Readiness and Response Plan for

Ceratocystis fimbriata affecting kiwifruit and kiwiberries

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Biosecurity through Partnership

Ministry for Primary Industries
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Contents

Foreword

Ceratocystis fimbriata is a fungal complex with a wide host range and wide geographic and genetic diversity. Strains (or "types") may be host specific and/or have restricted distributions in some instances. This plan only caters to one host – kiwifruit and kiwiberry (*Actinidia* sp.) – and has been created under the Government Industry Agreement for Biosecurity Readiness and Response, via the Kiwifruit and Kiwiberry Sector Operational Agreement.

The plan provides information on:

- What we know about *C. fimbriata* (context).
- How we would respond.
- What knowledge gaps exist.

The audience for this plan includes members of *C. fimbriata* responses and readiness projects.

When considering this plan, it needs to be noted that a *C. fimbriata* strain may enter the country affecting any potential host or a variety of hosts, which may or may not include kiwifruit. Those strains identified as potentially affecting kiwifruit may also affect other host species.

Due to the limited understanding of *C. fimbriata*, it is difficult to predict with any great certainty which species may be affected by any one strain. For this reason, this initial plan has only focused on the kiwifruit and kiwiberry sectors, which identified the fungus as a high-risk organism.

This plan was drafted for readiness purposes in response to non-NZ strains of *C. fimbriata* or those pathogenic to kiwifruit and kiwiberry.

Document Purpose

The purpose of this readiness plan is to inform decision-making when preparing for and responding to *Ceratocystis fimbriata*. **This document is divided into three parts, each of which may be read and used independently to provide information to progress response work and readiness projects for *C. fimbriata.*** It provides an overview of the current knowledge of the organism (Part 1), a proposed high-level response action plan that broadly identifies the tools and resources required to respond to a positive detection of a harmful strain of *C. fimbriata* to kiwifruit in New Zealand (Part 2), and current knowledge gaps and research that could improve readiness (Part 3). More detailed information is included in the appendices. This document is a 'living document' and shall be reviewed and updated if and when new response tools become available.

PART 1 – CURRENT KNOWLEDGE OF THE ORGANISM

Part 1 provides known information on *Ceratocystis fimbriata*, including the risk pathways. This part is suitable for those that need to familiarise themselves with *C. fimbriata* for readiness or response purposes, e.g. the Intelligence workstream in a response.

1 Summary of Risk

Ceratocystis fimbriata is emerging worldwide as a major plant pathogen. In Brazil, it has caused significant damage to kiwifruit orchards, with some growers reporting up to 50% vine loss over the past five years.

A specific strain of this pathogen is considered one of the most significant biosecurity threats to the New Zealand kiwifruit industry, and is likely to be a threat to the kiwiberry sector also.

Likelihood of entry: Moderate. *C. fimbriata* is present in over 35 countries, including New Zealand, in a wide range of hosts. There is significant uncertainty about which strains present a risk to kiwifruit, where these strains are present and the possible entry pathways.

Likelihood of exposure and establishment: Moderate. The likelihood is dependent on the host and entry pathway, and therefore significant uncertainty is associated with this assessment. There is likely to be suitable host material and climatic conditions in the kiwifruit growing regions of New Zealand, although this may also be strain dependent. Existing control tools have limited effectiveness.

Impact: High. The pathogenic kiwifruit strain in Brazil would likely cause significant production impacts to the New Zealand kiwifruit industry if it were to establish here as potentially all kiwifruit cultivars are susceptible. The impact of other strains is unknown. Market access impacts are unlikely for fruit, however pollen and germplasm may be affected.

(Please note: this is a summary of the current understanding of risk. A comprehensive risk assessment has not been completed and there is significant uncertainty associated with both the entry and establishment values, although impact is likely to be high given the issues observed in Brazil and the pathogenicity screening undertaken.)

2 Surveillance and Detection

Should this pathogen arrive, early detection would contribute to retaining containment and possibly eradication options.

With current knowledge, surveillance for this pathogen may consist of combining visual inspections of vines together with on-site investigation and recognition of symptoms, including examining lesions under low power magnification and cutting into stems with a sterilised blade to look for tissue staining. This work may best fit with general orchard inspections for other diseases.

In most orchards, inspections like this are likely to consist of moving through and scanning vines. There may be benefits in developing an informed structured approach to see if detection probabilities can be improved.

In the event that structured inspections take place in orchards throughout the industry, planning will be needed to cover triaging to separate suspect samples requiring formal diagnostic input from non-suspect samples. Clear definition and labelling of samples to be sent to MPI diagnostic laboratories is essential.

It is understood that most risk pathways associated with commerce or travellers involve organisms first appearing in our internationally connected cities and towns. However, there are examples where viable spores may have been brought back by a grower from an affected overseas area e.g. on unlaundered clothing, shoes which are then exposed to crops.

2.1 Current active surveillance

There is no current active surveillance programme targeting *Ceratocystis fimbriata* specifically. However, MPI runs the High Risk Site Surveillance (HRSS) programme which carries out biosecurity surveillance on trees in urban areas. This programme covers the full range of pests that attack trees (including fungal pathogens).

Once the dynamics of the HRSS are well understood suggest we could explore other options for surveillance (e.g. funding, beneficiaries, etc.).

Recommendation: Engage with New Zealand Plant Producers Incorporated (NZPPI) to include *C. fimbrata* into any active surveillance development for plant material.

2.2 Current passive surveillance

A passive surveillance programme is key for the reporting of risk organisms to MPI. A report to the biosecurity hotline (0800 80 99 66) is the active approach for identifying and responding to a possible incursion. The MPI passive surveillance programme is focused on utilising all available residents within the country to identify biosecurity risk organisms.

Passive surveillance is the primary surveillance tool utilised by MPI and KVH for kiwifruit pests. KVH constantly encourages the kiwifruit industry (growers and post-harvest) to report any unusual symptoms on kiwifruit orchards. Efforts have been made to raise awareness of this pathogen by profiling it in the "Most Unwanted" collateral, articles in the KVH Bulletin and Kiwifruit Journal on the KVH website, and profiling it at various industry meetings. Further work to raise grower awareness (e.g. development of handouts) can be completed as readiness activities under the kiwifruit and kiwiberry sector OA.

Recommendation: Develop a handout for growers to help to identify *C. fimbriata* symptoms to aid in early detection and help to differentiate from some more common pathogens such as *Armillaria* spp. or *Phytophthora* spp.

2.3 Biology and Epidemiology

Ceratocystis fimbriata is a complex of soil-borne fungal pathogens, which cause wilt disease in a number of plant species, including kiwifruit (*Actinidia* sp.), by compromising the vascular system. The *C. fimbriata* complex has a wide and unpredictable host range, both as a simple wound coloniser and as an aggressive plant pathogen.

In the past 15 years, new host crops and new epidemics of *Ceratocystis* wilt have been reported worldwide, especially in Brazil and Asia. In 2010, significant impacts were observed on kiwifruit orchards in the Farroupilha area of Rio Grande do Sul, Brazil. There have been no reports of impacts to kiwifruit from this pathogen outside of Brazil to date.

In New Zealand, one strain of the *C. fimbriata* complex is known to be present. It was first identified in 1907 and causes black rot on kumara (*Ipomoea batatas*), however, this strain has been found to be non-pathogenic to kiwifruit and is also believed to be host-specific to kumara.

(See Appendix 5, for further background information).

2.4 Symptoms

(See also Section 3: Diagnostics)

It is unknown how long it takes for an infected plant to show symptoms in the field. In pathogenicity trials, kiwifruit plants inoculated with *C. fimbriata* showed symptoms within 10-12 days on average. How this correlates to natural infection and symptom expression in the field is not known and is a key knowledge gap to be addressed with research, however anecdotal evidence suggests plants may be infected but remain asymptomatic for many years.

At some point after infection the vascular system becomes blocked, resulting in vine wilting and collapse soon after. Rapid vine collapse in absence of injury is a distinctive characteristic and complete vine collapse can occur within three days of the first observation of symptoms

Dead kiwifruit vines are often adjacent to each other creating a circle of dead vines as the disease moves through soil and root systems. Browning of the xylem can be seen in infected vines moving from canes to leaders, trunks and even down to roots.

Wilting and dying plants should be inspected closely for vascular discoloration of the woody xylem. A horizontal cross section of the wood will often show a radial pattern to the staining, while longitudinally the discoloration is often in streaks (Figure 1). Other fungi can induce similar discoloration, although this will typically be more solid and less “streaky”.

There is currently no information yet if it can be detected on asymptomatic plants.

2.5 Risk strains

The most dramatic disease losses and the greatest array of hosts have been found in Brazil, mostly on non-native hosts.

The *C. fimbriata* complex is broken up into "clades" of closely related strains and potentially a number of species native to different regions of the world. The most aggressive plant pathogens are in the Latin America Clade (LAC), which is native to South America, Central America, the Caribbean, and eastern USA. Strains of the LAC pose the greatest threat to crop production, both where the strains are native and where they have been introduced. Impacts to kiwifruit have only been reported from strains in the LAC, however other clades within the *C. fimbriata* complex may also present a risk and must also be considered in risk assessments (Harrington 2015).

Two strains in particular have been highlighted as particular concerns in addition to the known kiwifruit pathogenic strain in Brazil as they have similar genetic characteristics to South American *C. fimbriata* populations;

1. South China – where a group of closely related strains have been found on eucalyptus, taro and loquat and are also causing substantial mortality on pomegranate in Yunnan and Sichuan,
2. An outbreak causing mortality to mango in Oman and Pakistan, pomegranate in India, and Acacia in Indonesia.

For further information on host/country combinations of strains see Appendix 6.

2.6 Natural spread mechanisms

Spread mechanisms are covered in section 4 & 5, the following is a brief overview of natural spread mechanisms from a biological perspective taken from Harrington (2015).

Sporulation on and in hosts
Disease cycles for *Ceratocystis* wilt on various hosts are complicated, in part due to the multitude of spore forms and means of dispersal of the pathogen.

The pathogen may sporulate on canker surfaces, wounded parts of diseased trees, and pruning cuts within 24–48 hours. Sporulation occurs during periods of high moisture content during warm months, and infection of pruning wounds may be limited during cold winter periods.

Thin-walled conidia (asexual spores) are produced by most members of the complex which may be spread by insects or rain and enter soil or waterways, but these spores are probably most important in mechanical transmission. Mycelium mats are generally thought to be important as a site for fungal feeding and acquisition of spores by insect vectors, though it is not clear if this is an important dispersal mechanism for members of the LAC. Spores from mats do not normally spread far by rain or insects. Walter (1949) found that only wounds on trees within 8 m of a diseased London plane became infected in an undisturbed stand.

Along with conidia, ascospore masses form from black ascocarps (perithecia) held together in a sticky, hydrophobic matrix, so the spores are not readily dispersed in water but instead have an affinity for the hydrophobic exoskeleton of insects. All species in the *C. fimbriata* complex are homothallic through unidirectional mating type switching, and most sporulating mats will produce this sexual stage even if there is no cross-fertilization from other strains. With such selfing, the sexual state may persist in introduced populations derived from even a single genotype. However, perithecia and ascospores may not be essential for epidemics, and the relative importance of ascospores vs. phialoconidia is not clear.

Members of the complex are also capable of outcrossing, so introduction of two or more genotypes of the pathogen to a region allows for generation of new recombinants, and such recombinants may be more aggressive than either of the originally introduced genotypes. Fungal propagules expelled from infected trees by sawing or as boring insects clean their tunnels may be dispersed by wind or rain splash for relatively short distances. Aleurioconidia of *C. platani* are abundant in stained sapwood and, once liberated, can infest soil and waterways. Aleurioconidia are believed to be the most common survival units because they are thick-walled, pigmented and durable, and aleurioconidia are abundant in discolored wood and insect frass. The contaminated frass of the boring insects may be important for wound colonization of nearby trees, for contributing to soilborne inoculum, and for contamination of waterways. The fungus may survive in wood fragments in the soil and in river water for months or years.

These natural spread mechanisms are summarised in the table below.

Table 1. Natural spread mechanisms of spores

	Short distance spread, less robust			**Long distance spread, more robust**
	Phialoconidia (A)	**Doliformconidia (B)**	**Ascospores (C)**	**Aleurioconidia (D)**
Shape	Thin-walled, cylindrical	Thin-walled, barrel shaped	Sticky hydrophobic matrix	Thick walled, durable
Found	Mycelium mats on open wounds & cankers		Mycelium mats	In sap inside infected plant
Survival	Short			Long (months to years)
Dispersal mechanisms	Rain (short distance), insects, mechanical via tools, waterways & soil (but not as durable as D).		Adhere to insects, mechanical via tools, not spread via water	Enter wounds via frass, root grafts, mechanical via tools, enter soil & waterways via wood fragments, sawdust & frass, plant propagative material

3 Diagnostics

3.1 Visual symptoms

Wilting and dying plants should be inspected closely for vascular discoloration which is typically a radial pattern in a cross section, and streaky discoloration in a longitudinal section.

Figure 1. Symptoms of *C. fimbriata* infection in kiwifruit (Brazil) Clockwise from top; leaf wilt and curl, cane shrivelling and vine discoloration.

This discoloration can be differentiated from other vascular wilt which tend to follow the annual growth rings (on a cross section cut). Other fungi, such as *Botryosphaeria* spp. or *Lasiodiplodia theobromae*, can induce similar xylem discoloration, especially in stressed hosts, although the discoloration is generally more solid and less "streaky" with these other pathogens. LAC *C. fimbriata* do form characteristic pigmented growth that a mycologist (fungal scientist) may be able to recognise with using a microscope (dark brown aleurioconidia in the stained sapwood) (Panconesi et al. 2003).

3.2 Isolation

Due to the lack of available DNA-based specific diagnostic methods, current testing in New Zealand is based on isolating the fungus into culture using baiting methods or special media, which is followed by morphological and molecular identification. The fungus is fast growing and does produce characteristic structures in culture within less than one week. This process has a 1 -2 week turnaround time but is highly reliable due to the distinct morphology of *C. fimbriata.*

3.3 Molecular methods

If the detection of *C. fimbriata* is suspected, culturing of the material and a PCR test will be performed. If the PCR is positive, it will be followed by sequencing (this may be urgently done overnight). And the Incursion Investigation (II) team will be alerted.

It currently takes two weeks for a PCR test to be performed, including the culturing and preparing of material, the testing and the sequencing. The development of rapid diagnostic PCR tests is underway, these tests should be developed by mid-2019.

A detection assay for the Brazilian isolates of *C. fimbriata* has only been recently developed as a KVH / Zespri readiness activity (Templeton and Anderson 2018). Due to the presence of a number of isolates of *C. fimbriata* pathogenic on kiwifruit, there were additional complications to the development of a simple assay. The approach chosen was to design a set of primers to the Internal Transcribed Spacer I (ITS I) region, common to all members of the Latin American Clade of *C. fimbriata*. A second set of primers could then be used to identify the specific isolate involved, and distinguish the isolate of *C. fimbriata* (a pathogen of kumara) that is present in New Zealand. Extensive screening of these primers has been completed against soil eDNA samples and a limited number of orchard samples. All these samples were negative suggesting there is unlikely to be an endemic population of *Ceratocystis* in New Zealand that could lead to a false positive detection should an incursion occur. The primers were also tested by Hill Laboratories and are found to be suitable to be outsourced to a commercial organisation for high-throughput sample analysis.

While the developers of these primers are confident they will work as a rapid diagnostic tool in an incursion response, they have not been tested against infected kiwifruit material. Field testing is being undertaken by Plant and Food Research in collaboration with researchers in Brazil to test the efficacy of these primers with results expected by 2020.

3.4 Diagnostic service providers

There are multiple service providers available for diagnostics, however under the Biosecurity Act 1993, MPI must be the agency to complete the initial testing where the organism is suspected. Other service providers may be utilised once the organism has been found to be present in New Zealand, providing protocols can be agreed.

Recommendation: Discuss with diagnostic providers about developing commercial capacity in advance for high throughput testing.

4 How *C. fimbriata* could get into New Zealand

This information is considered accurate within the current knowledge base, however it will be updated upon completion of a formal risk assessment.

4.1 Country of origin pathways

Although widespread, it is considered that goods, travellers and transport from the following countries hold a higher risk for *C. fimbriata* than other areas:

Tier 1 Risk Areas (Highest Risk Area)	Tier 2 Risk Areas
• Brazil	• South China • Oman • Pakistan • India • Indonesia

Tier 1 – Brazil is considered the greatest risk area as a strain that impacts kiwifruit is present.

Tier 2 – a pathogenic strain is present in these countries which Dr Tom Harrington suggests is likely to impact kiwifruit, in addition to the hosts it is currently impacting in those countries.

4.2 Item specific pathways

4.2.1 Movement of infected plant material

A range of plant species have been identified as hosts for *C. fimbriata* including kiwifruit (*Actinidia* sp.), which is known to be infected by multiple genotypes of this fungus. Infected host plant material is considered to be the most important pathway for introducing the pathogen to new areas. This identifies plant material imports as a high-risk entry pathway, most likely through the imports of ornamental nursery stock (cuttings, whole plants, dormant bulbs and tubers) alongside kiwifruit cultivars for propagation. *Ceratocystis fimbriata* has been identified as a target organism in the Kiwifruit Plant Certification Scheme (run by KVH), a biosecurity standard that all kiwifruit nurseries must meet.

4.2.2 Soil

Soil, used machinery, containers, or passenger belongings such as shoes or camping gear are a risk of containing soil sourced from the *C. fimbriata* infested area. As soil is considered a main source of inoculum for *C. fimbriata*, it is important to note that any personal items (shoes, camping gear etc.) could harbour the fungus, whether they stem from rural or urban areas.

Fungal diseases carried by soil are managed on potential entry pathways by basic (general) and/ or specific requirements in the relevant Import Health Standards (IHS).

4.2.3 Saw dust and frass

Used machinery, tools and passenger belongings contaminated with saw dust or frass (excrement from larvae) present another potential entry pathway for *C. fimbriata.* Saw dust and

frass can be produced by wood boring insects feeding on infected trees and harbour *C. fimbriata*. This is a much lower risk for entry than infected nursery stock and may be more important as an internal dispersal pathway.

4.2.4 Wood packaging

This pathway is unlikely to be a significant threat, when treatment procedures are correctly followed. Wood packaging is mainly ISPM 15 stamped, therefore wood packaging has been heat treated or fumigated on pre-export which will mitigate the insects. In addition, inspection for pests and diseases is carried out on arrival.

5 How *C. fimbriata* could spread within New Zealand

Natural spread of *C. fimbriata* is limited as the pathogen is soil borne and does not produce windborne spores (see Section 2.6 Natural Spread Mechanisms). Human assisted transmission on propagation material, soil and tools present the greatest risk of spread within orchards and between growing regions.

5.1 Modes of dispersal

5.1.1 Plant propagative material

Nurseries have been strongly associated with movement of *C. fimbriata* around the world. Of particular concern are symptomless cuttings dispersing the pathogen over long distances.

5.1.2 Transmission on tools and equipment

Tools and equipment used on infected plants can carry the pathogen between vines. Pruning tools especially create wounds that are a common entry point for the pathogen.

5.1.3 Root graft transmission

Root grafting is when roots of neighbouring plants become intertwined. This can provide a pathway for pathogen transmission and is thought to have contributed to the spread of *C. fimbriata* within orchards in Brazil.

5.1.4 Water run-off

As a soil-borne pathogen, *C. fimbriata* may be spread via water run-off in heavy rain. This may be of higher consideration in hill country, or in the event of a heavy weather event.

5.1.5 Vector transmission (insects)

Ceratocystis fimbriata produces fruity odours that attract fungal feeding insects. Many insects can acquire spores of *C. fimbriata*, however most do not transmit the pathogens to new wounds

and are not vectors. Wood boring ambrosia beetles may carry *C. fimbriata* on their bodies and the fungus can survive passage through the gut. However, these insects generally do not attack healthy trees and are not expected to be a common vector

5.1.6 Dispersal in plant fragments, saw dust and frass

The thick-walled aleurioconidia (type of asexual spore) can be transported with plant material and sawdust originating from infected plants. In addition, Ambrosia and other bark beetles produce frass, which like sawdust, is known to harbour inoculum which may be spread very locally in the wind and contribute to soil borne inoculum.

5.1.7 Transmission in contaminated soil

As a soil-borne pathogen *C. fimbriata* may be spread through movement of soil. If soil from an infected plant or orchard is moved, then the thick walled aleurioconidia can be transported with the soil.

5.1.8 Sporulation

C. fimbriata does not commonly spread through spore dispersal. While limited sporulation may occur during warm moist periods which can then be spread mechanically or be released by boring insects or sawing activities and travel short distances by wind or rain, this is a relatively low risk vector.

5.2 Likelihood of various mechanisms spreading *C. fimbriata*

	Likelihood of spread			
Spread mechanism	**Between vines**	**Between orchards**	**Between growing regions**	**Mitigation Measures**
Plant propagative material	Low	High	High	KPCS (Kiwifruit Plant Certification Scheme; See 5.3.2 below)
Tools and equipment	High	High	High	Biosecurity Hygiene Practices (See 5.3.1 below)
Root graft	High	Low	Low	-
Water run-off	High	Moderate	Low	-
Vector transmission	Moderate	Low	Low	-
Plant fragments, saw dust & frass	Moderate	Low	Low	-
Contaminated soil	Low	High	High	Movement controls (during a response)
Sporulation	Moderate	Low	Low	-

5.3 Current systems to manage pathway spread

5.3.1 On-orchard biosecurity-hygiene practices

Good hygiene practices will prevent or mitigate the spread from vine to vine on an orchard and between orchards in the early stages of a response and in any long-term management phase. KVH is working on orchard biosecurity plans to establish industry best practice for mitigating risks during pruning and other high risk activities. *C. fimbriata* will be considered as a target organism as part of this program development. Theoretically, on-orchard hygiene practices could be very effective in preventing long distance spread as the modes of travel are primarily human assisted. Ensuring people, vehicles, tools, and machinery are cleaned of plant material, ideally cleaned between rows and bays, can reduce the spread of disease. Ideally, all equipment and tools should be exclusively assigned to one property. Footbaths should always be used at the entrance to orchards to minimise the risk of soil transfer.

KVH is working on improving overall uptake of best practice on orchards.

5.3.2 Nursery biosecurity controls

Controlling risk across the nursery pathway will mitigate the risk of spread in the early stages of a response and be effective in the long-term management of the organism. The Kiwifruit industry has already implemented such a scheme for kiwifruit rootstock material, the Kiwifruit Plant Certification Scheme (KPCS, www.KVH.org.nz/KPCS), and has made the decision to include *C. fimbriata* as a target organism within this scheme. Nurseries have been provided with symptom guides and are monitoring for all target organisms on a monthly basis, providing a means for early detection for this pathogen. It is likely that similar schemes will be developed for other plant material such as budwood in the future.

6 Overview of market access readiness

Ceratocystis fimbriata is listed as a quarantine pest in the following countries; Indonesia, Korea, Russia, South Africa, Taiwan, Vietnam.

Impacts from market access restrictions are expected to be low as fruit is not considered a pathway of entry as the pathogen is not known to infect fruit (EFSA 2008).

However, this is more likely to be relevant for the movement of plant material, as opposed to produce. New Zealand is a world leader for the development of new kiwifruit cultivars and regularly sends plant material offshore, either through Zespri to support their global supply, or through other kiwifruit organisations independent of Zespri.

PART 2- RESPONDING TO A POSITIVE DETECTION

Part 2 identifies possible actions which may be included in any response to *C. fimbriata*. This Part may be used in an actual incursion/infection by members of the response team, particularly the Incident Controller/Response Manager, Planning and Operations workstreams.

7 Investigation phase (MPI accountability)

Upon receipt of information regarding a likely biosecurity incursion, an incursion investigation will be initiated by MPI. The investigation phase is outside the joint decision making of GIA. The investigation phase identifies the organism, confirms the diagnosis, assesses the risk, determines the extent of the incident and may include urgent measures to limit organism movement prior to the formal joint decision to stand up a response.

For a pathogen with significant implications such as *C. fimbriata*, a precautionary approach will be adopted to preserve response options. Actions may include:

- MPI to arrange for prompt field investigation, mobilising experienced incursion investigators;
- Providing information and explanation to property owners of the process and actions required, as well as assistance available to cope with the incident;
- Putting urgent measures in place to preserve response options;
- Gaining an understanding of diagnostics, such as degree of confidence in current identification, time frame to achieve validation of identification, and any complications related to strains and projected pathogenicity;
- Making decisions on property status and declaring property/properties to be infected if necessary;
- Preparing diagnostic facilities for high through-put sample processing if necessary.

8 Decision making beyond the investigation phase (Joint accountability)

8.1 Decision to stand up a response

If this pathogen is confirmed in kiwifruit, actions to manage the response will follow commitments entered into under GIA. MPI will notify any potentially affected GIA signatories if presence of this organism is suspected (and likely to be confirmed) in New Zealand (Deed 3.2.2). Depending on diagnostic outcomes and implications, the joint decision to initiate a response will be made and, if agreed, Response Governance is established.

All strategic decisions of a response will be made by Response Governance, which includes both MPI and industry. The decision to respond and how to respond sits with Response Governance. This group must make that decision based on the information collected within the investigation phase. Responding to eradicate may be the preferable option, however where evidence indicates that this is not feasible, containment or area freedom may become better options in return for response investment.

It is recommended that the Response Controller provides Governance with response options as soon as possible (options found in Section 9 below), that reassessment of the strategic direction is regularly made, and all decision-makers are aware of the appropriate courses of action.

8.2 Decision to stand down

The decision to stand down an investigation or response may occur if the infection is no longer present during the investigative phase or not confirmed. The decision to stand down may also occur when the cost of responding is outweighing the benefit of doing so or if no response options exist to take action. The decision will be made in joint discussion.

Note: The "standing down" of an investigation or response is different to a response being "closed out". A response is closed out when the response is complete (response objectives achieved).

8.3 Decision to transition to long term management

Long term management may need to be considered in the event that multiple orchards are affected across multiple regions, or when additional host plants are discovered to be susceptible to the *C. fimbriata* strain. This may occur immediately instead of initiating a response, or when all eradication options have been explored during a response and proven to be ineffective. In this instance the MPI process for transition into long term management will be followed (developing this process is under progress).

9 Response phase (Operational phase, Joint accountability)

Response management and workstreams will be structured using MPI's Single Scalable Response Model which is based on the Coordinated Incident Management System (CIMS).

See Appendix 2 for CIMS structure, including responsibilities under CIMS.

9.1 Response options

Essentially, two broad response options for the damaging strain for kiwifruit of *C. fimbriata* in New Zealand are:

9.1.1 **Eradication-** eradication from New Zealand.

- Eradication may be feasible in the event that the infection is detected early, found to be localised and limited. Given the longevity of this organism in soil and plant material, eradication may only be achieved under a long-term management plan.

9.1.2 **Containment or area freedom**- containment of *C. fimbriata* to areas where it cannot be eradicated, prevention of further spread.

- Where eradication is not considered feasible, measures may be implemented to contain the pathogen and limit its spread. Containment may need to be considered when infection extends to multiple orchards, particularly if these orchards are not within close proximity of each other.
- Aiming for containment may lead to long term management, however it may also provide for a second window of eradication with the development of new technology or tools should these be identified.

Within these overall options, the general principles for the management of *C. fimbriata* include:

- Rapid detection and confirmation of infection.
- Rapid identification of the extent of the problem.
- Rapid selection and implementation of response control measures.
- Prevention of pathogen spread by controlling movements of plants, tolls and equipment and contaminated soil within and between orchards and other sites considered susceptible to infection.
- Minimize water run-off where possible.
- Maintenance of appropriate plant health management practices and high standards of hygiene.

The most appropriate option will depend on:

- Geographical location of the issue.
- Effective treatment.
- Chances of successful *C. fimbriata* eradication.
- Level of risk accepted for any future spread of infection.
- Short-term costs of response control measures and disruption to kiwifruit production.
- Long-term costs to kiwifruit production in the presence or absence of *C. fimbriata.*
- long-term management costs should *C. fimbriata* become endemic.

10 Operational activities

10.1 Summary response strategy

The detection of *C. fimbriata* on a kiwifruit orchard may result in the following actions in the first instance (*distances identified are indicative only based on an initial assessment by KVH staff. Testing distances and strategies with an expert panel would be useful*). Further detail can be found in Sections 10.2- 10.5:

- Delimiting survey to determine extent of infection. Testing would include asymptomatic and symptomatic vines. Intensive sampling and testing may be carried out to 500m and less intensive to 1 km plus any high-risk sites identified through tracing activities.
- Issuing a Notice of Direction (s122 of the Biosecurity Act 1993), making the on-orchard hygiene protocols mandatory.
- Establishing movement controls (s130/131 of the Biosecurity Act 1993) to either the orchard boundary or 500m (depending on what is closer). Other high risk sites, such as source nurseries, may also need movement controls applied until testing can verify absence of the pathogen.
- Carrying out enhanced surveillance at all other nurseries and monitoring of orchards

- Constructing two layers of trenches 1.5m deep and lined with plastic around the infected trees, constructing the inner layer around the infected trees and the outer layer including a ring of healthy trees surrounding the infection site.
- Minimising risk of spread by removing infected vines and sanitising tools. Other orchards should halt pruning activities until the delimiting survey is complete, especially those orchards within 1 km of the infection site.

The response to a strain of *Ceratocystis fimbriata* harmful to kiwifruit may include the components/actions and tasks listed below. Individual response components may be mapped on a high-level timeline. A high-level response action plan needs to be drafted when a response is initiated (see Appendix 2). The details will depend on the specific circumstances but the below provides guidance to what actions may be necessary.

10.2 Delimiting survey, tracing and surveillance

To determine the appropriate course of action, a thorough delimiting survey should be conducted, followed by tracing of risk goods and active and passive surveillance. This may include the following:

- Intensive surveillance to determine extent of infection of symptomatic and asymptomatic vines within the immediate high-risk zone (within a 500m radius, based on an assumed natural spread distance).
- Passive surveillance to detect other potential focal points of infection.
- Conduct tracing based on: plant material movements, movements of pruners or other contractors, movements of soil or sites with close linkages to the infected property/properties (note fruit movements are not required to be traced).
- Tracing should be conducted to determine connectedness of infected property to other sites, which would then be prioritised for diagnostic testing.
- Conduct surveillance at high risk trace sites, considering how long the risk item has been there and therefore the probability of detecting a latent infection.

10.3 Movement Controls

10.3.1 Declare a Restricted Place (s130 of the Biosecurity Act 1993)

Infected properties and suspected properties may be declared restricted places as per the case definition below:

- Case definition of an Infected Place (IP): Any property with a MPI validated or confirmed diagnosis of *C. fimbriata.*
- Case definition of a Suspected Place (SP): Any property immediately adjacent to an IP, or currently under investigation of having received a high-risk trace item.

10.3.2 **Establish a Controlled Area (s131 of the Biosecurity Act 1993):**

A Controlled Area may initially be based on the natural spread zone of *C. fimbriata*, using a precautionary approach until a delimiting survey has been completed. It may therefore include:

- Any infected place and all adjacent properties within a 500m radius.
- Any properties that are at risk of water run-off from an infected place. A hydrologist can map how far the organism can spread in water based on spatial spread observed in Brazil.

The Controlled Area may increase or decrease in size as delimiting survey results become available.

Things and activities subject to movement controls may include the following:

- No high risk material to leave the Area (high risk material includes all plant material except commercially harvested fruit, as hygiene protocols will apply, and soil).
- No machinery, tools and equipment used in the Area are to be removed unless under permit which will require cleaning and disinfection.
- Restrict all pruning activities within the Zone, unless permission is given. This provides oversight of this high-risk activity and associated hygiene and pruning waste. A cleaning and disinfection site may be set-up within the Controlled Area.
- Cleaning and disinfection is required for all IP's and SP's.
- Stringent hygiene practices for movements of risk items, machinery, vehicles etc.; all movements out of the Controlled Area are only allowed under permit.

10.3.3 **Issue a Notice of Direction, NOD, (s122 of the Biosecurity Act 1993)**

- A NOD imposes restrictions on property owners with confirmed infections in Outliers; where MPI will perform activities (organism management) to attempt local elimination of an infection.
- The intent of the NOD is to give the most favourable circumstances for the OM to eliminate the infection locally by minimising human spread of latent spores. It does this by controlling movement from the property of plant material or items that come into contact with plant material.
- This is a hard control with compliance monitored and enforced if needed.
- As outliers are designated after taking into account that impacts should be minimal, it is likely that commercial plant production sites would be designated known infected rather than outlier. For this reason NODs are mainly expected to be issued in relation to non (plant based) commercial properties.
- While the use of declared "Restricted Places" is not used in LTM, the use of "RP" to describe an infected site carries on from Response. This particularly applies to the GIS application and Current Restricted Places spreadsheet.

10.3.4 **Require Permissions (s52 and 53 of the Biosecurity Act 1993)**

- This highlights the existing controls with statutory duties of anyone in NZ to act in a manner that does not further spread an unwanted organism.

10.3.5 Further considerations for movement controls

- Restricting movement of the infected plant material upon removal is necessary, therefore burning the plants in place may prove effective. However, it is currently unknown whether this may facilitate spread.
- Once all plant material is removed, it is possible that fungicide may speed up the death of *C. fimbriata* in the soil – however this has not been proven. A quarantine policy and testing of the soil after the quarantine period before replanting is likely to be required or looking at the cultivation of alternative crops resistant to the *C. fimbriata* strain.
- Research suggests that the spores can survive for years in the soil. There may be a need for the property/ properties to remain host free until the spores are no longer considered viable. The planting of an alternate crop is an option, but it may not be a crop that requires tilling or disturbance of the soil, or which could potentially move soil to new sites.
- Nurseries that have recently supplied rootstock to the infected site(s) should be quarantined until testing verifies absence of the pathogen. However due to the nature of the pathogen, proving absence may prove challenging and therefore a conservative approach of destroying nursery stock may be required. Consideration as to the best method for managing a nursery stock infection will need to be carefully considered in regard to the confidence of this pathway being the cause.
- The kiwifruit growing regions used in the Psa-V response are familiar boundaries that could be used as the basis for movement controls for *C. fimbriata.*

10.4 Organism management

Organism management on all confirmed infected places is vital in managing the infection. To date, no proven effective treatments exist to eradicate the pathogen. However, activities to contain the infection and mitigate the impacts may include the following:

10.4.1 Treatment and removal of infected material

- In general, symptomatic plants should be completely removed. Asymptomatic neighbours will also need to be removed to manage root transmission, which has been observed in infected kiwifruit in Brazil. In kiwifruit, it is typical to see a discrete area of infected vines with symptomatic plants at the edge of the expanding infection centre.
- Cutting a ring of healthy vines around the infected margin and applying a herbicide treatment (e.g. Tordon Brushkiller which is commonly used on kiwifruit) to all plants within this ring may help kill the root systems. This may be beneficial because it is believed that the fungus can spread within living root tissue. Care needs to be taken to remove as much of the root system as possible.
- All sawdust generated should be collected in tarps and properly disposed through deep burial or burning. Diseased plants should not be sawn on a windy day. Removal of vines may occur only after the application of herbicide and once the material is dead, but before leaves and shoots become brittle.
- Contaminated soil should be removed carefully. If soil from an infected plant or orchard is moved then the thick-walled aleurioconidia spores can be transported with the soil. The entire area will require treatment with disinfectant or fungicide, to ensure control of the pathogen, however these treatments are unlikely to eradicate the organism.

- It is unknown how effective soil drenches are against the robust aleurioconidia, however if drenches could eliminate the thin-walled and more susceptible conidia spores this would be beneficial as it would reduce inoculum spreading by water movement.
- KVH maintains a list of contractors experienced in removing kiwifruit vines as this is routine practice for dealing with abandoned orchards. However, they will need to meet the pruning waste management and cleaning and disinfection requirements under biosecurity movement controls.
- Destruction of the removed plant material may involve deep burial or burning. It is currently unknown which destruction would provide the least risk of spreading the organism further.
- Deep burial for disposal of *C. fimbriata* infected vines may be suitable once the plant material is dead and the pathogen inactivated. However the pathogen appears to live for a long period in soil so this could contribute to the spread.

10.4.2 Cleaning and disinfection

- Standard biosecurity protocols for cleaning and disinfection need to be adhered to, these are available on the KVH website (www.kvh.org.nz/KVH_Protocols). Ensuring the disinfection of all tools, equipment, machinery and footwear with an effective sanitiser (such as alcohol and sodium hypochlorite) is key to managing any infection and mitigating spread.

10.4.3 Pruning

- Pruning wounds have been associated with *Ceratocystis* epidemics internationally. Pruning is especially risky during the warm and moist months of the year when sporulation occurs. If *Ceratocystis* is detected, pruning should cease in the immediate vicinity until delimiting surveys have been completed. The risk of pruning can be reduced by limiting these activities to cold dry periods and by applying a fungicide or appropriate sealant to the pruning wound. Care needs to be taken not to introduce sawdust from pruned material into the sealant and to use a clean applicator.

10.4.4 Trenching

- Trenching may be used to reduce the risk of spread of the pathogen to healthy plants within the area.
- Trenching involves putting a primary barrier outside the healthy ring of trees, and a secondary barrier inside the healthy trees. This protects healthy plants from infected vines by preventing any contact between vines, leaves or roots, and effectively providing two layers of protection.
- Trenches are usually 1.5m deep, and plastic barriers can be placed inside the trenches to increase their effectiveness.

10.4.5 Chemical controls

- There are no chemical controls with proven effectiveness against *C. fimbriata.*
- Wilts of trees are difficult to manage with fungicides because of the large mass of xylem tissue to treat and the difficulty of delivering a sustained dose of protection throughout the tree at a reasonable cost.
- Systemic triazole compounds, such as propiconazole are the common choice for chemical control of *Ceratocystis* wilt. However, these are costly to apply, have limited effectiveness in

moving into the root system where preventive doses are needed and are short lived in a living tree.

- There is potential in using propiconazole as a soil drench, but it is not clear if vines or trees pick up enough of the material to apply adequate protection of the whole tree for a significant period of time.

10.4.6 Disposal

- Removed vines and soil/material from digging trenches needs to be disposed of carefully to avoid further spread of the issue. Operational Specifications for the collection and disposal of infected vines, soil and other garden waste should be developed, including:
- A general permission to remove waste material for deep burial at an approved waste disposal site will be granted to the preferred waste management service by the Chief Technical Officer under s52/53 of the Biosecurity Act 1993.
- All waste will be transported to an approved deep burial site and covered immediately with at least 0.5m of compacted soil.
- All personnel handling waste will use footbaths upon entering and exiting an orchard.
- Transport directly to landfill.

10.4.7 Resistance

- With most *Ceratocystis* diseases, there is substantial variation in aggressiveness in the pathogen and there is substantial variation in resistance among host species and within host species or hybrids. Selection for resistance and elimination of susceptible cultivars have been major tools for managing *Ceratocystis* in many crops, such as mango, cacao and sweet potato.
- There is potential to identify and utilize resistance in kiwifruit. The three tested cultivars in Rio Grande do Sul all appear to be highly susceptible, but it may be possible to develop resistant rootstocks over the longer term (15 years +). Highly aggressive isolates should be used to select resistant rootstocks. However, resistance is not likely to be the sole answer to *Ceratocystis* wilt in kiwifruit (Harrington 2015).

10.5 Communications

10.5.1 With Stakeholders

- A liaison cascade will be developed to ensure appropriate engagement occurs across a range of key stakeholders and partners (listed as a priority project in Part 3).
- A stakeholder matrix will be developed outlining the level of importance of each stakeholder in terms of maintaining engagement and mitigating outrage to any proposed response activity and to the incursion of a harmful strain of *C. fimbriata* (listed as a priority project in Part 3).

10.5.2 With Wider industry

- Provide all growers with best practice advice for high-risk activities (such as pruning), which includes hygiene recommendations and other measures to mitigate risk.
- Passive surveillance messages, reporting process and symptom and monitoring guides issued to the entire industry (including all growers, post-harvest organisations and nurseries).

PART 3- CURRENT KEY KNOWLEDGE GAPS AND RESEARCH

Part 2 identifies key knowledge gaps and potential improvements for readiness that can be addressed through research in subsequent work programmes. This Part may be used as a starting point for further investment and prioritisation for industry and government.

The following have been identified as priority projects:

1. Run cost benefit analyses based on a few simple response scenarios to support decision making.
2. Determine the lag between infection and symptom expression for surveillance.
3. Determine natural spread distances to underpin high risk area, movement control zone and size of vine removal area.
4. Determine how long *C. fimbriata* can survive in the soil.
5. Determine the best option to achieve eradication.
6. Develop a liaison cascade.
7. Develop a stakeholder matrix.
8. Develop generic Operational Specifications as per the MPI template.
9. Develop a case for MPI's CTO/DCTO to sign-off movement controls.

11 Knowledge Gaps

11.1 Biology and Epidemiology

- The suitability of New Zealand climate for different *C. fimbriata* strains to cause disease.
- Understanding of all the strains of *C. fimbriata* pathogenic to kiwifruit and kiwiberry.
- Are there other potential host species of kiwifruit strains?
- What likelihood is there of different strains of *C. fimbriata* adapting to infect different hosts?
- How long is the dormancy period before the symptoms appear (particularly in kiwifruit)?
- Can the pathogen be detected in asymptomatic carriers?
- For surveillance and follow-up action; should it be detected, what other species would need to be considered besides kiwifruit?
- How long does *C. fimbriata* take to spread and become transmittable?
- In Brazil what is the annual incidence (i.e. new case of disease appearing each year) within regions, and what is the annual within orchard incidence of new vines developing symptoms. In particular, what is the incidence rate per year and has this increased each year or is it weather dependant?
- If the other risk strains were pathogenic on kiwifruit, would the field symptoms be different to *C. fimbriata* in Brazil? What would need to go onto a field diagnostics and passive surveillance guide to address this? I.e. could we detect it using the current awareness material?
- It would be useful for a small number of "first responders" from KiwiNet and MPI (Incursion Investigators and PHEL mycologists) to have seen the organism in the field in Brazil. This will help with triage of reports of disease and with the development of response surveillance protocols.

- Symptoms and distinguishing features must be clearly described and available to the industry to improve effectiveness of surveillance efforts. This could be achieved by creating a field diagnostic guide that clearly differentiates *C. fimbriata* symptoms from NZ fungal pathogens.

11.2 Detection and Diagnostics

- The feasibility of promptly detecting infection in an orchard and throughout a growing region.
- The best sampling methodology for *C. fimbriata* (including the detection limit from different plant parts and plants with different infection level).
- Seasonal effect (climate) for presence of *C. fimbriata* in symptomless infection (enables reliable detection by PCR).
- Preparedness for expanded diagnostic testing should sample numbers exceed MPI capacity. What is required for another lab to begin performing the diagnostic test? Can measures be implemented in advance to fast track this?
- Given the potential for false positives from a PCR test, how do we treat an initial positive result until morphological confirmation?

11.3 Dispersal pathways

- What species of beetles actively feed on the phloem of sapwood of kiwifruit?
- What is the efficacy of treatments for commercial sawdust against *C. fimbriata?*

11.4 Response options

- The feasibility of promptly detecting infection in an orchard and throughout a growing region.
- What is the best option to eradicate *C. fimbriata*?
- What is the best option to contain *C. fimbriata* on an orchard (or multiple orchards)?
- How long can *C. fimbriata* survive in the soil?
- How far can *C. fimbriata* spread in water – observations from Brazil?
- Optimising current vine disposal techniques.
- What are alternative hosts?
- Cost benefit analysis based on simple scenarios.
- Need to determine efficacy of soil drenches against the durable spores which are robust.
- Removal of infected vines – how large of an area would need to be removed given the likelihood of short distance spread via wounds, rain splash, contaminated tools etc. Biological & economic modelling to support removal of vines/block/orchard for eradication to be effective.
- Based on the likelihood of spread by various mechanisms, is the proposed 500m radius suitable for the size of a high-risk zone?
- Are there any agrichemicals that can be used to control sporulation?

11.5 Long term management / recovery

- Is there the potential to breed resistant kiwifruit varieties with marketable fruit?
- Is there value in developing and implement pest management plans across the wider industry?

12 Research

12.1 Current research

Ceratocystis fimbriata is a pathogen of international significance, impacting a range of hosts in many countries. As a result, there is an opportunity to utilise international research capability or collaborate with countries with mutual interest. For example; Australia may be a potential research partner given that Eucalyptus are one of the most susceptible hosts, and a native species of great significance to Australia.

Table 3. Research projects and status to improve readiness.

Project	**Status**
Field trips to visit infected orchards and observe symptoms in Brazil. Multiple trips to the region which have included KVH staff, Zespri staff and Board members and PFR scientists.	Complete. Trip report on KVH website, (www.kvh.org.nz/emerging_risks)
Literature review to determine the impacts of *Ceratocystis fimbriata* on kiwifruit by Professor Tom Harrington, an international expert in this field.	Complete, Harrington (2015)
Pathogenicity screening of the kumara *C. fimbriata* strain on New Zealand kiwifruit. Study indicated that the only strain present in New Zealand, on kumara, is not pathogenic to kiwifruit.	Complete; Tyson JL, Manning MA, Curtis CL, Wright PJ. (2015)
Pathogenicity screening of isolates on kiwifruit cultivars. A collaboration with a Brazilian University to determine the degree of pathogenicity of various strains on kiwifruit, and whether tolerant kiwifruit varieties exist.	Completed
Sequencing and primer development. The project aims to sequence and compare a number of strains of *C. fimbriata*, including the Brazilian and kumara strains, in order to provide the basis for a DNA-based detection assay that could be used to identify risk strains of the fungus and underpin an eradication strategy in the event of an incursion.	Completed

13 References

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Appendix 1: Measures to prevent the spread of myrtle rust relevant for *Ceratocystis fimbriata* during organism management

ENTERING THE SITE

Prepare to decontaminate when leaving the site:

- Set up a 'wash down' area to enable people to decontaminate themselves and any equipment when leaving the site. Signage recommended for clarity.
- Consumable materials used in wash down are to be double bagged and disposed of as quarantine waste.
- Where there are multiple sites in an area, limit movement of people and equipment between these sites.

VEHICLES/ VEHICLE TOWED MACHINERY

- For vehicles required on site:
  - Ensure these are free from debris before entering the site.
  - Scrub down to remove debris before leaving the worksite. Include any debris from these vehicles in the ground spraying.
  - Spray the vehicle with Sterigene and wipe down before leaving the worksite.
  - Designate a 'clean area' and 'dirty area' in the vehicle i.e. boot for quarantine waste and used items.
  - The dirty area is to be wiped with Sterigene if any quarantine waste is removed at the end of each day.

EQUIPMENT

- Only take items that will be used in OM activities over the Clean/ Dirty line. **Minimise personal items taken onto the site.**
- If a site is suspected or confirmed as infected all reusable equipment is to be soaked, sprayed or wiped with Sterigene (to the degree that the waterproofing of the equipment allows) at the wash down area before leaving the site.

PLANT WASTE

- Live plants are to be sealed before removal.
- Waste is to be triple bagged (in bags, fadges or containers), sprayed, moved as a covered load and disposed as permitted waste at an approved landfill.

PERSONNEL, CLOTHING AND FOOTWEAR

- Normal footwear is to be used, ensuring they are debris free before entering the site.
- When leaving a site that is suspected or confirmed of being infected:
  - Footwear is cleaned while still in overalls and gloves; debris is scrubbed off, sprayed and wiped with Sterigene. Dispose of detergent from footbaths or other containers in an area where it will be dispersed without impact on the environment e.g. a gravel area. If this is not possible, empty into a waste container and remove from site.

- Gloves are to be removed and double bagged and treated as quarantine waste (sprayed with Sterigene and placed in the “dirty” section of the vehicle and disposed of in Quarantine waste bins).

Appendix 2: MPI Response Control Structure, based on CIMS

MPI's Single and Scalable Response Model is based on the New Zealand standard for incident management, the Coordinated Incident Management System (CIMS), which is used by all major emergency services in New Zealand. This model provides a framework for responses. MPI extends CIMS to meet needs common across MPI responses which are not already addressed by CIMS.

The functions in this model may be amended or added to depending on an agency's needs, responsibilities, or the specific objectives of a particular response.

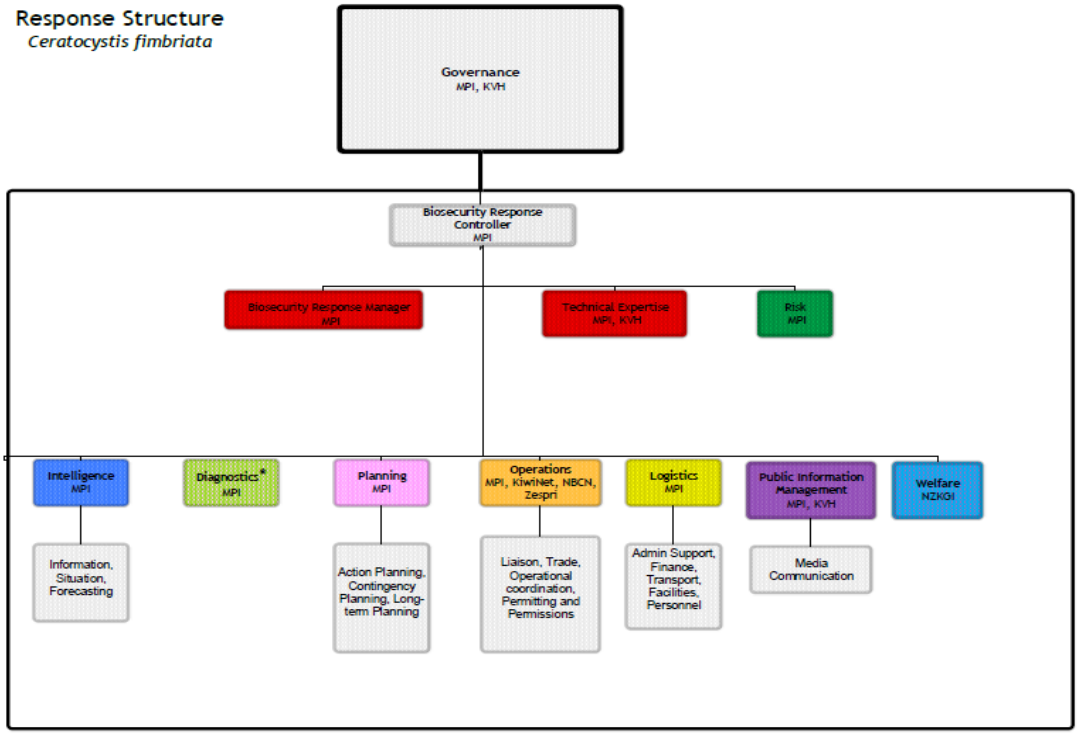

Figure 2. Proposed response structure for a positive detection of *Ceratocystis fimbriata*

* Diagnostic may be a function in its own right in a large response. In some cases, Diagnostics is more appropriate to sit under the Intelligence or Operations workstreams to suit the response.

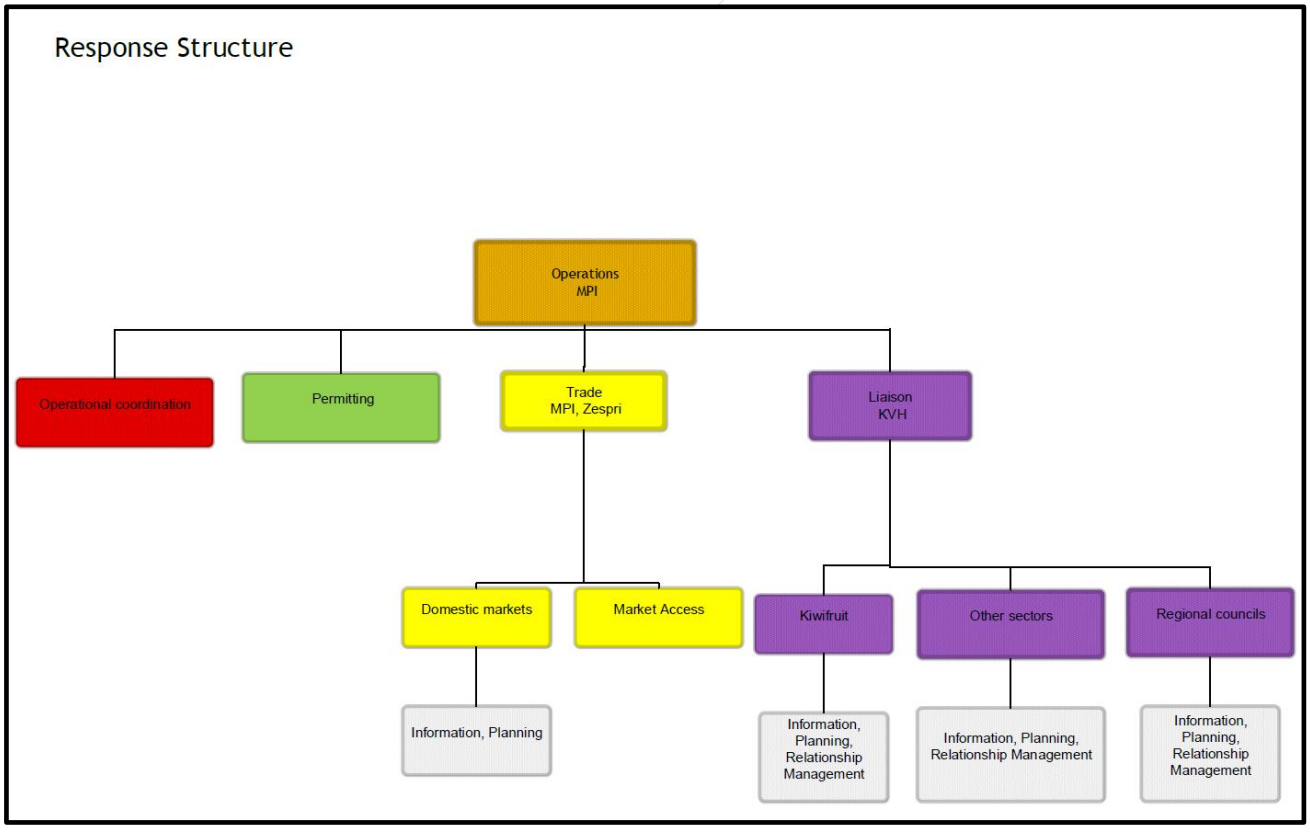

Figure 3. Proposed Operations workstream structure

Appendix 3: Legislative tools

The following legislations should be considered when formulating or implementing a plan for *C. fimbriata* (this is not an exhaustive list):

Legislation	Reason
Biosecurity Act 1993	• Ensuring that the actions within the plan are allowed under the powers bestowed under this Act • Considering potential compensation claims • Joint decision making under GIA • Requirements of long term pest management
Conservation Act 1987	Should native or DOC estate plants be infected, this Act may come into play
Hazardous Substances and New Organisms Act 1996	Any chemical treatments will need to be used in compliance with this Act
Health and Safety at Work Act 2015	MPI & GIA signatories involved in readiness and response activities need to ensure; • safety of staff; and • safety of contractors hired and that they have suitable health and safety procedures.
Local Government Act 2002	Should Regional or District Councils be involved, this Act may need to be considered in terms of what a Council may or may not do
Resource Management Act	May require consulting – however certain exemptions are possible under Section 7A of the Biosecurity Act

For further information, refer to Section 7 of the Biosecurity Act 1993

Appendix 4: Additional information on *C. fimbriata*

Impacts to kiwifruit

Kiwifruit is a particularly susceptible crop to this pathogen with infection resulting in severe production impacts.

Production impacts - The kiwifruit epidemic in Rio Grande do Sul (Brazil)

In 2010, *Ceratocystis* wilt was first observed in kiwifruit plants in the Farroupilha area of Rio Grande do Sul, Brazil where it is now causing significant mortality on some orchards. Since its first report, kiwifruit vine mortality has varied 10-30% per year in affected orchards and some growers are likely to cease commercial production of kiwifruit. Kiwifruit, a crop considered to have significant potential profitability for the region, may no longer be economically viable.

It is thought that Rio Grande do Sul is the first location of commercial kiwifruit within the natural range of *C. fimbriata,* explaining why impacts on kiwifruit have not been reported previously. However, the genetic diversity of strains infecting kiwifruit in Rio Grande do Sul indicates that *C. fimbriata* strains from across South America could potentially be aggressive on kiwifruit. Pathogenicity testing of eight isolates from kiwifruit, representing the maximum genetic diversity, were all found to be not only pathogenic but capable of killing vines in each of the three kiwifruit cultivars inoculated into (Elmwood, Monty and Hayward). While all three of these cultivars were highly susceptible, Elmwood showed less mortality that Monty and Hayward (Harrington 2015).

Observation of infected vines in Brazil, suggest that Hayward on Bruno rootstock is one of the most susceptible varieties (O'Neil 2014). This is extremely concerning for the New Zealand kiwifruit industry as Hayward represents over 60% of the industry by volume and the overwhelming majority is grown on Bruno rootstock.

The conclusion of **these genetic and pathogenicity studies is that other kiwifruit production areas around the world are likely vulnerable to other *C. fimbriata* strains, not just Brazil.**

Symptoms

Wilting is the first symptom, with complete vine collapse occurring as quickly as three days after infection. Dead vines are often adjacent to each other creating a circle of dead vines as the disease moves through soil and root systems. Browning of the xylem can be seen in infected vines moving from canes to leaders, trunks and even down to roots. Some Psa-like leaf spotting can be present (Figure 4).

Wilting and dying plants should be inspected closely for vascular discoloration of the woody xylem. A horizontal cross section of the wood will often show a radial pattern to the staining, while longitudinally the discoloration is often in streaks. Other fungi can induce similar discoloration, although this will typically be more solid and less "streaky". If *C. fimbriata* infection is suspected diagnosis can be confirmed with microscopic examination or PCR analysis (see Section 3 Diagnostics).

Figure 4. Symptoms of *C. fimbriata* infection in kiwifruit (Brazil) Clockwise from top; leaf wilt and curl, cane shrivelling and vine discoloration

Host range

In the last 15 years, new host crops and new epidemics of Ceratocystis wilt have been reported frequently, especially in Brazil and Asia (Harrington 2015). Kiwifruit is an example of a sudden appearance on a new host. Kiwifruit has been cultivated in Rio Grande do Sul (Brazil) for many years with little previous loss to Ceratocystis wilt, however recently impacts have becomes so severe that cultivation of this crop may no longer be economical in this region.

Of the four *C. fimbriata* clades, the Latin American Clade (LAC) contains the most commonly reported plant pathogens, the most aggressive strains have been detected on hosts that are not native to South America.

Over 30 types of plants are attacked by the *Ceratocystis fimbriata* complex (see Appendix 5 for a complete list). Eight hosts in particular, have been identified as being as highly susceptible to multiple genotypes of the pathogen, these are;

- Mango (*Mangifera*);
- *Eucalyptus* sp. and their hybrids;
- Pomegranate (*Punica*)
- *Acacia* spp.;
- edible figs (*Ficus*);
- taro and other *Araceae* family (a.k.a. arum family or aroids);
- *Crolotaria* (genus of herbaceous plants & woody shrubs); and
- **Kiwifruit (*Actinidia* sp.)**

Current distribution

Ceratocystis fimbriata has a worldwide distribution, including a strain within New Zealand infecting kumara which is host specific and not pathogenic to kiwifruit (Tyson et al. 2015). The *Ceratocystis fimbriata* complex has caused notable losses in a diverse range of hosts on over 40 countries, a complete list is provided in Appendix 6.

Impacts on kiwifruit have only been reported in Brazil in the region of Rio Grande do Sul. This strain is of particular concern to the New Zealand kiwifruit industry along with the strains causing two other recent outbreaks in other hosts. One is in South China where a closely-related *C. fimbriata* strain has been found on *Eucalyptus*, taro, and loquat, and these strains are causing substantial mortality of pomegranate in Yunnan and Sichuan. A second population is causing extensive mortality of mango in Oman and Pakistan, pomegranate in India, and Acacia in Indonesia. These populations of *C. fimbriata* have genetic characteristics of South American populations of *C. fimbriata*, but the threat of new introductions from Asia may be greater than the threat of new introductions from South America (Harrington 2015).

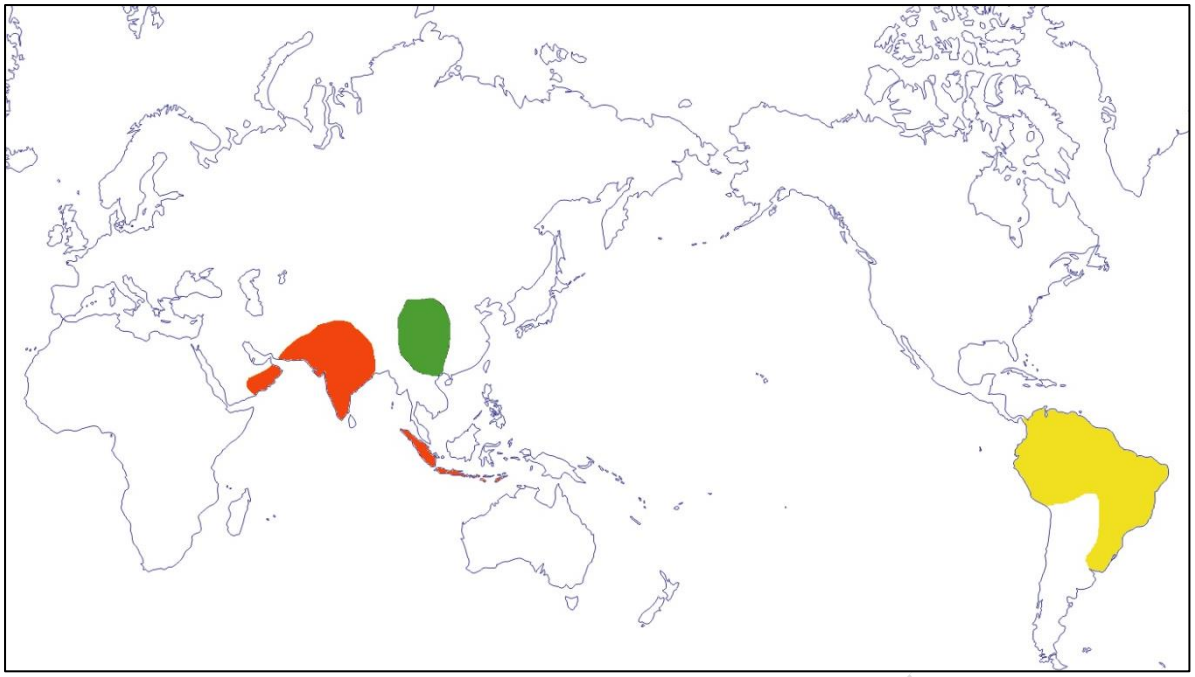

Figure 5. Populations of *C. fimbriata* known, or most likely, to be pathogenic to kiwifruit; South America (yellow), South China outbreak (green), and the Oman/Pakistan outbreak (orange).

Figure 6. Rio Grande do Sul Brazil, marked in yellow, where *Ceratocystis fimbriata* is causing significant production impacts to kiwifruit.

Appendix 5: Key Documents and Contacts

Key documents on the KVH website

Unless stated otherwise, the following documents are available on the KVH website (www.kvh.org.nz/emerging_risks)

Literature review on the threat to kiwifruit production (Feb 2015)

Professor Tom Harrington, an international *Ceratocystis* expert, was commissioned to complete a literature review to better understand the potential impact of this pathogen to the New Zealand kiwifruit industry. A summary of this review can be found on the KVH website, the full document is available from KVH or Zespri.

Ceratocystis fimbriata **fact sheet** – one page summary document

Presentation providing overview of symptoms & research, Joy Tyson (PFR) presented to KiwiNet (Dec 2015)

Trip report to infected orchards in Brazil, Barry O'Neil (Feb 2014)

Sources of technical information and advice

Name & organisation	Area of expertise	Contact details
Brett Alexander	Manager Mycology and Bacteriology	Brett.alexander@mpi.govt.nz 09 909 5724
Joy Tyson (PFR)	Plant pathologist - visited Brazil site and conducted NZ pathogenicity trials	joy.tyson@plantandfood.co.nz 021 026 76200
Mike Manning (PFR)	Plant pathologist - visited Brazil site and conducted NZ pathogenicity trials	Mike.Manning@plantandfood.co.nz 021 226 8130
Tom Harrington (Iowa State University, USA)	International Expert – Author of literature review for Zespri / KVH	tcharrin@iastate.edu

Other sectors involved who may have an interest

Although at this time, kiwifruit (and kiwiberry) is the focus of this plan for *C. fimbriata*, should a strain enter the country, the following sectors and agencies may be affected or interested:

- Department of Conservation
- Regional Councils
- Nursery sector
- Forestry industry
- Farm forestry sector
- Citrus growers
- Other horticulture growers

Appendix 6: Host and country associations of *C. fimbriata*

Countries and host genera with notable disease losses caused by members of the Australasian (AAC), African (AFC), North American (NAC) and Latin American (LAC) Clades of the *Ceratocystis fimbriata* complex.

REGION / COUNTRY	**HOSTS AFFECTED**	**CLADE AND PROBABLE SPECIES**	**REFERENCES**
NORTH AND CENTRAL AMERICA			
CANADA	*Populus* (poplar tree)	NAC (*C. harringtonii*)	Hinds 1985, Vujanovic et al. 1999
COSTA RICA	*Theobroma* (Cacao), *Herrania* (close rel to Cacao)	LAC (*C. cacaofunesta*)	Baker et al. 2003, Engelbrecht et al. 2007a
	Hevea (rubber)	LAC (unconfirmed)	Martin 1949
	Coffea (coffee)	LAC (*C. fimbriata*)	Baker et al. 2003, Echandi and Segall 1956, Siller 1958
CUBA	*Spathodea* (African tulip tree)	LAC (*C. fimbriata*)	Herreira Isla and Ravelo 1989
	Citrus	LAC (unconfirmed)	Rodriguez and Alfonso 1978
	Colocasia (flowering plant)	LAC (*C. fimbriata*)	Thorpe et al. 20015, Triana and Diaz 1989
DOMINICAN REP	*Theobroma* (Cacao)	LAC (*C. cacaofunesta*)	Schieber 1969
GUATEMALA	*Coffea* (coffee)	LAC (*C. fimbriata*)	Baker et al. 2003, Schieber and Sosa 1960, Szkolnik 1951, Tejada 1983
	Hevea (rubber)	LAC (*C. fimbriata*)	unpublished
HAITI	*Ipomoea* (sweet potato)	LAC (*C. fimbriata*)	Barker 1926
JAMAICA	*Pimenta* (flowering plant)	LAC (unconfirmed)	Leather 1966

MEXICO	*Hevea* (rubber)	LAC (*C. fimbriata*)	Martin 1947, unpublished
ST VINCENT	*Ipomoea* (sweet potato)	LAC (*C. fimbriata*)	BPI specimen 596219
TRINIDAD	*Ipomoea* (sweet potato)	LAC (*C. fimbriata*)	Baker and Dale 1951
	Theobroma (Cacao)	LAC (*C. cacaofunesta*)	Iton 1959
UNITED STATES	*Populus* (poplar tree)	NAC (*C. harringtonii*)	Hinds 1972a, Hinds 1985, Johnson et al. 2005
	Platanus (plane trees)	LAC (*C. platani*)	McCracken and Burkhardt 1977, Perry and McCain 1988, Walter 1946
	Prunus (plums, cherries, peaches, nectarines, plums and apricots)	NAC (*C. variospora*)	DeVay et al. 1968, Johnson et al. 2005, Teviotdale and Harper 1991
	Quercus (Oak)	NAC (*C. variospora*)	Johnson et al. 2005
	Carya (Hickory)	NAC (*C. smalleyi*)	Johnson et al. 2005, Park et al. 2010, 2013
	Tilia (aka lime tree but not citrus)	NAC (*C. variospora*)	Johnson et al. 2005
	Colocasia, Syngonium (flowering plants)	LAC (*C. fimbriata*)	Alfieri et al. 1994, Davis1953, Thorpe et al. 2005, Uchida and Aragaki 1979
	Ipomoea (sweet potato)	LAC (*C. fimbriata*)	Baker et al. 2003, Webster and Butler 1967
	Colocasia (flowering plants)	AAC (unknown)	Hawaii Thorpe et al. 2005, unpublished
SOUTH AMERICA			
BRAZIL	*Theobroma* (Cacao)	LAC (*C. cacaofunesta*)	Baker et al. 2003, Bastos and Evans 1978, Bezerra 1997, Engelbrecht et al. 2007a

	Hevea (rubber)	LAC (*C. fimbriata*)	Albuquerque et al. 1972, Pereira and Santos 1986, Silveira et al. 1985
	Eucalyptus	LAC (*C. fimbriata*)	Ferreira et al. 1999, Alfenas and Ferreira 2008
	Crotolaria (woody shrub)	LAC (*C. fimbriata*)	Batista 1947, Chardon et al. 1940, Melo-Filho et al. 2002, Muller 1937
	Gmelina (flowering plant sp)	LAC (*C. fimbriata*)	Muchovej et al. 1978
	Acacia (Acacia tree)	LAC (*C. fimbriata*)	Ribeiro et al. 1988, Santo and Ferreira 2003
	Annona (sugar apple)	LAC (*C. fimbriata*)	Baker et al. 2003, Silveira et al. 2006
	Cassia (flowering plant sp.)	LAC (*C. fimbriata*)	Galli 1958, Ribeiro et al. 1987
	Ficus (Fig)	LAC (*C. fimbriata*)	Figueiredo and Pinheiro 1969, Valarini and Tokeshi 1980
	Mangifera (mango)	LAC (*C. fimbriata*)	Arruda 1940, Batista 1960, Viégas 1960
	Colocasia (flowering plant)	LAC (*C. fimbriata*)	Harrington et al. 2005
	Actinidia (kiwifruit)	LAC (*C. fimbriata*)	Ferreira et al. 2013, Sonego et al. 2010
	Carapa (Mahogony)	LAC (*C. fimbriata*)	Halfeld-Vieira et al. 2012
	Tectona (teak)	LAC (*C. fimbriata*)	Firmino et al. 2012
COLOMBIA	*Coffea* (coffee)	LAC (*C. colombiana*)	Marin et al. 2003, Pontis 1951, van Wyk et al. 2010, Harrington et al. 2014

	Citrus	LAC (*C. colombiana*)	Borja et al. 1995, Marin et al. 2003, Mourichon 1994, van Wyk et al. 2010, Harrington et al. 2014
	Theobroma (Cacao)	LAC (*C. cacaofunesta*)	Arbelaez 1957, Garces 1944, Engelbrecht et al. 2007a
ECUADOR	*Theobroma* (Cacao)	LAC (*C. cacaofunesta*)	Desrosiers and Diaz 1956, Engelbrecht et al. 2007a, Rorer 1918
GUYANA	*Theobroma* (Cacao)	LAC (*C. cacaofunesta*)	Bisessar 1965
PERU	*Theobroma* (Cacao)	LAC (*C. cacaofunesta*)	Krug and Quartey-Papafio 1964, Soberanis et al. 1999
	Ipomoea (sweet potato)	LAC (*C. fimbriata*)	Rada 1939
SURINAME	*Coffea* (coffee)	LAC (*C. fimbriata*)	Baker et al. 2003
URAGUAY	*Eucalyptus*	LAC (*C. fimbriata*)	Barnes et al. 2003b
VENEZUELA	*Coffea* (coffee)	LAC (unconfirmed)	Pontis 1951
	Crotolaria (woody shrub)	LAC (unconfirmed)	Malaguti 1952a
	Theobroma (Cacao)	LAC (*C. cacaofunesta*)	Malaguti 1952b
ASIA			
CHINA	*Ipomoea* (sweet potato)	LAC (*C. fimbriata*)	Hu et al. 1999, Sy 1956
	Punica (pomegranate)	LAC (*C. fimbriata*)	Harrington et al. 2015, Huang et al. 2003, Xu et al. 2011
	Eucalyptus	LAC (*C. fimbriata*)	Chen et al. 2013, Harrington et al. 2015
	Eriobotrya (flowering plants)	LAC (*C. fimbriata*)	Li et al. 2014a, Harrington et al. 2015

	Colocasia (flowering plants)	LAC (*C. fimbriata*)	Harrington et al. 2015, Huang et al. 2003
	Colocasia (flowering plants)	AAC (near *C. polychroma*)	Thorpe et al. 2005, unpublished
	Eucalyptus	AAC (near *C. polychroma*)	Li et al. 2014b, unpublished
INDIA	*Punica* (pomegranate)	LAC (*C. fimbriata*)	Somasekhara 1999, Somasekhara and Wali 2000, unpublished
	Hevea (rubber)	AAC (unconfirmed)	Ramakrishnan and Radhakrishna 1963
INDONESIA	*Acacia* (Acacia tree)	LAC (*C. fimbriata*)	Tarigan et al. 2011, unpublished
	Ipomoea (sweet potato)	LAC (*C. fimbriata*)	Unpublished
	Hevea (rubber)	AAC (unconfirmed)	Leefmans 1934, South and Sharples 1925, Tayler and Stephens 1929, Wright 1925
	Coffea (coffee)	AAC (unconfirmed)	Zimmermann, 1900
	Styrax (large shrubs)	AAC (*C. larium*)	van Wyk et al. 2009
JAPAN	*Ipomoea* (sweet potato)	LAC (*C. fimbriata*)	Asuyama 1938, Kajitani and Kudo 1993, Okamoto 1940
	Colocasia (flowering plants)	AAC (unconfirmed)	Shimizu 1939
	Ficus (fig)	AAC (*C. ficicola*)	Kajitani and Kudo 1993, Kato et al. 1982
MALAYSIA	*Hevea* (rubber)	AAC (unconfirmed)	Beeley 1929, South and Sharples 1925

MYANMAR	*Hevea* (rubber)	AAC (unconfirmed)	Turner and Myint 1980
PAKISTAN	*Mangifera* (mango)	LAC (*C. fimbriata*)	Fateh et al. 2006, Harrington et al. 2014, van Wyk et al. 2007
	Dalbergia (shrub)	LAC (*C. fimbriata*)	Poussio 2010, Harrington et al. 2014
TAIWAN	*Crotolaria* (woody shrub)	Unknown	Lee and Kuo, 1997
OCEANIA			
AUSTRALIA	*Syngonium* (tropical flowering plant)	LAC (*C. fimbriata*)	Thorpe et al. 2005, Walker et al. 1988
FIJI	*Xanthosoma* (tropical flowering plant)	AAC (near *C. polychroma*)	Firman 1972, Graham1965, Thorpe et al. 2005, Walker et al. 1988, unpublished
NEW ZEALAND	*Ipomoea* (sweet potato)	LAC (*C. fimbriata*)	Baker et al. 2003, Slade 1960
PAPUA NEW GUINEA	*Ipomoea* (sweet potato)	LAC (*C. fimbriata*)	Baker et al. 2003
	Hevea (rubber)	AAC (unconfirmed)	Mann 1953
WESTERN SAMOA	*Colocasia* (flowering plant)	AAC (unconfirmed)	Walker et al. 1988
MIDDLE EAST			
OMAN	*Mangifera* (mango)	LAC (*C. fimbriata*)	Harrington et al. 2014, van Wyk et al. 2007
	Prosopis (spiny trees & shrubs)	LAC (*C. fimbriata*)	Al-Adawi et al. 2013
AFRICA			
CONGO	*Eucalyptus*	LAC (*C. fimbriata*)	Roux et al. 2000
COTE D'IVOIRE	*Crotalaria* (woody shrub)	unconfirmed	Davet 1962

KENYA	*Ipomoea* (sweet potato)	LAC (unconfirmed)	Kihurani et al. 2000
UGANDA	*Eucalyptus*	LAC (*C. fimbriata*)	Roux et al. 2001
	Acacia (Acacia tree)	AFC (*C. albifundus*)	Barnes et al. 2005
SOUTH AFRICA	*Eucalyptus*	LAC (*C. fimbriata*)	van Wyk et al. 2012, Harrington et al. 2014
	Acacia (Acacia tree)	AFC (*C. albifundus*)	Roux et al. 2000, Barnes et al. 2005
EUROPE			
AZORES	*Ipomoea* (sweet potato)	LAC (*C. fimbriata*)	Bensaude 1927
FRANCE	*Platanus* (plane trees)	LAC (*C. platani*)	Ferrari and Pechenot 1974, Grosclaude et al. 1991, Vigouroux 1986
ITALY	*Platanus* (plane trees)	LAC (*C. platani*)	Panconesi 1999
GREECE	*Platanus* (plane trees)	LAC (*C. platani*)	Ocasio-Morales et al. 2007
POLAND	*Populus* (poplar trees)	NAC (*C. harringtonii*)	Gremmen and de Kam 1977, Przybyl 1984
SWITZERLAND	*Platanus* (plane trees)	LAC (*C. platani*)	Matasci and Gessler1997