Management of fall armyworm in vegetable crops in Australia

Key points

1. Fall armyworm (FAW) is a significant threat to horticultural production globally, and is now a threat to Australian horticulture.
2. FAW was first detected in Australia in January 2020 and has since travelled from the Torres Strait to Tasmania in just 14 months.
3. An integrated pest management program is key to controlling FAW populations. Field monitoring is important for early detection and implementation of control methods.
4. There are several insecticides that are available to control FAW in Australia.

AUSVEG

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Resource prepared as part of the AUSVEG Farm Biosecurity Project

About fall armyworm

The fall armyworm (FAW; *Spodoptera frugiperda*) is a destructive pest that attacks more than 350 plant species overseas.

Affected vegetable crops include sweet corn, capsicum, beetroot, tomato, onion, cauliflower, cucumber, lettuce and potato. Other crops affected include maize, rice, sorghum, sugarcane and wheat.

Lifecycle and damage

FAW has four life stages (Figure 1, Figure 4).

Damage is caused by FAW larvae (caterpillars) consuming foliage and attacking leaves, stems, shoots, flowers and fruit. Damage includes pinholes or windows, leaf tattering or complete defoliation (Figure 2, Figure 3).

The larger the caterpillar, the more significant the damage. FAW are nocturnal, laying eggs and causing feeding damage at night.

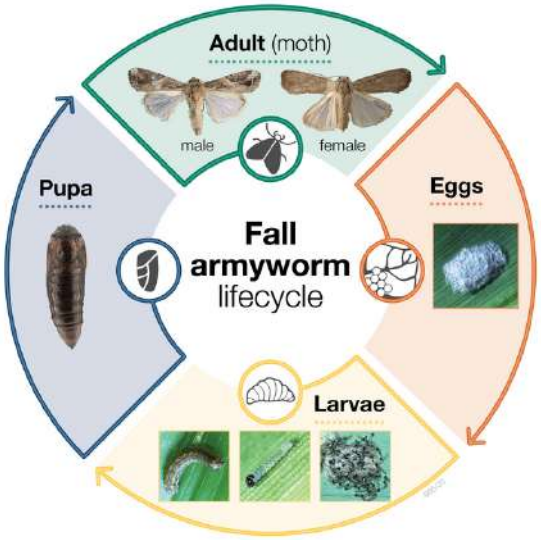

Figure 1. FAW life cycle. Image: Department of Primary Industries and Regional Development Western Australia (DPIRD WA).

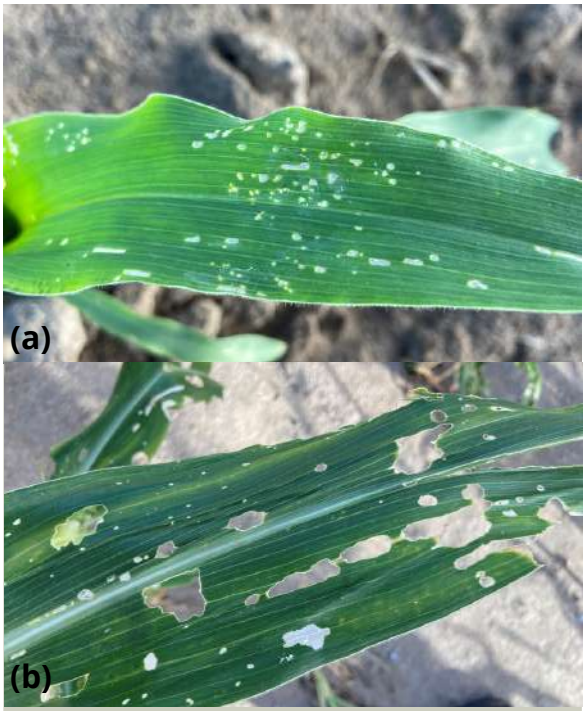

Figure 2. FAW leaf damage, (a) windowing symptoms of young FAW larvae, and (b) 'shotgun' holes in leaves caused by older larvae feeding. Image: AUSVEG.

Figure 3. FAW windowing damage on a field of sweetcorn in Queensland. Image: Dr Siva Subramaniam, Queensland Department of Agriculture and Fisheries (QLD DAF).

1. Female adult moths lay eggs on the top or underside of leaves in clusters of 100 to 200 eggs within the first 4 to 5 days of their adult lives.
2. Eggs hatch after 2 to 4 days when temperatures are favourable (21 to 27 degrees Celsius).
3. Newly hatched larvae cause superficial leaf damage (Figure 2a). Older larvae cause considerably more leaf damage (Figure 2b).
4. Larvae will burrow into the soil and pupate (develop) into adults. In 8 to 9 days, the adult moth emerges and restarts the cycle.

Figure 4. Image credit: (1 to 3) Helen Spafford, DPIRD WA; (4) Robert J. Bauernfeind, Kansas State University, Bugwood.org.

Worldwide distribution

FAW is a pest native to tropical and sub-tropical regions of the Americas, but has now spread worldwide (Figure 5).

FAW was first detected in January 2020 in northern Australia. Since, it has been detected in key growing regions across the country.

Its range expansion can be attributed to transportation by infected produce and its flying capabilities, however, its invasiveness is attributed to its ability to adapt to its environment.

Figure 5. Worldwide spread of FAW since 2016 (as of May 2021). This map was compiled using information from FAO, International Plant Protection Convention, CABI, the European and Mediterranean Plant Protection Organisation and national governments. Image: FAO.

How do I know if I have seen FAW?

FAW larvae do look similar to other armyworms present in Australia. There are two main distinguishing features of FAW larvae:

1. **Four dark spots at the end of their body arranged in a square (Figure 6a).**
2. **Dark head with an upside down, pale Y-shaped marking (Figure 6b).**

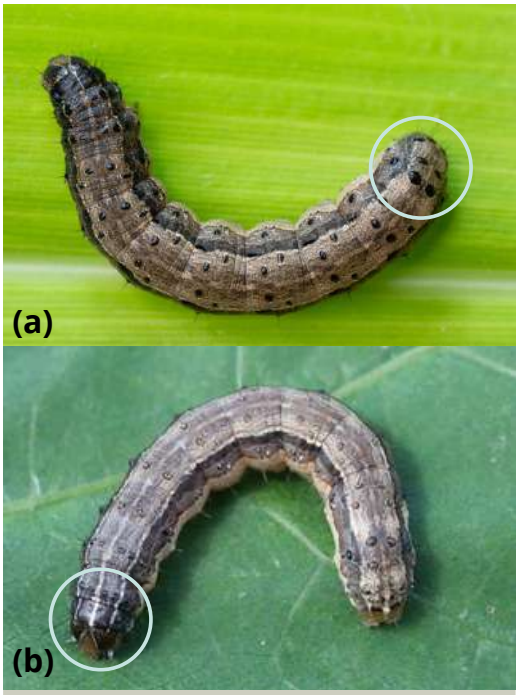

Figure 6. (a) Four dark spots on FAW larvae, and (b) dark head with Y-shaped marking on FAW larvae. Images: Russ Ottens, University of Georgia, Bugwood.org.

Observations and photos of suspect FAW larvae and crop damage can be uploaded to the MyPestGuide Reporter app. Use of this reporting service is available for each state and territory in Australia. State department experts verify reports, identify the pests, and provide the user with feedback and advice.

Alternatively, contact your local agricultural department for diagnostic or identification assistance.

MyPestGuide Reporter

A communication tool for everyone to report pests.

MyPestGuide Reporter is a free photo reporting app built for the public, farmers, agronomists, landholders, pest controllers, researchers and the entire industry community to quickly and easily report pests (insects, animals, weeds, diseases) across Australia.

More information regarding MyPestGuide Reporter available here https://www.agric.wa.gov.au/apps/mypestguide-reporter or via the QR code.

Watch out for these FAW look-a-likes

FAW is often easily mistaken with similar species that are present in Australia (Figure 7). The species listed below are only a sample of the FAW look-a-likes that are present in Australia.

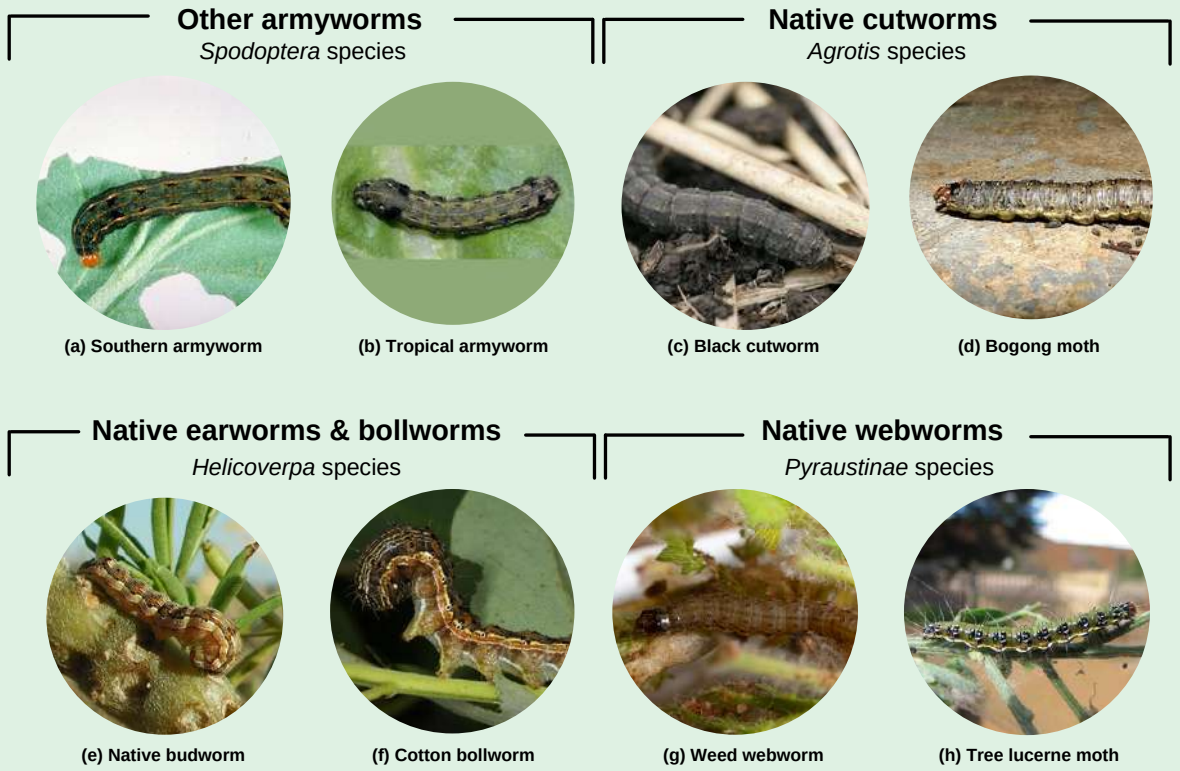

Figure 7*. FAW larvae can be hard to distinguish against other caterpillar species. Images: (a) Central Science Laboratory, Harpenden, British Crown, Bugwood.org; (b) SK Duttamajumder; (c) Roger Schmidt, University of Wisconsin-Madison, Bugwood.org; (d) Vic's Wimmera Wildlife (all rights reserved); (e) Western Australian Agriculture Authority; (f) Gyorgy Csoka, Hungary Forest Research Institute, Bugwood.org; (g) Andrew Weeks, Cesar Australia; (h) Rod Carter.

Integrated pest management

The key to efficient control of FAW is an integrated pest management (IPM) program, inclusive of an artillery of sustainable practices that are effective against FAW. Cultural farm practices, biological control or conservation of natural enemies, as well as biopesticides and conventional insecticide applications offer opportunities for future management of FAW.

Pesticide failure or insecticide resistance?

Pesticide failure can occur due to many reasons, including but not limited to:

1. Wrong spray application method,
2. Inappropriate tank mixtures and spray volumes,
3. Timing of insecticide application,
4. Life stage of plants, and
5. Life stage of pests.

Insecticide resistance is when a pest develops resistance to a particular group of insecticide, meaning a higher proportion of FAW survive after exposure to a particular group of insecticides.

Figure 8. Severe leaf damage on corn caused by FAW in USA. Images: John French, Auburn, GA, Clemson and U of MO, Bugwood.org.

* Reference: NSW Department of Primary Industries, Available at: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/1205735/fall-armyworm-poster.pdf

Chemical control

Use of chemical control methods should be mindful of the potential selection for resistance populations in FAW and other pests (e.g. *Heliocoverpa* species), as well as harm to beneficial insects (natural enemies and pollinators). Best management practices to include in your IPM program include:

1. Rotate insecticides that belong to different Mode of Action groups,
2. Appropriate timing - sprays should target vulnerable egg and larval stages of FAW development,
3. Consider off-target impacts (e.g. beneficial insect and pollinator populations), and
4. Regular crop monitoring to target sprays and for early detection (Figure 9).

Figure 9. FAW larvae commonly hide in protected areas of plants, like leaf whorls, which can affect chemical control. Image: AUSVEG

No economic thresholds have been developed for FAW management in Australia yet. Thresholds developed in America exist, however, should be treated with caution due to climatic and FAW population differences between countries*.

Preliminary investigations into Australia's FAW populations^ observed two important findings: (1) gene mutations (at the target site) for Group 1A insecticides were common, and (2) (target site) resistance relating to pyrethroids and diamides was not detected. However, further investigation is necessary to determine the extent of insecticide resistance within Australia's FAW populations, encompassing a larger sample size.

There are several emergency minor-use permits issued by the Australian Pest and Veterinary Medicine Authority (APVMA; apvma.gov.au) available for FAW management (Table 1).

Access the APVMA website via this QR code and search 'fall armyworm' for a comprehensive permit list:

Table 1. Chemicals available for use against fall armyworm under minor-use permits in Australia. Note: MoA = Mode of Action. All efforts have been made to provide the most current, complete and accurate information on these permits. However, we recommend that you confirm the details at the APVMA website. This table was developed in November 2021.

Chemical	Celery	Brassicas	Bulb vegetables	Cucurbits	Fruiting vegetables	Leafy vegetables (excl. lettuce)	Lettuce	Onion	Peas & beans	Root & tuber vegetables (excl. potato)	Potato	Sweetcorn	Stalk & stem vegetables
Alpha-cypermethrin (MoA: 3A; Contact)												■	
Chlorantraniliprole (MoA: 28; Systemic)		■		■	■	■	■		■	■	■	■	■
Chlorantraniliprole & Thiamethoxam (MoA: 4A, Translaminar)		■			■	■	■						
Emamectin benzoate (MoA: 6; Translaminar)		■		■	■	■	■		■	■		■	
Fawligen (MoA: 31; Ingestion by larvae)		■			■	■	■		■	■		■	
Indoxacarb (MoA: 22A; Contact)	■	■			■	■						■	
Methomyl (MoA: 1A; Systemic)	■	■	■	■	■	■	■	■	■	■	■	■	
Spinetoram (MoA: 5; Contact/Translaminar		■	■	■	■	■		■	■	■		■	■
Spinosad (MoA: 5; Contact/Translaminar		■		■	■	■			■	■		■	■
Zeta-cypermethrin (MoA: 3A; Contact)												■	

* Reference: The Beatsheet, FAW Management. Available at: https://thebeatsheet.com.au/key-pests/fall-armyworm/faw-management/
^ Reference: Nguyen, DT, Chen, Y, Herron, GA, 2021, 'Preliminary characterisation of known pesticide resistance alleles in Spodoptera frugiperda (Lepidoptera: Noctuidae) in its invasive Australian range', Austral Entomology.

Biological control

Biological control refers to the utilisation of natural enemies, including parasitoids, predators and pathogens, to suppress pest populations. Overseas, the conservation and inundate releases of natural enemies has had varied success in FAW IPM programs. Viable biological control options for FAW populations in Australia are currently being studied, however, research is in its early stages.

Conservation biological control

Refers to the aim of preserving and encouraging natural enemy populations which have shown effectiveness overseas, however, more research is required under Australian conditions.

For more information, access Food and Agriculture Organization of the United Nations (FAO) 'Technical Guidelines for sustainable management of fall armyworm in its year-round breeding areas' (2020) at: www.fao.org/3/ca8967en/CA8967EN.pdf

Augmentative biological control

Refers to the artificial or inundate release of natural enemies for the control of a target pest. There are natural enemies that attack FAW eggs and larvae that are present in Australia. Several species have been found to be effective in reducing FAW populations overseas. However, further research is required on the potential of these species under vegetable production systems in Australia.

Currently, there are some records of these natural enemies attacking FAW in Australia.

Current knowledge for Australia

Overseas, research suggests that while FAW does have several natural enemies (predators, parasitoids and pathogens), due to the pest's strong migratory ability, high reproductive capacity, shorter lifecycle with multiple generations and range of plant hosts, many natural enemies are not able to solely prevent economic losses in commercial crops. Natural enemies will play a significant contribution in future FAW IPM programs.

Predators

Generalist predators that attack FAW life stages have been observed in Australia (Figure 10) and with abundant prey (FAW eggs and larvae), these predators will contribute to the regulation of FAW populations in the cropping system. The following predators have been observed feeding on FAW eggs and larvae in the field:

- Assassin bugs,
- Black ants,
- Earwigs,
- Spiders, and
- Spine shield bugs (*Oechalia schellenbergii*).

The exact potential of these predators to control FAW in Australian crops remains unknown. Survey work to determine the abundance and seasonal patterns of predators is currently being undertaken through Hort Innovation funded project (MT19015) by the Queensland Department of Agriculture and Fisheries (QLD DAF).

Conservation and augmentative biological control can maintain or improve generalist predator populations, which may play a significant role in future IPM programs for FAW and other crop pests.

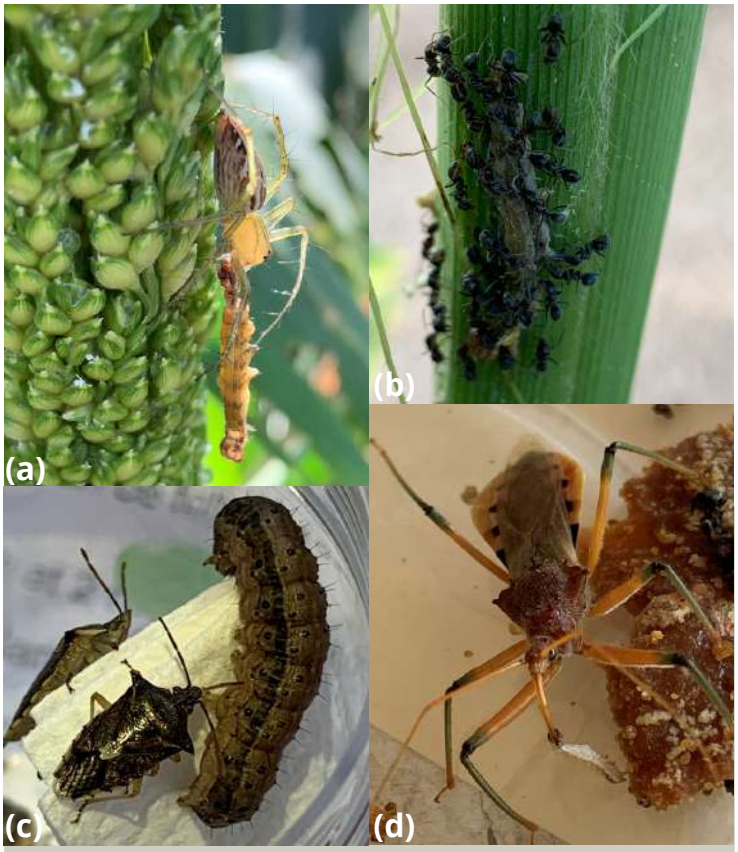

Figure 10. Different predators eating FAW larvae in Australia: (a) a spider, (b) black ants, (c) spinde shield bugs, and (d) an assassin bug. Images: (a) Dr Melina Miles, QLD DAF, (b-d) Dr Siva Subramaniam, QLD DAF.

Parasitoids

A parasitoid is an insect whose larvae survive as parasites inside another organism, eventually killing their host. Overseas, Hymenopteran wasp and Dipteran fly parasitoids (larvae live inside FAW eggs, larvae or pupae) play an important role in IPM programs (Figure 11). Female parasitoid wasps 'sting' FAW egg masses or larvae to lay their eggs inside. This allows the parasitoid's larvae to hatch, feed and develop into adults while living off different FAW life stages.

Common species include:

- **Egg parasitoid** species: *Trichogramma* species, *Telenomus remus.*
- **Egg-larval parasitoid** species: *Chelonus insularis*.
- **Larval parasitoid** species: *Cotesia icipe*, *Habrobracon hebetor*.

Overseas, these species have been observed to reduce the number of FAW and are key biological control agents for the pest. In Australia, early field surveys indicated that five species of endemic parasitoids attack egg and larval stages of FAW (Hort Innovation project MT19015).

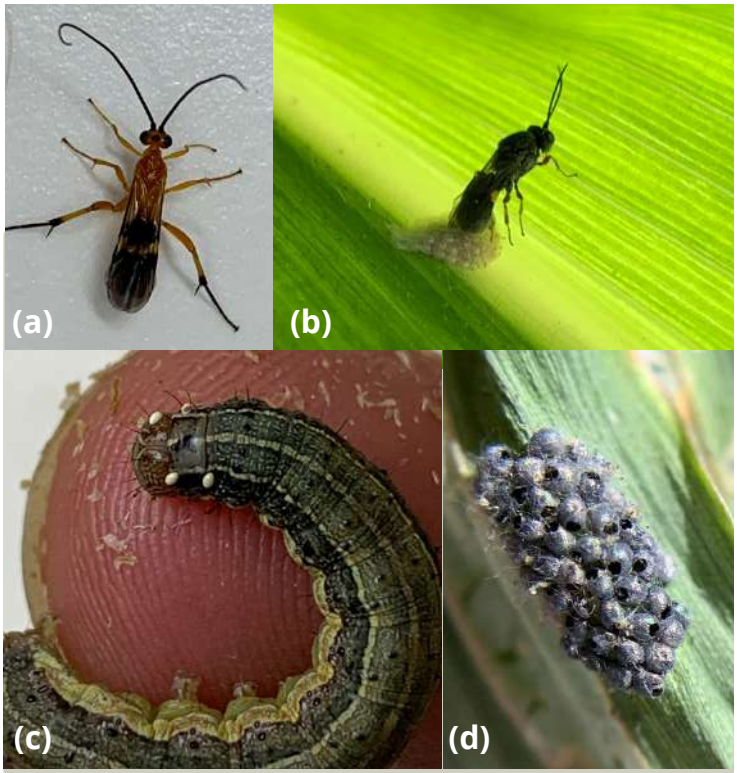

Figure 11. (a) Common parasitoid species, (b) common parasitoid species laying eggs in FAW egg mass, (c) tachinid fly parasitoid eggs on a FAW larvae, and (d) a FAW egg mass parasitised by *Trichogramma* species. Images: (a, c, d) Dr Melina Miles, QLD DAF, (b) Dr Siva Subramaniam, QLD DAF.

Pathogens

Bacteria

Bacillus thuringiensis (Bt) is an insecticide for lepidopteran (moth and butterfly) pests, which produces insecticidal proteins able to kill pests when ingested.

Bt foliar applications are available for specific vegetable crops (check permits regularly at apvma.gov.au). However, effectiveness can vary as the product must be ingested and FAW larvae tend to occupy protected areas of the plant (e.g. leaf whorls; Figure 9). Applications should be used with caution.

Viruses

Nucleopolyhedroviruses (NPV) have shown potential for effective FAW management (Figure 12). In March 2021, an emergency use permit for 'Fawligen' was introduced. It's a NPV-based biological insecticide designed to selectively control FAW. Effectiveness varies with crop coverage and FAW larval growth stage. Fawligen application should target neonate (young; Figure 4(2)) and early stages of FAW.

NPV's included in IPM programs should be used strategically with biological control options and conventional chemistry.

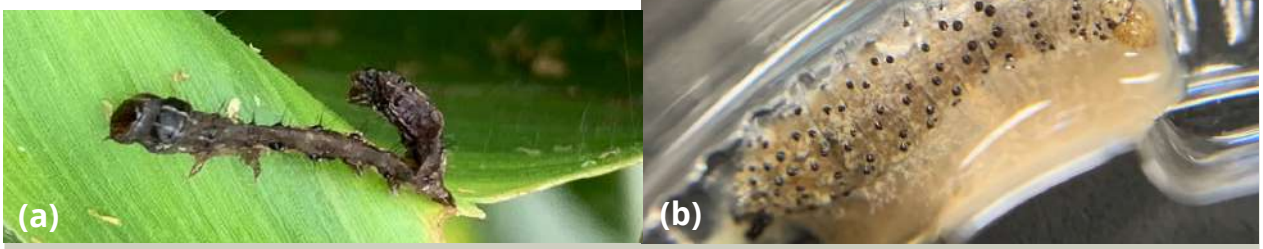

Figure 12. (a) FAW larva infected by a NPV in the field, (b) a FAW larvae killed by Fawligen. Images: (a) Dr Siva Subramaniam, QLD DAF, (b) Dr Melina Miles, QLD DAF.

Fungi

While there are no commercial products available in Australia currently, naturally occuring entomopathogenic fungi (fungi that causes disease on insects) like *Metarhizium rileyi*, have shown to cause moderate mortality to FAW larvae (Figure 13).

Figure 13. FAW larvae infected with fungus, *Metarhizum rileyi*. Images: (a) Dr Melina Miles, QLD DAF, (b) Dr Siva Subramaniam, QLD DAF.

Cultural control

Best management practices provide the foundation for IPM programs. Adoption of practices that reduce pest establishment, reproduction, dispersal and survival will lead to improved pest management.

Suggested cultural management practices that have the potential to reduce the likelihood of FAW establishing in a crop include:

1. Practicing 'Come Clean, Go Clean',
2. Clean up crop residue soon after harvest,
3. Implement good farm hygiene,
4. Crop rotation with non-favoured hosts (Figure 14),
5. Control weeds and volunteer plants to reduce alternative hosts for pests, and
6. Regular monitoring of crops.

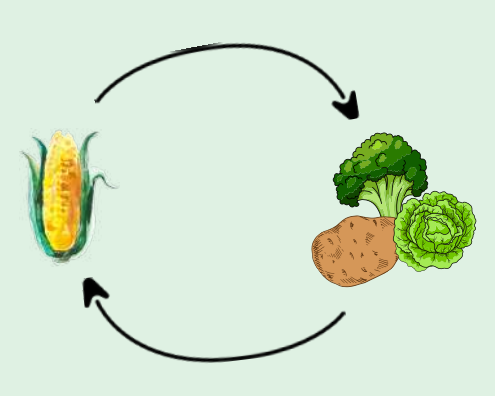

Figure 14. Rotate susceptible crops like sweetcorn with crops that are less preferred hosts (e.g. potato, leafy vegetables, brassicas).

Further study of the success and value of cultural practices for FAW management is required for the Australian situation.

Crop monitoring

Early detection of FAW ensures a quick response and accurate timing of control methods. Regular crop surveillance and monitoring for FAW eggs and larvae is the foundation of a successful IPM program and helps minimise damages and reduce harvest losses.

How do I monitor for FAW?

1. Check a sample of seedlings prior to planting for egg masses and/or young larvae.
2. Monitor susceptible host crops as soon as plants emerge.
   - Check top and underside of leaves.
   - Monitor at several locations within a crop to ensure infestations are caught early and hot spots are not missed (Figure 15).
3. Monitor regularly - weekly is recommended to ensure accurate timing of control methods.
4. While monitoring, record:
   - Number of plants infested with eggs and larvae.
   - Leaf damage observed - 'windowing' indicates presence of young larvae, 'shotgun' damage indicates presence of older larvae.

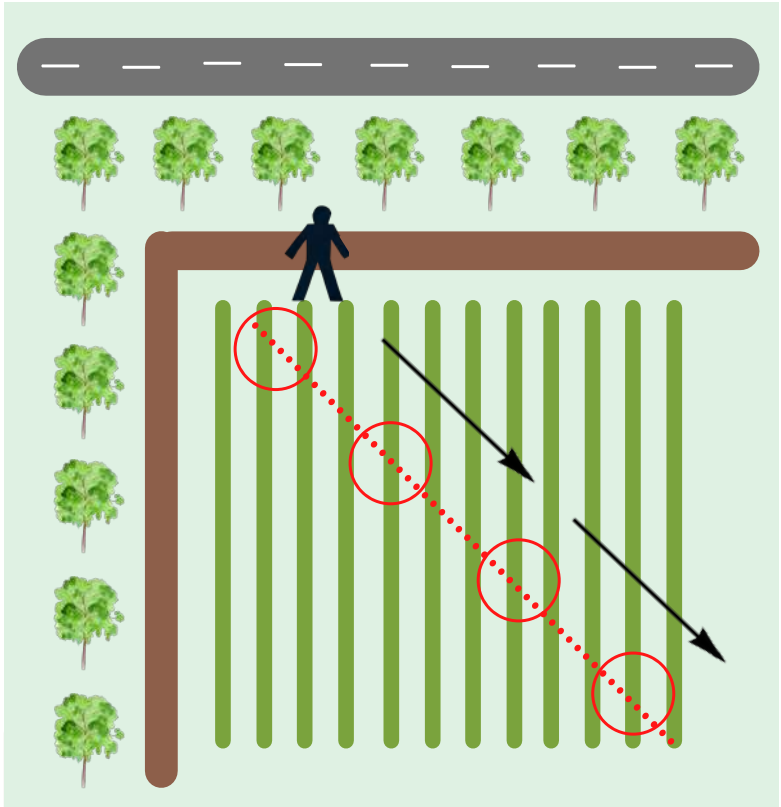

Figure 15. This is one simple way to ensure monitoring is representative of the entire field. Walk a transect across a crop at regular intervals. As illustrated above, this can be achieved by walking across a field and stopping at regular intervals as indicated by the red circles.

For more information and other useful monitoring techniques, go to Plant Health Australia's Quick FAW Guide* via the QR code.

* Reference: Plant Health Australia, 2020, FAW Quick Guide. Available at: https://www.planthealthaustralia.com.au/wp-content/uploads/2020/11/Fall-Armworm-Quick-Guide.pdf

Monitoring with traps

Crop monitoring combined with FAW pheromone lure traps (Figure 16) enables the identification of egg and larval stages, feeding damage and can provide an indication of overall population levels.

Monitoring enables control methods to target emerging larvae before they become intrenched (and protected) from sprays in leaf whorls.

Two pheromone monitoring lures are currently available*

*Permit (PER89169) available here as a PDF (https://bit.ly/3zziPzL) or via the QR code.

Figure 16. A bucket trap used with a FAW-specific pheromone lure to attract male moths for monitoring purposes. Image: Dr Helen Spafford, DPIRD WA.

These traps attract adult male FAW and play a primary role in monitoring, acting as an early warning for migration of moths and egg lays into crops.

Trap setup

Pheromone traps for FAW surveillance require specific assembly (Figure 17).

For detailed instructions, read DPIRD WA's instruction manual available here: https://bit.ly/38zaK26 or via this QR code.

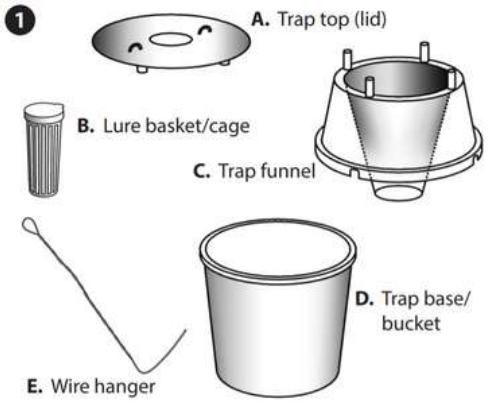

Figure 17. FAW pheromone trap components. Image: Trécé's pherocon bucket assembly guide.

Trap site selection

Choosing a site for a pheromone lure trap should consider several aspects to increase the likelihood of FAW detection. These include*:

1. Safe access,
2. Proximity to host plants - preferred feeding and breeding sites,
3. Open space - not hidden in vegetation, and
4. Dark - not near building lights.

When placing pheromone traps near a susceptible crop, ensure traps are placed on each side of the crop (where possible; Figure 18). FAW migratory flights should be detected, no matter the direction.

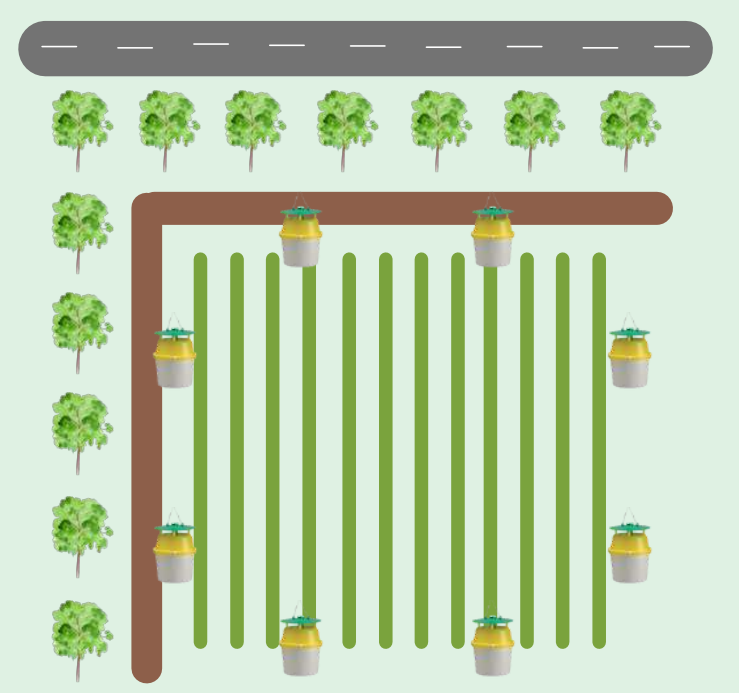

Figure 18. Diagram illustrating suitable areas to place pheromone traps.

* Reference: DPIRD WA (2020). Fall Armyworm Surveillance Trapping Manual. Available at: https://bit.ly/38zaK26

Further reading

Plant Health Australia, 2020, Fall Armyworm Continuity Plan

AUSVEG, Fall Armyworm Resources.

Department of Primary Industries and Regional Development, 2021, Fall armyworm in Western Australia.

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This resource was developed as part of the AUSVEG Farm Biosecurity Project. It is a joint communication initiative between AUSVEG and Plant Health Australia.

Arming industry with strategies and tools to manage fall armyworm

The Australian vegetable industry will soon have access to an interim FAW management strategy that has been co-developed by farm agronomists, land managers and researchers, and tested on crops grown under commercial conditions. The strategy will provide growers and consultants with better FAW management options and lead to more sustainable use of insecticides.

In a new project that commenced in July 2021, Queensland and New South Wales researchers are working with growers and agronomists in the most affected regions, starting with Bowen, to co-design, test and validate integrated FAW management strategies for sweet corn. The project team are drawing on FAW knowledge and strategies developed through industry's experience of managing FAW since early 2020 when the pest first arrived. Potential strategies will include the use of monitoring and decision-making tools together with tactical applications of insecticides, lure and kill techniques, biopesticides and biocontrol agents. Outcomes from the work will be extended to capsicum crops where possible and will give all Australian vegetable growers access to better FAW management strategies and tools.

The project team will test two interim FAW strategies in sweet corn trials at the Bowen Research Facility in 2021, with on-farm trials starting in Autumn 2022. Virtual trial sites will be established on the Department of Agriculture and Fisheries online eHub to extend research outcomes to the vegetable industry nationally.

As part of the project, researchers are testing FAW populations for resistance to the major chemistries used in vegetable crops to help understand insecticide resistance levels and inform resistance management strategies. The project team will also conduct a review to identify research, development and extension gaps in FAW management to help guide future investments by the vegetable industry.

'VG20003 Co-developing and extending integrated Spodoptera frugiperda (FAW) management systems for the Australian vegetable Industry' is funded by Hort Innovation and led by Dr Siva Subramaniam, senior entomologist with the Department of Agriculture and Fisheries at the Bowen Research Facility.

Contact Dr Siva Subramaniam at siva.subramaniam@daf.qld.gov.au for more information.

Figure 20. Growers, agronomists, researchers and industry representatives inspect a sweet corn trial at a FAW workshop at Bowen Research Facility in December 2020. Image: Queensland Department of Agriculture and Fisheries.

Hort Innovation Strategic levy investment | VEGETABLE FUND

This project has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

NSW GOVERNMENT Regional NSW

Queensland Government

Project industry partners: Mulgowie Fresh, Vee Jay's Kalfresh, Rugby Farm, and Arable Field Research.

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