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Commodity risk assessment of *Citrus* L. fruits from South Africa for *Thaumatotibia leucotreta* under a systems approach

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Abstract

The European Commission requested to the EFSA Panel on Plant Health to evaluate a dossier from South Africa where the application of the systems approach to mitigate the risk of entry of the false codling moth, *Thaumatotibia leucotreta* (Lepidoptera: Tortricidae), into the EU when trading citrus fruits is explained. After collecting additional evidence from the Department of Agriculture, Land Reform and Rural Development of South Africa, and reviewing the published literature, the Panel performed an assessment on the likelihood of pest freedom for *T. leucotreta* on citrus fruits at the point of entry in the EU considering the proposed systems approach. An expert judgement is given on the likelihood of pest freedom following the evaluation of the risk mitigation measures on *T. leucotreta*, including any uncertainties. There are three options (i.e. A, B and C) within the systems approach followed in South Africa that differentiate mainly in the sampling intensity in the field and the packing house as well as in temperature conditions during shipment. Therefore, three independent elicitations were conducted, one for each option. The main uncertainties were: (1) whether sampling once per orchard is representative for subsequent harvests (within 4 weeks) from the same orchard; (2) the correct implementation of the temperature regimes during shipment; (3) the mortality rate in fruit estimated for the different temperature regimes. The Expert Knowledge Elicitation indicated with 95% certainty that 9,182 out of 10,000 pallets for option A, 8,478 out of 10,000 pallets for option B, and 9,743 out of 10,000 pallets for option C will be free from *T. leucotreta*. In light of the additional information provided by South Africa once the elicitations were performed, it became apparent that the setting temperature during shipment was not achieved in 12 out of 14 cases of interceptions. Therefore, there is increased uncertainty on pest freedom. The Panel identified the weaknesses associated with the risk mitigation measures in the systems approach and made recommendations that could increase its effectiveness.

Keywords: sweet oranges, mandarins, false codling moth (FCM), European Union, priority pest

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1. Introduction

1.1. Background and Terms of Reference as provided by the European Commission

1.1.1. Background

In COMMISSION IMPLEMENTING REGULATION (EU) 2019/2072 of 28 November 2019 uniform conditions for the implementation of Regulation (EU) 2016/2031 of the European Parliament and the Council are established, as regards protective measures against pests of plants, and Commission Regulation (EC) No 690/2008 repealed and Commission Implementing Regulation (EU) 2018/2019 amended. Point 62 of Annex VII to Commission Implementing Regulation (EU) 2019/2072 defines the list of plants, plant products and other objects, originating from third countries and the corresponding special requirements for their introduction into the Union territory. In particular, fruits of *Capsicum* (L.), *Citrus* L., other than *Citrus limon* (L.) Osbeck. and *Citrus aurantifolia* (Christm.) Swingle, *Prunus persica* (L.) Batsch and *Punica granatum* L. an official statement is required that the fruits:

a) originate in a country recognised as being free from *T. leucotreta* (Meyrick), or;
b) originate in an area established by the national plant protection organisation in the country of origin as being free from *T. leucotreta* (Meyrick), or;
c) originate in a place of production established by the national plant protection organisation in the country of origin as being free from *T. leucotreta* (Meyrick) or;
d) have been subjected to an effective cold treatment to ensure freedom from *Thaumatotibia leucotreta* (Meyrick) or an effective systems approach or another effective post-harvest treatment to ensure freedom from *T. leucotreta* (Meyrick).

A systems approach is defined in the ISPM14 as a pest risk management option that integrates different measures, at least two of it act independently, with cumulative effect.

T. leucotreta is listed as a priority pest for the EU (Commission Delegated Regulation (EU) 2019/1702, EFSA PLH Panel 2019).

1.1.2. Terms of Reference

In accordance with point 62 of Annex VII to Commission Implementing Regulation (EU) 2019/2072 on specific import requirements for certain fruits of *Citrus* L. in relation to the pest *T. leucotreta,* South Africa has chosen to apply a systems approach (option (d)) for the management of that risk. Despite the application of those systems approaches, the number of interceptions has remained high, which has triggered the need for reviewing the systems approach.

EFSA is expected to provide a scientific opinion assessing the level of certainty to which the systems approach followed by South Africa ensures freedom of *Citrus* L. fruits from *T. leucotreta*. When key weaknesses of those systems approaches are identified, they should be analysed, and risk reduction options which could lead to the increase of the level of pest freedom of the commodity shall be described, where appropriate.

In view of the above and in accordance with Article 29 of Regulation (EC) No 178/2002, the Commission asks EFSA to provide a scientific opinion in the field of plant health.

1.1.3. Interpretation of the Terms of Reference

In its evaluation of the systems approach the Panel:

1) reviewed the information provided by the Department of Agriculture, Land Reform and Rural Development of South Africa in the Dossier;
2) evaluated the effectiveness of the proposed measures included in the systems approach described in the Dossier;
3) identified the critical aspects of the current system and made recommendations for improvements.

Risk management decisions are not within EFSA's remit. Therefore, the Panel provided a rating for the likelihood of pest freedom for *T. leucotreta* at the point of entry.

2. Data and methodologies

2.1. Data

2.1.1. Data provided by the Department of Agriculture, Land Reform and Rural Development

The Panel considered all the data and information provided in the Dossier. The Dossier and supplementary material are stored and are accessible by EFSA.

Table 1: Structure and overview of the information provided by South Africa

Dossier section	Overview of contents	Filename
1	Technical Dossier	
1.1	Description of systems approach for 2018	ZA_FCM_SA_v2018.pdf
1.2	Description of systems approach for 2020	ZA_FCM_SA_v2020.pdf
1.3	Description of systems approach for 2021	Systems_approach_ZA_2021.doc
1.4	Additional information provided by South Africa NPPO following EFSA request for clarification	Annexure A (Questionnaires on the False Codling Moth Risk Management System for export of fresh Citrus fruit produced in South Africa during 2020 export season)
1.5	Additional information provided by South Africa NPPO following EFSA request for clarification. Temperature readings during shipping for intercepted consignments	ANNEXURE 1: ADDITIONAL INFORMATION ON THE SYSTEMS APPROACH FOR THAUMATOTIBIA LEUCOTRETA ON CITRUS FRUIT IN SOUTH AFRICA
2	**Technical literature provided by South Africa**	
2.1	False Codling Moth, pest-sheet from Citrus Research International, Vol. III Chapter 3. APHIDS (citrusres.com) https://www.citrusres.com/system/files/documents/production-guidelines/Ch%203-9-4%20False%20Codling%20Moth%20-%20Nov%202019.pdf	
2.2.	Moore SD, Kirkman W, Hattingh V, 2016. Verification of inspection standards and efficacy of a systems approach for *Thaumatotibia leucotreta* (Lepidoptera: Tortricidae) for export citrus from South Africa. Journal of Economic Entomology, 109, 1564–1570. https://doi.org/10.1093/jee/tow139	
2.3	Hattingh V, Moore S, Kirkman W, Goddard M, Thackeray S, Peyper M, Sharp G, Cronjé P, Pringle K, 2020. An improved systems approach as a phytosanitary measure for *Thaumatotibia leucotreta* (Lepidoptera: Tortricidae) in export citrus fruit from South Africa. Journal of Economic Entomology, 113, 700–711. https://doi.org/10.1093/jee/toz336	
2.4	Moore SD, Kirkman W, Albertyn S and Hattingh V, Comparing the use of laboratory-reared and field-collected *Thaumatotibia leucotreta* (Lepidoptera: Tortricidae) larvae for demonstrating efficacy of postharvest cold treatments in citrus fruit. Journal of Economic Entomology, 109, 1571–1577. https://doi.org/10.1093/jee/tow137	

The data and supporting information provided by South Africa, together with additional information collected from the literature, formed the basis of this commodity risk assessment.

2.1.2. Literature searches performed by EFSA

A literature search was undertaken by EFSA to assess the state of the art regarding the efficacy of pre- and post-harvest measures applied to control *T. leucotreta*. The searches were run between 6/2/2020 and 17/6/2021. No language, date or document type restrictions were applied in the search strategy. Additional searches, limited to retrieve documents, were run when developing the opinion. The available scientific information, including previous EFSA opinions on the relevant pest (see pest data sheets in Appendix A) and the relevant literature and legislation (e.g. Regulation (EU) 2016/2031; Commission Implementing Regulations (EU) 2018/2019; (EU) 2018/2018 and (EU) 2019/2072; and Delegated Regulation (EU) 2019/1702) were taken into account.

2.1.3. Commodity data

The characteristics of the commodity were summarised mainly based on the information provided in the Dossier.

2.2. Methodologies

When developing the opinion, the Panel followed the EFSA Guidance on commodity risk assessment for the evaluation of high-risk plant dossiers (EFSA PLH Panel, 2019). Therefore, the proposed risk mitigation measures for *T. leucotreta* were evaluated in terms of efficacy or compliance with EU requirements.

2.2.1. Listing and evaluation of risk mitigation measures

All risk mitigation measures included in the systems approach in South Africa were listed and evaluated. The risk mitigation measures adopted in the production places and packing houses as communicated by the Department of Agriculture, Land Reform and Rural Development were evaluated.

Quantitative estimates of the efficacy of the systems approach in South Africa are given by Moore et al. (2016a) and Hattingh et al. (2020). The pathway model described in Hattingh et al. (2020) and Moore et al. (2016) was reviewed and recalculated. It follows the management of citrus fruits from individual orchards, packing house and export procedures field to the place of import into the European Union. Monte Carlo simulations were used to estimate the infestation levels upon delivery in the packing house, and the efficacy of the different steps in reducing the infestation as described in the systems approach (Appendix B).

To estimate the pest freedom of the commodity i.e. citrus fruits, the methodology for Commodity Risk Assessments was adopted following the EFSA guidance (EFSA PLH Panel, 2018). Therefore, an Expert Knowledge Elicitation (EKE) was performed to estimate the likelihood of pest freedom of the commodity at the point of entry into the EU. The outcome of the estimations from the recalculation of the pathway model of Hattingh et al. (2020) and Moore et al. (2016a) was considered by the experts during the EKEs.

There are three options (A, B and C) within the systems approach followed in South Africa that differentiate mainly in the sampling intensity in the field and the packing house and in temperature conditions during shipment. Therefore, three independent elicitations were conducted, one for each option. The result of each elicitation indicates how many pallets out of 10,000 will be infested with *T. leucotreta* when arriving in the EU following the specific option of the systems approach. A pallet was considered as a unit for the evaluation because the systems approach followed in South Africa is considering a uniform level of infestation at a pallet level within each option.

The uncertainties associated with the EKEs were considered and quantified in the uncertainty distribution applying the semi-formal method described in Section 3.5.2 of the EFSA-PLH Guidance on quantitative pest risk assessment (EFSA PLH Panel, 2018). Finally, the results were reported in terms of the fraction of pallets that are pest free. The lower 5% percentile of the uncertainty distribution reflects the opinion that the fraction of pest free pallets is with 95% certainty above this limit.

2.2.2. Identification of points for improvement under the systems approach

Following the EFSA guidelines for quantitative pest risk assessment (EFSA PLH Panel, 2018), the panel, based on the description of the systems approach implemented in South Africa, identified all the steps in the production and handling that could be considered as risk mitigation measures to decrease the likelihood of entry of *T. leucotreta* in the EU and evaluated their efficacy. Limiting factors that reduce the efficacy of each measure were identified based on the available scientific and technical data and/or expert knowledge (EFSA PLH Panel, 2018). Available evidence and uncertainties for each measure were listed to identify weak points in the systems approach. Those risk mitigation measures with apparent limiting factors affecting the efficacy of the measure were considered as those steps in the systems approach that could be further improved.

3. The pest

Thaumatotibia leucotreta (Lepidoptera: Tortricidae) (synonym *Cryptophlebia leucotreta,* False Codling Moth, FCM) is a Union quarantine pest listed in Part A of Annex II of Commission

Implementing Regulation (EU) 2019/2072, included in the list of priority pests in Commission Delegated Regulation (EU) 2019/1702.

Special import requirements are specified in Annex VII of Commission Implementing Regulation (EU) 2019/2072 regarding the fruit of *Capsicum*, *Citrus* spp. (other than *Citrus limon* and *C. aurantifolia*), *Prunus persica* and *Punica granatum*. Other major hosts, such as cut flowers, need to have a phytosanitary certificate for their introduction into the EU, as they are listed in Annex XI of the same regulation.

T. leucotreta is native to sub-Saharan Africa. In South Africa, *T. leucotreta* is a pest of citrus fruits.

3.1. Biology of *Thaumatotibia leucotreta*

T. leucotreta is a multivoltine insect species that can develop two to five overlapping generations annually, depending on biotic (i.e. food availability, natural enemies and diseases) and abiotic (i.e. temperature, photoperiod, humidity, latitude) conditions (Venette et al., 2003). The life cycle proceeds from an egg, through five larval instars to the pupa and then adults emerge without diapause (Figure 1) (CABI, 2019). It takes, on average, 42–46 days to complete the life cycle at the optimum temperature of 25°C (Opoku-Debrah et al., 2014). However, the length of the life cycle varies between 30 and 117 days, depending on the temperature (de Jager, 2013). Survival decreases substantially at temperatures below 10°C (NAPPFAST, 2003).

Female adults fly at night and attract the males with a sex pheromone. Pheromone release peaks about 5 h after dark, and then decreases until sunrise (Stibick, 2007). One female can lay up to 800 eggs during her lifetime, which spans about 3 weeks ranging from 14 to 70 days (Daiber, 1980). Females deposit their eggs in late afternoon and evening (Stibick, 2007; de Jager, 2013). Eggs can be deposited individually or in aggregations, up to 10–25 eggs per fruit depending on fruit size (Mkiga et al., 2019). Eggs are laid on smooth, non-pubescent surfaces, in the depressions of the rind of a fruit, on fallen fruit or on foliage (Stibick, 2007). Although visible to the naked eye or with a hand lens they are difficult to detect since they are small (0.8 mm), flat and often have a similar colour as the substrate.

After hatching, larvae feed inside the fruit, nuts, pods, seeds, berries, flower buds, cotton bolls, maize ears, etc. (EPPO, 2013). Hard green fruit may also be infested. On oranges, larvae prefer the stylar end of 'Navel' sweet orange cultivars but can burrow anywhere on the fruit as well as in other citrus species and cultivars. There may be one to three larvae per citrus fruit. Larvae bore into the albedo and usually feed just below the fruit rind. Young larvae can be found by checking fruits for entrance holes with or without frass and/or because the surface surrounding the hole of infestation turns yellowish-brown (Figure 2). Mature larvae can be found by cutting fruits showing symptoms. Larvae pupate away from their feeding substrate and can be found in the leaf litter underneath host plants, in fallen fruit, attached to bark or any manmade structure or surface in greenhouses, storing facilities and packing stations (EPPO, 2019).

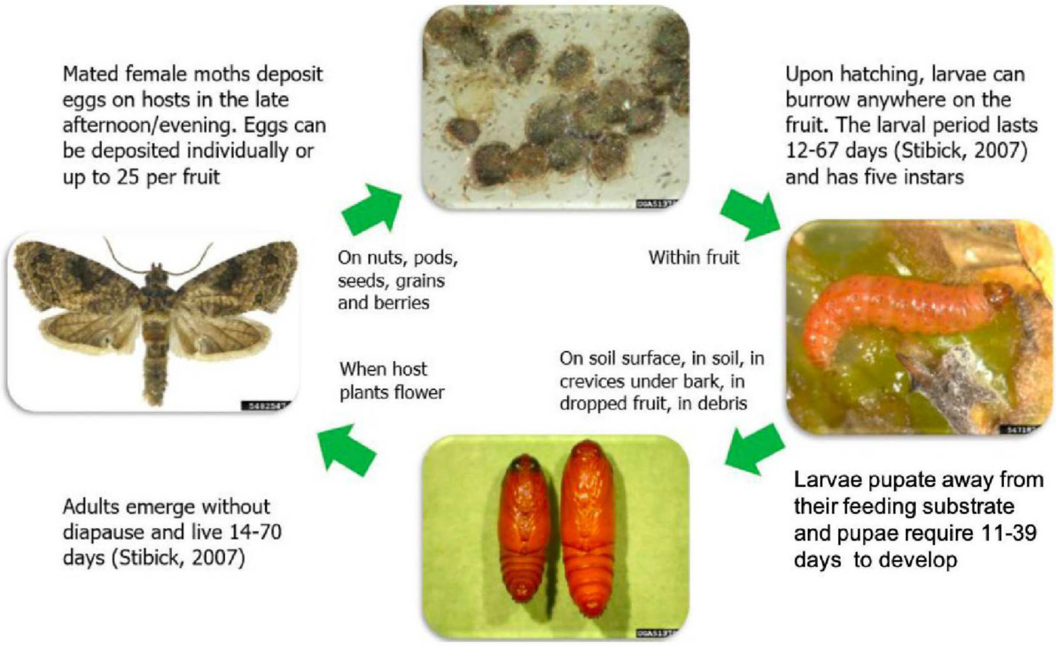

Figure 1: Life cycle of *Thaumatotibia leucotreta* (Sources: (top) JH Hofmeyr, Citrus Research International, Bugwood.org; (right) Marja van der Straten, NVWA Plant Protection Service, Bugwood.org; (bottom) JH Hofmeyr, Citrus Research International, Bugwood.org; (left) Todd M Gilligan and Marc E Epstein, TortAI: Tortricids of Agricultural Importance, USDA APHIS PPQ, Bugwood.org)

3.2. Host plants

T. leucotreta is a polyphagous species with a wide range of host plants. The species is currently known from 105 genera of plants in 51 families encompassing more than 130 different plant species (EPPO 2013, EFSA 2019). The host range includes both cultivated and wild plant species (de Jager, 2013; de Prins and de Prins, 2019; Gilligan et al., 2011).

In Africa, false codling moth is a serious pest of crops of major economic importance such as *Persea americana* (avocado), *Punica granatum* (pomegranate), *Theobroma cacao* (cacao), *Coffea* sp. (coffee), *Citrus* spp, *Gossypium* sp. (cotton), *Psidium* guajava (guava), Zea mays (maize), *Mangifera indica* (mango) and *Prunus persica* (peach) (de Prins and de Prins, 2019). Navel oranges are considered the most susceptible citrus type, although there is considerable variation in susceptibility between Navel cultivars. Mandarin types other than Satsumas and Star Ruby grapefruit are considered less susceptible. White grapefruits are rarely damaged by *T. leucotreta* (Moore, 2019).

Figure 2: Entrance hole and symptoms on orange fruit skin of *Thaumatotibia leucotreta* (left) and larvae inside a citrus fruit (right) (Source EPPO)

3.3. Possibility of spread

In agricultural habitats, such as citrus orchards, adults are mostly confined to the habitat of origin or nearby when occurring outside these habitats. Females will fly a short distance only to reach another host plant for mating and egg-laying and, as a result, dispersal is limited (Newton et al., 1998). However, individuals occurring in urban environment may disperse over medium to long distances to locate host plants (Timm, 2005). EFSA estimated the spread rate of *T. leucotreta* with a median of 1.4 km per year, with a 99% percentile of 8.5 km per year and with a 1% percentile for 233 m per year (EFSA, 2019). During mating flights at night, males can respond to females more than one kilometre away (Omer-Cooper, 1939 in Schwartz, 1981; Stotter et al., 2009).

4. General aspects of citrus production

The genus Citrus, comprising some of the most widely cultivated fruit crops worldwide, includes a large number of species and numerous commercial varieties and rootstocks that allow growing citrus under different conditions. Typically, sweet orange, mandarin, satsuma and grapefruit varieties flower in spring and fruit grows during summer and matures (change colour) between fall and winter. The flowering period lasts 2–4 weeks. Two flowerings may occur in humid subtropical regions, e.g. Brazil, Central Africa.

Fruit growth can be divided in cell division (late spring to early summer) and cell expansion (mid-summer to early-autumn). During cell division, citrus trees have a self-regulatory mechanism whereby they shed part of their fruit load (Gómez-Cadenas et al., 2000; Agustí et al., 2020). Fruit shedding ensures that fruits in excess under prevailing environmental conditions are not retained by the tree (Bangerth, 2000). For example, fruit drop can be exacerbated by low potassium levels when citrus trees are bearing high crop loads. Some pests, including *T. leucotreta* (Hattingh et al., 2020), can also induce fruit fall (Planes et al., 2014; Cass et al., 2020)

Fruit maturation is highly variable among citrus varieties and can last up to a year depending on the variety. Therefore, citrus fruit is vulnerable to *T. leucotreta* attack all year long.

5. Overview of available measures

A systems approach consists of a set of risk mitigating measures targeted to control a specific pest. In this section, a review of the available risk mitigating measures for *T. leucotreta*, including monitoring, inspection and control techniques, is given largely based on the reviews by Moore (2019), Moore et al. (2016a) and Hattingh et al. (2020) and references therein. For each risk mitigation measure, the factors affecting its efficacy are identified.

5.1. General phytosanitary procedures

The NPPO of the exporting country is responsible for the design and implementation of systems approach according to ISPM 14. This includes the official registration of producers and packing stations involved in the export of citrus. At several points of the production chain, inspection should take place to check compliance with the systems approach.

Efficacy and limiting factors: A systems approach protocol should be available, including inspections and/or sampling points in the production, packaging and shipping chain.

5.2. Monitoring with pheromone traps

Pheromone-based trapping systems have been developed to provide means to monitor insect species presence in an area or to assess local population activity and density. Traps contain dispensers loaded with species-specific synthetic components of the female pheromone, which attracts male moths to the trap. The monitoring data of male moth trap captures can inform on female moth activity.

To monitor *T. leucotreta* activity in citrus production in South Africa one monitoring trap per 4 ha is used. A peak in *T. leucotreta* moth activity is in general followed by a peak in *T. leucotreta* -induced fruit drop 3–5 weeks later. Research in South Africa indicates that when 10 or more moths are caught per trap per week, subsequent *T. leucotreta* infestation is likely to exceed one *T. leucotreta* infested fruit dropping per tree per week. This trap capture threshold has been used in South Africa as a guideline to trigger control measures targeted against *T. leucotreta* (Hattingh et al., 2020), such as entomopathogenic virus-based products targeting neonate larvae (Moore et al., 2015) or augmentative parasitoid releases targeted at eggs.

Although moth activity is fairly well synchronised in the beginning of the season, as the season progresses, generations begin to overlap.

Historical data with a standard trapping protocol (trap type and density, monitoring schedule) in the same orchard or region can give time series information on expected population pressure.

Efficacy and limiting factors: Trapping efficacy is dependent on lure durability and trap placement. There are different traps and lures available in the market. Monitoring of adult activity within an orchard with pheromone traps is usually achieved with more than one trap per orchard.

5.3. Field inspection of fruits on tree

Confirmation of the presence and prevalence of the pest can be done with inspection of fruits on the tree if an appropriate sampling scheme is followed. Citrus fruits are susceptible to *T. leucotreta* infestation from the early pea-sized fruit to the mature fruits at harvest (this period in some varieties can last more than one year). Eggs and fresh larval penetration holes in fruit can only be found with the aid of thorough visual inspection. The penetration hole becomes easier to detect after a few days due to decay of damaged tissue and changes in the colour of the peel. An infested fruit usually falls from the tree 3–5 weeks after penetration by a larva. The mature larva enlarges the original hole sufficiently to leave the fruit about a month later and pupates just under the soil surface.

Efficacy and limiting factors: Thoroughness of inspection. A protocol should be defined for the inspection method and sampling design and intensity. Some early-infested fruit may remain undetected.

5.4. Field inspection of dropped fruits

A citrus fruit colonised by a *T. leucotreta* larva usually drops from the tree 3–5 weeks after infestation. Monitoring the level of *T. leucotreta* infestation of dropped fruit is an important information source to estimate pest pressure in the orchard. Monitoring infestation levels of dropped fruit has been used in insecticide efficacy trials in South Africa (Moore et al., 2015). In this case, dropped fruit from specific reference trees selected early in the growing season, where historically *T. leucotreta* infestation occurs, were collected and carefully dissected for any signs of *T. leucotreta* larval infestation. Infested fruits were identified either by the presence of a *T. leucotreta* larva or its tunnelling and frass.

The relationship between infested fallen fruit and the infestation percentages at the packing house is weak (based on the data reported in Moore et al., 2016).

Efficacy and limiting factors: A protocol should be defined for the sampling design and intensity and inspection method.

5.5. Examination of fruit at harvest

Citrus fruits are generally harvested by hand therefore, individual fruit can be examined for quality and fruits with clear symptoms of (cosmetic) damage are not harvested or discarded. However, this process is carried out by field workers that are not trained at detecting potentially infested fruit and it is a fast procedure that does not allow for proper fruit inspection.

Efficacy and limiting factors: Early stages of *T. leucotreta* infestation may remain undetected.

5.6. Official inspection at entry of packing station

Before a packing house accepts a citrus consignment for the sorting, grading and packaging procedures, a visual inspection is usually carried out for the presence of pests. The inspection protocol used by the packing house staff (or NPPO inspector) determines the inspection method as well as the sampling design and intensity.

Efficacy and limiting factors: The sampling protocol determines the inspection efficacy in detecting infested fruits. Early infested fruit may remain undetected with external inspections and destructive sampling may be required. Inspection protocols should follow ISPM 31.

5.7. Examination of fruit during packaging process

In the packaging process, non-marketable fruit will be sorted out by packing house staff, and in general, this procedure is not specifically targeted to pests. However, citrus fruit with clear visible signs of damage will be sorted out and packing house staff can be specifically trained to recognise *T. leucotreta* symptoms. Artificial vision equipment (e.g. image processing camera) can also routinely be used in the packing house, as an automatic pre-grading before the 'in-person' grading.

Efficacy and limiting factors: Packing house staff may need training to recognise *T. leucotreta* symptoms. Early stages of *T. leucotreta* may remain undetected without destructive sampling.

5.8. Official inspection of fruit prior to export

In a packing house fruits that go for packaging will be ready to package within a short time (hours to 1 or 2 days). A pre-export inspection is carried out to ensure that the consignment meets specified phytosanitary requirements of the importing country at the time of inspection. Typical damage symptoms on fruits of citrus may be detected by visual inspection of the consignment. However, as *T. leucotreta* is an internal feeder, these symptoms are not always easy to detect, particularly if infestation takes place close to the time of harvest.

Efficacy and limiting factors: The inspection protocol should be based on ISPM 31 defining sampling design, intensity and inspection method. Early stages of *T. leucotreta* may remain undetected.

5.9. Orchard sanitation

T. leucotreta larvae remain in dropped fruit from citrus trees. Late instar larvae will leave the fruit and pupate in the soil. The population of pupae in the soil forms the basis of the following generation of *T. leucotreta* in the orchard. Interruption of this population cycle by picking, removing and destructing of all fallen fruit on at least a weekly basis can prevent population build up in the orchard. It is estimated that in South Africa, 60–75% of the larvae present in dropped fruit will be removed when fallen fruits are collected weekly (Moore and Kirkman, 2009). Collected fruits are either buried in the soil (at least 30 cm deep) or submerged to water for a week. Alternatively, fruits can be mechanically destroyed. It should be noted that it is a labour-intensive activity.

Efficacy and limiting factors: a sanitation protocol (either by hand or mechanical) defining frequency and phytosanitary-sound disposal of waste (e.g. burying place of removed fruit) should be in place. Time from fruit drop to leaving of larvae can be very short if temperature is favourable. Mechanical sanitation is difficult to be done between trees within the same row.

5.10. Sterile Insect Technique

The Sterile Insect Technique (SIT) is based on the mass production and release of sterile males that compete with the wild target population. In general, SIT is used for area wide control of high impact insect pests with a low reproductive rate (Vreysen et al., 2007).

The SIT has been developed in South Africa to control *T. leucotreta* in specified areas. In general, a ratio of 10 sterile to 1 wild male moth is recommended for successful application of SIT (Hofmeyr et al., 2016). After mating with the sterile males, wild female moths lay infertile eggs. In South Africa, the recommendation is to release 1,000 sterile adults/ha biweekly.

Efficacy and limiting factors: SIT should be applied on an area wide basis. Because the technique is based on the probability that a calling female attracts and mates with a sterile male, the efficacy is dependent on the local pest density and more reliable in areas with low pest prevalence.

5.11. Mating disruption

Mating disruption (MD) technology uses synthetically produced sex pheromones in large amounts to confuse males and limit their ability to locate calling females. The synthetic pheromone used in the orchard is distributed by dispensers.

The mechanism and factors affecting the efficacy of mating disruption has been reviewed by Miller and Gut (2015). The release of sufficiently large quantities of synthetic sex pheromone into the orchard air interferes with mate location by affecting the males' ability to respond to calling females (desensitisation) and causing the male to follow 'false pheromone trails' at the expense of finding mates (competitive disruption). As a result, mating is either delayed, with a subsequent negative effect on overall fertility, or prevented. However, the possibility that some females still will mate always exist.

According to Miller and Gut (2015), the competitive disruption effect is the most important mechanism. The mating disruption dispensers are in competition with the calling (i.e. pheromone releasing) females. Therefore, the efficacy of the technique is density-dependent and less reliable at high population densities. The more females and males are present, the higher will be the chance of mating, even when many dispensers are deployed.

It should be noted that catches in the monitoring traps cannot be a reliable indicator of population density (Ioriatti et al., 2004; Miller and Gut, 2015; EPPO, 2019).

Two main products are available for MD of *T. leucotreta:* a sprayable encapsulated formulation (Checkmate® FCM-F) and a passive hand-applied dispenser formulation (Isomate® FCM). Both products are effective against low-density populations, with reductions of up to 95% (Moore and Hattingh, 2012). A total of 800 dispensers per ha per production season are used irrespective of the tree density with a minimum orchard size of 6 ha. To compensate for the dilution border effect along the edges, the number of dispensers is doubled along the outer side of the perimeter of the treated area.

Capture of zero (complete shutdown) or very few moths in pheromone-baited traps within the crop is the most common parameter used to indicate successful disruption of the pest.

<u>Efficacy and limiting factors:</u> Moths are not killed, and some males may be able to locate and mate with females; therefore, it is an unreliable method of control at high population densities; when orchards are small (< 6 ha), there can be an edge effect of immigrating gravid females. When temperatures are relatively low, pheromone release may be too low to induce the disruptive effect.

5.12. Attract and Kill

The lure and kill approach is based on the mass trapping principle. However, instead of using costly cumbersome physical traps, a formulation is used that contains the attractant (e.g. sex pheromone) and an insecticidal agent. Droplet killing potential is a combination of the relative attractiveness of the pheromone component and the knockdown potential of the insecticidal component (e.g. pyrethroid). Hence, in contrast to the mating disruption technique, males are removed from the population. The probability that a male is killed by an attracticide spot is dependent on the number of attracticide spots and their relative attractiveness compared to a calling female. The use of an attracticide paste allows the necessary density of killing spots needed to compete with the local population of calling females.

No information is publicly available for *T. leucotreta*, but for the closely related codling moth (*Cydia pomonella,* Lepidoptera: Tortricidae), Lösel et al (2000) reported efficacy values in the attract and kill plots of 80–90% comparable to the efficacy values of the insecticide treatment (73–88%). However, the attracticide droplet potency decreases with exposure time to ambient weather conditions (Lösel et al., 2002).

<u>Efficacy and limiting factors:</u> The factors limiting the reliability of an attract and kill technique include the durability of pheromone and insecticide in the formulation, and the density and spacing of the formulation in relation to the local pest density effect. In case orchards are small, there can be an edge effect of immigrating gravid females. Determining efficacious number of killing spots requires estimation of pest population density.

5.13. Virus-based products

There are three virus-based products on the market in South Africa against *T. leucotreta*: Cryptogran®, Cryptex® and Gratham®. All of the products are based on the naturally occurring pathogen of *T. leucotreta*, called the *Cryptophlebia leucotreta* granulovirus (CrleGV), therefore a biological control agent. Timing of application of a virus-based product is very important. The only *T. leucotreta* life stage which can be targeted with viruses is the neonate larva. Therefore, there is a very small window of opportunity for a virus application to be effective. In order to achieve this, pheromone traps must be used to monitor moth activity. Virus should be sprayed within a few days after the start of moth catches. Neonate larvae sometimes do not spend more than a few minutes on the surface of the fruit and do not move more than a few centimetres before penetrating into the fruit. During this brief period, a larva will need to encounter and ingest sufficient virus to induce mortality. Hence, spray coverage of the canopy must be ensured.

Moore et al. (2015) reported efficacy levels of CrleGV against *T. leucotreta* between 30% and 92%. In this field experiment in South Africa, results were comparable with and sometimes better than those achieved with chemical insecticides.

<u>Efficacy and limiting factors:</u> The target of a virus application is the neonate larvae before entering the fruit. Therefore, timing of application of virus and spray coverage on the fruits are sensitive.

A homogenous spray coverage is difficult to achieve on citrus trees. The risk of development of resistance by *T. leucotreta* to CrleGV has been reported (Moore et al., 2015).

5.14. Other biological control techniques

For biological control of *T. leucotreta*, mass production and augmentative release of the egg parasitoid *Trichogrammatoidea cryptophlebiae* Nagaraja (Hymenoptera: Trichogrammatidae) has been developed in South Africa (Moore and Richards, 2001; Hofmeyr, 2003). In general, a total of 100,000 parasitoids per ha are recommended (in four monthly releases of 25,000) to achieve population control. Moore and Hattingh (2004) reported an efficacy of 60% reduction in *T. leucotreta* infestation with *T. cryptophlebiae*. Other natural enemies include parasitoid species that have been reported to parasitise larvae of *T. leucotreta* (Prinsloo, 1984) and generalist predators (e.g. *Orius* bugs and ants) that have been found to prey on *T. leucotreta* (Moore et al., 2017).

Entomopathogenic nematodes (*Heterorhabditis bacteriophora*), and fungi (*Beauveria bassiana, Metarhizium anisopliae*) have been tested targeting pupae in the soil, with variable efficacy (Moore et al., 2013; Coombes et al., 2016).

Bacillus thuringiensis subsp. *kurstaki* (Bt) is used for control of immature stages of Lepidoptera. The efficacy of their formulations is considered as poor because larvae enter into fruits soon after hatching (Kirkman, 2007). However, if targeted properly against neonate larvae on the fruit, a Bt application could be effective.

Efficacy and limiting factors: Entomopathogenic nematodes and fungi are affected by soil properties such as moisture, temperature, soil type and aeration (Love 2015). The target of Bt is the neonate larvae before entering the fruit. Therefore, timing and spray coverage of the fruits are sensitive. Insecticide treatments can disrupt the control efficacy of parasitoids and predators.

5.15. Insecticide treatments

The effectiveness of chemical control on the destructive larval stage of *T. leucotreta* is limited due to the protection that the larva gains by living within the fruit of the attacked host. Most of the insecticides used are targeted at adults, eggs and neonate larvae. There are several active substances available for control of *T. leucotreta*. In South Africa, various active substances are used to control *T. leucotreta* in citrus orchards; the chitin synthesis inhibitors triflumuron (Alsystin®) and teflubenzuron (Nomolt®), the anthranilic diamide chlorantraniliprole (Coragen®) and the carbohydrazide methoxyfenozide (Runner® and Walker®), are all effective against *T. leucotreta* eggs and larvae (Newton, 1989; Moore et al., 2017). Moreover, the pyrethroid cypermethrin has a larvicidal effect on *T. leucotreta*, whereas spinetoram (Delegate®) of spinosyn group is active across multiple insect growth stages.

The influence of cypermethrin, deltamethrin, fenpropathrin, fenvalerate, flucythrinate and permethrin on various developmental stages of *T. leucotreta* was investigated on citrus in the laboratory and field in South Africa (Hofmeyr, 1983). These synthetic pyrethroids were found to have wide detrimental effects on *T. leucotreta*, including an inhibitory effect on egg laying and direct and residual action against eggs. Fruit damage by larvae was prevented for several months following a single application of a suitable pyrethroid. A single spray application of 0.00125% cypermethrin or 0.005% deltamethrin 2–3 months before harvest reduced fruit drop in Navel sweet oranges (caused by *T. leucotreta*) in South Africa by an average of 90%.

In Ghana, the binary insecticides acetamiprid 16 g L^{-1} + indoxacarb 30 g L^{-1} (Viper®) and lambda cyhalothrin 15 g L^{-1} + acetamiprid 20 g L^{-1} EC (Protocol®) gave a 100% protection to the chilli fruits against *T. leucotreta*, while dimethoate (400 g L^{-1}) + cypermethrin (36 g L^{-1}) (Cydim Super®) and maltodextrin (Eradicoat T GH®®) offered 71.2% and 85.8% protection, respectively (Adom et al., 2020).

T. leucotreta has developed resistance to some insecticides in South Africa, principally chitin synthesis inhibitors (i.e. triflumuron) (Hofmeyr and Pringle, 1998). Though the rational use of insecticides by alternating different modes of action will minimise the possibility of pest resistance (Fening et al., 2016), the maximum residue limits established by some foreign markets and the steady demand for fruits with zero residues has recently translated into a need for the adoption of new, efficient and effective integrated pest management (IPM) strategies (Malan et al., 2018).

Treatments of *T. leucotreta* with pyrethroids caused an increase in populations of *Panonychus citri* (McGregor) (Acari: Prostigmata) in South Africa (Hofmeyr, 1983).

Efficacy and limiting factors: The use of pyrethroids and/or neonicotinoids in some crops such as citrus or pepper can result in serious disruptions of the IPM programmes currently in place. Because of their negative impact on beneficial insects, pyrethroids and neonicotinoids are not recommended, in order to avoid high infestations caused by other pests. *T. leucotreta* developed resistance against some active substances hampering the efficacy of chemical control.

5.16. Cold treatment

T. leucotreta is cold sensitive and mortality occurs at temperatures below zero. Postharvest cold treatment of citrus fruit is suggested as a standalone measure based on the authorised cold treatment protocols for citrus fruit imported into the US (EPPO, 2013). A cold treatment is the process in which a commodity is cooled until it reaches a specified temperature for a minimum period of time according to an official technical specification in order to eliminate all life stages of the targeted pest in the commodity. The cold treatment for *T. leucotreta* was developed under laboratory conditions based on larvae feeding on artificial diet. However, the efficacy of cold treatment is lower (i.e. higher LD_{50} and $LD_{99.9}$) in citrus fruit than in artificial diet (Moore et al., 2016b). Using artificial diet, Moore et al. (2016a) evaluated the probit 9 level efficacy of near-zero temperature exposure of fourth- and fifth-instar *T. leucotreta,* which are the most tolerant instars to cold treatment, for 16, 18 and 20 days. All treatments were shown to cause mortality at or in excess of the probit 9 level (99.9968% efficacy at the 95% confidence level).

A draft annex to ISPM 28 for two cold treatment schedules for *T. leucotreta* in *Citrus sinensis* is currently under review by the IPPC.

Efficacy and limiting factors: Although several citrus varieties are cold tolerant, there are some varieties that are cold susceptible. A cold treatment should be applied in accordance with the specifications of ISPM 42 (Requirements for the use of temperature treatments as phytosanitary measures).

5.17. Stand alone: pest-free area

A pest-free area (PFA) is defined according to ISPM 4 as an area in which a specific pest is absent as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained. To verify the pest-free status of an area pheromone trap monitoring data can be used with additional checks of the presence of the pest in harvested produce of host plants.

Efficacy and limiting factors: A surveillance protocol should be provided defining the inspection and sampling design and efforts in place.

6. The commodity

6.1. Description

South Africa is major producer of citrus fruits on a global scale, being the largest exporter in the Southern Hemisphere. The main production regions are located in the Western Cape, the Eastern Cape, along the Orange River in the Northern Cape, the KwaZulu Natal Midlands, Eastern Mpumalanga and Limpopo.

6.2. Data on exports to the EU

The EU is one of the main export markets for citrus fruits from South Africa (Table 2)

Table 2: Export volumes (in tons) per marketing year (October–September) from 2014 to 2019 for citrus fruits from South Africa to the EU (EU28) (source: Eurostat Comext)

Commodity	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020
Sweet orange	390,384	371,414	328,862	372,869	395,927	449,231
Grapefruit	79,255	82,525	89,095	98,138	91,933	85,560
Lemon	26,820	43,142	38,703	81,711	93,133	145,445
Small citrus	38,991	54,175	48,222	63,149	71,992	94,221

The majority of the citrus fruits exported to the EU are sweet oranges and mandarins which are susceptible to *T. leucotreta* infestation.

6.3. Overview of interceptions

Since the implementation of the systems approach for *T. leucotreta* in South Africa in 2018, the pest (i.e. alive immatures) has been intercepted in 38 consignments from South Africa imported into the EU (Table 3). In relation to the proportion of consignments, in 2019, 14 out of 18,475 consignments inspected were rejected (0.08%) at import in the Netherlands (data kindly provided by the NPPO of the Netherlands).

Table 3: List of interceptions found in EUROPHYT/TRACES-NT (online) of citrus fruits from South Africa for *T. leucotreta*, from 2018 until 2020 (Accessed 1/5/2021)

Year	Interceptions	Country	Months	Citrus species	Shipping regime*
2018	5	NL	July, October	*C. reticulata*	Unknown
	2	UK	March, April	*C. sinensis*	Unknown
2019	14	NL	July, September	*C. sinensis*	Unknown
	1	BE	October	*C. sinensis*	Unknown
	2	BG	July	*C. paradisi*	Unknown
2020	13	NL	June, August, September	*C. sinensis*	2 times regime C (0°C) 11 times regime A (2°C)
	1	FR	August	*C. sinensis, C. paradisi*	Regime A (2°C)

*: For details on different shipping regimes, see Table 6.

7. The systems approach followed by the Department of Agriculture, Land Reform and Rural Development of South Africa

Since January 2018, the export of citrus fruit from South Africa to the EU is under a systems approach. The systems approach described in the dossier in South Africa is incorporated within the Citrus FCM Management System (Citrus FMS).

The systems approach includes risk mitigation measures for *T. leucotreta* at several stages: production, harvesting, handling, packing, inspection, certification and shipment during export of citrus fruit. Therefore, the systems approach is applied pre- and post-harvest on an orchard and a consignment basis. The components included in the systems approach are the following (based on dossier – section 1):

- Registration of eligible orchards in the database system Phytclean (central online database tool, operated under the control of the NPPO).
- Monitoring of *T. leucotreta* presence in the orchard by pheromone traps and systematic monitoring of infestation in fallen fruit with associated thresholds for infestation in fallen fruits indicating if additional preharvest control measures are required and handling options.
- Orchard sanitation (removal of all fallen fruit).
- Use only registered preharvest control measures.
- In-orchard fruit sorting of damaged fruits at harvest.
- Official registration of packing houses handling citrus for export
- Post-harvest fruit inspections (by trained packing house staff) targeted at *T. leucotreta* infestation on delivery at packing house, indicating which subsequent handling options are available.
- Packing house grading out of potentially infested fruit.
- Phytosanitary inspections of fruit packed for export - by inspectors of Perishable Products Export Control Board (PPECB). PPECB is an official inspection body operating as an assignee of the NPPO and undertakes inspections on packed citrus fruit at a 2% sampling intensity per pallet.
- Verification of orchard status using PPECB inspection data.
- Specific set of post-harvest shipping options (shipping temperature regime) for application to individual export consignments as determined by the level of compliance with other aspects of the systems approach.

- Certification of export consignments by inspectors of Department of Agriculture, Land Reform and Rural Development phytosanitary certification of compliant consignments.
- Shipment of export consignments with specified temperature regimes (i.e. set point temperature) during shipment and checked by temperature data loggers.

The combination of pre- and post-harvest measures with specific shipping conditions is used to formulate the three groups of available options (A, B and C) within the systems approach (Tables 4–6).

Table 4: Overview of the required actions in the systems approach within each available option

Action	Required for option	
	A and B	**C**
Registration of orchard	Yes	Yes
Trap monitoring	Yes	Yes
Orchard sanitation	Yes	Yes
Fruit infestation monitoring to determine need for control measure (last 12 weeks before start of harvest)	Yes & apply treatment if threshold surpassed	No
Fruit infestation monitoring to determine export option (last 4 weeks before start of harvest)	Yes & must not exceed threshold	No
Packing house delivery inspection	Yes & must not exceed threshold	Yes & must not exceed threshold
PPECB 2% inspection sample per pallet, no live *T. leucotreta* detected in pallet	Yes	Yes

Table 5: Overview of the thresholds applied to options A, B and C of the systems approach

Measurement	Threshold (live larvae)	Consequence of exceeding threshold
Pheromone trap catches (A, B & C)	None Pheromone traps are only used to monitor the activity and population dynamics of the pest in the orchard	None
Fruit infestation (A and B)	During the 12-week preharvest period ≥ 1 infested fruit per week	Apply a registered control measure, as listed on PhytClean.
	4-week average: ≥ 1 infested fruit per week in last 4 weeks before start of harvest.	Orchard defaults to Option C.
Packing house delivery inspection (A, B & C)	Option A: More than 2 infested fruit in sample	Orchard defaults to Option C
	Option B: More than 1 infested fruit in sample	Orchard defaults to Option A (if compliant with A) or C
	Option C:: More than 5 infested fruit in sample	Orchard defaults to 'Not Permitted' and cannot be exported under FMS
PPECB 2% Sample	One or more infested fruit	Pallet cannot be exported under FMS (Options A, B and C).

Table 6: Overview of the different shipping regimes and sampling intensity within each available option of the systems approach in South Africa

Option	Shipping regime code	Load-out temperature (°C)	Set point (°C)	Ports to which applicable: Durban (D), Port Elizabeth (PE), Cape Town (CT)	Packing house delivery sample size and qualification threshold
A	EC2	≤ 5	2	D, PE, CT	800 fruits. Infested fruit ≤ 2. *Infested fruit ≤ 1.
	EW2	≤ 25	2	D, PE (CT*)	
	EC1	≤ 4	1	D, PE, CT	
	EW1	≤ 25	1	D, PE, CT	

Option	Shipping regime code	Load-out temperature (°C)	Set point (°C)	Ports to which applicable: Durban (D), Port Elizabeth (PE), Cape Town (CT)	Packing house delivery sample size and qualification threshold
	EW01	≤ 25	–1	D, PE, CT	
B	EC3	≤ 5	3	D, PE, CT	800 fruits. Infested fruit ≤ 1.
	EC35	≤ 5.5	3.5	D, PE, CT	1,000 fruits. Infested fruit ≤ 1.
	EC4	≤ 6	4	D	1,000 fruits. Infested fruit ≤ 1.
				PE	1,900 fruits. Infested fruit ≤ 1.
				CT	2,800 fruits. Infested fruit ≤ 1.
C	EC0	≤ 1.2	0	D, PE, CT	800 fruits. Infested fruit ≤ 5.
	ECW0	≤ 10	0	D, PE	
	EC01	≤ 0	–1	D, PE, CT	
	ECW01	≤ 10	–1	D, PE, CT	

8. Evaluation of risk mitigation measures included in the systems approach.

All the different risk mitigation measures applied during the production and handling of citrus fruits in South Africa were identified and evaluated. The information used in the evaluation of the effectiveness of the risk mitigation measures under a systems approach is summarised in a data sheet (Appendix A) and Tables 7–9.

Table 7: Summary of the evaluation of measures to be implemented in the field under a Systems approach in South Africa

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
1	Registration of export orchards	Export of citrus fruit with reliance on the FMS as assurance of compliance with *T. leucotreta* phytosanitary import regulations requires each participating orchard to be registered with DALRRD, using the PhytClean system		Registration procedures seem to be adequate.	No
2	Pheromone trapping for monitoring of *T. leucotreta*	1 trap per orchard and no more than 1 trap for orchards larger than 4 ha.		Traps are envisaged (a) to compare *T. leucotreta* activity between seasons, which enables to gauge if the current season is experiencing generally higher or lower *T. leucotreta* infestation than in the past; (b) to compare *T. leucotreta* activity levels between areas or sections of a farm, which will enable prioritisation of treatment application; (c) to assist in the accurate timing of treatment application; (d) to determine if the application of a mating disruption product is resulting in trap shutdown, as it should; and (e) to measure sterile to wild moth ratios in a sterile insect technique (SIT) programme	Actual monitoring of adult activity at each orchard may be limited and could jeopardise timely application of control measures such as virus-based insecticides. Orchard monitoring should be based on a minimum of 3 traps per orchard.

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
3	Monitoring of infestation on fallen fruit	Monitoring of fruit infestation is mandatory in options A and B. Monitoring must be undertaken for a minimum of 12 weeks prior to start of harvest, unless the orchard is harvested sooner than 12 weeks after 15 January, as monitoring need not to be initiated earlier than 15 January. Orchard monitoring entails marking a minimum of 5 data trees in each orchard (up to 3 ha). The 5 data trees (set) must be positioned wherever fruit drop shows the highest *T. leucotreta* population. If any single orchard is larger than 3 ha, additional data trees should be marked and monitored in sets of 5 data trees (Appendix A). Guidance is given in the PhytClean system. The detection of any infested fruit under a data tree in the period 12 to 4 weeks prior to the commencement of harvest should trigger corrective measures. If any infested fruit is detected 4 weeks before harvest then orchard would be eligible only for option C. During the inspection of fallen fruit not only larval presence, but other signs of infestation are taken into account (emergence holes on fruits or presence of frass).	The number of fallen fruits inspected during the monitoring in the orchard is uncertain. It is uncertain the relationship between the level of infestations in fallen fruits and the level of infestation in the orchard (no experimental data provided). It is uncertain if corrective measures applied soon after finding an infested fallen fruit are effective against the life stages present on fruits on the tree e.g. larvae in the fruits.	– Practical way of monitoring population pressure in the orchard in order to apply corrective measures. – The implemented monitoring system is appropriate to decide when to apply corrective measures, however it is not recommended to estimate pest prevalence. – The relationship between infested fallen fruit and the infestation percentages at the packing house is weak (based on the data reported in Moore et al., 2016). – The system assumes that every infested fruit will drop after a certain time, which is not the case. – Newly infested fruits can be present on the tree and not fall; the dropping of infested fruits may vary among varieties. – Based on standard sampling calculations the sample size is too small.	Before harvest the monitoring should not only rely on the inspection of fallen fruit but also on representative sample of the fruits in the orchard at the moment of harvest. It is also recommended to take into account the length of the harvesting period; if longer than 4 weeks, additional inspections with similar sampling intensities should be considered.

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
4	Orchard sanitation	Orchard sanitation entails the manual collection and removal of dropped fruit and hanging fruit, which show signs of damage or infestation. Sanitation must be conducted weekly and continue until harvesting has been completed, and within 14 days thereafter the orchard must be cleared of the current season's fruit (both fruit on the tree and fallen fruit). After collection, fallen fruit must be destroyed either by burying the fruit at least 30 cm deep in the ground or pulped with a hammermill. Pulping occurs outside the orchard (Moore, 2019).	Official inspection of the actual implementation of the method is not feasible due to the large number of orchards and spread of citrus production areas in the country. No data on the efficacy of the method in causing mortality to larvae of *T. leucotreta*.	Removal/destruction of dropped fruit is very important to disrupt the population build-up in the orchard if applied frequently. Post-harvest destruction of remaining fruits on the tree is an important factor and is considered in the dossier. According to Moore and Kirkman (2009), it might be possible to remove an average of up to 75% of FCM larvae from fallen fruit by conducting weekly orchard sanitation.	The frequency of sanitation may have to be increased in areas with high summer temperatures as larval development is faster and larvae may have emerged before fruit is removed (Moore and Kirkman, 2008; Moore, 2019).
5	Sterile Insect Technique (SIT)	SIT is reported to be used, as one of the FCM control options, over approximately 16, 500 ha of citrus in South Africa, which is approximately 23% of South Africa's FCM-susceptible commercial citrus production. Traps are used to check the effect of SIT. A ratio of 10 sterile to 1 wild male moth is used as a ratio guideline.		SIT has to be applied on area-wide basis; in areas with low population density to prevent mating of females with wild males the immigration of gravid females.	Regional-based decisions.

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
6	Mating Disruption (MD)	Mating disruption is envisaged to be applied to approximately 28,000 ha of citrus production, being approximately 39% of South Africa's FCM susceptible commercial citrus production. The area of commercially grown citrus cultivars susceptible to *T. leucotreta* is 72,132 ha. Four registered products are now available for FCM control: Isomate FCM, Checkmate FCM-F (Suterra, USA), Splat-FCM (ISCA Technologies, USA) and X-Mate (Insect Science, South Africa) (Moore and Hattingh, 2012; Moore, 2019). Traps are aimed to monitor the effect of MD.	Variation in population density of the pest across different production areas and orchards in South Africa is uncertain. It is uncertain how orchard size is considered in the application of MD.	Efficacy of MD depends on the initial population density of *T. leucotreta*, the size of the orchard and the history of application on the same plot. Trapping data can be unreliable to evaluate the efficacy of MD. Size of non-isolated orchards may be too small (lower than 6 ha) for reliable mating disruption due to pheromone dispersal and edge effects of immigrating gravid females as mentioned in the South African citrus management guidelines (CRI).	Regional-based application of mating disruption would improve pest management.
7	Pheromone based attracticide	The attract and kill product i.e. Last Call FCM, is registered for *T. leucotreta* control. The product consists of a synthetic pheromone and a pyrethroid incorporated into a transparent gel like base material. Three to four applications of up to 3,000 droplets of the product per hectare per application have to be applied by hand with a special applicator. Reapplication is necessary every 4 weeks.		Efficacy depends on initial population density of *T. leucotreta* in relation to the density of applied droplets.	
8	Biological control	Egg parasitoids for *T. leucotreta* are augmented over about 2,000 ha; insect viruses are applied over approximately 29,000 ha; and entomopathogenic fungi are applied over an estimated 10,000		Virus application can be highly effective. The time of application is crucial (targeted at neonate larvae) as mentioned in the South African citrus management guidelines (CRI).	

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
		ha. For parasitoids, viruses and fungi, these convert into ~ 3%, 40% and 14%, respectively, of South Africa's FCM-susceptible commercial citrus production. Releases of 100,000–125,000 parasitoids per ha are recommended. There are three virus-based products registered (i.e. Cryptogran, Cryptex and Gratham).			
9	Insecticides	Registered insecticides in South Africa against *T. leucotreta* are: Insect Growth Regulators (Nomolt, Alsystin, Runner), pyrethroids, Delegate, Coragen and Warlock.		Registered products target adults, eggs or first instar larvae. Larvae feeding inside citrus fruits are difficult to control with insecticides. Timing of insecticide application is important for the effective control of eggs and first instar larvae. There are limited options of available insecticides in the last four weeks prior to harvest due to maximum residue levels as per registration restrictions.	

Table 8: Summary of the evaluation of the measures to be implemented in the packing house under a Systems approach in South Africa

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
1	Sorting/Culling at harvest	Fruit showing signs of potential FCM infestation should be removed during the picking process within the orchard as far as it is feasible to do so, prior to delivery of the fruit to the packing house. Culled fruit must be excluded from packing for export under the systems approach.	Training level of people involved in harvest and time required to detect infestations of *T. leucotreta* is uncertain.	Recent infested fruit are difficult to detect. Harvest happens fast and not meticulously done for detecting infested fruits.	
2	Protected transport to packing house	Harvested fruits are transported in tarpaulin covered trucks.			
3	Inspection infestation level at entry station	On delivery of citrus fruit from an orchard to the packing house, for packing under the FMS, a sample of fruit per orchard must be removed and inspected for *T. leucotreta* infestation (one sample per orchard per season, unless harvesting continues beyond 4 weeks). The sample size for Option A and C fruit is 800. Depending on the desired shipping condition, the sample size for Option B fruit is 800, 1,000, 1,900 or 2,800. The fruit sample must be selected randomly without selecting for fruit that looks more or less likely to be infested. All fruit with suspicious marks are destructively inspected for the presence of the pest. Packing house delivery inspection must be repeated for any orchard where harvesting continues for more than 4 weeks after the first delivery inspection at the packing house. The status of an orchard cannot improve from C to A, C to B or A to B as a result of the 4 weeks repeat inspection.	Considering the population dynamics of the pest, it is uncertain whether sampling once per orchard per season is representative for subsequent harvests (within 4 weeks) from the same orchard. It is uncertain whether during selection of fruits for destructive inspection all recent infestations are recognised (have 'suspicious marks').	The minimum sample size of 800 fruits upon delivery is an adequate sampling intensity (95% confidence for 0.5% pest prevalence, with a sensitivity of 80% in RiBESS+). Considering that one female can lay more than 400 and up to 800 eggs during her lifetime, which spans about 3 weeks (ranging from 14 to 70 days; Daiber, 1980), it is reasonable to assume that new ovipositions and infestations may occur within 4 weeks.	A higher frequency of sampling of deliveries from the same orchard could improve the reliability of the sampling.

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
4	Sorting and grading	During the grading process citrus fruit with blemishes or any signs of stylar-end splitting are removed by trained packing house staff.	The reasons for the differences between the reported efficacies are unclear (i.e. 23 and 66%)	According to Moore et al. (2016) the efficacy in detecting and removing infested material during grading was estimated in 23% and according to Hattingh et al. (2020) it was 66% for Valencia sweet oranges. Recently infested fruit difficult to detect. There could be differences in the detectability of the pest among the different citrus species.	
5	Official inspection of fruit boxes prior to export and certification	After packing a 2% sample of citrus fruit per pallet (i.e. with a sampling intensity of 144 fruits out of ca. 5,760 fruits in a pallet, Hattingh et al., 2020) is done by PPECB inspectors. A pallet is rejected for export if any fruit infested with live larvae is detected.		Recent infestations can be overlooked. For a single pallet, the sampling intensity used would correspond with a 95% confidence to detect a 2.5% infestation with test sensitivity 0.8. If test sensitivity is set to 0.6, then the design prevalence is 3.4% (RiBESS+).	Detection of an infested pallet does not disqualify other inspected pallets from the same orchard (See point 1.2 of Appendix VII of the Systems Approach) Inspected pallets coming from the same orchard should be then exported only under option C.

Table 9: Summary of the evaluation of the measures to be implemented during shipping under a Systems approach in South Africa

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
1	Shipping conditions	The systems approach prescribes shipping conditions available for each consignment of FMS qualifying export fruit, according to the phytosanitary status (Options A, B or C) of the orchards from which the fruit was harvested and inspected. The temperature regimes and inspection sample sizes are reported in the description of the systems approach (Appendix D, Table 1 of the systems approach, see also Table 5 in this opinion). The temperature during shipment is recorded with data loggers and recorded data are uploaded into Phytclean within seven days after arrival.	Based on the data provided in the dossier, South Africa estimated the mortality at 2°C as 99.41% for 16 days and 100% after 19 days, 100% at 1°C after 19 days and at 0°C after 16 days, however the sampling size in these experiments is not reported. To compute the confidence interval, it would be necessary to have the sample size. Additional data with sample size (dossier Section 1.5) were provided by South Africa.	62% of the containers shipped to the EU use temperature regime A/EW2 which corresponds with a continuous temperature of 2°C during shipment and 800 fruits of the consignment have been inspected at delivery at the packing station. 17% of the containers shipped to the EU use temperature regime C/ECW0 which corresponds with a continuous temperature of 0°C during shipment and 800 fruits of the consignment have been inspected at delivery at the packing station. According to the draft annex ISPM28 Cold treatment on *T. leucotreta* on *Citrus sinensis* 95% confidence that at -0.2 °C for 16 days kills at least 99.9969% of eggs and larvae of the pest using data from Moore et al. (2016b) coming from experiments on artificial diet. For other temperatures, e.g. 2°C, no details on the experiments are available. In 2020, there were 14 interceptions (NT-Traces) of alive larvae of *T. leucotreta* in the EU on citrus fruit from South Africa. According to the Dossier, these interceptions correspond with 12 consignments shipped at set temperatures of 2°C and 2 consignments with set temperatures of 0°C (dossier section 1.4). Additional information provided by the NPPOs of the Netherlands and France indicated that one or more alive larvae were present in all intercepted consignments. The total cooling time (cold storage plus container cooling time) ranged from 18 to 84	The conclusions on mortality data coming from the experimental work reported in Moore et al. (2016b) based on artificial diet cannot be directly related to fruits because the mortality rate reported is lower in fruits. The sample size reported in trial 1 in Moore et al. (2016b) to compare the susceptibility to low temperatures of larvae in fruit and artificial diet at 2°C, (i.e. 25 for fruits) was too small to confirm a mortality rate. In trial 2, the mortality after the cold treatment of 2°C for 18 days was 90.36% in fruits. In trial 3, data for the control treatment are not provided in the results for fruits and again the sample size tested (i.e. 33–52) was too small to confirm a mortality rate in the magnitude needed for the risk assessment. As a conclusion, more reliable data (with statistically sound sample sizes) should be provided for the mortality rates for different durations and temperatures. As specified in ISPM42 the use of at least 3 data loggers per container are recommended to monitor temperature during shipment. It is recommended to check the data from the data loggers on the ship to verify the correct implementation of the cold treatment during shipment.

No.	Measure	Description of measure as reported by South Africa	Uncertainties	Evaluation	Limitations and suggestions for improvement
				days with a mean of ca. 42 days (dossier section 1.4). However, according to the dossier, shipping conditions are obliged up to 30 days, after that period temperatures during shipment is allowed to set at 4°C. The presence of alive larvae indicates that either the shipping conditions may not be implemented correctly or the mortality rate of the shipping conditions (i.e. shipping time and set temperature) is not guaranteeing 100% mortality. According to the data provided by South Africa (Section 1.5 of dossier), in 12 out of 14 consignments intercepted in 2020 the reading of the logger shows that set-point temperature was not reached.	

It is clear from the description of the systems approach and the outcomes of the recalculation of the pathway model (Appendix B) that the implemented system relies heavily on the temperatures applied during shipment and, as such, it was considered during the EKE conducted for the three described options. Moreover, in light of the additional information provided by South Africa once the EKEs were performed (dossier section 1.5), it became apparent that the setting temperature during shipment was not achieved in 12 out of 14 cases of interceptions. Therefore, there is increased uncertainty about the actual mortality rates during shipment under different temperature regimes and this might have a great impact on pest-freedom at entry in the EU.

9. Outcome of Expert Knowledge Elicitation

Table 10 and Figure 3 show the outcome of the EKEs regarding pest freedom after the evaluation of the currently used systems approach for *T. leucotreta* on citrus in South Africa. Figure 3 provides an explanation of the descending distribution function describing the likelihood of pest freedom after the evaluation of the systems approach for citrus fruits designated for export to the EU from South Africa for *T. leucotreta*.

Table 10: Assessment of the likelihood of pest freedom following evaluation of the risk mitigation measures in the Systems approach against *T. leucotreta* on citrus from South Africa designated for export to the EU. In panel A, the median value for the assessed level of pest freedom for each option is indicated by 'M', the 5% percentile is indicated by L and the 95% percentile is indicated by U. The percentiles together span the 90% uncertainty range regarding pest freedom. The pest freedom categories are defined in panel B of the table

Number	Group*	Pest species	Sometimes pest free	More often than not pest free	Frequently pest free	Very frequently pest free	Extremely frequently pest free	Pest free with some exceptional cases	Pest free with few exceptional cases	Almost always pest free
1		Option B		L		M			U	
2		Option A			L	M				U
3		Option C				L		M		U

PANEL A

	Pest freedom category	Pest free fruits out of 10,000	Legend of pest freddom categories	
	Sometimes pest free	≤ 5,000	L	Pest freedom category includes the elicited lower bound of the 90% uncertainty range
	More often than not pest free	5,000–≤ 9,000	M	Pest freedom category includes the elicited median
	Frequently pest free	9,000–≤ 9,500	U	Pest freedom category includes the elicited upper bound of the 90% uncertainty range
	Very frequently pest free	9,500–≤ 9,900		
	Extremely frequently pest free	9,900–≤ 9,950		
	Pest free with some exceptional cases	9,950–≤ 9,990		
	Pest free with few exceptional cases	9,990–≤ 9,995		
	Almost always pest free	9,995–≤ 10,000		

PANEL B

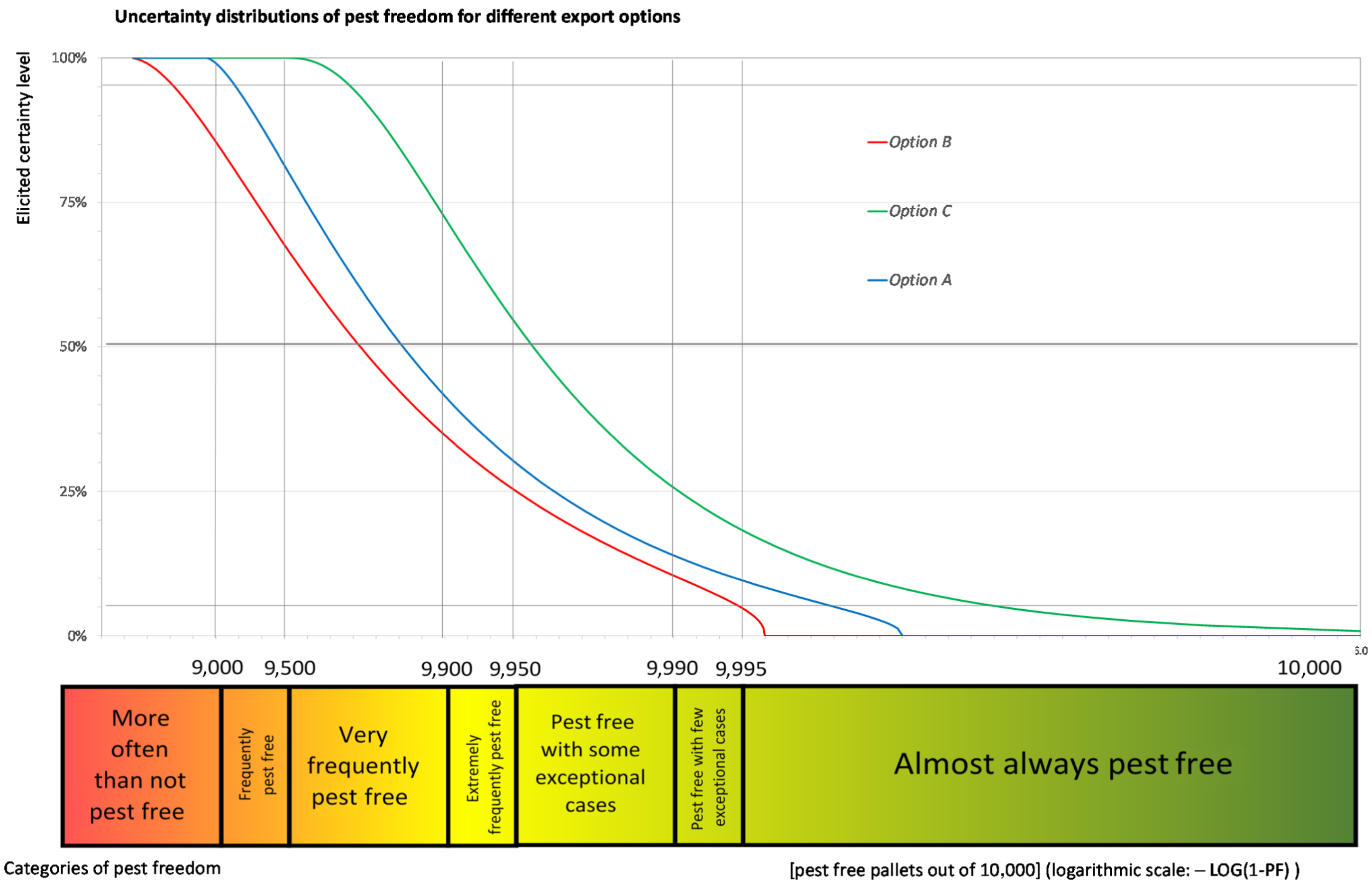

Figure 3: Uncertainty distribution for the likelihood of pest freedom for *T. leucotreta* after the evaluation of the systems approach (options A, B, C) for citrus fruits designated for export to the EU from South Africa

10. Conclusions

For *T. leucotreta* on citrus fruits from South Africa, an expert judgement is given on the likelihood of pest freedom following the evaluation of the risk mitigation measures, after the defined systems approach, acting on *T. leucotreta*, including identified uncertainties. The systems approach in South Africa mainly relies on inspections in the packing house in combination with specified temperature regimes during shipment. The main uncertainties were: (1) whether sampling once per orchard is representative for subsequent harvests (within four weeks) from the same orchard; (2) the correct implementation of the temperature regimes during shipment; (3) the mortality rate in fruit estimated for the different temperature regimes. The Expert Knowledge Elicitation indicated, with 95% certainty that for option A, 9,182 out of 10,000 pallets will be free from this pest, for option B 8,478 out of 10,000 pallets will be free from this pest and for option C 9,743 out of 10,000 pallets will be free from this pest. Considering the additional information provided by South Africa once the EKEs were performed, it became apparent that the setting temperature during shipment was not achieved in 12 out of 14 cases of interceptions. Therefore, there is increased uncertainty on pest freedom.

11. Recommendations

Based on the review of the systems approach and the associated mitigation measures foreseen in South Africa to reduce the likelihood of infestation in citrus fruits exported to the EU, the following points may be considered to improve the systems approach:

1) In the field:
    - For Orchard monitoring a minimum of three traps per orchard may considered for better accuracy.
    - International standards could be considered for the monitoring system in the field to increase its reliability.
    - It is also recommended to take into account the length of the harvesting period; if longer than four weeks, additional inspections with similar sampling intensities should be considered.
    - It is recommended to extend the monitoring for infested fruits to option C.
    - The frequency of sanitation may have to be increased in areas with high temperatures during summer as larval development is faster and larvae may have emerged before fruit is removed.
2) Packing procedure:
    - A higher frequency of sampling of deliveries from the same orchard is needed to improve the reliability of the inspection.
    - In case a pallet is rejected for the regime requirements A or B, other inspected pallets coming from the same orchard may be considered for export only under option C. Similarly, if a pallet is disqualified under option C, other inspected pallets coming from the same orchard it is recommended to be disqualified.
3) Shipping conditions:
    - Reassess options A, B and C by using more reliable data to sustain the mortality rates for different duration and temperatures using larvae feeding in infested citrus fruit; or provide additional evidence to demonstrate that the mortality rate in artificial diet can be used to estimate the mortality rate in citrus fruits.
    - As specified in ISPM42 the use of at least three data loggers per container are recommended to monitor temperature during shipment.
    - It is recommended to verify the data from the data loggers on the ship to confirm the correct implementation of the temperature regime during shipment.

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Abbreviations

EKE	Expert Knowledge Elicitation
FCM	false codling moth
MD	Mating disruption
PFA	pest-free area
PLH	Panel on Plant Health
SIT	Sterile Insect Technique

Appendix A. – Data sheet for the evaluation of the systems approach of Thaumatotibia leucotreta in citrus from South Africa

A.1. Organism information

Taxonomic information	*Thaumatotibia leucotreta* (Meyrick) (Lepidoptera: Tortricidae) Synonyms: *Argyroploce batrachopa* *Argyroploce leucotreta* *Cryptophlebia leucotreta* *Enarmonia batrachopa* Common name: False Codling Moth (FCM)
Group	Insects
EPPO code	ARGPLE
Regulated status	*T. leucotreta* is regulated in the EU (A1 Quarantine pest (Annex II A) of Commission Implementing Regulation (EU) 2019/2072. *T. leucotreta* is regulated as priority pest in the EU by Commission Delegated Regulation (EU) 2019/1702. *T. leucotreta* is listed in EPPO A2 list and it is currently regulated in America, Turkey in A1 list. *T. leucotreta* is a quarantine pest in Israel since 2009.
Pest status in South Africa	*T. leucotreta* is present in South Africa.
Pest status in the EU	*T. leucotreta* is not present in the EU.
Host status on Citrus spp.	*T. leucotreta* is a polyphagous insect and citrus are common host plants.
PRA information	Report of a Pest Risk Analysis for *T. leucotreta* (EPPO, 2013) EFSA Pest report on priority pests (EFSA, 2019)
Host plant range	Other common hosts in South Africa are apple, maize, pomegranate, macadamia, cotton, peach, pepper, avocado and guava. For a full list of potential host plants see PRA of EPPO (2013).
Interceptions (Europhyt/ Traces NT)	Since 2016 there are 41 interceptions with 17 interceptions in 2019 and 14 in 2020. The systems approach is in place in south Africa since 2018.

A.1.1. Pest pressure in the production area

T. leucotreta is native in South Africa and it is present throughout the country. It is a major pest for several crops. In the past, fruit losses ranged from 2% to as high as 90% due to FCM damage. The pest can maintain itself in citrus orchards (Navel and Valencia sweet oranges), since larvae escaping just prior to the picking of navel sweet oranges in May or June have a pupal stage lasting about 35 days (Stofberg, 1954).

Hattingh et al. (2020) report in table 3 the infestation level after harvest for 10 mandarin orchards at delivery at packing house ranged from 0% to 1 %. Moore et al. (2016) report infestation levels of 33 sweet orange orchards of Naval (N) and Valencia (V) sweet oranges. The sample sizes are unknown. Infestation of citrus fruits by FCM ranged from 0% to 4.8%.

According to South Africa NPPO the average number of moths caught per trap per week in the ~ 16,500 ha where the company Xsit does the monitoring and the ~ 6,000 ha where QMS FoodTech is responsible for monitoring, was under 0.5 moths.

A.2. Overall likelihood of pest freedom of *T. leucotreta* for pallets with citrus fruits

The conditions for the different shipping regimes are explained in Table A.1.

Table A.1: Overview of the different shipping regimes and sampling intensity within each available option of the systems approach in South Africa

Option	Shipping regime code	Load-out temperature (°C)	Set point (°C)	Ports to which applicable: Durban (D), Port Elizabeth (PE), Cape Town (CT)	Packing house delivery sample size and qualification threshold
A	EC2	≤ 5	2	D, PE, CT	800 fruits. Infested fruit ≤ 2. *Infested fruit ≤ 1.
	EW2	≤ 25	2	D, PE (CT*)	
	EC1	≤ 4	1	D, PE, CT	
	EW1	≤ 25	1	D, PE, CT	
	EW01	≤ 25	-1	D, PE, CT	
B	EC3	≤ 5	3	D, PE, CT	800 fruits. Infested fruit ≤ 1.
	EC35	≤ 5.5	3.5	D, PE, CT	1,000 fruits. Infested fruit ≤ 1.
	EC4	≤ 6	4	D	1,000 fruits. Infested fruit ≤ 1.
				PE	1,900 fruits. Infested fruit ≤ 1.
				CT	2,800 fruits. Infested fruit ≤ 1.
C	EC0	≤ 1.2	0	D, PE, CT	800 fruits. Infested fruit ≤ 5.
	ECW0	≤ 10	0	D, PE	
	EC01	≤ 0	–1	D, PE, CT	
	ECW01	≤ 10	–1	D, PE, CT	

A.2.1. Exported citrus fruits shipped under option A

Elicited values *Thaumatotibia leucotreta* for pallets with citrus fruits					
Rating of the likelihood of pest freedom	**Very frequently pest free** (based on the median).				
Percentile of the distribution	5%	25%	Median	75%	95%
Proportion of pest free pallet	**9,182** out of 10,000 pallets	**9,597** out of 10,000 pallets	**9,848** out of 10,000 pallets	**9,,967** out of 10,000 plants	**9,998** out of 10,000 pallets
Percentile of the distribution	5%	25%	Median	75%	95%
Proportion of infested pallet	**1.98** out of 10,000 pallets	**33.3** out of 10,000 pallets	**152** out of 10,000 pallets	**403** out of 10,000 pallets	**818** out of 10,000 pallets

A.2.1.1. Reasoning for a scenario which would lead to a reasonably low or high number of infested consignments (pallet); Option A (set-point temperature –1–2°C and the sample size is 800 fruits)

Uncertainties	Reasoning for a scenario which would lead to a reasonably low number of infested consignments (pallet)	Reasoning for a scenario which would lead to a reasonably high number of infested consignments
Field		
The actual pest prevalence in the orchards exporting to the EU.	Pest abundance is low. Fruits originate from areas with low pest prevalence (e.g. Port Elizabeth).	Pest abundance is high. Fruits originate from areas with high pest prevalence (e.g. Limpopo).
The location of the orchard in relation to orchards not within the systems approach.	Export plots are isolated from other orchards where mating disruption or SIT are not applied.	Export plots are close to other orchards where mating disruption or SIT are not applied.

Uncertainties	Reasoning for a scenario which would lead to a reasonably low number of infested consignments (pallet)	Reasoning for a scenario which would lead to a reasonably high number of infested consignments
The consistency of the application of the required measures within the systems approach by the exporting orchards.	Compliance with the systems approach is consistent throughout all citrus production orchards.	Compliance with the systems approach is not consistent throughout all citrus production orchards.
The reliability of the monitoring system in the field (e.g. using data-trees and fallen fruits).	Inspection of fallen fruits is effective to detect infested fruit in the field, e.g. large larvae, exit holes.	Inspection of fallen fruits under specific data trees is not reflecting the situation in the whole orchard.
The proper implementation of the sanitation throughout the season in all export orchards.	Sanitation and fruit destruction occur frequently and accordingly disrupts population build-up in orchards.	Sanitation and fruit destruction is not properly applied and accordingly it may not disrupt population build-up in orchards.
The efficacy and proper application of the control measures for FCM.	Biological control (virus) is applied timely and therefore is effective in controlling *T. leucotreta*.	The proper timing in the application of biological control (virus) is difficult for an organism with overlapping generations and hence is not controlling properly *T. leucotreta*.
Sorting at harvest biases the infestation level and detectability in the packing houses.	During the harvesting only symptomless fruit is collected for packing and infestation level of fruit arriving to the packing house is reduced.	Collecting only symptomless fruit reduces the detectability in the packing house and the efficiency of the inspection before packing.
The delivery was already rejected for option B.	The material coming directly from the orchard for option A.	The material was rejected, not complying for option B.
Packing house		
The representativeness of the sample at the packing house level for the entire orchard and season.	The sampling done in the packing house is representative for the whole harvest in the orchard (i.e. harvested in 1 day, or in the same period).	There is spatial and temporal variation in the infestation levels of harvested lots of the same orchard while the inspection is only checking the first delivery.
The efficacy of the visual inspection at delivery at the packing house.	Visual inspection at delivery in the packing house is effective in detecting and removing infested lots.	Because only clean fruit is taken to the packing house, it will mask a higher infestation level identified by visual inspection.
The consistency in implementation of the systems approach requirements by the packing houses across the whole country.	The systems approach requirements are properly applied by the packing houses.	The systems approach is not consistently applied by the packing houses.
The proportion of different cultivars in the consignments handled under the chosen regime.	Exported citrus cultivars are not susceptible to *T. leucotreta* infestations (e.g. grapefruit).	Most of the exported citrus cultivars are susceptible to *T. leucotreta* infestations (e.g. mandarins).
Export procedure		
The efficacy of the visual inspection before export.	Visual inspection before export is effective in detecting and removing infested lots.	Visual inspection before export is not effective in detecting and removing infested lots.
Shipping temperature regime		
The actual time and proper application of the cooling treatment during storage and shipping.	The duration of the shipping and cooling time and the temperature applied lead to a high mortality rate of the pest in the consignment.	The duration of the shipping and cooling time and the temperature applied is not sufficient to kill all the larvae of the pest in the consignment.

Uncertainties	Reasoning for a scenario which would lead to a reasonably low number of infested consignments (pallet)	Reasoning for a scenario which would lead to a reasonably high number of infested consignments
The reliability of mortality data presented for the different temperature regimes.	The mortality rates presented in Dossier Section 1.4 are reliable.	Mortality rates are not reliable due to unknown sample sizes and experimental conditions.
The level of implementation of the treatment of the temperature regimes during shipment.	The cooling treatment during shipment (below 2°C) is applied, monitored and verified properly.	Cooling treatment is not properly applied, monitored and verified during storage and shipment.

A.2.1.2. Reasoning for the median value

- In 2020, 12 consignments using option A (EW2) were rejected at import in the Netherlands due to the presence of living stages of *T. leucotreta* (dossier Section 1.4).
- If cold treatment is not applied properly during shipment, *T. leucotreta* larvae could survive in fruit leading to infested consignments and interceptions.
- Inadequate experimental assessment of the mortality rates of *T. leucotreta* under the cold treatment regimes.

A.2.1.3. Exported citrus fruits shipped under option B

Elicited values *Thaumatotibia leucotreta* for pallets with citrus fruits					
Rating of the likelihood of pest freedom	**Very frequently pest free** (based on the median).				
Percentile of the distribution	5%	25%	Median	75%	95%
Proportion of pest free pallets	**8,478** out of 10,000 pallets	**9,332** out of 10,000 pallets	**9,766** out of 10,000 pallets	**9,951** out of 10,000 plants	**9,,995** out of 10,000 pallets
Percentile of the distribution	5%	25%	Median	75%	95%
Proportion of infested pallets	**5.11** out of 10,000 pallets	**48.7** out of 10,000 pallets	**234** out of 10,000 pallets	**668** out of 10,000 pallets	**1,522** out of 10,000 pallets

A.2.1.4. Reasoning for a scenario which would lead to a reasonably low or high number of infested consignments (pallet) and main uncertainties: Option B (the set-point temperature is 3–4°C), sample size is 800–2,800 fruits

Uncertainties	Reasoning for a scenario which would lead to a reasonably low number of infested consignments (pallet)	Reasoning for a scenario which would lead to a reasonably high number of infested consignments
Field		
The actual pest prevalence in the orchards exporting to the EU.	Pest abundance is low. Fruits originate from areas with low pest prevalence (e.g. Port Elizabeth).	Pest abundance is high. Fruits originate from areas with high pest prevalence (e.g. Limpopo).
The location of the orchard in relation to orchards not within the systems approach.	Export plots are isolated from other orchards where mating disruption or SIT is not applied.	Export plots are close to other orchards where mating disruption or SIT is not applied.
The consistency of the application of the required measures within the systems approach by the exporting orchards.	Compliance with the systems approach is consistent throughout all citrus production orchards.	Compliance with the systems approach is not consistent throughout all citrus production orchards.

Uncertainties	Reasoning for a scenario which would lead to a reasonably low number of infested consignments (pallet)	Reasoning for a scenario which would lead to a reasonably high number of infested consignments
The reliability of the monitoring system in the field (e.g. using data-trees and fallen fruits).	Inspection of fallen fruits is effective to detect infested fruit in the field, e.g. large larvae, exit holes.	Inspection of fallen fruits under specific data trees is not reflecting the situation in the whole orchard
The proper implementation of the sanitation throughout the season in all export orchards.	Sanitation and fruit destruction occur frequently and accordingly disrupts population build-up in orchards.	Sanitation and fruit destruction is not properly applied and accordingly it may not disrupt population build-up in orchards.
The efficacy and proper application of the control measures for FCM.	Biological control (virus) is applied timely and therefore is effective in controlling *T. leucotreta*.	The proper timing in the application of biological control (virus) is difficult for an organism with overlapping generations and hence is not controlling properly *T. leucotreta*.
Sorting at harvest biases the infestation level and detectability in the packing houses.	During the harvesting only symptomless fruit is collected for packing and infestation level of fruit arriving to the packing house is reduced	Collecting only symptomless fruit reduces the detectability in the packing house and the efficiency of the inspection before packing.
Packing house		
The sample at the packing house level is representative for the entire orchard and season.	The sampling done in the packing house is representative for the whole harvest in the orchard (i.e. harvested in 1 day, or in the same period).	There is spatial and temporal variation in the infestation levels of harvested lots of the same orchard while the inspection is only checking the first delivery.
The efficacy of the visual inspection at delivery at the packing house in relation to the actual sample size.	Visual inspection at delivery in the packing house is effective in detecting and removing infested lots.	Because only clean fruit is taken to the packing house, it will mask a higher infestation level identified by visual inspection.
The consistency in implementation of the systems approach requirements by the packing houses across the whole country.	The systems approach requirements are properly applied by the packing houses.	The systems approach is not consistently applied by the packing houses.
The proportion of different cultivars in the consignments handled under the chosen regime.	Exported citrus cultivars are not susceptible to *T. leucotreta* infestations (e.g. grapefruit).	Most of the exported citrus cultivars are susceptible to *T. leucotreta* infestations (e.g. mandarines).
Export procedure		
The efficacy of the visual inspection before export	Visual inspection before export is effective in detecting and removing infested lots.	Visual inspection before export is not effective in detecting and removing infested lots.
Shipping temperature regime		
The actual time and proper application of the cooling treatment during storage and shipping.	The duration of the shipping and cooling time and the temperature applied leads to a high mortality rate of the pest in the consignment	The duration of the shipping and cooling time and the temperature applied is not sufficient to kill all the larvae of the pest in the consignment.
The mortality data presented for the different temperature regimes are reliable.	The mortality rates presented in the Dossier Section 1.4 are reliable.	Mortality rates are not reliable due to unknown sample sizes and experimental conditions.
The implementation of the treatment of the temperature regimes during shipment.	The cooling treatment during shipment (below 4°C) is applied, monitored and checked properly.	Cooling treatment is not properly applied and monitored during storage and shipment.

A.2.1.5. Reasoning for the median value

- Option B has the highest temperature which is the less effective in killing the larvae of *T. leucotreta*.

A.2.1.6. Exported citrus fruits shipped under option C

Elicited values *Thaumatotibia leucotreta* for pallets with citrus fruits					
Rating of the likelihood of pest freedom	**Pest free with some exceptional cases** (based on the median).				
Percentile of the distribution	5%	25%	Median	75%	95%
Proportion of pest free pallets	**9,743** out of 10,000 pallets	**9,890** out of 10,000 pallets	**9,959** out of 10,000 pallets	**9,991** out of 10,000 plants	**9,999.6** out of 10,000 pallets
Percentile of the distribution	5%	25%	Median	75%	95%
Proportion of infested pallets	**0.371** out of 10,000 pallets	**9.49** out of 10,000 pallets	**41.1** out of 10,000 pallets	**110** out of 10,000 pallets	**257** out of 10,000 pallets

A.2.1.7. Reasoning for a scenario which would lead to a reasonably low or high number of infested consignments (pallet); Option C (set-point temperature -1–0°C and the sample size is 800 fruits)

Uncertainties	**Reasoning for a scenario which would lead to a reasonably low number of infested consignments (pallet)**	**Reasoning for a scenario which would lead to a reasonably high number of infested consignments**
Field		
The actual pest prevalence in the orchards exporting to the EU. The actual pest prevalence in the orchards exporting to the EU.	Pest abundance is low. Fruits originate from areas with low pest prevalence (e.g. Port Elizabeth).	Pest abundance is high. Fruits originate from areas with high pest prevalence (e.g. Limpopo).
The location of the orchard in relation to orchards not within the systems approach.	Export plots are isolated from other orchards where mating disruption or SIT is not applied.	Export plots are close to other orchards where mating disruption or SIT is not applied.
The consistency of the application of the required measures within the systems approach by the exporting orchards.	Compliance with the systems approach is consistent throughout all citrus production orchards.	Compliance with the systems approach is not consistent throughout all citrus production orchards.
The proper implementation of the sanitation throughout the season in all export orchards.	Sanitation and fruit destruction occur frequently and accordingly disrupts population build-up in orchards.	Sanitation and fruit destruction is not properly applied and accordingly it may not disrupt population build-up in orchards.
The efficacy and proper application of the control measures for FCM.	Biological control (virus) is applied timely and therefore is effective in controlling *T. leucotreta*.	The proper timing in the application of biological control (virus) is difficult for an organism with overlapping generations and hence is not controlling properly *T. leucotreta*.
Sorting at harvest biases the infestation level and detectability in the packing houses.	During the harvesting only symptomless fruit is collected for packing and infestation level of fruit arriving to the packing house is reduced.	Collecting only symptomless fruit reduces the detectability in the packing house and the efficiency of the inspection before packing.
The delivery was already rejected for option A.	The material coming directly from the orchard for option C	The material was rejected, not complying for option A

Uncertainties	Reasoning for a scenario which would lead to a reasonably low number of infested consignments (pallet)	Reasoning for a scenario which would lead to a reasonably high number of infested consignments
Packing house		
The sample at the packing house level is representative for the entire orchard and season.	The sampling done in the packing house is representative for the whole harvest in the orchard (i.e. harvested in 1 day, or in the same period).	There is spatial and temporal variation in the infestation levels of harvested lots of the same orchard while the inspection is only checking the first delivery.
The efficacy of the visual inspection at delivery at the packing house in relation to the actual sample size.	Visual inspection at delivery in the packing house is effective in detecting and removing infested lots.	Because only clean fruit is taken to the packing house, it will mask a higher infestation level identified by visual inspection.
The consistency in implementation of the systems approach requirements by the packing houses across the whole country.	The systems approach requirements are properly applied by the packing houses.	The systems approach is not consistently applied by the packing houses.
The proportion of different cultivars in the consignments handled under the chosen regime.	Exported citrus cultivars are not susceptible to *T. leucotreta* infestations (e.g. grapefruit).	Most of the exported citrus cultivars are susceptible to *T. leucotreta* infestations (e.g. mandarines).
Export procedure		
The efficacy of the visual inspection before export.	Visual inspection before export is effective in detecting and removing infested lots.	Visual inspection before export is not effective in detecting and removing infested lots.
Shipping temperature regime		
The actual time and proper application of the cooling treatment during storage and shipping.	The duration of the shipping and cooling time and the temperature applied leads to a high mortality rate of the pest in the consignment.	The duration of the shipping and cooling time and the temperature applied is not sufficient to kill all the larvae of the pest in the consignment.
The mortality data presented for the different temperature regimes are reliable.	The mortality rates presented in the dossier section 1.4	Mortality rates are not reliable due to unknown sample sizes and experimental conditions.
The implementation of the treatment of the temperature regimes during shipment.	The cooling treatment during shipment (below 0°C) is applied, monitored and checked properly.	Cooling treatment is not properly applied and monitored during storage and shipment.

A.2.1.8. Reasoning for the median value

- In 2020, there were two shipments applying option C (EC0 and ECW0) were rejected at import in the EU due to the presence of living stages of *T. leucotreta*.
- Unrestrictive screening system which would allow higher infestations.
- Uncertainty on the mortality rate at 0°C and/or the correct application of the temperature regime as underlined by the intercepted consignments in EU.

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Hattingh V, Moore S, Kirkman W, Goddard M, Thackeray S, Peyper M and Pringle K, 202). An improved systems approach as a phytosanitary measure for *Thaumatotibia leucotreta* (Lepidoptera: Tortricidae) in Export Citrus Fruit From South Africa. Journal of Economic Entomology, 113, 700–711.

Appendix B – Recalculation of the pathway model

In the following appendix the pathway model described in Hattingh et al. (2020) and Moore et al. (2016) is reviewed and recalculated. It follows the harvest of an individual orchard from the orchard to the place of import into the European Union.

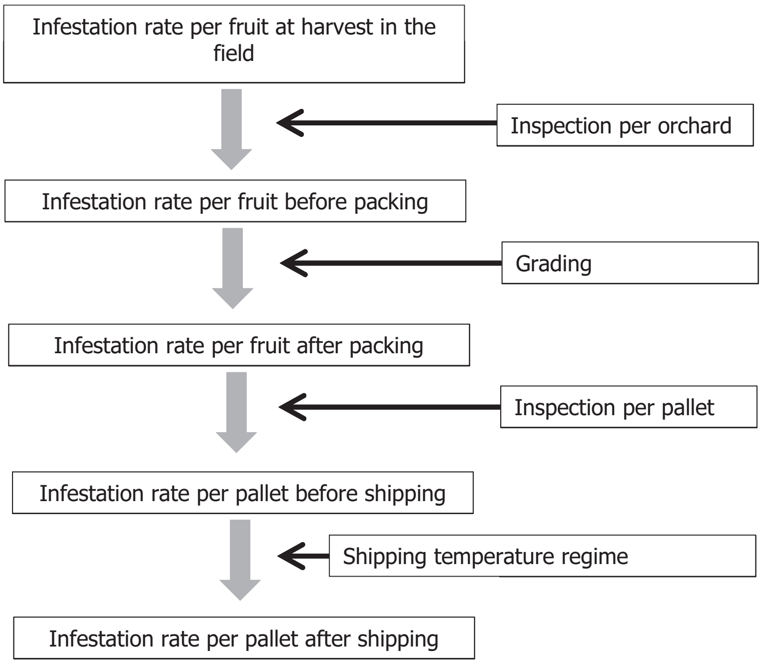

Figure B.1: Pathway of citrus fruits from harvest to import and measures of the system approach

To calculate the infestation rates on the different steps in the pathway following parameter were modelled with corresponding uncertainty distributions. An infestation is defined as a citrus fruit containing at least one live larvae. For the mortality during the cold treatment it is assumed, that each infested fruit contains one larvae.

Table B.1: Parameters of the pathway model as reported in Moore et al. (2016a,b,c) and Hattingh et al. (2020)

Abbreviation	Unit	Description
I	%	Infestation level in the field: Proportion of infested fruits after harvest in the field
D	%	Visual detectability: Proportion of infested fruits, which show visual signs of infestation
H	%	Human Performance: Proportion of infested fruits with visual signs, which will be detected by visual inspection
G	%	Grading factor: Proportion of infested fruits, which will be discarded by sorting and grading at the packing house
T	%	Mortality rate: Proportion of infested fruits, where the larvae will die during the cold treatment.

According to the system approach, the inspection intensity and shipping temperature regimes setting depend on the selection of different options. The calculations were made for two different scenarios, how the options are selected.

1) Selection of the option with minimal required temperature regime during shipping

The fruit harvested in each orchard is tested at the packing house according to the system approach. When the criteria for an option/scheme is fulfilled, the harvest is shipped under the option/scheme with the mildest cold treatment. Following order of options/schemes is applied in the calculations.

Table B.2: Parameters of testing and shipping conditions for the different options/schemes in the system approach

Option	Scheme	Testing before packing	Shipping	Temp.	Cooling time
		Sample size: N Rejection criterium: > k		[°C]	[d]
B	1	2,800, > 1	EC4 CT	4	16 or more
B	2	1,900, > 1	EC4 PE	4	16 or more
B	3	1,000, > 1	EC4 D	4	16 or more
B	4	1,000, > 1	EC35	3.5	16 or more
B	5	800, > 1	EC3	3	16 or more
A	6	800, > 1	EW2	2	16 or more
A	7	800, > 2	EC2	2	16 or more
A	8–9	800, > 2	EC1, EW1[1]	1	14 or more
A	10	800, > 2	EW01	–1	14 or more
C	11–12	800, > 5	EC0, ECW0	0	16 or more
C	13–14	800, > 5	EC01,ECW01	–1	16 or more

[1]This implies that shipments under an option/scheme with less restricted testing were rejected during the testing of the options above. The system approach is describing the procedure as follows:

'***Option B****: To use Option B, there may not be more than 1 infested fruit detected in the sample of 800, 1,000, 1,900 or 2,800 fruit. If 2 or more infested fruit are detected in the sample, the fruit from the orchard defaults to export under Option A for the season, if the detected infestation does not exceed the requirements for Option A.'* (System approach section 7.2.6)

'***Option A****: To use Option A, there may not be more than 2 infested fruit detected in the sample of 800 fruit. If 3 to 5 infested fruit are detected in the sample, the fruit from the orchard defaults to export under Option C for the season.' [...] 'To be able to use Option A, with regime code EW2[...], there may not be more than 1 infested fruit detected in the sample of 800 fruit.'* (System approach section 7.2.5)

'***Option C****: To use Option C, there may not be more than 5 infested fruit detected in the sample of 800 fruit. If 6 or more infested fruit are detected in the sample, the fruit from the orchard cannot be exported under the FMS'* (System approach section 7.2.7)

2) Randomly selected option

In this scenario the harvest is randomly assigned to an option/scheme and will not be exported, if the requirements of the selected option are not fulfilled. Thus in this scenario each option is evaluated independently from the other options.

Both scenarios defining a range of possible infestation rates for each option/scheme. The first scenario gives an upper limit for the infestation rate, while the second describes a lower limit. Depending on the actual allocation process of a harvest to an option/scheme, the infestation rate will be placed in the range.

B.1. Infestation level in the field: I

Hattingh et al. (2020) reports in table 3 the infestation level after harvest for 10 mandarin orchards at delivery at packing house. To estimate the infestation level, 300 fruits were sampled:

Table B.3: Infestation rates of fruits at harvest reported in Hattingh et al. (2020)

No. of packing houses	No of infested fruits per sample	Estimated infestation level	Lower limit of the 95% CI	Upper limit of the 95% CI
6	0 per 300	**0.000%**	0.000%	0.017%[(1)]
3	1 per 300	0.333%	0.008%	1.843%
1	3 per 300	1.000%	0.207%	**2.894%**
All 10	6 per 3000	**0.2000%**	0.073%	0.435%

(1): One-sided 95% CI, otherwise: two-sided Clopper–Pearson 95% CI

Moore et al. (2016a,b,c) reports infestation levels of 33 sweet orange orchards of Navel (N) and Valencia (V) sweet oranges. The sample sizes are not reported.

Table B.4: Infestation rates of fruits at harvest reported in Moore et al. (2016a,b,c)

Orchards	Sample size	Minimum reported infestation level	Average reported infestation level	Maximum reported infestation level
All 33 orchards	unknown	0.000%	0.607%	4.810%
Only 22 orchards compliant on fields in the last 4 weeks	unknown	0.000%	0.300%	2.160%

For the simulation, the infestation rates of the 22 compliant orchards were used. It is assumed, that the reported infestation rates resulting from a sampling of 600 fruits, as foreseen in the testing scheme of Moore et al. (2016a,b,c). The CI for the infestation rate is calculated for each orchard:

Table B.5: Infestation rates of citrus fruits at harvest in compliant orchards as reported in Moore et al. (2016a,b,c).

Orchard	Reported rate (%)	N sample	Infested	Low-CI	High-CI	Values for fitting
SO73	0	600	0	0.00%	0.0085%	0.0043%
LD1	0	600	0	0.00%	0.0085%	0.0043%
KD17	0	600	0	0.00%	0.0085%	0.0043%
BH2	0	600	0	0.00%	0.0085%	0.0043%
EN13	0	600	0	0.00%	0.0085%	0.0043%
ITSCE7	0	600	0	0.00%	0.0085%	0.0043%
MH8C	0	600	0	0.00%	0.0085%	0.0043%
MH15A	0	600	0	0.00%	0.0085%	0.0043%
MH24C	0	600	0	0.00%	0.0085%	0.0043%
GR8A	0	600	0	0.00%	0.0085%	0.0043%
LA29B	0	600	0	0.00%	0.0085%	0.0043%
LA35A	0	600	0	0.00%	0.0085%	0.0043%
LA7A	0	600	0	0.00%	0.0085%	0.0043%
MI10aA	0	600	0	0.00%	0.0085%	0.0043%
GR3.5B	0.17	600	1	0.00%	0.93%	0.170%
AK5	0.2	600	1	0.00%	0.93%	0.200%
HA51	0.24	600	1	0.00%	0.93%	0.240%
ITSCC7	0.35	600	2	0.04%	1.20%	0.350%
EL42	0.8	600	5	0.27%	1.93%	0.800%
RV55	1.12	600	7	0.47%	2.39%	1.120%
WV51	1.56	600	9	0.69%	2.83%	1.560%
WV50	2.16	600	13	1.16%	3.68%	2.160%
Sum		**12,600**	**26**	**0.13%**	**0.30%**	**0.206%**

Finally for zero infested orchards the half of the detection limit was used and a Generalised Beta-distribution fitted to these data:

BetaGeneral(0.26125, 2.8049, 0, 0.0368)

The range is set from 0% to 3.68%, which is the upper confidence level of the orchard with the highest infestation rate.

It should be noted, that this distribution relates to the former selection criteria in the field, which was changed later. Nevertheless no other data are available.

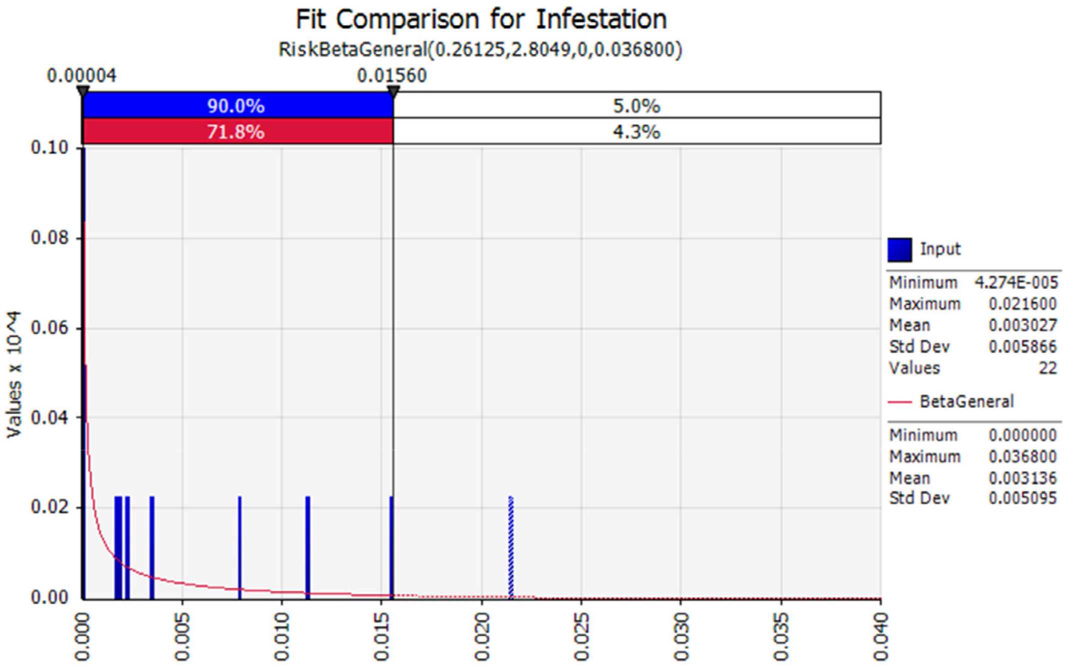

Figure B.2: Uncertainty distribution of the infestation rate of compliant citrus orchards in South Africa as used in the recalculation of the pathway model

Table B.6: Percentiles of the uncertainty distribution of the infestation rate of compliant citrus orchards in South Africa as used in the recalculation of the pathway model

	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
I	0.314%	0.000%	0.000%	0.000%	0.001%	0.005%	0.015%	0.074%	0.237%	0.396%	0.654%	1.001%	1.461%	2.327%

B.2. Post-harvest inspection

The quality of the inspection is determined by three factors:

a) the visual detectability D of an infection,
b) the human performance H during the inspection,
c) and the sample size N and rejection rule: 'Reject, if number infested > k'

While the first two factors decrease the likelihood to identify an infection by visual inspection, influences the latter the proportion of orchard deliveries, which are passing although principally detectable.

The proportion of visual detectable fruits is:

$$I \times D \times E,$$

this is the proportion of infested fruits 'I'; times the proportion of infested fruits, which are externally detectable 'D'; times the proportion of detectable fruits, which will be detected by staff under real conditions in the packing house 'H' (human factor).

Proportion of infested fruits per sample is binomial distributed: BINOMIAL(N, I × D × H)

B.2.1. Visual detectability: D

From Table B.7 in Hattingh et al. (2020) updating the data of Moore et al. (2016a,b,c) on external detectability. Ten samples were reported with following detection rates:

Table B.7: Detectability rates D reported in Hattingh et al. (2020)

Packing house	N infested fruits	N visually detected	Detection rate	Lower 95% CI	Upper 95% CI
SK	8	6	75.00%	34.91%	96.81%
SH	13	10	76.92%	46.19%	94.96%
UF	17	12	70.59%	44.04%	89.69%
SC	14	10	71.43%	41.90%	91.61%
SK	5	4	80.00%	28.36%	99.49%
SH	5	5	100.00%	98.98%	100.00%
SS	3	2	66.67%	9.43%	99.16%
W	4	4	100.00%	98.73%	100.00%
UF	16	11	68.75%	41.34%	88.98%
PSB	24	21	87.50%	67.64%	97.34%
All	109	85	**77.98%**	**69.03%**	**85.35%**

Hattingh et al. (2020) reporting the average and standard deviation of the detection rate, which leads to a 95% confidence interval of the mean estimate 79.69% of [72.08–87.29%].

For the simulation a Triangular distribution was chosen with the confidence interval of the combined sample (TRIANG(69.03%, 77.98%, 85.35%)). This assumption is close to the 95% CI of the mean estimate.

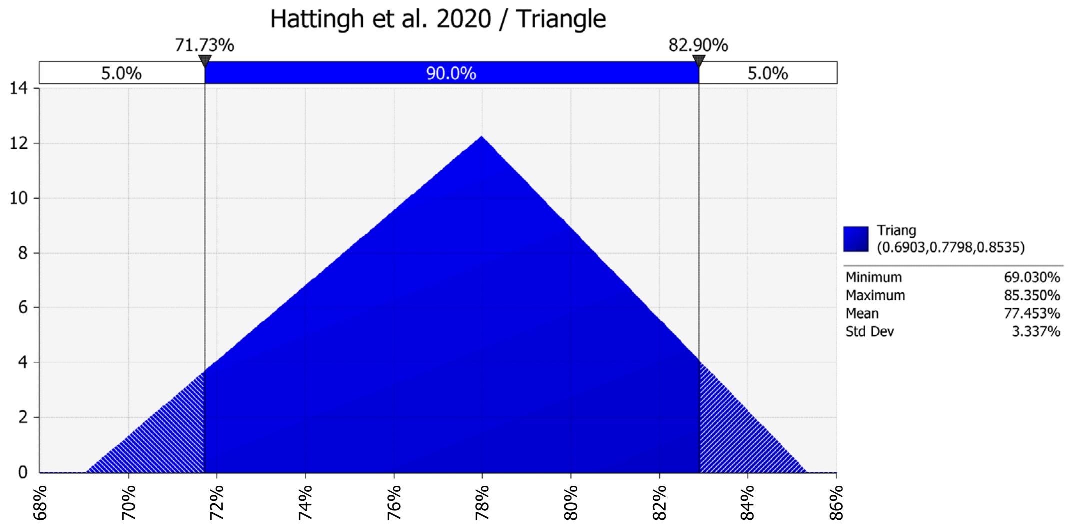

Figure B.3: Uncertainty distribution of the detectability rate D at packing houses in South Africa as used in the recalculation of the pathway model

Table B.8: Percentiles of the uncertainty distribution of the detectability rate D at packing houses in South Africa as used in the recalculation of the pathway model

	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
D	77.5%	70.2%	71.7%	72.9%	74.0%	75.1%	76.0%	77.6%	79.0%	79.9%	80.9%	81.9%	82.9%	84.3%

B.2.2. Human Performance: H

The human performance is roughly estimated by Moore et al. (2016a,b,c, 1,568) as 50%. It is described as follows:

'*H = human factor as a proportion (conservatively and arbitrarily assuming only a 50% efficiency of the person conducting the inspection i.e., 0.5)*' (ibid.)

For the simulation, a Triangular distribution was chosen with modus at 50% and a range from 40% to 75% (TRIANG(40%, 50%, 75%)).

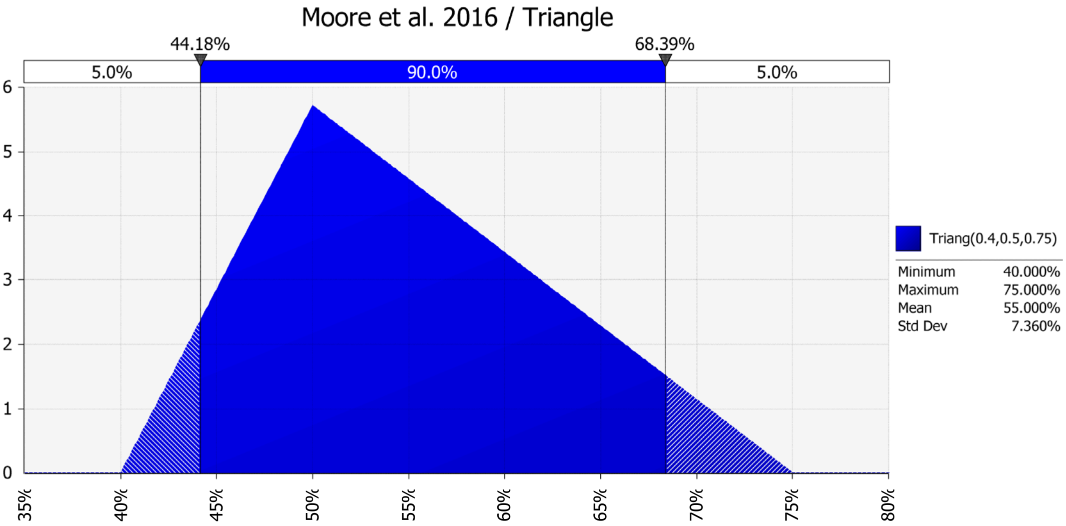

Figure B.4: Uncertainty distribution of the human factor H at packing houses in South Africa as used in the recalculation of the pathway model

Table B.9: Percentiles of the uncertainty distribution of the human factor at packing houses in South Africa as used in the recalculation of the pathway model

	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
H	55.0%	41.9%	44.2%	45.9%	47.6%	49.4%	50.8%	54.1%	57.9%	60.2%	62.9%	65.6%	68.4%	72.0%

This leads to the distribution of fruits with detectable infections:

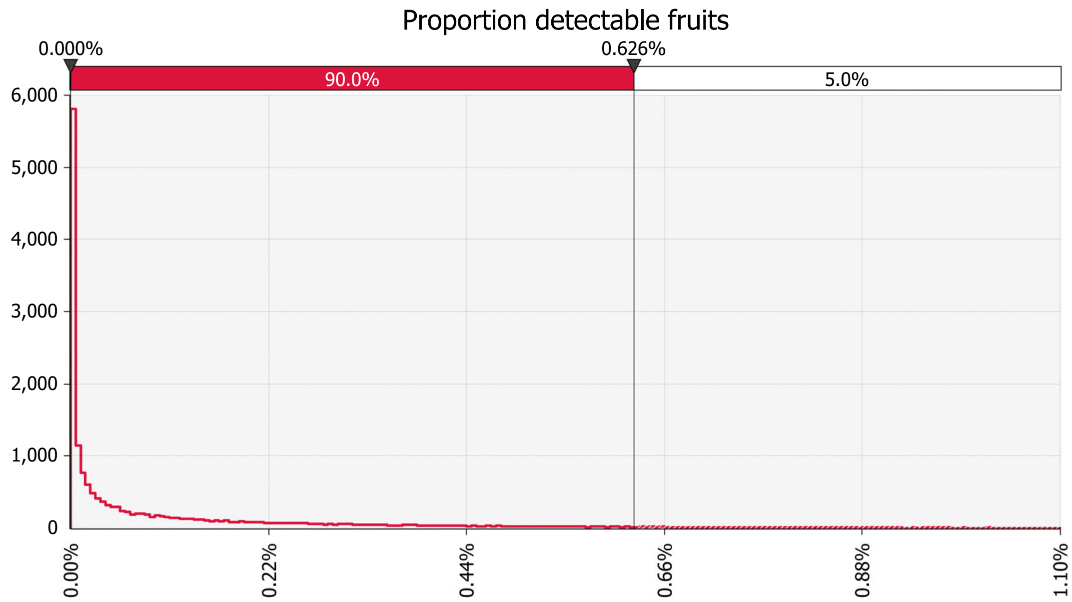

Figure B.5: Uncertainty distribution of the of detectable fruits at visual inspections (I × D × H) at packing houses in South Africa as used in the recalculation of the pathway model

Table B.10: Percentiles of the uncertainty distribution of detectable fruits at visual inspections (I × D × H) at packing houses in South Africa as used in the recalculation of the pathway model

	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
Prop. of detectable fruits	0.134%	0.000%	0.000%	0.000%	0.000%	0.002%	0.006%	0.031%	0.100%	0.167%	0.276%	0.423%	0.626%	1.008%

The following numbers of detectable fruits will be in the samples of different sizes:

Table B.11: Percentiles of the uncertainty distribution of detectable fruits within samples of different sizes for visual inspections (BINOMIAL(N, I × D × H)) at packing houses in South Africa as used in the recalculation of the pathway model

Sample size N	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
800	1.1	0	0	0	0	0	0	0	1	1	2	4	5	10
1000	1.3	0	0	0	0	0	0	0	1	2	3	4	7	12
1900	2.5	0	0	0	0	0	0	0	2	3	5	8	12	21
2800	3.8	0	0	0	0	0	0	1	3	5	8	12	18	30

B.3. Testing at packing house

In the system approach different testing strategies were defined:

Table B.12: Testing strategies for different options/schemes in the system approach

Scheme	Option	Shipping	Sample size	Rejection criteria
			N	> k
1	**B**	EC4 CT	2,800	> 1
2	**B**	EC4 PE	1,900	> 1
3, 4	**B**	EC35, EC4 D	1,000	> 1
5, 6	**B/A**	EC3, EW2	800	> 1

Scheme	Option	Shipping	Sample size	Rejection criteria
7–10	**A**	EC2, EC1, EW1, EW01	800	> 2
11–14	**C**	EC0, ECW0,EC01,ECW01	800	> 5

In the simulation study 50,000 orchards were simulated with an infestation rate of I and tested for all test strategies with parameters D, H, N, k.

According to the System Approach, an orchard delivery can enter with scheme no. 1 and in case of rejection be used in one of the following schemes, if the specific criteria are fulfilled. In the simulation each delivery is allocated to the first scheme, it fulfils the testing criteria. This means, that a delivery allocated in scheme no. (5-)6 is not fulfilling the criteria of schemes no. 1–4.

Table B.13: Allocation of the harvest of different orchards in the scenario of allocation to the option/scheme with minimal required cold treatment

First possible scheme	Proportion of deliveries
1	58.5%
2	5.7%
3, 4	9.8%
5, 6	3.4%
7–10	7.6%
11–14	10.3%
none	4.9%

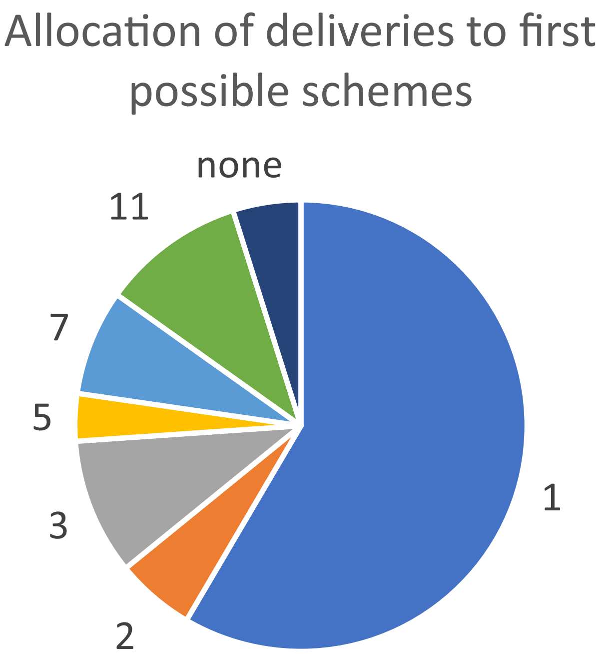

Figure B.6: Allocation of the harvest of different orchards in the scenario of allocation to the option/scheme with minimal required cold treatment

In the scenario of allocation to the option/scheme with minimal required cold treatment 58.5% of the orchards are qualified for the scheme 1 under Option B, and 4.9% of the orchard harvests are not qualified at all for export after the first testing at the packing house.

Regarding the reported figures on the allocation of containers to the different schemes:

Table B.14: Allocation of the harvest of different orchards in the scenario of allocation to the option/scheme with minimal required cold treatment

Scheme	Option	Transport cooling regime and harbour	Proportion of containers going from South Africa to the EU
1	B	EC4 CT	0.52%
2	B	EC4 PE	0.52%
3	B	EC4 D	0.52%
4	B	EC35	1.34%
5	B	EC3	0.83%
6	A	EW2	61.76%
7	A	EC2	10.23%
8–10	A	EC1, EW1, EW01	0.78%
11–14	C	EC0, ECW0,EC01,ECW01	23.49%

Some orchard deliveries fulfilling more stringent criteria will be also used in later schemes. Thus, the simulation study is estimating an upper limit of the infestation rates allowed by the System Approach.

After testing before entering the packing house following infestation rates are possible under the different schemes

Table B.15: Infestation rates per fruits before packing

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	0.038%	0.000%	0.000%	0.000%	0.000%	0.001%	0.002%	0.009%	0.029%	0.047%	0.075%	0.115%	0.170%	0.307%
2	0.223%	0.019%	0.043%	0.064%	0.086%	0.112%	0.138%	0.186%	0.251%	0.296%	0.358%	0.433%	0.529%	0.726%
3, 4	0.360%	0.029%	0.072%	0.103%	0.140%	0.181%	0.218%	0.298%	0.404%	0.473%	0.580%	0.702%	0.845%	1.240%
5, 6	0.530%	0.042%	0.105%	0.154%	0.214%	0.273%	0.337%	0.464%	0.615%	0.711%	0.832%	0.996%	1.179%	1.626%
7–10	0.562%	0.062%	0.123%	0.172%	0.227%	0.292%	0.355%	0.488%	0.641%	0.753%	0.893%	1.056%	1.271%	1.727%
11–14	0.958%	0.176%	0.307%	0.392%	0.487%	0.588%	0.684%	0.884%	1.108%	1.247%	1.424%	1.629%	1.877%	2.350%
none	1.738%	0.576%	0.804%	0.989%	1.130%	1.290%	1.431%	1.694%	1.980%	2.147%	2.361%	2.568%	2.817%	3.183%

The level of infestation is increasing from scheme 1 to scheme 14, showing the decrease in testing rigour made to select the schemes.

B.4. Measures at packing house

B.4.1. Grading factor: G

Table B.5 in Hattingh et al. (2020) update the grading effect estimated by Moore et al. (2016a,b,c) from 17 orchards. Fruits were tested before packing:

Table B.16: Infestation rates before packing reported in Hattingh et al. (2020)

Orchard	No. fruits	No infested	Infestation rate	Lower 95% CI	Upper 95% CI
	568	1	0.18%	0.004%	0.977%
	645	0	0.00%	0.000%	0.008%
	568	2	0.35%	0.043%	1.266%
	567	0	0.00%	0.000%	0.009%
	657	2	0.30%	0.037%	1.095%
	655	1	0.15%	0.004%	0.848%
	382	3	0.79%	0.162%	2.278%
	610	2	0.33%	0.040%	1.179%
	610	1	0.16%	0.004%	0.910%
	469	0	0.00%	0.000%	0.011%
	382	5	1.31%	0.426%	3.028%

Orchard	No. fruits	No infested	Infestation rate	Lower 95% CI	Upper 95% CI
	463	0	0.00%	0.000%	0.011%
	590	4	0.68%	0.185%	1.727%
	612	0	0.00%	0.000%	0.008%
	589	0	0.00%	0.000%	0.009%
	734	4	0.54%	0.149%	1.389%
	587	8	1.36%	0.590%	2.668%
All orchards	**9,688**	**33**	**0.34%**	**0.235%**	**0.478%**

And after packing:

Table B.17: Infestation rates after packing reported in Hattingh et al. (2020)

Orchard	No. fruits	No infested	Infestation rate	Lower 95% CI	Upper 95% CI
	615	0	0.00%	0.000%	0.008%
	630	0	0.00%	0.000%	0.008%
	630	1	0.16%	0.004%	0.881%
	630	0	0.00%	0.000%	0.008%
	630	2	0.32%	0.038%	1.142%
	628	0	0.00%	0.000%	0.008%
	600	0	0.00%	0.000%	0.009%
	517	0	0.00%	0.000%	0.010%
	620	0	0.00%	0.000%	0.008%
	630	0	0.00%	0.000%	0.008%
	629	1	0.16%	0.004%	0.883%
	543	0	0.00%	0.000%	0.009%
	615	3	0.49%	0.101%	1.419%
	616	0	0.00%	0.000%	0.008%
	722	0	0.00%	0.000%	0.007%
	420	1	0.24%	0.006%	1.319%
	649	9	1.39%	0.636%	2.616%
All orchards	**10,324**	**17**	**0.16%**	**0.096%**	**0.264%**

In comparison of the total numbers the infestation rate reduced by 51.7% with a range from 0% to 79.93%.

Hattingh et al. (2020) report the average and standard deviation of the reduction rate, which leads to a 95% confidence interval of the mean estimate 66.10% of [37.50–94.70%]. Low infestations (zero infested before packing) were not used by Hattingh et al. (2020).

For the simulation a Triangular distribution were chosen with modus at 51.7% and a range from 0% to 79.93%. (TRIANG(0%, 51.7%, 79.93%))

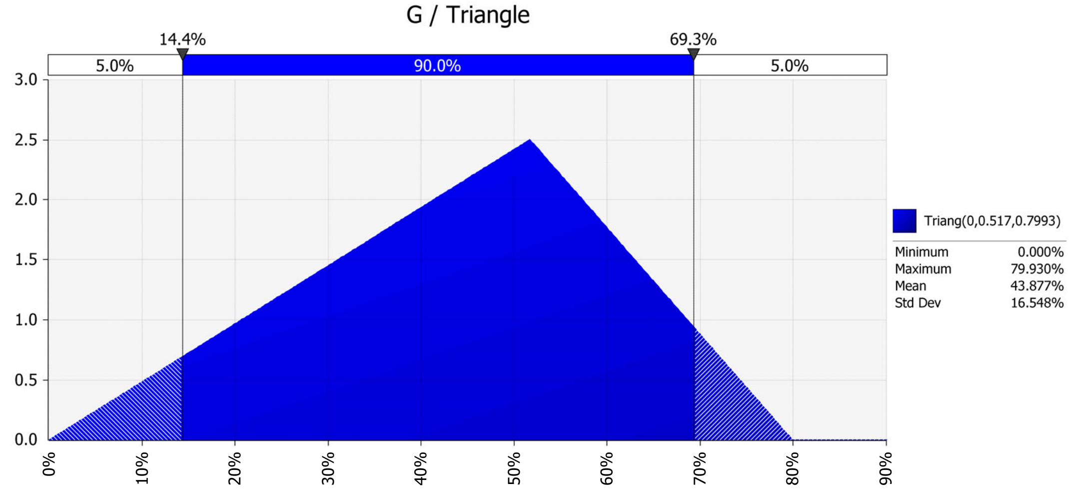

Figure B.7: Uncertainty distribution of the grading rate G at packing houses in South Africa as used in the recalculation of the pathway model

Table B.18: Percentiles of the uncertainty distribution of the grading rate at packing houses in South Africa as used in the recalculation of the pathway model

	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
G	43.9%	6.4%	14.4%	20.3%	26.2%	32.1%	37.1%	45.5%	52.5%	56.2%	60.5%	64.9%	69.3%	75.2%

Because the grading is acting on the individual fruits, it is assumed that the proportion of infested fruits per orchard delivery and grading efficiency are independent.

The following infestation rates are calculated after grading:

Table B.19: Infestation rates per fruits before packing

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	0.021%	0.000%	0.000%	0.000%	0.000%	0.000%	0.001%	0.005%	0.015%	0.025%	0.041%	0.064%	0.098%	0.186%
2	0.125%	0.010%	0.021%	0.032%	0.044%	0.058%	0.070%	0.102%	0.139%	0.163%	0.200%	0.247%	0.318%	0.481%
3, 4	0.202%	0.014%	0.036%	0.052%	0.072%	0.092%	0.115%	0.160%	0.222%	0.266%	0.327%	0.407%	0.510%	0.769%
5, 6	0.297%	0.020%	0.054%	0.077%	0.108%	0.138%	0.166%	0.240%	0.334%	0.398%	0.487%	0.580%	0.725%	1.140%
7–10	0.313%	0.027%	0.061%	0.085%	0.115%	0.149%	0.183%	0.255%	0.355%	0.419%	0.503%	0.605%	0.753%	1.071%
11–14	0.539%	0.080%	0.140%	0.191%	0.239%	0.301%	0.353%	0.466%	0.615%	0.709%	0.838%	0.979%	1.185%	1.589%

B.4.2. Inspection before export

According to the scheme each pallet will be visually inspected before export. A pallet consists of 80 cartons with 72 fruits each: In total 5,760 fruit. At least 2% = 116 fruits will be inspected.

The inspection takes two cartons with M = 144 fruits for inspection with a rejection rule:

A pallet is rejected, if at least 1 infested of 144 fruits are visually detected.

The simulation model applies the same detection factor and human performance as before to model the inspection:

Proportion of infested per sample is binomial distributed:

$$\text{BINOMIAL}(M, I \times (1 - G) \times D \times H).$$

With $I \times (1\text{–}G)$, the reduced infestation rate, and $D \times H$ the visual detectability by human inspection.

The following numbers of detectable fruits will be in the samples before export:

Table B.20: Percentiles of the uncertainty distribution of detectable fruits within samples of two boxes for visual inspections (BINOMIAL(M, I × (1 – G) × D × H)) at packing houses in South Africa as used in the recalculation of the pathway model

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	0.0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0.1	0	0	0	0	0	0	0	0	0	0	0	1	1
3, 4	0.1	0	0	0	0	0	0	0	0	0	0	1	1	2
5, 6	0.2	0	0	0	0	0	0	0	0	0	0	1	1	2
7–10	0.2	0	0	0	0	0	0	0	0	0	1	1	1	2
11–14	0.3	0	0	0	0	0	0	0	0	1	1	1	2	2

Following infestation rate is passing the test before export:

Table B.21: Percentiles of the uncertainty distribution of infestation rates per fruit before export from South Africa as used in the recalculation of the pathway model

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	0.021%	0.000%	0.000%	0.000%	0.000%	0.000%	0.001%	0.005%	0.015%	0.024%	0.040%	0.061%	0.094%	0.180%
2	0.120%	0.010%	0.020%	0.030%	0.043%	0.057%	0.069%	0.098%	0.133%	0.157%	0.190%	0.236%	0.303%	0.429%
3, 4	0.188%	0.013%	0.034%	0.050%	0.069%	0.087%	0.109%	0.152%	0.208%	0.248%	0.303%	0.370%	0.468%	0.682%
5, 6	0.268%	0.020%	0.050%	0.071%	0.098%	0.128%	0.156%	0.219%	0.304%	0.356%	0.438%	0.536%	0.673%	0.868%
7–10	0.285%	0.026%	0.057%	0.079%	0.105%	0.137%	0.166%	0.233%	0.322%	0.381%	0.455%	0.553%	0.689%	1.014%
11–14	0.481%	0.074%	0.128%	0.169%	0.215%	0.271%	0.321%	0.418%	0.543%	0.631%	0.735%	0.881%	1.045%	1.416%

B.5. Shipping temperature regime

B.5.1. Mortality rate T

Mortality rates were taken for different travel durations, as reported in the dossier:

Table B.22: Assumed transport conditions in the model with reported mortality rates in the dossier

	Temperature	Minimum	Maximum
EC4 CT/PE/D	4°C	16 days	26 days or more
EC3/EC35(1)	3°C	16 days	24 days or more
EW2/EC2	2°C	16 days	19 days or more
EC1, EW1, EW01(1)	1°C	14 days	19 days or more
EC0, ECW0, EC01,(1)ECW01(1)	0°C	ISPM standard(2)	16 days or more

(1): approximate temperature.
(2): minimum approximated by the ISPM standard.

Regarding the cold regime and the travel time following mortality rates were assumed in the pathway model. The Modus were taken as average rate of minimum and maximum.

Table B.23: Assumed mortality rates in the pathway model

	Option	Shipping	Mortality rate		
			Min	Modus	Max
1	**B**	EC4 CT	84.0100%	97.0800%	99.5600%
2	**B**	EC4 PE	84.0100%	97.0800%	99.5600%
3	**B**	EC4 D	84.0100%	97.0800%	99.5600%
4	**B**	EC35	96.3000%	99.7000%	99.9999%
5	**B**	EC3	96.3000%	99.7000%	99.9999%
6	**A**	EW2	99.4100%	99.9600%	99.9999%
7	**A**	EC2	99.4100%	99.9600%	99.9999%

	Option	Shipping	Mortality rate		
			Min	Modus	Max
8–10	**A**	EC1, EW1, EW01	99.1000%	99.9700%	99.9999%
11–14	**C**	EC0, ECW0,EC01,ECW01	99.9972%	99.9986%	99.9999%

On 5 July 2021, South Africa provided additional data (dossier section 1.5) on the sample size of the mortality experiments which were reviewed by the Panel. It was concluded that the updated information did not change the conclusions of the simulation performed. In Table B.24, the revised information is listed.

Table B.24: Mortality rates to update the pathway model including information on the precision of the experiments on mortality rates for different shipping temperature regimes provided on 5 July 2021

	Option	Shipping	Mortality rate		
			Min	Modus	Max
1	**B**	EC4 CT	83.5669%(1)	97.0800%	99.6435%(1)
2	**B**	EC4 PE	83.5669%(1)	97.0800%	99.6435%(1)
3	**B**	EC4 D	83.5669%(1)	97.0800%	99.6435%(1)
4	**B**	EC35	95.9221%(1)	99.6900%	99.9999%
5	**B**	EC3	95.9221%(1)	99.6900%	99.9999%
6	**A**	EW2	99.1894%(1)	99.9100%	99.9999%
7	**A**	EC2	99.1894%(1)	99.9100%	99.9999%
8–10	**A**	EC1, EW1, EW01	98.9534%(1)	99.9700%	99.9999%
11–14	**C**	EC0, ECW0,EC01,ECW01	99.9972%(2)	99.9986%	99.9999%

(1): 95% CI of the corresponding estimate of the mortality rate for the shipping temperature regime (temperature and duration).
(2): approximated by the ISPM standard.

In the simulation Triangular distributions were chosen with the parameters above to model the mortality rates.

Following mortality rates are taken for the different cooling schemes:

Table B.25: Percentiles of the uncertainty distribution of mortality rates during cold treatment as used in the recalculation of the pathway model

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	93.6%	85.4%	87.2%	88.5%	89.8%	91.1%	92.2%	94.1%	95.7%	96.4%	97.0%	97.6%	98.2%	98.9%
2	93.6%	85.4%	87.2%	88.5%	89.8%	91.1%	92.2%	94.1%	95.7%	96.4%	97.0%	97.6%	98.2%	98.9%
3	93.5%	85.4%	87.2%	88.5%	89.8%	91.1%	92.2%	94.1%	95.7%	96.4%	97.0%	97.6%	98.2%	98.9%
4	98.7%	96.7%	97.1%	97.4%	97.7%	98.1%	98.3%	98.8%	99.2%	99.4%	99.5%	99.7%	99.8%	99.9%
5	98.7%	96.7%	97.1%	97.4%	97.7%	98.1%	98.3%	98.8%	99.2%	99.4%	99.5%	99.7%	99.8%	99.9%
6	99.8%	99.5%	99.5%	99.6%	99.6%	99.7%	99.7%	99.8%	99.9%	99.9%	99.9%	100.0%	100.0%	100.0%
7	99.8%	99.5%	99.5%	99.6%	99.6%	99.7%	99.7%	99.8%	99.9%	99.9%	99.9%	100.0%	100.0%	100.0%
8–10	99.7%	99.2%	99.3%	99.4%	99.5%	99.5%	99.6%	99.7%	99.8%	99.9%	99.9%	99.9%	100.0%	100.0%
11–14	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Resulting into following average infestation rates within pallets from different orchard deliveries (in number of infested fruits out of 10,000) after cold treatment:

Table B.26: Percentiles of the uncertainty distribution of infestation rates per pallet after cold treatment as used in the recalculation of the pathway model

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	0.13	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.08	0.13	0.23	0.38	0.62	1.35
2	0.78	0.04	0.08	0.12	0.18	0.25	0.33	0.53	0.82	1.00	1.33	1.72	2.36	3.81
3	1.21	0.049	0.12	0.20	0.30	0.42	0.54	0.82	1.25	1.59	2.08	2.73	3.55	5.76
4	0.25	0.007	0.020	0.034	0.050	0.07	0.10	0.16	0.25	0.32	0.43	0.57	0.79	1.36
5	0.36	0.012	0.029	0.046	0.071	0.10	0.14	0.23	0.37	0.48	0.61	0.81	1.14	1.84
6	0.055	0.001	0.004	0.007	0.011	0.015	0.021	0.035	0.057	0.075	0.10	0.13	0.17	0.27
7	0.060	0.002	0.005	0.008	0.012	0.017	0.023	0.041	0.063	0.082	0.11	0.14	0.18	0.29
8–10	0.089	0.002	0.006	0.010	0.016	0.023	0.032	0.055	0.089	0.119	0.16	0.21	0.29	0.46
11–14	0.00071	0.00007	0.00014	0.00019	0.00026	0.00034	0.00042	0.00058	0.00078	0.00094	0.0011	0.0014	0.0017	0.0026

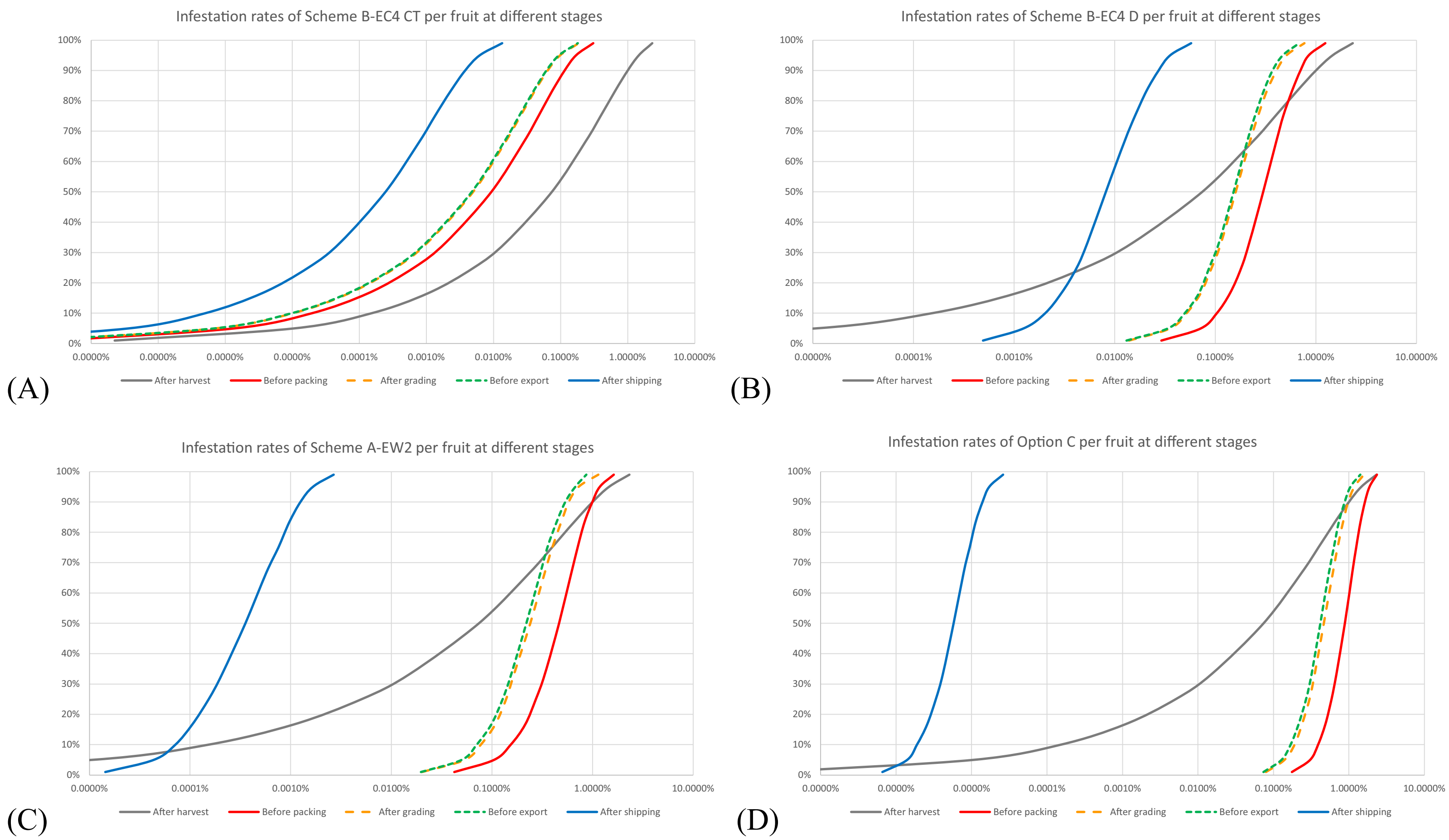

Figure B.8: Uncertainty distributions of the infestation rate per fruit after different steps of the pathway model under the scenario of allocation to the option with minimal required cold treatment for different option/schemes: (A) Scheme 1: B-EC4 CT; (B) Scheme 2: B-EC4-D; (C) Scheme 6: A-EW2; (D) Schemes 11-14: C. The steps are: 'grey' = after harvest; 'red' = before packing; 'yellow' = after packing; 'green' = before export; and 'blue' = after cold treatment. The 'grey' curve is similar in all four figures (starting point).

On the level of pallets with N = 5,760 fruits following numbers of larvae are expected per pallet before export:

Table B.27: Percentiles of the uncertainty distribution of number of infested fruits **per pallet** before applying the cold treatment as result of the recalculation of the pathway model

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	1.2	0	0	0	0	0	0	0	1	1	2	4	6	11
2	6.9	0	0	1	2	3	4	5	8	9	12	15	19	28
3, 4	10.8	0	1	2	3	5	6	9	12	14	18	22	28	42
5, 6	15.6	0	2	3	5	7	9	13	18	21	26	31	40	54
7–10	16.3	1	2	4	5	7	9	13	18	22	27	33	41	59
11–14	27.7	3	6	9	12	15	18	24	32	36	43	51	63	83

B.5.2. Infested pallets after transport: S (out of 10,000) under the scenario of allocation to the option with minimal required cold treatment

Applying the mortality rates for the consignment size 'pallet' following infestation rates **of pallets** from different orchard deliveries (in number of infested pallets out of 10,000):

Table B.28: Percentiles of the uncertainty distribution of proportion of infested pallets out of 10,000 after applying the cold treatment as result of the recalculation of the pathway model under the scenario of allocation to the option with minimal required cold treatment

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	632	0	0	0	0	0	0	0	365	773	1286	2156	3334	6005
2	3093	0	0	478	791	1190	1583	2578	3826	4592	5624	6726	7768	9252
3	4150	0	477	868	1315	1954	2553	3800	5260	6133	7154	8080	8917	9747
4	1238	0	76	153	251	363	497	854	1354	1716	2236	2847	3761	5730
5	1697	0	135	218	342	519	727	1250	1950	2453	3090	3896	4937	6692
6	306	0	19	34	53	81	114	197	323	437	555	727	951	1461
7	332	5	22	38	61	91	128	221	350	457	597	770	1034	1578
8–10	479	6	29	50	83	123	173	304	501	651	870	1153	1541	2341
11–14	4.1	0.2	0.7	1.0	1.4	1.8	2.3	3.3	4.5	5.5	6.7	8.2	11	15

Finally the average (using the initial distribution of the orchard deliveries to the options) infestation rates per Option (A, B, C) in the System Approach are calculated (in number of infested pallets out of 10,000) under the scenario of allocation to the option with minimal required cold treatment

Table B.29: Percentiles of the uncertainty distribution of the average proportion of infested pallets per out of 10,000 per option after applying the cold treatment as result of the recalculation of the pathway model under the scenario of allocation to the option with minimal required cold treatment

Option	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
B	1076	0.0	0.0	0.0	0.0	0.0	0.0	226	990	1543	2435	3494	4743	7161
A	387	61	75	89	114	146	184	271	404	489	631	825	1083	1628
C	4.1	0.2	0.7	1.0	1.4	1.8	2.3	3.3	4.5	5.5	6.7	8.2	11	15

These estimates indicate the infestation rates (out of 10,000 pallets) including the uncertainties mentioned in the papers of Hattingh et al. (2020) and Moore et al. (2016a,b,c).

Additional corrections will be done by the final uncertainty assessments per EKE.

B.5.3. Infested pallets after transport: S (out of 10,000) under the scenario of random allocation to the option/scheme in the system approach

The following table assumes that an orchard delivery is randomly allocated to the different schemes. Reported are infestation rates of pallets from different orchard deliveries (in number of infested pallets out of 10,000). The calculations follow the same pathway model.

Table B.30: Percentiles of the uncertainty distribution of proportion of infested pallets out of 10,000 after applying the cold treatment as result of the recalculation of the pathway model under the scenario of random allocation to the option/scheme in the system approach

Scheme	Mean	P1	P5	P10	P17	P25	P33	P50	P66	P75	P83	P90	P95	P99
1	632	0	0	0	0	0	0	0	358	762	1278	2137	3349	6069
2	839	0	0	0	0	0	0	0	615	1058	1801	2811	4245	7091
3	1245	0	0	0	0	0	0	0	1016	1685	2813	4242	5957	8697
4	335	0	0	0	0	0	0	0	195	334	611	1036	1725	3471
5	387	0	0	0	0	0	0	28	222	386	708	1210	1968	3969
6	67	0	0	0	0	0	0	4	35	62	115	198	339	773
7	88	0	0	0	0	0	0	11	46	85	154	265	442	932
8–10	128	0	0	0	0	0	0	14	68	123	224	383	643	1406
11–14	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	1.0	1.7	2.8	4	9

Appendix C – Elicited values for pest freedom

C.1. Elicited values for pest freedom (Option A)

The following Tables show the elicited and fitted values for pest infestation/infection (Table C.1) and pest freedom (Table C.2).

Table C.1: Elicited and fitted values of the uncertainty distribution of pest infestation by *Thaumatotibia leucotreta* per 10,000 pallets with citrus fruits

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Elicited values	2					50		100		450					1000
EKE	1.03	1.22	1.98	5.39	14.4	33.3	61.7	152	300	403	535	676	818	915	996

The EKE results is BetaGeneral(0.46142, 1.5574, 1, 1100) distribution fitted with @Risk version 7.6.

Based on the numbers of estimated infested pallets the pest freedom was calculated (i.e. = 10,000 − number of infested pallets with citrus fruits per 10,000). The fitted values of the uncertainty distribution of the pest freedom are shown in Table C.2.

Table C.2: The uncertainty distribution of pallets free of *Thaumatotibia leucotreta* per 10,000 pallets with citrus fruits calculated by Table C.1

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Values	9,000					9,550		9,900		9,950					9,998
EKE results	9,004	9,085	9,182	9,324	9,465	9,597	9,700	9,848	9,938	9,967	9,986	9,995	9,998	9,998.8	9,999.0

The EKE results are the fitted values.

C.2. Elicited values for pest freedom (Option B)

The following Tables show the elicited and fitted values for pest infestation/infection (Table C.3) and pest freedom (Table C.4).

Table C.3: Elicited and fitted values of the uncertainty distribution of pest infestation by *Thaumatotibia leucotreta* per 10,000 pallets with citrus fruits

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Elicited values	5					75		150		750					2000
EKE	4.03	4.23	5.11	9.44	21.6	48.7	91.1	234	483	668	918	1205	1522	1764	1989

The EKE results is BetaGeneral(0.43755, 1.9952, 4, 2400) distribution fitted with @Risk version 7.6.

Based on the numbers of estimated infested pallets the pest freedom was calculated (i.e. = 10,000 − number of infested pallets with citrus fruits per 10,000). The fitted values of the uncertainty distribution of the pest freedom are shown in Table C.4.

Table C.4: The uncertainty distribution of pallets free of *Thaumatotibia leucotreta* per 10,000 pallets with citrus fruits calculated by Table C.1

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Values	8,000					9,250		9,850		9,925					9,995
EKE results	8,011	8,236	8,478	8,795	9,082	9,332	9,517	9,766	9,909	9,951	9,978	9,991	9,994.9	9,995.8	9,996.0

The EKE results are the fitted values.

C.3. Elicited values for pest freedom (Option C)

The following Tables show the elicited and fitted values for pest infestation/infection (Table C.5) and pest freedom (Table C.6).

Table C.5: Elicited and fitted values of the uncertainty distribution of pest infestation by *Thaumatotibia leucotreta* per 10,000 pallets with citrus fruits

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Elicited values	1					13		25		130					350
EKE	0.01	0.093	0.371	1.49	4.18	9.49	17.2	41.1	81.0	110	151	199	257	305	356

The EKE results is BetaGeneral(0.49989, 2.8852, 0, 500) distribution fitted with @Risk version 7.6.

Based on the numbers of estimated infested pallets the pest freedom was calculated (i.e. = 10,000 – number of infested pallets with citrus fruits per 10,000). The fitted values of the uncertainty distribution of the pest freedom are shown in Table C.6.

Table C.6: The uncertainty distribution of pallets free of *Thaumatotibia leucotreta* per 10,000 pallets with citrus fruits calculated by Table C.5

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Values	9,650					9,870		9,975		9,987					9,999
EKE results	9,644	9,695	9,743	9,801	9,849	9,890	9,919	9,959	9,983	9,991	9,996	9,998.5	9,999.6	9,999.9	10,000

The EKE results are the fitted values.

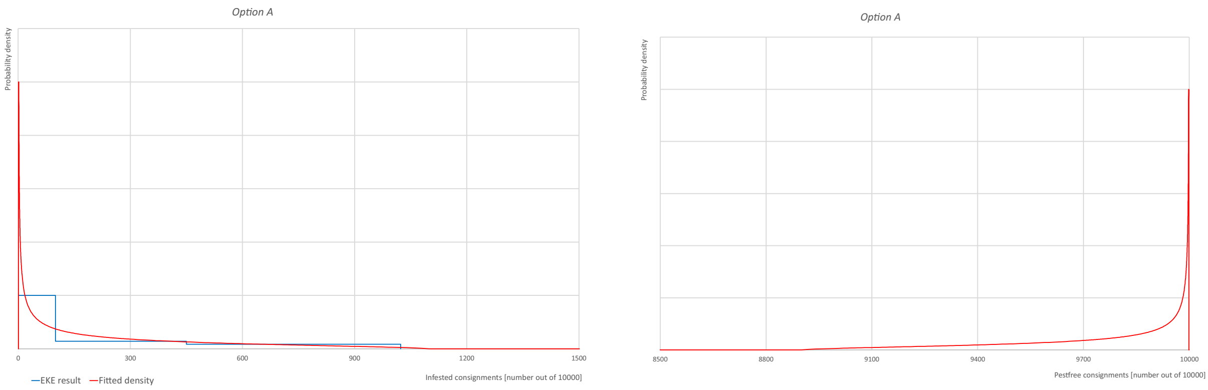

Figure C.1: Probability densities for the number of infested and pest-free pallets under option A out of 10,000 designated for export to the EU

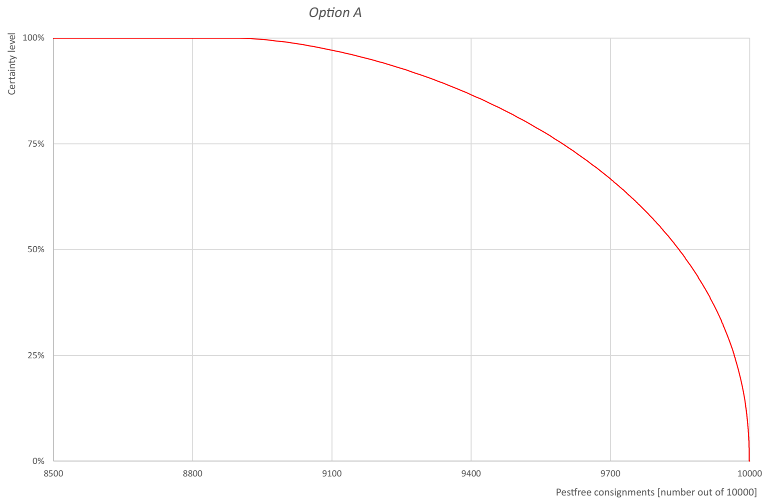

Figure C.2: Elicited certainty (y-axis) of the number of pest-free pallets under option A (x-axis is log-scaled) out of 10,000 pallets designated for export to the EU visualised as a descending distribution function. Horizontal lines indicate the percentiles (starting from the bottom 5%, 25%, 50%, 75%, 95%). The Panel is 95% sure that 9,182 or more pallets per 10,000 will be free from the pest

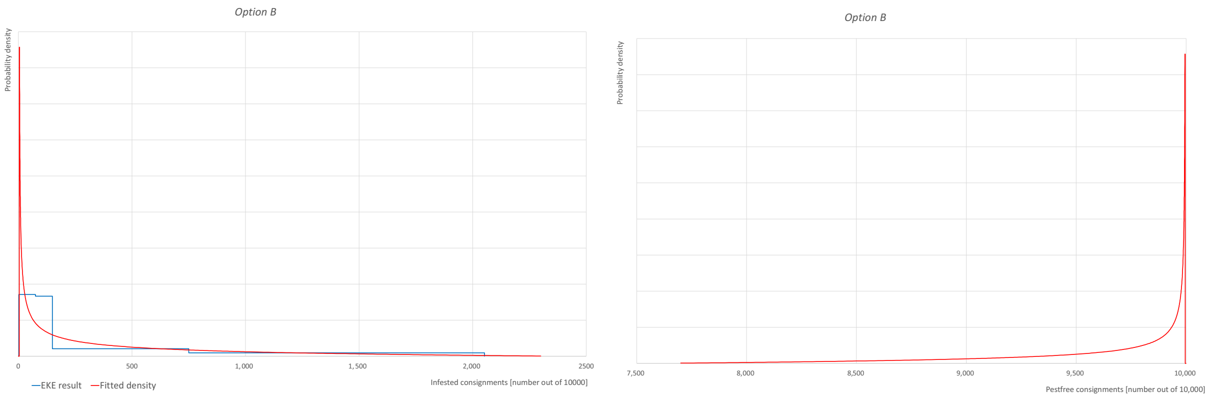

Figure C.3: Probability densities for the number of infested and pest-free pallets under option B out of 10,000 designated for export to the EU

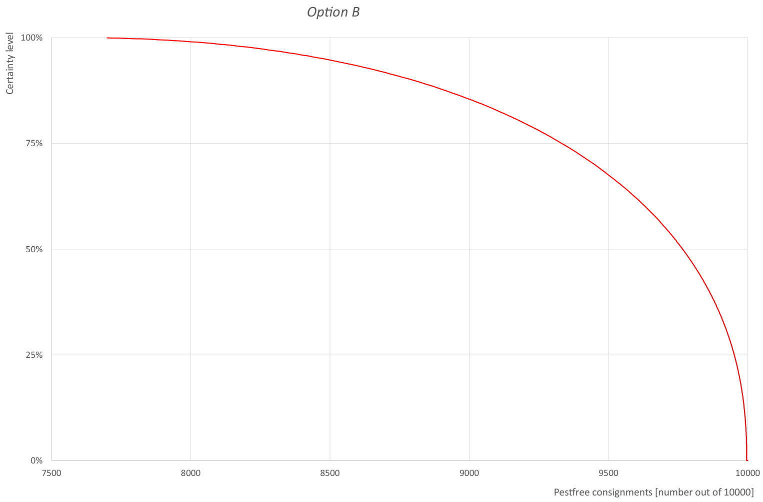

Figure C.4: Elicited certainty (y-axis) of the number of pest-free pallets under option B (x-axis is log-scaled) out of 10,000 pallets designated for export to the EU visualised as a descending distribution function. Horizontal lines indicate the percentiles (starting from the bottom 5%, 25%, 50%, 75%, 95%). The Panel is 95% sure that 8,478 or more pallets per 10,000 will be free from the pest

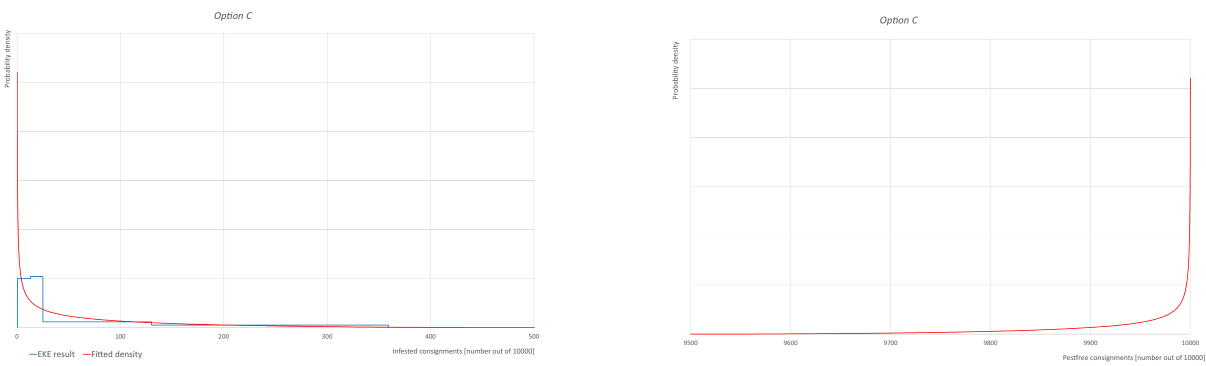

Figure C.5: Probability densities for the number of infested and pest-free pallets under option C out of 10,000 designated for export to the EU

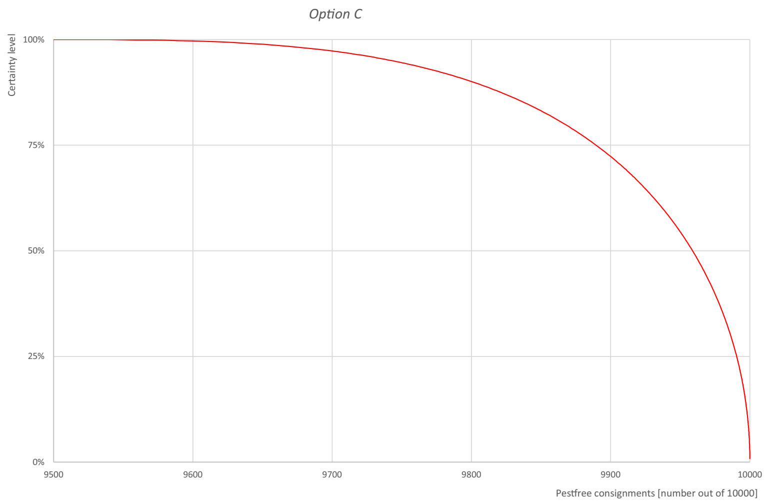

Figure C.6: Elicited certainty (y-axis) of the number of pest-free pallets under option C (x-axis is log-scaled) out of 10,000 pallets designated for export to the EU visualised as a descending distribution function. Horizontal lines indicate the percentiles (starting from the bottom 5%, 25%, 50%, 75%, 95%). The Panel is 95% sure that 9,743 or more pallets per 10,000 will be free from the pest

Appendix D – Web of Science All Databases Search String

In the table below, the search strings used in Web of Science are reported. Totally, 265 papers were retrieved. Titles and abstracts were screened.

Web of Science All databases	1st search-16 Results **TOPIC:** ("Thaumatotibia leucotreta" or "FCM" or "false codling moth" or "citrus codling moth" or "orange codling moth" or "Cryptophlebia leucotreta" or "Cryptophlebia roerigii" or "Olethreutes leucotreta" or "Thaumatotibia roerigii" or "T. leucotreta") **AND** **TOPIC:** ("Citrus") **AND** **TOPIC:** ("chemical control") **AND** **TOPIC:** ("biological control" or "biocontrol") 2nd search – 2 Results **Topic:** ("Thaumatotibia leucotreta" or "FCM" or "false codling moth" or "citrus codling moth" or "orange codling moth" or "Cryptophlebia leucotreta" or "Cryptophlebia roerigii" or "Olethreutes leucotreta" or "Thaumatotibia roerigii" or "T. leucotreta") **AND** **TOPIC:** ("Citrus") **AND** **TOPIC:** ("South Africa") 3rd search-235 Results **TOPIC:** ("Thaumatotibia leucotreta" or "FCM" or "false codling moth" or "citrus codling moth" or "orange codling moth" or "Cryptophlebia leucotreta" or "Cryptophlebia roerigii" or "Olethreutes leucotreta" or "Thaumatotibia roerigii" or "T. leucotreta") **AND** **TOPIC:** ("Citrus") **AND** **TOPIC:** ("control*") 4th search – 7 Results **TOPIC:** ("Thaumatotibia leucotreta" or "FCM" or "false codling moth" or "citrus codling moth" or "orange codling moth" or "Cryptophlebia leucotreta" or "Cryptophlebia roerigii" or "Olethreutes leucotreta" or "Thaumatotibia roerigii" or "T. leucotreta") **AND** **TOPIC:** ("South Africa") 5th search – 5 Results **TOPIC:** ("Thaumatotibia leucotreta" or "FCM" or "false codling moth" or "citrus codling moth" or "orange codling moth" or "Cryptophlebia leucotreta" or "Cryptophlebia roerigii" or "Olethreutes leucotreta" or "Thaumatotibia roerigii" or "T. leucotreta") **AND** **TOPIC:** ("insecticide$ resistance" or "chemical$ resistance")