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Xanthomonas citri
Pest Report to support ranking of EU candidate priority pests

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1. Introduction to the report

This document is one of the 28 Pest Reports produced by the EFSA Working Group on EU Priority Pests under task 3 of the mandate M-2017-0136. It supports the corresponding Pest Datasheet published together on Zenodo[1] and applies the methodology described in the Methodology Report published on the EFSA Journal (EFSA, 2019).

This Pest Report has five sections. In addition to this introduction, a conclusion and references, there are two key sections, sections 2 and 3.

Section 2 first summarises the relevant information on the pest related to its biology and taxonomy. The second part of Section 2 provides a review of the host range and the hosts present in the EU in order to select the hosts that will be evaluated in the expert elicitations on yield and quality losses. The third part of Section 2 identifies the area of potential distribution in the EU based on the pest's current distribution and assessments of the area where hosts are present, the climate is suitable for establishment and transient populations may be present. The fourth part of Section 2 assesses the extent to which the presence of the pest in the EU is likely to result in increased treatments of plant protection products. The fifth part of section 2 reviews additional potential effects due to increases in mycotoxin contamination or the transmission of pathogens.

In Section 3, the expert elicitations that assess potential yield losses, quality losses, the spread rate and the time to detection are described in detail. For each elicitation, the general and specific assumptions are outlined, the parameters to be estimated are selected, the question is defined, the evidence is reviewed and uncertainties are identified. The elicited values for the five quantiles are then given and compared to a fitted distribution both in a table and with graphs to show more clearly, for example, the magnitude and distribution of uncertainty. A short conclusion is then provided.

The report has two appendices. Appendix A contains a host list created by amalgamating the host lists in the EPPO Global Database (EPPO, online) and the CABI Crop Protection Compendium (CABI, 2019). Appendix B provides a summary of the evidence used in the expert elicitations.

It should be noted that this report is based on information available up to the last day of the meeting[2] that the Priority Pests WG dedicated to the assessment of this specific pest. Therefore, more recent information has not been taken into account.

For *Xanthomonas citri*, the following document was used as key reference: pest risk assessment (PRA) by EFSA (2014).

[1] Open-access repository developed under the European OpenAIRE program and operated by CERN, https://about.zenodo.org/

[2] The minutes of the Working Group on EU Priority Pests are available at http://www.efsa.europa.eu/sites/default/files/wgs/plant-health/wg-plh-EU_Priority_pests.pdf

2. The biology, ecology and distribution of the pest

2.1. Summary of the biology and taxonomy

The strains of *Xanthomonas campestris* pathogenic to *Citrus* spp. have been reclassified as four distinct taxa within two distinct species. Among these, *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* are the bacteria responsible for citrus canker disease and South-American canker, respectively the only ones significantly impacting the citrus industry (EFSA, 2014). In this report, the species assessed is *Xanthomonas citri*, for which only the two pathovars *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* are responsible for the citrus bacterial canker. From now on, we refer to these two pathovars as *X. citri*.

All aerial citrus organs are susceptible to *X. citri* pv. *citri*. Lesions on leaves are small water-soaked spots, turning into slightly raised blister-like lesions and further evolving into raised, corky, canker-like lesions with a colour varying from beige to dark brown (Pruvost et al., 2015). Fruit symptoms typically consist of raised and corky lesions, although their aspect depends on the period of infection, being in late infections relatively flat and not erumpent or only pustule-like, taking the shape of a pimple or a blister, without any rupture of the epidermis (Koizumi, 1972). Such atypical symptoms (i.e. not erumpent or blister-like) can be observed on leaves of partially resistant cultivars and most frequently on fruit of these cultivars. Twig cankers remain visible and infectious for long periods on woody branches or trunks, including rootstocks (EFSA PLH Panel, 2014). Fruit drop is the primary factor responsible for yield losses (Graham and Gottwald, 1991). Although blemished fruit are not marketable for fresh consumption, their internal quality is not affected (EFSA PLH Panel, 2014). Mature leaves can be infected through injuries but not through stomatal invasions (Stall and Seymour, 1983; Vernière et al., 2003).

X. citri pv. *citri* enters the plant tissue primarily through stomata, as well as wounds caused by wind, thorns, insects, orchard or nursery maintenance operations (EFSA PLH Panel, 2014).

Disease expression occurs on young leaves of different cultivars of sweet oranges between a minimum of 12 °C and a maximum of 40 °C, with an optimum range of 25–35 °C. However, this can differ when it occurs on other citrus species (Dalla Pria et al., 2006). Disease incidence is influenced by temperatures and leaf wetness duration. The length of the latent period depends on temperature, growth stage of plant material, availability of wounds and amount of inoculum (EFSA PLH Panel, 2014).

There are no data on length of the latent period on fruit, but its relationship with growth stage and temperature is clear (Vernière et al., 2003). In optimal temperature conditions, short duration rainfall periods support the exudation of *X. citri* pv. *citri* from canker lesions that are readily available for infection (Pruvost et al., 2002) while increases in wetness duration increase disease severity (Dalla Pria et al., 2006).

Under field conditions, lesions mostly develop during periods of rainfall (or overhead irrigation), medium to high temperatures and availability of susceptible tissues (vegetative flushes, or young, actively growing fruit). An extended dry season does not inhibit the seasonal development of the disease because, when the wet season arrives, new incidences of canker occur.

Extended dry periods (i.e. over approximately five to six consecutive months) do not stop epidemics in sub-Saharan African areas as confirmed by the first reports from Mali and Burkina-Faso (Traoré et al., 2008; Juhasz et al., 2013). The persistence of high levels of inoculum in leaf and stem lesions and its reactivation during the rainy season associated with human dispersal most probably explain the disease establishment in this region (Leduc et al., 2011, 2015).

2.2. Host plants

2.2.1. List of hosts

Citrus, *Poncirus*, *Fortunella* and their hybrids are the only common natural host genera. All *Citrus* and *Poncirus* species are affected by defoliation, premature fruit drop and general tree decline (Graham and Gottwald, 1991). Furthermore, the level of susceptibility by cultivar translates into greater yield losses for some citrus cultivars over others (Gottwald et al., 1993).

Appendix A provides the full list of hosts.

2.2.2. Main hosts in the European Union

The experts assessed the hosts according to their level of susceptibility (Table 1). As calamondin (*C. mitus*) and kumquats (*Fortunella* spp.) are described as highly resistant to the pest (Gottwald et al., 2002), they were excluded from the assessment. In a 5-year evaluation in natural conditions including 186 citrus genotypes of species *C. reticulata, C. unshiu, C. sinensis, C. aurantium, C. limon, C. deliciosa*, *C. paradisi*, *C. aurantifolia* and a few hybrids, none of the genotypes were immune to citrus canker (de Carvalho et al., 2015). The most resistant genotypes were from the satsuma and *C. reticulata* species with some variation according to the genotypes. Some genotypes from the mandarin group (i.e. tangors *C. reticulata* x *C. sinensis* or clementine *C. clementina*) were susceptible. The most susceptible genotypes were from the grapefruit and lime species. The susceptibility of sweet oranges varied from susceptible to moderately susceptible. Goto (1992) provides summary tables on susceptibility of different orange cultivars and citrus hybrids to citrus canker.

Table 1: Assessment of different host species susceptibility to *Xanthomonas citri*

Species name	**In assessment** **X – less susceptible** **XX – susceptible** **XXX – highly susceptible**	**Out of assessment**
Calamondin (*C. mitus*)		X
Mandarins (*C. reticulata*)	X	
kumquats (*Fortunella* spp.)		X
Tangerines, tangors, tangelos (*C. reticulata* hybrids)	X	
Sour oranges (*C. aurantium*)	X	
Sweet oranges (*C. sinensis*)	XX	
Orlando tangelos, Clementine, Natsudaidai	XX	
Pomelo (*C. maxima*)	XX	
Limes (*C. latifolia*)	XX	
Trifoliate orange (*Poncirus trifoliata*)	XX	
Citranges/citrumelos (*P. trifoliata* hybrids)	XX	
Grapefruit (*C. paradisi*)	XXX	
Mexican/key lime (*C. aurantiifolia*)	XXX	
Lemons (*C. limon*)	XXX	
Kaffir lime (*C. hystrix*)	XXX	

2.2.3. Hosts selected for the evaluation

The impacts on all commercial Citrus species and varieties were assessed. Highly susceptible crops (XXX in Table 1) such as lemon and grapefruit were assessed separately from less susceptible crops (XX and X in Table 1), such as sweet orange, tangelos, clementines and mandarins.

2.3. Area of potential distribution

2.3.1. Area of current distribution

Figure 1 provides an overview of the current area of distribution of the pest. In the EU no outbreaks have yet been reported.

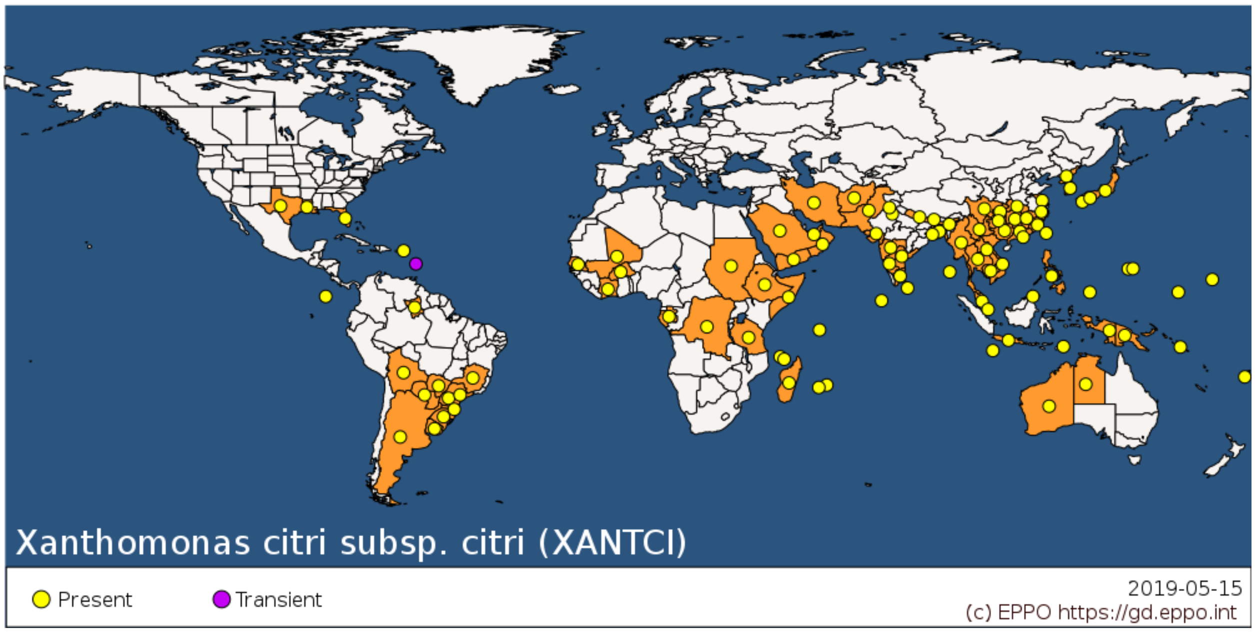

Figure 1 Distribution map of *Xanthomonas citri* from the EPPO Global Database accessed 15/05/2019.

2.3.2. Area of potential establishment

Citrus species and varieties are widely planted as commercial crops in Southern Europe, where they are grown in 8 Member States (Table 2).

Table 2: Citrus production area in the European Union in 2016. Source: Eurostat, extracted on 30.05.2018.

Member States	**Area (1000 ha)**
Croatia	2.19
Cyprus	3.41
France	4.22
Greece	45.39
Italy	147.65
Malta	NA*
Portugal	20.36
Spain	295.33
European Union (current composition)	518.54

* data on Malta not available in EUROSTAT (not significant); 193 ha reported in EFSA PLH Panel (2014)

In the same citrus growing countries, citrus plants are also present in nurseries (Spain 10,665,000 trees/year; Italy 5,771,000 trees/year; Portugal 844,000 trees/year; Greece 826,000 trees/year and France 819,000 trees/year), as well as ornamental trees in city streets and public and private gardens. Citrus production regions in the EU correspond to plant hardiness zones 8 to 10, while, based on its global distribution, citrus canker can establish in plant hardiness zones 8 to 12 (EFSA PLH Panel, 2014). Therefore, for the purposes of this EKE, the area of potential distribution of citrus canker is considered to correspond to the entire EU citrus-growing area.

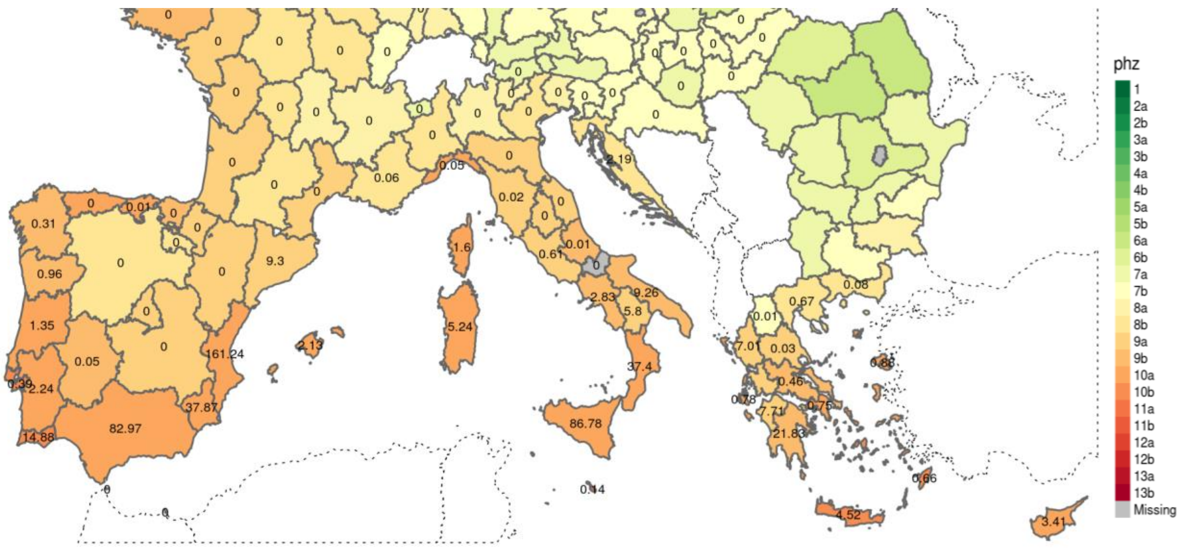

Figure 2 Plant hardiness zones (PHZ) classification (8-13) obtained from the 2007-2017 average of minimum temperature (data provided by JRC) at NUTS2 level (version 2016). Where citrus is grown, the citrus production area (x1,000 ha) of 2016 is given (EUROSTAT, 30.05.2018).

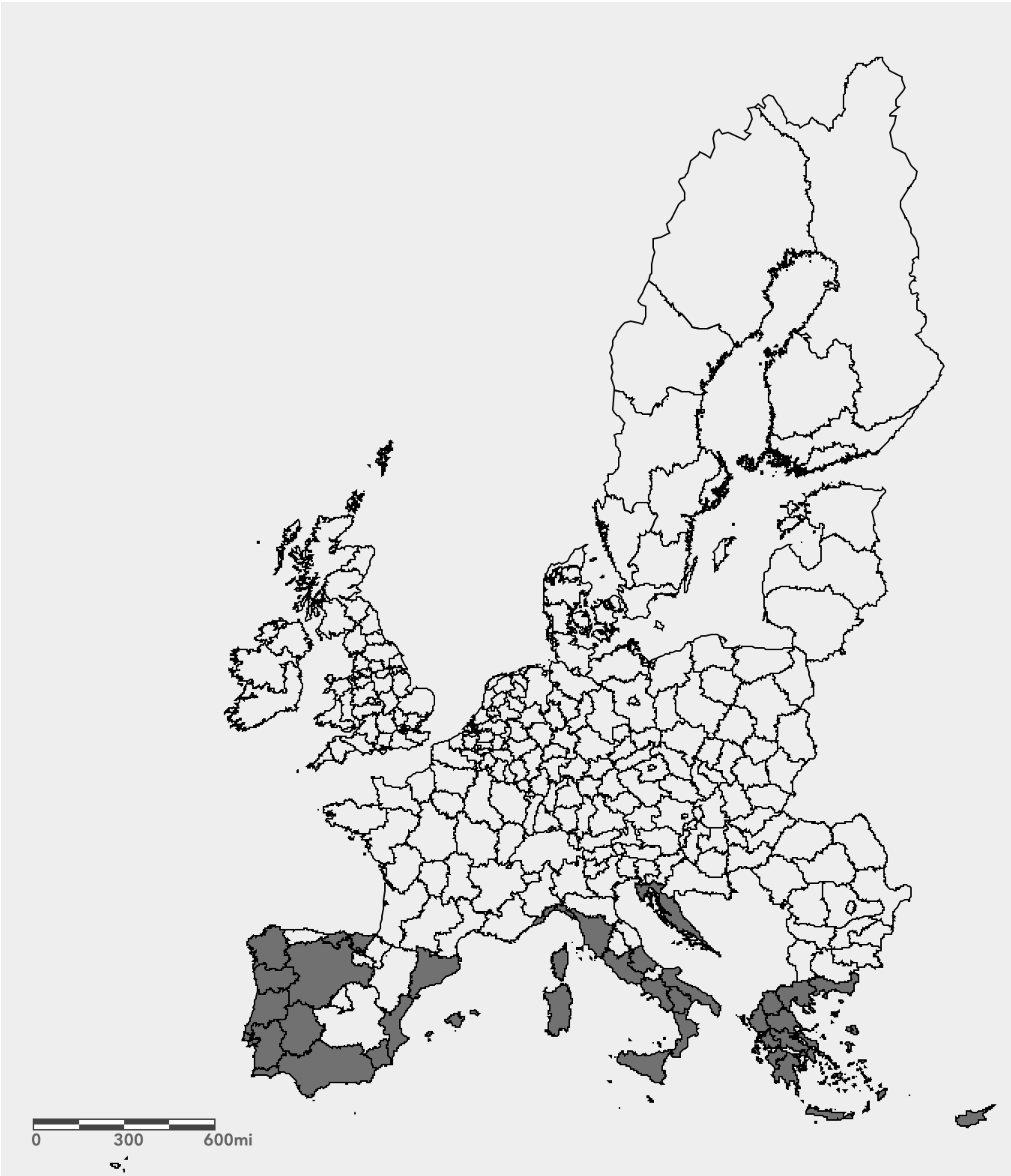

Figure 3 The potential distribution of the pest in the EU NUTS2 regions based on the scenarios established for assessing the impacts of the pest by the EFSA Working Group on EU Priority Pests (EFSA, 2019). This link provides an online interactive version of the map that can be used to explore the data further: https://arcg.is/0LjX5i

2.3.3. Transient populations

Xanthomonas citri is not expected to form transient populations in the EU (for "transient" see the definition in EFSA, 2019).

2.3.4. Conclusions on the area of potential distribution

The area of potential distribution of *X. citri* pv. citri is equivalent to the area where the main hosts (i.e. *Citrus* spp.) occur in the EU (Figure 3). The mean abundance of the pest, the main driver of pest impact, is considered to be the same throughout the area of potential distribution.

2.4. Expected change in the use of plant protection products

Based on the conclusion that plant protection products (PPPs) applied against other pests in the risk assessment area, such as copper sprays, are also effective against *X. citri* only if the amount of treatments is increased, the most suitable PPP indicator is Case "C" and the category is "1" based on Table 3.

Table 3: Expected changes in the use of Plant Protection Products (PPPs) following *Xanthomonas citri* establishment in the EU in relation to four cases (A-D) and three level score (0-2) for the expected change in the use of PPPs

Expected change in the use of PPPs	Case	PPPs indicator
PPPs effective against the pest are not available/feasible in the EU	A	0
PPPs applied against other pests in the risk assessment area are also effective against the pest, without increasing the amount/number of treatments	B	0
PPPs applied against other pests in the risk assessment area are also effective against the pest but only if the amount/number of treatments is increased	**C**	**1**
A significant increase in the use of PPPs is not sufficient to control the pest: only new integrated strategies combining different tactics are likely to be effective	D	2

2.5. Additional potential effects

2.5.1. Mycotoxins

The species is not known to be related to problems caused by mycotoxins.

2.5.2. Capacity to transmit pathogens

The species is not known to vector any plant pathogens.

3. Expert Knowledge Elicitation report

3.1. Yield and quality losses

3.1.1. Structured expert judgement

3.1.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.1.1 of the Methodology Report (EFSA, 2019).

3.1.1.2. Specific scenario assumptions

- Current quality definitions and thresholds are applied in order to assess quality losses setting the limits for commercialization in internal market equal to those for export. The working group assumes that one lesion is sufficient to downgrade the product even though in some situations, e.g. the internal market, quality standard may be less strict.

3.1.1.3. Selection of the parameter(s) estimated

Percentage yield loss has been estimated based on reductions in marketable fresh fruit due to i) tree decline, ii) premature fruit drop, iii) unharvested fruit and iv) unmarketable fruit.

Percentage quality loss has been estimated based on the proportion of citrus production downgraded from sale as fresh fruit to juice production.

3.1.1.4. Defined question(s)

What is the percentage yield loss in high impacted citrus (e. g. grapefruit and lemon) under the scenario assumptions in the area of the EU under assessment for *Xanthomonas citri*, as defined in the Pest Report?

What is the percentage yield loss in medium impacted citrus (e. g. sweet orange, tangelos, clementines and mandarins) under the scenario assumptions in the area of the EU under assessment for *Xanthomonas citri*, as defined in the Pest Report?

What is the percentage of the harvested high impacted citrus (e. g. grapefruit and lemon) damaged by *Xanthomonas citri*, that would lead to downgrading the final product because of quality issues under the scenario assumptions in the area of the EU under assessment as defined in the Pest Report?

What is the percentage of the harvested medium impacted citrus (e. g. sweet orange, tangelos and pomelo) damaged by *Xanthomonas citri*, that would lead to downgrading the final product because of quality issues under the scenario assumptions in the area of the EU under assessment as defined in the Pest Report?

3.1.1.5. Evidence selected

The experts reviewed the evidence obtained from the literature (see Table B.1 in Appendix B) selecting the data and references used as the key evidence for the EKE on impact.

Two points were made:

- Copper treatments currently applied in the EU for brown rot (*Phytophthora* spp.) are mainly concentrated in autumn, therefore protection against citrus canker is not complete, as it would require additional applications in spring and summer.
- In general, climate conditions in the EU citrus-growing areas are expected to act in the direction of lowering the impact of citrus canker compared with that in its current geographic range.

3.1.1.6. Uncertainties identified

- Empirical data on yield loss are only available from geographic areas with climates that are not comparable to those in the EU
- The frequency of copper sprays is usually higher in the areas affected by citrus canker compared with current copper spray programs in the EU citrus-growing areas.
- Data on losses are not available for some of the citrus species considered (e.g. lemons, clementines).
- Some data are from citrus cultivars not grown in Europe (Derso et al., 2007)
- Favourable weather events for infection are mainly in the susceptible growing period (early fruiting) in Europe
- Few data are available on the severity of impact.
- Some references do not explain if the incidence is on fruits in the field or after harvest.

3.1.2. Elicited values for yield losses for high impacted citrus

What is the percentage yield loss in high impacted citrus (e. g. grapefruit and lemon) under the scenario assumptions in the area of the EU under assessment for *X. citri*, as defined in the Pest Report?

The five elicited values on yield loss on high impacted citrus on which the group agreed are reported in the table below.

Table 4: Summary of the 5 elicited values on yield loss (%) on high impacted citrus

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	2%	7%	12%	22%	60%

3.1.2.1. Justification for the elicited values for yield loss on high impacted citrus

Reasoning for a scenario which would lead to high yield loss (99th percentile / upper limit)

The upper value of yield loss is based on a scenario that considers on average (a) EU climatic conditions (in terms of temperature, rain fall and wind velocity) favourable to infection and symptom expression; (b) extreme climatic events (strong winds and storms) having a frequency that facilitates disease spread.

Reasoning for a scenario which would lead to low yield loss (1st percentile / lower limit)

The lower value of yield loss is based on a scenario that considers on average (a) EU climatic conditions (in terms of temperature, rain fall and wind velocity) not favourable to infection and symptom expression; (b) that extreme climatic events (strong winds and storms), facilitating disease spread, are rare.

Reasoning for a central scenario equally likely to over- or underestimate the yield loss (50th percentile / median)

The median value of yield loss is mainly based on the observations by Stall and Seymour (1983). Yield losses include prematurely fallen fruits (15%) and unmarketable fruits used for juice extraction and has to be adjusted to EU climatic conditions and agricultural practices (timing of copper applications not effective in controlling citrus canker).

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision is mainly affected by uncertainty in the values below the median. The first quartile is estimated as 7% due to lack of knowledge concerning factors that can limit the level of damage.

3.1.2.2. *Estimation of the uncertainty distribution for yield loss on high impacted citrus*

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 5: Fitted values of the uncertainty distribution on the yield loss (%) on high impacted citrus

Percentile	**1%**	**2.5%**	**5%**	**10%**	**17%**	**25%**	**33%**	**50%**	**67%**	**75%**	**83%**	**90%**	**95%**	**97.5%**	**99%**
Expert elicitation	2%					7%		12%		22%					60%
Fitted distributio n	2%	2%	3%	4%	5%	7%	9%	12%	17%	21%	27%	35%	48%	62%	84%

Fitted distribution: Lognorm(0.17185,0.17054), @RISK7.5

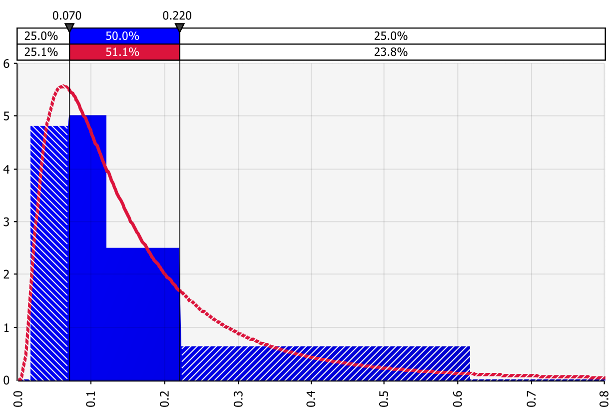

Figure 4 Comparison of judged values (histogram in blue) and fitted distribution (red line) for yield loss on high impacted citrus.

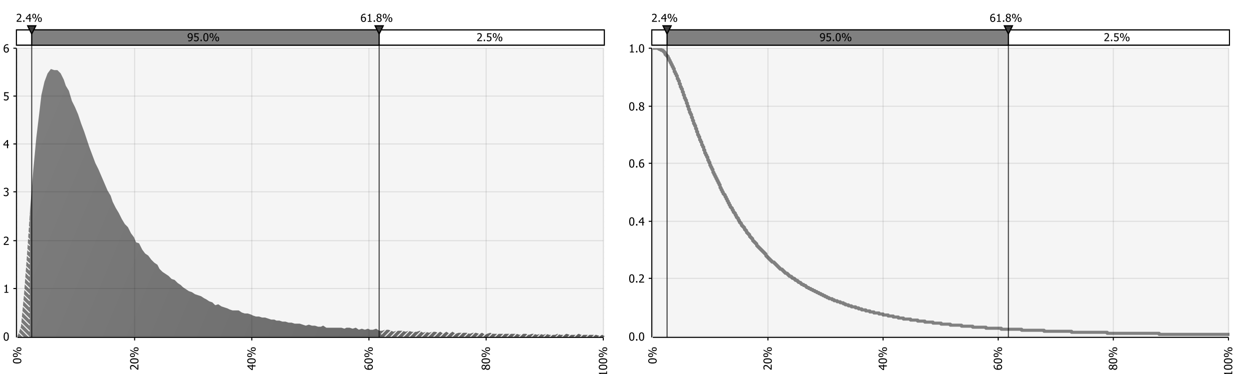

Figure 5 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for yield loss on high impacted citrus.

3.1.3. Elicited values for yield losses for medium impacted citrus

What is the percentage yield loss in medium impacted citrus (e. g. sweet orange, tangelos, clementines and mandarins) under the scenario assumptions in the area of the EU under assessment for *X. citri*, as defined in the Pest Report?

The five elicited values on yield loss on medium impacted citrus on which the group agreed are reported in the table below.

Table 6: Summary of the 5 elicited values on yield loss (%) on medium impacted citrus

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	0%	3%	5%	8%	20%

3.1.3.1. Justification for the elicited values for yield loss on medium impacted citrus

Reasoning for a scenario which would lead to high yield loss (99th percentile / upper limit)

The upper value of yield loss is based on a scenario with the following assumptions: climatic conditions, in terms of temperature, rain fall and wind velocity, more favourable to infection and symptom expression; more frequent extreme climatic events (strong winds and storms) facilitating disease spread. It is also considered that susceptibility is lower reducing the expected impact compared to that on lemon and grapefruit.

Reasoning for a scenario which would lead to low yield loss (1st percentile / lower limit)

The lower value of yield loss is based on a scenario with the following assumptions: climatic conditions are less favourable to infection and symptom expression and less frequent extreme climatic events. It is also considered that susceptibility is lower reducing the expected impact compared impact to that on lemon and grapefruit.

Reasoning for a central scenario equally likely to over- or underestimate the yield loss (50th percentile / median)

The median value of yield loss is mainly based on the observations by Behlau et al. (2008) and Graham et al. (2013) scaled to the EU climatic conditions.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision is mainly affected by uncertainty in the values below the median. The first quartile is estimated as 3% due to lack of knowledge concerning factors that can limit the level of damage.

3.1.3.2. Estimation of the uncertainty distribution for yield loss on medium impacted citrus

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 7: Fitted values of the uncertainty distribution on the yield loss (%) on medium impacted citrus

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	0%					3%		5%		8%					20%
Fitted distribution	0%	0%	1%	1%	2%	3%	3%	5%	7%	8%	10%	12%	14%	17%	20%

Fitted distribution: Weibull(1.3643,0.063893), @RISK7.5

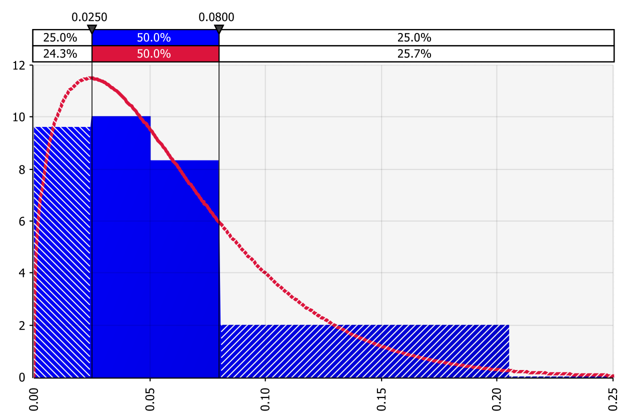

Figure 6 Comparison of judged values (histogram in blue) and fitted distribution (red line) for yield loss on medium impacted citrus.

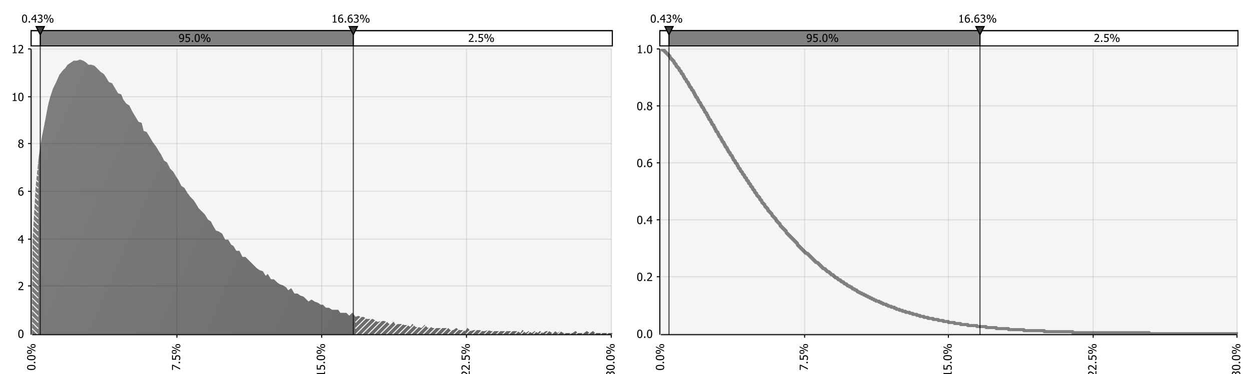

Figure 7 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for yield loss on medium impacted citrus.

3.1.4. Elicited values for quality losses for high impacted citrus

What is the percentage of the harvested high impacted citrus (e. g. grapefruit and lemon) damaged by *X. citri*, that would lead to downgrading the final product because of quality issues under the scenario assumptions in the area of the EU under assessment as defined in the Pest Report?

The five elicited values on quality loss on high impacted citrus on which the group agreed are reported in the table below.

Table 8: Summary of the 5 elicited values on quality loss (%) on high impacted citrus

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	5%	20%	25%	40%	75%

3.1.4.1. Justification for the elicited values for quality loss on high impacted citrus

Reasoning for a scenario which would lead to high yield loss (99th percentile / upper limit)

The upper value of quality loss is based on a scenario with the following assumptions: climatic conditions in terms of temperature, rainfall and wind velocity are more favourable to infection and symptom expression, and more frequent extreme climatic events (strong winds and storms) facilitating disease spread.

Reasoning for a scenario which would lead to low yield loss (1st percentile / lower limit)

The lower value of quality loss is based on a scenario with the following assumptions: climatic conditions are less favourable to infection and symptoms expression and less frequent extreme climatic events.

Reasoning for a central scenario equally likely to over- or underestimate the yield loss (50th percentile / median)

The median value of yield loss is mainly based on the observations by Behlau et al. (2008) and Graham et al. (2013) scaled to the EU climatic conditions.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision of the distribution indicates a relatively high confidence in the median value.

3.1.4.2. Estimation of the uncertainty distribution for quality loss on high impacted citrus

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 9: Fitted values of the uncertainty distribution on the quality loss (%) on high impacted citrus

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	5%					20%		25%		40%					75%
Fitted distribution	8%	10%	11%	14%	16%	19%	21%	27%	34%	38%	44%	52%	63%	75%	91%

Fitted distribution: Lognorm(0.30736,0.17306), @RISK7.5

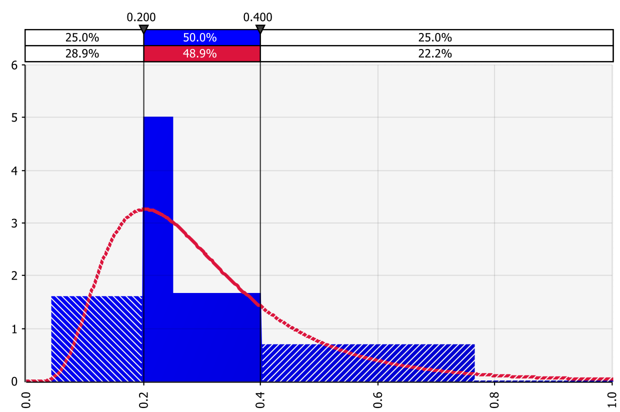

Figure 8 Comparison of judged values (histogram in blue) and fitted distribution (red line) for quality loss on high impacted citrus.

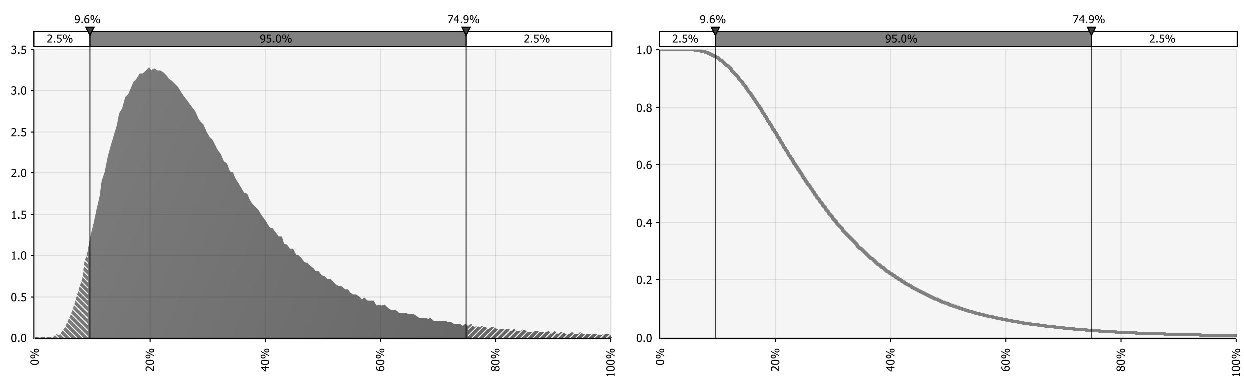

Figure 9 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for quality loss on high impacted citrus.

3.1.5. Elicited values for quality losses for medium impacted citrus

What is the percentage of the harvested medium impacted citrus (e. g. sweet orange, tangelos and pomelo) damaged by *X. citri*, that would lead to downgrading the final product because of quality issues under the scenario assumptions in the area of the EU under assessment as defined in the Pest Report?

The five elicited values on quality loss on medium impacted citrus on which the group agreed are reported in the table below.

Table 10: Summary of the 5 elicited values on quality loss (%) on medium impacted citrus

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	2%	10%	15%	25%	50%

3.1.5.1. Justification for the elicited values for quality loss on medium impacted citrus

Reasoning for a scenario which would lead to high quality loss (99th percentile / upper limit)

The upper value of yield loss is based on a scenario with the following assumptions: favourable climatic conditions in terms of temperature, rainfall and wind velocity for infection and symptom expression; presence of extreme climatic events (strong winds and storms) facilitating disease spread. It is also considered that susceptibility is lower compared to the expected impact on lemon and grapefruit.

Reasoning for a scenario which would lead to low quality loss (1st percentile / lower limit)

The lower value of yield loss is based on a scenario with the following assumptions: climatic conditions unfavourable to infection and symptoms expression; no extreme climatic events. It is also considered that susceptibility is lower compared to the expected impact on lemon and grapefruit.

Reasoning for a central scenario equally likely to over- or underestimate the quality loss (50th percentile / median)

The median value of yield loss is mainly based on the observations by Behlau et al. (2008) and Graham et al. (2013) scaled to the EU climatic conditions.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision indicates a relatively high confidence on the median value.

3.1.5.2. Estimation of the uncertainty distribution for quality loss on medium impacted citrus

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 11: Fitted values of the uncertainty distribution on the quality loss (%) on medium impacted citrus

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	2%					10%		15%		25%					50%
Fitted distribution	3%	4%	5%	7%	8%	10%	12%	15%	20%	24%	29%	36%	45%	56%	71%

Fitted distribution: Lognorm(0.19067,0.13977), @RISK7.5

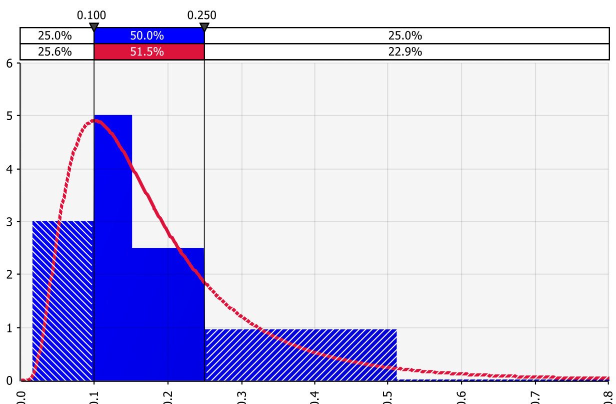

Figure 10 Comparison of judged values (histogram in blue) and fitted distribution (red line) for quality loss on medium impacted citrus.

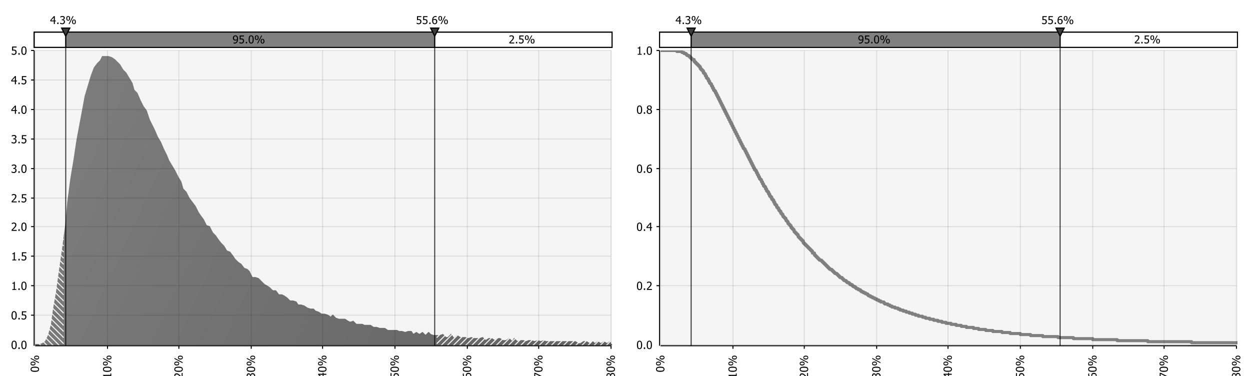

Figure 11 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for quality loss on medium impacted citrus.

3.1.6. Conclusions on yield and quality losses

Based on the general and specific scenarios considered in this assessment:

- the percentage of yield losses (due to tree decline, fruit drop and unharvested fruit), under current EU cropping practices for high impacted citrus (e.g. grapefruit and lemon) is estimated to be 12% (with a 95% uncertainty range of 2 - 62%)
- the percentage of yield losses (due to tree decline, fruit drop and unharvested fruit), under current EU cropping practices for medium impacted citrus (e.g. sweet orange, tangelos, clementines and mandarins) is estimated to be 5% (with a 95% uncertainty range of 0 - 17%)
- the percentage of harvested fruits from high impacted citrus (e.g. grapefruit and lemon) due to infection by *X. citri* that would lead to downgrading from sale as fresh fruit to juice production is estimated to be 27% (with a 95% uncertainty range of 10 - 75%)
- the percentage of harvested fruits from medium impacted citrus (e.g. sweet orange, tangelos and pomelo) due to infection by *X. citri* that would lead to downgrading from sale as fresh fruit to juice production is estimated to be 15% (with a 95% uncertainty range of 4 - 56%)

3.2. Spread rate

3.2.1. Structured expert judgement

3.2.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.2.1 of the Methodology Report (EFSA, 2019).

3.2.1.2. Specific scenario assumptions

No specific assumptions are introduced for the assessment of the spread.

3.2.1.3. Selection of the parameter(s) estimated

The spread rate has been assessed as the number of metres per year.

3.2.1.4. Defined question(s)

What is the spread rate in 1 year for an isolated focus within this scenario based on average European conditions? (units: m/year)

3.2.1.5. Evidence selected

The experts reviewed the evidence obtained from the literature (see Table B.2 in Appendix B) selecting the data and references used as the key evidence for the EKE on spread rate.

3.2.1.6. *Uncertainties identified*

- Extrapolation of data from Florida, Australia, Argentina to the EU situation
- Frequently dispersal is reported as a single event and/or as distance with high coverage
- There are no data on spread from Iran or other areas with climates more similar to those in the EU production area.

3.2.2. Elicited values for the spread rate

What is the spread rate in 1 year for an isolated focus within this scenario based on average European conditions? (units: m/year)

The five elicited values on spread rate on which the group agreed are reported in the table below.

Table 12: Summary of the 5 elicited values on spread rate (m/y)

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	30	90	150	250	600

3.2.2.1. *Justification for the elicited values of the spread rate*

Reasoning for a scenario which would lead to wide spread (99th percentile / upper limit)

The upper value is mainly based on the observations by Gottwald et al. (2001) concerning the majority of new infections occurring within approximately 600 m, scaled to the EU situation with less strong and frequent winds compared to Florida.

Reasoning for a scenario, which would lead to limited spread (1st percentile / lower limit)

The lower value is based on the observation by Stall et al. (1980) on the spread of the pathogen and on the process involved in symptom development.

Reasoning for a central scenario, equally likely to over- or underestimate the spread (50th percentile / median)

The median value is based on observations of Gottwald et al. (1992) taking into account the fact that extreme wind-driven rain events in the EU are less frequent and of lower magnitude.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision is given by the level of uncertainty which is higher for the values below the median.

3.2.2.2. *Estimation of the uncertainty distribution for the spread rate*

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 13: Fitted values of the uncertainty distribution on the spread rate (m/y)

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	30					90		150		250					600
Fitted distribution	27	35	45	58	73	91	109	150	205	246	305	384	501	632	827

Fitted distribution: Lognorm(196.06,165.98), @RISK7.5

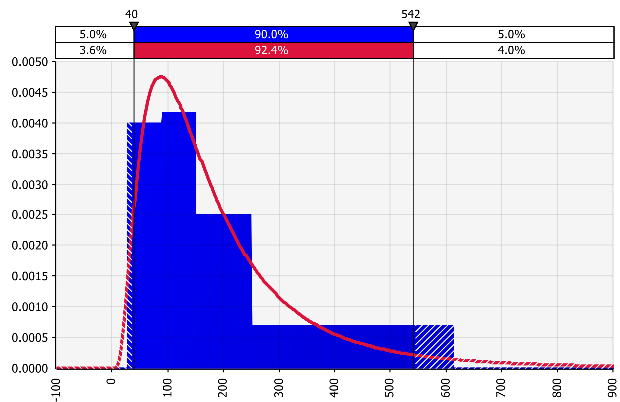

Figure 12 Comparison of judged values (histogram in blue) and fitted distribution (red line) for spread rate.

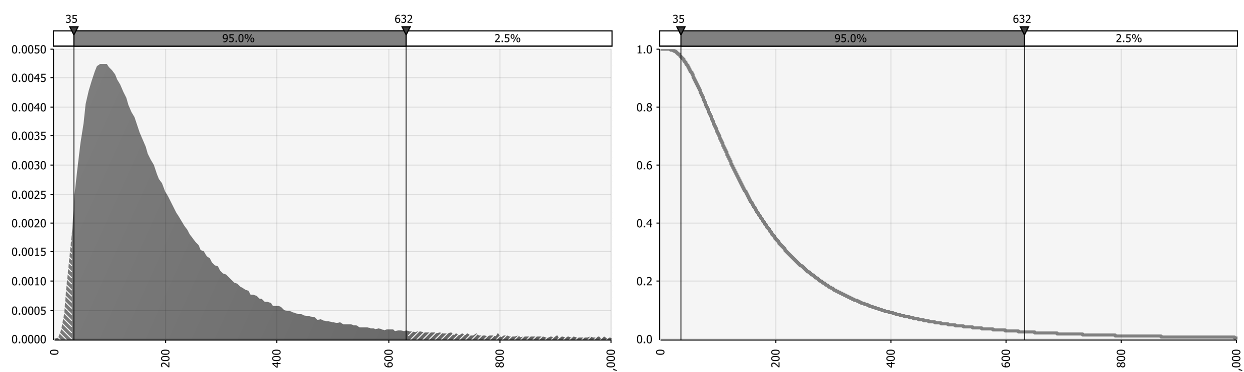

Figure 13 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for spread rate.

3.2.3. Conclusions on the spread rate

Based on the general and specific scenarios considered in this assessment, the maximum distance expected to be covered in one year by *X. citri* is 150 m (with a 95% uncertainty range of 35 - 632 m).

3.3. Time to detection

3.3.1. Structured expert judgement

3.3.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.2.1 of the Methodology Report (EFSA, 2019).

3.3.1.2. Specific scenario assumptions

3.3.1.3. Selection of the parameter(s) estimated

The time for detection has been assessed as the number of days between the first event of pest transfer to a suitable host and its detection.

3.3.1.4. Defined question(s)

What is the time between the event of pest transfer to a suitable host and its first detection within this scenario based on average European conditions? (unit: days)

3.3.1.5. Evidence selected

- Spread rate
- Incubation period
- Pruning activity

3.3.1.6. Uncertainties identified

- Time from infection to symptom detection

3.3.2. Elicited values for the time to detection

What is the time between the event of pest transfer to a suitable host and its first detection within this scenario based on average European conditions? (unit: days)

The five elicited values on time to detection on which the group agreed are reported in the table below.

Table 14: Summary of the 5 elicited values on time to detection (days)

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	60	250	390	550	720

3.3.2.1. Justification for the elicited values of the time to detection

Reasoning for a scenario which would lead to a long time for detection (99th percentile / upper limit)

The upper value takes into account the spread rate sufficient to create an outbreak large enough to be detected even by untrained people. Symptoms are visible but should be present in an amount sufficient to make them visible (and farmers could recognise them).

Reasoning for a scenario which would lead to a short time for detection (1st percentile / lower limit)

The lower value corresponds to the minimum incubation period without interaction with other factors.

Reasoning for a central scenario, equally likely to over- or underestimate the time for detection (50th percentile / median)

The median value takes into account the fact that there is a maximum of two pruning times (winter, spring) and then the harvesting period during which visual control and identification of symptoms can be made.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision is affected by the high uncertainty concerning this parameter given the absence of data on the time between infection and detection.

3.3.2.2. *Estimation of the uncertainty distribution for the time to detection*

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 15: Fitted values of the uncertainty distribution on the time to detection (days)

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	60					250		390		550					720
Fitted distribution	65	81	104	143	190	245	297	397	496	546	599	644	681	702	717

Fitted distribution: BetaGeneral(1.2755,1.2378,50,730), @RISK7.5

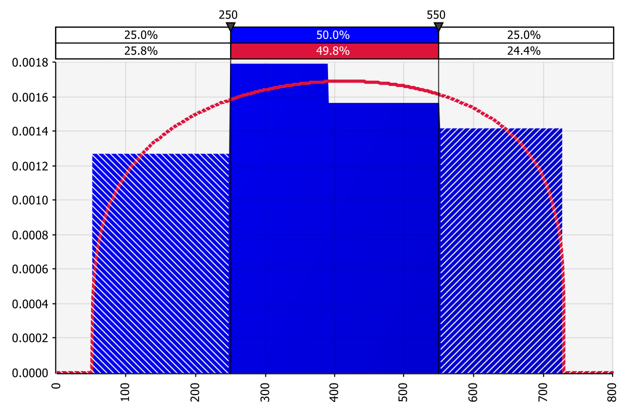

Figure 14 Comparison of judged values (histogram in blue) and fitted distribution (red line) for time to detection.

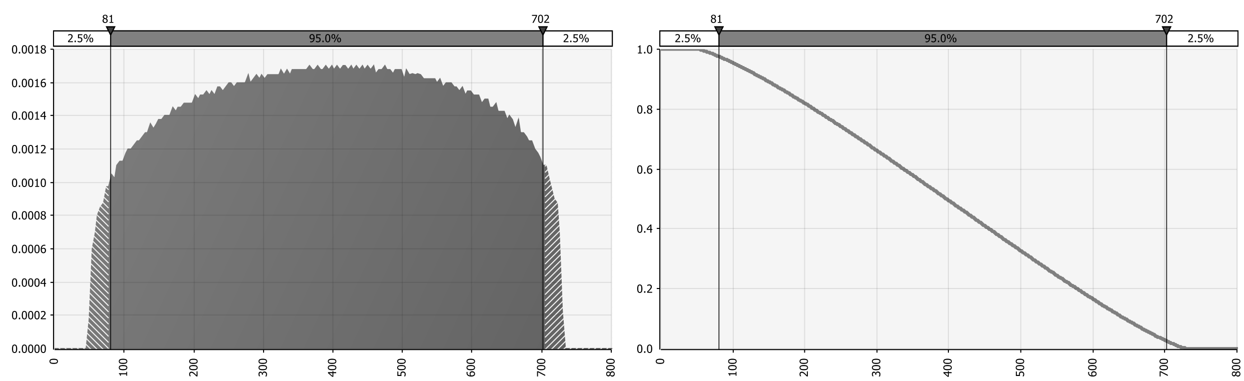

Figure 15 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for time to detection.

3.3.3. Conclusions on the time to detection

Based on the general and specific scenarios considered in this assessment, the time between the event of pest transfer to a suitable host and its detection is estimated to be 397 days (with a 95% uncertainty range of 81 - 702 days).

4. Conclusions

Hosts selection

The impacts on all commercial Citrus species and varieties were assessed. Highly susceptible crops such as lemon and grapefruit were assessed separately from less susceptible crops, such as sweet orange, tangelos, clementines and mandarins.

Area of potential distribution

The area of potential distribution of *X. citri* is equivalent to the area where the main hosts (i.e. *Citrus* spp.) occur in the EU. The mean abundance of the pest, the main driver of pest impact, is considered to be the same throughout the area of potential distribution.

Increased number of treatments

Based on the conclusion that plant protection products (PPPs) applied against other pests in the risk assessment area, such as copper sprays, are also effective against *X. citri* only if the amount of treatments is increased, the most suitable PPP indicator is Case “C” and the category is “1”.

Yield and quality loss of citrus

Based on the general and specific scenarios considered in this assessment:

- the percentage of yield losses (due to tree decline, fruit drop and unharvested fruit), under current EU cropping practices for high impacted citrus (e.g. grapefruit and lemon) is estimated to be 12% (with a 95% uncertainty range of 2 - 62%)
- the percentage of yield losses (due to tree decline, fruit drop and unharvested fruit), under current EU cropping practices for medium impacted citrus (e.g. sweet orange, tangelos, clementines and mandarins) is estimated to be 5% (with a 95% uncertainty range of 0 - 17%)
- the percentage of harvested fruits from high impacted citrus (e.g. grapefruit and lemon) due to infection by *X. citri* that would lead to downgrading from sale as fresh fruit to juice production is estimated to be 27% (with a 95% uncertainty range of 10 - 75%)
- the percentage of harvested fruits from medium impacted citrus (e.g. sweet orange, tangelos and pomelo) due to infection by *X. citri* that would lead to downgrading from sale as fresh fruit to juice production is estimated to be 15% (with a 95% uncertainty range of 4 - 56%)

Spread rate

Based on the general and specific scenarios considered in this assessment, the maximum distance expected to be covered in one year by *X. citri* is 150 m (with a 95% uncertainty range of 35 - 632 m).

Time for detection after entry

Based on the general and specific scenarios considered in this assessment, the time between the event of pest transfer to a suitable host and its detection is estimated to be 397 days (with a 95% uncertainty range of 81 - 702 days).

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Appendix A – CABI/EPPO host list

The following list, defined in the Methodology Report (EFSA, 2019) as the full list of host plants, is compiled merging the information from the most recent PRAs, the CABI Crop Protection Compendium and the EPPO Global Database. Hosts from the CABI list classified as 'Unknown', as well as hosts from the EPPO list classified as 'Alternate', 'Artificial', or 'Incidental' have been excluded from the list.

Genus	Species epithet
Aegle	*marmelos*
Ageratum	*conyzoides*
Casimiroa	*edulis*
Citrofortunella	*microcarpa*
Citroncirus	
Citrus	
Citrus	*aurantiifolia*
Citrus	*aurantium*
Citrus	*hystrix*
Citrus	*junos*
Citrus	*latifolia*
Citrus	*limetta*
Citrus	*limon*
Citrus	*macrophylla*
Citrus	*madurensis*
Citrus	*maxima*
Citrus	*medica*
Citrus	*natsudaidai*
Citrus	*paradisi*
Citrus	*reshni*
Citrus	*reticulata*
Citrus	*sinensis*
Citrus	*sunki*
Citrus	*tankan*
Citrus	*unshiu*
Eremocitrus	*glauca*
Fortunella	
Fortunella	*japonica*
Fortunella	*margarita*
Limonia	*acidissima*
Mangifera	*indica*
Poncirus	*trifoliata*
Rutaceae	

Appendix B – Evidence tables

B.1 Summary on the evidence supporting the elicitation of yield and quality losses

<table>
<tr><th>Susceptibility</th><th>Infection</th><th>Symptoms</th><th>Impact</th><th>Additional information</th><th>Reference</th></tr>
<tr><td></td><td>Incidence</td><td>Severity</td><td>Losses</td><td></td><td></td></tr>
<tr><td></td><td>Incidence on harvested fruits directly related to incidence on abscised fruits</td><td></td><td></td><td>Canker-infected orchards in absence of control</td><td>Behlau et al., 2008</td></tr>
<tr><td></td><td><table>
<tr><td>Parameter</td><td>2004</td><td>2005</td><td>2006</td></tr>
<tr><td>Harvested fruit (%)</td><td>44.2</td><td>92.9</td><td>83.9</td></tr>
<tr><td>Harvested with citrus canker (%)</td><td>87.0</td><td>30.0</td><td>15.0</td></tr>
<tr><td>Dropped fruit with citrus canker (%)</td><td>98.6</td><td>90.3</td><td>82.5</td></tr>
</table></td><td></td><td></td><td></td><td>Behlau et al., 2008</td></tr>
<tr><td></td><td>Disease intensity: low with low spring and summer rainfall high with abundant spring and summer rainfall.</td><td>In years of low infection only grapefruit differs from other cultivars in canker severity on fruits.</td><td></td><td>Argentina
Successful management of citrus canker</td><td>Canteros et al., 2017</td></tr>
<tr><td>C. aurantifolia, C. maxima and C. hystrix</td><td>Leaves: incidence 36.5%
Fruits: incidence 18.7%</td><td>Severity 15.2% (leaves), 7.5% (fruits)</td><td></td><td>Survey in 16 locations of 8 West Malaysian States. Severity significantly correlated with temperature, not with rainfall altitude and tree age.</td><td>Derso et al., 2007</td></tr>
<tr><td>4-yar-old Hamlin SO</td><td>Lesions on fruit: 30-40% on plants treated with copper (in 2012)</td><td></td><td>Fruit drop (2011): 70% (untreated), 40% (copper-treated). In 2012: minor fruit drop.</td><td>Effect of weather on a trial on 4-yar-old Hamlin SO
2011: intense rains in April and May
2012: April and May relatively dry</td><td>Graham et al., 2013</td></tr>
<tr><td>grapefruit, orange and mandarin</td><td></td><td>Fruit size and lesion expansion</td><td></td><td>Fruit inoculation experiment. Rapidly expanding fruit (20-40 mm diameter = first 60-90 days of fruit set; lesions expanded up to 106 days) much more susceptible to the pathogen than larger size fruit</td><td>Graham et al., 1992</td></tr>
</table>

				(> 60 mm diameter; lesions did not expand).	
grapefruit	83-97% of fruit diseased	> 88% of lesioned leaves in summer growth flushes	~82% - 96% of fruit diseased and harvested. 15% of fruit fell prematurely	Observations in diseased unsprayed grapefruit plots, Argentina	Stall and Seymour, 1983
orange (cv. Hamlin)			> 50% of diseased fruit fell prematurely	Observations in diseased orange (cv. Hamlin) plots	Stall and Seymour, 1983
Lemon		Effect of citrus canker in terms of quality standards		Figure on p. 115 of the online document	OECD, 2010

B.2 Summary on the evidence supporting the elicitation of the spread rate

Spread	**Additional information**	**Reference**
Bacteria collected 1 m from the source 1.48×10^6 bacteria after 10' 3.60×10^5 bacteria after 1 h 1 6.21×10^4 after 52 h	Bacteria collected 1 m from the source in continuous wind at intervals from 0 to 52 h after the simulated rain splash event started (Table2) The immediate release of high inoculum concentrations maximizes the pest dispersal in tropical/subtropical climates (rain showers often of short duration, intense, and accompanied by strong, gusting wind).	Bock et al., 2005
Relation between wind speed and citrus canker dispersal and severity	Distance of dispersal and the amount of inoculum are related to wind speed (mean CFU ml^{-1} in linear relationship with wind speed)	Bock et al., 2010
9-11 km	Distribution and spread of citrus canker in Emerald, Australia, after its introduction. Disease has been present on the initial site several months before detection. Disease established at autumn 2004 in 4 points distant 9-11 km from the initial site (dispersal mechanism?)	Gambley et al., 2009
The majority of secondary foci developed within 3-4 m of the original focus	Models comparison: Gompertz model the most adequate for nurseries. Fig. 3 isopathic contour maps	Gottwald et al., 1989
230 m / year consecutive to a rainstorm	Epidemiological analysis in natural conditions (Florida). Disease spread of 230 m from dooryard trees to an adjacent orchard within one-year consecutive to a rainstorm	Gottwald et al., 1992

Up to 17,942 m	Presentation of the scientific basis of regulatory eradication policy for citrus canker epidemic in Florida. Spatial arrangement of citrus canker-infected trees during four time periods. Table 1 presents the results of the epidemiology study of citrus canker dispersal. Although disease spread was detected up to 17,942 m, the majority of new infections occurred within approximately 579 m (see Annex 1)	Gottwald et al., 2001
Rain driven at wind speeds > 8 m/sec is essential for spread of the bacteria	Susceptibility of foliage and fruit	Graham and Gottwald, 1991
Water-soaking most prone stage (50-70% expanded leaves) 1.0 g/mm2 wind pressure	Cultivars of differing susceptibility are equally accessible by the bacteria but differ in the rate of lesion expansion later on.	Graham and Gottwald, 1991
> 50 km after a hurricane	Citrus canker dispersal in extreme weather events (hurricanes) in Florida. A distance of dispersal greater than 50 km observed after a hurricane.	Irey et al., 2006
Bacteria didn't transfer to susceptible hosts placed in close proximity to detached infected fruits.	2 consecutive years of analysis on Satsuma mandarins harvested from severely infected trees.	Shiotani et al., 2009
Dispersal of up to 32 metres	Direct relationship between size of lesions on leaves of grapefruit and days after infection. Number of viable cells remains constant. 75 days after infection: 2.92 mm lesion diameter;258 days after infection 9.33 mm lesion diameter Range of number of cells for the whole period: 1.5-14.0 x 106 (Table 1 and Fig 1)	Stall et al., 1980

B.3 Summary on the evidence supporting the elicitation of the time to detection

Reference	Case	Aspect	Results / evidence
Detection methods			
Ference et al., 2018		Effects on detectability	*X. citri* ssp. *citri* pathogenesis and citrus canker disease management. Serology-based tests are usually sufficient for *X. citri* pv. *citri* detection from symptomatic tissue
Biology of the pest			
Al-Saleh and Ibrahim, 2010	Population dynamics		Population dynamics of epiphytic populations of X. citri pv. citri on symptomless fruits of grapefruit and mandarin. Under laboratory conditions at room temperature: populations found for as long as 6 dpi. Under orchard conditions: no longer detected by 5 dpi. (Kingdom of Saudi Arabia)

Bock et al. 2010		Effects on symptoms expression	Relation between wind speed and citrus canker dispersal and severity Distance of dispersal and the amount of inoculum are related to wind speed (mean CFU ml-1 in linear relationship with wind speed) (Florida)
Canteros, 2004		Effects on detectability	Management of citrus canker in Argentina New lesions evident after 20 days but visible to untrained person after > 30-40 days […] Most misidentifications occur when only old lesions are present.
Canteros et al., 2017			Sampling during four consecutive growing seasons (2004-2008) from infected groves. (Argentina) External washing of fruits 105 -107 CFU of X. citri-A on diseased fruits 102 -106 CFU on 36% of symptomless fruits Rainwater collected from leaves 102 -105 CFU on diseased leaves 10-104 CFU on 55-87% of symptomless leaves
Christiano et al., 2007		Effects on symptoms expression	Citrus leaf miner exacerbates the infection of citrus canker and decreases the necessary inoculum to initiate infection (Brazil)
Ference et al., 2018	Population dynamics	Effects on detectability	*X. citri* ssp. *citri* pathogenesis and citrus canker disease management. 1–3 weeks post-infection (depending on temperature, host citrus type and initial inoculum concentration): the host epidermis ruptures, releasing bacteria.
Ference et al., 2018	Population dynamics	Effects on detectability	*X. citri* ssp. *citri* pathogenesis and citrus canker disease management. 1–3 days: survival of the pathogen outside of lesions on inanimate surfaces max 2 months: survival in soil Viable cells can persist longer in the margins of older lesions on leaves, fruit and twigs under tropical conditions.
Gambley et al., 2009			Distribution and spread of citrus canker in Emerald, Australia, after its introduction. Disease has been present on the initial site several months before detection.
Graham and Gottwald, 1991		Effects on symptoms expression	Lesions develop on intact leaves in the greenhouse 10-14 days after inoculation, on detached leaves under artificial light 7 days after inoculation.
Graham et al., 2016	Population dynamics		After 2 weeks of inoculation (fruit < 40 mm size) erupted lesions appeared and expanded 1-9 mm in diameter 30-120 dpi. Study on population dynamics on needle injected fruit of grapefruit in situ. Bacterial population (CFU) fluctuations over the year is also presented. (Florida)
Hall et al., 2010		Effects on symptoms expression	Citrus leaf miner exacerbates the infection of citrus canker (Florida)

Peltier, 1920		Effects on symptoms expression	Influence of temperature and humidity on disease development. Lesion development occurs 7-10 days after infection.
Schubert et al., 2001		Effects on detectability	Eradication in Florida Optimal temperature, humidity and inoculum: symptoms can manifest around 7 days after infection With low temperatures or inoculum levels > 2 months
Shiotani et al., 2009		Effects on symptoms expression	2 consecutive years of analysis on Satsuma mandarins harvested from severely infected trees. (Japan) Healthy, asymptomatic Satsuma mandarin fruits are unlikely to harbour detectable populations of X. citri pv. citri. Bacterial numbers decreased significantly in the first 3 d after fruits are detached.
Stall et al., 1980		Effects on symptoms expression	Direct relationship between size of lesions on leaves of grapefruit and days after infection. Number of viable cells remains constant. (Argentina) 75 days after infection: 2.92 mm lesion diameter;258 days after infection 9.33 mm lesion diameter Range of number of cells for the whole period: 1.5-14.0 x 106
Verniere et al., 2003		Effects on detectability	Study on factors influencing disease expression in natural conditions. (Reunion Island, France) Latency period can extend over several weeks according to the temperature at the time of infection
Host conditions during the period of potential detection			
Goto, 1992	Host age	Effects on detectability	Latency period: 4-5 day in young tissues, a few days more in mature tissues
Gottwald et al., 1989	Host species	Effects on symptoms expression	Susceptibility Duncan grapefruit > Pineapple sweet orange and Swingle citrumelo rootstock. Disease increase over time measured in terms of incidence (proportion of infected plants) and severity (infected leaves/plant). (Argentina) Disease severity parameter more informative than disease incidence. Fig. 1 disease incidence and severity over time.
Graham and Gottwald, 1991	Cultivar	Effects on symptoms expression	Cultivars of differing susceptibility are equally accessible by the bacteria but differ in the rate of lesion expansion later on. (Florida) Water-soaking most prone stage (50-70% expanded leaves) 1.0 g/mm2 wind pressure