*. Aust. Ent. 55:324-329.

Shadmany J et al. 2021. Patterns of sperm use by twice-mated female Queensland fruit flies. Insect Sci. 29:957-1238.

Subramaniam S. 2011. Alternative fruit fly control and market access for capsicums and tomatoes. HIA Final Report VG06028.

Vijaysegaran S, Walter GH, Drew RAI. 1997. Mouthpart structure, feeding mechanisms and natural food sources of adult *Bactrocera*. Ann. Ent. Soc. Am. 90:184-201.

Weldon C, Meats A. 2007. Short-range dispersal of recently emerged males and females of *Bactrocera tryoni* monitored by sticky sphere traps baited with protein and Lynfield traps baited with cue-lure. Aust. Ent. 46:160-166.

Zamek A et al. 2012. Parasitoids of Queensland fruit fly *Bactrocera tryoni* in Australia and prospects for improved biological control. Insects: 3:1056-1083.

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