Department
for Environment
Food & Rural Affairs

Pest specific plant health response plan:

Outbreaks of *Thaumatotibia leucotreta*

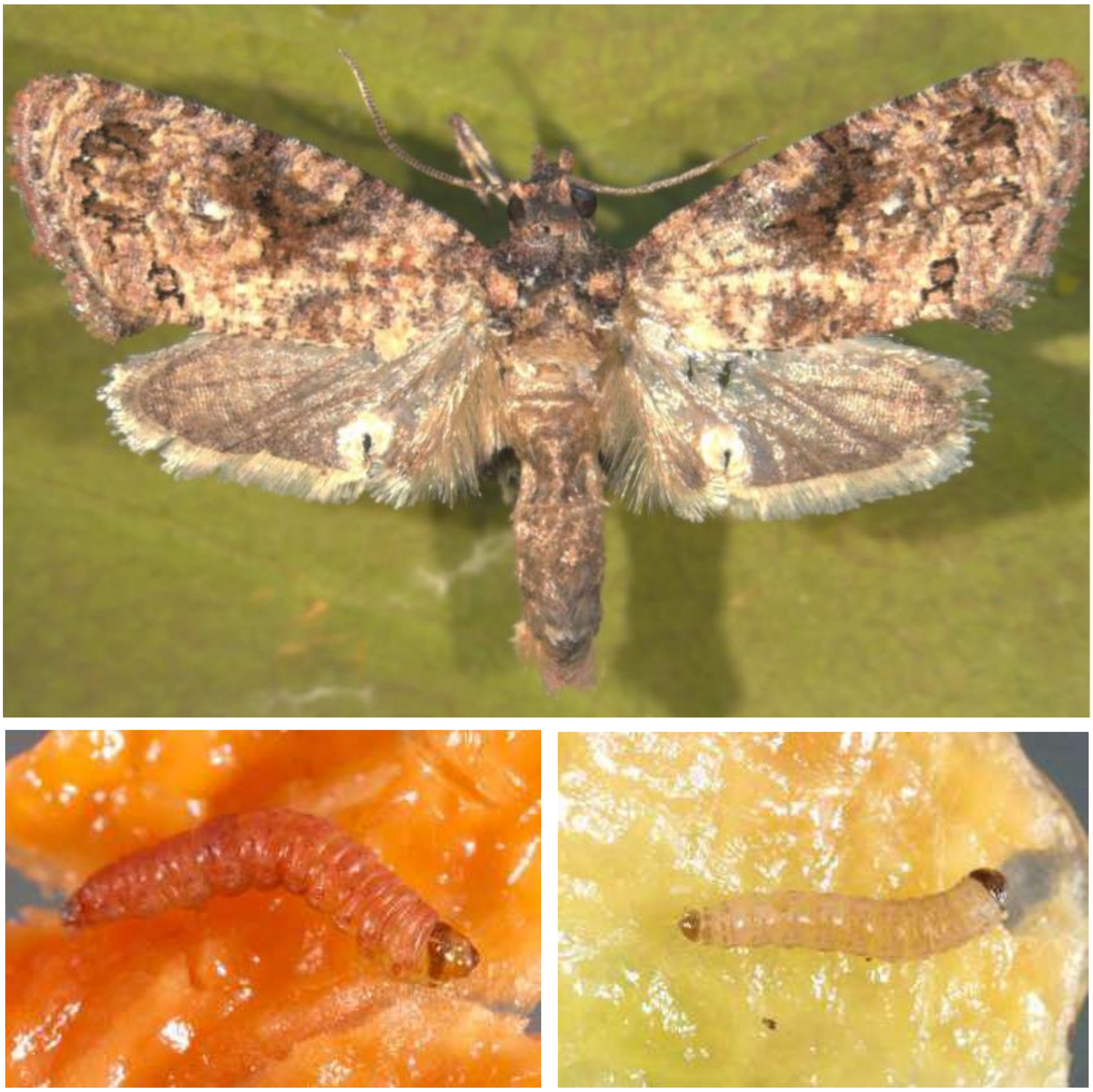

Figure 1. Adult and larvae of *Thaumatotibia leucotreta* (false codling moth). Adult moth image courtesy of Marja van der Straten, National Reference Centre, National Plant Protection Organisation (NL). Larvae © Fera Science Ltd.

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This publication is available at

https://planthealthportal.defra.gov.uk/pests-and-diseases/contingency-planning/

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Executive summary

Background	
Regulation	GB Quarantine pest
Key Hosts (2.2)*	Peppers and aubergines
Distribution	Angola, Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Cote d'Ivoire, Democratic Republic of the Congo, Eritrea, Eswatini, Ethiopia, Gambia, Ghana, Israel, Kenya, Madagascar, Malawi, Mali, Mauritius, Mozambique, Niger, Nigeria, Reunion, Rwanda, Saint Helena, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Togo, Uganda, USA, Zambia, Zimbabwe
Key pathways	Produce and plants for planting
Industries at risk	Protected crops of peppers and aubergines
Symptoms (2.3)	Larval feeding leads to reduced yields and fruit contaminated with copious amounts of frass. Infestation can lead to premature ripening and fruit drop.
Surveillance	
Demarcated zones (5.27)	Infested zone = Defined infested area e.g., glasshouse Buffer zone = ≥ 1 km
Surveillance activities (5.18-20)	• Visual surveys of fruit. • Pheromone trapping.
Response measures	
Interceptions (5.1-5.8)	• Destruction via deep burial or incineration. • Visual surveys of production sites if intercepted inland. • Tracing exercises are carried out where required
Outbreaks (5.31-5.43)	• Foliar insecticide treatment of plants • Removal and destruction of fruit • Destruction of infested plants. • Post-crop clean up measures. • Host crop free period with monitoring carried out.
Key control measures	
Biological	*Heterorhabditis bacteriophora, Bacillus thuringiensis, Beauveria bassiana, Metarhizium anisopliae and M. brunneum*
Chemical	A treatment regime will be developed in consultation with the nursery or grower
Cultural	Removal of infested fruit, sticky traps, good hygiene
Declaration of eradication	
Thaumatotibia leucotreta can be declared eradicated if it is not found after at least two lifecycles under the prevailing conditions after the infested crop has been removed.	

* Numbers refer to relevant points in the plan

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1. Introduction and scope

1.1. This pest specific response plan has been prepared by the Defra Risk and Horizon Scanning team. It describes how the Plant Health Service for England will respond if an infestation of *Thaumatotibia leucotreta* (false codling moth) is discovered in protected pepper and aubergine crops.

1.2. The plant health authorities in Northern Ireland, Scotland, Wales and the Crown Dependencies have been consulted on this plan and will use it as the basis for the action they will take in the event of *T. leucotreta* being detected in their territories.

1.3. This document will be used in conjunction with the *Defra Generic Contingency Plan for Plant Health in England* (https://planthealthportal.defra.gov.uk/assets/uploads/Generic-Contingency-Plan-for-Plant-Health-in-England-FINAL-2.pdf), which gives details of the teams and organisations involved in pest response in England, and their responsibilities and governance. It also describes how these teams and organisations work together in the event of an outbreak of a plant health pest.

1.4. The aims of this response plan are to facilitate the containment and eradication of *T. leucotreta* and to make stakeholders aware of the planned actions and statutory requirements pre and post border.

2. Summary of threat

2.1. *Thaumatotibia leucotreta* is native to Africa, where it is widely distributed south of the Sahara (Newton, 1998, as cited in USDA, 2010). In 1984, it was reported outside of Africa for the first time in macadamia nuts in Israel (EPPO Reporting Service, 2003). The cultivation of macadamia nuts for commercial purposes was stopped soon after, but the moth was still able to persist in areas of cotton and castor bean as of 2003, and more recently it has been recorded from coastal areas between Ashdod and Hadera (EPPO Reporting Service, 2003; Opatowski personal communication, 2012, as cited in EPPO, 2013). The moth has also been reported in the Netherlands, in 2009 and 2013, and in Germany, in 2018, but, following eradication measures, it is no longer considered to be present in these countries or in Europe as a whole (EPPO Reporting Service 2010, 2014, 2018, 2019).

2.2. *Thaumatotibia leucotreta* is a polyphagous pest, the caterpillars (larvae) of which have been recorded to feed on more than 70 plant species from 40 families (EPPO, 2011). Hosts considered to be of major importance, and which are of significance to the UK, include *Capsicum* spp. (sweet and chili pepper), *Quercus robur* (oak), *Solanum melongena* (aubergine), *Vitis vinifera* (grape) and *Zea mays* (maize)

(EPPO, 2020). Of these, only **protected crops of *Capsicum* spp. and *S. melongena* are likely to be at risk**, as *T. leucotreta* is not considered to be able to establish outdoors in the UK (Korycinska, 2016). Rose, which is a minor host of *T. leucotreta*, is also considered to be at risk when grown under protection (Potting and Straten, 2010). Given the wide host range of *T. leucotreta*, other plant species grown under protection that have not previously been exposed to this pest may likewise be susceptible, even though they are not currently recorded as hosts (Korycinska, 2016).

2.3. Larvae of *T. leucotreta* feed inside the fruit of host plants and excrete copious amounts of frass, damaging and contaminating the fruit and sometimes leading to premature ripening and fruit drop (EPPO, 2011, 2019; Martin *et al.*, 2012; Ostoja-Starzewski *et al.*, 2017). Openings made by the larvae can also allow the ingress of secondary pathogens, which accelerate the deterioration of the fruit (Ostoja-Starzewski *et al.*, 2017).

2.4. *Thaumatotibia leucotreta* is a damaging pest throughout sub-Saharan Africa and its nearby islands (EPPO, 2013). Significant yield losses have been reported across a number of different crops, including citrus, peach, macadamia and cotton (DROPSA, 2016; van der Geest *et al.*, 1991, as cited in EPPO, 2013; Wysoki, 1986). The introduction of the moth may also have impacts on trade, as it did for the Netherlands where, following outbreaks of the moth in that country, the USDA temporarily prohibited the import of Dutch peppers (Korycinska, 2016).

2.5. Eggs and larvae of *T. leucotreta* can be found on the fruit of *Capsicum* spp. and *S. melongena*. While plants for planting of these species are prohibited from most third countries outside of Europe and the Mediterranean, they can still be imported from Israel and therefore remain a potential, albeit low risk, pathway into the GB. In contrast, fruit is not prohibited from any of the moth's range and is therefore considered to be a higher risk pathway, particularly when infested fruit is packed on the same site as production facilities (Korycinska, 2016). This risk is reduced by GB measures requiring that fruit of *Capsicum* spp. from the African continent, Cape Verde, Saint Helena, Madagascar, La Reunion, Mauritius and Israel must originate from either a country free of *T. leucotreta*; an area free of *T. leucotreta*; a place of production free of *T. leucotreta*; or have been subjected to an effective cold treatment, systems approach or post-harvest treatment to ensure freedom of *T. leucotreta* In spite of these measures, eggs and larvae are still regularly intercepted on *Capsicum* spp. in GB.

2.6. As of November 2021, there have been 846 interceptions of the moth in England, including 766 interceptions on *Capsicum* spp. (Table 2).

3. Risk assessments

3.1. *Thaumatotibia leucotreta* has an unmitigated and mitigated UK Plant Health Risk Register score of 27 and 18, respectively. Overall scores range from 1 (very low risk) to 125 (very high risk). These scores are reviewed as and when new information becomes available (https://planthealthportal.defra.gov.uk/pests-and-diseases/uk-plant-health-risk-register/viewPestRisks.cfm?cslref=24229).

3.2. Pest risk analyses have been carried out by EPPO and the Netherlands (EPPO, 2013; Potting and Straten, 2010).

3.3. The EPPO PRA considers areas near the Mediterranean coast in North Africa (Morocco, Algeria and Tunisia), the Near East (Israel and Jordan) and Europe (Spain, Italy, Malta, Cyprus, Southern Greece, Portugal, the Canary Islands and the Azores) to have a climate suitable for establishment. The Netherlands PRA also considers establishment outside to be unlikely in the Netherlands, and that establishment of the moth will be limited to glasshouses of aubergine, pepper, rose and tomato, with pepper being the main host of concern. Both PRAs conclude that the moth could cause major economic impacts, at least in the short term, though deem eradication of the moth to be achievable in glasshouses, where effective controls, such as a host break, can be implemented.

4. Actions to prevent outbreaks

4.1. *Thaumatotibia leucotreta* is a GB quarantine pest (Schedule 1 of The Plant Health (Phytosanitary Conditions) (Amendment) (EU Exit) (Regulations) 2020) and is therefore prohibited from being introduced into, or spread within GB. There are also further pest specific requirements in Schedule 7.

4.2. *Thaumatotibia leucotreta* is an EU Union quarantine pest (Annex II Part A (Pests not known to occur in the Union Territory) and is therefore prohibited from being introduced into, or spread within, EU member states.

4.3. *Thaumatotibia leucotreta* is an EPPO A2 listed pest and is therefore recommended for regulation by EPPO member countries (EPPO, 2019).

4.4. The Plant Health Service should be aware of the measures described in this plan and be trained in responding to an outbreak of *T. leucotreta*. It is important that capabilities in detection, diagnosis, and risk management are available.

5. Response

Official action to be taken following the suspicion or confirmation of *Thaumatotibia leucotreta* on imported plants, including fruit

5.1. If *T. leucotreta* is suspected by the Animal and Plant Health Agency, Plant Health and Seeds Inspectorate (APHA PHSI) to be present in a consignment moving in trade, the PHSI must hold the consignment until a diagnosis is made. Ideally, the consignment should be placed in a sealed cold store and any opened containers should be resealed (which could be via wrapping in plastic if this facility is available). Other consignments of host plants of significance that are at risk of cross-contamination should also be held pending a risk assessment on whether cross-contamination has or could have potentially occurred. Samples should be sent to Fera Science Ltd., Plant Clinic, York Biotech Campus, Sand Hutton, York, YO41 1LZ (01904 462000) in a sealed crush proof container, within at least two other layers of containment.

5.2. When an infestation of *T. leucotreta* is confirmed, the PHSI should advise the client of the action that needs to be taken by way of an official plant health notice. The consignment should be double bagged and destroyed by either incineration or deep burial.

5.3. If the moth is intercepted inland and there is the potential for spread from the imported consignment, host plants at risk of contamination should be surveyed on the site and again in the following year for signs of pest presence. Fruit consignments assessed as being at risk of contamination should also be held and inspected for the moth (and released if found free). When a site is in an area where hosts are grown, a survey of protected environments should be established within 1 km of the infested site. The size of the survey area will be influenced by the local climatic and meteorological conditions, and the density of host crops. Waste disposal processes and areas should also be agreed to ensure best practice is followed.

5.4. A UKPHINS (UK Plant Health Interception Notification System) notification should be made upon confirmation of an interception of live *T. leucotreta*. UKPHINS is the IT system for recording findings and non-compliance in order to maintain records and notify other National Plant Protection Organisations (NPPO) of plant health issues.

5.5. If all or part of the consignment has been distributed to other premises prior to diagnosis, trace forward and trace back inspections should take place upon suspicion or confirmation of *T. leucotreta*. Details of recent past and future consignments from the same grower/supplier should also be obtained.

5.6. A pest factsheet to raise awareness of *T. leucotreta* and its symptoms should be distributed or recommended to packers/processors and importers where *T. leucotreta* has been found, and, where suitable, to those in the local area and those associated with the infested premises. The pest factsheet can be found on the Plant Health Portal - https://planthealthportal.defra.gov.uk/pests-and-diseases/pest-and-disease-factsheets/notifiable-pests/.

Official action to be taken following the suspicion of a *Thaumatotibia leucotreta* outbreak

5.7. Each outbreak will be assessed on a case by case basis. An Outbreak Triage Group (OTG), chaired by the Chief Plant Health Officer (CPHO) or their deputy and including specialists from APHA, Defra and other organisations, may need to be set up to assess the risk and decide on a suitable response at strategic, tactical and operation levels. Where appropriate, the OTG will also decide who will be the control authority, and the control authority will then nominate an Incident Controller. An Incident Management Team (IMT) meeting, chaired by the Incident Controller, will subsequently convene to produce an Incident Action Plan (IAP) to outline the operational activities. See the *Defra Generic Contingency Plan for Plant Health in England* for full details.

5.8. The OTG will set an alert status, which will consider the specific nature of the outbreak. These levels, in order of increasing severity, are white, black, amber and red (more details of these levels can be found in table 2 of the *Defra Generic Contingency Plan for Plant Health in England*). Under most scenarios, a suspected infestation of *T. leucotreta* in a protected crop is likely to be given a black alert status. A black alert status refers to a plant pest with potential for limited geographical spread leading to moderate economic, environmental or social impacts.

Restrictions on movement of plants and plant products to and from the place of production

5.9. When *T. leucotreta* is found in association with plants for planting, fruit and flowers of its host plants, these should be prevented from leaving the site, other than for destruction by deep burial, incineration or another approved method.

Precautionary measures

5.10. The infested area and other areas potentially at risk should be sealed as far as practically possible to prevent the escape or further spread of *T. leucotreta* e.g. minimising movement of people, closing of vents etc.

5.11. Volunteer plants and possibly some weeds may act as reservoirs for *T. leucotreta*. Controlling these plants within and around glasshouses reduces the chance of the crop becoming infested and reduces the risk of survival and persistence of the pest in the event of an outbreak. Volunteer plants and weeds can be controlled mechanically (e.g. hoeing), chemically (e.g. herbicides), and manually (e.g. rogueing).

5.12. All fallen fruit and other debris that may harbour the moth should also be regularly removed and destroyed.

Preliminary trace forward / trace backward

5.13. If an infested consignment is considered as being the source of the suspect outbreak, investigations regarding the origins of infested consignments will be undertaken to locate other related and therefore potentially infested consignments of products moving to and from the site. If applicable the relevant NPPO should be contacted.

Confirming a new outbreak

How to survey to determine whether there is an outbreak

5.14. Information to be gathered by the PHSI on the suspicion of an infestation of *T. leucotreta*, in accordance with ISPM 6; guidelines for surveillance (https://www.ippc.int/en/publications/615/):

- The origin of the host plants and associated pathways.
- Details of other premises or destinations where the host plants/products have been sent, where *T. leucotreta* may be present.
- The layout of the premises and surrounding area (in relation to potential buffer zones of at least 1 km), including a map of the fields/cropping/buildings, at risk growers, and details of neighbouring crops, especially any commercial or non-commercial hosts in glasshouses.
- Details of the host variety, growth stage and any other relevant information.
- Description of the surrounding habitat, including main crops and predominant hosts.

- Area and level of infestation, including life stages and a description of symptoms (photos should be taken).
- The date and time the sample was taken, and by whom.
- Current treatments/controls in place e.g. chemical treatments and biological control agents being used.
- Details of the movement of people, equipment, machinery etc. to and from the infested area.
- Cultural, biosecurity and working practices.
- The name, address, email and telephone number of the person who found the pest and/or its symptoms, and the business owner.

5.15. This information should be included on the plant pest investigation template. As much of this information should be gathered prior to the OTG as possible, but where not all of this information can be gathered in time, the most relevant information should be prioritised. The rest of the information can be gathered after the OTG.

5.16. Further to information gathering, samples of other infested plants should be taken to confirm the extent of the infestation e.g. in associated glasshouses. This initial survey will be used to determine if it is an isolated finding or an established outbreak.

5.17. Finance for the surveys will depend on the individual circumstances of the outbreak, and will be subject to discussion, usually between Defra policy and the PHSI.

Sampling

5.18. Fruit should be visually inspected for holes, eggs attached to the outer surface (particularly around calices), discolouration and decay (EPPO, 2013). Premature ripening and early abscission of developing fruit can also be an indication of an infestation in a growing crop (EPPO, 2013). Fruit suspected to be infested should be cut open and inspected for the presence of larvae and feeding damage.

5.19. Adults of *T. leucotreta* are nocturnal, and generally spend the day hidden within shaded portions of a host plant (Ostoja-Starzewski *et al.*, 2017). Trapping is therefore the best option for sampling adults:

- In the USA, delta traps accompanied by a pheromone lure are used to capture adults (USDA, 2010). Funnel traps and wing traps have also performed well against the moth, and in one study, funnel traps even outperformed delta traps (Levi-Zeda *et al.*, 2019; Newton and Mastro, 1989).
- The two most important pheromone components with respect to male attractiveness are (E)-8-dodecenyl acetate and (Z)-8-dodecenyl acetate (Levi-Zeda *et al.*, 2019). The USDA apply them in a ratio of 1:1, but various studies have identified different ratios depending on the population of *T. leucotreta*: work

on populations of moths from the Ivory Coast identified a ratio of 3:1 (E/Z) (Angelini *et al.*, 1981 and Zagatti *et al.*, 1983, as cited in Levi-Zeda *et al.*, 2019), work on populations of moths from Malawi identified a ratio of 2:3 (Hall *et al.*, 1984, as cited in Levi-Zeda *et al.*, 2019), and work on populations of moths from Israel identified a ratio of 9:1 (Levi-Zeda *et al.*, 2019).

- Traps and lures are sold by a number of suppliers, including Great Lakes IPM (https://www.greatlakesipm.com/product_search/12/1/1/?displayMode=grid&q=false+codling+moth) and ISCA Technologies (https://www.iscatechnologies.com/products/false-codling-moth?variant=16597924673). A comprehensive list of suppliers is provided in USDA (2010).

5.20. Following the capture/putative identification of an adult, pupa, larva, egg and/or symptoms of damage, samples should be sent for confirmatory diagnosis as in point 5.1. Each sample should be labelled with full details of the sample number, location (including grid reference if possible), variety, and suspect pest.

Diagnostic procedures

5.21. EPPO diagnostic protocol PM 7/137(1) (EPPO, 2019) provides guidance on the morphological identification of *T. leucotreta*. In addition, other diagnostic guides provide additional useful information, including Gilligan and Passoa (2014) and Link 1.

5.22. However, eggs, early instar larvae (L1 & L2) and pupae cannot be accurately identified to species on the basis of their morphological characteristic and need to be reared to an identifiable life stage i.e. L3 to L5 or the adult stage. Alternatively, all life stages can be identified using molecular methods such DNA barcoding or the species specific GENIE assay developed by Fera Science Ltd.

Criteria for determining an outbreak

5.23. If *T. leucotreta* is detected at a port or confined to a particular consignment with no risk of spread, then an outbreak should not be declared. If it is found to have spread or likely to have spread beyond its original consignment, for example across multiple lots in a glasshouse, then an outbreak should be declared.

Official Action to be taken following the confirmation of an outbreak

5.24. The scale of the outbreak will determine the size and nature of the IMT/management team and action.

Communication

5.25. The IMT will assess the risks and communicate details to the IPPC, EU and EPPO, in accordance with ISPM 17: pest reporting (https://www.ippc.int/en/publications/606/), as well as within Government to Ministers, senior officials and other government departments, devolved administrations, and agencies (e.g., the Environment Agency) on a regular basis as appropriate; and to stakeholders.

5.26. A pest factsheet to raise awareness of *T. leucotreta* and its symptoms should be distributed or recommended to growers, packers/processors and importers where *T. leucotreta* has been found, and, where suitable, to those in the local area and those associated with the infested premises. The pest factsheet can be found on the Plant Health Portal - https://planthealthportal.defra.gov.uk/pests-and-diseases/pest-and-disease-factsheets/notifiable-pests/.

Demarcated zones

5.27. Once an outbreak has been confirmed, a demarcated area should be established that includes:

- A defined infested zone (e.g. the infested glasshouse)
- A buffer zone, which should extend out to at least 1 km from the infested zone, but may extend out further. The size of the buffer zone will be influenced by the local climatic and meteorological conditions, and the density of host crops. The buffer zone may include other premises in which staff/growers have visited or worked in, premises in which stock has been sent or received, and/or any other premises where there is a perceived risk.

5.28. Initial maps of outbreak sites should be produced by officials.

5.29. All host plants and potential host plants under protected conditions in the infested and buffer zones should be visually inspected and any suspect samples should be sent for diagnosis. Traps with lures should be used.

5.30. The demarcated area should be adjusted in response to further findings. If *T. leucotreta* is found within a glasshouse outside of the infested zone, this should subsequently be designated as infested and the buffer zone changed accordingly.

Pest Management procedures

5.31. The whole crop should be treated as soon as possible with a foliar insecticide. The PHSI will advise on an appropriate insecticide treatment regime in consultation with the Defra Risk and Horizon Scanning team. These treatments should also be used on other susceptible hosts in the glasshouse.

- Prior to any pesticides being used, the risk posed by the pesticide to people and the environment will be assessed.

- Any applications should be made following the advice on the product label and be in accordance with HSE guidance. In some cases there may be a requirement to carry out a Local Environment Risk Assessment for Pesticides (LERAP) depending on the product used and the situation of the finding.

- If the situation demands it, it may be necessary to require the use of pesticides even in organic crops or those where biological control agents are being used.

- Growers will be placed under notice to apply the recommended pesticides and make the applications using their own or contractor's equipment. Records of applications will be kept, including details of the amount of product and water use.

5.32. The moth is difficult to control using insecticides, as the majority of its lifecycle is protected within the fruit (Ostojá-Starzewski *et al.*, 2017). Insecticides can still have some effect, however, such as on adults. Use of contact insecticides requires good coverage of the foliage, buds, flowers and fruit.

- Visual inspection and pheromone traps should be used to assess the efficacy of insecticide treatments.

5.33. Following insecticide use, immature fruit, and ideally all fruit, should be removed and destroyed by incineration or deep burial to reduce the population of the moth and minimise the risk of spread when the affected crop is removed.

5.34. All susceptible host crops in the glasshouse should then be removed and destroyed by incineration or deep burial, including volunteers, weeds and waste. If possible, host crops in the vicinity of the glasshouse (e.g. out to 50 m) should also be treated and destroyed. If there is a large volume of material, plants could be shredded first to reduce the population and minimise the risk of spread. In exceptional circumstances, there may be justification for not removing all of the affected crop, but this should be decided by the IMT. For example, where the outbreak is assessed as being restricted to a small area of the crop.

5.35. Once the infested crop has been removed, all remaining material e.g. string, plastic flooring and growing media, should be destroyed or recycled (if no risk of escape), or if reused, thoroughly cleaned with water and detergent to remove any remaining plant material and life stages of the moth. The permanent facility should also be cleaned.

5.36. Ideally, no host plants should be grown in the infested glasshouse for a period covering the lifespan of adult *T. leucotreta* in the absence of host plants. This will depend on the climatic conditions within the glasshouse, particularly the temperature. If possible, the temperature should be raised to speed up the lifecycle of the moth. Pheromone traps should be used to monitor the empty glasshouse. Alternatively, lowering the temperature to kill any moths present could be considered in certain situations.

5.37. Inspections, with the frequency determined by the IMT, should be carried out on the next crop. These inspections could include trapping.

Measures to be taken in the case of detection of infestation in fruit after harvest (e.g. during processing/packaging and grading)

5.38. The following should be designated as infested:

- The lot from which the sample was taken.
- The waste from the infested lot, such as processed waste.
- The glasshouse where the lot was grown where relevant.

5.39. As in 5.25, a buffer zone should be created that extends out to at least 1 km from the infested glasshouse.

5.40. Areas where potentially infested equipment, waste, and other articles, have been used should be surveyed, and any fruit harvested from these areas should be inspected.

5.41. Points 5.2-5.3 and 5.5-5.6 should be followed.

5.42. Refer to the pest management procedures section if *T. leucotreta* is found in a glasshouse.

Crops growing within the buffer zone (at least 1 km around the infested zone) in the year of the outbreak

5.43. If no infestation is found in protected host crops growing in the buffer zone following surveillance, they should continue to be monitored with the use of pheromone traps. A programme of foliar insecticides (including biopesticides) until harvest and a crop-free period between crops is also advised, but not statutory. The programme of foliar insecticide treatments should be within legally specified safe use guidelines and compatible, where possible, with any existing biological control programmes.

Disposal plan

5.44. When deciding on the most appropriate method(s) of disposal, several factors need to be taken into account such as the likelihood of the more mobile adults being present, the level of handling and transportation required and the climatic conditions. For all methods, measures need to be taken to ensure that there is no risk of spread during transport, treatment or disposal. This may include keeping the distance of travel to a minimum. Material that can be moved safely should be destroyed by incineration at a licensed facility (if in small quantities) or by deep burial. Disposal and/or destruction should be under the approval of the PHSI through a statutory plant health notice, with any supervision decided on a case by case basis. If the material has to be moved off the premises, it should be contained within at least two layers if possible, and placed in a sealed vehicle for transport. Deep burial may be done at an approved landfill site, on the outbreak site or another suitable site nearby, but only in agreement with the local Environment Agency. Incineration must comply with appropriate waste management regulations i.e. as specified by the Environment Agency in England.

5.45. Other viable methods of destruction should be agreed by the IMT.

6. Criteria for declaring eradication / change of policy

6.1. *Thaumatotibia leucotreta* can be declared eradicated (by the Chief Plant Health Officer) if it has not been found for a period allowing for at least two lifecycles under the prevailing conditions after the infested crop has been removed.

7. Evaluation and review of the contingency plan

7.1. This pest specific contingency plan should be reviewed regularly in order to consider any changes in legislation, control procedures, pesticides, sampling and diagnosis methods, and any other relevant amendments.

7.2. Lessons should be identified during and after any outbreak (of *T. leucotreta* or other pest), including what went well and what did not. These should be included in any review of the contingency plan leading to continuous improvement of the plan and response to outbreaks.

8. Appendix A

Data sheet for *Thaumatotibia leucotreta*

Identity

PREFERRED SCIENTIFIC NAME	AUTHOR (taxonomic authority)
Thaumatotibia leucotreta	(Meyrick, 1913)

KINGDOM: Metazoa

PHYLUM: Arthropoda

CLASS: Insecta

ORDER: Lepidoptera

SUPERFAMILY: Tortricoidea

FAMILY: Tortricidae

SUBFAMILY: Olethreutinae

TRIBE: Grapholitini

SYNONYMS

Argyroploce leucotreta (Meyrick, 1913)

Cryptophlebia leucotreta (Meyrick, 1913)

Thaumatotibia roerigii (Zacher, 1915)

COMMON NAMES

False codling moth (English)

Citrus codling moth (English)

Orange codling moth (English)

Orange moth (English)

Faux carpocapse (French)

Palomilla de la naranja (Spanish)

Teigne de l'oranger (French)

Notes on taxonomy and nomenclature

Thaumatotibia leucotreta is a member of the moth family Tortricidae, which contains more than 11300 described species (Gilligan *et al.* 2018), some of which are economically important plant pests. In general appearance, the adults are small drab moths with a wingspan of between 1 and 3.3 cm (BAMONA, 2019). First described under the name *Argyroploce leucotreta* (Meyrick, 1913) from a single female specimen collected near Pretoria, South Africa, this species was again described under the now junior synonym *Thaumatotibia roerigii* (Zacher, 1915) (the type for the genus *Thaumatotibia*) from material collected in Togo. Subsequently and for many years it was referred to by the name *Cryptophlebia leucotreta*, but in 1999 it was formally transferred into the genus *Thaumatotibia* (Komai, 1999, as cited in CABI, 2019). *Thaumatotibia* is a small genus currently containing 25 species. Of these, 13 species including *T. leucotreta* were described from specimens collected in Africa and some of the nearby islands; the remaining species are described from Asia (4), Australia (3), and Oceania (5) (Gilligan *et al.* 2018).

Biology and ecology

Life history

Adults of *T. leucotreta* are nocturnal, and generally spend the day hidden within shaded portions of a host plant (Ostoja-Starzewski *et al.*, 2017). At night, females attract males by emitting a pheromone, which peaks in abundance after 8 hours of darkness (Levi-Zeda *et al.*, 2019). After mating, females lay eggs at irregular intervals either singly or in groups on fruit, foliage or smooth surfaces (USDA, 2010). The optimum temperature for egg laying is 25°C, but eggs can be laid at any temperature above 10°C (Daiber, 1980). Over their 16 - 70 day lifespan, females lay on average 87-456 eggs but can produce as many as 800 eggs (Gilligan and Epstein *et al.*, 2014; Ostoja-Starzewski *et al.*, 2017). Males have a shorter lifespan of 14-57 days (Plant Health Australia Ltd, 2015).

Eggs hatch 2-22 days after being laid (depending on the temperature) and the emergent first instar larvae burrow through the outer surface of fruit, nuts and seeds, leaving a small entry hole of about 1 mm in diameter (EPPO, 2013; Plant Health Australia Ltd, 2015). Larvae continue to feed internally, developing through five larval instars over 12-67 days (USDA, 2010). Younger larvae feed near the surface, whereas older larvae feed towards the centre. When mature, the final instar larvae exit the fruit and lower themselves to the ground using a silken thread (Ostoja-Starzewski *et al.*, 2017). The larvae then spin a cocoon and enter a pre-pupal stage in soil, bark crevices or fruit debris, which lasts for 2-27 days (USDA, 2010). They subsequently pupate and form a new cocoon, before emerging as adults 11-47 days later (Ostoja-Starzewski *et al.*, 2017).

The complete lifecycle of *T. leucotreta* takes between 30 and 174 days to complete depending on the temperature (Ostoja-Starzewski *et al.*, 2017). In warmer climates, this species is capable of producing several generations per year, usually 2-5, but as many as 10 generations per year have been recorded in culture (Gilligan and Epstein, 2014; Ostoja-Starzewski *et al.*, 2017). Diapause has not been reported for *T. leucotreta*, and was not induced in an experimental study by Terblanche *et al.* (2014).

Hosts/crops affected

Thaumatotibia leucotreta is a polyphagous pest, the larvae of which have been recorded feeding on more than 70 plant species from 40 families (EPPO, 2011). Hosts considered to be of major importance are listed in table 1, and include species of significance to the UK, namely *Capsicum* spp. (sweet and chili pepper), *Quercus robur* (oak), *Solanum melongena* (aubergine), *Vitis vinifera* (grape), and *Zea mays* (maize). Of these, only protected crops of *Capsicum* spp. and *S. melongena* are likely to be at risk, as *T. leucotreta* is not considered to be able to establish outdoors in the UK (Korycinska, 2016). Given the wide host range of *T. leucotreta*, other plant species grown under protection that have not previously been exposed to the moth may also be susceptible, even though they are not currently recorded as hosts.

Extensive host lists for *T. leucotreta* can be found on the EPPO Global Database (https://gd.eppo.int/taxon/ARGPLE/hosts) and Browne *et al.* (2014).

Table 1. Hosts of major importance for *T. leucotreta* (EPPO, 2020).

Host species	Common name	Family
Capsicum annuum	Sweet pepper	Solanaceae
Capsicum chinense	Chili pepper	Solanaceae
Citrus paradisi	Grapefruit	Rutaceae
Citrus reticulata	Mandarin orange	Rutaceae
Citrus sinensis	Orange	Rutaceae
Gossypium hirsutum	Cotton	Malvaceae
Litchi chinensis	Litchi	Sapindaceae
Macadamia integrifolia	Macadamia	Proteaceae
Macadamia ternifolia	Small-fruited Queensland nut	Proteaceae
Mangifera indica	Mango	Anacardiaceae
Persea americana	Avocado	Lauraceae
Prunus persica	Peach	Rosaceae
Punica granatum	Pomegranate	Lythraceae
Quercus robur	Oak	Fagaceae
Ricinus communis	Castor oil plant	Euphorbiaceae
Solanum melongena	Aubergine	Solanaceae
Vitis vinifera	Grape	Viticeae
Zea mays	Maize	Poaceae

Plant stage affected

Fruiting and flowering stage.

Plant parts affected

Fruit (nuts, pods, seeds, grain heads, and berries) and flower buds

Symptoms/signs - description

Fruit

On hatching, the larvae of *T. leucotreta* penetrate the skin of the fruit, leaving a small hole approximately 1mm in diameter that later oxidises turning yellowish-brown to brown as the tissues decay and collapse (Figure 2; EPPO, 2011; Ostoja-Starzewski *et al.*, 2017). Once inside the fruit, larvae preferentially feed on the seeds before boring tunnels into the flesh and in the process produce copious amounts of frass. When mature they leave the fruit, produce a new exit hole, which will similarly oxidise and discolour in time (Figure 3, 4; EPPO, 2019; Ostoja-Starzewski *et al.*, 2017). Entry and exit holes made by the larvae can facilitate the ingress of secondary pathogens, which can accelerate the deterioration of the fruit (Ostoja-Starzewski *et al.*, 2017). The damage caused by the larvae on growing fruit can also result in premature ripening and fruit drop (EPPO, 2011; Martin *et al.*, 2012, as cited in DROPSA, 2016).

Maize

Larvae enter the husk through the silk channel, and damage the developing seed head (USDA, 2010).

Cotton

Larvae tunnel in the walls of the bolls, before feeding on the seeds (EPPO, 2011). A characteristic symptom of larval presence is a filamentous waxy secretion, which effuses from entrance holes (EPPO, 2011).

Macadamia

Larvae enter the husk and feed on the developing kernel of the nut (USDA, 2010).

Rose

Holes can be seen on the petals, and frass can be observed within the buds (Figure 5, 6; EPPO, 2019).

Figure 2. Damaged oranges, with characteristic brown spots ringed by a yellow halo. J. H. Hofmeyr, Citrus Research International, Bugwood.org. Licensed under a [Creative Commons Attribution-Noncommercial 3.0 License](#).

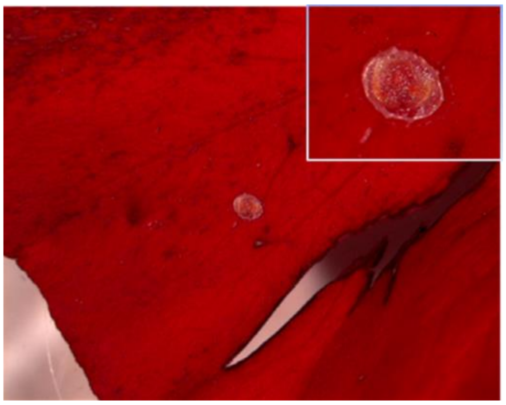
Figure 3. Internal larval feeding damaged in orange fruit. J. H. Hofmeyr, Citrus Research International, Bugwood.org. Licensed under a [Creative Commons Attribution-Noncommercial 3.0 License](#).

Figure 4. Two dead larvae inside a grape from South Africa, and right external condition of grape. © Fera Science Ltd.

Figure 5. Damage inside a rose flower. The image courtesy of Marja van der Straten, National Reference Centre, National Plant Protection Organisation (NL).

Figure 6. Frass in a rose. The image courtesy of Marja van der Straten, National Reference Centre, National Plant Protection Organisation (NL).

Morphology (As provided in EPPO (2019), unless stated otherwise)

Egg: Oval and flattened. Translucent in colour, but later turning orange, with the dark head of the larvae visible before hatching. The mean length and width of the egg is described by EPPO (2019) as being 0.77 and 0.60 mm, respectively, though other sources report sizes between 0.5 and 1 mm (Hoop, 2018; USDA, 2010). The image is courtesy of Marja van der Straten, National Reference Centre, National Plant Protection Organisation (NL).	
Larva: Early instars (1-2) are whitish, with a dark head and dark spots, and are 1-2 mm in length. Later instars (3-5) are orange-pink, with the last instar turning dark pink, and have a brown head and thoracic shield. Fully mature larvae are approximately 7-10 mm long. Lengths of between 12 and 20 mm have also been reported by Ostoja-Starzewski *et al.* (2017), Plant Health Australia Ltd (2015) and USDA (2010). The image is courtesy of Marja van der Straten, National Reference Centre, National Plant Protection Organisation (NL).	
Pupa (described by Komai, 1999, as cited in EPPO, 2019; Timm *et al.*, 2007): Medium brown and is 7.9 – 9.8 mm long. Abdominal segments 2-7 have two rows of dorsal spines; the spines of the anterior row are coarse and the spines of the posterior row are fine. Abdominal segments 8-9 have one row of dorsal spines in females, but only segment 9 has a row of dorsal spines in males. Abdominal segment 10 has several pairs of strong projections. The image is courtesy of Marja van der Straten, National Reference Centre, National Plant Protection Organisation (NL).	
Adult: The length of the body is about 7-8 mm (Ostoja-Starzewski *et al.*, 2017), and males and females have a wingspan of 15-16 mm and 19-20 mm, respectively. The forewing shape is also different between males and females. In the former, it is triangular with an acute apex, while in the latter, it	

is more elongate with a rounded apex. Conversely, the pattern of the forewing is similar between the sexes. There is a small white dot near the end of the discal cell; there are often raised, rust or orange coloured scales near the middle of the wing; a question mark '?' shaped band of dark scales toward the end of the wing (on the termen); and there is a semi-circular band of dark scales in the middle of the costa (anterior end of the wing). The hindwing of males is distinct from the females in that it has a semi-circular keyhole shaped pocket of opalescent scales. Image of female courtesy of Todd M. Gilligan and Marc E. Epstein, TortAI: Tortricids of Agricultural Importance, USDA APHIS PPQ, Bugwood.org. Licensed under https://creativecommons.org/licenses/by-nc/3.0/us/.	

Detection and inspection methods

Visual inspection

Fruit can be inspected externally for holes, eggs, discolouration, premature ripening, decay and fruit drop (in growing crops) and crawling larvae (EPPO, 2013; USDA, 2010). These external symptoms and signs of infestation are initially inconspicuous. Eggs are well camouflaged, less than 1 mm in diameter and occur singly or in small groups; larval entry holes are only up to 1 mm in diameter and take time to oxidise before becoming noticeable; and the majority of damage is hidden within the confines of the fruit (particularly early on in an infestation). Cutting open fruit to look for larvae and internal damage is therefore advised (EPPO, 2013; USDA, 2010). In addition larvae remain within the fruit until mature and appear only briefly before descending the plant to pupate (EPPO, 2013; USDA, 2010).

Arendse *et al.* (2018) has explored microfocus X-ray computed tomography as a further visual inspection technique for *T. leucotreta*. They found that the density of whole fruit and fruit fractions (arils and albedo) was significantly higher than larvae in pomegranate fruit, and could potentially be used for the detection of the moth. However, this has only been investigated in pomegranate, and is likely to be limited in where it can be used.

Soil sampling

Samples of surface soil and soil debris can be taken to locate larvae, cocoons and pupae (USDA, 2010). The USDA recommends that samples are taken within 200 yards of any egg and/or larval infestation and nearby to any dropped, particularly prematurely dropped, fruit (USDA, 2010).

Trapping

Delta traps have performed well in various studies and are recommended by the USDA for trapping *T. leucotreta* (La Croix and Hall, 1985; Newton and Mastro, 1989; USDA, 2010). Although, when Levi-Zeda *et al.* (2019) compared funnel traps with delta traps, funnel traps performed better. Newton and Mastro (1989) also demonstrated that wing traps are effective for catching the moth. When different colour delta traps were compared, colour was not considered to be an important factor (Newton and Mastro, 1989). Further work also showed traps to be more attractive higher in the canopy when tested in a citrus plantation (Levi-Zeda *et al.*, 2019).

The female *T. leucotreta* moth emits a pheromone to attract males, and traps can be augmented with pheromone lures to improve capture rates. The first report of the *T. leucotreta* female pheromone claimed that (E)-7-dodecenyl acetate was the sole component (Read *et al.*, 1968, as cited in Levi-Zeda *et al.*, 2019), but more recent studies have identified different components, and as many as 11 (Levi-Zeda *et al.*, 2019). The two most important components with respect to male attractiveness are (E)-8-dodecenyl acetate and (Z)-8-dodecenyl acetate (Levi-Zeda *et al.*, 2019). Various studies have identified different ratios depending on the population; work on populations of moths from the Ivory Coast identified a ratio of 3:1 (E/Z) (Angelini *et al.*, 1981 and Zagatti *et al.*, 1983, as cited in Levi-Zeda *et al.*, 2019), work on populations of moths from Malawi identified a ratio of 2:3 (Hall *et al.*, 1984, as cited in Levi-Zeda *et al.*, 2019), and work on populations of moths from Israel identified a ratio of 9:1 (Attygalle *et al.*, 1986, as cited in Levi-Zeda *et al.*, 2019; Levi-Zeda *et al.*, 2019). Levi-Zeda *et al.* (2019) also demonstrated that ratios of 9:1 and 19:1 were more attractive than a ratio of 8:2.

Distribution

Thaumatotibia leucotreta is native to Africa, where it is widely distributed south of the Sahara (Newton, 1998, as cited in USDA, 2010). Up to date distribution data can be found on the EPPO Global database, available here - https://gd.eppo.int/taxon/ARGPLE/distribution.

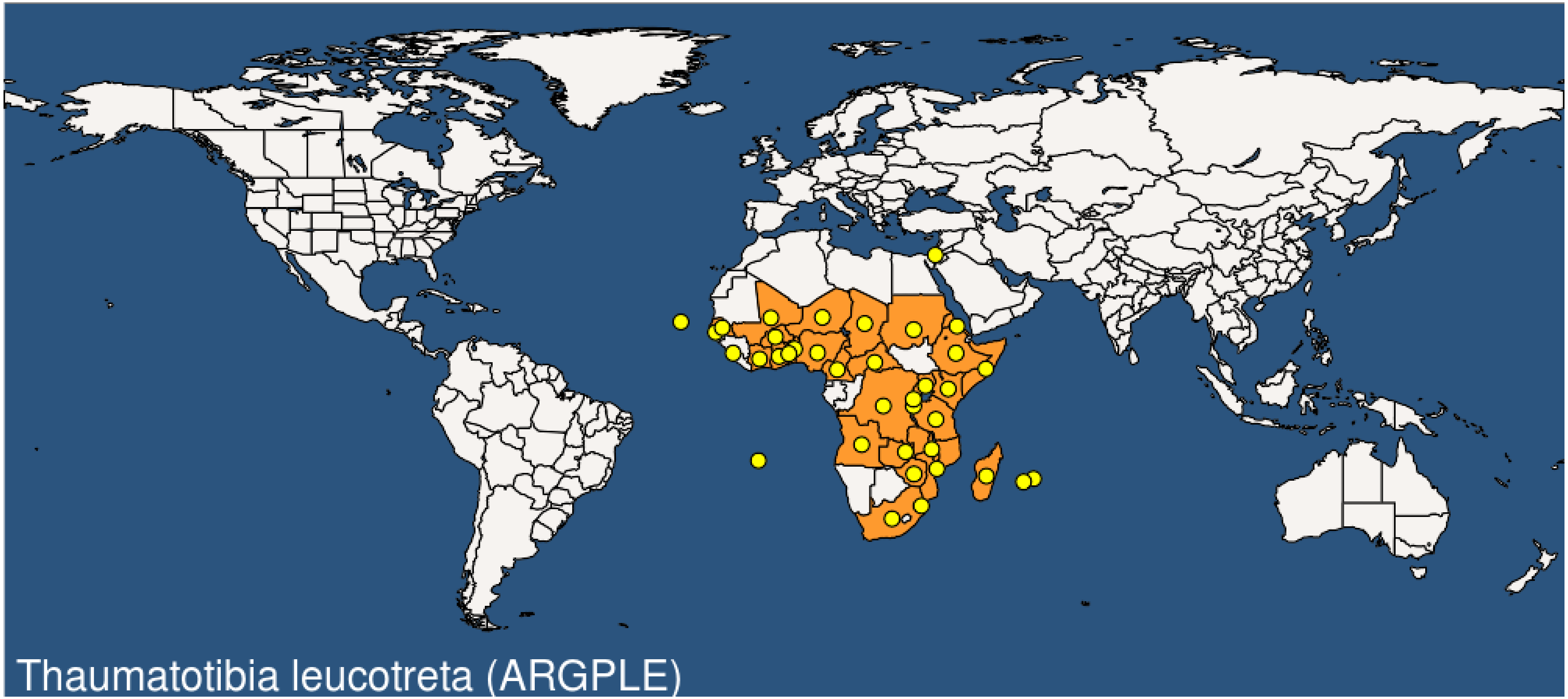


Figure 7. Distribution map for *Thaumatotibia leucotreta* as of August 2022. (Source EPPO Global Database). The link below provides up to date distribution data. https://gd.eppo.int/taxon/ARGPLE/distribution

History of introduction and spread

Global spread

Thaumatotibia leucotreta is native to Africa, where it is widely distributed south of the Sahara (Newton, 1998, as cited in USDA, 2010). Outside of Africa, it is only present in Israel, where it was first reported in 1984 on macadamia nuts (EPPO Reporting Service, 2003). While the growth of macadamia nuts for commercial purposes was stopped soon after, the moth was still able to persist in areas of cotton and castor bean as of 2003, and more recently it has been recorded from coastal areas between Ashdod and Hadera (EPPO Reporting Service, 2003, Opatowski personal communication, 2012, as cited in EPPO, 2013). Following its introduction into Israel, the moth temporarily established in Europe, in Germany and the Netherlands, and has been frequently intercepted in other European countries, but it is now considered to be absent from the continent (EPPO Reporting Service 2010, 2014, 2018, 2019). The moth has similarly been intercepted numerous times in the US, but it has yet to establish in the country (Plant Health Australia Ltd, 2015).

The Netherlands

Thaumatotibia leucotreta was first detected in October 2009, when a larva was found inside a deformed *Capsicum chinense* fruit in a glasshouse (EPPO Reporting Service, 2010). *Capsicum* fruit originating from Uganda was regularly processed and packed in a packaging area associated with the glasshouse, and it is thought that this may have been the route of entry (EPPO Reporting Service, 2010). Eradication measures were taken against the moth (EPPO Reporting Service, 2010).

In October 2013, there was a second finding of *T. leucotreta* in a greenhouse of *Capsicum annuum* in Honselersdijk (EPPO Reporting Service, 2014). As with the previous finding, eradication measures were taken, which in this case included the use of pheromone traps, application of insecticides and the controlled disposal of waste (EPPO Reporting Service, 2014). A survey was also carried out over a 2 x 3 km area from the infested site, covering 29 companies (EPPO Reporting Service, 2014). There were no subsequent findings and the moth was declared eradicated (EPPO Reporting Service, 2014).

Germany

In June 2018, a single male was caught in a pheromone trap in a glasshouse producing sweet pepper in Saxony (EPPO Reporting Service, 2018). It is hypothesised that the moth spread from a container of fruit and vegetable waste at a nearby supermarket (EPPO Reporting Service, 2018). Official phytosanitary measures were taken and a survey was carried out between September 2018 and May 2019 (EPPO Reporting Service, 2018, 2019). The moth was not found during these surveys and was subsequently declared eradicated (EPPO Reporting Service, 2019).

Phytosanitary status

Thaumatotibia leucotreta is a GB quarantine pest (Schedule 1 of The Plant Health (Phytosanitary Conditions) (Amendment) (EU Exit) (Regulations) 2020) and is therefore prohibited from being introduced into, or spread within GB. It is also present on a number of other phytosanitary lists (Table 1).

Table 1. Global phytosanitary categorisation of *Thaumatotibia leucotreta* (EPPO, 2020).

Country/NPPO/RPPO	List	Year of addition
AFRICA		
East Africa	A2 list	2001
Egypt	A1 list	2018
Morocco	Quarantine pest	2018
Southern Africa	A2 list	2001
AMERICA		
Argentina	A1 list	2019
Brazil	A1 list	2018
Canada	Quarantine pest	2019
Chile	A1 list	2019
Mexico	Quarantine pest	2018
Paraguay	A1 list	1992
USA	Quarantine pest	1989
Uruguay	A1 list	1992
ASIA		
Israel	Quarantine pest	2009
Jordan	A1 list	2013
EUROPE		
GB	Quarantine Pest	2020
Turkey	A1 list	2016
OCEANIA		
New Zealand	Quarantine pest	2000
RPPO		
APPPC	A1 list	1988

COSAVE	A2 list	2018
EPPO	A2 list	2013
OIRSA	A1 list	1992
PPPO	A1 list	1993

Means of movement and dispersal

Natural dispersal

Thaumatotibia leucotreta is not considered to be a strong flyer, and populations tend to remain highly localised (EPPO, 2011). In a study by Stotter (2009), as cited in EPPO (2013), for example, moths tended to cluster in citrus orchards in the Citrusdal area of South Africa, and where moths were found outside, most of them remained close to the orchards or to identified alternative host plants. Newton (1998), as cited in Potting and Straten (2010), also showed only short distance movement of the moth in South Africa, and Timm (2005) showed that regional populations were genetically distinct, even for populations in orchards that were close together.

While dispersal is generally limited, Stotter (2009), as cited in EPPO (2013), caught some males 1.5 km away from infested orchards, and Omer-Cooper (1939), as cited in EPPO (2013), observed males to move to females more than 1 km distant. Populations of the moth up to 6 km apart in the urban area of Retreat also showed gene flow, though this is not considered to be representative, as urban areas are more variable habitats than orchards (Timm, 2005).

With respect to the UK situation, where the moth is only likely to establish under protection, it is thought that natural dispersal between glasshouses is unlikely to be significant, unless the crop is removed or repellent insecticides are used (Potting and Straten, 2010).

Human assisted spread

Long distance spread

Eggs and larvae of *T. leucotreta* are associated with fruit (nuts, pods, seeds, grain heads, and berries) and flower buds. As only hosts under protection are likely to be at risk in the UK, nuts, maize ears and cotton bolls are not considered pathways for the moth (Korycinska, 2016). *Rosa* plants for planting are also prohibited from third countries, other than dormant plants free from leaves, flowers and fruit (EU, 2019), and is therefore not considered a pathway given the current distribution of the moth. It has been intercepted multiple times on imported *Rosa* cut flowers in the Netherlands (107 times between 2004 and April 2013), but only twice on this commodity in the UK between 2007 and 2020. The pathway from cut flowers to indoor rose production is also thought to be small (EPPO, 2013). Major fruit hosts of the moth that are present under protection in the UK, namely

Capsicum spp. and *Solanum melongena*, therefore present the most risk of introducing the moth.

Capsicum spp. and *S. melongena* plants for planting are prohibited from third countries outside of Europe and the Mediterranean, but this does not include Israel (EU, 2019). Fruit, which is not prohibited from any of the moth's range, is considered to be even more of a risk, due to the pathway from infested fruit packed on the same site as production facilities (Korycinska, 2016). This risk is reduced by EU measures requiring that fruit of *Capsicum* spp. from countries of the African continent, Cape Verde, Saint Helena, Madagascar, La Reunion, Mauritius and Israel must originate from either a country free of *T. leucotreta*, an area free of *T. leucotreta*, a place of production free of *T. leucotreta*, or have been subjected to an effective cold treatment, systems approach or post-harvest treatment to ensure freedom of *T. leucotreta* (EU, 2019). Despite these measures, *T. leucotreta* is still regularly intercepted on *Capsicum* spp. in the EU and in the UK (EU, 2020; Table 3).

Table 2. Confirmed interceptions of *T. leucotreta* in England between 30 April 2007 and November 2021.

Host genus	Number of interceptions	% of findings
Capsicum	766	90.54
Citrus	31	3.66
Solanum	22	2.60
Zea	10	1.18
***Annona*.**	5	0.59
Prunus	3	0.35
Rosa	2	0.234
Persea	2	0.23
Momordica	1	0.111
Punica	1	0.11
Vaccinium	1	0.11

Control

Cultural controls and sanitary methods

Resistance

There are currently no varieties or cultivars of host plants that are considered to be resistant to *T. leucotreta* (Plant Health Australia Ltd, 2015). However, the damage caused by the moth to different cultivars is not always uniform. In a study by Love et al. (2014), early season cultivars of navel oranges (Fischer Navels) were preferred for oviposition and were the most susceptible to larval penetration, in contrast to mid and late season cultivars. Late season Cambria and Glen Ora were also less susceptible to larval penetration than mid-season Palmer Navels.

Crop management

A number of crop management methods are available for *T. leucotreta* such as sourcing material from reputable, accredited suppliers, and using certified material (Plant Health Australia factsheet). Other methods include:

Crop rotation (Plant Health Australia Ltd, 2015)

Selecting crops that mature before the pest emerges (Plant Health Australia Ltd, 2015). For example, one study showed that early sown cotton crops were less affected than late sown cotton crops (Reed, 1974, as cited in Plant Health Australia Ltd, 2015).

Removing weeds that can act as reservoirs for the moth (Plant Health Australia Ltd, 2015)

Good hygiene practice to reduce the spread of potentially infested plant material across a site (Plant Health Australia Ltd, 2015). This could include cleansing and disinfecting equipment and machinery in a designated wash down area prior to movement (Plant Health Australia Ltd, 2015)

Destroying crop residue and regularly removing fruit (Plant Health Australia Ltd, 2015; Moore and Kirkman, 2009, as cited in EPPO, 2013)

Monitoring the crop for signs and symptoms of the moth (Plant Health Australia factsheet)

Trap crops e.g. maize has been used to reduce moth damage in Ugandan cotton crops (Reed, 1974, as cited in Plant Health Australia Ltd, 2015)

Using pheromones for mating disruption (ISOMATE and CHECKMATE-FCM) and attract and kill (LAST CALL-FCM) (Potting and Straten, 2010)

Using non-permanent netting, which has been shown to reduce trap catches of T. leucotreta in mandarin (Stander et al., 2019)

Post-harvest treatments

In the 1960s, a series of studies commenced, which eventually identified a post-harvest cold treatment for T. leucotreta in citrus fruit of -0.6°C for 22d (Myburgh, 1963, as cited in Hofmeyr et al., 2016). This regime was later adopted by South Africa for the export of citrus fruit to the USA, South Korea and China (Hofmeyr et al., 2016). Effective cold treatment regimens have also been identified for grapes (20d at 0.8°C and 18d at -0.6°C, no survivors) and avocado (20d at 2°C, 1 survivor) (Ware and Du Toit, 2016, 2018). In addition, Moore et al. (2016) investigated the use of a partial cold treatment of 18d at 2°C as part of a systems approach in citrus fruit. The treatment regime resulted in a mortality rate of 99.94% in fourth and fifth instar larvae, which are considered to be the most cold tolerant life stages. The efficacy of the treatment was further enhanced to 99.99% when the inability of survivors to develop to adult and/or reproduce and produce viable offspring were considered.

While cold treatments have been readily used as a post-harvest treatment, some fruits, including lemon, lime and ‘marsh’ grapefruit, are highly susceptible to chilling injury (Kays and Paull, 2004, as cited in Hofmeyr et al., 2016). Ionising radiation has therefore been investigated as an alternative treatment. Initial experiments showed that larvae were unable to develop into moths at between 200 and 400 GY (Hofmeyr, unpublished, as cited by Hofmeyr et al., 2016b). Subsequent experiments at 100 GY showed that 49.4% of larvae were unable to survive to pupation, 85.6% of larvae were unable to survive to eclosion, and, of those that did develop to adulthood, none of them could fly or produce eggs (Hofmeyr et al., 2016). As with cold treatments, high levels of ionising radiation can damage the fruit (Hofmeyr et al., 2016c). Lower levels of ionising radiation in combination with a cold treatment have therefore also been explored. These experiments identified a treatment of 60 GY followed by 16d at 2.5°C as having potential (Hofmeyr et al., 2016c).

Controlled atmosphere temperature treatments have also been investigated as a post-harvest treatment option, with some success (Johnson and Neven, 2010; Smit et al., 2018).

Biological control

Predators

When nests of the generalist ant species *Anoplolepsis custodiens* and *Pheidole megacephala* were poisoned in citrus orchard plots, pupae of *T. leucotreta* survived better than in untreated control plots (Bownes et al., 2014). Management methods that preserve these ant species have therefore been recommended for the control of the moth (Bownes et al., 2014). *Orius* sp. and *Rhynocoris albopunctatus* have also been reported as predators of *T. leucotreta* (Bedford et al., 1998, as cited in Malan et al., 2018).

Parasitoids

Trichogrammatoidea cryptophlebiae and *Agathis bishopi* are considered to be effective parasitoids of *T. leucotreta*. *Trichogrammatoidea cryptophlebiae* has recorded parasitism rates of greater than 80% in citrus orchards and may be commercially available (Moore and Hattingh, 2012, as cited in Kaspi et al., 2018; VitalBugs, 2008), while *A. bishopi* has recorded parasitism rates of between 11.43 and 38% (Gendall, 2007; Sishuba, 2003; Zimba et al., 2016). Other reported parasitoids include *Apophua leucotretae, Chelonus curvimaculatus, Trichogrammatoidea fulvum, T. lutea, Trichogramma danausicida* and *T. cacaeciae* (CABI, 2019; Kaspi et al., 2018).

Entomopathogenic nematodes

In laboratory studies, *Steinernema yirgalemense* has been particularly virulent against *T. leucotreta*, killing up to 100% of larvae (Malan et al., 2011; Steyn et al., 2017). *Heterorhabditis bacteriophora*, which is commercially available, *Heterorhabditis zealandica* and *Steinernema litchii* have also performed well in the laboratory (Malan et al., 2011; Steyn et al., 2017). In semi-field trials, *S. yirglaemense* has continued to excel (Steyn et al., 2019), and *H. bacteriophora* and *H. zealandica* have also proven effective, causing larval mortality of > 95% and > 80%, respectively (Malan and Moore, 2016). In these semi-field trials, nematodes persisted for at least 14 days and longer in some cases (Malan and Moore, 2016; Steyn et al., 2019). *Heterorhabditis zealandica* has also provided good control under natural conditions; in a citrus orchard in the Nelspruit area, naturally high populations of *H. zealandica* reduced the level of moth infested fruit by ~59%, compared to when a nematicide was applied (Manrakhan et al., 2014, as cited in Malan et al., 2018).

Bacteria

In a study by Li and Bouwer (2012), six *Bacillus thuringiensis* Cry proteins were evaluated for their efficacy against *T. leucotreta*: Cry9Aa, Cry1Ca, Cry1Ac, Cry2Aa, Cry1Aa and Cry1Ab. Of these, Cry2Aa and Cry1Ac caused significantly higher larvicidal activity against neonate larvae of the moth, while Cry9Aa and Cry1Ca caused significantly lower larvicidal activity. In the UK, there are a number of commercially available *B. thuringiensis* products for use in a multitude of different crops (HSE, 2020).

Viruses

The *Cryptophlebia leucotreta granulovirus* (CrleGV) was first discovered in the Ivory Coast by Angelini et al. (1965), as cited in Malan et al. (2018). Further isolates of the granulovirus were described and characterised from Cape Verde and South Africa (Malan et al., 2018). The isolate CrleGV-SA was developed into the commercial product Cryptogran (Moore et al., 2004, as cited in Malan et al., 2018), and another isolate was developed into the commercial product Cryptex (Malan et al., 2018). The granulovirus has been effective in a number of trials, with moth larval infestation being reduced by 30-92%, and efficacy continuing at 70% for 17 weeks in some cases (Moore et al., 2015). In trials using Cryptogran and/or Cryptex, Cryptogran has been consistently more effective than Cryptex, and is likely to be due to the higher concentration of occlusion bodies in the product, which is 7.6 x higher than in Cryptex (Malan et al., 2018). Although, it is also possible that local populations of the moth are differentially susceptible to the different isolates of the virus (Malan et al., 2018). Opoku-Debrah et al. (2013a), for example, showed that *T. leucotreta* larvae from the Addo Region, South Africa, were more susceptible to the isolate in Cryptogran than Cryptex. Given this possibility, there is value in finding more isolates that may be more effective than the commercial isolates, as well as finding substitutes for the commercial isolates should the moth develop resistance. Opoku-Debrah et al. (2013b) attempted just this and recovered five new isolates (CrleGV-SA Ado, Crle-SA Mbl, Crle-SA Cit, CrleGV-SA MixC, and CrleGV-SA Nels) from geographically distinct moth populations, which could be used in future research.

Fungi

Laboratory studies have shown *Beauveria bassiana, Metarhizium anisopliae* and *M. brunneum* to be effective against *T. leucotreta* (Goble et al., 2011; Mkiga et al., 2020; Mondaca et al., 2020). These results have been confirmed in commercial orchards for *B. bassiana* and *M. anisopliae*, with their application reducing pest infestation by 28-82% (Coombes et al., 2016). These two species are also able to persist in the soil for up to 6 months (Coombes et al., 2013). In the UK, *B. bassiana* and *M. anisopliae* are commercially available for use on a number of different crops (HSE, 2020).

Sterile insect technique (SIT)

The sterile insect technique involves sterilising males using ionising radiation and releasing them en masse to flood the wild population. Any wild females that mate with these sterile males will subsequently lay sterile eggs, suppressing the build-up of the target pest population (Knipling, 1955, as cited in Malan et al., 2018). Semi-field trials of the SIT in the Citrusdal area, South Africa, in 2005-2006 reduced crop losses due to *T. leucotreta* by 95.2% (Hofmeyr et al., 2016d). The SIT programme for *T. leucotreta* was then commercialised in 2007, and was rolled out in the Citrusdal area for three years until 2010 (Hofmeyr et al., 2015). By the third year, wild populations of the moth had been reduced by 10-fold, pre-harvest crop losses had decreased by 93%, and post-harvest fruit rejections had fallen by 38%. Since the inception of the SIT programme in the Citrusdal area, it has now expanded to include the Sundays River and the Cam toos River Valleys in the Eastern Cape Province, the Hex River Valley in the Western Cape Province, and the Lower Orange River area in the Northern Cape Province (Hofmeyr et al., 2019). Beneficially, the SIT is also complementary with other forms of biological control. Carpenter (2004), for example, showed that *T. cryptophlebiae* could accept, develop in, and emerge from eggs laid by sterile females or females that had mated with sterile males.

Chemical control

Thaumatotibia leucotreta is difficult to control using insecticides alone, as the majority of its lifecycle is protected within the fruit and it has overlapping generations (EPPO, 2011; Ostoja-Starzewski et al., 2017). In South Africa, insecticides are still used, however, and those registered against the moth are listed in table 4.

Table 4. Insecticides registered for use in South Africa against *Thaumatotibia leucotreta* (Plant Health Australia Ltd, 2015).

Insecticide	Registered use	Approved for use in GB	Comments
Alpha cypermethrin	Peach	Yes	
Azinphos-methyl	Peach	No	
Beta-cyfluthrin	Peach	No	
Beta-cypermethrin	Peach and plum	No	
Chlorantraniliprole	Citrus	Yes	Females oviposited significantly fewer eggs than controls in detached fruit bioassays. The reproductive output of females was also affected during topical insecticide trials (Fullard and Hill, 2013).
Cypermethrin	Peach and plum	Yes	
Fenpropathrin	Citrus	No	
Methomyl	Peach	No	
Methoxfenozide	Various types of orchard	No	
Novaluron	Orange	No	
Permethrin	Traps	No	Permethrin is used with a pheromone in an attract and kill strategy (Insect Science, 2017). The attract and kill strategy works more effectively at lower population sizes, as at higher population sizes, some males will miss the insecticide and reproduce (Hofmeyr, 2003 and Pedigo and Rice, 2006, as cited in Kirkman, 2007).
Spinetoram	Citrus, persimmon, pomegranate and stone fruit	No	Females oviposited significantly fewer eggs than controls in detached fruit bioassays (Fullard and Hill, 2013).
Triflumuron	Citrus and peach	No	Triflumuron is able to provide good control of *T. leucotreta* (Hofmeyr and Pringle, 1998; Newton, 1987).

Neem (*Azadirachtin indica*) has also been shown to be effective against the moth, and as effective as some synthetic insecticides (Bonni *et al.*, 2018).

Thaumatotibia leucotreta can develop resistance if these insecticides are used too frequently, as observed for triflumuron (Hofmeyr and Pringle, 1998). Populations of the moth from Citrusdal and Swellendam, where triflumuron was regularly used, were shown to require 9.63 and 3.27 x more chemical to register similar levels of mortality to susceptible populations of the moth.

Impacts

Economic impact

Thaumatotibia leucotreta is a damaging pest throughout Africa and its nearby islands (EPPO, 2013). In South Africa, for example, Moran (1983), as cited in EPPO (2013), ranked the moth as the 33rd most important phytophagous pest and the 14th most important lepidopteran pest. Bell and McGeoch (1996), later ranked the moth even higher, as the 9th most important lepidopteran pest.

Economic damage has been reported across a number of different crops, as outlined below.

Citrus

In the Citrusdal area of Western Cape, South Africa, yield losses of 10-20% were recorded (van der Geest *et al.*, 1991, as cited in Potting and Straten, 2010). Likewise, in Eastern Transvaal Lowveld, South Africa, yield losses of 7.8% and 16.8% were reported in Navel orange orchard trials in 1975-76 and 1976-77, respectively, when no control measures were applied (EPPO, 2013). When control measures were applied, however, yield losses were only 0.72% (Schwartz, 1978, as cited in EPPO, 2013). While there is some variability across regions and studies, as of 2004, the moth was reported to cost the South African citrus industry €10.5 million per year (Moore *et al.*, 2004, as cited in EPPO, 2013). Outside of South Africa, damaging symptoms were reported on 2.88 – 42.16% of fruit samples either taken from the ground, after trees were shaken or when trees were not shaken, in orange crops in Kenya and Tanzania (Mkiga *et al.*, 2019).

Peach

In the Transvaal area, South Africa, in the early 1970s, yield losses of 29% on average and up to 55% were reported on peach grown nearby to citrus (DROPSA, 2016). High infestations of 27.99% were also observed on the late peach cultivar Malherbe and low infestations of less than 1% were recorded in the early peach cultivar Flordabella between 1982 and 1983 in South Africa (Blomefield, 1989). The level of infestation on peach is thought to depend on the availability of alternative winter hosts, such as citrus, which, if present, allow populations to build up to damaging levels (Daiber, 1987, as cited in EPPO, 2013).

Litchi

Losses of 6% were reported in South Africa (Grove *et al.*, 2004, as cited in Potting and Straten, 2010).

Pepper

Thaumatotibia leucotreta is considered to be a pest of pepper, if only intermittently (Korycinska, 2016). The moth was found on average in 8.72% and 10.96% of sweet and chili pepper, respectively, in a mid-altitude growing region of Tanzania (Mkiga *et al.*, 2019).

African eggplant

The moth was found on average in 12% of African eggplants (*Solanum aethiopicum*) in a mid-altitude growing region of Tanzania (Mkiga *et al.*, 2019).

Plum

Less than 1% of early cultivars of the plum Santa Rosa were infested in a study in South Africa (Blomefield, 1989).

Macadamia

Yield losses of about 30% were reported from Israel in combination with *Cryptoblabes gnidiella* and *Spectrobates ceratoniae* (Wysoki, 1986).

Maize

Losses of 17-44% in combination with stem borers were reported in West Africa (Ndemah and Schultess, 2003).

Cotton

Yield losses of 20% were recorded in early varieties, and 42-90% in late varieties, in Uganda (DROPSA, 2016).

The introduction of the moth into the UK may have impacts on trade, as it did for the Netherlands, when the USDA temporarily prohibited the import of Dutch peppers following outbreaks of the moth in the country (Korycinska, 2016).

Environmental impact

The moth can have an indirect negative impact on arthropod biodiversity because of the increased use of insecticides used to control it.

Social impact

The high losses incurred by the moth may cause the abandonment of crops due to low margins in some EPPO countries (EPPO, 2013).

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