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SCIENTIFIC OPINION

Pest risk assessment of African *Leucinodes* species for the European Union

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Abstract

Following a request from the European Commission, the EFSA Panel on Plant Health performed a quantitative risk assessment for the EU of African *Leucinodes* species (Lepidoptera: Crambidae), which are fruit and shoot borers, especially of eggplant type fruit. The assessment focused on (i) potential pathways for entry, (ii) distribution of infested imports within EU, (iii) climatic conditions favouring establishment, (iv) spread and (v) impact. Options for risk reduction are discussed, but their effectiveness was not quantified. *Leucinodes* spp. are widely distributed across sub-Saharan Africa but are little studied and they could be much more widespread in Africa than reported. Much African literature erroneously reports them as *Leucinodes orbonalis* which is restricted to Asia. The import of eggplant type fruit from sub-Saharan Africa consists of special fruit types and caters mostly to niche markets in the EU. The main pathway for entry is fruit of *Solanum aethiopicum* and exotic varieties of eggplant (*S. melongena*). CLIMEX modelling was used with two possible thresholds of ecoclimatic index (EI) to assess establishment potential. Climates favouring establishment occur mostly in southern Europe, where, based on human population, 14% of the imported produce is distributed across NUTS2 regions where EI ≥ 30; or where 23% of the produce is distributed where EI ≥ 15. Over the next 5 years, an annual median estimate of ~ 8600 fruits, originating from Africa, and infested with African *Leucinodes* spp. are expected to enter EU NUTS2 regions where EI ≥ 15 (90% CR ~ 570–52,700); this drops to ~ 5200 (90% CR ~ 350–32,100) in NUTS2 regions where EI ≥ 30. Escape of adult moths occurs mostly from consumer waste; considering uncertainties in pathway transfer, such as adult emergence, mate finding and survival of progeny, the annual median probability of a mated female establishing a founder population in NUTS regions where EI ≥ 15 was estimated to be 0.0078 (90% CR 0.00023–0.12125). This equates to a median estimate of one founder population ~ every 128 years (90% CR approximately one every 8–4280 years). Using an EI ≥ 30, the median number of founder populations establishing in the EU annually is 0.0048 (90% CR 0.0001–0.0739), equating to a median estimate of one founder population approximately every 210 years (90% CR approximately one every 14–7020 years). Under climate change for the period

2040–2059, the percent of infested produce going to suitable areas would be increased to 33% for EI ≥ 15 and to 21% for EI ≥ 30. Accordingly, the waiting time until the next founder population would be reduced to median estimates of 89 years for EI ≥ 15 (90% CR ~ 6–2980 years) and 139 years for EI ≥ 30 (90% CR 9–4655 years). If a founder population were to establish, it is estimated to spread at a rate of 0.65–7.0 km per year after a lag phase of 5–92 years. *Leucinodes* spp. are estimated to reduce eggplant yield by a median value of 4.5% (90% CR 0.67%–13%) if growers take no specific action, or 0.54% (90% CR between 0.13% and 1.9%) if they do take targeted action, matching previous estimates made during a risk assessment of *L. orbonalis* from Asia.

KEYWORDS
@Risk, African eggplant, eggplant fruit and shoot borer, expert knowledge elicitation (EKE), pathway model, quantitative PRA

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SUMMARY

Following a request from the European Commission, the EFSA Panel on Plant Health performed a quantitative risk assessment for the EU of African *Leucinodes* species (Lepidoptera: Crambidae), which are fruit and shoot borers, especially of eggplant type fruit (*S. aethiopicum* and *S. melongena*). The assessment focused on potential pathways for (i) entry, (ii) the distribution of imported material within the EU after entry, (iii) climatic conditions favouring establishment, (iv) spread and (v) impact. Options for risk reduction are discussed, but effectiveness was not quantified because insufficient information was obtained on production practices in countries of origin.

Currently, nine species of *Leucinodes* are known from sub-Saharan Africa, with a wide, but incomplete known distribution. Literature predominantly reports *Leucinodes orbonalis* (now known to be a complex of at least five different species) and *L. laisalis* (as *Sceliodes* or *Daraba laisalis*). The species *L. orbonalis* is not known to be established in Africa, though a single finding has been made at entry in France of *L. orbonalis* in product imported from Cote d'Ivoire. There is no confirmation, however, that *L. orbonalis* is established in Cote d'Ivoire. The larvae of *Leucinodes* are oligophagous fruit and stem borers of solanaceous plants.

This opinion focuses on the African species of *Leucinodes* that occur in sub-Sahara Africa. The species *L. laisalis* occurs in northern Africa, but this species has been present in Spain since 1958, has not resulted in reports of impact and is not under official control. Hence, this species was left out of consideration for this assessment.

The main pathway for entry of sub-Saharan species of *Leucinodes* is fruit of the Gilo and Kumba types of African eggplant (*Solanum aethiopicum*), from which most EU interceptions were reported, as well as exotic varieties of eggplant (*S. melongena*). The import of eggplant type fruit from Africa is small in volume, expensive due to transport by airplane, and consists of special fruit types that mostly cater to niche markets in the EU.

Using expert knowledge elicitation (EKE) and pathway modelling, the Panel estimated that some millions of *Solanum* fruits enter the EU from Africa each year. In the model, these fruits are distributed across EU NUTS2 regions according to their population, as the niche markets receiving these products are assumed to be homogeneously distributed across populations in the EU.

The Panel used a CLIMEX model for the related Asian species *L. orbonalis* to assess the climatic suitability of the European territory for sub-Saharan African *Leucinodes* spp. This CLIMEX model gave a good match for the areas of occurrence of African *Leucinodes* species in Africa, and this model was used because species-specific data on larval and pupal development rates in response to, e.g. temperature, were sparse and the available data were in agreement with data previously obtained for *L. orbonalis*.

NUTS regions where climatic conditions are conducive for establishment of sub-Saharan *Leucinodes* species (median estimate with Ecoclimatic Index (EI) ≥ 15) receive ~ 7.7 million transfer units (90% CR ~ 3.7–18.1 million). With an EI threshold of 30, the number of fruits entering NUTS2 regions where parts are suitable for establishment drops to ~ 4.7 million transfer units (90% CR ~ 2.2–11.0 million).

Infested fruits represent only a small proportion of the total number of African eggplant fruit entering the EU. The number of transfer units infested with live larvae of African *Leucinodes* species entering NUTS2 areas with EI ≥ 15 is estimated to be ~ 8600 per year (90% CR ~ 570–52,700); using an EI threshold of 30, the median number of infested transfer units drops to ~ 5200 per year (90% CR ~ 350–32,100).

Climatic conditions are most suitable for establishment in parts of the southern EU. When imports are allocated in proportion to the human population, between 14% and 23% of transfer units enter regions of the EU suitable for establishment (lower estimates based on EI ≥ 30, higher estimate based on EI ≥ 15). Of the infested units entering NUTS regions where EI ≥ 15, ~ 12% are discarded before reaching the final consumer and ~ 50% of infested units are discarded by the consumer. Furthermore, 1.0% (median; 90% CR, 0.2%–1.9%) of larvae survive to adulthood and escape from commercial waste while a median of 5.1% (90% CR 0.98%–12.2%) escape from consumer household waste.

When the resulting numbers of adults emerge across NUTS2 regions, the likelihood that a female will find a mate depends on the window of encounter in space and time. In combination with the likelihood that the subsequent progeny survives to initiate a founder population, the number of established founder populations in NUTS2 regions with EI ≥ 15 was estimated to be 0.0078 per year (90% CR 0.00023–0.12125). This equates to a median estimate of one founder population approximately every 128 years (90% CR approximately one every 8–4280 years). For the stricter version of NUTS2 regions with EI ≥ 30, the median number of founder populations establishing in the EU annually is estimated at 0.0048 (90% CR 0.0001–0.0739), equating to a median estimate of one founder population approximately every 210 years (90% CR approximately one every 14–7020 years).

The Panel used four climate models to generate projections of climate for the period 2040–2059 under the RCP8.5 (Business as usual) scenario. The CLIMEX model was run for each of the four generated future climates, and the average CLIMEX prediction was used for interpretation. A warmer climate as predicted for 2040–2059 would increase the rate at which new founder populations emerge in the EU territory, with a median estimated value of 0.01120 per year (90% CR 0.00034–0.17416 per year) with EI ≥ 15 and a median value of 0.00717 per year (90% CR 0.00021–0.11145 per year) with EI ≥ 30. The corresponding times until the next founder population occurs would be a median value of 89 years (90% CR 6–2979 years) with EI ≥ 15 and a median value of 139 years (90% CR 9–4655 years) with EI ≥ 30.

Were African *Leucinodes* species to be introduced into the EU (and in fact, *L. laisalis* is established in the southern Iberian Peninsula since at least 1958), the Panel estimates that it would take between 5 and 92 years (90% CR; median 34.5 years) for

populations to grow sufficiently before a steady rate of spread of ~2.3 km/year (90% CR 0.65–7.02 km/year) was reached. These estimates are the same as used previously for *L. orbonalis* as no evidence to the contrary was found.

In a scenario where one of the African *Leucinodes* species enters, establishes and spreads within the EU and the population reaches an approximate equilibrium such that EU farmers consider the organism a member of the general pest fauna, median eggplant yield losses are estimated to be 4.5% (90% CR 0.67%–13.0%) when no specific control measures are in place, and 0.54% (90% CR 0.13%–1.94%) when growers apply targeted pest control against *Leucinodes* spp. These estimates are the same as used previously for *L. orbonalis* as no evidence was found for differences with *L. orbonalis*.

The Panel did not assess the potential of damage to potato and tomato, alternative hosts of African *Leucinodes* species that are widely grown in the potential area of establishment. There is sparse information in the literature on damage to these two crops, even though they are widely grown in sub-Saharan countries. This suggests that the damage is unimportant, though there are few papers that state the contrary. Based on the scant information available, the Panel judges there to be insufficient evidence to regard African *Leucinodes* species as a threat to the production of potato and tomato in the EU.

This PRA on African *Leucinodes* species has several uncertainties as the Panel was unable to find information on (i) the true identity of the African *Leucinodes* species previously referred to in the African literature and in EU interceptions as *L. 'orbonalis'* (ii) specific trade data on the commodities that are a pathway for African *Leucinodes* species, (iii) information on inspection practices for all the EU countries importing African eggplants, (iv) production practices in the countries of origin for African eggplant destined for the European market, (v) practices for selecting and sorting product for the European market and (vi) specific data demonstrating the potential for damage to potato and tomato.

In conclusion, African *Leucinodes* species arrive with current measures in the EU with produce from African countries exporting African eggplant (*S. aethiopicum*) and exotic varieties of Asian eggplant (*S. melongena*) to the EU. The numbers of insects entering are so low that establishment is anticipated to be a rare event and the median probability estimate of a single founder population in the time horizon of 5 years considered by the assessment is 4%. Nevertheless, were *Leucinodes* spp. to establish, they would spread over the area suitable for establishment. After having reached equilibrium in the potential area of establishment, which includes a major part of the production area of eggplant in the EU, the African species of *Leucinodes* are expected to cause losses of ~0.5% when farmers use control measures and they would add to the pest complex in this crop. Impacts of about 5% are expected if growers do not specifically control the insect, if established. Measures are available to reduce the likelihood of entry and consequently establishment, spread and impact.

1 | INTRODUCTION

1.1 | Background and Terms of Reference as provided by the requestor

1.1.1 | Background

The new Plant Health Regulation (EU) 2016/2031, on the protective measures against pests of plants, is applying from 14 December 2019. Conditions are laid down in this legislation in order for pests to qualify for listing as Union quarantine pests, protected zone quarantine pests or Union regulated non-quarantine pests. The lists of the EU regulated pests together with the associated import or internal movement requirements of commodities are included in Commission Implementing Regulation (EU) 2019/2072. Additionally, as stipulated in the Commission Implementing Regulation 2018/2019, certain commodities are provisionally prohibited to enter in the EU (high risk plants, HRP). EFSA is performing the risk assessment of the dossiers submitted by exporting to the EU countries of the HRP commodities, as stipulated in Commission Implementing Regulation 2018/2018. Furthermore, EFSA has evaluated a number of requests from exporting to the EU countries for derogations from specific EU import requirements.

In line with the principles of the new plant health law, the European Commission with the Member States are discussing monthly the reports of the interceptions and the outbreaks of pests notified by the Member States. Notifications of an imminent danger from pests that may fulfil the conditions for inclusion in the list of the Union quarantine pest are included. Furthermore, EFSA has been performing horizon scanning of media and literature.

As a follow-up of the above-mentioned activities (reporting of interceptions and outbreaks, HRP, derogation requests and horizon scanning), a number of pests of concern have been identified. EFSA is requested to provide scientific opinions for these pests, in view of their potential inclusion in the lists of Commission Implementing Regulation (EU) 2019/2072 and the inclusion of specific import requirements for relevant host commodities, when deemed necessary.

1.1.2 | Terms of Reference (ToR)

EFSA is requested, pursuant to Article 29(1) of Regulation (EC) No 178/2002, to provide scientific opinions in the field of plant health.

EFSA is requested to deliver 50 pest categorisations for the pests listed in Annex 1A, 1B and 1D. Additionally, EFSA is requested to perform pest categorisations for the pests so far not regulated in the EU, identified as pests potentially associated with a commodity in the commodity risk assessments of the HRP dossiers (Annex 1C). Such pest categorisations are needed in the case where there are not available risk assessments for the EU.

When the pests of Annex 1A are qualifying as potential Union quarantine pests, EFSA should proceed to phase 2 risk assessment. The opinions should address entry pathways, spread, establishment, impact and include a risk reduction options analysis.

Additionally, EFSA is requested to develop further the quantitative methodology currently followed for risk assessment, in order to have the possibility to deliver an express risk assessment methodology. Such methodological development should take into account the EFSA Plant Health Panel Guidance on quantitative pest risk assessment and the experience obtained during its implementation for the Union candidate priority pests and for the likelihood of pest freedom at entry for the commodity risk assessment of High Risk Plants.

Annex 1 List of pests.

A)

1. *Amyelois transitella*
2. *Citripestis sagittiferella*
3. *Colletotrichum fructicola*
4. *Elasmopalpus lignosellus*
5. *Phlyctinus callosus*
6. *Resseliella citrifrugis*
7. *Retithrips syriacus*
8. *Xylella taiwanensis*

E)

List of pests identified to develop further the quantitative risk assessment (phase 1 and phase 2) methodology followed for plant pests, to include in the assessments the effect of climate change for plant pests (for more details see Annex 3).

1. *Leucinodes orbonalis*
2. *Leucinodes pseudorbonalis*
3. *Xanthomonas citri* pv. *viticola*

1.2 | Interpretation of the Terms of Reference

The terms of reference request the EFSA Panel on Plant Health to perform a quantitative risk assessment for the EU of *Leucinodes pseudorbonalis* (Lepidoptera: Crambidae). The Panel interpreted this mandate as a request to conduct a PRA on African *Leucinodes* spp., which includes *L. pseudorbonalis* among other species. There are currently nine species of *Leucinodes* known to occur in Africa including Madagascar (Table 1) (Nuss et al., 2003–2024), to which we refer as 'African *Leucinodes* spp.'. These species are *Leucinodes africensis*, *L. kenyensis*, *L. malawiensis*, *L. pseudorbonalis* and *L. rimavallis* with predominantly white forewings (Figure 1A–E), and *L. ethiopica*, *L. laisalis*, *L. raondry* and *L. ugandensis* with mainly brown forewings (Figure 1F–I).

There is confusion in the literature on the names of *Leucinodes* spp. Historically, African specimens morphologically appearing like *L. orbonalis* have been identified as *L. orbonalis* before 2015. Mally et al. (2015) studied African *Leucinodes* species in detail and concluded that all African material that was described as *L. orbonalis* was misidentified and instead belonged to a complex of at least five new species with predominantly white-winged adults. Several of these newly discovered species cannot be distinguished from the Asian *L. orbonalis* based on external morphology of the larvae or adults, which explains their previous misidentification as *L. orbonalis*. To identify these species, dissection of the male genitalia or analysis of the 'DNA Barcode' sequence is necessary.

Furthermore, Mally et al. (2015) did not find any specimens of the Asian *L. orbonalis* among the studied museum material originating from Sub-Saharan Africa. It is therefore extremely unlikely that *L. orbonalis* is present in Africa (or it is only locally present due to an unintentional potential incursion from Asia, see Appendix A, paragraph 2).

None of the literature reporting the misidentified *L. 'orbonalis'* from Africa mentions identification efforts of the investigated African specimens by means of genitalia dissection and/or DNA sequences, and their correct identification is therefore almost impossible; the Panel is currently almost certain that all African specimens identified as *L. orbonalis* in the African literature are misidentifications of the species first described by Mally et al. (2015) or of still undiscovered species, and the Panel therefore applies the term *L. 'orbonalis'* (i.e. with *'orbonalis'* in quotation marks) to all reports in the African literature referring to *L. orbonalis*. If the Panel uses *L. orbonalis* (without quotation marks), the Asian species is meant. The literature on African *Leucinodes* published since 2015 appears to be largely unaware of the African species complex described by Mally et al. (2015); hence, the African literature continues being ambivalent about species identity.

Apart from the description of new species, Mally et al. (2015) furthermore merged the genus *Sceliodes* with *Leucinodes*. The adult moths of the former *Sceliodes* are characterised by a grey to brown ground colour of the forewings (Figure 1F–I), and they were hence kept separately from the predominantly white-winged *Leucinodes* species (Figure 1A–E). Like *Leucinodes*, *Sceliodes* larvae feed internally in Solanaceae fruits. Mally et al. (2015) re-investigated these two groups of moths and found that their division was based on a typological species concept, and that the overwhelming majority of evidence pointed to a direct close relationship, delegitimising their classification into two genera.

Currently, nine species of *Leucinodes* are known from the Afrotropical region, i.e. Sub-Saharan Africa including Madagascar (Table 1; Figure 1) (Nuss et al., 2003–2024).

TABLE 1 Known African *Leucinodes* species, their interception status for the EU, known distributions and sources of information.

Species of *Leucinodes*	Intercepted in the EU?	Known distribution	Information sources
L. africensis (Mally et al., 2015)	Yes	Sub-Saharan Africa	Mally et al. (2015), Pace et al. (2022), G. Goergen (personal observation)
L. ethiopica (Mally et al., 2015)	No	East Africa, Arabian Peninsula	Mally et al. (2015)
L. kenyensis (Mally et al., 2015)	No	East and Southeast Africa	Mally et al. (2015)
L. laisalis (Walker, 1859)	Yes	Sub-Saharan Africa, Morocco, Europe (Spain, Portugal)	Hill (1966), Huertas Dionisio (2000), Hayden et al. (2013), Mally et al. (2015), G. Goergen (personal observation)
L. malawiensis (Mally et al., 2015)	No	Malawi	Mally et al. (2015)
L. pseudorbonalis (Mally et al., 2015)	Yes	Sub-Saharan Africa (Uganda, Angola, Senegal)	Mally et al. (2015), Poltavsky et al. (2019)
L. raondry (Viette, 1981)	No	Madagascar	Viette (1981), Mally et al. (2015), R. Mally (personal observation)
L. rimavallis (Mally et al., 2015)	Yes	East and Southeast Africa	Mally et al. (2015)
L. ugandensis (Mally et al., 2015)	No	East Africa	Mally et al. (2015)

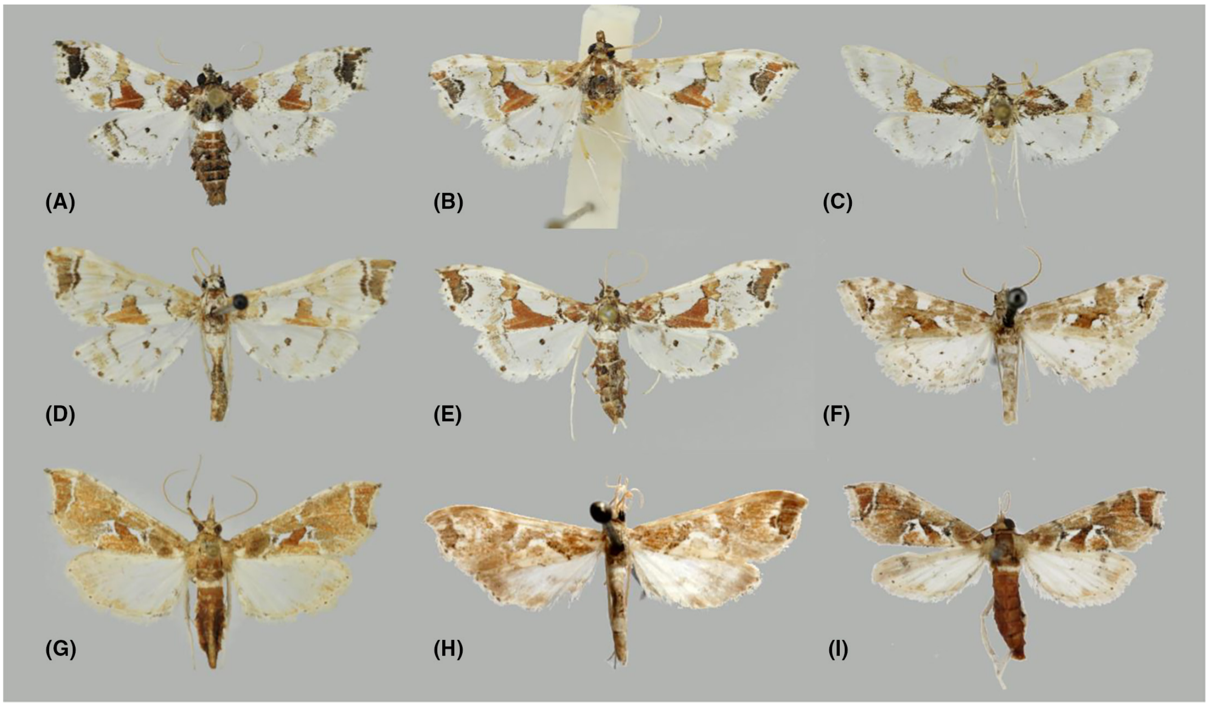


FIGURE 1 Adults of the nine *Leucinodes* species known from Africa. (A) *L. africensis*, (B) *L. kenyensis* (abdomen missing), (C) *L. malawiensis* (abdomen missing), (D) *L. pseudorbonalis*, (E) *L. rimavallis*, (F) *L. ethiopica*, (G) *L. laisalis*, (H), *L. raondry* and (I) *L. ugandensis*. © R. Mally.

Four of the African *Leucinodes* species have been intercepted in Europe in imports at the border and identified to species based on genitalia morphology and/or DNA 'barcode' sequences (Mally et al., 2015): *L. africensis*, *L. pseudorbonalis* and *L. rimavallis*, which are externally indistinguishable from each other and from the Asian *L. orbonalis*, and the greyish-brown *L. laisalis*, which was reported as *Sceliodes laisalis* or *Daraba laisalis* in earlier literature. The latter species has established in the south of Spain and Portugal, with observations from 1958 to 2023 (EFSA PLH Panel et al., 2024, Appendix D). The African *Leucinodes* species have mainly been intercepted from garden egg (*S. aethiopicum*), contrary to the Asian *L. orbonalis*, which is mainly intercepted from aubergine/eggplant/brinjal (*Solanum melongena*).

This opinion focuses on the African species of *Leucinodes* that occur in sub-Sahara Africa. The species *L. laisalis* occurs in northern Africa, but this species has been present in Spain since 1958 (Huertas Dionisio, 2000), has not resulted in reports of impact and is not under official control. Hence, this species was left out of consideration for this assessment.

Spread, establishment and impact are to be quantitatively evaluated. An analysis of risk reduction options is also required. The Panel will therefore undertake a quantitative pest risk assessment according to the principles laid down in its guidance on quantitative pest risk assessment (EFSA Panel on Plant Health, 2018) while recognising the need of the Commission for an express (i.e. as fast as possible) risk assessment.

Formerly, the Panel had agreed with the Commission to conduct an analysis of the consequences of climate change for *Elasmopalpus lignosellus* (EFSA PLH Panel, 2023) and not for species of *Leucinodes* as was specified in the terms of reference. After having seen the results of the analysis for current climate conditions, the Panel judged it appropriate to invest nevertheless in an analysis of climate change consequences for the risk of African species of *Leucinodes*. As the results of the climate change analysis were done at a late stage after an advanced draft of the opinion had already been circulated to the Panel, these results are added in Appendix E.

2 | DATA AND METHODOLOGIES

To obtain a deeper understanding of the organism and to inform the necessary steps in the risk assessment, a literature review was conducted using the Web of Science databases. The review built on the information collected for the pest categorisation (EFSA PLH Panel, 2021). The scientific and common names of the pest were used as search terms, no filters (limits) for either time of publication nor language were implemented, and all Web of Science databases were selected. The following search string was used to retrieve results: *Leucinodes* OR *Leucinodes orbonalis* OR *Leucinodes pseudorbonalis*.

The Web of Science search resulted in 1293 hits after removal of duplicates in the Endnote software. An additional search was conducted via the Google Scholar search engine to specifically find literature published in French, with the following French names inserted individually (with number of results in parentheses): foreuse des solanées (8), perceuse de l'aubergine (2). Of the altogether 2164 references found to mention *Leucinodes*, full texts of 583 references could not be retrieved, leaving 1581 papers. The Web of Science search was conducted on 23 March 2021, and the Google Scholar search in August 2023.

Additional searches, limited to retrieve documents, were run when developing the opinion. The available scientific information, including the previous EFSA pest categorisation (EFSA PLH Panel, 2021) and the relevant literature and legislation, e.g. Regulation (EU) 2016/2031 and Commission Implementing Regulation (EU) 2019/2072, were taken into account.

Filtering papers from the various searching methods used provided 41 African papers that provided information about African *Leucinodes* spp. to inform this opinion.

In performing the risk assessment, the following assessment steps were distinguished:

- Assessing the host range of the sub-Sahara African species of *Leucinodes,*
- Estimating the number of host fruit that enter the EU (based on a forecast of imports and an estimate of fruit weight),
- Estimating the number of infested host fruit that enter the EU (based on an estimation of infestation rate, informed by previous interceptions and other information),
- Identifying the areas where *Leucinodes* spp. can establish in the EU,
- Quantifying the number of infested host fruit entering NUTS2 areas of the EU where climatic conditions are suitable for establishment and where the pest could reproduce and transfer to a host in those areas, leading to the initiation of a founder population,
- Estimating the duration of the lag period before a founder population begins to spread as well as the steady rate of spread,
- Estimating the potential loss in yield of solanaceous host crops in situations with and without specific pest management of African *Leucinodes* spp. being used by farmers.

Given the similarities with *L. orbonalis* from Asia, and the paucity of data on African species of *Leucinodes,* much of the assessment of African *Leucinodes* spp. follows the same steps and uses the same values for model inputs as were used in the quantitative assessment of *L. orbonalis* from Asia (EFSA PLH Panel, 2024). However, new estimate values were determined for three key steps in the pathway model (i) quantity of *Solanum* host fruit imported from sub-Sahara Africa to the EU, (ii) weight of an individual *Solanum* host fruit (e.g. African eggplant, aubergine varieties, bitter tomato) and (iii) infestation rate of *Solanum* host fruit. The estimates for these inputs were based on a combination of literature review, meta-analysis, information collected during interviews with hearing experts and expert knowledge elicitation involving Panel members and EFSA staff to assess quantities that could not be well identified from the literature or databases alone (EFSA, 2014). To link commodity entry volumes into the EU with the assessment of establishment, imported commodities were distributed by apportioning the imported plant products to NUTS2 regions on the basis of the human population in each NUTS2 region, on the assumption that consumer demand is proportional to population size, as was the assumption in the quantitative assessment of *L. orbonalis*. This assumption was deemed fit for purpose because the African eggplant trade caters to niche markets in the EU (particularly ethnic food markets) for which a distribution proportional to human population is both reasonable and feasible. Human population data were sourced from Eurostat.

In the assessment of entry, the Panel first identified pathways for entry of African *Leucinodes* spp. into EU, finding there is one main pathway, the import of exotic eggplant and eggplant-related species, primarily *Solanum aethiopicum* and *S. melongena*. The volume of imports from sub-Saharan African countries into the EU was estimated based on past imports. An estimate of the level of infestation was informed by previous interception data (Section 2.1).

To determine the area of the EU where *Leucinodes* spp. could establish, the results from the previous assessment of *L. orbonalis* from Asia were used (section 2.2 in EFSA PLH Panel, 2024). Pest transfer in a NUTS2 area was modelled using a stochastic pathway model only for the areas where establishment is potentially possible; it was assumed that no populations of African *Leucinodes* spp. will be founded in areas that are not climatically suitable. Section 2.2.4 presents the overall pathway model for introduction, encompassing both entry and establishment.

2.1 | Entry

2.1.1 | Identifying pathways

African *Leucinodes* spp. are oligophagous pests that feed on different plants within the nightshade family (Solanaceae), with African eggplant (*Solanum aethiopicum*) being by far the most important and impacted plant (Appendix B). The larvae bore into the stems and fruits, partly with high infestation rates, weakening the host plant and rendering the fruits unfit for sale (Appendix D). The Panel compiled a list of host plants that are imported into the EU that could plausibly act as vehicles for entry (e.g. Appendix C: Entry, Table C.1). Entry would require the importation of fruits with eggs or pupae attached to the outside or with larvae feeding in or on the fruit. Efforts to identify plausible pathways focused on commodities on which interceptions had been found. Species of *Leucinodes* are distributed widely across Africa although not reported from every country (see Section 3.2.1, Figure 6). However, taking the known distribution of species into account, it was assumed at least one *Leucinodes* species is present in each country of sub-Saharan Africa. As such, all imports from sub-Saharan Africa within the CN classification of 0709 3000 (fresh or chilled eggplants/aubergines) were used to inform the estimate of commodity flow on the pathway. When classifying commodities within the HS (6 digit) and CN (8 digit) system, commodities are not described using Linnean taxonomy but using common names and aggregating commodities. It is assumed that hosts such as *S. aethiopicum* (known as African eggplant) and *S. macrocarpon* (known as bitter tomato) would be classified within CN 0709 3000 with eggplant (*S. melongena*). In this opinion, we use the term 'African eggplant' to refer to *S. aethiopicum* as well as to exotic African aubergine (*S. melongena*) varieties. The name 'African eggplant' is not used in this opinion to refer to *S. macrocarpon*, the bitter tomato, even though some other sources (e.g. Wikipedia) use the term 'African eggplant' as a common name for *S. macrocarpon*. In this opinion, when referring to all *Solanum* fruit that can act as a pathway of entry (which does include the bitter tomato), the Panel will use the term '*Solanum* fruit from Africa' which excludes fruit of tomato (*S. lycopersicum*) as tomato fruit is not a pathway as the fruit does not produce viable pupae, even though it can get infested by the larvae of *Leucinodes* spp. Future trade flow of goods into the EU was estimated based on the trend of imports recorded in Eurostat data (2013–2022).

Interceptions: Data on interceptions of *Leucinodes* spp. from Africa were extracted from Europhyt and Traces (last check January 29th, 2024) and combined into a single Excel spreadsheet. Duplicates were removed. The Panel was able to identify and focus on the pathway most likely to lead to pest entry after excluding hosts whose import practice was judged unlikely to provide a pathway.

2.1.2 | Scenario definition for entry

An evidence dossier was developed based on literature review to inform judgements of entry. The collected evidence is summarised in Appendix C and was reviewed during the EKE to inform estimates of imported fruit weight and infestation rate. Estimates of the probability of units of the imported commodity being infested with *Leucinodes* spp. were made and uncertainties identified using expert judgement following EFSA guidance (Annex B.8 of EFSA Scientific Committee, 2018).

Scenario 1: considering existing practices and phytosanitary measures

To estimate the number of host commodity units entering the EU infested with the pest, the Panel developed a general scenario with the following description:

- The vegetable fruit of African eggplant and similar species (e.g. bitter tomato) are considered the only significant possible pathway for introduction of African *Leucinodes* spp.
- Import data were sourced from Eurostat. The trend of increasing quantities of EU imports of special and exotic varieties of eggplants (e.g. *S. aethiopicum*, *S. melongena*) from Africa continues at its current rate.
- The proportion of infested fruit is based on information on production practices in countries of origin, literature on impact in countries of origin and the frequency of EU interceptions in combination with information on import inspections practices.
- Production and pest management: eggplant, garden egg (*S. aethiopicum*) and bitter tomato are grown primarily in the open field, very rarely in protected conditions (greenhouses); in Africa, there is organic production as well as production with chemical pesticides (personal communication, Prof. E. Balyejusa Kizito).
- Production by individual growers is at a relatively small scale and groups of growers producing fruit for export often subscribe to organisations and receive extension service advice, e.g. on pest management. The organisations then pool production from several growers for export. Sorting and grading production for export by organisations working for growers will further reduce the levels of pest infestation.
- Transport to EU: In containers via airplane, mostly in small quantities (too small to further split up before distribution in the EU) and in mixed consignments, purchasers are mostly restaurants and ethnic food shops (personal communication, Prof E. Balyejusa Kizito).

The uncertainties associated with the EKE were taken into account and quantified in the probability 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).

2.2 | Establishment

Having developed a CLIMEX model for *L. orbonalis* (EFSA PLH Panel, 2024; Rossi, Gobbi, et al., 2024), the same parameters were used and applied to African *Leucinodes* spp. after also considering alternative modelling approaches (EFSA PLH Panel, 2024). Point locations of African *Leucinodes* spp. were plotted on the CLIMEX map. The ecoclimatic index (EI) map generated by CLIMEX was found to give good congruence with actual known locations of the species (see Section 3.2).

Establishment in greenhouses (i.e. occurrence of permanent populations) was not considered because production is primarily in open fields and any producers that do grow eggplants in greenhouses have much greater control of pests in contained conditions; furthermore, there can be periods of host freedom when greenhouses are cleared out.

2.2.1 | Literature search: Distribution and ecophysiology of African *Leucinodes* spp.

An extensive literature search for pest distribution was conducted in Web of Science (all databases, excluding Data Citation Index and Zoological Record) and Scopus on 14 September 2022 (Rossi, Gobbi, et al., 2024). The search string was based only on the scientific and common names of the pest. Other keywords such as 'biology', 'physiology' and 'temperature' were not used, so as not to limit the retrieval of distribution data, often reported as secondary information. The review followed a two-step approach for selecting relevant papers, the first step was based on screening the title and abstract of the paper, while the second step was based on the full-text analysis. A full description of the literature search methodology is available in Rossi, Gobbi, et al. (2024).

2.2.2 | CLIMEX analysis

Within CLIMEX (version 4.1.0.0, Kriticos et al., 2015), the ecoclimatic index (EI) spans the integers from 0 to 100, where 0 means that a place is unsuitable for the establishment of an organism whereas 100 means a place is highly suitable. It is expected that, with increasing EI, the density and impact of an organism will increase. According to Kriticos et al. (2015), a value of EI greater than 30 demarcates areas where climate is (very) favourable for the species whereas areas where EI < 30 are less favourable. They state: 'An EI of more than 30 represents a very favourable climate for a species, as it means that during the (say) six months suitable for growth with a maximum Growth Index (GI) of 50, the species has achieved 60% of the potential population growth'. However, a precise threshold value for establishment and impact cannot be given and any cut-off value of EI may be species-specific and should be operationally defined on the basis of additional evidence. The Panel used two EI thresholds (≥ 15 and ≥ 30) to identify areas where climate suitability favoured establishment. See also assessment Section 3.4 on Impact.

Climate change

A CLIMEX simulation was performed for four different regional climate change models for the 20-year period 2040–2059 under the RCP8.5 ('Business as usual') scenario. CLIMEX results for the four climate data sets were averaged to create an ensemble model (details in Rossi, Czwienczek, et al., 2024). Using the ensemble model, the NUTS2 regions and area suitable for establishment were identified based on EI thresholds ≥ 15 and ≥ 30.

2.2.3 | Transfer and initiation of a founder population

The process of transfer and initiation of a founder population was broken down into four steps:

- Estimating the proportion of imported host-plant material discarded by commercial stakeholders in the supply chain due to e.g. infestation, physical damage, substandard quality or oversupply;
- Estimating the proportion of infested material discarded by consumers;
- Estimating the proportion of larvae that develop to adulthood and escape from discarded material;
- Estimating the proportion of females that find a mating partner and lay fertilised eggs from which another generation emerges whose adults develop to reproduce and initiate a founder population.

Information pertaining to support judgements relating to the steps necessary for establishment was sought within the literature review. None of the papers on African *Leucinodes* spp. provided sufficient justification for the Panel to deviate from previous estimates of transfer or initiation used in the quantitative assessment of *L. orbonalis* from Asia (EFSA PLH Panel, 2024). Thus, the input values for such estimates, the assumptions and uncertainties used for *L. orbonalis* were also used for African *Leucinodes* spp.

2.2.4 | Overall model for introduction (entry and establishment)

The pathway model for introduction is a product of the following components:

- EU import quantity of African eggplant and related fruits from Sub-Saharan Africa (i.e. excluding North Africa)
- Identification of NUTS2 regions suitable for establishment (EI ≥ 15 and EI ≥ 30)
- Inverse weight of a single eggplant type fruit (to calculate the number of fruits imported to suitable NUTS2 regions as the volume of trade divided by the weight of a single fruit)
- Proportion of infested fruits imported to NUTS2 regions where establishment may be possible
- Proportion of infested fruit disposed of as waste in suitable NUTS2 regions
- Probability of larva in discarded fruit surviving to become an adult in suitable NUTS2 regions
- Probability of a female mating in suitable NUTS2 regions
- Probability of a mated female initiating a founder population that persists

Figure 2 illustrates the model for pest introduction.

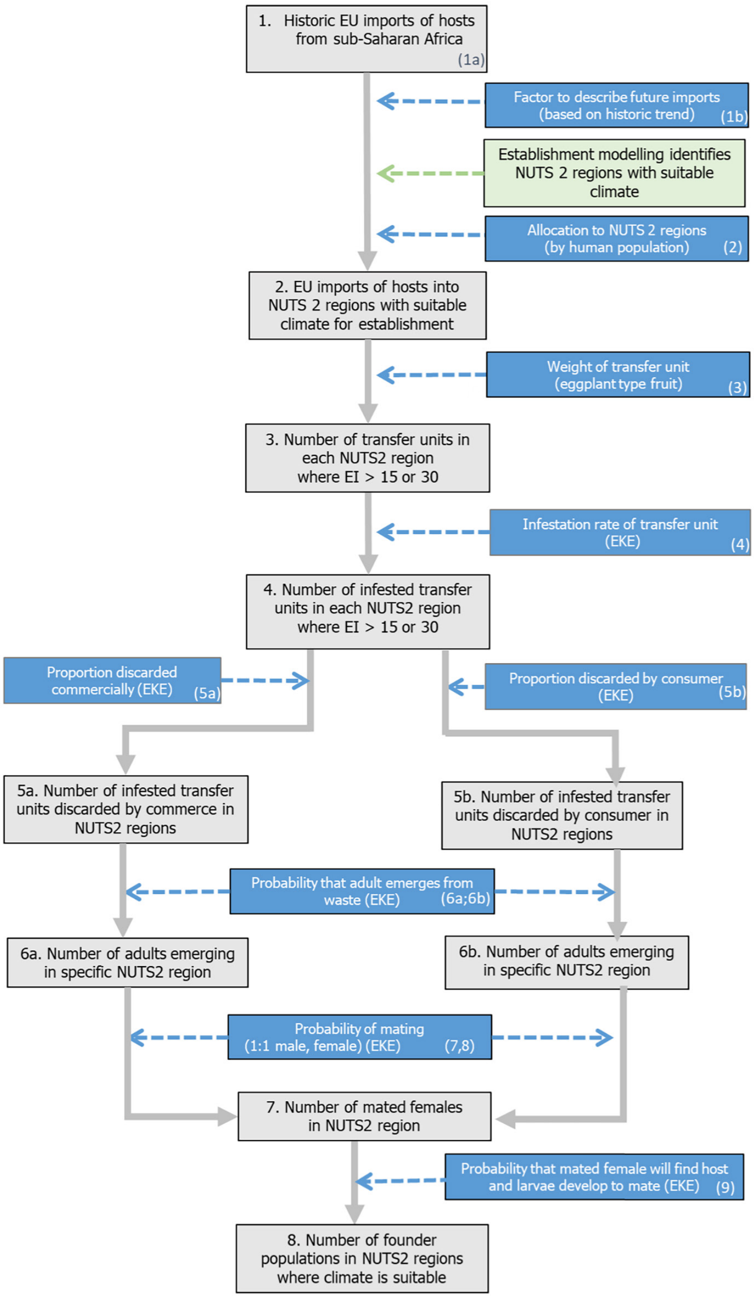


FIGURE 2 Conceptual diagram of pathway model to quantitatively estimate the likelihood of introduction of African *Leucinodes* spp. into the EU. Blue boxes are parameters and grey boxes are variables in the model. Numbers in brackets within the boxes correspond to numbering of parameters in the spreadsheet model (see Figure 3 and Supporting materials – Annex A). A mathematical description of the pathway model is given in Appendix C (Entry). The Excel implementation of the pathway model, with a user-friendly presentation of the parameters and intermediate results of the calculation, is available in the supplementary materials to this opinion. See also the screenshot of the Excel model interface in Figure 3.

2.2.5 | Mathematical model to estimate likelihood of founder population establishment of African *Leucinodes* spp.

A pathway model is mathematically the product (multiplication) of a set of random variables (Douma et al., 2016; van der Gaag et al., 2019). Most of the variables are uncertain having a probability distribution, which is either based directly on data or on EKE. The model also contains some constants.

The Panel used for this risk assessment the following pathway model:

$$y = x_1 * x_2 * x_3 * 10^6 * \frac{1}{x_4} * \frac{x_5}{10^4} * \left(x_6 * x_8 + \left(1 - x_6\right) * x_7 * x_9\right) * 0.5 * x_{10} * x_{11},$$

where the meaning of the symbols is given in Table 2.

TABLE 2 Definitions of terms in mathematical model.

Variable	Meaning	Units of measurement	Excel name[a]
y	Outcome variable of the pathway model: number of founder populations per year across the EU	Number per year	ab
Quantification of entry			
x_1	Average import of African eggplant from sub-Sahara Africa in the period 2013–2022	*t* (1000 kg) per year	a_1
x_2	Multiplication factor, accounting for an increase in trade in the future (2024–2028) compared to the reference period	–	a_2
x_3	Proportion of the European population living in NUTS regions with an EI ≥ 15 or EI ≥ 30 (depending on the scenario)	–	b
10^6	Conversion factor from ton (1000 kg) to gram (g)	g/t	
x_4	Average weight of an African eggplant fruit	g	c
x_5	Infestation rate: proportion of single African eggplant fruit infested with *Leucinodes* spp.	Per 10,000	e
10^4	Factor to convert proportion expressed as infested fruit per 10,000 to proportion of infested fruit		
Quantification of post-entry processes resulting in establishment			
x_6	Proportion waste pre-consumer (commercial waste)	–	g
x_7	Proportion waste consumer	–	h
x_8	Proportion of adults emerging from commercial waste		k
x_9	Proportion of adults emerging from consumer waste		l
0.5	Proportion of females among adults	–	p
x_{10}	Proportion of females finding mating partner		q
x_{11}	Likelihood that mated female finds a host and founds a persistent population (i.e. a population surviving for an indefinite period, under pressures such as predation and overcoming an initial Allee effect)		s

[a]Excel name refers to the name of the variable in the Excel implementation of the pathway model. See the Excel implementation of the pathway model, which is available in the Supplementary Materials.

	Model Suitable NUTS2 region		Distribution CLIMEX: EI>30, no moisture, population, current		Unit Descending	Mean
				[%]		
1a parameter	Import from infested countries (Total EU, aubergines, turkey berry)	a1	1131	[t]	[t]	1130.5
1b parameter	Trend in trade predicted from past to 2024-2028	a2	1.72	[-}	[-}	1.72
2nd parameter	Proportion of the population in suitable NUTS2	b	23.12%	[%]	[%]	23%
Suitable import	Import from infested countries to suitable area	c=a1*a2*b	450	[t]	[t]	449.8
3 parameter	Average weight of one African aubergine fruit	c	57.0	[g/fruit]	[g/fruit]	57.0
Transfer units	Number of transfer units imported from infested countries	d=c*1000000/c	7896130	[transfer units]	[transfer units]	8906716
4th parameter	Infestation rate of transfer units from Sub-sahara Africa at border	e	17.18	[1/10000]	[1/10000]	17.18
Infested units	Number of infested transfer units entering in suitable areas	f=d*e/10000	13563	[transfer units]	[transfer units]	15334
5a parameter	Proportion of discarded infested transfer units during distribution	g	13%	[%]	[%]	12.5%
5b parameter	Proportion of discarded infested transfer units at consumer	h	48%	[%]	[%]	48.3%
Discarded distribution	Number of transfer units discrded during distribution	i=f*g	1697	[transfer units]	[transfer units]	1925
Discarded consumer	Number of transfer units discarded at consumer	j=f*(1-g)*h	5730	[transfer units]	[transfer units]	6481
6a parameter	Proportion of adults emerging from the commercial waste	k	1.03%	[%]	[%]	1.03%
6b parameter	Proportion of adults emerging from the consumer waste	l	5.67%	[%]	[%]	5.67%
Emerged commercial	Number of discarded infested aubergines in risk areas	m=i*k	17.57	[adults]	[adults]	19.96
Emerged consumer	Number of emerged adults in risk areas	n=j*l	324.80	[adults]	[adults]	367.92
Emerged insects	Number of emerged adults in risk areas	o=m+n	342.37	[adults]	[adults]	387.88
7th parameter	Proportion of females	p	50%	[%]	[%]	50%
8th parameter	Proportion of females finding mating partner	q	0.086%	[%]	[%]	0.086%
Mated	Number of mated females in suitable areas	r=o*p*q	0.1476	[mated females]	[mated females]	0.16771
9th parameter	Probability of established founder populations	s	17%	[%]	[%]	17.0%
Founder pops	Number of founder populations in suitable areas	t=r*s	0.02508	[founder populations]	[founder populations]	0.02881
Final (number)	Number of founder populations in suitable areas	u=t	0.02508	[founder populations]	[founder populations]	0.02881
Final (years)	Expected number of years until first founder population	v=1/t	40	[years]	[years]	1544

FIGURE 3 Screenshot of the pathway model in Excel (available in the Supplementary material).

Each of the variables x_i was random, except x_1 and x_2 which were derived from a regression analysis of trade in African eggplants (see Appendix C).

The outcome variable y represents the number of founder populations per year due to the introduction of the organism in the EU with the trade in African eggplant. That is the frequency at which new populations are founded.

Calculations with the pathway model are made using Monte Carlo simulations. This is done by randomly drawing the values of the variables on the right-hand side from their probability distributions, and calculating for each set of values of x_i the corresponding value of y and determining the distribution of y across the Monte Carlo replicates.

The inverse of each rate of y, i.e. $\frac{1}{y}$ represents the expected waiting time until the next founding event.

The pathway model has several intermediate results that are interpretable.

For instance, $x_1 * x_2 * x_3 * 10^6$ is the import volume of African eggplant into areas suitable for establishment of African *Leucinodes* species in the EU during 1 year, measured in g/year.

$x_1 * x_2 * x_3 * 10^6 * \frac{1}{x_4} * \frac{x_5}{10^4} * \left(x_6 * x_8 + \left(1 - x_6\right) * x_7 * x_9\right)$ is the total number of moths emerging from waste discarded in the suitable areas of the EU during 1 year.

Additional intermediate results are available. Further information is given in the Excel implementation of the pathway model that is included in the supplementary information of this opinion.

2.3 | Spread

The area of the colonised territory occupied during spread is expected to follow a sigmoid curve (Figure 4). After an initial lag phase during which the founder population builds up and spread is slow, the spread rate accelerates and reaches a constant rate for some time before declining again as the suitable area gets fully colonised (saturation phase). Rather than estimate the parameters for logistic spread (i.e. Figure 4), this assessment followed the method of EFSA (2019) to estimate the duration of a lag phase, during which the initial founder population may adjust population genetically to the selection pressures in the new environment, building up in abundance before starting to spread, and the linear rate of range expansion when spread is at its fastest. In this way, spread assessment is simplified.

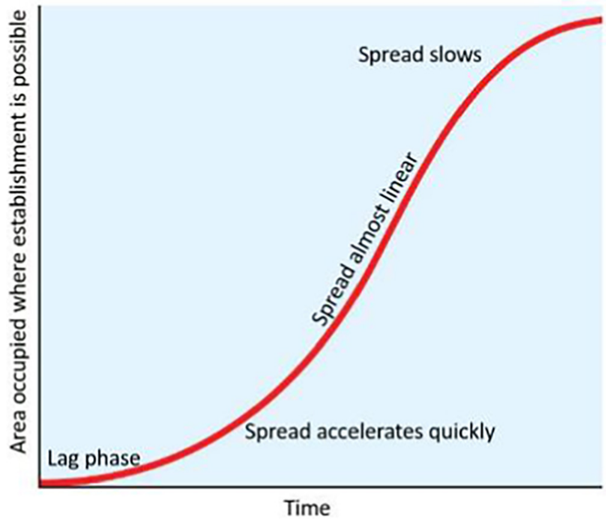


FIGURE 4 Stages of conceptual logistic spread: Following the lag phase (lag period) spread accelerates, becomes almost linear then slows.

The Panel used the lag phase and spread rate estimated in the pest risk assessment of *L. orbonalis* (EFSA PLH Panel, 2024). That estimation was based on *L. laisalis*, a species related to the Asian *L. orbonalis* and one of the nine *Leucinodes* species present in Africa. Thus, the input values for estimates, the assumptions and the uncertainties used for *L. orbonalis* were also used for African *Leucinodes* spp.

2.4 | Impact

The scientific literature on African *Leucinodes* species was screened for information on impact of the pest on host plants. An evidence dossier on impact was assembled by the Working Group. Evidence of impacts in Africa is summarised in Appendix D (Impact). The literature on African *Leucinodes* spp. provided sufficient justification for the Panel to not deviate from previous estimates of impact used in the quantitative assessment of *L. orbonalis* (EFSA PLH Panel, 2024). Thus, the input values for such estimates, the assumptions and uncertainties used for *L. orbonalis* were also used when assessing impacts for African *Leucinodes* species.

2.5 | Evaluation of risk reduction options/risk mitigation measures

As noted in Section 1.2, the EFSA PLH Panel planned to evaluate how additional risk mitigation measures may reduce the likelihood of pest entry. Recognising that there are a variety of eggplant type *Solanum* hosts and that there is likely great variation in production practices within and between African countries, mostly with small-scale production, the Panel was unable to make assumptions about typical production systems and pest management regimes. The estimates for the model parameter infestation rate were mostly informed by analysis of EU interception data. Lack of detailed knowledge of the practices currently applied in Africa prevented the Panel from determining what additional risk reduction options (RRO) could be put in place and more importantly how effective they would be. However, increasing the intensity of sampling and inspection of imports in the EU would lead to an increase in detecting infested consignments. Increasing the number of consignments that are rejected would likely feedback and result in improved production practices and pre-export inspection practices in Africa and thus lower the likelihood of infested consignments arriving into the EU. Such a future scenario was not quantified. This opinion therefore presents an assessment of pest risk taking into account the trend of increasing trade volumes, existing practices (as known) and generic phytosanitary measures.

2.6 | Temporal and spatial scales

The pathway model calculates the flow per year, on average, over the next 5 years (2024–2028). The distribution of potentially infested plant material entering the EU was assessed using NUTS2 spatial resolution using EU census data from 2021 (Eurostat, accessed 31 December 2022). The CLIMEX model used 30 years of climate data, 1981–2010.

3 | ASSESSMENT

A synthesis of the biology of African *Leucinodes* species based on the literature review is provided in Appendix B. Two principal species were reported in the African literature: *Sceliodes* (or *Daraba*) *laisalis*, a species now placed in *Leucinodes*, and *Leucinodes 'orbonalis'*. Identifications of *Leucinodes orbonalis* in Africa are, however, erroneous. The species *L. orbonalis* is of Asian origin and is not known to occur in Africa (Mally et al., 2015). *L. orbonalis* has white wings; hence specimens from Africa previously described to *L. orbonalis*, probably belong to one of the at least five species with predominantly white-winged adults: *L. africensis*, *L. kenyensis*, *L. malawiensis*, *L. pseudorbonalis* and *L. rimavallis*, (Figure 1). Brown-winged specimens of *Leucinodes* (*L. ethiopica*, *L. laisalis* and *L. ugandensis*) captured on the African continent were probably all attributed to *S. laisalis* (now: *L. laisalis*) up to 2015 (and erroneously thereafter). *L. raondry* was described by Viette (1981) and is endemic in Madagascar.

All African reports on *Leucinodes* spp. state that the larvae feed on Solanaceae, where they bore into the stems and especially the fruits of their host plants (e.g. Aina, 1984; Frempong, 1979; Huertas Dionisio, 2000; Nwana, 1992; Ogunwolu, 1978; Onekutu et al., 2013). The concealed feeding inside the shoot or fruit makes the larvae difficult to detect and control.

3.1 | Entry

3.1.1 | Identifying pathways (interceptions on produce)

The combined search of Europhyt and TRACES revealed 266 unique interceptions of African *Leucinodes* spp. from 11 African countries between 2004 and 2023 (Figure 5; Appendix C). As for the quantitative assessment of *L. orbonalis* (EFSA PLH Panel, 2024), the Panel analysed the host status of plants on which interceptions have been reported to distinguish actual pathways of introduction and incidental interceptions due to consignments with mixed plant material. The majority of intercepted plant species are in the Solanaceae, but a number of species from other families are reported (Appendix C: Entry, Table C.1). Most EU interceptions of African *Leucinodes* species were from *Solanum aethiopicum* (78%, 208 of 266 interceptions) and *S. melongena* (16%, 43 of 266 interceptions) (Table 3).

TABLE 3 Summary of produce on which African *Leucinodes* species were intercepted 2004–2023.

Produce intercepted	Common names	Number of interceptions 2004–2023	% of all interceptions
Solanum aethiopicum	African eggplant Garden egg Gilo	207	77.8
Solanum melongena (most likely mini-eggplants)	Eggplant	43	16.2
Unspecified *Solanum*	–	8	3.0
Solanum macrocarpon	Bitter tomato	3	1.1
Other	–	5	1.9
Sum		266	100.0

Note that African eggplant is used in the literature as a common name across a variety of *Solanum* species. In this opinion, we use the term 'African eggplant' to refer to *S. aethiopicum* as well as to exotic African aubergine (*S. melongena*) varieties, but it does not include any other *Solanum* species.

Figure 5 shows that, between 2004 and 2012, most interceptions were from Ghana. In more recent years, interceptions from Ghana have declined while interceptions from Cameroon and Uganda have increased.

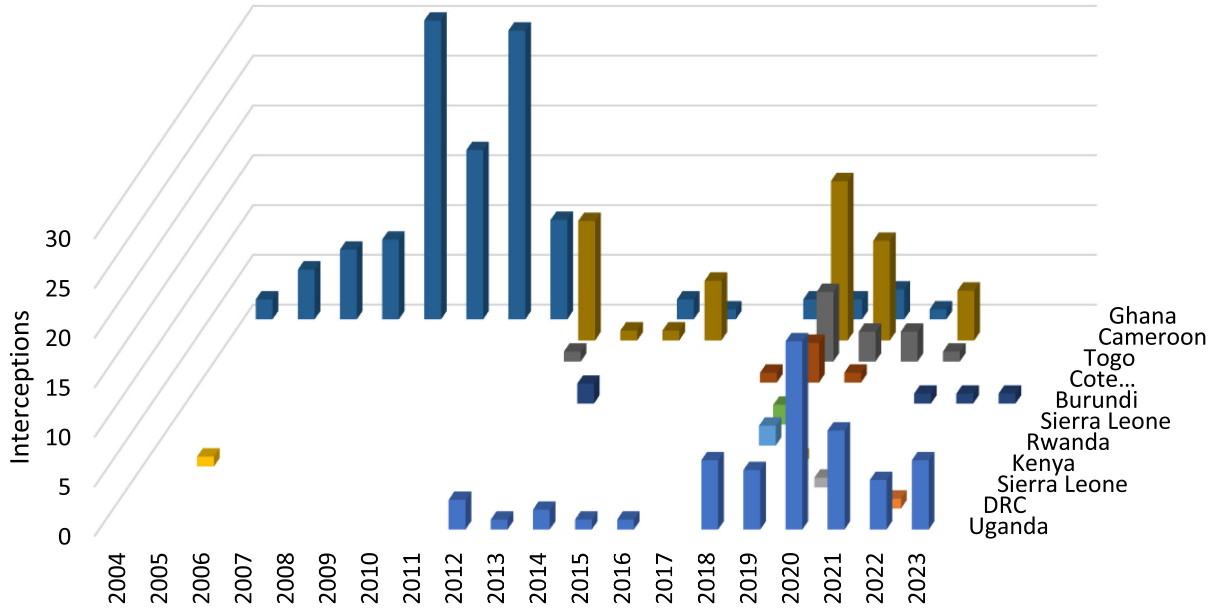


FIGURE 5 EU interceptions of *Leucinodes* species from African countries, 2004–2023 ($n=266$).

Examining the interception records shows that a variety of eggplant type *Solanum* species provide a pathway into the EU. Interceptions on *S. melongena* are likely exotic varieties such as mini-aubergines, imported for European niche markets. Most interceptions occurred on *S. aethiopicum*. Four general morphotypes of *S. aethiopicum* are distinguished in Africa, of which only the Gilo and Kumba types are grown for their fruits, which are exported to the EU and therefore qualify as entry pathways. The Shum type is grown for consumption of the leaves, which are too perishable to be a transcontinental export good; furthermore, *Leucinodes* larvae do not feed on leaves. The Aculeatum group has mostly ornamental uses (personal Communication, Prof E. Balyejusa Kizito).

In conclusion, we identify garden egg (*S. aethiopicum*), eggplant varieties (*S. melongena*) and similar produce such as *S. macrocarpon* (bitter tomato) as providing pathways for African *Leucinodes* to enter the EU.

3.1.2 | Identifying pathways (plants for planting)

Solanaceae (nightshades) are the only confirmed host plant family of *Leucinodes* species (Appendix C: Entry, Table C.1). Plants for planting of Solanaceae, other than seeds, are largely prohibited from entering the EU except from a few European and Mediterranean countries and parts of European Russia (Commission Implementing Regulation (EU) 2019/2072, Annex VI, 18). Annex VI prohibitions also concern potato (*S. tuberosum*) which has more detailed prohibitions. Plants for planting were therefore excluded as a potential pathway to consider.

3.1.3 | Pathway evaluation (EKE results)

Based on an estimate of the quantity of future imports, and the average weight of imported fruits, the degree of infestation and with imports being allocated to NUTS regions in proportion to human population, results from the entry pathway model are shown in Table 4 below focussing on the estimated number of infested eggplant type fruit entering EU NUTS2 regions where EI ≥ 15 (see Section 3.2).

TABLE 4 Model results illustrating the range in estimates of mean imports and subsequent range in number of infested host fruit entering the EU each year into regions suitable for establishment (EI ≥ 15) (each infested fruit is assumed to be infested with one live larvae) (Blue shaded rows in this table correspond to blue boxes in Figure 2).

Percentile	1%	5%	25%	50%	75%	95%	99%
Historic import of fresh eggplants and related fruits from Africa (excluding north Africa) into the EU (tonnes) (1a)	472.8	599.6	841.0	1063.9	1345.9	1887.5	2393.6
Anticipated average increase in trade over next 5 years based on past import trend (fixed factor) (1b)	1.72	1.72	1.72	1.72	1.72	1.72	1.72
Forecast mean annual imports in next 5 years (tonnes)	813.2	1031.3	1446.5	1829.9	2314.9	3246.5	4117.0
Quantity of imports going to NUTS2 regions with suitable climate (EI ≥ 15) (23.12%) (tonnes) (2)	188.1	238.6	334.6	423.3	535.5	751.0	952.3
Average weight of one eggplant type fruit (g) (3)	20.1	28.7	44.0	56.2	69.1	87.7	100.0
Projected annual mean number of fruits going to suitable NUTS2 regions (millions)	2.729	3.651	5.595	7.699	10.789	18.123	27.335
Infestation rate of eggplants (per 10,000 fruits) (4)	0.30	0.80	4.37	11.27	23.72	53.70	84.15
Number of infested fruits entering suitable NUTS2 regions annually	205	567	3185	8566	19,216	52,696	96,837

3.1.4 | Uncertainties affecting the assessment of Entry

- Based on recent trends, volumes of eggplant from Africa are expected to increase in future; however, some African type varieties are being grown in the EU already; increases in EU production might substitute for import and alter the projected trend.
- The assessment of the proportion of infested eggplant fruit was informed by literature on effects of variety and management on insect infestations of *S. aethiopicum* in Africa, an interview with a hearing expert and data on interceptions (Europhyt and TRACES). The interpretation of interception data is affected by uncertainty on the distribution of consignment sizes, the percentage of consignments inspected in each country, the sample size at inspection and the chance of detection of infestation if an inspector examines an infested eggplant fruit.

3.1.5 | Conclusion on the assessment of Entry

The pathway most likely to provide a route for entry of African *Leucinodes* species into the EU was judged to be fresh eggplant (*S. melongena*) and eggplant type fruits (predominantly *S. aethiopicum*). In the order of 9000 fruit infested with *Leucinodes* are expected to enter the EU each year (median estimate ~ 8600; 90% CR ~ 5700–52,700) in areas potentially suitable for establishment (EI ≥ 15) (Table 3). In the order of 5000 fruit infested with *Leucinodes* are expected to enter the EU each year (median estimate ~ 5200; 90% CR ~ 350–32,100) in areas potentially suitable for establishment (EI ≥ 30) (Table 5).

3.2 | Establishment

Climatic mapping is a common approach to identify new areas that might provide suitable conditions for the establishment of alien organisms (Baker, 2002; Venette, 2017). Climatic mapping is based on combining information on climate in the known distribution of a poikilothermic organism, the organisms' physiological responses to environmental conditions and the climate in the risk area. The distribution of African *Leucinodes* species is presented in Section 3.2.1. The results of climatic mapping are presented in Sections 3.2.2–3.2.5.

3.2.1 | Distribution of *Leucinodes* spp. in Africa

In total, 144 observations of *Leucinodes* species in Africa were retrieved from literature. These included 32 reports of presence at the level of administrative units and 112 reports on presence at point locations described by coordinates (Figure 6). From these 112 point locations, 76 were identified in Mally et al. (2015), 31 additional locations originated from the systematic literature search and five came from additional documents (Rossi, Czwienczek, et al., 2024). *Leucinodes* species are widely distributed in sub-Sahara Africa. Nigeria, Ghana, Uganda and Kenya are the most represented countries in this dataset, accounting for more than 50% of recorded observations.

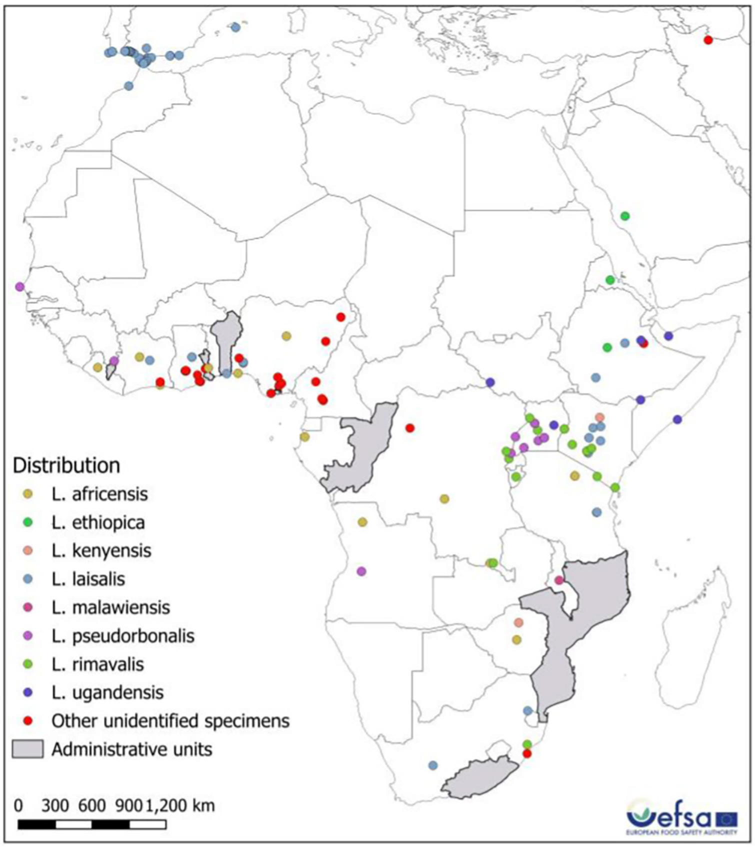


FIGURE 6 Distribution of African *Leucinodes* species shows observations based on reported coordinates, and administrative units where coordinates were not recorded (grey polygons).

3.2.2 | CLIMEX projection

A CLIMEX model parameterised to describe the relationship between climatic conditions and occurrence of *L. orbonalis* in Asia (Rossi, Gobbi, et al., 2024) gave good congruence with occurrence of *Leucinodes* species in Africa when the CLIMEX-predicted suitability was projected over Africa (Figure 7). Most of the presence points are where EI ≥ 30. Three locations (one in South Africa, one in Saudi Arabia and one in Iran) have an EI = 0. For all the other locations, the minimum EI was 33 (Daleti, Ethiopia).

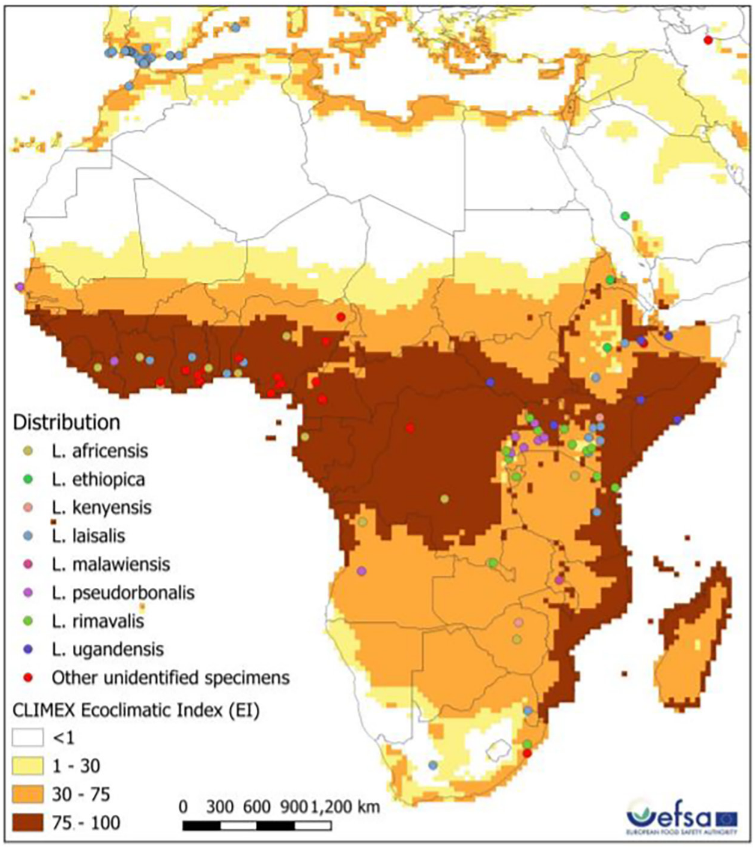


FIGURE 7 CLIMEX projection for Africa, showing four categories of Ecoclimatic index. Darker shades or yellow/brown indicate regions that are more climatically suitable for long-term survival of *Leucinodes* species. The CLIMEX model was parameterised for *L. orbonalis* using presence observations of this species in Asia, and is here used to predict independent data for African *Leucinodes* species in Africa.

The CLIMEX projection in Europe shows a higher likelihood of establishment around the Mediterranean coast, especially in Cyprus, Greece, Italy, Malta and Spain, and the south of Portugal (Figure 8). In conclusion, the areas where the climate suitability is highest are the warm areas on the coast of the Mediterranean Sea, while inland areas of Spain, France, Italy and most of the Portuguese territory have a lower suitability.

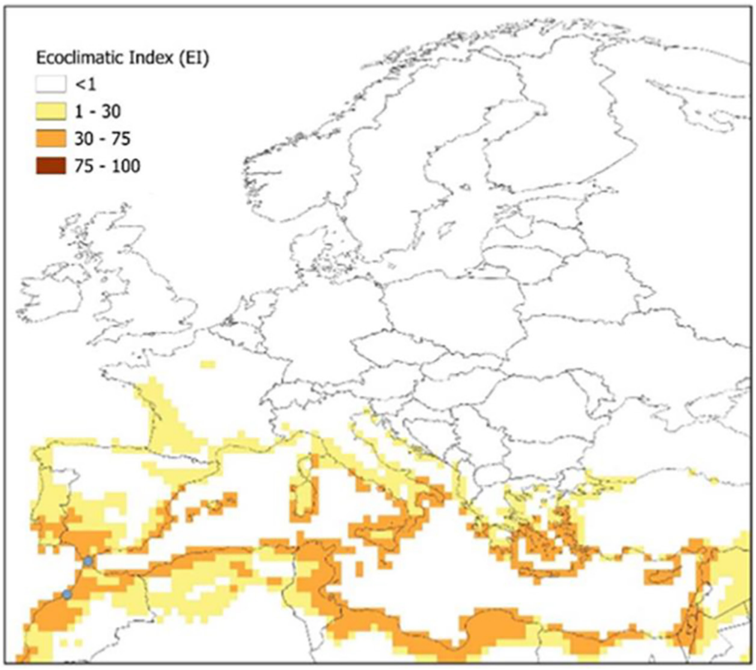


FIGURE 8 CLIMEX projection for the Euro-Mediterranean area, showing four categories of Ecoclimatic index. Darker regions are more climatically suitable for long-term survival of *Leucinodes* species. (Rossi, Czwienczek, et al., 2024).

3.2.3 | Identifying suitable NUTS2 regions for Establishment

NUTS2 regions of the EU containing grid cells with EI ≥ 15 or EI ≥ 30 were determined and are the same as reported in the quantitative risk assessment of *L. orbonalis* (EFSA PLH Panel, 2024). Table 5 lists the NUTS2 regions in which climate is suitable for *Leucinodes* species to establish.

TABLE 5 NUTS2 regions where climate is suitable for *Leucinodes* species to establish.

EU member state	EU NUTS2 regions where climate is suitable for *Leucinodes* spp. to establish
Croatia	Jadranska Hrvatska
France	Aquitaine, Corse, Languedoc-Roussillon, Midi-Pyrénées, Provence-Alpes-Côte d'Azur
Greece	Attiki, Dytiki Elláda, Ionia Nisia, Ipeiros, Kentriki Makedonia, Kriti, Notio Aigaio, Peloponnisos, Sterea Elláda, Thessalia, Voreio Aigaio
Italy	Abruzzo, Basilicata, Calabria, Campania, Lazio, Liguria, Molise, Puglia, Sardegna, Sicilia, Toscana, Umbria
Malta	Malta
Portugal	Alentejo, Algarve, Área Metropolitana de Lisboa, Centro, Norte, Região Autónoma da Madeira, Região Autónoma dos Açores
Spain	Andalucía, Aragón, Castilla-La Mancha, Cataluña, Comunidad Valenciana, Extremadura, Galicia, Islas Baleares, Principado de Asturias, Región de Murcia

Climate change

Compared to the assessment of establishment within current climate conditions (1993–2022), the CLIMEX model indicated an increase in the area climatically suitable for establishment under climate change, based on data from the ensemble model for future climate in 2040–2059 (Appendix E, Figure E.1). Furthermore, the model predicted an increase in the suitability for areas in Spain, Portugal, Greece and Italy that are already predicted to be suitable with current climate.

3.2.4 | Introduction of African *Leucinodes* species into the EU

The entry and establishment of a pest results in pest introduction (FAO, 2017). The Panel used Monte Carlo simulations with a probabilistic pathway model to assess the number of infested host fruit entering each year into those parts of the EU that are climatically suitable for establishment. The model then quantifies the subsequent steps of waste production, escape of adult insects from waste, mating and subsequent initiation of a founder population by an egg-laying female. Results presented in Tables 4 and 6 are based on a threshold for establishment of EI ≥ 15. This threshold is uncertain, so an alternative EI threshold of ≥ 30 was also considered (Table 7).

TABLE 6 Model output results illustrating the range in estimates for each model step from entry to initiation of founder population. (EI ≥ 15) (Blue rows in this table correspond to blue boxes in Figure 2).

Percentile Model step	1%	5%	25%	50%	75%	95%	99%
Number of infested fruit in suitable climatic regions (from Table 3)	205	567	3185	8566	19,216	52,696	96,837
% discard by industry (5a)	5.0%	6.3%	9.1%	11.8%	15.2%	21.1%	26.0%
% discard by consumer (5b)	20.0%	23.5%	35.8%	48.6%	61.0%	72.1%	74.9%
Number of discarded infested fruit in areas suitable for establishment (industry waste)	21.4	63.4	358.6	991.0	2335.7	6917.6	13,350.9
Number of discarded infested fruit in areas suitable for establishment (consumer waste)	74.8	216.2	1213.2	3359.3	7976.4	22,945.1	44,705.1
Proportion of adults emerging from industry waste (6a)	0.10%	0.19%	0.58%	1.03%	1.48%	1.90%	2.01%
Proportion of adults emerging from consumer waste (6b)	0.36%	0.98%	2.92%	5.13%	7.89%	12.22%	14.99%
Number of adults emerging via industry waste	0.1	0.4	2.7	8.3	22.5	77.6	161.2

TABLE 6 (Continued)

Percentile Model step	1%	5%	25%	50%	75%	95%	99%
Number of adults emerging via consumer waste	1.9	7.2	47.2	147.9	408.9	1433.3	3128.9
Sum of emerged adults in NUTS2 areas suitable for establishment (50% are female)	2.5	8.8	53.9	161.8	435.3	1492.9	3214.6
Proportion of females finding mating partner (8)	0.007%	0.018%	0.049%	0.081%	0.119%	0.171%	0.199%
Number of mated females in areas for establishment	0.0006	0.0024	0.0170	0.0575	0.1725	0.6740	1.6250
Probability of establishment of a founder population (9)	1.0%	2.4%	9.0%	17.0%	25.0%	31.6%	33.0%
Mean number of founder populations in suitable regions each year	0.00005	0.00023	0.00200	0.00780	0.02639	0.12125	0.31978
Expected number of years till first founder population	3	8	38	128	500	4279	20,782

TABLE 7 Selected model output results illustrating the range in estimates of mean imports and subsequent range in number of infested host fruit entering the EU each year into regions suitable for establishment (scenario EI ≥ 30) and selected results for model steps leading to initiation of a founder population.

Percentile	1%	5%	25%	50%	75%	95%	99%
Forecast mean annual imports in next 5 years (tonnes)	813.2	1031.3	1446.5	1829.9	2314.9	3246.5	4117.0
Quantity of imports going to NUTS2 regions with suitable climate (EI ≥ 30) (14.1%)	188.1	238.5	334.6	423.2	535.4	750.9	952.3
Projected annual mean number of fruits going to suitable NUTS2 regions (millions)	1.664	2.226	3.411	4.694	6.577	11.048	16.664
Number of infested fruits entering suitable NUTS2 regions annually (EI ≥ 30)	125	346	1941	5222	11,715	32,124	59,034
Sum of emerged adults in NUTS2 areas suitable for establishment (50% are female)	2	5	33	99	265	910	1960
Mean number of founder populations in suitable regions each year	< 0.0001	0.0001	0.0012	0.0048	0.0161	0.0739	0.1950
Expected number of years till first founder population	5	14	62	210	820	7020	34,090

3.2.5 | Uncertainties affecting the assessment of Introduction

- Whether *Leucinodes* species occur in all sub-Saharan countries is unknown; however, based on known distributions, the Panel assumed that *Leucinodes* spp. were present in all sub-Saharan countries. Such an assumption meant that exports of eggplant type fruits from all sub-Saharan countries were included in the entry model. If *Leucinodes* spp. do not occur in all countries considered, then the estimated number of fruit infested with *Leucinodes* entering the EU is likely to be an overestimate.
- While the quantitative assessment focused on official import of African eggplants from Africa, other potential pathways exist, including via passenger baggage. Further considerations on the relevance of passenger baggage are given in Section 4.1.
- The quantity of eggplant type fruits imported by EU from Africa has been increasing in recent years and this trend is expected to continue, at least over the next 5 years (the time horizon of this assessment). However, some EU growers are already producing exotic varieties of eggplants of the type currently sourced from Africa and increased production in the EU could impact imports from Africa.

- CN and HS codes do not sufficiently discriminate between types of eggplant (e.g. garden egg, bitter tomato and varieties of *S. melongena*). The quantity of each fruit type imported from Africa is unknown. Assumptions and simplifications had to be made during this assessment to keep this assessment practical.
- No detailed literature on the growing practices used in Africa by exporters was identified. Assumptions had to be made and are captured in the EKE description (Appendix C).
- The distribution of imported African eggplant type fruit was based on human population in NUTS2 regions. This might not be a true reflection of how fruits for niche markets are really distributed within the EU. The number of fruits entering NUTS2 regions could therefore be an over- or under-estimate.
- The threshold EI for establishment is uncertain. Two thresholds were selected (E ≥ 15, EI ≥ 30) and these informed the NUTS2 regions where establishment is thought to be possible. Were the threshold lower than 15 then a bigger area of the EU may be suitable for establishment and the likelihood of a founder population establishing would increase.

3.2.6 | Conclusion on Entry and Establishment (Pest Introduction)

Pest interceptions indicate that African *Leucinodes* species can enter the EU. Modelling estimates that, depending on the EI threshold used for establishment, the number of transfer units infested with live *Leucinodes* entering NUTS2 areas where establishment may be possible varies from a median of ~ 8600 per year (90% CR ~ 570–52,700) (EI ≥ 15) to ~ 5200 per year (90% CR ~ 350–32,100) (EI ≥ 30).

Table 6 provides key results from the pathway modelling. It shows the likelihood that a founder population will be initiated in the EU each year. Using an EI ≥ 15, the median number of founder populations establishing in the EU annually is 0.0078 (90% CR 0.00023–0.12124). This equates to a median estimate of one founder population approximately every 128 years (90% CR approximately one every 8–4280 years).

Using an EI ≥ 30, the median number of founder populations establishing in the EU annually is 0.0048 (90% CR 0.0001–0.0739). This equates to a median estimate of one founder population approximately every 210 years (90% CR approximately one every 14–7020 years) (Table 7).

3.3 | Spread

The Panel used the assessment of spread of the Asian *L. orbonalis*, published in Appendix E of EFSA PLH Panel (2024), as an estimate of the spread rate of African *Leucinodes* species. The estimated spread for the Asian *L. orbonalis* (EFSA PLH Panel, 2024) was based on the spread of *L. laisalis*, which has already established and spread in the EU (in Spain and Portugal).

Were the African *Leucinodes* species to be introduced into the EU, the Panel estimates that it would take between 4.9 and 92.2 years (90% CR; median 34.5 years) for populations to grow sufficiently before a steady rate of spread of ~ 2.28 km/year (90% CR 0.65–7.02 km/year) was reached. For the underlying reasoning, estimates and uncertainties, please see Appendix E of EFSA PLH Panel (2024).

3.4 | Impact

Larvae of African *Leucinodes* species are oligophagous and feed on species of *Solanum* (Appendix C: Entry, Table C.1). Eggplant (*S. melongena*) is a confirmed host for *L. africensis*, *L. laisalis*, *L. pseudorbonalis*, *L. rimavallis* and *L. 'orbonalis'* in earlier African literature (Degri et al., 2012; Huertas Dionisio, 2000; Mally et al., 2015; Ogunwolu, 1978; Sevastopulo, 1977).

3.4.1 | Assessment of Impact

In parts of Africa, *Leucinodes* species can be the most destructive insects of *S. aethiopicum* and *S. melongena* (Elono Azang et al., 2016; Fouelifack-Nintidem et al., 2021; Frempong & Buahin, 1977; Nwana, 1992). Appendix D summarises the little information available describing the impact of *Leucinodes* species on African solanaceous crops. Given the similar biology of African *Leucinodes* species and *L. orbonalis* from Asia, and with little additional information available, the previous estimates of impact used in the quantitative assessment of *L. orbonalis* (EFSA PLH Panel, 2024) were used in this assessment. Thus, impacts from African *Leucinodes* species in the EU are anticipated to be limited to regions where EI ≥ 30. Such locations coincide with the area most suitable for establishment and relatively rapid population growth. While establishment may be possible where EI ≥ 15, population development would be less rapid, resulting in less, if any, noticeable impact. In southern European countries with EI ≥ 30, the Panel estimates that in a scenario with specific pest management practices being used against *Leucinodes*, the median yield loss in eggplant crops due to *Leucinodes* damage would be 0.54% (90% CR 0.13%–1.9%). In a scenario where no specific pest management measures are in place, the median yield loss is estimated to be 4.5% (90% CR 0.67%–13.0%).

3.4.2 | Uncertainties affecting the assessment of impact

- Little quantitative information is available describing *Leucinodes* impacts in Africa. The Panel had to draw on information on the closely related species *L. orbonalis* from Asia and assume impacts would be the same. Whether the transferability of reports from Asia on impacts caused by *L. orbonalis* are truly applicable to African *Leucinodes* species is uncertain.
- Literature on impact of insect pests reports high values that may not accurately reflect expected impacts over a large area (EFSA PLH Panel, 2023). The Panel estimated expected impacts taking into account climate suitability in the EU as compared to hotter regions where *Leucinodes* spp. are endemic, thereby considering estimations of pest impacts made by Oerke (2006).
- Options available for pest control in the EU may be reduced in the future due to a reduction in the number of biocides allowed and the potential for African species to arrive with resistance against pesticides could constrain the effectiveness of control measures.

3.4.3 | Conclusions on impact

In a scenario where African *Leucinodes* species enter, establish and spread within the EU and populations reach an approximate equilibrium such that EU farmers consider the organism a member of the general pest fauna and take targeted action against it, estimated median eggplant yield losses are estimated to be 0.54% (90% CR 0.13%–1.94%) but if no action is taken, median yield losses are estimated to be 4.5% (90% CR 0.67%–13.0%) if no specific control measures are applied.

3.5 | Evaluation of risk reduction options

As noted in Section 2.5, the effectiveness of pest management practices in Africa could not be quantified, and hence, the effect of imposing additional risk reduction measures could not be assessed. Nevertheless, careful monitoring of interceptions and continuing to feedback information to African countries when interceptions are found would likely improve practices in Africa lowering the likelihood of infested consignments arriving into the EU. However, such speculation was not quantified.

3.6 | Consequences of climate change

Using results from the ensemble model for climate change (2040–2059) and its impact on pest establishment, using CLIMEX (Rossi, Czwienczek, et al., 2024) the Panel estimates that using a threshold of EI ≥ 15, ~ 33% of infested fruit enter NUTS regions where climate is potentially suitable for establishment (compared to 23% under current conditions, an increase by 44%). As a consequence, the likelihood of a founder population being initiated increases and the median wait time until a founder population is initiated falls by ~ 30% from around 130 years to about 90 years. The lower 5% point of the uncertainty distribution is reduced from 8 to 6 years. Based on the threshold EI ≥ 30, ~ 21% of infested fruit enter NUTS regions where climate is potentially suitable for establishment, similar to the current situation if a threshold EI of 15 is assumed. In this scenario, the median wait time until a founder population is initiated falls from a median of ~ 210 years to about 140 years.

4 | UNQUANTIFIED PATHWAYS

4.1 | Passenger baggage

The movement of people and any plant material they carry with them provides opportunities for plant pests to spread internationally. The plant health regime in the EU allows travellers to bring small quantities of plants and plants products, such as fruit, into the EU without the need of a phytosanitary certificate, if the plants or plant products are part of their personal luggage and if not used for professional or commercial purposes (Article 75 of 2016/2031). Airline hand baggage poses significant challenges for border biosecurity in terms of identifying pest and disease threats and little research has focused on this problem in the EU. McCullough et al. (2006) analysed US border interceptions for the years 1984–2000 and found that 62% of interceptions were from baggage carried by travellers, 30% were associated with cargo and 7% concerned plant propagating material. Most (73%) of the interceptions were at airports, followed by the Mexico–US border crossing (13%) and marine ports (9%). Of the interceptions in baggage, 50% were with fruit, 29% with 'plant parts', this included ornamental plants and some propagating material, 11% with seeds, 6% with cut flowers and 4% with other categories, including bulbs, soil and wooden items. Inspectors checking airline baggage in the US noted that the most commonly infested and intercepted commodity was fruit; Lepidoptera represented ~ 17% of interceptions after Homoptera (44%) and Diptera (23%) (Liebhold et al., 2006). A baggage survey of 6816 passengers entering New Zealand at international airports demonstrated that 3% of these travellers carried food items including fruits (MPI, 2013).

Solanum aethiopicum is one of the most widely grown vegetables in Africa and is an important food source; immature fruits are eaten raw. Mature fruits, shoots and leaves are used in stews and soups (Han et al., 2021). Roots, branches and leaves are used in herbal medicines (Emeasor et al., 2022; Han et al., 2021), as such the plant is of cultural significance and is used to welcome visitors (PROTA, 2021 as cited by Emeasor et al., 2022).

Three findings of *Leucinodes* spp. from Africa are recorded in Europhyt as being intercepted within garden eggplant (S. *aethiopicum*) in passenger baggage from Cote d'Ivoire in October 2017 and from Ghana in November 2017 and May 2019. Similarly, Pace et al. (2022) report interceptions in the Italian Campania region of *L. africensis* and *Leucinodes* sp. from *S. aethiopicum* fruit carried in passenger baggage.

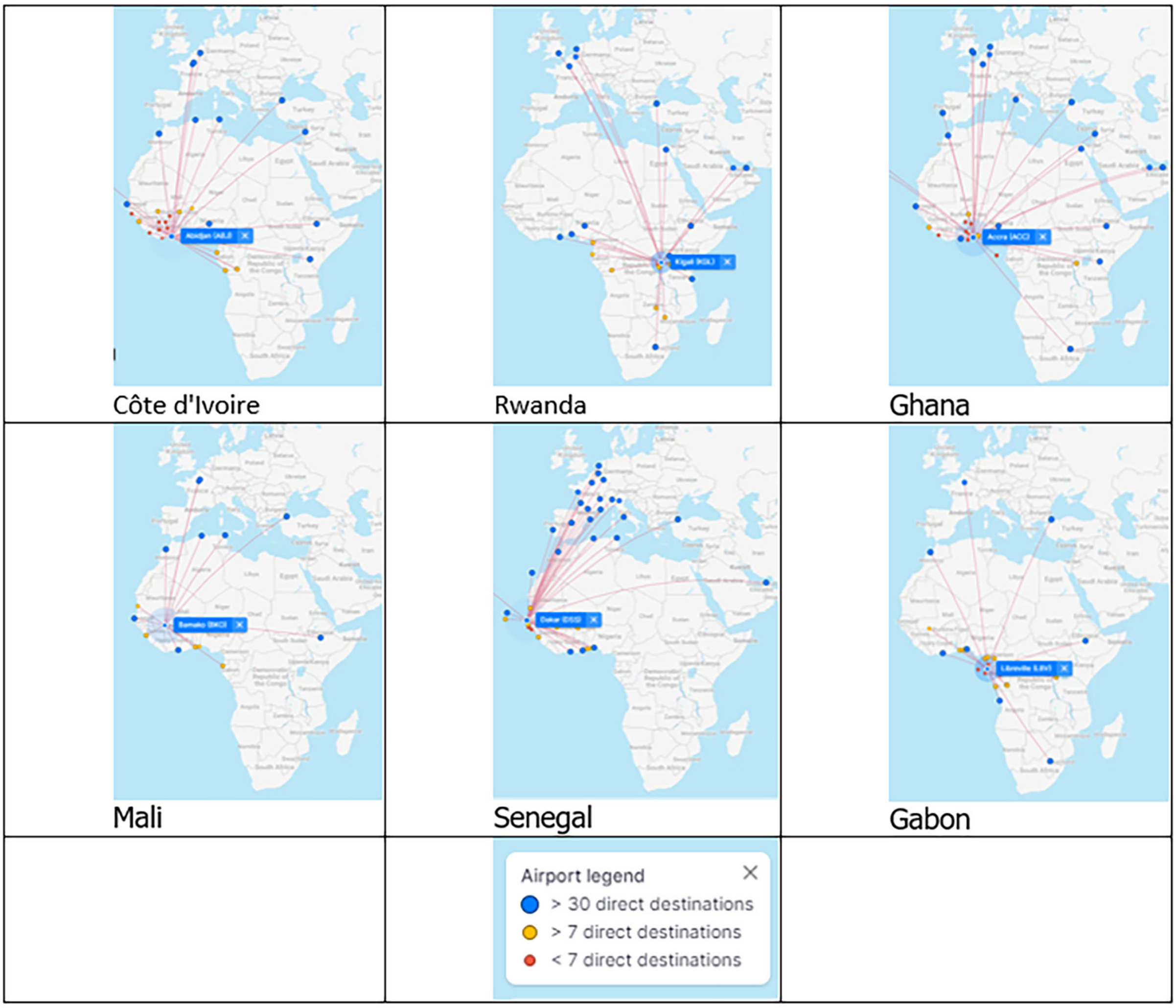
Table 8 shows the area of eggplant production in sub-Saharan Africa for countries where FAOSTAT data are available, together with an indication of whether *Leucinodes* spp. are known to occur there and whether there are direct flights to the EU. In addition to the African countries shown in Table 8, other countries growing an unknown area of eggplants could have *Leucinodes* present and might have direct flights to the EU.

TABLE 8 Sub-Saharan African countries ranked by area of eggplant production (FAOSTAT), known presence of *Leucinodes* spp. and with direct flights to the EU.

Country	Area eggplant production (ha)	*Leucinodes* spp. known to be present	Direct flights to EU?
Côte d'Ivoire	24,532	Yes	Yes
Rwanda	8691	Yes	Yes
Ghana	6278	Yes	Yes
Malawi	1085	Yes	No
Senegal	431	Yes	Yes
Gabon	42	Yes	Yes
Sudan	9296	No	No
Mali	5266	No	Yes
Niger	691	No	Yes
Madagascar	428	No	Yes
Mauritius	291	No	Yes
Congo	261	No	Yes
Djibouti	2	No	Yes

Table 9 provides examples of direct passenger flights from African countries where *Leucinodes* spp. are known to occur, and where the area of eggplant production is reported by FAOSTAT. The flights, and consequently the number of passengers travelling from those countries to the EU, represent a potential pathway for *Leucinodes* spp. if passengers carry infested hosts.

TABLE 9 Example direct airline routes from African countries where *Leucinodes* spp. occur, and where the area of eggplant production is reported by FAOSTAT (Maps are screenshots from https://www.flightconnections.com 24 December 2023).



5 | ADDITIONAL UNCERTAINTY

Overarching uncertainty

- Ideally pest risk assessment should focus on organisms at the species level (Devorshak, 2012). However, where justified, groups of species could be assessed collectively, although this leads to more assumptions being made in the assessment of risk and hence increases uncertainty.
- The Panel did not assess climate change effects in detail but expects increased temperature would enlarge the area suitable for establishment.

Entry pathways

- This assessment focused on African eggplant (mainly *S. aethiopicum*) as pathway, imported from different sub-Saharan countries of Africa. The commodity is part of a niche market and enters the EU in small, but largely uncertain quantities. The fruits of *S. aethiopicum* imported to the EU are mostly of the Gilo and Kumba morphotypes, both of which have a large range of fruit sizes and thus fruit weights (Seck, 2012). The import volume of *S. aethiopicum* has been increasing by ~ 500 tonnes per year over the time of 2010–2022 (Appendix C: Entry, Figure C.2), continuing this trend will likely increase the number of infested fruit entering the EU.
- The EU also imports specialist eggplant varieties of *S. melongena* to a certain degree from sub-Saharan Africa. Fruit of other *Solanum* plants may become popular and imported in larger quantities. This may change the composition and relative importance of pathways over time.
- Other *Leucinodes* species could be present and not reported in north Africa, and could potentially infest conventional varieties of eggplant grown for the EU market.

Transfer and establishment of founder populations

- Precisely what happens to organisms invading a new area is a field of invasion biology that is little known or understood (Puth and Post, 2005; Rosace et al., 2023; Fenn-Moltu et al., 2023); hence, there is uncertainty e.g. regarding the likelihood of pest transfer to alternative hosts and initiation of a founder population.

Climatic modelling of establishment

- Climate change effects would alter the area of establishment.

Spread

- Estimates of lag phase and constant rate of range expansion were made based on the spread of a single species of *L. laisalis* which occurs in North Africa and has established and spread in the southern Iberian Peninsula. It is not known whether the spread of *L. laisalis* was from one or multiple founder populations, which affects the certainty of the estimates.

Impact

– No additional uncertainties.

Does the expected impact of sub-Sahara species of Leucinodes differ from that caused by L. laisalis which is already present in Spain?

- As stated in the terms of reference, this opinion focuses on the species of *Leucinodes* that occur in sub-Sahara Africa. The species *L. laisalis* was left out of consideration for this assessment. This is the only species of *Leucinodes* that is known to occur in northern Africa, but it occurs across Africa, e.g. also in South Africa. This species has been present in Spain since 1958 (Huertas Dionisio, 2000), has not resulted in reports of impact and is not under official control. The question may be raised why it is that *L. laisalis* has to date not caused recognised impacts in the European territory and how this accords with the estimates made for the sub-Sahara species. There are several possible reasons why *L. laisalis* has so far not caused impacts, which are conjectural at this stage.

  1. One possibility is that the preferred hosts of *L. laisalis* do not occur in sufficient densities in the wild to allow the insect to build sizable populations that are capable of causing impacts in production. *Solanum melongena* is thought to be a secondary host of *L. laisalis*, its main host being other species of *Solanum*, e.g. *S. incanum* (Sodom apple) (Huertas Dionisio, 2000). Perhaps, impacts would only materialise if the species attains locally high densities due to presence in high density of its preferred host such that large enough numbers spill over to less preferred *S. melongena*.
  2. Another possibility is that *L. laisalis* is still in a phase of building up populations that are large enough to cause impacts. This explanation would be in accordance with the estimated lag phase before spreading (90% certainty range: 5–92 years). The Panel did not assess population growth of *L. laisalis* because there is no biological information to parameterise a population model for this species. Furthermore, building a credible population model would require not only information on the bionomics of the species in response to climate factors but it would also require information on the impact of natural enemies on its population dynamics.
  3. Current crop protection measures (i.e. not specifically targeting *Leucinodes* spp.) are sufficient to suppress infestation or discernible yield losses.
  4. Impacts do occur but go largely unnoticed because the species is not recognised in production.

- Considering the uncertainties the Panel opined that insufficient information was available to make estimates of impact of sub-Sahara *Leucinodes* spp. despite the lack of reports of impact of *L. laisalis* in Europe.

Decomposition of uncertainty

The decomposition of uncertainty with the pathway model (Table 10) indicates that the largest uncertainty is due to the estimate of the infestation rate of African eggplant (46% of model outcome uncertainty). The level of pest infestation in trade is often the largest uncertainty in quantitative pest risk assessments (e.g. EFSA PLH Panel, 2016a, 2016b, 2017a, 2017b, 2023, 2024). The next largest uncertainty in the model is the estimate of the proportion of adults that escape from discarded domestic waste and complete their development (14%). The likelihood of adults emerging from discarded waste and finding a mating partner contributes 12% to overall uncertainty, as does the probability that eggs laid by a mated female will survive and the progeny develop to establish a founder population. Combining the factors involved in transfer (x_9, x_{10}, x_{11}), 38% of the model uncertainty is due to lack of information about transfer which is an area of invasion biology that typically lacks empirical evidence on the detailed steps involved because such steps are largely unobserved and there is little empirical evidence around the processes involved although successful invasion is often attributed to propagule pressure (Leung et al., 2004; Simberloff, 2009).

TABLE 10 Decomposition of explained variance in the pathway model for introduction of African *Leucinodes* spp. R^2 in the third column gives the partial r^2 of each regressor in a linear regression meta-model of pathway model results in which the number of founder populations is the response variable and the parameter values in the model are regressors. The fourth column indicates the relative contribution of each parameter to explained variance. Here, variance represents the uncertainty in pathway model calculations, and the contribution of each parameter is the contribution to uncertainty.

Variable in mathematical model	Parameter estimate	R^2	% of explained variance
x_5	Infestation rate	0.18	46
x_9	Proportion of adults that escape from domestic waste	0.06	14
x_{10}	Likelihood of mating	0.05	12
x_{11}	Likelihood of mated female establishing a founder population	0.05	12
x_1	Quantity of imports	0.02	6
x_4	Weight of African eggplants	0.02	6
x_7	Proportion of infested hosts discarded by consumer	0.02	4
x_8	Proportion of adults that escape from commercial waste	0.00	< 1
x_6	Proportion of infested hosts discarded by industry	0.00	< 1
	R^2 =	0.39	100

6 | CONCLUSIONS

Following a request from the European Commission, the EFSA Panel on Plant Health performed a pest risk assessment of African *Leucinodes* spp. for the EU. The quantitative assessment focused on pathways and likelihood of entry, climatic conditions allowing establishment, the distribution of imported material within the EU after entry, the likelihood of establishment, the rate of spread following a lag period and potential impacts to eggplant production in the EU.

African *Leucinodes* species are oligophagous insects feeding mainly on solanaceous plants, including crops such as eggplants, tomatoes and potatoes. Although tomato fruit can be infested, pupae that develop are not viable. Potato tubers are not infested (*Leucinodes* are stem and shoot borers). The main pathway (*S. aethiopicum* and exotic varieties of *S. melongena* from African countries where the presence of *Leucinodes* species is recorded) was deduced from the potential combinations between crops and countries of the origin. African *Leucinodes* species are not known to occur outside of sub-Saharan Africa, with the exception of *L. laisalis*, which also has established populations in North Africa and in Europe in the south of the Iberian Peninsula. The species complex has been intercepted in the EU27 264 times from 2004 to 2023. Based on the size and frequency of imports, and with evidence of interceptions in the EU, the interceptions were mainly on *S. aethiopicum* and *S. melongena* fruits. Imports of these species are aggregated within trade statistics using the HS code 0709 3000 for 'eggplants'.

The import data for 'eggplants' (HS code 0709 3000) were downloaded from the Eurostat database for the years 2010–2022 for all sub-Saharan countries assuming *Leucinodes* species occur throughout sub-Saharan Africa. Based on the size and frequency of imports, and with evidence of interceptions in Europe, the importation of eggplant type fruit from African countries was identified as the most likely pathway for entry.

CLIMEX modelling indicates that conditions are most suitable for establishment of African *Leucinodes* species in parts of the southern EU, especially around the Mediterranean Sea. Two possible scenarios for establishment were considered based on two EI thresholds. Using EI ≥ 15, ~ 23% of imports of African eggplant type fruit is distributed to NUTS2 regions in which climatic conditions are suitable for establishment. Using EI ≥ 30, ~ 14% of imports reach such areas. With climate change estimated for the period 2040–2059, these percentages would increase to 33% (EI ≥ 15) and 21% (EI ≥ 30).

Each infested eggplant entering the EU is likely to contain only one larva. An important limiting factor in establishing a founder population is the likelihood of a male and a female emerging in temporal and spatial proximity to locate each other and mate and then for the female to find a host and lay eggs. With respect to the need of larval development to adulthood from discarded infested produce, then mating, host finding, egg laying and the progeny surviving, the number of newly established founder populations developing was estimated to be 0.0078 per year (90% CR 0.00023–0.12124) for NUTS2 regions with an EI ≥ 15. Accordingly, a new founder population is estimated to establish approximately every 128 years on average (90% CR approximately one every 8–4280 years). For NUTS2 regions with EI ≥ 30, the median number of founder populations establishing in the EU annually is estimated at 0.0048 on average (90% CR 0.0001–0.0739), corresponding to a median estimate of one founder population approximately every 210 years (90% CR approximately one every 14–7020 years). Thus, the Panel would not expect new founder populations within the time horizon of this assessment. Nevertheless, if a founder population were to establish it would likely remain local for a number of years and the lag period before sustained spread was estimated to be 34.5 years (90% CR 5–92 years) following the establishment of a founder population. *Leucinodes* species are not considered to be strong flyers. Were African *Leucinodes* species to establish, the median rate of natural spread was estimated to be 2.3 km/year (90% CR 0.65–7.0 km per year).

Climate change foreseen for the period 2040–2059 would increase the rate at which new founder populations are produced in the EU territory, with a median estimated value of 0.01120 per year (90% CR 0.00034–0.17416 per year) when the minimum EI for establishment is chosen to be 15 and a median value of 0.00717 per year (90% CR 0.00021–0.29395 per year) for a minimum EI of 30. The corresponding times until the next founder population occurs would be a median value of 89 years (90% CR 6–2979 years) for an EI ≥ 15 and a median value of 139 years (90% CR 9–4655 years) for an EI ≥ 30.

Impact assessment focused on potential yield losses to *S. melongena* eggplants under current climate conditions. In a scenario where a species of the African *Leucinodes* complex has spread and is managed by farmers as part of the general pest fauna, i.e. no specific official phytosanitary measures are in place against it, and growers apply targeted pest control against the *Leucinodes* species, median yield losses in eggplant were estimated to be 0.54% (90% CR 0.13%–1.94%). *Leucinodes laisalis*, which has been established in the south of Spain for 65 years, does not cause reported damage in eggplant production in this region. The Panel found insufficient evidence to consider EU tomato and potato production to be at risk from infestation by African *Leucinodes* spp. because tomato and potato are unpreferred hosts and are likely to be attacked only when high densities of *Leucinodes* develop, driving individuals from more preferred hosts, such as wild Solanaceae and *S. melongena*.

Concluding overall, this opinion shows that the EU encompasses regions with climate suitable for the establishment of African *Leucinodes* species, and that these species could cause damage if they established. However, they are unlikely to be introduced in the foreseeable future because of the relatively low volume of commodities providing a pathway, and the low likelihood that adults emerging in the EU will successfully mate and initiate a founder population.

ABBREVIATIONS

CN	Combined nomenclature (8-digit code building on HS codes to provide greater resolution)
CR	certainty range
DD	degree days
DNA	Deoxyribonucleic acid
EI	ecoclimatic index (an index of climatic suitability used by CLIMEX)
EKE	Expert Knowledge Elicitation
EPPO	European and Mediterranean Plant Protection Organisation
HRP	High Risk Plants
HS	Harmonised System (6-digit World Customs Organisation system to categorise goods)
IPM	Integrated Pest Management
ISPM	International Standard for Phytosanitary Measures
MS	Member state (of the EU)
NUTS	Nomenclature Units for Territorial Statistics
RRO	risk reduction option
ToR	Terms of Reference

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CONFLICT OF INTEREST

If you wish to access the declaration of interests of any expert contributing to an EFSA scientific assessment, please contact interestmanagement@efsa.europa.eu.

REQUESTOR

European Commission

QUESTION NUMBER

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MAP DISCLAIMER

The designations employed and the presentation of material on any maps included in this scientific output do not imply the expression of any opinion whatsoever on the part of the European Food Safety Authority concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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SUPPORTING INFORMATION

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APPENDIX A

Identity of African *Leucinodes*

There are currently nine species of *Leucinodes* known from Africa (incl. Madagascar) (Nuss et al., 2003–2024). Based on the dominant forewing ground colour, these can be divided in the white-winged species (Figure 1A–E), comprising *Leucinodes africensis*, *L. kenyensis*, *L. malawiensis*, *L. pseudorbonalis* and *L. rimavallis*, and the brown-winged species (Figure 1F–I) comprising the four species *L. ethiopica*, *L. laisalis*, *L. raondry* and *L. ugandensis*. Apart from these, several putative species are known that have not yet been described due to insufficient material and/or inconclusive results (Mally et al., 2015). Additional species may be discovered in the future.

A single specimen of *L. orbonalis* (identified through dissection of the male genitalia) was intercepted from fruit of *Solanum* sp. imported from Côte d'Ivoire to France (J.-M. Ramel, personal communication). This could indicate the presence of a founder population of the Asian *L. orbonalis* in Côte d'Ivoire. Additional investigations are necessary to shed light on this possibility. The African *L. africensis* has been intercepted in Bangladesh, brought from Africa in passenger baggage (Pace et al., 2022), and a similar pathway could introduce *L. orbonalis* to Africa.

Although all African species are known from their adult stage, only three of them are known and described from their larval stages: *L. africensis*, *L. pseudorbonalis* and *L. laisalis* (Huertas Dionisio, 2000; Mally et al., 2015; Ogunwolu, 1978). The pupal stage has been described for *L. africensis* and *L. laisalis* (Huertas Dionisio, 2000; Mally et al., 2015).

The African *Leucinodes* spp. are difficult or impossible to differentiate from each other based on external characters. Among the white-winged African *Leucinodes* species (Figure 1A–E), only the adult of *L. malawiensis* (Figure 1C) can be distinguished from the other four *Leucinodes* species by the absence of the subapical mark of the forewing termen, while the other four *Leucinodes* species can only be reliably distinguished from each other based on examination of the male genitalia; the same is the case for distinguishing the brown-winged *L. laisalis* (Figure 1G) from *L. ugandensis* (Figure 1I) (Mally et al., 2015). In the larval stages, none of the three species with known larvae has morphologically consistent characters that would allow species identification or separation from other African *Leucinodes* species or from the Asian *L. orbonalis* (Mally et al., 2015).

APPENDIX B

Biology of African *Leucinodes* spp.

Leucinodes is a genus of Lepidoptera in the family Crambidae, where it is placed in the tribe Lineodini in the subfamily Spilomelinae (Mally et al., 2019). The life cycle comprises an egg stage, several larval stages, a pupal stage and an adult stage. As far as known, the larvae of all species of the tribe Lineodini feed on Solanaceae (Mally et al., 2019).

Biolog

The biology of African *Leucinodes* (under the name *L. 'orbonalis'*) has been investigated by Ghesquière (1931) in the Democratic Republic of the Congo, by Frempong (1979) in Ghana and by Nwana (1992) and Onekutu et al. (2013) in Nigeria. The biology of *L. laisalis* was reported by Ogunwolu (1978) and Aina (1984) in Nigeria, and by Huertas Dionisio (2000) in Spain. Bordat and Goudegnon (1991) report that *L. laisalis* is often found together with *L. 'orbonalis'* in Benin. Durations and sizes of developmental stages of *L. 'orbonalis'* based on Onekutu et al. (2013) are summarised in Table B.1, those of *L. laisalis* based on Aina (1984) in Table B.2.

Egg

Eggs are ovoid and initially creamy white, but later turn grey (in *L. laisalis*; Aina, 1984) or deep orange (in *L. 'orbonalis'*; Nwana, 1992). Females of *L. 'orbonalis'* lay eggs singly (Nwana, 1992) and sometimes in small clusters (Onekutu et al., 2013), and those of *L. laisalis* in batches of two to nine eggs, preferably under the fruit sepals but also on other parts of the fruit (Aina, 1984). In the field, *L. 'orbonalis'* eggs are laid on young plants 6–7 weeks after transplanting; under laboratory conditions, however, female moths have been observed ovipositing on 6-week old potted plants (Frempong, 1979). Incubation time of the eggs takes a mean of 4.9–5.7 days (*L. 'orbonalis'*; Nwana, 1992) or 4.5 days (*L. laisalis*; Aina, 1984).

Larva

Nwana (1992) and Onekutu et al. (2013) each report five larval instars for *L. 'orbonalis'*; *L. laisalis* passes through at least four instars (Aina, 1984). Eclosion of the first-instar larvae of *L. 'orbonalis'* is asynchronous (Nwana, 1992). Aina (1984) states that high humidity appears to be a prerequisite for hatching of the larvae of *L. laisalis*, and that hatching therefore primarily takes place at night. The neonate larvae (*L. laisalis*) bore into the fruit, preferably under the fruit sepals, within 20–30 min after hatching and block the entry hole with excreta during this process (Aina, 1984). The larva then spends its entire development inside the fruit; mature *L. laisalis* larvae exit in the distal portion of the fruit they were feeding in (Aina, 1984). Larval development of *L. 'orbonalis'* ranges from 12 to 25 days, with a mean of 15.6–20.2 days (Nwana, 1992). The overall growth ratio from one instar to the next based on head capsule width measurements is 1.41 (Onekutu et al., 2013) to 1.43 (Nwana, 1992).

Elono Azang et al. (2023) reported 1.19–4.37 *L. 'orbonalis'* larvae per infested fruit of *S. aethiopicum* var. *zong* in South Cameroon. Duodu (1986), comparing 14 *S. melongena* cultivars for resistance against *L. 'orbonalis'* in Kumasi (Ghana), found a mean total number of 0.83–1.73 larvae or exit holes per infested fruit. Frempong (1979) observed 1–20 *L. 'orbonalis'* larvae per fruit in variety Local Katakyie of *S. melongena*, and 1–14 larvae per fruit for variety Long Purple. Kotey et al. (2023) state a mean number of 1.32 exit holes of *L. 'orbonalis'* per *S. aethiopicum* fruit. In their comparison of six varieties (Barbetene, Ywowgs, Yellow white oval, F1 African beauty, Yellow big white, Gauta) of *S. aethiopicum* and *S. melongena*. Zakka, Lale, et al. (2018) found the number of *L. 'orbonalis'* larvae per fruit to range from 0.33 to 1.28 larvae per fruit, depending on the variety and the treatment (mulching, nipping). Elono Azang et al. (2023) stated that in Central Cameroon, the number of individuals of *L. 'orbonalis'* emerging from a single *S. aethiopicum* fruit varies, from 1.19 ± 0.08 in harvests during rainy season up to 4.37 ± 0.66 during the short dry season, with an average of 2.43 ± 1.33 individuals per fruit. Nwana (1992) very rarely found more than one larva per *S. melongena* fruit, but occasionally up to 12 larvae per fruit. In the case of *L. laisalis*, an infested fruit usually harbours two to five larvae (Ogunwolu, 1978), but Huertas Dionisio (2000) reported up to 70 caterpillars emerging from a large (11 cm x 8 cm), heavily infested *S. melongena* fruit.

Larval host plants

The literature reports exclusively plants of the family Solanaceae as host plants of African ***Leucinodes*** spp. (see Appendix C, Table C.1). The larval host plants of ***L. malawiensis***, ***L. ethiopica*** and ***L. raondry*** are still unknown, but are expected to be native African species of Solanaceae.

Pupa

After exiting the host plant tissue through a large exit hole, the mature larva searches 20–30 min for a suitable pupation place, generally in dry place on the leaves or branches (Aina, 1984; Frempong, 1979; Huertas Dionisio, 2000). There, a silken cocoon is woven, in which then the actual pupation cocoon is constructed, where the larva turns into a prepupa and after

2–4 days of inactivity turns into a pupa (Aina, 1984; Huertas Dionisio, 2000). Zakka, Nwosu, et al. (2018) report that pupation of *L. 'orbonalis'* raised on varieties of *S. aethiopicum* and *S. melongena* under lab conditions in Port Harcourt (Nigeria) takes 10–13 days. Onekutu et al. (2013) give an average time of 11.2 ± 1.27 days for pupation. *Leucinodes laisalis* pupates for 8–15 (mean 10.5) days (Aina, 1984); Huertas Dionisio (2000) reports a pupation time of 9–11 days after cocoon construction.

Adult

During the day, the nocturnal adults rest with wings spread out and the abdomen curved upwards; feeding has not been observed, and it is likely that adults do not feed at all (Aina, 1984). Males are somewhat smaller than females, but in general live longer than females, with a range of 3–7 days for males and 2–7 days for females (Aina, 1984).

Information on *L. 'orbonalis'* adults is primarily reported from Nigeria. The adults are short-lived, with female moths living 2–6 days, and males 3–7 days (Onekutu et al., 2013). Zakka, Nwosu, et al. (2018) report an adult live duration of 4–5 days, and according to Nwana (1992), females live 1–4 days. Onekutu et al. (2013) furthermore found that unmated adults lived on average longer (female: 5.86 ± 1.19 days; male: 4.37 ± 1.17 days) than mated adults (female: 4.14 ± 1.03 days; male: 4.31 ± 1.17 days). The sex ratio female:male was reported as 2.0 by Onekutu et al. (2013), whereas Nwana (1992) found an average sex ratio of 1.2 (range 0.8–2.0). Oviposition starts 1 day after eclosion, with the females laying an average of 123 eggs/day (range 72–207 eggs/day) (Onekutu et al., 2013). Nwana (1992) observed that females would lay 87–375 eggs during an oviposition period of 1–3 days, with the number of eggs laid positively correlating with female longevity.

TABLE B.1 Developmental stages of *Leucinodes 'orbonalis'* (a presumed misidentification of one of the white-winged African *Leucinodes* spp.), their durations and body measures; from Onekutu et al. (2013; Ibadan, Nigeria).

Instar	Duration of instar	Length	Width
Egg	5.93 ± 0.92 days	0.94 ± 0.10 mm	0.5 ± 0.07 mm
1st larval	1.00 ± 0.00 days	4.19 ± 0.58 mm	0.49 ± 0.07 mm
2nd larval	1.16 ± 0.40 days	6.98 ± 2.16 mm	0.90 ± 0.16 mm
3rd larval	1.48 ± 0.41 days	11.10 ± 2.32 mm	1.38 ± 0.16 mm
4th larval	2.63 ± 0.45 days	16.58 ± 1.75 mm	1.71 ± 0.15 mm
5th larval	4.46 ± 0.71 days	18.44 ± 0.28 mm	2.15 ± 0.29 mm
Pupa	11.2 ± 1.27 days	13.9 ± 0.65 mm	5.48 ± 0.58 mm
Adult	4.14 ± 1.02 days (female), 4.31 ± 1.17 days (male)	14.17 ± 1.04 mm (female), 13.26 ± 0.88 mm (male)	Body width: 4.59 ± 0.39 mm (female), 4.20 ± 0.35 mm (male) Wingspan: 24.33 ± 1.41 mm (female), 21.59 ± 1.34 mm (male)
Total time	28.17 days	–	–

TABLE B.2 Developmental stages of *Leucinodes laisalis*, their durations and body measures; from Aina (1984; Lagos, Nigeria).

Instar	Duration of instar	Length	Width
Egg	4.5 ± 0.5 days, range 4–5 days	0.6–0.7 mm	
Larva (4+ instars)	11 ± 0.63 days, range 10–12 days	First instar: 1.0–1.2mm Final instar: 13.0–19.5 mm	First instar: 0.2–0.25 mm Final instar: 2.5–3.0 mm
Pupa	10.5 ± 1.48 days, range 8–15 days (incl. 2–4 days of prepupa)	Males: 8.9 ± 1.2 mm, range 7.5–10.5 mm Females: 10.6 ± 1.2 mm, range 8–12 mm	Males: 2.3 ± 0.19 mm, range 2.2–2.5 mm Females: 2.5 ± 0.33 mm, range 2–3 mm
Adult	2–7 days (female), 3–7 days (male)	7.5–11.5 mm	Body width: 2.0–2.5 mm Forewing length: 8.0–11.5 mm
Total time	24.8 ± 0.75 days, range 24–26 days	–	–

Environmental conditions

Like in the Asian *L. orbonalis*, pre-imaginal development in the African *Leucinodes* spp. is temperature dependent. Onekutu et al. (2013) report that with increasing temperature and decreasing humidity, total life duration in *L. 'orbonalis'* decreases and female fecundity increases. Information on the influence of humidity is, however, contradictory, with Degri (2014) stating that peak reproduction is achieved during the seasons with the highest temperature and the highest relative humidity. Also, Elono Azang et al. (2023) found that rainfall caused a significant reduction in the number of *L. 'orbonalis'* individuals in their study, but at the same time rainfall was reported to positively contribute to 75% of attacks by this species. Finally, Nwana (1992) found that the pre-imaginal development of *L. 'orbonalis'* was significantly negatively correlated with both maximum and minimum temperature but showed no relationship with relative humidity.

Mortality

According to Nwana (1992), egg mortality of *L. 'orbonalis'* is 5.0%–12.5%. The highest mortality for *L. 'orbonalis'* is in the 1st larval instar, followed by the 5th larval instar preparing for pupation, and the pupa (Nwana, 1992). Life stages outside of plant tissue therefore appear to have higher mortality rates. Fouelifack-Nintidem et al. (2021) reared *L. 'orbonalis'* from *S. aethiopicum* in West Cameroon and observed a survival rate of 64.9% of fruit-boring larvae to adulthood, as well as a 34.9% survival rate of shoot-boring larvae.

Natural enemies

Frempong and Buahin (1977) mention no specific natural enemies of *Leucinodes* but list several generalist predators that were found on *S. melongena* in Kumasi (Ghana): *Belonogaster griseus* (Hymenoptera: Vespidae), *Philodicus doris* (Diptera: Asilidae), *Polyspilota aeruginosa* and *Sphodromantis lineola* (Mantodea: Mantidae) and *Pseudocreobotra ocellata* (Mantodea: Hymenopodidae). Obodji, Aboua, Tano, and Seri-Kouassi (2015) report the ladybird *Cheilomenes sulphurea* (Coleoptera: Coccinellidae) as predator.

APPENDIX C

Entry

Introduction: Identification of pathways

A commodity may be pathway for pest introduction if a pest is associated with this pathway, for instance, because a pest produces viable propagules on the commodity, the pest is known to infest the commodity in the country of origin, and this commodity is transported under conditions that ensure that the propagules arrive in the destination country in a viable state, capable of starting a founder colony of the pest in the destination country. Alternatively, a commodity may be an inert carrier for the pest. Analysis of host status of plant species for alien pests is a key step in assessing whether a pest is associated with a commodity. The Panel used information in the literature on the known hosts of African species of *Leucinodes*.

To be considered a genuine host, a phytophagous insect must be able to complete its development from egg to adult and produce viable progeny following mating by feeding only on the plant regarded as a host. Such information is rarely found in the literature, which often only summarises the information on insect species and plants they are associated with. Reports of different life stages being found on the plant can often be a good indicator of a plant being a true host. Table C.1 lists the plant species (2nd column) that African *Leucinodes* species have been intercepted from (3rd column) and/or reported to live on in the African literature (4th column). Based on literature reports and museum specimens that were reared to adults, the fifth column reports on which plant species the larvae of African *Leucinodes* spp. are confirmed to feed, and on which they completed their development and emerged as adults (6th column). Plant species on which African *Leucinodes* species were intercepted but which were not mentioned or confirmed as hosts in the literature were excluded as potential pathways because this likely indicates movement of larvae between different plant products within a consignment (e.g. from eggplant to *Momordica* or mango). Plant species were qualified as pathway only if there was evidence of confirmed larval feeding on fruits as well as of confirmed completion of the life cycle to adult on these fruits.

TABLE C.1 Compilation of African *Leucinodes* species (1st column) with plant commodities (2nd column), on which these species were intercepted (3rd column, during 2004–2023), and which were reported as host plants in the literature (4th column), including confirmed feeding (5th column) and confirmed completion of the life cycle (6th column).

Leucinodes species	Plant species	Number of interceptions	Number of publications reporting as host	Is the larva feeding on this host?	Does the insect complete the life cycle?
L. 'orbonalis' (misidentified African spp.)	*Capsicum* sp. (bell and chilli pepper)	1	0	No information	No information
	Momordica sp. (bitter melon) [Cucurbitaceae]	2	0	No information	No information
	Physalis angulata (= *P. minima*; wild gooseberry)	0	1	No information	No information
	P. peruviana (cape gooseberry)	0	1	No information	No information
	***S. aculeastrum* (soda apple)**	0	1	Yes	Yes
	***S. aculeatissimum* (love-apple)**	0	1	Yes	Yes
	***S. aethiopicum* (= *S. integrifolium*, *S. gilo*; African eggplant, gilo, garden egg)**	138	10	Yes	Yes
	***S. lycopersicum* (tomato)**	0	1	Yes	Yes
	***S. macrocarpon* (bitter tomato)**	2	1	Yes	No information
	***S. melongena* (eggplant, aubergine)**	39	7	Yes	Yes
	***S. torvum* (turkey berry)**	1	1	Yes	Yes
	***S. tuberosum* (potato)**	0	4	Yes	Yes
	***Solanum* sp.**	6	0	No information	No information
L. laisalis	*Capsicum* sp. (bell and chilli pepper)	0	1	No information	No information
	***S. aethiopicum* (= *S. integrifolium*, *S. gilo*; African eggplant, gilo, garden egg)**	0	1	Yes	Yes
	***S. campylacanthum* (= *S. panduriforme*)**	0	0	Yes	Yes
	***S. incanum* (bitter apple)**	0	2	Yes	Yes

TABLE C.1 (Continued)

Leucinodes species	Plant species	Number of interceptions	Number of publications reporting as host	Is the larva feeding on this host?	Does the insect complete the life cycle?
	S. linneanum **(=** ***S. sodomeum*****, devil's apple)**	0	2	Yes	Yes
	S. lycopersicum **(tomato)**	0	1	No information	No information
	S. macrocarpon **(bitter tomato)**	0	3	Yes	No information
	S. melongena **(eggplant, aubergine)**	0	4	Yes	Yes
L. pseudorbonalis	***S. aethiopicum*** **(=** ***S. integrifolium, S. gilo*****; African eggplant, gilo, garden egg)**	22	1	Yes	Yes
	S. macrocarpum **(bitter tomato)**	1	0	No information	No information
	S. melongena **(eggplant, aubergine)**	1	1	Yes	Yes
L. africensis	***S. aethiopicum*** **(=** ***S. integrifolium, S. gilo*****; African eggplant, gilo, garden egg)**	0	1	Yes	Yes
	S. lycopersicum **(tomato)**	0	1	Yes	Yes
	S. melongena **(eggplant, aubergine)**	0	1	Yes	Yes
	Solanum **sp.**	0	1	No information	No information
L. rimavallis	***S. melongena*** **(eggplant, aubergine)**	0	1	Yes	Yes
	Withania somnifera **(winter cherry, ashwagandha)**	0	1	Yes	Yes
L. ugandensis	***Solanum*** **sp.**	0	1	Yes	Yes
L. kenyensis	***Withania somnifera*** **(winter cherry, ashwagandha)**	0	1	Yes	Yes
Leucinodes sp.	*Abelmoschus esculentus* (okra) [Malvaceae]	1	0	No information	No information
	Mangifera indica (mango) [Anacardiaceae]	1	0	No information	No information
	S. aethiopicum **(=** ***S. integrifolium, S. gilo*****; African eggplant, gilo, garden egg)**	48	0	No information	No information
	S. melongena **(eggplant, aubergine)**	3	0	No information	No information

Note: Potential pathways (plant species) of introduction requiring action are marked in bold; plant families of non-Solanaceae plants are given in square brackets.

African *Leucinodes* species have been intercepted from three non-Solanaceae commodities (mango, bitter melon, okra), each with only one or two interceptions in the 20 years of 2004–2023 (Table C.1). None of these three plant species has been reported in the African literature as host plant of *L. 'orbonalis'* or other African *Leucinodes* species, and the Panel therefore excluded them as principal pathways for introduction.

Among Solanaceae, one interception of *Capsicum* sp. infested with *L. 'orbonalis'* is reported (Table C.1), although no literature reference mentions African *Leucinodes* species feeding on *Capsicum*. Rungs (1979) lists *Capsicum annuum* as host plant of *L. laisalis*, but no larvae were found in bell pepper fruits by either Akinlosotu (1977), Ogunwolu (1978) or Huertas Dionisio (2000); the species was also not reported by Ofori et al. (2015) to occur on *Capsicum* in Ghana. *Physalis* spp. were cited in the literature as host plants (Ghesquière, 1931, 1942), but no interceptions of African *Leucinodes* species on this commodity are known. No confirmed cases of larvae feeding on *Capsicum* or *Physalis* are reported, and the Panel thus excluded them as principal pathways for introduction.

Potato (*Solanum tuberosum*) was reported as host plant of African *L. 'orbonalis'* (Delobel, 1996; Ghesquière, 1931, 1942; Ngamaleu-Siewe et al., 2021). Ngamaleu-Siewe et al. (2021) reared 23 adult *Leucinodes* sp. from 3600 damaged potato stems and tubers. According to Delobel (1996), the female lays eggs in the leaf axils of potato plants, but also on tubers when these are exposed in the soil, where they cause damage similar to that of the larvae of the potato tuber moth, *Phthorimaea operculella* (Gelechiidae). Potato plants are not imported into the EU, and interceptions of *Leucinodes* on tubers are not known (Table C.1), so that we excluded potato as principal pathway for introduction.

Ghesquière (1942) stated to have reared *L. 'orbonalis'* on 'indigenous and European tomatoes' ('Tomates indigènes et européennes') in the Democratic Republic of the Congo. It is not clear whether his 'Tomates européennes' refer to *S. lycopersicum*, and on which plant part the larvae were reared. The larvae of the Asian *L. orbonalis* can only develop to pupation in the stems of tomato plants, but there is uncertainty on whether they can develop into viable adults in the fruit due to the high-water content (EFSA PLH Panel, 2024). Based on the strong similarities in the biology of Asian and African *Leucinodes* species, tomato fruit are not considered a pathway of entry for African *Leucinodes* species.

Leucinodes kenyensis and *L. rimavallis* have been reared from *Withania somnifera* (Mally et al., 2015), known as ashwagandha in Indian traditional medicine where its root powder finds use (Pandit et al., 2013). The Panel knows of no interceptions of *Leucinodes* larvae on fruits of this species from Africa, and therefore exclude it as principal pathway for introduction.

In conclusion, the Panel identified *Solanum* species in the Solanaceae plant family as potential produce pathway for African *Leucinodes* species to enter the EU. The Panel focused on *S. aethiopicum* and small exotic fruit varieties (mini-aubergines) of *S. melongena* as main entry pathways, as these accounted for the majority of interceptions (Table C.1) but considered that fruit of any species of *Solanum* might act as a pathway. However, due to less trade and fewer interceptions compared to *S. aethiopicum* and *S. melongena*, these pathways were not considered during the quantitative assessment.

Growing *Solanum aethiopicum* in Africa

Solanum aethiopicum is a cultigen of the wild *S. anguivi* (Horna et al., 2007; Plants of the World Online, 2024). It is phenotypically diverse, and four main morphological groups are recognised: the Aesculentum, Kumba, Shum and Gilo groups (Horna et al., 2007; Seck, 2012). The Kumba and Gilo types (Figure C.1) are mainly grown for their fruits, while Shum (and also Kumba) is grown as leafy vegetable; the Aculeatum type has more ornamental value (personal communication, Prof E. Balyejusa Kizito).

FIGURE C.1 Fruit of *Solanum aethiopicum* (African eggplant) sampled at a local market in Parma, Italy; left: Kumba type; right: Gilo type. Photo: © Richard Mally.

The following is a summary from Han et al. (2021) who provide a review of the cultivation of *S. aethiopicum* together with a description of its nutrient quality and potential for genetic improvement. *Solanum aethiopicum* grows best on well-drained soil and requires irrigation during the dry season. It is grown from seed, and seed is sown in nursery beds of sandy soil or in containers. The seeds germinate in 3–9 days. Seedlings are transplanted to the field after 30–35 days when they have 5–7 leaves and are 15–20 cm tall. The crop is important to subsistence and low-income farmers and is widely cultivated in Africa. On farms in Africa, *S. aethiopicum* is sometimes intercropped with cowpea, sorghum, tomatoes, peppers and other crops. In Ghana, a farm survey showed that producers manage plots of less than 1 ha. Despite their limited size, these plots represent around 60% of their total cultivated area. The plant is mostly grown for domestic consumption, with exports generally representing a small fraction and mostly going to neighbouring African countries, with a small part exported to Europe (Horna et al., 2007; personal communication, Prof E. Balyejusa Kizito). *Solanum aethiopicum* is consumed on an almost daily basis by rural and urban families and is the main source of income for many rural households (Horna et al., 2007). The crop is traded internationally on a limited scale in the West African sub-region, and only a very small share of the total production in Ghana is exported to Europe where consumers of garden egg tend to be of African origin, African restaurants and African expatriates (Horna et al., 2007).

For reported impacts of infestations by African *Leucinodes* species, see Appendix D: Impact.

Introduction model: Quantity of imports

Quantity of import is the first step in a pathway model. The quantity of import of African aubergines (imported under CN code 070930) was obtained from Eurostat (Figure C.2). Based on these import data, the Panel estimated the average import in recent 10 years (2013–2022) and import in the foreseeable future (2024–2028). The average yearly import in the period 2013–2022 was ~ 1130 tonnes while the yearly import in the foreseeable future is expected to be a factor 1.72 as large, representing 72% increase in import.

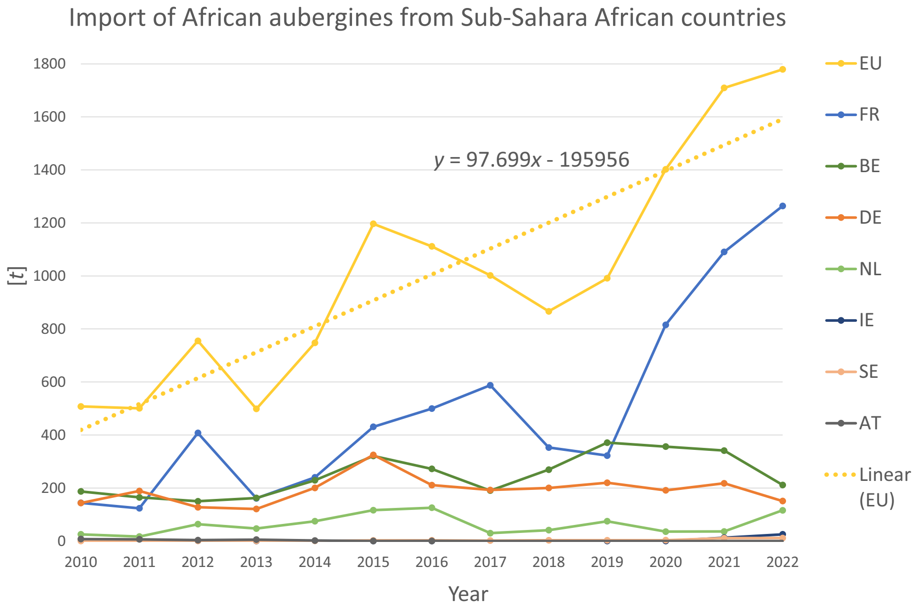


FIGURE C.2 Tonnes of African eggplants imported from Sub-Saharan Africa into EU27 from 2010 to 2022. Different line colours indicate EU – EU27; FR – France; BE – Belgium; DE – Germany; NL – the Netherlands; IE – Ireland; SE – Sweden; AT – Austria. The 10-year period with data from 2013 to 2022 was used to estimate recent import while the average level during the year 2024–2028 was used to estimate expected import in the future. The expected import in the future is a factor 1.72 greater than the import during 2013–2022.

Import data to the EU27 (Figure C.2) show a steep increase in import volume of about 500 tonnes/year (largely driven by imports to France). Table C.2 (copied from the pathway model file in Excel-Supporting information) shows the uncertainty bands of the estimated import 2013–2022 as well as the uncertainty in the multiplication factor.

TABLE C.2 Mean and quantiles (uncertainty distribution) of the average import volume 2013–2022 and the multiplication factor used to account for an increase of import in the period 2024–2028 compared to 2013–2022.

Unit	Mean	1%	2.5%	5%	10%	16.7%	25%	33.3%	50%	66.7%	75%	83.3%	90%	95%	97.5%	99%
[t]	1130.5	472.8	537.2	599.6	680.6	759.3	841.0	915.6	1063.9	1236.3	1345.9	1490.6	1663.0	1887.5	2106.7	2393.6
[–}	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72

Introduction model: Weight of an African eggplant fruit

The average weight of imported fruit is required to calculate in the pathway model the number of imported fruit from the import volume in kg. Taher et al. (2017) state ranges of fruit diameters for the principal morphotypes of *S. aethiopicum*, where Gilo fruit range from 2 to 10 cm in diameter, while Kumba fruit range from 5 to 10 cm in diameter.

There is variation in the size and weight of African eggplant fruit imported into the EU (see e.g. Figure C.1). African eggplant fruits were obtained at a local African market (Figure C.1), supplied by a wholesaler in Bologna (Fresh Tropical Srl BV). The mean weight for the Gilo type fruits was 65 g, and 109 g for the Kumba type fruits.

Eurostat data do not distinguish between African eggplant cultivars, and therefore, an EKE was performed to estimate the mean weight of eggplant fruit imported from Africa (Table C.3).

TABLE C.3 Results of an expert knowledge elicitation (EKE) to estimate the mean weight of an African eggplant fruit (grams).

Question	What is the mean weight of an African eggplant fruit imported into the EU from countries where African *Leucinodes* species occur?						
Results	**Estimated mean weight of exotic/special fresh eggplant fruit imported into EU (kg)**						
Percentiles %	1%	5%	25%	50%	75%	95%	99%
Fitted results (g)	20	29	44	56	69	88	100
Fitted distribution	BetaGeneral (5.7731, 9.0238, 0, 146)						

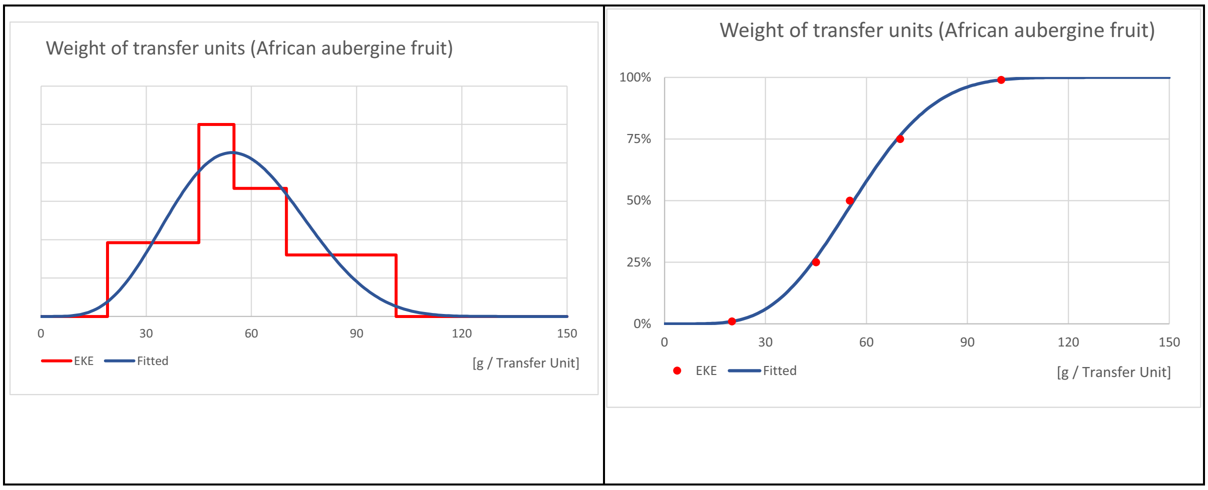


FIGURE C.3 Distribution of weight of African eggplant/aubergine fruit fitted to EKE estimates (Left hand chart shows probability density function to describe the remaining uncertainties of the parameter; right hand chart shows cumulative distribution function (CDF) of the likelihood of the parameter).

The median weight of an African eggplant fruit was estimated to be 56 g (90% CR is from 29 to 88 g).

Uncertainties

- No information was obtained on the actual varieties and preferences in the import
- There are no precise data available on size and weight of imported exotic eggplant (*S. melongena*) fruits
- No information was obtained on the relative proportion of smaller (berry-sized) fruit varieties in the import

Reasoning

Upper Limit:

- Market preference for bigger fruits

Lower Limit:

- Wild varieties have smaller sizes
- Gilo is on the smaller end of the size range and may dominate the trade
- Fruit of *S. aethiopicum* is generally smaller than the common eggplant *S. melongena* (Brinjal)

Median:

- Gilo type is dominating the market
- Some data on mean values of Gilo type

Interquartile Range (IQR):

Median uncertainties on both sides of the median, mainly about the composition of traded African eggplants (mainly *S. aethiopicum*).

Introduction model: Proportion of infested fruit

An analysis was made of interception records in Europhyt and TRACES. This analysis is detailed before the results of the EKE are described.

Analysis of interception data as a basis for eliciting the proportion of infested aubergines in the incoming trade from sub-Saharan Africa to Europe

Analysis of interceptions provides information on the level of infestation present in the trade. This information is imperfect (e.g. due to imperfect knowledge on sampling procedures across EU), but contributes usefully to the estimation of the true proportion of infested fruit in the incoming product. The Panel analysed therefore interceptions in the EU of African *Leucinodes* spp. in African eggplant fruit (*Solanum aethiopicum, S. melongena* and other *Solanum* spp.) from sub-Saharan countries, imported to the EU27 (i.e. without the UK) from 2004 till 2022 (Table C.4). Interception data were derived from Europhyt (https://food.ec.europa.eu/plants/plant-health-and-biosecurity/europhyt_en) and TRACES (https://food.ec.europa.eu/animals/traces_en) while trade data were derived from Eurostat (https://ec.europa.eu/eurostat/data/database). Data from the interceptions databases were identified using the CN code for aubergines 0709 30 while the countries of origin are given in the figure below.

TABLE C.4 Interceptions of African *Leucinodes* species from countries from sub-Saharan Africa 2004–2022, based on information in Europhyt and TRACES.

	Belgium	Germany	Italy	Netherlands	France	UK	Sweden	Spain	Total
2004			1	1					**2**
2005			4	2					**6**
2006		6				(1)			**6 (7)**
2007		7				(1)			**7 (8)**
2008		30							**30**
2009		17							**17**
2010		29							**29**
2011		10							**10**
2012	16								**16**
2013	3						1		**4**
2014	5								**5**
2015	7	1							**8**
2016								1	**1**
2017			3						**3**
2018	40								**40**
2019	22		2						**24**
2020	19		3		2				**24**
2021	16				1				**17**
2022	7								**7**
2023	(8)								**0 (8)**
	143	**100**	**13**	**3**	**3**	**(2)**	**1**	**1**	**256 (266)**

Note: The Panel used the interceptions from EU27 (i.e. excluding UK). Interceptions in 2023 are mentioned but were not included in the analysis because matching trade data were unavailable at the time of analysis. Numbers in brackets in the table are therefore given for completeness but were not used in the analysis.

Figure C.4 shows the African countries (here collectively referred to as sub-Saharan Africa) considered as potential sources of eggplant type fruits and *Leucinodes* spp.

FIGURE C.4 Map of Africa indicating sub-Saharan countries (©Eurostat) that are considered as possible sources of African *Leucinodes* species.

Table C.5 gives the total trade 2004–2022 in African eggplants (e.g. ***Solanum aethiopicum***, incl. exotic ***S. melongena*** varieties) from sub-Saharan Africa. Countries are listed in order of the volume of trade to the EU. Over this period, the biggest exporter was Uganda (30% of the trade), followed by Burkina Faso (23%), Kenya (17%), Cameroon (7%) and Senegal (7%). The remaining countries were responsible for 15% of the trade in African eggplant to EU.

TABLE C.5 Trade in African eggplant from Africa to the EU 2004–2022. Data from Eurostat.

Country	Export (100 kg)	Proportion (%)
Total	143,826	100
Uganda	43,077	30.0
Burkina Faso	33,695	23.4
Kenya	25,342	17.6
Cameroon	10,047	7.0
Senegal	9618	6.7
Ghana	7821	5.4
South Africa (incl. Namibia 'NA' ≥ 1989)	3263	2.3
Togo	3243	2.3
Mali	2919	2.0
Burundi	2482	1.7
Côte d'Ivoire (Ivory Coast)	957	0.7
Rwanda	532	0.4
Gambia	395	0.3
Eswatini (Ngwane)	140	0.1
Congo, Democratic Republic of	100	0.1
Guinea-Bissau	84	0.1
Madagascar	39	< 0.05
Sudan (incl. South Sudan 'SS' ≥ 2012)	21	< 0.05
Nigeria	15	< 0.05
Mauritius	12	< 0.05
Sierra Leone	9	< 0.05
Ethiopia (incl. Eritrea 'ER' ≥ 1993)	8	< 0.05
Guinea	6	< 0.05
Congo	1	< 0.05
Tanzania, United Republic of	< 0.5	< 0.05

The total trade in African eggplant to the EU over the years 2004–2022 amounted to 14,383 tons, for an average of 757 tons/year. Eurostat does not provide information on the size of consignments, but the interceptions database TRACES does provide this information (Figure C.5). Figure C.5 shows a histogram of the sizes (kg) of consignments of African eggplant imported from countries in sub-Saharan Africa and included in the database TRACES. At the time of preparing this opinion TRACES covered imports of African aubergines in the years 2020 (January) to 2024 (February).

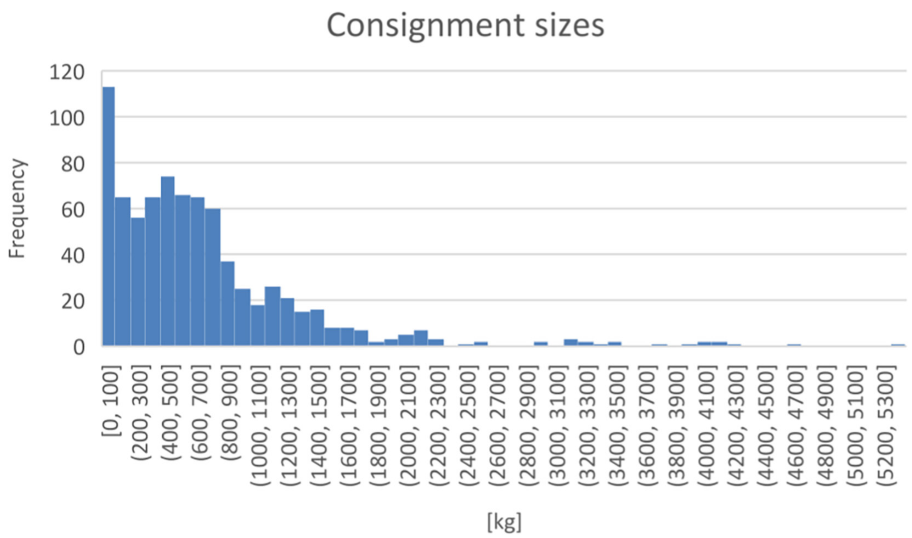


FIGURE C.5 Histogram of sizes of consignments of African eggplant imported to EU from sub-Saharan Africa based on information in TRACES 01-01-2020 to 04-02-2024. The average consignment size was 688.3 kg.

The average size of intercepted consignments in TRACES was 688.3 kg. Assuming this value applies over the whole period 2004–2022, the number n of imported consignments over the 19 years (2004–2022) would be equal to:

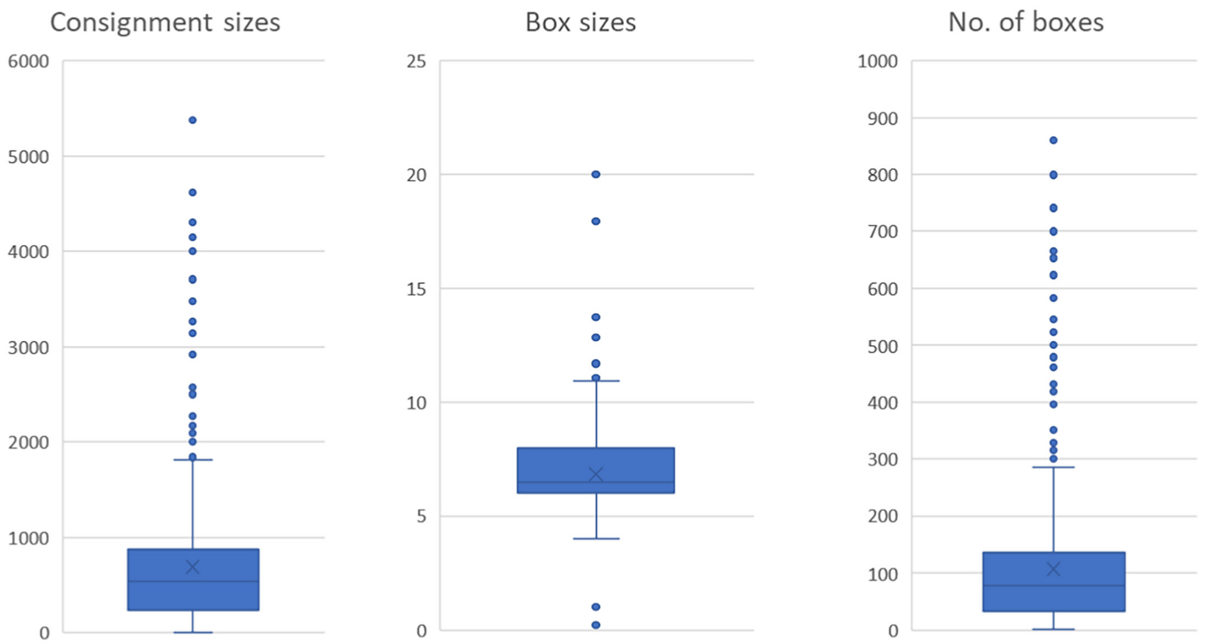
$$n = \frac{14{,}382.6 \times 1000}{688} = 20{,}905.$$

That is 1100 consignments per year.

Some key data from the above calculations are summarised in Table C.6.

TABLE C.6 Summary of key quantities from the analysis of incoming trade in African eggplants to the EU (data from Eurostat) and the number of interceptions (data from Europhyt and TRACES).

Trade (Eurostat)		
	2004–2022	**Per year**
Tons	14,383	799
# consignments (estimated)	20,905	1161
Interceptions (Europhyt and TRACES)		
	2004–2023	**Per year**
Interceptions	256	14



Mean=	688.3 kg		Mean=	6.83 kg		Mean=	107
StdDev=	691.4 kg		StdDev=	1.50 kg		StdDev=	118.8536
Median=	540.00 kg		Median=	6.5 kg		Median=	78
P62.5%	681.25 kg		P75%	8.0 kg		P62.5%	100

FIGURE C.6 Information on consignments of African eggplant based on information in TRACES 01-01-2020 to 04-02-2024. From left to right: weight of consignments (kg), weight of boxes within a consignment (kg; potentially relevant for sampling the consignment) and number of boxes per consignment (also potentially relevant for sampling).

All consignments should be inspected, but inspection practices may vary per country across the EU and the sample size may vary based on the number of boxes in a consignment and the number of fruit per box. EU member states follow ISPM31 regarding the choice of sample size and the number of boxes inspected. For instance, a minimum sample size of 60 fruit might be used. This sample size gives 95% certainty that a 5% level of infested fruit would be detected during inspection if inspection is 99% effective (Table C.7; from ISPM 31).

TABLE C.7 Relationship between sample size (numbers within table), the % efficacy of inspection (left column) and the confidence level attained in the case of no finding of a pest in a consignment (numbers in the top row). Calculated numbers are based on the binomial distribution, assuming a large consignment is inspected, and the infested product is randomly mixed within the consignment. Table copied from ISPM 31 (Table 3 in the ISPM).

	P = 95% (confidence level) % level of detection					*P* = 99% (confidence level) % level of detection				
% efficacy	5	2	1	0.5	0.1	5	2	1	0.5	0.1
100	59	149	299	598	2995	90	228	459	919	4603
99	60	150	302	604	3025	91	231	463	929	4650
95	62	157	314	630	3152	95	241	483	968	4846
90	66	165	332	665	3328	101	254	510	1022	5115
85	69	175	351	704	3523	107	269	540	1082	5416
80	74	186	373	748	3744	113	286	574	1149	5755
75	79	199	398	798	3993	121	305	612	1226	6138
50	119	299	598	1197	5990	182	459	919	1840	9209
25	239	598	1197	2396	11,982	367	919	1840	3682	18,419
10	598	1497	2995	5990	29,956	919	2301	4603	9209	46,050

As there is uncertainty on how many fruits will be inspected, scenarios are elaborated for 60, 120, 200 and 300 inspected fruit where 60 is the minimum number of fruit that should be inspected to reach 95% certainty that the pest level is not above 5%. Greater sample sizes give greater certainty of pest freedom.

The Panel made calculations on the overall proportion of infested fruit in the incoming trade of African aubergines from sub-Saharan Africa to the EU. Two methodologies are elaborated, one frequentist and the other one based on Bayesian analysis. Frequentist analysis is the classical statistics that is commonly taught in university courses. Bayesian analysis is more advanced and makes different assumptions. Bayesian analysis has strengths when analysing and characterising uncertainty. More information is given in statistical textbooks, e.g. Bolker (2009). The frequentist methodology is elaborated first.

Frequentist analysis

Three metrics were estimated: (1) a point estimate of the proportion of infested fruit, (2) a lower 2.5% confidence limit and (3) an upper 2.5% confidence limit. These metrics were estimated based on the following information and assumptions:

1. The total incoming trade into EU from 2004 to 2022 is ~14,383 tons.
2. The number of consignments is unknown but can be estimated from the trade volume in kg if the average consignment weight is known. Based upon analysis of information in TRACES (2020-01-01 to 2024-02-04), the Panel assumed the average weight of a consignment is 688.3 kg.
3. The sample size is not well known. The Panel used four options: (a) 60 fruit per consignment, (b) 120 fruit per consignment, (c) 200 fruit per consignment, (d) 300 fruit per consignment.

Standard statistical formulas were used to calculate the metrics of interest. A point estimate of the proportion of infested fruit in consignments was obtained by solving the equation:

$$P(\text{detection in a sample of } S \text{ fruit}) = 1 - \exp(-pS),$$

where p is the proportion of infested fruit, assumed constant across the entire population of imported consignments, and N is the sample size, assumed constant across all imported consignments. If n consignments are imported and k are found infested based on a sample size S, we may solve the proportion of infested fruit, p, from:

$$\frac{k}{n} = 1 - \exp(-pS),$$

which has as solution:

$$\hat{p} = -\frac{1}{S}\ln\left(1 - \frac{k}{n}\right). \quad \text{(C.1)}$$

If the sampling of a single consignment with sample size S is regarded as a Bernoulli trial with constant success chance P_B, an α percentile for this success chance can be derived from:

$$P_{\text{binomial}}\left(n, P_B(\alpha), k\right) = \alpha, \quad \text{(C.2)}$$

where P_{binomial} represents the cumulative binomial distribution, $P_B(\alpha)$ represents an α percentile of the chance of finding an insect in an imported consignment using a sample size S when the proportion of infested fruit is p, and k is the number of rejected consignments. This equation was solved in *R*. Then, the proportion of infested fruit was solved from:

$$1 - P_B(\alpha) = (1 - p(\alpha))^S. \quad \text{(C.3)}$$

The Panel made these calculations for $\alpha = 0.05, 0.5$ and 0.95.

TABLE C.8 Estimation results: point estimate of p using Equation C.1, three quantiles of P_B using Equation C.2 and three quantiles of p using Equation C.3.

Sample size	Point estimate of p[a] [per 10,000 fruits]	0.05 quantile of P_B[b]	0.50 quantile of P_B	0.95 quantile of P_B	0.05 quantile of p[b]	0.50 quantile of p	0.95 quantile of p
60	2.05	110.7	122.8	135.8	1.86	2.06	2.28
120	1.03	110.7	122.8	135.8	0.93	1.03	1.14
200	0.62	110.7	122.8	135.8	0.56	0.62	0.68
300	0.41	110.7	122.8	135.8	0.37	0.41	0.46

[a] p is the proportion of infested fruit, expressed as a number per 10,000. For p, both a point estimate is provided based on equation 1, and quantiles based on equation 3. Estimates of p depend on the sample size.

[b] $P_B(\alpha)$ is an α percentile of the chance of finding an insect in an imported consignment when k is the number of rejected consignments out of n consignments inspected. The quantity $P_B(\alpha)$ is estimated from the interception records and the trade volume and does not depend on the (unknown) sample size in this calculation.

The final result of the analysis is given in Table C.8. The table shows that the pest is found in more than 1% of the incoming consignments. The likely level of infestation estimated from this information depends on the sample size that was used during inspections, and ranges from a minimum of 0.37 to a maximum of 2.28 infested fruit per 10,000 according to the data available, the assumptions made (e.g. 100% inspection efficacy and physical inspection of all incoming consignments) and the mathematical framework chosen. The results were used as input for the expert knowledge elicitation on the proportion of African eggplant fruit infested with African ***Leucinodes*** species arriving in Europe from sub-Saharan African exporting countries.

Estimation of the infestation rate using Bayesian analysis

An alternative mathematical framework for estimating prevalence of the pest in imported consignments is provided by Bayesian analysis. This method is explained in this section.

To estimate the average infestation rate of imports of African aubergines from Sub-Saharan African countries, the Panel used information on interceptions at the EU border (Europhyt/TRACES). From 2004 until 2022 in total 256 interceptions (see Table C.4) of African *Leucinodes* species on African eggplant were reported by the current 27 EU countries. During these 18 years, EUROSTAT lists an import of 14,383 tons of aubergines (International trade; CN code 07093000) from the Sub-Saharan African countries.

Additionally, the TRACES system includes since 2020 until now (January 2024) information on the traded size of a consignment in weight and number of boxes.

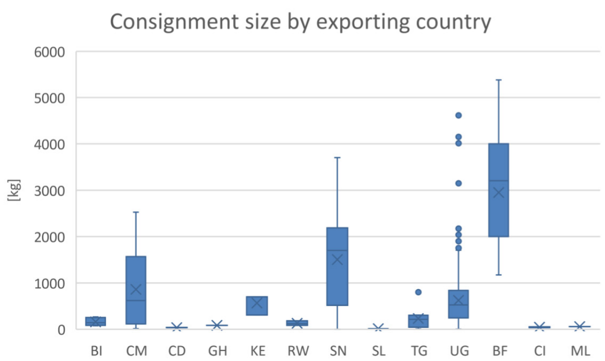


FIGURE C.7 Different consignment sizes of aubergines from Sub-Saharan Africa by classes and exporting country.

According to data in TRACES (January 2020 to February 2024), the average consignment size was 688 kg with a range from 0.2 to 5380 kg (Figures C.6, C.7). Assuming that this average is similar for the years before 2020, the estimated number of consignments from 2004 until 2022 is:

$$\text{Numberconsignments} = \text{Totalimport} / \text{Averageconsignmentsize} \;\; = 14{,}383t / 0.688\ t = 20{,}905.$$

In conclusion, the interception rate (per consignment) can be estimated:

$$\text{Interceptionrate} = \text{Numberinterceptions} / \text{Numberconsignments} \;\; = 256 / 20{,}905 = 1.22\,\%.$$

The interception rate is calculated as 1.22%. The 95% confidence interval ranges from 1.08% to 1.38% and is calculated using the Clopper–Pearson approximation (see Table C.9).

The confidence interval for the proportion of infested consignments is calculated using a Beta distribution BETA ($k+1$, $N-k+1$) with the parameters: k = Number interceptions, N = Number consignments, resulting in a Bayesian estimate of the distribution of the rate with a non-informative prior (Bolker, 2009).

TABLE C.9 Calculation of the 95% confidence intervals for Binomial (N, p) distributed rates with the Clopper–Pearson approximation to adjust for non-continuous observations. The exponential approximation for full presence/absence is less conservative than Clopper–Pearson (minimal change).

Observation k out of N	Lower bound	Upper bound
$k=0$ (full absence in the sample)	0%	1 – EXP(LN(0.05)/N) 'Upper 95% level'
$k=N$ (full presence in the sample	EXP(LN(0.05)/N) 'Lower 95% level'	100%

Table C.10 shows the rate of interception per each year from 2004 to 2022 (Figures C.8, C.9).

TABLE C.10 Interception rate of African *Leucinodes* species on imports of African aubergines from Sub-Saharan Africa to the EU27. In each case, the 95% CI is determined by using the Clopper–Pearson approximation (see Table C.9).

Year	Trade	Number consignments	Interceptions	Interception rate		
	[t]	[–]	[–]	Estimate	95% CI	
2004	222	322	2	0.621%	0.075%	2.225%
2005	164	238	6	2.525%	0.932%	5.414%
2006	128	186	6	3.225%	1.193%	6.887%
2007	166	242	7	2.898%	1.173%	5.879%
2008	248	361	30	8.309%	5.676%	11.649%
2009	384	558	17	3.048%	1.786%	4.836%
2010	508	738	29	3.929%	2.647%	5.594%
2011	501	728	10	1.374%	0.661%	2.513%
2012	755	1098	16	1.457%	0.835%	2.356%
2013	499	725	4	0.552%	0.151%	1.407%
2014	748	1087	5	0.460%	0.150%	1.071%
2015	1197	1740	8	0.460%	0.199%	0.904%
2016	1112	1616	1	0.062%	0.002%	0.344%
2017	1002	1457	3	0.206%	0.042%	0.601%
2018	866	1259	40	3.176%	2.278%	4.300%
2019	992	1442	24	1.664%	1.069%	2.466%
2020	1403	2039	24	1.177%	0.755%	1.746%
2021	1709	2485	17	0.684%	0.399%	1.093%
2022	1779	2586	7	0.271%	0.109%	0.557%
Sum	**14,383**	**20,905**	**256**	**1.22%**	**1.08%**	**1.38%**

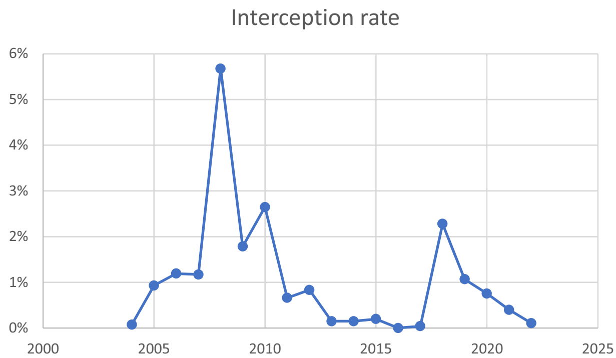


FIGURE C.8 Proportion of rejected consignments ('interceptions') due to a finding of African *Leucinodes* species on imports of African eggplant from Sub-Saharan Africa in the years 2004–2022 (Figure C.9).

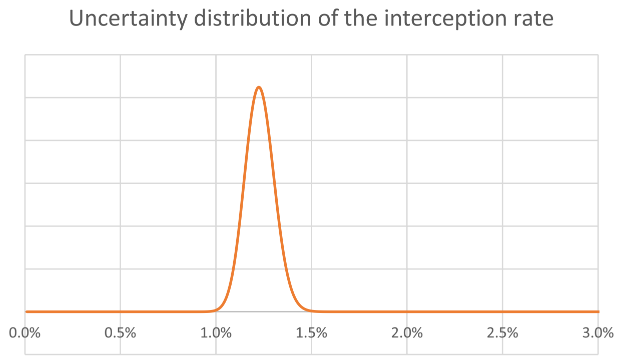


FIGURE C.9 Uncertainty distribution of the interception rate of African *Leucinodes* species on imports of aubergines from Sub-Saharan Africa estimated as BETA(257, 20,650) distribution.

For the estimation of the infestation rate within a consignment additional information on the control procedure is needed. The Panel assumes that African aubergines are traded in boxes of 6.8 kg while the average fruit weight is 55 g. Thus, a single box contains about 124 fruits. A box size of 6.8 kg combined with an average consignment weight of 688 kg implies that an average consignment has around 100 boxes. Roughly two-thirds of the imported consignments have less than 100 boxes, or less than 680 kg (Figures C.5, C.6).

The Panel further assumes that a usual inspection protocol requires the examination of the content of two boxes (or at least 60 fruits according to ISPM 31). Thus, $N = 248$ fruits will be checked for a typical consignment.

The number of specimens or infested fruits detected per consignment are not reported in TRACES. Following estimates of the infestation rate can be calculated:

$$\text{Infestation rate} = \text{Number infested fruits} / \text{Number inspected fruits}.$$

TABLE C.11 Estimated infestation rate in dependence of the number of infested fruit within a sample of 248 fruits.

		Infestation rate		
			95% CI (see above)	
Number sampled fruits	Number infested fruits		Lower bound	Upper bound
N	k	Estimate k/N	BETA.INV (0.025, k, $N-k+1$)	BETA.INV (0.975, $k+1$, $N-k$)
248	1	0.40%	0.01%	2.23%
248	2	0.81%	0.10%	2.88%
248	3	1.21%	0.25%	3.49%
Etc.				

Assuming a low infestation level the estimate for $k = 1$ detected specimen is reasonable. This results in an infestation level of 0.40% of the fruits (95% confidence interval 0.01%–2.23%) in an intercepted consignment. The uncertainty can be described again with a BETA distribution (Figure C.10):

$$\text{BETA}\ (k+1, N-k+1) = \text{BETA}\ (2, 248).$$

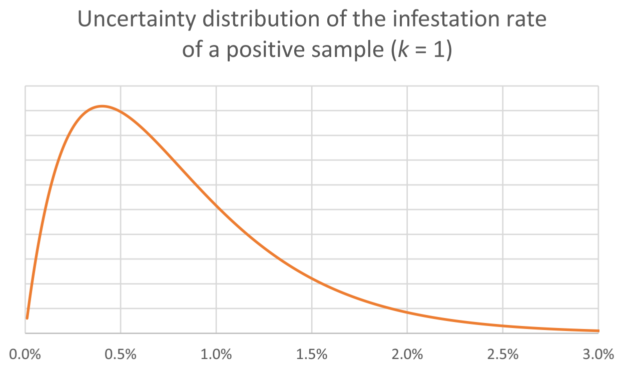


FIGURE C.10 Uncertainty distribution of the infestation rate for intercepted consignments estimated as a BETA(2, 248) distribution.

A negative inspection does not guarantee a pest-free consignment but depending on the size of the inspected sample higher infestation rates can be excluded, known as limit of detection of the inspection procedure (Table C.12).

TABLE C.12 Estimated infestation rate if no fruit were infested out of a sample of 248 fruit (See Table C.10).

		Infestation rate		
Number sampled fruits	**Number infested fruits**	**Estimate**	**95% CI**	
248	0	0.00%	0.00%	1.20%

For a sample size of 248 (from a large consignment of about 12,500 fruits), an infestation level higher than 1.2% would be detected with a probability of above 95%, thus can be excluded in a consignment that has tested negative. But lower infestation levels are possible with different likelihoods.

The same approach as for interceptions can be used to estimate the probability distribution of the proportion of infested fruit in consignments that tested negative (with $k=0$) (Figure C.11):

$$\text{BETA}\ (k+1, N-k+1) = \text{BETA}\ (1, 249).$$

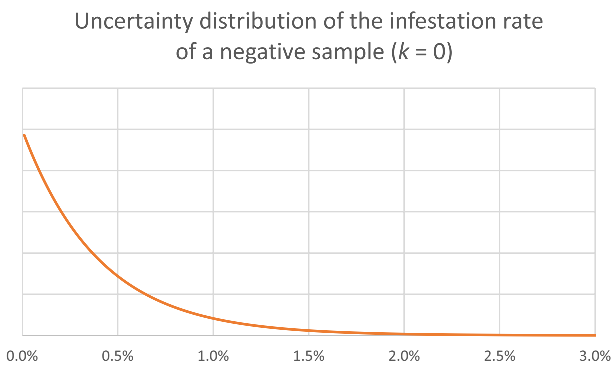


FIGURE C.11 Uncertainty distribution of the infestation rate for consignments with no pest findings, estimated as BETA(1, 249) distribution.

Lower infestation rates have higher likelihood than larger, and it is around 50% likely that the infestation level is below 0.25%, but the power of the inspection is not large enough to exclude higher infestation rates (up to 1.2%).

In the final step, the estimated proportion of the 98.8% negative samples, and 1.22% interceptions are combined by weighted averaging 'compounding' (Bolker, 2009) of the corresponding beta distributions. The resulting uncertainty distribution is as follows:

$p=\text{BETA}\ (257, 20{,}650)$	Uncertaintyof theinterceptionrate
$(1-\text{p})^{*}\ \text{BETA}\ (1, 249)+p^{*}\ \text{BETA}\ (2, 248)$	Uncertainty of the total infestation rate

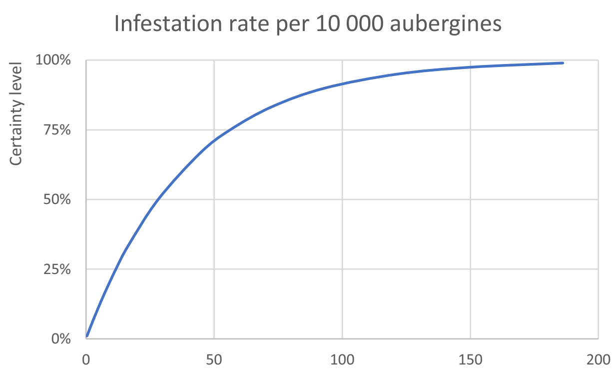


FIGURE C.12 Cumulative distribution of the number of infested African eggplant per 10,000 estimated from the interception records in Europhyt and TRACES and the trade data in Eurostat.

TABLE C.13 Estimated infestation rate [per 10,000] of African aubergines from Sub-Saharan Africa with *Leucinodes* spp. complex in Africa.

Percentile	1%	2.5%	5%	10%	16.7%	25%	33.3%	50%	66.7%	75%	83.3%	90%	95%	97.5%	99%
Interception rate	1.06%	1.08%	1.11%	1.13%	1.16%	1.18%	1.20%	1.22%	1.26%	1.28%	1.30%	1.33%	1.36%	1.38%	1.41%
	Per 10,000 aubergine fruits														
Infestation rate of a negative inspected consignment	0.402	1.015	2.06	4.23	7.32	11.5	16.3	27.8	44.0	55.5	71.7	92.0	120	147	183
Infestation rate of an intercepted consignment	5.96	9.72	14.3	21.4	29.4	38.6	47.7	67.3	91.7	107.8	129	155	189	222	264
Combined infestation rate of all consignments	0.410	1.043	2.10	4.31	7.44	11.7	16.5	28.2	44.6	56.3	72.7	93.2	121	150	186

Introduction model: Infestation rate of African eggplant fruit when entering the EU

The Panel used information from the literature, from the expert hearing and the analyses of interceptions to elicit the proportion of infested fruit in the trade of African eggplant from sub-Saharan Africa to the EU.

Elicited mean annual rates of infestation per 10,000 eggplant fruits are given in the table below with the probability distribution under the table. EKE estimates are consensus estimates. Model inputs are derived from the distribution fitted to the EKE estimates.

TABLE C.14 Estimated mean number of African eggplant fruit infested with African *Leucinodes* species when entering the EU (per 10,000 fruit).

Question:	How many out of 10,000 fresh African eggplant fruit will be on average infested with African *Leucinodes* species when entering the EU from countries where the pests occur?						
Results	Infestation rate of eggplant fruit when entering the EU (per 10,000 fruit)						
Percentiles %	1%	5%	25%	50%	75%	95%	99%
EKE estimates	0.3		5.0	10	25		100
Fitted values (fruit infested per 10,000)	0.30	0.798	4.374	11.27	23.72	53.7	84.2
Fitted distribution	BetaGeneral (0.86398, 508.36, 0.21, 10,000)						

The median rate of African eggplant fruit infestation is 11.27 per 10,000 (= 1.1 per 100,000); (90% CR is from 0.008 per million to 0.537 per million).

Uncertainties

Uncertainties have been provided in the pages of evidence leading up to the EKE. The total trade in African eggplant is known from information in Eurostat, but the variation (species, fruit sizes) in the trade is not well known as all produce falls under a single CN code.

No information was obtained on sorting processes in countries of origin. Sorting is indispensable as *Leucinodes* fruit and shoot borers are common pests in sub-Saharan Africa, and a hearing expert mentioned 10% infestation of fruit on the local market as a ballpark estimate. The Panel judges it unlikely that fruit is produced in pest-free places of production. Literature summarised in Appendix D (Impact) lists high percentages of infestation under particular conditions in the field, up to more than 50%.

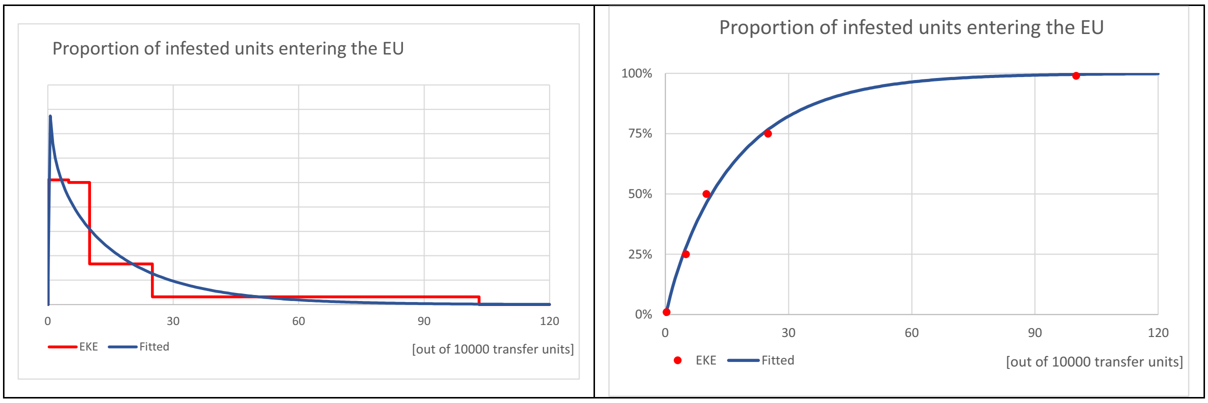


FIGURE C.13 Distribution of infestation rate of African eggplant fruit fitted to EKE estimates (Left hand chart shows probability density function to describe the remaining uncertainties of the parameter; right hand chart shows cumulative distribution function (CDF) of the likelihood of the parameter).

Import inspection in the EU serves to assure pest freedom, but there is uncertainty on the sample sizes used, which may be as small as ~60 fruits according to ISPM31. Such small sample sizes, while posing a challenge for importing countries due to the labour involved, do not guarantee pest freedom.

Despite the uncertainties on sample size, *Leucinodes* spp. are found in more than 1% of the imported fruit, suggesting the level of infestation may be substantial but not accurately known. Based on these uncertainties and the reasonings given below, the Panel gave a wide range to the level of infestation (Table C.14).

Reasoning

Lower limit:

- Pesticide treatments are used and are assumed to be effective.
- Careful post-harvest handling of individual fruits allows sorting and rejection of infested fruit prior to export.
- Exotic/special eggplant varieties are high quality, high value and imported in small volumes.
- Growers of eggplant for export get advice on cultivation methods and pest control.
- Production from one site is integrated with supply chain.
- Later larvae will show clear damages.
- Insect is native to export countries where natural enemies could lower pest abundance.
- Occurrence of any pest on harvested materials is recognised as an export problem to access EU markets.
- Real quality issue for the consumer hence careful sorting/grading pre-export.
- Inspection required before phytosanitary certificate is issued; 0% infestation tolerance for exports to EU.

Upper limit:

- Overlapping generations, continuous development year round.
- A most important pest of eggplant.
- Fast infestation of new plots.
- Early larvae do not show damage.
- Biological control not effective.
- High pest pressure in the country of origin/production areas.
- High impact reported in eggplant for domestic consumption (not exported).
- Interceptions at EU border may not be reported (no need to notify as not QP).
- When exports are combined from many sites of production.

Median:

- The pest is prevalent under field conditions.
- Harvesting is done by hand, and harvesters would avoid bad looking fruit.
- Within the packing house stringent procedures are followed to ensure pest freedom.
- Pest freedom is of paramount interest to exporters.
- However, with the pest being prevalent under field conditions, and with human resources and time being limiting, zero infestation may not be reached in practice.

Further steps in the pathway model (post-entry: transfer) were not separately quantified for *Leucinodes* spp. from Africa. The Panel used estimates for *L. orbonalis* (EFSA PLH Panel, 2024) as no information was obtained that would suggest differences between this species and Leucinodes spp. from sub-Saharan Africa. There was therefore no justification for further elicitations.

APPENDIX D

Impact

Relatively little is known about impacts of *Leucinodes* species in Africa. While several papers mention high impact on *S. aethiopicum* and *S. melongena* (Table D.1), the interviewed hearing experts from Uganda and Nigeria considered other insect species to be more damaging and thus of higher concern (personal communication, Prof E. Balyejusa Kizito, L. Chinaru Nwosu). Frempong and Buahin (1977) consider *L. 'orbonalis'* the most destructive insect of *S. melongena* in Ghana, as does Nwana (1992) for Nigeria. In South Cameroon, Elono Azang et al. (2016) found *L. 'orbonalis'* to be the by far most abundant and most damaging insect on two varieties of *S. aethiopicum* and one variety of *S. melongena,* without substantial differences in the numbers of larvae per fruit on these hosts. The insect was accountable for 65.9%–75.1% of the total damage to fruit inflicted by all insect species recorded on these plants (Elono Azang et al., 2016). Fouelifack-Nintidem et al. (2021) found *L. 'orbonalis'* to occur in both well-maintained and unmaintained plots of *S. aethiopicum* and was by far the most abundant insect in these. Zakka, Nwosu, et al. (2018) found *L. 'orbonalis'* to be present at all of the eight farms surveyed in four government areas in Rivers State, Nigeria, indicating a wide and permanent presence of *Leucinodes*.

In nature, larvae have not been observed to attack seedlings, but under lab conditions, eggs are laid on 6-week-old potted plants and the larvae are feeding in the shoots of the young plants (Frempong, 1979). In the seedling stage, mainly shoots are attacked by *L. 'orbonalis'* larvae, where they cause drooping, fading and the eventual die-off of the shoot; once fruit development sets in, larvae shift their feeding mostly to the inside of fruits, sometimes causing fruit malformation or complete failure of the fruit (Frempong, 1979; Nwana, 1992). Frempong (1979) mentions that in a few occasions, *L. 'orbonalis'* larvae bored into petioles of large *S. melongena* leaves. When fruits are affected by phytopathogenic moulds like *Phytophthora parasitica*, *L. 'orbonalis'* larvae may leave the damaged fruit and change to undamaged fruits (Frempong, 1979). Mature larvae of *L. laisalis* leave the fruit through a large exit hole, through which fungi can enter, causing the fruit to rot (Ogunwolu, 1978).

Leucinodes laisalis is established in the south of Spain since at least 1958 (Huertas Dionisio, 2000), and since then has spread along the coast of Andalusia, including into main production areas of *S. melongena*, especially in Cádiz, Málaga and Almería (Ministerio de Agricultura, Pesca y Alimentación, https://www.mapa.gob.es/app/MaterialVegetal/fichaMaterialVegetal.aspx?idFicha=3995). Despite the species' presence in these regions, the Panel is not aware of any European reports of *L. laisalis* infestations threatening the production of eggplant or other agriculturally relevant Solanaceae in Spain. Fondio et al. (2008) report low plant infestation rates of 5.75%–10.5% for *S. macrocarpon*, but up to 76.25% plant infestation rates for *S. aethiopicum*.

The impact of African *Leucinodes* spp. on potato appears to be negligible: Ngamaleu-Siewe et al. (2021) reared 23 adult *L. 'orbonalis'* from 3600 damaged potato stems and tubers (0.6% of rearings), compared to 102 adults of *Helicoverpa armigera* (Lepidoptera: Noctuidae) (2.8% of rearings).

TABLE D.1 Reported infestation rates of African *Leucinodes* species.

Species	Host	Country/ region	Shoot infestation	Fruit infestation	Reference
Leucinodes 'orbonalis'	*S. melongena* (varieties Local Katakyie/Long Purple)	Kumasi, Ghana	–	Minor season (August–December): 81.17%/77.50%; Major season (March–July): 52.46%/22.39%	Frempong (1979)
Leucinodes 'orbonalis'	*S. melongena*, 14 cultivars	Kumasi, Ghana	31.4%–61.1%	14.8%–53.5%	Duodu (1986)
Leucinodes 'orbonalis'	26 *Solanum* germplasm accessions	Bunso, Ghana	–	0.3%–41.7% (2009, among 26 accessions); 24.5%–85.1% (2010, re-evaluation of five accessions)	Kotey et al. (2013)
Leucinodes 'orbonalis'	*S. aethiopicum*	Bunso, Ghana	–	41.71%–86.64%	Kotey et al. (2023)
Leucinodes 'orbonalis'	*S. aethiopicum* (2 vars), *S. melongena* (1 var.)	S-Cameroon	–	51.99% (Okola, Southern Plateau), 44.42% (Koutaba, Western Highlands)	Elono Azang et al. (2016)
Leucinodes 'orbonalis'	*S. aethiopicum* var. zong	S-Cameroon	–	9%–13% (infested fruits/plant)	Elono Azang et al. (2023)
Leucinodes 'orbonalis'	*S. melongena*, local cultivar	Lagos, Nigeria	3%–13%	15%–19%	Nwana (1992)
Leucinodes 'orbonalis'	*S. aethiopicum* gilo	Umudike, SE-Nigeria	–	38.8%–52.2% fruits/plant (calculated from the data)	Emeasor and Uwalaka (2018)
Leucinodes 'orbonalis'	*S. aethiopicum*, two Gilo varieties	Umudike, SE-Nigeria	–	67.1% (control group)	Emeasor et al. (2022)
Leucinodes 'orbonalis'	*S. aethiopicum*, three varieties	Azaguié, Côte d'Ivoire	–	var. Djamba F1: 28.26%–82.67% (208/173 days after transplanting [DAT]); var. Kotobi: 21.67%–69.89% (208/173 DAT); var. N'drowa issia: 14.27%–40.04% (208/166 DAT)	Obodji, Aboua, Seri-Kouassi, et al. (2015)
Leucinodes laisalis	*S. aethiopicum*, *S. macrocarpon*	Côte d'Ivoire	Cumulative number of damaged plants after 8 weeks: 5.75% (Aub26G/06Dv cultivar) up to 76.25% (Aub42K/06Ti)		Fondio et al. (2008)

APPENDIX E

Consequences of climate change

Table E.1 shows the distribution of expected numbers of infested fruit entering NUTS2 regions where EI ≥ 15 under the current climate, together with the likelihood of a founder population being initiated and the waiting time for a founder population. Table E.2 presents the same model outputs for EI ≥ 15 using results from the ensemble climate change scenario (average of four regional climate change models, 2040–2059) (Rossi, Czwienczek et al., 2024).

TABLE E.1 Model output results illustrating the range in estimates for selected model steps of entry, number of founder populations initiated each year and the corresponding waiting time for a founder population (EI ≥ 15, current climate).

	Percentile						
Model step	**1%**	**5%**	**25%**	**50%**	**75%**	**95%**	**99%**
Number of infested fruit in suitable climatic regions	205	567	3185	8566	19,216	52,696	96,837
Mean number of founder populations in suitable regions each year	0.00005	0.00023	0.00200	0.00780	0.02639	0.12125	0.31978
Expected number of years till first founder population	3	8	38	128	500	4279	20,782

TABLE E.2 Model output results illustrating the range in estimates for selected model steps of entry, number of founder populations initiated each year and the corresponding waiting time for a founder population (EI ≥ 15, climate change scenario).

	Percentile						
Model step	**1%**	**5%**	**25%**	**50%**	**75%**	**95%**	**99%**
Number of infested fruit in suitable climatic regions	294	815	4574	12,303	27,602	75,690	139,093
Mean number of founder populations in suitable regions each year	0.00007	0.00034	0.00287	0.01120	0.03790	0.17416	0.45932
Expected number of years till first founder population	2	6	26	89	348	2979	14,469

In the climate change scenario and using a threshold of EI ≥ 15, ~44% more infested fruit enter NUTS regions where climate is potentially suitable for establishment. The likelihood of a founder population being initiated increases by ~44% and the median wait time until a founder population is initiated falls by ~30% from around 130 years to about 90 years.

Table E.3 shows the distribution of expected numbers of infested fruit entering NUTS2 regions where EI ≥ 30 under the current climate, together with the likelihood of a founder population being initiated and the waiting time for a founder population. Table E.4 presents the same model outputs for EI ≥ 30 using results from the ensemble climate change scenario (Rossi, Czwienczek, et al., 2024).

TABLE E.3 Model output results illustrating the range in estimates for selected model steps of entry, number of founder populations initiated each year and the corresponding waiting time for a founder population (EI ≥ 30, current climate).

	Percentile						
Model step	**1%**	**5%**	**25%**	**50%**	**75%**	**95%**	**99%**
Number of infested fruit in suitable climatic regions	125	346	1941	5222	11,715	32,124	59,034
Mean number of founder populations in suitable regions each year	0.00003	0.00014	0.00122	0.00476	0.01609	0.07392	0.19495
Expected number of years till first founder population	5	14	62	210	820	7020	34,090

TABLE E.4 Model output results illustrating the range in estimates for selected model steps of entry, number of founder populations initiated each year and the corresponding waiting time for a founder population (EI ≥ 30, climate change scenario).

	Percentile						
Model step	**1%**	**5%**	**25%**	**50%**	**75%**	**95%**	**99%**
Number of infested fruit in suitable climatic regions	188	522	2927	7874	17,664	48,439	89,014
Mean number of founder populations in suitable regions each year	0.00004	0.00021	0.00184	0.00717	0.02426	0.11145	0.29395
Expected number of years till first founder population	3	9	41	139	544	4655	22,608

In the climate change scenario and using a threshold of EI ≥ 30, ~ 50% more infested fruit enter NUTS regions where climate is potentially suitable for establishment. The likelihood of a founder population being initiated increases by ~ 50% and the median wait time until a founder population is initiated falls by just over a third, from a median of ~ 210 years to about 140 years (Figure E.1).

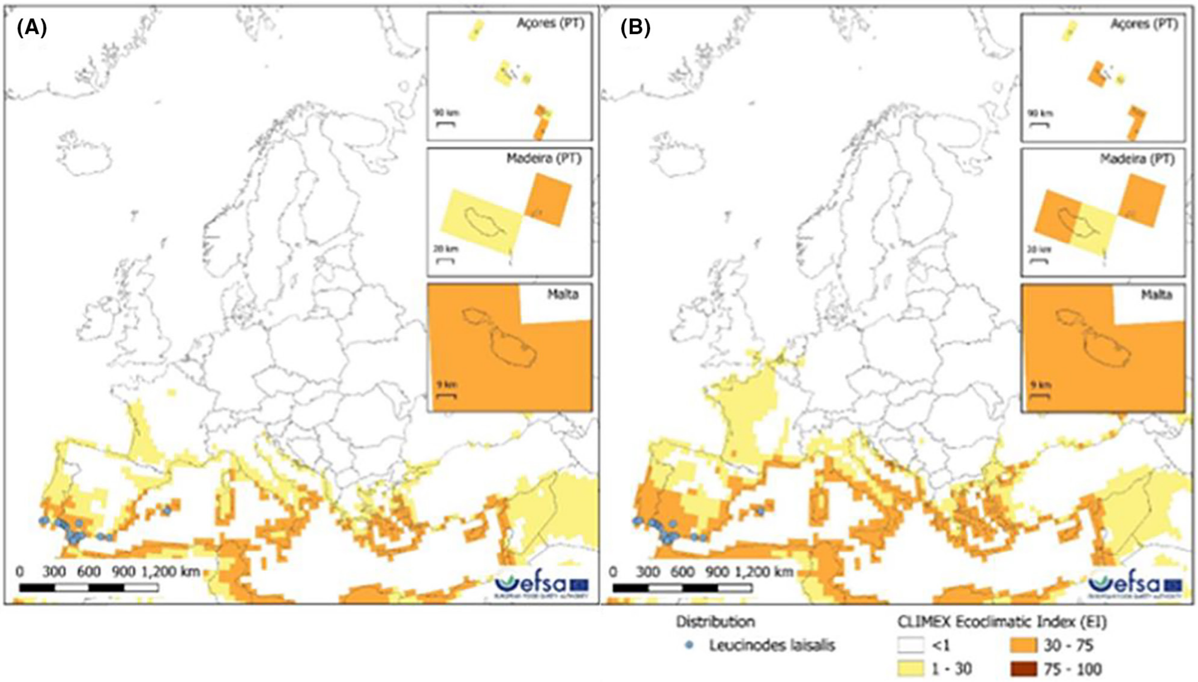


FIGURE E.1 Ecoclimatic Index (EI) for African *Leucinodes* spp. (A) Under current climate (1993–2022); (B) Using results from an ensemble climate change model (2040–2059). Darker colours suggest more favourable conditions for establishment (higher EI). Blue points indicate coordinates of observed locations of *Leucinodes laisalis*. Administrative boundaries: © FAO-UN. Cartography: EFSA February 2024 (*Source*: Rossi, Czwienczek, et al., 2024).