Department for Environment Food & Rural Affairs

Rapid Pest Risk Analysis (PRA) for:

Diaporthe sojae

Date: September 2024

Summary and conclusions of the rapid PRA

Diaporthe sojae is a fungus that primarily causes stem and pod blight on *Glycine max* (soybean). The pathogen is absent from Great Britain and listed as a provisional quarantine pest. A PRA has been undertaken to decide its future status in legislation.

This rapid PRA shows:

Diaporthe sojae is a weak pathogen of soybean that can be transmitted by infected seeds and overwinters to infect future soybean crops in field stubble. It causes lesions on stems which weaken the plant, and infects pods at late stages of growth, reducing seed quality.

Risk of entry

The primary pathway of entry identified is soybean seeds for planting which is rated **moderately likely** to be a source of introduction with **medium confidence**. The pathways of plants for planting (excluding seed) and used farm machinery have been rated **unlikely** with **medium** and **high confidence** (respectively) while soil/ growing medium and plants for consumption are **highly unlikely**. While the rating for soil comes with **high confidence**, the rating for plant material for consumption has **low confidence** due to a lack of information.

Risk of establishment

It is **likely** with **high confidence** that *Diaporthe sojae* would establish outdoors in GB in soybean crops as our climate is comparable with other regions where the pest is present. It is **unlikely** with **medium confidence** to establish under protection.

Economic, environmental and social impact

Diaporthe sojae could cause reduction of yield, unmarketable seed and reduction of quality/ value. It would also require a significant change of practices from UK industry to manage should it arrive. However, in the USA it is one of the less damaging pathogens of soybean compared to other organisms of concern within the region. None of these organisms are present in GB and without these other pressures it is not clear if it would have the same impact in the UK. Therefore, the economic impact has been rated **small** with **low confidence**. While it is likely to infect some weeds, evidence is lacking so environmental impact is rated as **very small** with **low confidence**. Social impact has been rated **very small** with **high confidence** as soybean is not culturally significant or a common plant grown in gardens or allotments in the UK.

Endangered area

The endangered area is currently the south and southwest of England where the vast majority of soybean is currently grown. The potential range of spread could extend into southeast England and south Wales if soybean production were to expand.

Risk management options

Eradication of the pest would not be possible as it remains dormant overwinter and could spread to other plants in the field margins. Statutory action could be used to mitigate against infected seed imports, however sourcing seed from UK stock would be the most effective way to prevent the disease from entering the PRA area. If it were to establish, it can be managed by a combination of deep tillage, crop rotation with a non-host such as maize (*Zea mays*) or grains, planting resistant varieties, using potassium fertilisers and selective harvesting at the optimal time.

Currently fungicides are not a viable option for controlling the disease. However, authorisation to use effective fungicides approved for bean could be sought in the future.

Key uncertainties and topics that would benefit from further investigation

<u>Taxonomy:</u> DNA sequencing has helped define *D. sojae,* however there is still debate over whether it is a complex of sub-species, a species of its own, or a variety of *D. phaseolorum*. Work continues in this area.

Field weed hosts: It is likely some arable weeds present in the UK could be a source of inoculum for *D. sojae*. If this is the case this could affect the ability of the fungus to spread between farms and increase its environmental impact.

Interaction with other diseases: Almost all field studies find *D. sojae* present with other diseases so it is possible it is not responsible for all symptoms observed, or it may react differently when infecting the plants in isolation. Studies to confirm if it would act as a primary pathogen without other soybean pests present would be beneficial.

Lack of European data: Most studies originate from the USA where this disease is endemic. Most papers from Europe relate to identification or first findings. It is uncertain why there is little research coming from this region, but it could be possible that it is having less of an impact on the industry than in the USA.

Images of the pest

Photo 1: Fruiting bodies of *Diaporthe sojae* on *Glycine max.*	Photo 2: Lesions on an infected *Glycine max* stem.
	
Source: Grau, C. (2023) *bugwood.org*.	Source: Mueller, D. (2021) *bugwood.org.*

Is there a need for a detailed PRA or for a more detailed analysis of particular sections of the PRA? If yes, select the PRA area (UK or EPPO) and the PRA scheme (UK or EPPO) to be used.

No	X

Yes		PRA area: UK or EPPO		PRA scheme: UK or EPPO	

Given the information assembled within the time scale required, is statutory action considered appropriate / justified?

Whilst *D. sojae* does affect yield and seed quality, it does not cause crop failure and management options are available. In the USA it has a smaller financial impact on growers than many other pests and diseases of soybean. Therefore, the recommendation is to deregulate *Diaporthe sojae.* This is in line with *Diaporthe caulivora* (stem canker of soybean) which is part of the same complex and was deregulated and removed as an RNQP in 2022. This change would only apply to Plant Health Regulations and would not change the requirements of the Seed Marketing Regulations 2011, where *D. sojae* would remain an RNQP on seed to be marketed and RNQP requirements would have to be met in order for seed to be certified.

Yes Statutory action		No Statutory action	X

Stage 1: Initiation

1. What is the name of the pest?

Diaporthe sojae Lehman

Synonyms: *Diaporthe phaseolorum* var. *sojae* (Lehman) Wehmeyer; *Diaporthe phaseolorum* (Cooke & Ellis) Sacc.; *Phomopsis phaseoli* (Desm.) Sacc.; *Phomopsis sojae* Lehman; *Phomopsis glycines* Petrák.

Common names: pod and stem blight of soybean, seed decay of soybean.

There has been much taxonomic confusion within the *Diaporthe/ Phomopsis* genus- *D. sojae* can only accurately be identified using DNA sequencing. Historically, it was identified using morphological and physiological factors, but there is much overlap between species and so this cannot be accurately relied on (Udayanga *et al.,* 2015). *Diaporthe sojae* is also part of a wider species- complex and regularly infects plants alongside other *Diaporthe* spp. It has also been suggested that *D. sojae* may itself be a complex of several subspecies (Zhang *et al.,* 1998). Taxonomists continue to work in this area and this species may be redefined in the future as molecular methods of identification develop. Taxonomy is further explored in section 7 of this PRA in relation to hosts.

2. What initiated this rapid PRA?

The EU legislation lists this pest as a regulated non-quarantine pest (RNQP), and this listing was initially carried over into the plant health legislation for Great Britain. However, as *D. sojae* is absent from the UK and RNQPs must be present, the RNQP status was inappropriate and it was changed to being listed as a provisional quarantine pest for Great Britain. Therefore, the primary purpose of this PRA is to consider its future regulatory listing in legislation for Great Britain and whether listing as a quarantine pest is appropriate.

Northern Ireland remains aligned to the EU, and this pest is likely to remain an RNQP for the EU.

3. What is the PRA area?

The PRA area is the United Kingdom of Great Britain and Northern Ireland.

Stage 2: Risk Assessment

4. What is the pest's status in the plant health legislation, and in the lists of EPPO[1]?

The legislation for Great Britain is the Phytosanitary Conditions Regulation (assimilated Regulation (EU) 2019/2072[2]). *Diaporthe sojae* is listed (as *Diaporthe phaseolorum* var. *sojae)* as a provisional quarantine pest in Annex 2A.

The legislation which applies to Northern Ireland is the EU legislation: 2019/2072[3]. *Diaporthe sojae* is listed (as *Diaporthe phaseolorum* var. *sojae)* as an RNQP for seed of oil and fibre crops in Annex IV on *Glycine max* (soybean).

The pest is not on the EPPO A1, A2 or alert lists, nor does EPPO have a PRA for it. This is likely due to it already being present in much of Europe and therefore managed by the trade. EPPO do however include it in their RNQP categorisation.

5. What is the pest's current geographical distribution?

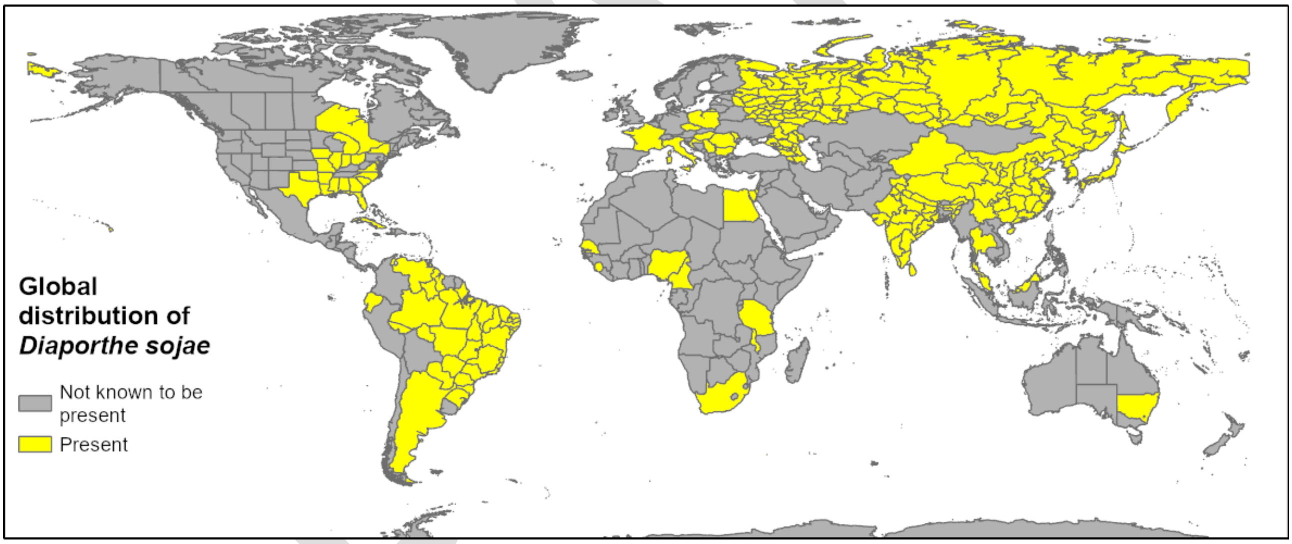

Figure 1: A map showing the geographical distribution of *Diaporthe sojae.*

[1] https://www.eppo.int/ACTIVITIES/quarantine_activities

[2] https://www.legislation.gov.uk/eur/2019/2072

[3] The latest consolidated version can be accessed on the left-hand side of https://eur-lex.europa.eu/eli/reg_impl/2019/2072/oj

Table 1: Distribution of *Diaporthe sojae*	
North America:	Canada, United States of America (Alabama, Arkansas, Delaware, Florida, Georgia, Hawaii, Illinois, Indiana, Iowa, Louisiana, Maryland, Michigan, Mississippi, Missouri, New York, North Carolina, Ohio, Oklahoma, South Carolina, Texas and Virginia)
Central America:	Cuba, Puerto Rico (Udayanga *et al.,* 2015),
South America:	Argentina, Brazil, Colombia, Ecuador, Guyana, Paraguay, Venezuela
Europe:	Armenia, Azerbaijan, Bulgaria, Croatia, Czechia, France, Georgia, Hungary, Italy, Moldova, Poland, Romania, Russia, Serbia, Spain
Africa:	Cameroon, Egypt, Malawi, Nigeria, Senegal, Sierra Leone, South Africa, Tanzania
Asia:	China, Democratic People's Republic of Korea, India, Israel, Japan, Malaysia, Nepal, Republic of Korea, Sri Lanka, Taiwan, Thailand
Oceania:	Australia

The following information on distribution has been compiled from EPPO Global Database (2024) and CABI Compendium (2022) unless otherwise stated. In North America the fungus is widespread throughout the eastern states of the USA and Hawaii, however there are no records of its presence in the western states. In Canada its distribution is restricted to Ontario. Distribution within Australia is limited to New South Wales. It has a scattered range throughout Africa.

6. Is the pest established or transient, or suspected to be established/transient in the UK/PRA Area?

Diaporthe sojae is not known to be present in Great Britain or Northern Ireland. There have been no interceptions in the United Kingdom of this pathogen.

7. What are the pest's natural and experimental host plants; of these, which are of economic and/or environmental importance in the UK/PRA area?

Main host:

Glycine max (soybean)

Alternative/ experimental hosts:

Abutilon theophrasti (velvet leaf), *Amaranthus spinosus* (spiny amaranth), *Arctium lappa* (greater burdock), *Helianthus annuum* (sunflower), *Lotus corniculatus* (bird's foot trefoil), *Lupinus* spp. (lupins), *Phaseolus vulgaris* (common bean), *Phaseolus lunatus* (lima bean) (Mahmodi *et al.,* 2013), *Vigna unguiculata* (black-eyed pea) and *Vaccinium corymbosum* (blueberry).

Diaporthe sojae is primarily a pathogen of soybean causing pod and stem blight throughout crops. It has been found to affect *Phaseolus lunatus* and *Phaseolus vulgaris,* however, *D. longicolla* within the same complex is the primary pest on these crops.

There has been much debate over taxonomic identification of this complex which makes true identification of hosts difficult. A comprehensive review of this was undertaken by Udayanga *et al.* (2015) which attempted to accurately identify the most common *Diaporthe* soybean pathogens using DNA sequencing techniques. *Diaporthe longicolla* is a primary pathogen of seed decay on soybeans and symptoms between the species often overlap. Some studies for instance have considered *Diaporthe logicolla* and *D. sojae* to be the same species (Gomez *et al.,* 2013 for example) but these have since been separated by Udayanga *et al.* in 2015. Further to this, *D. phaseolorum* was an earlier synonym given to *D. sojae* (as *Diaporthe phaseolorum* var *sojae),* often describing symptoms found on *Phaseolus* spp. Historically however this has been the name given to a complex of *Diaporthe* spp. and therefore, it is not always possible to isolate results specific to *D. sojae. Diaporthe kochmanii,* as first described by Thompson *et al.* (2011) on *Helianthus annuum,* has also since been redescribed as a synonym of *D. sojae* (Udayanga *et al.,* 2015). *Phaseolus lunatus, Phaseolus vulgaris, Vigna unguiculata* and *Helianthus annuum* have been considered as minor hosts because *D. sojae* is not the primary pathogen of any of these species, and in each study the pathogen was shown to be present in a complex alongside other *Diaporthe* spp.

Studies have shown that *D. sojae* can infect certain field weed species such as *Abutilon theophrasti* (velvet leaf), *Amaranthus spinosus* (spiny amaranth), *Lupinus* spp. (lupins) and *Arctium lappa* (greater burdock), of which only greater burdock is present in the UK and studies are inconclusive regarding their role as reservoirs for inocula. Other species of *Diaporthe* such as *D. longicolla* have also been documented infecting field weed species (Udayanga *et al.,* 2015) so it is likely further species are susceptible to infection that have not been documented yet.

Diaporthe sojae has been isolated from other crop plants that are grown in the UK including *Capsicum frutescens* (pepper), *Solanum lycopersicum* (tomato), *Allium cepa* (onion) and *Allium sativum* (garlic), however in these instances it was shown to be a secondary invader or saprophyte and not a pathogen (Luttrell, 1947). Therefore, these have not been considered hosts in this PRA.

There has been a first finding of *D. sojae* infecting blueberry in China (Li *et al.,* 2023) where *D. sojae* was identified as the causal pathogen of the symptoms. As this is a developing situation, blueberry is considered an alternative host.

Given the above evidence, this PRA will focus on *D. sojae* as primarily a soybean pathogen.

8. Summary of pest biology and/or lifecycle

The fungi overwinters in field debris or dormant mycelia within infected seed, and infects newly emerging plants in the spring. Initial infections result from the planting of diseased seed or develop from rain-splashed spores from infected plant debris, that land on susceptible plant tissue (Backman, Weaver and Morgan-Jones, 1985). Symptoms show on soybean pods growing on broken side branches and on the lower nodes. Lesions that develop spread around wounds as well as trichomes. Lesions that originate on infected peduncles can move downwards to invade pod tissues causing pod lesions which are usually a chocolate brown colour. Pods may become infected any time during their development (Malvick, 1997), but only infections that started in pods can infect seeds and cause seed decay. Seeds usually become infected by the fungus during, or after, the time that the pods turn yellow (pre-harvest). At first, seed infections are concentrated at the lower plant nodes; later, if harvest is delayed, infections start to spread throughout the plant. When moisture or water film is present alongside higher light intensity, the microscopic spores can germinate in 4 to 18 hours and start to penetrate the tissue. The fungi penetrate immature, senescent, or wounded tissue directly. Plants that are shaded or have aging leaves and side branches exhibiting weather or insect damage, are usually heavily colonized early in the growing season (Malvick, 1997). There is some evidence to show that closely related species of *Diaporthe* can survive in plant debris and remain active and able to infect plants up to 7 months after harvest (Grijalba and Ridao, 2012).

9. What pathways provide opportunities for the pest to enter and transfer to a suitable host and what is the likelihood of entering the UK/PRA area?

Infected seeds or plants may be imported and planted out in fields, infecting future crops. This is likely to be the primary pathway of infection if *Diaporthe sojae* was to enter the country. It should be noted, however, that there have been no interceptions of *Diaporthe sojae* entering the UK on imported material to date.

Import of seeds for planting:

Currently, seeds and plants for planting from any third country must be accompanied by a phytosanitary certificate and inspected at 5% or (for trials or testing) 10% at the point of entry. Due to the proportion of checks and the fact that the disease can be latent within the plant, physical inspections may not be sufficient to ensure the commodity is free from *Diaporthe* spp.

Within the EU, there is a 15% tolerance of *Diaporthe* presence on traded *Glycine max* seeds which means seed sourced from EU countries may be infected, including if the exporting country is free from the disease but the country of origin is from an infected area.

Although the disease is widely distributed worldwide, volume of imported plants and seeds for planting into the UK is low- since 2017, the UK has only imported roughly 500 tonnes of seeds for planting versus 5.5 million tonnes of soybeans for other uses (HMRC, 2024). Many varieties of *Glycine max* have been bred specifically to suit the UK climate and trade requirements, so much of our seed is produced and sold within the UK. These varieties are non-GM (known as "Hard Identity Preserved") which attract a premium rate for export, and therefore encourage growers to use UK sourced seed (Soya UK, 2024).

Given the wide geographical distribution of the fungus but the lack of any interceptions, probably due to the low levels of imports, the chance of *D. sojae* entering the country via seeds for planting has been rated **moderately likely** with **medium confidence**.

Seeds for planting	Very unlikely	☐	Unlikely	☐	Moderately likely	✓	Likely	☐	Very likely	☐
Confidence	High Confidence	☐	Medium Confidence	✓	Low Confidence	☐				

<u>Import of plants for planting (other than seed):</u>

Diaporthe sojae is the common cause of pod and stem blight in *Glycine max*. However, *G. max* is almost always sourced from the UK and grown from seed. There is no history of importing plants for planting of this species. If import trends change then the import of infected plants for planting would likely be the primary pathway for this disease to enter the UK, but with current trading patterns this scenario is unlikely. Whilst some plants of *Phaseolus* spp. are imported, the lack of interceptions indicate that whilst possible, the likelihood of importing infected material is low.

Blueberry is a newly reported host for *Diaporthe sojae*, first reported in China (Li *et al.,* 2023). The UK has no history of importing plants for planting or seeds of blueberry from China (HMRC, 2024). Blueberry plants from third countries must also be accompanied by an official statement declaring that they originate in an area free from, or show no symptoms of *D. vaccinii,* which is present in China. As such, this is not currently a pathway of concern. This may need to be revisited if the disease emerges on blueberry plants in other countries, or trade of blueberry plants for planting starts between the UK and China.

Plants for planting has been assessed to be un **unlikely** pathway for entry with **medium confidence** due to import trends and lack of interceptions.

Plants for planting	Very unlikely	☐	Unlikely	✓	Moderately likely	☐	Likely	☐	Very likely	☐

Confidence	High Confidence ☐	Medium Confidence ☑	Low Confidence ☐

Plant material for consumption:

Glycine max is an important crop both for animal and human consumption. Soybeans are eaten whole or used to make various food products including oil. Soybean products for human consumption pose no risk of disease transmission to field crops and therefore are not considered to be a pathway for infection. Animal feed comes in two forms- meal pellets created using bi-products of the oil making process and wholecrop silage using the remainder of the plant.

Meal pellets are highly unlikely to act as a pathway- infection from *Diaporthe sojae* discolours the oil and creates an unpalatable taste, making it unmarketable. Due to tight regulation on colouration of soybean oil, it is highly unlikely that infected crops would be used in this process and therefore would not be turned into meal. Although it is not clear how waste material is disposed of in this industry, it is unlikely that infected material would reach growing crops in the field.

Glycine max plants are also harvested for wholecrop silage. Whole plants are baled, fermented and stored before being fed; typically to housed livestock during the winter. Heat from the fermentation process will likely reduce the infection rate of crops used- some studies of the effects on soybean seeds infected with various *Diaporthe* spp. range from storage at 40°C for 200 days (Hobbs, 1984) to up to 160°C for only 20 seconds (Zinnen, 1982). Both studies achieved a reduction of infection rates, however neither fully eliminated the fungus. This is likely because both papers were concerned with disease management and therefore were also attempting heat treatments that maintained seed germination viability. Unfortunately, no data can be found that confirms a set point where the fungus is completely eliminated, therefore it cannot be assumed that the fermenting silage would fully destroy any traces of infection. This feed is mostly used overwinter so it is likely it would be fed to livestock in barns, but it is not impossible that it would be placed back into a field. Again, the likelihood of that field then being used for soybean production are very small.

As evidence is lacking regarding some of the pathways around wholecrop silage, plant material for consumption has been rated **very unlikely** with **low confidence** as this pathway seems less likely to provide a pathway for introduction than plants for planting which was deemed unlikely. If evidence arises that *D. sojae* can survive the temperatures involved in the fermentation process, then this may be raised to unlikely in the future.

Plant material for consumption	Very unlikely ☑	Unlikely ☐	Moderately likely ☐	Likely ☐	Very likely ☐

Confidence	High Confidence ☐	Medium Confidence ☐	Low Confidence ☑

Soil/ growing medium:

Soil is **very unlikely** with **high confidence** to be a viable pathway of entry for *D. sojae.* Whilst there is little research specifically on the presence of *D. sojae* in soil, a study on the closely related *D. caulivora* (soybean stem canker) confirms that it does not sporulate beneath the soil surface and spores would only be viable on the soil surface (Subbarao *et al.,* 1992). This means that it would only be present immediately around host plants for planting and, as previously discussed, plants for planting are not imported for agricultural use.

There is a prohibition on the movement of soil into GB, and restrictions on growing media attached to or associated with growing plants from third countries other than EU Member States, Liechtenstein and Switzerland (assimilated Regulation (EU) 2019/2072), with equivalent legislation being in place for Northern Ireland (EU legislation: 2019/2072). As *Glycine max* plants for planting are very unlikely to be brought in, the risk is therefore limited to soil being imported direct to agricultural land from EU Member States, Liechtenstein and Switzerland. This is considered very unlikely.

Soil/ growing medium	Very unlikely ☑	Unlikely ☐	Moderately likely ☐	Likely ☐	Very likely ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		

Used farm machinery (UFM):

Used farm machinery are classed as high-risk commodities due to the risk of transmitting pathogens from field to field. *Diaporthe sojae* is known to survive on soybean stems, so used machinery could provide a pathway if not sufficiently cleaned of plant debris and then used in soybean production. Currently, GB and Northern Ireland have broadly equivalent import regulations which require UFM to be thoroughly cleaned, along with an export inspection and phytosanitary certificate declaring that they are free from all soil and plant debris which significantly mitigates against this risk. UFM traded between GB and Northern Ireland have the same requirements for cleaning and must either be accompanied by a phytosanitary certificate or, for machines moved to Northern Ireland, traders can register for the Northern Ireland Plant Health Label scheme. This, once approved, allows machines to be traded without a phytosanitary certificate, but with a label declaring that the machine must remain in Northern Ireland (not cross into Republic of

Ireland and therefore the EU). This lowers the likelihood of entry to be **unlikely** with **high confidence**. It should be noted however, that UFM is frequently traded within GB with no such cleaning requirements so if the disease were to establish, this could become a significant pathway of spread between farms. These regulations also do not apply to construction or military vehicles which could also transfer soil but are less likely to be moved between farms.

Used farm machinery	Very unlikely ☐	Unlikely ☑	Moderately likely ☐	Likely ☐	Very likely ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		

10. If the pest needs a vector, is it present in the UK/PRA area?

There are no known vectors of *D. sojae*.

11. How likely is the pest to establish outdoors or under protection in the UK/PRA area?

Outdoors:

It is likely that *D. sojae* would be able to establish outdoors in the UK. The climate in western USA, France and much of central and eastern Europe where the disease is currently present is in the same Köppen-Geiger category as the UK (Kottek *et al*., 2006) so it is assumed the fungus would be able to survive in the PRA area (although this is a broad generalisation used due to a lack of better information). While exact details on the preferred temperatures of *D. sojae* are lacking, *D. caulivora*, the main cause of soybean stem canker, grows optimally in wet conditions of over 20°C (Goode, 1989). It is also unclear if optimal temperatures need to be sustained for active growth. Assuming the conditions favourable for *D. sojae* growth are similar, climate data of the UK between 1991 – 2020 shows that this would potentially allow active infection and spread to occur between June and August inclusive (Fig. 2). The average maximum temperature in the south central and southeast of England in these months is over 20°C, with average rainfall of 53-60 mm across 8-9 days per month (UK Met Office, 2024). The areas that reach over 20°C indicate the areas suitable for growing soybeans in GB (Fig. 3). It can be assumed that with average temperatures predicted to increase due to climate change, the season suitable for *D. sojae* growth will expand.

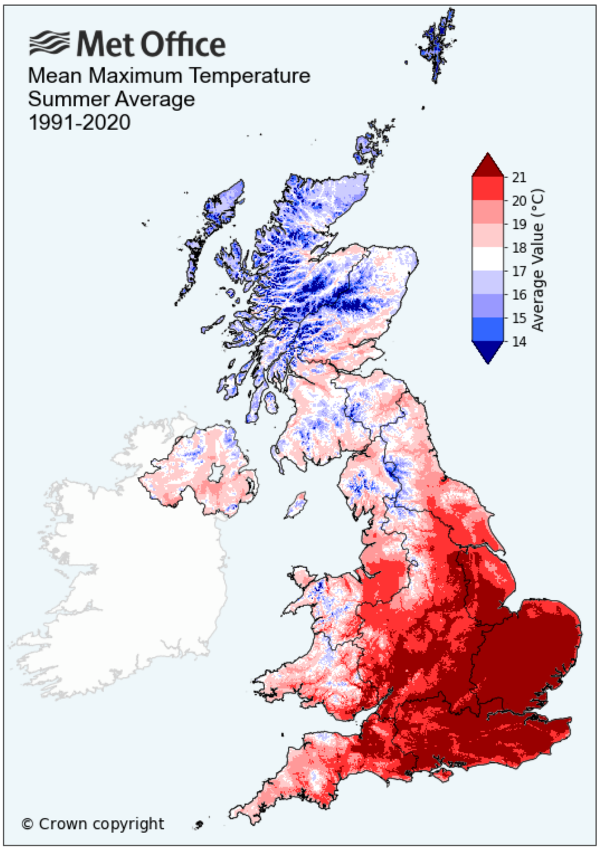

Figure 2: UK Met Office (2024) Mean maximum temperature (in °C) for summer months (June – August) 1991 – 2020.

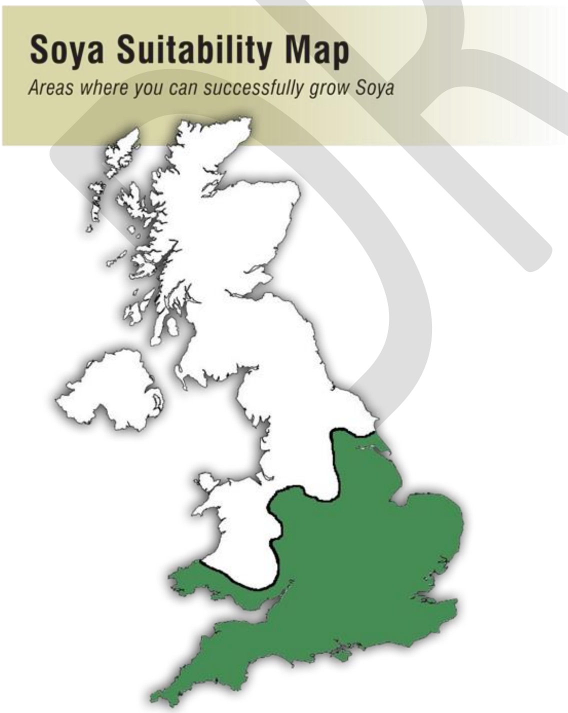

Figure 3: Map of areas in the UK suitable to growing soybeans based on climate data. Source: David McNaughton, [Soya – Soya UK (soya-uk.com)](soya-uk.com)

Most soybean varieties grown in the UK are early ripening as later ripening varieties will not ripen in the UK due to cooler temperatures from September onwards. This coincides with climate conditions that are optimal for *D. sojae* which infects pods as well as plant stems. Once the pods ripen, if harvest is delayed due to rain this is likely to result in high yield losses.

Given the evidence it is **likely** that *D. sojae* would be able to establish outdoors with **high confidence.**

Outdoors	Very unlikely	☐	Unlikely	☐	Moderately likely	☐	Likely	☑	Very likely	☐
Confidence	High Confidence	☑	Medium Confidence	☐	Low Confidence	☐				

<u>Under protection:</u>

Capsicum frutescens (peppers) and *Solanum lycopersicum* (tomato) are important plants frequently grown under protection in the UK. Tomato crops are a particularly highly valued commodity. Whilst *D. sojae* has been isolated from both species, it was a secondary invader on plants already suffering from blossom end rot (a physiological disease caused by a lack of calcium in the fruit), acting as a saprophyte with little evidence of it acting as a pathogen (Luttrell, 1947) and they have been excluded as hosts in this PRA. Fruits already suffering from blossom end rot would already be commercially unviable, therefore fruit or seed infected with *D. sojae* are unlikely to be traded or create further financial loss. Overhead irrigation and hydroponic systems could allow the fungus to spread through the glasshouse, simulating natural spread through rainfall. Unlike outdoor crops however, which are harvested with stubble remaining in the fields, plants grown under glass are usually grown in closed systems, allowing infected plants to be completely removed at any time to help prevent or slow infection. The lack of more recent research or findings on these hosts and the fact that it has never been intercepted in the UK on these hosts despite regular trade of seeds, plants for planting and fruits confirms that this is unlikely to become problematic. Due to the age of the research, it is also possible that another species in the *Diaporthe/ Phomopsis* complex was responsible and not *D. sojae*.

In the situation that *D. sojae* is introduced under protection, even assuming worst case scenario that it can infect peppers and tomatoes, it would cause a transient outbreak that is unlikely to spread further. Eradication would then be attempted at the end of the growing season. Therefore, the risk of establishment under protection has been assessed as **unlikely** with **medium confidence**.

Under Protection	Very unlikely	☐	Unlikely	☑	Moderately likely	☐	Likely	☐	Very likely	☐

Confidence	High Confidence ☐	Medium Confidence ☑	Low Confidence ☐

12. How quickly could the pest spread in the UK/PRA area?

Natural spread:

Diaporthe sojae is a fungus that has a very slow spread outside of human-mediated dispersal. It is only able to grow 5 cm from the inoculation site but can be spread further via rain splash (Roth *et al.,* 2020). However, once introduced to a site it can remain for a long time, including overwintering in field stubble, and is then able to reinfect the next year's crop. If *G. max* is rotated with other legume crops such as *Phaseolus vulgaris,* it may remain as a latent infection within the crop and then symptoms re-emerge the next time *Glycine max* is planted. Continuous years of growing *Glycine max* have also been shown to increase infection rates (Pedersen and Grau, 2010). There is some evidence to show that weed species such as *Arctium lappa* (greater burdock), which is a common weed species in the UK, may act as a reservoir for inoculum (Santos *et al.,* 2011). However, this study merely identifies the presence of *D. sojae* on this host and does not mention symptoms or pathogenicity, therefore further study is required to identify the possible impact this host may have on spread of the pathogen. There is no evidence to suggest that *D. sojae* is airborne or spreads via mechanical means/ vectors (e.g. insects).

It has been suggested that high light intensity is required for infection and symptom development, which favours glasshouse environments more so than outdoors (Whitehead, 1966), but there are no recent sources that discuss this further. The average Daily Light Integral (DLI) in main soybean producing states of southwest USA is 31-35 mols/m^2/day, whereas in England and Wales it is only 21-24 mols/m^2/day (Fluence, 2024), which may limit the spread of this pathogen outdoors in the UK.

Evidence suggests that *Diaporthe sojae* will be able to spread naturally throughout a crop and establish on a site. However, it is highly unlikely to spread beyond the infected premises without further intervention. Therefore, the risk of natural spread has been rated as **slowly** with **high confidence**.

Natural Spread	Very slowly ☐	Slowly ☑	Moderate pace ☐	Quickly ☐	Very quickly ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		

Trade:

As soybean is a growing industry in the UK, there will be an increasing demand for seed for planting. Although *D. sojae* is a weak pathogen on seed, infected material could be traded and planted, allowing the fungus to be transmitted between farms and fields and then establish in the correct climatic conditions. UK seed is tested for *Diaporthe* spp. as part of the certification process (Soya UK, personal correspondence) so any infections if present would presumably be swiftly detected.

The geographic distribution of the disease in continents such as Africa suggests that traded planting material could be the main method of spread for the disease, as countries where the disease is present do not border each other. However, it is possible that *D. sojae* is more widely distributed and unreported in some countries, so natural spread is also possible.

Once on a farm, it is highly likely that agricultural machinery such as tractors and harvesters would be able to spread infected plant matter between fields and, if traded or used by contractors without being cleaned, between farms. Good biosecurity practices such as cleaning vehicles after each use would mitigate against this but that would rely on good practice within trade. As thoroughly cleaning machinery is labour intensive and time consuming, it is unlikely this would take place between each field unless the site owner was aware of the presence of the disease and actively taking action to prevent spread across their property. Therefore, the speed of spread via trade has been rated as a **moderate pace** with **medium confidence**.

With trade	Very slowly	☐	Slowly	☐	Moderate pace	✓	Quickly	☐	Very quickly	☐
Confidence	High Confidence	☐	Medium Confidence	✓	Low Confidence	☐				

13. What is the pest's economic, environmental and social impact within its existing distribution?

Diaporthe sojae infects soybean pods in late stages of growth, reducing seed and bean yield. Of the soybeans grown in the USA and Canada between 2010 – 2014, 2.23% were lost due to *D. sojae* infection (Allen *et al.,* 2017). Between 2015 – 2019, 8.74% of total soybeans produced were estimated to be lost to pests and diseases, but this time 3.41% of all losses were lost from pod and stem blight (*D. sojae)*, and a further 5% were lost due to seed decay (*D. sojae* and *D. longicolla).* The increase in loss is likely due to rain delaying harvest (Bradley *et al.,* 2021). However, even with the wetter weather this loss is small compared to the losses caused by other soybean pests such as *Heterodera glycines* (soybean cyst nematode) which was responsible for 26.22% of all losses in the same period (Bradley *et al.,* 2021). With upwards of 30 different pests and diseases affecting soybean crops in the USA and Canada, it is likely that multiple organisms attack the crop and compound the economic losses. Studies of losses from soybean diseases in China and India also demonstrate that losses from pod and stem blight are small in comparison to other pathogens (Wrather *et al.,* 2010). Comparable data does not seem to be available for EU countries- this could imply that it is not causing enough damage to be of concern to do a study summarising total losses, or that it is being sufficiently managed by farmers.

Associated costs of managing *D. sojae* infection, aside from yield losses, are from purchase and application of fungicides. Other costs occur from changing farming practices, loss of income and jobs, and devalued product.

The economic impacts within its current distribution are deemed to be **small** with **medium confidence**. While losses in yield occur, this number seems to be much lower thanks to management than unmitigated economic losses would otherwise be.

Economic impacts	Very small	☐	Small	☑	Medium	☐	Large	☐	Very large	☐
Confidence	High Confidence	☐	Medium Confidence	☑	Low Confidence	☐				

Diaporthe sojae has been shown to infect native wildflowers and weeds within its current range. It can cause stem cankers which cause premature death in *Abutilon theophrasti* (velvet leaf), the infected material of which can then go on to infest *Glycine max* (Hepperly, Kirkpatrick and Sinclair, 1980). Other closely related *Diaporthe/ Phomopsis* species have also been found to infect *Amaranthus spinosus* (spiny amaranth), *Leonotis nepetaefolia, Leonorus sibiricus* (Cerkauskas *et al.,* 1983), and *Lupinus* spp. (lupins) (Luttrell, 1947). Numerous weed hosts have been identified for *D. caulivora,* of which *Sesbania exaltata* (hemp sesbania) and *Indigofera hirsute* (hairy indigo) displayed symptomatic lesions while many others remained asymptomatic (Black *et al.,* 1986). *Diaporthe longicolla* has been demonstrated to infect *Ambrosia trifida* (giant ragweed), *Xanthium strumarium* (cocklebur), *Euphorbia maculata* (spotted spurge) and *Rumex crispus* (curly dock) (Roy, Ratnayake and McLean, 1997). Studies specifically on weed hosts for *D. sojae* are lacking and, given the variety of hosts susceptible to other species in the *Diaporthe/ Phomopsis* species complex, it could be assumed that there are other hosts species, however these may remain asymptomatic. As only a couple of weed species are known to show symptoms, the environmental impact is **small** with **low confidence**. Further studies would be beneficial to expand the host list and focus on the impact of the fungus on these species, and how quickly it can spread, as opposed to whether they are then able to inoculate *Glycine max.*

Environ - mental Impacts	Very small	☐	Small	☑	Medium	☐	Large	☐	Very large	☐

Confidence	High Confidence ☐	Medium Confidence ☐	Low Confidence ☑	

Social impacts in this case are linked to economic damages (such as loss of income, change in growing practices etc.) and soybeans are not commonly grown in gardens or allotments. Therefore, social impacts have also been rated as **very small** with **high confidence.**

Social Impacts	Very small ☑	Small ☐	Medium ☐	Large ☐	Very large ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		

14. What is the pest's potential to cause economic, environmental and social impacts in the UK/PRA area?

The value of UK soybeans is currently estimated at £525 per tonne (Soya UK, 2024) and is a growing industry. Soybeans grown in the UK are particularly valued as they can be certified as non-GM. For context, in 2015 83% of soybean produced globally was GM (The Royal Society, 2016). It is useful for controlling weeds such as blackgrass and as it fixes nitrogen in the soil, it is favoured as a break crop to be rotated with beans, peas and maize (*Zea mays*).

At present, the UK has very few pathogens of *Glycine max* which makes it particularly attractive as a crop - the most bothersome pests often being slugs and snails in its early growth period. Particularly damaging pathogens such as *Phytophthora sojae* (root and stem rot) and *Heterodera glycines* (soybean cyst nematode) are absent, as well as all species in the *Diaporthe/ Phomopsis* complex. Should *D. sojae* establish, while a reduced yield and unmarketable seeds would be expected, it may not have the same impact as in countries such as the USA as the crop will be under less stress from other pathogens. It is also possible that our cooler summers will be less favourable for high levels of the pathogen to build up. However, establishment of the disease could require major changes to crop management and, if the farm predominantly grows soybeans and green beans (*Vigna*), may require a complete change of agricultural practices to start growing a non-host species to prevent *Diaporthe* infection from growing year on year. Increased biosecurity measures and potential treatments would also need to be put in place.

One key uncertainty is whether the UK specific varieties of soybeans have disease resistance. Varieties have been bred for early planting (to suit our climate) and for harvestability, with disease resistance not a priority due to their absence. More recent varieties have been developed to have stronger stems, which will reduce breakages, with the canopy growing higher off the ground than traditional varieties which may help limit infection rate but will not prevent it. However, earlier planting on infected sites in Argentina was shown to increase infection rates (Meriles, Giorda and Maestri, 2008) so this may not be a simple solution. It is unclear whether taller crops may be more susceptible to lodging, but the stronger stems might mitigate this risk.

If introduced, seed growers could experience losses if disease prevalence within a seed lot exceeds 15% as they would no longer be able to get their crop certified under the Seed Marketing Regulations 2011, which is a requirement for marketing within the UK. Such seed could also not be exported to the EU where the RNQP threshold is also 15%.

In 2022, the UK planted 665 hectares of blueberry crop plants and produced 12 metric tonnes of fruit. Blueberry production overlaps with the area for growing soybeans, but they can also be grown more widely including in Scotland. However, the blueberry industry is struggling due to labour shortages impacting harvesting and increased costs. Blueberry is also not considered to be a British product and therefore there is little buyer loyalty to UK produce. It is predicted many of these soft fruit growers may switch to *Fragaria* production over the next few years as this presents the best value per labour hour (International Blueberry Organisation, 2023).

The economic impact within the PRA area based on worst case scenario is **small** with **low confidence.** More information on the economic impact the fungus has within Europe and the disease-resistance abilities of UK specific varieties would be helpful. However, the UK climate is suitable for *D. sojae* to establish and infected plants can suffer loss of yield, unmarketable product and a reduction in value. This would likely require large changes in industry practices to manage.

Economic Impacts	Very small	☐	Small	✓	Medium	☐	Large	☐	Very large	☐
Confidence	High Confidence	☐	Medium Confidence	☐	Low Confidence	✓				

Diaporthe sojae is a crop pest and there is little evidence of it infecting UK weed species. There is evidence of it infecting *Lotus corniculatus* (bird's foot trefoil) in the USA and Canada. This is a native wildflower in the UK which would likely grow in meadows and field borders surrounding soybean fields so could potentially come into contact with the pathogen. However, the infections studied in the USA were on nursery stock and not in the wider environment. It is also worth noting that the author acknowledged that, at the time of writing, it was not possible to distinguish between *D. sojae* and *D. caulivora*, so it is possible the *D. sojae* was not the pathogen responsible for the symptoms.

For now, the environmental impact is assessed as **very small** with **low confidence**, but this may change in the future if further research into its pathogenicity on field weed species is released.

Environ - mental Impacts	Very small	✓	Small	☐	Medium	☐	Large	☐	Very large	☐
Confidence	High Confidence	☐	Medium Confidence	☐	Low Confidence	✓				

Glycine max is an agricultural crop and not commonly grown in gardens or allotments. Social impacts are directly linked to economic losses, such as loss of income and changes to growing practices. Soybeans are not a culturally significant crop in the UK, unlike in some countries, particularly in Asia. Therefore, social impacts have also been rated as **very small** with **high confidence.**

Social Impacts	Very small	✓	Small	☐	Medium	☐	Large	☐	Very large	☐
Confidence	High Confidence	✓	Medium Confidence	☐	Low Confidence	☐				

15. What is the pest's potential as a vector of plant pathogens?

Diaporthe sojae is not known to be a vector for other plant pathogens, however in weakening the crop, the crop could become susceptible to infection from other diseases which would compound the impact.

16. What is the area endangered by the pest?

Soya UK indicate areas suitable for growing soybeans in the UK as the south and southeast of England and the south of Wales. Currently soybeans are almost exclusively grown in the south of England, however as a growing industry it has the potential to increase its range into the south of Wales and eastern England (Fig. 3). This would be the area endangered if *D. sojae* were to establish and spread to its maximum extent. Eastern England doesn't typically farm fodder crops, but it is worth noting that soil and climate would be suitable in case of changing practices in the future.

It is highly unlikely that *D. sojae* would extend into the north of England, central and north Wales, Scotland or Northern Ireland as *Glycine max* cannot be grown in these areas. Due to the experimental and minor hosts, on top of the uncertainty surrounding susceptibility of weed species, it is possible it could be moved to specific growing sites outside of this area. However, in this instance it would be unlikely to establish and spread.

Stage 3: Pest Risk Management

17. What are the risk management options for the UK/PRA area?

Excluding the pest:

The most likely pathway of entry is on imported seeds or plants for planting. There are currently no specific measures for plants or seeds of *Glycine max,* however they do require pre-notification, a physical inspection and to be accompanied by a phytosanitary certificate. Sourcing seeds or plants from areas outside of the pathogen's current distribution, or from within the UK, would be the most effective way of preventing outbreaks or establishment of *D. sojae.*

Eradication/ control:

There is currently no evidence of successful eradication methods for *D. sojae* once it has established outdoors. It may be attempted by removing the crop and prohibiting the growth of susceptible species on the site for a number of years whilst also conducting ongoing testing of plants within the field margin, however this seems highly disproportionate for the damage the pathogen causes, which may explain why there is no evidence of this in the literature. If it were to establish in a glasshouse, it would likely be able to be eradicated, although this would require destruction of the infected crop, application of fungicides and a switch to growing a non-host crop for a number of years.

The EU currently manage this crop as an RNQP on *Glycine max* seeds only. Seeds must be tested prior to export with a 15% tolerance of the pathogen presence permitted. UK seeds could undergo similar tests as part of plant passporting requirements. Alternatively, demarcated areas could be set up around outbreak areas to prevent infected seed from spreading around the UK, while still allowing local trade to take place.

Trade management:

There are numerous ways that industry manage *D. sojae* infections in its current distribution:

<u>Chemical control:</u> There is a lot of evidence to show that fungicides can reduce infection rates. Many of these however, such as carboxin, thiram, benomyl and salicylic acid which are used in Egypt (Ibrahim, 2015) are unregistered for use in the UK. Currently, the only fungicide registered for use on soybean crops is azoxystrobin (on dry harvested crops for human or animal consumption as the bean, or for oilseed production), plus bioagents *Aureobasidium pullulans* strains DSM 14940 and 14941 (on dry harvested crops as per azoxystrobin) and *Gliocladium catenulatum* (on fresh harvested crops for consumption fresh following the removal of the pod). There is currently no evidence to determine whether these agents would be effective or not against infection from *D. sojae*. On the

other hand, fungicides fludioxonil, metalaxyl and difenoconazole are registered for use on either beans or peas (or both), so it may be possible to extend use of these to soybean crops if necessary. These three active ingredients have all shown to reduce seed-borne infection rates of *D. sojae* in Canada (Xue *et al.,* 2010). Other novel seed treatments such as non-thermal plasma have been shown to be ineffective as a solution; whilst it kills *D. sojae* it also prevents germination (Pizá *et al.,* 2018).

Tillage systems: As plant debris from previous harvests are the main source of inoculum for *D. sojae*, removing this debris is a key method of managing infections. Conventional tillage, to a depth of at least 30 cm, has shown to significantly reduce frequency of infection from species in the *Diaporthe/ Phomopsis* complex. However, reduced tillage methods such as multiple disc harrowing and chiselling which are shallower have been demonstrated to make no significant difference in infection frequency compared to no tilling (Vrandečić *et al.,* 2014). A study in Nigeria suggests that a combination of ploughing and harrowing produces lower disease incidence compared to ploughing alone and no tillage, however this was based on physical symptoms alone and no testing was conducted to confirm presence of latent infections and little detail on the ploughing methodology was given (Salihu *et al.,* 2021).

Crop rotation: Rotating crops of *G. max* with non-host crops is an effective method of keeping infection rates low, although will not eradicate *D. sojae.* Maize and grain crops would be possible candidates for this. Soybeans planted after five years of continuous maize growth significantly reduces incidences of *D. sojae* infections compared to shorter rotations and soybean monocultures, although incidence levels will still vary depending on climatic conditions (Pedersen and Grau, 2010). Seed infection can also be lowered in crops rotated with as little as 2 years of maize compared to continuous soybean crops, even though plant infection rates may be similar (Kmetz, 1975). *Glycine max* fixes nitrogen in the soil and higher nitrogen levels also increase infection rates (Chin, Kim and Park, 1993), further suggesting soybean monocultures should be avoided.

Resistant varieties: Most varieties grown and developed in the UK are designed to suit early planting due to our climate. Early planting tends to increase *D. sojae* infection so this may mean our varieties will be more susceptible to infection, and as we have very few soybean pests currently in the UK, disease resistance is not a trait that has been a priority. However, resistance has been shown to be effective against this trend in other countries. For example, Amsoy 71 showed more than 50% infection rates when planted in early May compared to under 10% infection when planted in mid-June, whilst resistant variety Williams maintained infection rates under 10% regardless of planting date (Kmetz, 1975). Disease resistance of UK varieties is unknown, but this is a trait that could be developed. In comparison with seeds in the lower portion of the crop, seed quality in the upper portion of crop is less impacted by *D. sojae* infection even after wet conditions (Hepperley and Sinclair, 1980) so increasing pod density in the top canopy could be another trait to consider when breeding varieties for resistance. Varieties currently available in the UK are developed to have higher pod attachment which will be beneficial to minimise impact if infected with *D. sojae*. They are also developed to have stronger stems and an erect growth habit (Soya UK, 2024) which also favour disease resistance as pycnidia first develop on broken stems and on lower leaves of the plant (Athow and Laviolette, 1973).

Potassium fertilisers: Infection rates on soybean seeds have been shown to decrease as soil potassium levels increase, without affecting seed yield (Crittenden and Svec, 1974). Potassium chloride can also be applied in low enough concentrations (0.2meq per 100g of soil) to avoid leaf scorching from the increased salinity and still be effective at controlling *Diaporthe* infections (Mascarenhas, Hiroce and Braga, 1976).

Planting and harvesting methods: As crop density increases, germination rates drop and infection rates increase (Chin, Kim and Park, 1993), so growers could benefit by increasing spacing between crop rows, although they would need to consider losses due to lower planting numbers compared to lower yield. If weather conditions are wet at the point of harvest, selectively harvesting from the top of the plant may help maintain seed quality even if yield is reduced (Hepperley and Sinclair, 1980).

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This publication is available via the UK Plant Health Information portal https://planthealthportal.defra.gov.uk/

This PRA has been undertaken following IPPC International Standards for Phytosanitary Measures (ISPMs 2 and 11) and it provides technical evidence relating to the risk assessment and risk management of this pest.

This PRA has been undertaken taking into account the environmental principles laid out in the Environment Act 2021. Of particular relevance are:

The prevention principle, which means that any policy on action taken, or not taken should aim to prevent environmental harm.

The precautionary principle, which assists the decision-making process where there is a lack of scientific certainty.

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