FALSE CODLING MOTH

***Thaumatotibia leucotreta* Meyr.**

1 PEST PROFILE

1.1 Distribution and status

False codling, moth (FCM) occurs in all citrus production areas of southern Africa. However, pest pressure varies dramatically in these regions and at different times of the season. For example, FCM is generally less abundant in the far northern regions for most of the season, with an upsurge at the end of a warm winter into spring. Navel oranges are the most susceptible citrus type, but there is considerable variation in susceptibility between Navel cultivars. Satsumas and Turkey Valencias are also highly susceptible. Midseasons, mandarin types other than Satsumas and Star Ruby grapefruit are less susceptible. White grapefruit are seldom subject to serious attack. Valencias are also generally less susceptible but can experience significant attack late in the season and can thus serve as a bridge to carry FCM over from one season to the next. Lemons and limes at the commercially harvested stage of ripeness are not a host for FCM.

1.2 Description

The FCM adult is an inconspicuous nocturnal moth that is seldom noticed in citrus orchards. It has a variable grey colour with a noticeable plume of grey scales on the dorsal surface of the body. FCM eggs resemble an inverted saucer-shaped dome and are about 1 mm in diameter. The eggs are initially translucent but darken internally through a red stage to black shortly before hatching. The black part is the head capsule of the developing larva. Parasitised eggs also appear black in colour but in this case the whole egg is black, therefore easily differentiated. Newly hatched and young larvae are creamy white with a dark brown to black head. As they age, larvae darken through off-white and finally have a pink body colour. The pupae are dark brown and about 10 mm long.

1.3 Infestation sites on tree

Only fruit are infested by FCM and they are susceptible to damage from pea-size to harvest. Female moths lay their eggs directly on fruit and often near the stylar end. The newly hatched larva moves around for a while on the fruit surface until it finds a suitable spot at which to penetrate the fruit. The mature larva leaves the fruit about a month later and pupates just under the soil surface.

1.4 Damage

1.4.1 Symptoms

Fresh larval penetration holes in fruit can only be found with the aid of thorough inspection. In the case of green fruit, the peel around the penetration hole eventually assumes a yellow colour. On ripe fruit this area is initially orange-coloured, but can become sunken and brown as the damaged tissue decays. The mature larva enlarges the original hole sufficiently to leave the fruit and pupate. Granular excreta (frass) can be found in the larval work area in the fruit. An infested fruit usually falls from the tree three to five weeks after penetration by a larva. In the packhouse it is challenging, but not impossible, to identify fruit that become infested shortly before harvest. Consequently, such fruit may be a source of post-harvest decay.

1.4.2 Seasonal occurrence

The major fruit drop resulting from FCM infestation usually takes place during the period December to April, except in the northern Limpopo Province, where infestation increases from July.

However, more importantly, FCM is a phytosanitary pest for some of South Africa's export markets, as it is endemic to sub-Saharan Africa. Interception of even one individual in a consignment could mean rejection of the entire consignment.

2 MANAGEMENT ASPECTS

It is critical to understand that FCM control is dependent on a multidisciplinary approach to be (i) effective and (ii) least disruptive to natural enemies. In situations of high pest pressure, there is no single control measure currently available that will independently suppress FCM satisfactorily to the required degree. This means that available measures that can be integrated into an FCM control programme must be used wherever possible.

2.1 Monitoring

2.1.1 Trap monitoring

Pheromone-based trapping systems have been developed to provide a means to monitor population levels. Dispensers are loaded with the female pheromone, which attracts male moths to the trap. The first of the trapping systems, the Lorelei, was developed to aid in deciding whether or not chemical intervention was required for the control of FCM. However, due to the phytosanitary status of FCM for some export markets, this has changed. No longer should economic thresholds be applied for export citrus, but FCM should be controlled to as close to zero levels as possible. The purpose of trapping is now therefore:

- To compare FCM activity levels between seasons, which will enable one to gauge probable post-harvest risk;
- To compare FCM activity levels between orchards, which will enable prioritisation of treatment application;
- To assist in the accurate timing of treatment application – particularly relevant to virus products and egg parasitoid releases.
- To determine whether appropriate ratios of sterile to wild moths are being achieved in a sterile insect technique (SIT) programme.

There are currently only two pheromone monitoring systems registered and commercially available for FCM. These are FCM PheroLure and Chempac FCM Lure.

2.1.1.1 The pheromone dispenser

- Dispensers should be stored in the refrigerator until use.

- When replacing a dispenser, do not dispose of it or leave it lying in the orchard. This will result in the old dispenser competing with the new dispenser in the trap and will thus compromise moth catches in the trap.

2.1.1.1.1 The FCM Pherolure

- The FCM Pherolure dispenser is a sealed small vial. The vial should not be opened.

- The vial should be stored in the refrigerator until used.

- The galvanised wire, provided with the delta trap, must be pushed through the two open holes on top of the trap. The lure should be suspended from the wire on the inside of the trap.

- Lures should be replaced every 28-30 weeks.

2.1.1.1.2 The Chempac FCM Lure

- The Chempac FCM Lure dispenser is a round pill-like capsule.

- The lure must be placed in a small plastic cage, supplied with the trap, which is inserted through a hole in the trap roof.

- Lures should be replaced every 3 months.

2.1.1.2 The trap

The only trap recommended for use with the FCM PheroLure and Chempac FCM Lure dispensers is the yellow delta trap.

- The trap is acquired in unassembled format and should be assembled by folding the two longer outside flaps of the trap inwards towards the centre. Slide the two horizontal tabs through the diagonal openings.

- Sticky floors are provided for these traps, making them more user-friendly than the pipe trap. Open the sticky floor and slide it onto the bottom of the trap, before closing the horizontal flap on the entrance floor in a vertical position.

- Moths and debris should be removed from the sticky floor when the trap is inspected. Sticky floors can be reactivated by folding the two sides together, down the centrefold, and reopening the floor.

- The floor can be replaced at any stage as needed i.e. if the debris load in the glue is so much that it compromises the stickiness of the floor or the ability to clearly identify moths stuck to the floor. At best, this may happen once every 6 weeks, unless high numbers of moths are caught, as should be the case in an orchard under a sterile moth release programme.

2.1.1.3 Trap placement

a) <u>In the orchard</u>

- The trap should be placed in the fourth or fifth row from the perimeter of the orchard.

- Position the trap on the upwind side of the orchard. Avoid placing the trap in a windless part of the orchard, i.e. near tall windbreak trees, as trap efficiency can be impaired due to insufficient air movement.

- Do not use more than one trap per four hectares of FCM-susceptible citrus. One trap can represent more than one orchard, if the total area of the orchards is not more than four hectares and the orchards are adjacent to one another. Individual orchards in excess of 4 ha require no more than one trap.

b) <u>In the tree</u>

<u>It is essential to hang the traps as prescribed. Incorrect placement will jeopardise the accuracy of the monitoring system.</u>

- The trap should be placed on the southern side

of the tree. If the space between tree canopies is less than two metres, the trap must be relocated to the south-western side, but still avoiding too much direct exposure to sunlight.

- The trap must be suspended as high as possible (small tree) or as high as an outstretched arm can reach (big tree) i.e. at least 1.8 m from the ground. Place the trap in partial shade in the outer foliage canopy. The trap must be suspended in such a way that it is easily visible from the front and sides. Do not bury the trap inside the tree. The trap should rather receive too much sun than too much shade.

- Remove all twigs and leaves around the trap so that it can swing freely, even when the wind blows. Ensure that moths have unhindered sight of and access to the trap. Remember that the branch to which the trap is attached, will probably sag appreciably with the increase in fruit mass as the season progresses. Choose a branch which will not be significantly affected, or when necessary, relocate the trap to a higher branch on the same or an adjoining tree. Alternatively, all fruit can be removed from the branch.

- If a mating disruption product is being used, trap catches will be negatively influenced (see 2.2.3.2 for more details). In order to obtain trapping data that can be useful in decision-making, traps can be hung outside of treated orchards or can be hung on poles positioned higher than the treetops. If the latter practice is employed, it should be used consistently throughout the farm in order that trap catches are comparable, as increased trap height may lead to elevated trap catches.

2.1.1.4 Interpretation and usage of trap data

Trapping for FCM is not an exact science. Ultimately what one wants to determine is the risk or likelihood of fruit being infested and the estimated level of that infestation. By monitoring male moths in a trap, one is assuming that this will provide an accurate indication of female moth activity, which in turn will reflect egg laying and ultimately larval infestation of fruit. It is impossible for trap catches to always provide an accurate indication of the potential for fruit infestation. Having said this, trapping remains the most accurate and most practical way of predicting the risk of fruit infestation.

As experience with and confidence in the trapping system is accumulated, one can place greater reliance on it for assisting with decision making within a control programme, bearing in mind that it should no longer be used as a tool to determine whether to apply a treatment or not, but rather when to time the treatment, as explained below.

Trap catches must be counted weekly, on the same day every week. This will provide the best opportunity for establishing a relationship between trap catches and fruit infestation. Trap surveys must be initiated in spring and continued until harvest time. The first post-winter peak in moth activity, which reflects a generational peak, usually occurs early in October in the cooler Cape regions. However, this could be a couple of months earlier in the warm northern regions. This is followed by what is usually a much larger peak in activity, by the subsequent generation, in November or December, depending on the region and seasonal temperatures. The most reliable way to accurately identify these trends is by using data from as many traps as possible on the farm or in the area, rather than relying on individual traps, as generational peaks will be fairly synchronous throughout a climatically homogenous region.

A peak in moth activity should be followed by a peak in FCM-induced fruit drop 3 to 5 weeks later. This is likely to be particularly evident if trap catches are high. Research indicates that when 10 or more moths are caught per trap per week, subsequent FCM infestation is likely to exceed one FCM infested fruit dropping per tree per week. This used to be regarded as the economic threshold for intervention. However, due to the increased phytosanitary status of FCM, this no longer applies. Trapping is a valuable management practice but should not be used for deciding whether a registered control measure should be applied or not.

A peak in trap catches can be used for accurate timing of a virus application. One would expect that a peak in FCM egg hatching would occur within 1-2 weeks after a peak in trap catches. As this is the only window of opportunity for a virus to work against FCM, a spray should be applied at or shortly before this point. An insect growth regulator, such as methoxyfenozide, should also be applied immediately after the start of a flight peak has been identified, as ideally, eggs should be laid on the spray residue for optimal efficacy. Augmentative releases of egg parasitoids may also be best timed approximately one week after a peak in trap catches. Mating disruption should be initiated before a peak in moth activity occurs. This is something one can obviously only apply with historical data.

On average, there are 6 generations of FCM per year. One might expect all of these generational peaks to be detected by traps. However, this is often not the case. Although, moth activity is fairly well synchronised after winter, as the season progresses, generations begin to overlap with one another to an increasing extent. Moth peaks may become more blurred and can often be difficult to detect late in the

season. As FCM control has improved dramatically in the last few years, it has also become increasingly difficult to identify the early flight peaks. This further emphasises the importance of consulting the results of a regional network of traps to accurately identify these peaks.

Trap catches near harvest will not necessarily reflect the real potential for post-harvest problems due to FCM infestation. Increased crop damage at this time of the season is often not due to larger moth numbers in the orchard but the result of reduced natural larval mortality. However, a sudden increase in moth catches just before or during harvest is useful as a warning that the crop may be exposed to increased fruit infestation. This seems to be particularly true for late hanging Valencias in the warm northern areas.

2.1.2 Fruit drop surveys

Fruit drop surveying is the most important means of monitoring FCM

- This is the only way in which one can truly gauge the extent of the FCM situation in a particular orchard and hence the risk for post-harvest infestation and fruit decay.

- There are many other possible causes of fruit drop – particularly in Navel oranges – and it cannot be assumed that all or most fruit drop can be attributed to any one cause, such as FCM, without substantiating this through fruit drop surveys. Without doing this, incorrect conclusions can often be drawn. Also bear in mind that the major causes of fruit drop can change throughout the season. Therefore, one or two weeks' data is nothing more than a small window on the season and may not accurately reflect the whole season.

- The effectiveness of the chosen control programme can be measured. One can then determine whether any further control measures are required.

- Such surveys will also corroborate the accuracy of trap data and enable producers to gain confidence in their trap counts or indicate possible problems with the trapping procedure, in particular poor trap placement.

There are two possible prescribed preharvest infestation monitoring methods for conducting these fruit drop surveys i.e. sampling from sanitation fruit or using data trees. It is not necessary to employ both methods i.e. only one method need be used. Both methods should provide an accurate indication of infestation in the orchard as a whole, if employed correctly. The decision on which of the two methods to use should usually be based on regulatory requirements at that time e.g. what is stipulated within the FCM Risk Management System (FMS).

2.1.2.1 Sampling from sanitation fruit

On a day that orchard sanitation is conducted, all sanitation fruit should be collected from an orchard and counted. Techniques to make counting (or accurate estimating) easier can be developed e.g. counting the fruit in one bag/crate from an orchard and multiplying this by the number of crates/bags collected from the orchard; or weighing a small sample of known number of fruit to determine weight of a fruit, weighing all the fruit collected from the orchard, and dividing this by the weight of a fruit, to obtain the total number of fruit). A 100 fruit sample of this sanitation fruit should be randomly taken for analysis, regardless of orchard size. If fewer than 100 fruit were collected from the orchard, then all fruit collected must be sampled. All fruit must be dissected and number of fruit infested (larva still present or exited) must be recorded.

This system will only be of full value if infestation can be worked back to infested fruit per tree per week. In order to do this, the following data will be necessary: number of trees in the orchard, number of fruit sanitised from the orchard on the monitoring day, days since previous sanitation event, sample size (usually 100 fruit), number of fruit infested in sample. If the data management system, PhytClean, is being used, then the programme will calculate infested fruit per tree per week, once the necessary data have been entered.

2.1.2.2 Data tree monitoring system

It is recommended that at least five trees be used as a data station and that these data stations be replicated throughout FCM susceptible orchards, at a density of at least one data station per orchard or one data station per 3-6 ha, where orchards are larger than 3 ha, as follows:
a) 3 ha or less – 1 set of 5 data trees
b) More than 3 ha, up to 10 ha – 2 sets of 5 data trees
c) More than 10 ha, up to 20 ha – 3 sets of 5 data trees
d) More than 20 ha, up to 30 ha – 4 sets of 5 data trees
e) More than 30 ha – 5 sets of 5 data trees

More severe crop damage often occurs in parts of orchards where traps do not function properly, i.e. in sheltered spots, such as near windbreaks. If that is the case, the data stations must be positioned where, from experience, crop damage is usually most severe and not necessarily where the traps function best. This placement should be very easy to determine

during the course of the season, as on-tree orchard sanitation will indicate where in the orchard FCM infestation is the highest.

All dropped fruit must be collected under the five data trees per data station, cut open and the probable reason for the fruit drop recorded.

2.1.2.3 General for both monitoring systems

If the sanitation fruit sampling system is used, this is recommended to be conducted once every two weeks, even though sanitation is more frequent. If the data tree monitoring system is used, this should be once a week.
Fruit drop surveys should preferably be conducted on a set day each week or every second week, depending on the system being used. The surveys need not be initiated earlier than 15 January, but should be conducted for at least 12-16 weeks preceding harvest, unless the orchard is harvested earlier than that. Consequently, correct use of the sanitation sampling system will provide a minimum of 6 data sets, whereas one will have a minimum of 12 data sets with the data tree monitoring system.

Fruit must not only be recorded as FCM-infested if a larva is found in the fruit, but also if signs of tunnelling, frass and head capsules are recorded, as these are indicative of FCM infestation. Appropriate training and experience will enable the person conducting the survey to correctly identify these signs associated with FCM infestation. The monitor should also familiarise him/herself with the appearance of all stages of the FCM larva. As fruit can also be infested by other pests, such as fruit fly and carob moth larvae, and by secondary scavengers, such as vinegar fly and beetle larvae, it is quite possible for one of these to be confused with an FCM larva. Once again, appropriate training is essential in order to be able to do this reliably.

2.1.3 Egg surveys

It is difficult to monitor FCM by inspecting fruit for the presence of eggs. This is due to the eggs' size and their transparent appearance. Egg surveys can be useful to monitor FCM population fluctuations. However, there is a relatively poor and variable relationship between egg numbers and the resultant fruit drop and there are no thresholds available to relate these two factors to each other. This is because the eventual fruit drop due to FCM infestation is influenced by egg parasitism and the normally high natural mortality of newly hatched larvae due to factors such as cannibalism, predation, and accidental removal of larvae by brushing leaves and strong winds.

The only way in which egg surveys could be useful would probably be to reveal an increase in egg laying activity and the impact of naturally occurring and/or artificially released egg parasitoids.

2.2 Control options

There are three fundamental requirements for a successful control programme: firstly, it must be underscored by season-long, regular orchard sanitation; natural enemies, particularly egg parasitoids, must be preserved, through judicious selection of pesticides for control of other pests; and lastly, control of FCM must be initiated early in the season while FCM levels are still low. Ideally, this early initiation should be with an area-wide appropriate technology, such as the release of sterile moths or mating disruption.

Various options are available to control FCM. None of these are effective enough to be used as stand-alone treatments under extreme situations. It is therefore essential that FCM control is based on a multidisciplinary approach, aimed at the suppression of FCM from early in the season to prevent the build-up of subsequent potentially harmful population numbers. This will support any further control procedures that are applied later on in the season such as spray treatments.

Due to the phytosanitary status of FCM for most markets, control measures should be applied preventatively, rather than only in response to elevated trap catches or fruit infestation. However, if fruit drop surveys do indicate that infestation is elevated, additional control measures should be applied.

2.2.1 Cultural

Orchard sanitation is the cornerstone of FCM control

Research has shown that it is possible to remove an average of up to 75% of FCM larvae from an orchard by conducting weekly orchard sanitation of fallen fruit. However, this level of efficacy would be influenced by temperature and would thus oscillate between the cooler and warmer months of the season.

It is important to remove all injured or fallen fruit from orchards. The purpose of this sanitation procedure is twofold. Firstly, it eliminates FCM and fruit fly larvae, which may be present in such fruit. Secondly, it removes injured fruit which can be more attractive and susceptible to FCM attack. Thirdly, it will reduce the contribution made by rotting fruit to post-harvest decay.

- Orchard sanitation must be conducted in **ALL** orchards on the farm, including lemon orchards.

Although it has been shown that lemons as commercially harvested and packed for export are not a host for FCM, overripe and very small lemons can be infested by FCM and thus, orchard sanitation must be conducted as diligently in lemon orchards as in those of other more FCM-susceptible cultivars.

- Orchard sanitation begins immediately after harvesting in an orchard is completed. All fruit on the ground and all fruit left hanging in the trees must be removed. This will eliminate any possible means of FCM completing its life cycle in the orchard over winter. This process should be completed within a maximum of 2 weeks after completion of harvesting in the orchard in question

- In the following season, it is strongly advisable that orchard sanitation commence before fruit are marble-sized. This will help to restrict the overall size of the FCM population during the season.

- Notwithstanding the previous advice, orchard sanitation must commence no later than late November to mid-December, soon after the end of natural physiological November fruit drop.

- Larvae leave fruit soon after they have fallen. Therefore, sanitation must be conducted at least at weekly intervals. However, the more frequently sanitation is conducted, the more effective it will be.

- Mature larvae sometimes leave the fruit while they are still on the tree. Therefore, obviously infested fruit on the tree must be removed during sanitation. Additionally, any other damaged fruit must also be removed, as these could be attractive and susceptible to FCM attack.

- It is advisable that separate individuals are appointed to conduct sanitation on the tree and to conduct sanitation on the ground. This will reduce the possibility that infested and injured fruit on the tree are missed.

- As the rate of development of FCM larvae, and hence the rate at which larvae exit the fruit, is temperature dependent, sanitation should be conducted more frequently than once a week in the hotter months of the year.

- Out-of-season fruit must be removed from the trees as they are also a source of FCM infestation.

- Orchard sanitation must continue during the Valencia picking season. This procedure can help to reduce FCM infestation the following season.

Within one day after collection, fallen fruit must be destroyed in one of the following ways:

- Small hard fruit can be buried at least 30 cm deep and covered with compacted soil. Alternatively, they can be submerged in water for a week.

- Juicy fruit can be pulped with a hammermill. Ensure that the fruit is properly pulped to destroy the larvae. Merely slashing the fruit into large pieces with an ineffective hammermill will not be sufficient and another means of fruit disposal, such as burial, must then be considered. Pulping must be done as far outside of orchards as is practically feasible, but preferably not less than 50 m from the nearest orchard. Pulping must not be conducted within the orchard. The pulp must be spread out thinly, preferably on hard compacted ground, directly exposed to the sun, to facilitate rapid drying. This will (i) reduce the prospect of fungal growth, which plays a role in post-harvest decay, and (ii) reduce the possibility that fruit flies may be attracted into an orchard by the decaying pulp. When conditions are not conducive to rapid sun drying, the pulp should be buried.

With the exception of orchard sanitation there are no other cultural options that contribute to FCM control.

2.2.2 Natural enemies

The most effective biological suppression of FCM is provided by the egg parasitoid *Trichogrammatoidea cryptophlebiae* Nagaraja. It occurs naturally in all citrus-producing regions and if undisrupted, can parasitise more than 80% of FCM eggs from shortly after mid-summer. This level of parasitism has been shown to significantly reduce FCM levels in an orchard. Spray programmes for other pests should therefore be structured to minimise non-target effects on these parasitoids.

There are also several species of naturally occurring larval parasitoids that play a role in suppressing the pest. Most of these are wasps but a few are flies. Probably the most effective of these parasitoids is the wasp *Agathis bishopi*, which has been shown to parasitise up to 40% of FCM larvae in the Eastern Cape. Although very limited surveys conducted in the Western Cape and Mpumalanga have not shown the same levels of parasitism, it is still possible that larval parasitism could play a similarly influential role in regions other than the Eastern Cape.

Orius bugs have been noted to prey on FCM eggs and assassin bugs can attack FCM larvae. However,

probably the most effective predators are ants, which have been shown to dramatically reduce planted FCM pupae in research trials. This is a strong justification for not poisoning ants in an orchard. Trees should rather be banded with an ant barrier, or tree trunks sprayed or painted with a registered insecticide, to prevent ants from entering the trees and disrupting natural enemies of sucking pests, particularly mealybugs.

Two species of entomopathogenic fungus and two virus species have also been recovered from FCM larvae. Additionally, several species of entomopathogenic nematodes (EPN) and numerous isolates of entomopathogenic fungi (EPF) have been isolated from citrus orchard soil. However, the only pathogens for which there is evidence of a natural suppressant effect on FCM in the field are the *Cryptophlebia leucotreta* granulovirus (CrleGV) and an entomopathogenic nematode, *Heterorhabditis zealandica*.

2.2.3 Plant protection products

2.2.3.1 Biological Control

2.2.3.1.1 Egg parasitoids

Good results can be obtained with the mass-release of the egg parasitoid, *T. cryptophlebiae*. The parasitoid should be released repeatedly while the fruit is susceptible. Releases should be initiated as early as October. Research has shown that a total of 100 000 parasitoids per hectare (in four monthly releases of 25 000 each) is usually adequate in most areas. It may be possible to achieve good results with lower numbers, but this would have to be initiated very early in the season (no later than October) and conditions for establishment and proliferation of parasitoids would have to be ideal. However, in the Western Cape five releases, each of 25 000 parasitoids per hectare (a total of 125 000 parasitoids per hectare) should be made. Initiation of a release programme later than December has been shown to be minimally effective.

2.2.3.1.2 Virus

There are three virus-based products on the market: Cryptogran, Cryptex and Gratham. All of the products are based on the naturally occurring indigenous pathogen of FCM, called the Cryptophlebia leucotreta granulovirus (CrleGV), therefore a biological control agent. The main difference between Cryptogran and the other two products is the registered application rate, which is higher for Cryptogran. These virus products are fully compatible with an IPM programme as they have absolutely no effect on beneficial insects. However, unlike other biocontrol agents, virus can be used within a chemical control programme without any detrimental effects.

When virus is sprayed onto a crop, FCM larvae will ingest the virus particles, potentially even before they begin to actively feed. The virus will eventually infect the entire body of the larva, killing it and causing it to rupture. Millions of virus particles are spontaneously released back into the environment, ready for ingestion by other larvae.

Timing of application of virus is very important. The only FCM life-stage which can be targeted with virus is the neonate larva. Therefore, there is a very small window of opportunity for a virus application to be effective. In order to achieve this, pheromone traps must be used. Virus should be sprayed within a few days after the start of a peak in moth catches. The spray will then coincide with a peak in egg hatching. Commercial experience indicates that virus applied in November/December has been notably more effective than applications at other times of the year. This is almost certainly due to the greater synchrony of life-stages at this time than later in the season. However, a spray as early as October is a possibility, targeted after the flight peak at this time.

Note that not only virus, but all sprays applied for FCM control, should be applied as high volume medium cover film sprays. Neonate larvae sometimes don't spend more than a few minutes on the surface of the fruit and do not move more than a few centimetres before penetrating into the fruit. During this brief period, a larva will need to encounter and ingest sufficient virus to induce mortality. Hence, spray coverage must be absolutely thorough.

Virus can also be applied 4 weeks before harvest in order to reduce post-harvest problems. However, FCM must already be under commercial control at this stage. A virus spray is also recommended as a follow-up treatment where a mating disruption or attract and kill programme has been initiated earlier in the season.

Due to the ultra-violet sensitivity of insect viruses, they should be applied during the late afternoon or evening. Viruses should be used in the north-western region of the Western Cape and the Northern Cape with caution due to UV irradiation, which is higher in these regions from November to March than anywhere else in the country.

Viruses have traditionally been registered to be sprayed with molasses. However, some registrations have subsequently changed. Therefore, although there may be a temptation to exclude the molasses component, due to its messiness and cumbersomeness, numerous laboratory and field trials with two of the commercial viruses demonstrated that efficacy is superior when mixed

with molasses compared to without. However, application in a tank-mix with mancozeb (applied for citrus black spot control) has also been shown to improve virus efficacy.

2.2.3.1.3 Sterile Insect Technique

The principle of the sterile insect technique (SIT) is to flood citrus orchards with large numbers of partially sterile moths. A ratio of 10 sterile to 1 wild male moth is used as a ratio guideline. The result will be that the probability of a wild female moth mating with a sterile male moth will be significantly greater than the probability of it mating with a wild male moth.

Moths are mass reared and partially sterilised using gamma irradiation. Partial sterility is used, as it produces a more competitive moth than full sterility. However, very few, if any, viable eggs will be produced from a liaison between a sterile male moth and a wild female moth, most of this second generation are male and all individuals are completely sterile.

SIT is an area-wide approach and can only be employed on a large scale area-wide basis. Where it is employed on such a scale, particularly over several years, it can be extremely effective in suppressing the FCM population down to negligible levels. SIT is the most effective area-wide population suppression technique available.

2.2.3.1.4 Entomopathogenic fungi (EPF)

Two EPFs are registered for control of FCM. These are Broadband and Eco-Bb, both of the species, *Beauveria bassiana*. When the spores of the fungus come into contact with the FCM larva, they germinate secreting enzymes which weaken the larva's cuticle. The fungus then invades the larva through its weakened cuticle. Once inside the body of its host, the fungus continues to grow, feeding on the internal organs and consequently killing the larva.

Broadband is registered to be sprayed three times in a season at 3-7 day intervals. Eco-Bb is registered to be applied every 10-14 days. Like the virus products, these EPFs are UV-sensitive and are therefore recommended to be applied during the afternoon or evening.

2.2.3.2 Mating disruptants

The mating disruption (MD) approach for the control of FCM (and other insects) relies on the prevention of mating, thereby reducing the number of viable eggs deposited on fruit. In practice this is achieved by applying synthetic female sex pheromone (which usually attracts the males of the species) in such a way that the males are confused, repelled or habituated to such an extent that they are unable to find the females for mating. This effect is temporary and males can recover to try again later.

MD should be initiated early in the season i.e. while FCM levels are still low, in order to achieve the best results possible. MD is a negatively density dependent technology and will therefore not be optimally effective once FCM levels have begun to escalate. Initiation of MD only later in the season is therefore strongly discouraged. MD should also be employed over a large area in order to minimise the edge effect of mated female moths moving into the MD area from the outside and laying viable eggs on fruit. MD should be applied to the top third of the tree i.e. at the level at which moths would normally fly. The volatilised pheromone is heavier than air and if applied lower than this will not be detectable by flying moths and will not be effective. The rate of release of pheromone is influenced by temperature. If temperatures are too cool, inadequate pheromone might be released to induce control of FCM. In autumn, as harvest approaches, it is often necessary to follow up the use of MD with another product, which is not influenced by temperature.

There are currently four MD products registered and available for FCM control. These are Isomate FCM, Checkmate FCM-F, Splat-FCM and X-Mate FCM. Isomate consists of thin polyethylene tube dispensers containing liquid sex pheromone which is released through the tube walls into the atmosphere. Dispensers are distributed by hand with a special applicator twice per season: 500 in October and a further 300 in January.

Checkmate is a pheromone containing capsule suspension formulation. It is applied as a very low volume foliar spray to the top third of the tree. It is most conveniently applied using a fruit fly baiting machine. It should be reapplied every 21-28 days. It is not rainfast; therefore, in the event of rain, earlier reapplication may be necessary.

Splat FCM is an amorphous polymer matrix, containing pheromone. It is applied as 1000 g per ha, with a minimum of 400 point sources per ha, spaced evenly throughout. It should be applied using either a calibrated caulking gun or the Splat mechanical applicator. It should be reapplied every 10-12 weeks.

X-Mate consists of cellulose disc dispensers containing liquid sex pheromone. These are hung at a rate of 40-42 dispensers per ha and last up to 5 months.

It is important to note that where MD is employed, pheromone traps become virtually redundant. The pheromone emitted by the MD product causes shutdown of the trap, resulting in dramatically

reduced catches. Unfortunately, this does not necessarily mean that there is no FCM activity and therefore no FCM infestation of fruit taking place. It appears that the ability of male moths to find the synthetic pheromone in the trap may be disrupted more easily than their ability to find and mate with female moths. Despite this, pheromone traps should still be used in MD orchards. If moths are caught, then this should be taken as a sign that moths are not being adequately disrupted.

As pheromone is dependent on warm temperatures to be released at an adequate rate to be effective, these MD products tend to become less effective during the cooler months of the year. Consequently, their use is not recommended after the end of the warm summer months.

2.2.3.3 Attract and Kill

The attract and kill (A&K) technique approaches the control of certain insects along the same lines as MD. The major difference is that, instead of disrupting mating temporarily, the males are killed and thus permanently removed from the orchard environment.

The A&K product Last Call FCM, is registered for FCM control. The product consists of synthetic pheromone and a pyrethroid incorporated into a transparent gel like base material. Three to four applications of up to 3 000 droplets of the product per hectare per application are applied by hand with a special applicator.

As with MD, A&K should be used against low levels of FCM activity. Use of Last Call FCM should therefore be initiated early in season while FCM activity is still low or as a follow up to the application of another product, which has successfully suppressed FCM levels. Reapplication is necessary every 4 weeks. Similarly to MD, the efficacy of A&K is likely to decline during the cooler autumn months.

2.2.3.4 Insect growth regulators

Methoxyfenozide (Runner and several generics) is an ecdysone agonist, resulting in moulting acceleration. It is effective against both eggs and larvae of FCM. However, like the other IGRs it is more effective when applied preventatively i.e. when eggs are laid on its freshly applied residue. After ingestion, larvae cease feeding within 4-8 hours, as they undergo an incomplete and developmentally lethal premature moult.

Runner is registered to be sprayed 8 and 4 weeks prior to harvest, and not more than twice per season, in order to manage against the development of resistance.

Triflumuron (originally Alsystin) is a chitin synthesis inhibitor (benzoyl urea group). It is an ovicide that disrupts the embryonic development of larvae in the eggs. However, this occurs only when eggs are laid on the treatment residue. Thorough coverage of fruit with the product is therefore of the greatest importance.

Triflumuron is recommended as a single spray at 20 ml/100 L, which will protect the fruit for 12 weeks, or a double spray at 10 ml/100 L, which will provide 16 weeks protection.

A number of markets will not tolerate residues of Triflumuron on fruit. One should therefore familiarize one's self with these restrictions before use. Also note that FCM has developed tolerance to Triflumuron where this active ingredient was used frequently in the past.

2.2.3.5 Coragen

Coragen is an anthranilic diamide insecticide. It has a novel mode of action, in that it is a ryanodine receptor activator, which means that it prevents muscle contractions and causes death by paralysis. Although it does have some contact action, most of its activity is by ingestion. It is harmless against most beneficial insects and relatively safe to humans.

A single or double spray of Coragen can be applied any time from 16 weeks before harvest. Each spray should not exceed 8 500 L per hectare.

2.2.3.6 Warlock

Warlock (emamectin benzoate), like Coragen, has some contact action, but most of its activity is by ingestion. It has a translaminar action and is rapidly absorbed into the plant. It is known as a chloride channel activator, with nerve and muscle activity. Larval feeding stops after ingestion, with death occurring within four days. It has a relatively short period of residual activity, but is not recommended to be applied more than four times in a season.

2.2.3.7 Delegate

The active ingredient of Delegate is spinetoram, a member of the group of spinosyns, thus related to spinosad. Delegate targets a nicotinic acetylcholine receptor, leading to a series of events which cause insect death. It is registered as a two-spray programme, 8 and 4 weeks before the projected start of harvesting.

2.2.3.8 Pyrethroids

Two pyrethroids are currently registered for FCM control, i.e. cypermethrin and Meothrin. Growers

need to check for specific market tolerance to each of these. They are larvicides that kill FCM larvae by contact on the fruit surface. They are intended to be used to protect fruit against FCM infestation shortly before harvest. Pyrethroids are potentially toxic to a wide range of natural enemies and the necessity for their usage must first be very carefully considered.

A pyrethroid must be applied once only, four to five weeks before harvest. It must be applied thoroughly to ensure complete fruit coverage. To minimize the risk of pest repercussions the crop must be free from pests like red scale, mealybug and soft brown scale, at the time of application. To prevent pest repercussions on the following crop, pyrethroid usage against FCM in the late summer or autumn, must be followed by a comprehensive chemical control programme during spring. Pyrethroids should be avoided if previously used for thrips control in the same season. This is for the purpose of thrips resistance management.

A summary of registered spray options for trees is tabulated below in approximate order of IPM compatibility.

Product	Dosage/100 ℓ water
Cryptogran + molasses + wetter OR Cryptogran + mancozeb + spray oil	10 ml + 250 ml (or 225 g powdered) + registered volume 10 ml + 150/200 g + registered volume
Cryptex	3.3 ml
Gratham	3.3 ml
Broadband	50 ml
Eco-Bb	600-1000 g/ha[1]
Coragen	17.5 ml
Methoxyfenozide[2]	60 ml
Warlock	80-100 ml
Triflumuron	10-20 ml
Delegate	20 g
Meothrin	30 ml
Cypermethrin	25 ml

[1]Dose rate given per ha. Would translate to approximately 10 g/100 L as a full cover spray.
[2]Runner and several generic products.