

Industry Biosecurity Plan for the Grains Industry

Generic Contingency Plan

Exotic foliage affecting necrotrophic pathogens affecting the grains industry

Specific example used in this plan:

Banded leaf and sheath spot of maize (*Rhizoctonia solani* f. sp. *sasakii*)

Plant Health Australia

May 2014



Disclaimer

The scientific and technical content of this document is current to the date published and all efforts have been made to obtain relevant and published information on the pest. New information will be included as it becomes available, or when the document is reviewed. The material contained in this publication is produced for general information only. It is not intended as professional advice on any particular matter. No person should act or fail to act on the basis of any material contained in this publication without first obtaining specific, independent professional advice. Plant Health Australia and all persons acting for Plant Health Australia in preparing this publication, expressly disclaim all and any liability to any persons in respect of anything done by any such person in reliance, whether in whole or in part, on this publication. The views expressed in this publication are not necessarily those of Plant Health Australia.

Further information

For further information regarding this contingency plan, contact Plant Health Australia through the details below.



Address:	Level 1, 1 Phipps Close DEAKIN ACT 2600
Phone:	+61 2 6215 7700
Fax:	+61 2 6260 4321
Email:	biosecurity@phau.com.au
Website:	www.planthealthaustralia.com.au

An electronic copy of this plan is available from the web site listed above.

© Plant Health Australia Limited 2014

Copyright in this publication is owned by Plant Health Australia Limited, except when content has been provided by other contributors, in which case copyright may be owned by another person. With the exception of any material protected by a trade mark, this publication is licensed under a **Creative Commons Attribution-No Derivs 3.0 Australia licence**. Any use of this publication, other than as authorised under this licence or copyright law, is prohibited.



<http://creativecommons.org/licenses/by-nd/3.0/> - This details the relevant licence conditions, including the full legal code.

This licence allows for redistribution, commercial and non-commercial, as long as it is passed along unchanged and in whole, with credit to Plant Health Australia (as below).

In referencing this document, the preferred citation is:

Plant Health Australia Ltd (Version 1, May 2014) *Generic contingency plan – Exotic foliage affecting necrotrophic pathogens affecting the grains industry*. Plant Health Australia, Canberra, ACT.

1	Purpose and background of this contingency plan	6
2	Australian grains industry	6
2.1	Notification process for the reporting of suspect pests	7
3	Eradication or containment decision matrix	8
4	Pest information/status – Necrotrophic foliar pathogens	9
4.1	Background	9
4.2	Exotic necrotrophic foliar pathogens	10
4.3	Information on lifecycles	11
4.4	Dispersal	11
4.5	Symptoms	12
4.6	Sampling	14
4.7	General information on the diagnosis of soil-borne pathogens	14
4.8	General comments on control	14
5	Specific examples of exotic necrotrophic foliar pathogens	15
5.1	Pest Details – Banded leaf and sheath spot of maize (<i>Rhizoctonia solani</i> f. sp. <i>sasakii</i>) (AG1-IA)	15
5.1.1	Background	15
5.1.2	Disease cycle	16
5.1.3	Dispersal	16
5.1.4	Host range	16
5.1.5	Current geographic distribution	18
5.1.6	Potential geographic distribution in Australia	20
5.1.7	Symptoms	20
5.1.8	Diagnostic information	21
5.1.9	Pest risk analysis – Banded leaf and sheath spot	23
6	Pest management	25
6.1	Response checklist	25
6.2	Surveys and epidemiology	25
6.2.1	Technical information for planning surveys	25
6.2.2	Surveys for early detection of an incursion	26
6.2.3	Delimiting surveys in the event of an incursion	27
6.2.4	Collection and treatment of samples	28
6.2.5	Epidemiological study	29
6.2.6	Models of spread potential	30
6.2.7	Pest Free Area guidelines	30

6.3	Availability of control methods	31
6.3.1	Priorities	31
6.3.2	General procedures for control	31
6.3.3	Control of infected areas	32
6.3.4	Weed management.....	32
6.3.5	Chemical control.....	33
6.3.6	Cultural Control	35
6.3.7	Host-Plant Resistance.....	35
6.3.8	Biological control	36
7	Course of action – eradication methods.....	36
7.1	Destruction strategy.....	36
7.1.1	Destruction protocols	36
7.1.2	Decontamination protocols.....	37
7.1.3	Plants, by-products and waste disposal.....	37
7.2	Containment strategies.....	38
7.3	Quarantine and movement controls	38
7.3.1	Quarantine priorities	38
7.3.2	Movement controls	38
7.4	Zoning.....	39
7.4.1	Destruction Zone	40
7.4.2	Quarantine Zone	41
7.4.3	Buffer Zone.....	41
7.4.4	Restricted Area.....	41
7.4.5	Control Area	41
7.5	Decontamination and hygiene	41
7.5.1	Decontamination procedures	41
7.5.2	General safety precautions	42
7.6	Surveillance and tracing	42
7.6.1	Surveillance.....	42
7.6.2	Survey regions	42
7.6.3	Post-eradication surveillance	43
8	Technical debrief and analysis for stand down	44
9	References	44
10	Appendices	49
10.1	Appendix 1: Standard diagnostic protocols	49

10.2	Appendix 2: Resources and facilities.....	49
10.3	Appendix 3: Communications strategy.....	49
10.4	Appendix 4: Market access impacts.....	49

1 Purpose and background of this contingency plan

Developing a contingency plan for groups of exotic pests will ensure the industry is prepared for a wider range of new pest incursions. These broader focused contingency plans are designed to assist the grains industry during an incursion of a necrotrophic foliar pathogen that may not already be covered by a pest specific contingency plan. As most necrotrophic foliar pathogens have similar effects on host plants, spread mechanisms (i.e. spores spread on plant debris, seed, soil, water or air) and control options this contingency plan provides information for the management of various necrotrophic foliar pathogens.

This contingency plan provides background information on the biology of the pest, available control measures, management options and other relevant information to assist with preparing for and responding to an incursion into Australia of a range of necrotrophic pathogens that could impact on the grains industry. Banded leaf and sheath spot of maize (*Rhizoctonia solani* f. sp. *sasakii*) is used in this contingency plan as an example of an exotic foliage affecting necrotrophic pathogen that could potentially enter Australia and impact on the grains industry. It should be noted that although there are some foliage affecting necrotrophic pathogens with a high economic impact already present in Australia (such as; *Ascochyta* blight of chickpea (*Ascochyta rabiei*)) endemic pathogens are not considered in this contingency plan. Pest specific contingency plans for some Necrotrophic foliar pathogens such as *Alternaria humicola* (Murray and Plant Health Australia 2009a) and *A. triticina* (Murray and Plant Health Australia 2009b) have previously been prepared as part of the CRC3009 project.

The contingency plan provides guidelines and options for steps to be undertaken and considered when developing a Response Plan for an incursion of an exotic necrotrophic pathogen. Any Response Plan developed using information in whole or in part from this contingency plan must follow procedures as set out in PLANTPLAN and be endorsed by the National Management Group prior to implementation.

The information for this plan has been primarily obtained from documents as cited in the reference section. Information on the background, life cycle, host range, distribution and symptoms of one necrotrophic pathogen is used as an example, with the emphasis of this document on the management options in the event of an exotic necrotrophic pathogen incursion into Australia.

2 Australian grains industry

The grains industry is the largest plant industry in Australia and grain crops are grown in all states and territories. The grains industry is primarily situated in a narrow crescent running through the mainland states, known as the grain belt. This area stretches from central Queensland, through New South Wales, Victoria and southern South Australia. In Western Australia, the grain belt covers the south-west corner of the state. Wheat is the most widely planted grain and is grown in all areas of the grain belt (Figure 1).

The grains industry consists of 25 leviable crops; many are affected by necrotrophic pathogens.

Due to Australia's relatively small population and domestic demand, export markets are essential for the viability of Australian grain farms. Australia is one of the world's largest grain exporters, exporting millions of tonnes of grain annually. With this reliance on exports, maintaining our current plant health

status through appropriate biosecurity measures is of utmost importance in retaining access to these markets.

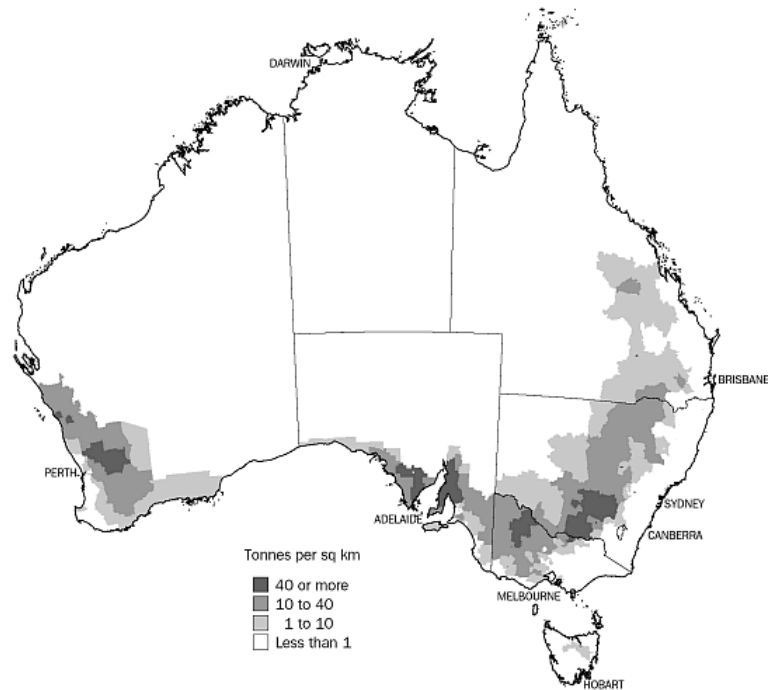


Figure 1 Map of wheat producing regions in Australia (i.e. the grain belt). (Source ABS 2007)

2.1 Notification process for the reporting of suspect pests

Early detection and reporting may prevent or minimise the long-term impact of an incursion into Australia of a foliage affecting necrotrophic pathogen. The notification process is described in Figure 2.

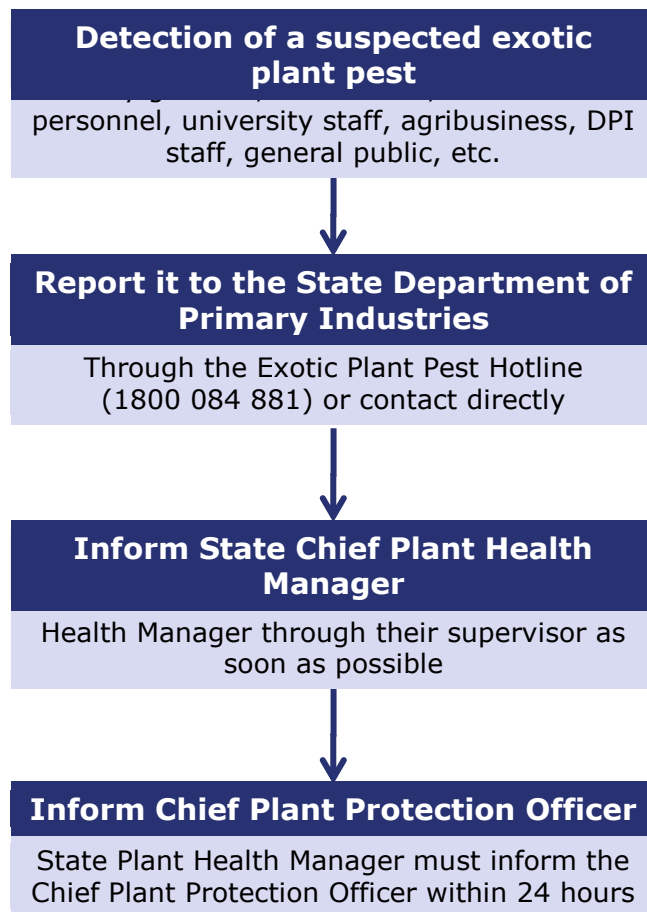


Figure 2. Notification process for the reporting of suspect pests

3 Eradication or containment decision matrix

The decision to eradicate should be based on the potential economic impact of host damage resulting from the introduction of a necrotrophic foliar pathogen, the cost of eradication and technical feasibility. Eradication costs must factor in long term surveys to prove the success of the eradication program.

A minimum of three years with no detection of the pathogen may be necessary before pest free status can be declared. The exact time required will depend on the survival ability of the specific pathogen in the absence of host plants.

No specific eradication matrix has been determined for foliage affecting necrotrophic pathogens; however the key decision points during the Investigation and Alert Phase are outlined in PLANTPLAN and Table 1 should be followed in determining if an incursion of a particular pathogen will result in eradication or management/containment. The final decision between eradication and management will be made through the National Management Group.

Table 1. Factors considered in determining whether eradication or alternative action will be taken for an EPP Incident (taken from: Table 2; Section 4.16 of PLANTPLAN)

Factors favouring eradication	Factors favouring alternative action
<ul style="list-style-type: none"> • Cost/benefit analysis shows significant economic loss to industry or the community if the organism established • Physical barriers and/or discontinuity of host between production districts. • The generation time, population dynamics and dispersal of the organism favour more restricted spread and distribution. • Vectors discontinuous in distribution and can be effectively controlled. • Outbreaks few and confined. • Trace back information indicates few opportunities for secondary spread. • Weather records show unfavourable conditions for pest development. • Ease of access to outbreak site and location of alternate hosts. • Pathways for reintroduction from international trade closed. 	<ul style="list-style-type: none"> • Cost/benefit analysis shows relatively low economic or environmental impact if the organism establishes. • Major areas of continuous production of host plants. • Short generation times, potential for rapid population growth and long distance dispersal lead to rapid establishment and spread. • Vectors unknown, continuous in distribution or difficult to control. • Outbreaks numerous and widely dispersed. • Trace back information indicates extensive opportunities for secondary spread. • Weather records show optimum conditions for pest development. • Terrain difficult and/or problems accessing and locating host plants. • Pathways for reintroduction from international trade open.

4 Pest information/status – Necrotrophic foliar pathogens

4.1 Background

Fungal plant pathogens are often classified into three classes or types of pathogen based on how they infect plants. These are: necrotrophic pathogens, biotrophic pathogens and hemibiotrophic pathogens.

Necrotrophic fungal pathogens kill host cells by means of toxic chemicals and enzymes, and then feed on the dead plant tissue. This group of pathogens are the subject of this contingency plan.

Biotrophic pathogens, such as rusts and powdery mildews, rely on a living host to grow and multiply and usually use sophisticated feeding structures such as haustoria to draw nutrients from their hosts.

Hemibiotrophic pathogens share aspects of both necrotrophic and biotrophic pathogens as they act as biotrophs before producing necrotic hyphae and killing the host plant's cells (Oliver and Ipcho 2004). Hemibiotrophs include pathogens such as: Wheat blast (*Magnaporthe grisea*) (Oliver and Ipcho 2004), Lentil anthracnose (*Colletotrichum truncatum*) (Bhadauria et al., 2011), Ramularia leaf spot (*Ramularia collo-cygni*) (Saville et al., 2011), Frog eye spot of soybean (*Passalora sojae*) (Whipps and Lewis 1981) and Sunflower stem canker (*Diaporthe helianthi*) (Custers et al., 2004).

The plant also has different mechanisms to deal with these fungal groups. For example the plant can defend itself against biotrophic fungi by causing programmed cell death in response to the pathogen, whereas necrotrophic fungi require different defences, including acids and ethylene signalling (Glazebrook 2005).

While there are a number of necrotrophic pathogens that affect grain crops (see Section 4.2), the control, biology and management of most foliage affecting necrotrophic pathogens is similar. Although, specific chemicals, application rates, biological controls, etc. are likely to vary between species and will have to be considered on a case by case basis. Details such as the general procedures for control (Section 6.3.1), sampling protocols (Section 6.2), quarantine and movement controls (Section 7.3), zoning requirements (Section 7.4) and other components of this contingency plan will be similar for all exotic necrotrophic foliar pathogens.

4.2 Exotic necrotrophic foliar pathogens

There are a number of exotic foliage affecting necrotrophic pathogens that have been identified in the Grains Industry Biosecurity Plan (IBP) (Plant Health Australia (2009-review 2014)). Necrotrophic foliar pathogens identified in the grains IBP include:

- *Alternaria* species such as *A. triticina* are necrotrophic pathogens that cause cell death and necrosis due to toxins that they produce (Kumar and Rao 1979; Mamgain et al., 2013). The two *Alternaria* species identified in the Grains IBP are considered to pose a Medium (*Alternaria humicola*) and Medium-Low (*A. triticina*) overall risk to the affected crops. Pest specific contingency plans have already been developed for *A. triticina* (Murray and Plant Health Australia 2009b) and *A. humicola* (Murray and Plant Health Australia 2009a).
- *Ascochyta* species cause the formation of necrotic lesions on infected plants. Three species have been identified in the reviewed Grains IBP (Plant Health Australia (2009-review 2014)) these are:
 - Leaf spot (*Ascochyta hordei*) affects barley in the United States and Japan, where it causes leaf necrosis (Figure 3) and causes minor losses (Mathre 1997). While, *A. hordei* var. *europaea* affects wheat in Argentina (Perello and Morerio 2003). This pathogen is considered to pose a Negligible overall impact to both the Australian wheat and barley industries.
 - Ascochyta blight (*Ascochyta rabiei* (exotic mating type MAT 1-2)), is a necrotrophic fungus that affects chickpea (Singh et al., 2012). Ascochyta blight causes leaf necrosis (Figure 4) and has a dramatic impact on the yield potential with complete losses reported overseas and losses of up to >70 % reported in Australia (Pande et al., 2005). Australia only has one mating type (MAT1-1 (Khan et al., 1999)) of the pathogen, so sexual reproduction doesn't occur. The presence of a second mating type may result in genetic recombination that could result in new pathotypes and cause a breakdown in host resistance making management of the disease in Australian chickpeas more difficult. Because of the pathogen's potential impact, and its risk of entry, establishment and spread *A. rabiei* MAT 1-2 is considered to pose a High overall risk to Australian chickpea production.
 - Rough yellow spot (*Ascochyta sorghi*) is a necrotrophic foliar pathogen that affects sorghum and causes the formation of red to brown coloured necrotic spots on the leaves on infected plants (Figure 5). The pathogen occurs in the Americas, Africa, Asia and parts of Europe. But generally only causes minor yield losses. Because of its impact and

entry, establishment and spread potentials it is considered to have a Very low overall impact.

- Yellow leaf blight of maize (*Mycosphaerella zeae-maydis* (anamorph: *Phyllosticta maidis*)) is a maize affecting necrotrophic fungal pathogen (Wolpert et al., 2002). But is generally considered to be of minor economic importance (White 1999). This pathogen is considered to pose a Negligible overall impact.
- Banded leaf and sheath spot (or blight) of maize (*Rhizoctonia solani* f. sp. *sasakii* (AG1) (teleomorph: *Corticium sasakii* (syn. *Thanatephorus cucumeris*))) is also classified as a necrotrophic pathogen (Laluk and Mengiste 2010). This pathogen affects maize and causes the formation of lesions and sclerotia on all aerial parts of the plant (except the tassels) (Saxena 2002). It is considered to pose a High overall risk to the Australian maize industry. Further information is provided in Section 5.1.
- Soybean brown spot (*Septoria glycines* (syn. *Mycosphaerella uspenskajae*)) is a necrotrophic pathogen that affects soybeans (Luck et al., 2011). It is found in North and South America, Europe and Asia (Lee and Hartman 1996; Hartman et al., 1999). The pathogen causes the formation of brown necrotic spots on the leaves (Figure 6), and sometimes on the seeds, pods and stems of infected plants. The Pathogen has been reported to cause yield losses of 8 – 15%, with losses of up to 34% reported from inoculation experiments (Hartman et al., 1999). Soybean brown spot is considered to pose a Low-Very low overall impact based on its entry, establishment, spread potentials and potential economic impacts.

All of these pathogens use similar pathways for their dispersal and spread and will be controlled and managed in a similar way using similar methods to Banded leaf and sheath spot. Although the specific controls (e.g. active ingredients of fungicides, etc.) will vary between the different pathogens the general procedures for control and surveillance of all necrotrophic foliage affecting pathogens will be similar to the example used in this contingency plan and those described in the threat specific contingency plans mentioned above.

4.3 Information on lifecycles

All foliage affecting necrotrophic pathogens share a similar lifecycle to Banded leaf and sheath spot (Section 5.1.2). The exact details of the pest's lifecycle (such as the spore stages that are involved, speed of the lifecycle, temperatures and environmental conditions required by the pathogen, etc.) are individual to the species concerned. In the event of a pest incursion the lifecycles and biology of each species would have to be considered on an individual basis.

4.4 Dispersal

Most foliage affecting necrotrophic pathogens are spread by the movement of spores in the air, water, soil, seeds, or crop debris. The exact mechanisms adopted by the pathogen vary slightly between species.

The ability of exotic pathogens to develop and establish in Australia will be determined by the presence of host plants, the movement of inoculum to new areas and the suitability of the environment to the establishment of the pest. In the absence of these it is unlikely that the pest will successfully establish.

4.5 Symptoms

The exact symptoms caused by necrotrophic pathogens vary between species. However all necrotrophic foliar pathogens cause necrosis of the leaves and/or stems usually in the form of spots and streaks (see: Figure 3 to Figure 6). These often begin as chlorosis and develop into necrotic areas. For example necrotic spots are often surrounded by a halo of chlorotic tissue (e.g. Figure 6).



Figure 3 Symptoms of Leaf spot of barley (*Ascochyta hordei*) symptoms. Source: Elizabeth Bush, Virginia Polytechnic Institute and State University, Bugwood.org



Figure 4 Typical symptoms of *Ascochyta* blight (*Ascochyta rabiei*) on chickpea. Source: Sam Markell, North Dakota State University, Bugwood.org



Figure 5 Symptoms of Rough yellow spot of sorghum (*Ascochyta sorghi*) Source: Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org



Figure 6 Soybean brown spot (*Septoria glycines*) symptoms on soybean leaf (Note: necrotic (brown) areas are surrounded by a chlorotic (yellow) halo). Source: Daren Mueller, Iowa State University, Bugwood.org

4.6 Sampling

Samples of plants thought to be affected by necrotrophic foliar pathogens should be collected and treated as described in Section 6.2. Exact details of what material needs to be collected and how many samples are required will need to be decided upon on a case by case basis.

4.7 General information on the diagnosis of soil-borne pathogens

For a current list of the endorsed National Diagnostic Protocols see the Subcommittee on Plant Health Diagnostic Standards (SPHDS) website:

<http://plantbiosecuritydiagnostics.net.au/resource-hub/protocols/national-diagnostic-protocols/>.

Generally pathogens are identified based on the morphological characteristics of fungal spores, hyphae, or other reproductive structures and by the use of molecular techniques. Mycologist expertise would be required to identify specimens to a species level.

For diagnostic facilities and advisory services that can be utilised in the event of an incursion see Section 10.2, Appendix 2.

4.8 General comments on control

If left unchecked exotic foliage affecting necrotic pathogens (such as those listed in Section 4.2) could cause significant damage to host crops.

In the event of an incursion of a necrotrophic pathogen the affected crop (and surrounding crops) would need to be treated to control the pathogen. The exact treatment and area requiring treatment will be determined on a case by case basis but would likely involve the destruction of the affected crop and application of fungicides to surrounding crops and crop debris.

The active ingredient required and rates that it should be applied at will be based on the identification of the individual pathogen (for possible chemicals that could be used in the event of an incursion of Banded leaf and sheath spot see Section 6.3.5).

Currently there are a large number of fungicides registered for the control of endemic pathogens on Australian grain crops. Such chemicals, if they have been proved to be effective overseas, could be used to manage/eradicate new pest incursions in Australia. Appropriate chemical permits may need to be granted by the Australian Pesticides and Veterinary Medicines Authority (APVMA) for their use in Australia or under certain conditions.

Host plant resistance and the use of cultural controls, such as crop rotations incorporating non-host crops, can be a low cost and effective way of managing pathogens. See Sections 6.3.6 and 6.3.7 for further information about cultural controls and host plant resistance for the management of Banded leaf and sheath spot.

The use of biological control of necrotrophic foliar pathogens is an area of research interest but is not widely used. Section 6.3.8 provides more information on biological control of Banded leaf and sheath spot.

5 Specific examples of exotic necrotrophic foliar pathogens

5.1 Pest Details – Banded leaf and sheath spot of maize (*Rhizoctonia solani* f. sp. *sasakii*) (AG1-IA)

Common name:	Banded leaf and sheath spot
Scientific name:	<i>Rhizoctonia solani</i> f. sp. <i>sasakii</i> (AG1-IA)
Teleomorph:	<i>Corticium sasakii</i>
Synonyms:	<i>Thanatephorus cucumeris</i> ; <i>Hypochochus sasakii</i> ; <i>Thanatephorus sasakii</i>
Taxonomic position:	Kingdom: Fungi Phylum: Basidiomycota Class: Agaricomycetes Order: Cantharellales Family: Ceratobasidiaceae Genus: <i>Rhizoctonia</i>

5.1.1 Background

Banded leaf and sheath spot (also known as Banded leaf and sheath blight) of maize (*Rhizoctonia solani* f. sp. *sasakii*) (anastomosis group AG1 subgroup IA) is a foliage affecting necrotrophic pathogen (Laluk and Mengiste 2010; De Vleeschauwer et al., 2006) that predominately affects maize, but also affects other hosts (see Section 5.1.4).

There are at least 14 anastomosis groups in the *Rhizoctonia solani* complex (Khodayari et al., 2009). Three are known to occur in Australia. These are AG3, which affects potatoes, AG8, which affects Australian cereals (Cubeta and Vilgalys 1997) and AG11, which was isolated from lupins (Carling et al., 1994). *Rhizoctonia solani* is a soil borne fungus that often affects the roots of its hosts and causes damping off and similar symptoms. Banded leaf and sheath blight is a disease which affects the leaves of maize plants and can therefore be classified as a foliar necrotrophic pathogen.

Banded leaf and sheath spot of maize (*Rhizoctonia solani* f. sp. *sasakii*) was chosen as an example of a necrotrophic foliar pathogen for this contingency plan as it is an exotic foliage affecting necrotrophic pathogen that is considered to have a High overall risk to the maize industry (Plant Health Australia (2009-review 2014)).

Banded leaf and sheath spot of maize occurs in Asia, South America, parts of Africa, Europe and North America. Particularly in areas with warm humid conditions (González-Vera et al., 2010; Singh and Shahi 2012). The pathogen causes damage to the leaves, sheaths, stalks and ears of maize plants (Singh and Shahi 2012; Figure 7). The disease typically affects the lowest leaves first and moves up the plant reaching the sheaths and ears. Typical leaf symptoms include spotting of the

leaves, reduction in leaf area, drying/death of leaves, leaf sheaths and husks. Kernels from infected plants are often wrinkled, dry and light weight (Singh and Shahi 2012). This disease has been reported to cause yield losses of 23 - 97 % (Saxena 2010). The pathogen is spread with seed (Ahuja and Payak 1982; DAFF 1999), irrigation water, contaminated soil and plant material and by contact between infected and non-infected leaves (Singh and Shahi 2012).

5.1.2 Disease cycle

R. solani doesn't create spores in its anamorph state (Gonzalez Garcia et al., 2006). It instead uses sclerotia and mycelia to overwinter and spread.

The general disease cycle for Banded leaf and sheath spot of maize consists of the following stages:

- Sclerotia (a hardened mass of mycelia, which contains food reserves) and mycelia overwinter in the soil and on crop debris (Lin et al., 2008). Sclerotia are the primary source of inoculum (Singh and Shahi 2012).
- Once environmental conditions are suitable and a susceptible host is present the Sclerotia germinate and infect the plant. Optimum conditions for the disease are described by Singh and Shahi (2012) as being 28°C with a relative humidity of 88 - 90 % during the first week of infection. Disease development is slow when relative humidity drops below 70 %.
- Symptoms first become apparent 30 - 50 days after germination (Rai 2012; Singh and Shahi 2012, Patra 2007). The fungus multiplies by feeding on dead plant cells, which are killed, by enzymes produced by the pathogen. Hyphae then colonise the dead cell and produce new sclerotia (Muis 2007).
- Sclerotia can then be spread either with water (irrigation, rain splash, etc.) or plant to plant contact causing secondary infection of other plants in the field.
- After the crop is harvested or dies the sclerotia and mycelia overwinter in the soil where they are able to survive for several years (Singh and Shahi 2012).

5.1.3 Dispersal

Banded leaf and sheath spot is spread with the movement of infected soil and plant debris (Singh and Shahi 2012; Lin et al., 2008). Irrigation water can also spread the pathogen (Singh and Shahi 2012). For shorter distances (i.e. between plants in a single field) the pathogen is spread by direct contact between infected and non-infected leaves (Singh and Shahi 2012).

Banded leaf and sheath spot is also able to be spread with seeds (Ahuja and Payak 1982; DAFF 1999). This suggests that the international and domestic movement of seed could potentially spread this pathogen over large distances.

Pascual et al., (2000a) suggests that basidiospores of this pathogen's teleomorph (*Corticium sasakii*) may also spread the disease under ideal conditions (warm humid conditions throughout the year, as experienced in parts of the Philippines).

5.1.4 Host range

Rhizoctonia solani has a wide host range, affecting plants in a large number of plant families. The strain that causes Banded leaf and sheath spot mostly affects maize and other grasses. However there are a number of species from various plant families that have been identified in the scientific literature as being able to host maize affecting strains of *R. solani* f. sp. *sasakii*. Table 2 provides a

summary of this information. In the event of a pest incursion all hosts should be considered in survey and containment programs.

Table 2 Hosts of Banded leaf and sheath spot

Species name	Common name	Family	Reference
<i>Bothriochloa ischaemum</i> ¹	-	Poaceae	Trivedi and Rathore (2006)
<i>Brachiaria ramosa</i> ¹	Signalgrass	Poaceae	Trivedi and Rathore (2006)
<i>Coffea</i> sp. ²	Coffee	Rubiaceae	Pascual et al., (2000a)
<i>Cynodon dactylon</i>	Bermuda grass	Poaceae	González-Vera et al., (2010)
<i>Durio</i> sp. ²	Durian	Malvaceae	Pascual et al., (2000a)
<i>Glycine max</i> ²	Soybean	Fabaceae	Pascual et al., (2000a)
<i>Gossypium</i> spp. ²	Cotton	Malvaceae	Pascual et al., (2000a)
<i>Heteropogon contortus</i> ¹	Black grass spear	Poaceae	Trivedi and Rathore (2006)
<i>Heteropogon melanocarpus</i> ¹	-	Poaceae	Trivedi and Rathore (2006)
<i>Imperata cylindrica</i> ²	Cogon	Poaceae	Pascual et al., (2000a)
<i>Ischaemum rugosum</i>	-	Poaceae	González-Vera et al., (2010)
<i>Oryza sativa</i> ^{2,3}	Rice	Poaceae	González-Vera et al., (2010); Pascual et al., (2000a)
<i>Panicum maximum</i> ¹	Guinea grass	Poaceae	Trivedi and Rathore (2006)
<i>Pennisetum glaucum</i>	Pearl millet	Poaceae	Williams et al., (1978)
<i>Rottboelia exaltata</i> ²	Itchgrass	Poaceae	González-Vera et al., (2010); Pascual et al., (2000a)
<i>Saccharum officinarum</i> ⁴	Sugarcane	Poaceae	Pascual et al., (2000a)

¹ All plants in the experiment by Trivedi and Rathore (2006) were found to cause symptoms on these species and on maize.

² Pascual et al., (2000a) isolated samples of the pathogen from a wide range of host plants showing foliar near maize fields. These were then used to inoculate maize plants. All caused symptoms of varying severity on the inoculated maize plants.

³ González-Vera et al., (2010) suggest that in Venezuela strains isolated from maize will infect rice and vice versa, but that the strains are most pathogenic on the plant species that they were originally isolated from.

Species name	Common name	Family	Reference
<i>Sorghum bicolor</i> ⁴	Sorghum	Poaceae	Kimigafukuro (1992); de Milliano (1992); Pascual et al., (2000a)
<i>Sorghum bicolor</i> subsp. <i>verticilliflorum</i> (<i>Sorghum verticilliflorum</i>)	Wild grass	Sudan Poaceae	González-Vera et al., (2010)
<i>Sorghum halepense</i>	Johnson grass	Poaceae	González-Vera et al., (2010)
<i>Vigna radiata</i> ⁴	Mungbean	Fabaceae	Pascual et al., (2000a)
<i>Vigna unguiculata</i> ⁴	Cowpea	Fabaceae	Pascual et al., (2000a)
<i>Zea mays</i> ^{4,5}	Maize	Poaceae	Lin et al., (2008); Pascual et al., (2000a); Trivedi and Rathore (2006); Pascual et al., (2000b)

5.1.5 Current geographic distribution

Banded leaf and sheath spot occurs in South America, Southern Asia, Africa and parts of Europe⁶. It is more prevalent in areas with warm and humid environmental conditions (González-Vera et al., 2010; Singh and Shahi 2012).

Singh and Shahi (2012) suggest that Banded leaf and sheath spot occurs in the USA. However other authors (Farr et al., 1989; DAFF 1999) suggest that this is not the case. *R. solani* AG 2-2, which causes Crown and brace root rot does occur in the USA (Sumner and Minton 1989). As maize is a major crop in the United States and there is limited information on the diseases presence it would appear likely that the strain of *R. solani* that causes Banded leaf and sheath spot is absent from North America.

A list of the countries where the pathogen has been reported in the scientific literature is given in Table 3.

⁴ Pascual et al., (2000a) isolated samples of the pathogen from a wide range of host plants showing foliar symptoms near maize fields. These were then used to inoculate maize plants. All caused symptoms of varying severity on the inoculated maize plants.

⁵ All plants in the experiment by Trivedi and Rathore (2006) were found to cause symptoms on these species and on maize.

⁶ Singh and Shahi (2012) appear to be the main reference to Banded leaf and sheath spot occurring in Europe.

Table 3 Geographic distribution of Banded leaf and sheath spot

Country	Continent	References
Angola ⁷	Africa	de Milliano (1992)
Bangladesh	Asia	Singh and Shahi (2012); Sivakumar and Sharma (2007)
Bhutan	Asia	González-Vera et al., (2010); Sivakumar and Sharma (2007)
Cambodia	Asia	Singh and Shahi (2012); Sivakumar and Sharma (2007)
China	Asia	Lin et al., (2008); González-Vera et al., (2010); Yang et al., (2008); Sivakumar and Sharma (2007)
England ⁸	Europe	Singh and Shahi (2012)
Germany ⁹	Europe	Singh and Shahi (2012)
India	Asia	Saxena (2010); González-Vera et al., (2010); Singh and Shahi (2012); Sivakumar and Sharma (2007)
Indonesia	Asia	Pascual et al., (2000a); González-Vera et al., (2010); Singh and Shahi (2012)
Ivory Coast	Africa	Singh and Shahi (2012)
Japan	Asia	Kimigafukuro (1992); Singh and Shahi (2012)
Korea	Asia	Singh and Shahi (2012)
Laos	Asia	Singh and Shahi (2012); Sivakumar and Sharma (2007)
Malaysia	Asia	Singh and Shahi (2012); Sivakumar and Sharma (2007)
Mozambique	Africa	de Milliano (1992)
Myanmar	Asia	Singh and Shahi (2012); Sivakumar and Sharma (2007)
Nepal	Asia	Singh and Shahi (2012); González-Vera et al., (2010); Sivakumar and Sharma (2007)
Nigeria	Africa	Singh and Shahi (2012)
Pakistan	Asia	Singh and Shahi (2012)
Philippines	Asia	Pascual et al., (2000a); González-Vera et al., (2010); Singh and Shahi (2012); Sivakumar and Sharma (2007)
Sierra Leone	Africa	Singh and Shahi (2012)
Sri Lanka	Asia	Saxena (2010); Singh and Shahi (2012); Sivakumar and Sharma (2007)
Swaziland ¹⁰	Africa	de Milliano (1992)
Taiwan	Asia	Singh and Shahi (2012); Sivakumar and Sharma (2007)
Thailand	Asia	Singh and Shahi (2012); Sivakumar and Sharma (2007)

⁷ Reported but not confirmed (de Milliano 1992).

⁸ No other references found to this disease occurring on maize in England and Germany

⁹ No other references found to this disease occurring on maize in England and Germany

¹⁰ Reported but not confirmed (de Milliano 1992).

Country	Continent	References
Venezuela	South America	González-Vera et al., (2010); Singh and Shahi (2012)
Vietnam	Asia	Pascual et al., (2000a); González-Vera et al., (2010); Singh and Shahi (2012); Sivakumar and Sharma (2007)

5.1.6 Potential geographic distribution in Australia

Pathogen mostly occurs in areas with warm and humid environmental conditions (González-Vera et al., 2010; Singh and Shahi 2012). Optimum conditions for the disease are described by Singh and Shahi (2012) as being 28°C with a relative humidity of 88 - 90 % during the first week of infection. Disease development is slow when relative humidity is below 70 %. This humidity requirement would likely limit where the pathogen could establish in Australia. Areas in Australia with these climatic conditions would include coastal and northern maize producing areas of the country.

5.1.7 Symptoms

Visual symptoms usually appear between 30 and 50 days after germination (Rai 2012; Singh and Shahi 2012, Patra 2007). The disease causes necrotic lesions (spots and bands) that affect all aerial parts of the plant (except the tassels) (Saxena 2002). Close inspection of lesions may reveal white to light brown mycelia (Williams et al., (1978). Small (1 - 6 mm (Patra 2007)), round, black-grey coloured sclerotia may also be visible on infected surfaces (Rai 2012).

5.1.7.1 LEAF AND SHEATH SYMPTOMS

The disease causes the formation of concentric spots on the leaves and sheaths of infected plants (Rai 2012). Over time these grow and cover larger areas of the leaf. Damage occurs in bands as the straw coloured, necrotic area progresses along the leaf. These bands (Figure 7) are a classic symptom of the disease (Ahuja and Payak 1982).

5.1.7.2 STALK SYMPTOMS

Dark coloured stalk lesions can develop under the infected leaf sheaths. Lesions can range from 2 - 10 mm by 3 - 15 mm (Saxena 2002). Occasionally these will girdle the stem near the nodes causing cankers, which can lead to lodging (Saxena 2002; Ahuja and Payak 1982).

5.1.7.3 HUSK, EAR AND KERNEL SYMPTOMS

Typically the bottom of the husk is the first area affected. Once infected husks become spotted (Ahuja and Payak 1982) and banded lesions form (Saxena 2002). Silk can also be affected (eg broken, clumped together, etc.) (Ahuja and Payak 1982).

The lesions can also develop on the ear giving infected ears a blackened appearance. Mycelia can be seen along the silk and sclerotia commonly appear on the husk (Saxena 2002). Horseshoe shaped lesions can develop on caryopses (kernels) (Ahuja and Payak 1982; Singh and Shahi 2012).



Figure 7 Banded leaf and sheath spot symptoms on maize. Source: CIMMYT

5.1.8 Diagnostic information

No National Diagnostic Protocol has been developed or endorsed for Banded leaf and sheath spot.

For a full list of diagnostic facilities and advisory services that can be utilised in the event of an incursion see Section 10.3 Appendix 2.

5.1.8.1 MORPHOLOGICAL AND PHYSIOLOGICAL DIAGNOSIS

The symptoms caused by the fungus on host plants (see Section 5.1.4) and the morphology of the fungus can aid in its identification.

Banded leaf and sheath spot of maize is caused by *R. solani* f. sp. *sasakii* (AG1-IA) is the anamorph of *Corticium sasakii*. The teleomorph, *C. sasakii*, is rarely seen as it requires specific conditions (high humidity and temperatures) to occur, so morphological identification of the fungus primarily relies on the identification of the anamorph (*R. solani* f. sp. *sasakii*). The anamorph is identified by examining hyphae and sclerotia, however molecular techniques would be required for an accurate diagnosis.

Hyphae of Banded leaf and sheath spot are usually colourless when young becoming a light brown when mature. Typical hyphae width is 8 - 12 μm , with a slight constriction at the base of the lateral branch, which is typically almost 90° to the main hyphae (Figure 8). Hyphae have dolipore septums, which are typically formed a short distance from the branch (Singh and Shahi 2012). The hyphae of this species also lack clamp connections

Sclerotia are grey-black in colour and 1 - 6 mm in diameter (Patra 2007). The rind and medulla of the sclerotia are not differentiated (Singh and Shahi 2012).

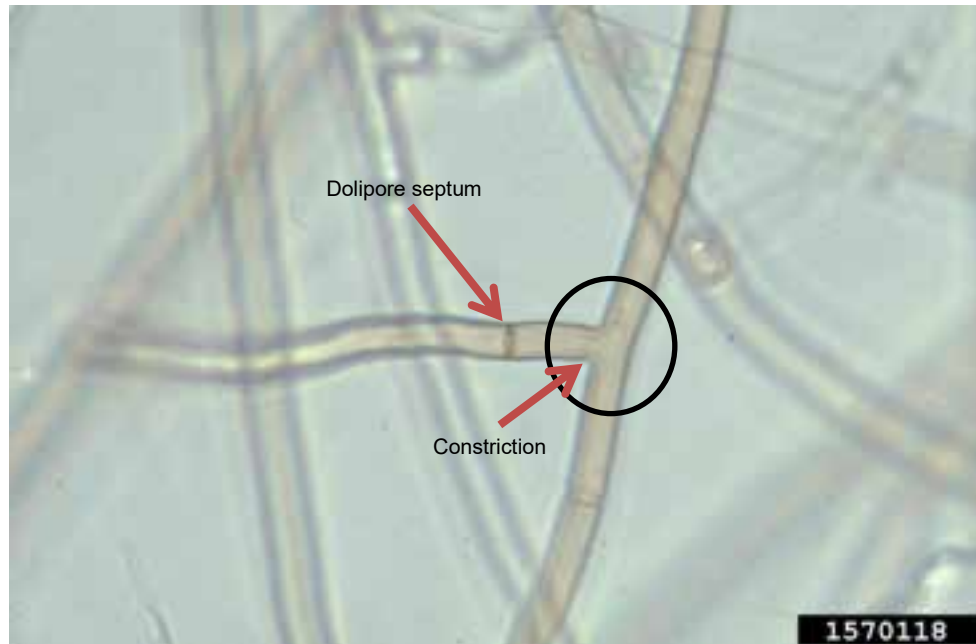


Figure 8 Typical hyphae of *R. solani*. Note right angled branching (circle), slight constriction at the base of the branch (arrow) and dolipore septum (arrow). Source: Gerald Holmes, Valent USA Corporation, Bugwood.org

5.1.8.2 PCR

Polymerase Chain Reaction (PCR) is a rapid, specific, and sensitive test that can be used to detect and diagnose Banded leaf and sheath spot of maize.

For example Pascual et al., (2000a) used PCR-RFLP and RAPD fingerprinting to characterise isolates of *R. solani* causing Banded leaf and sheath blight in the Philippines. Saylor and Yang (2007) have also investigated the use of Real-Time quantitative PCR for the identification of *R. solani* AG-1 IA causing Rice sheath blight on infected rice. This anastomosis group also affects maize (see Section 5.1.4). Similarly a PCR test was developed by Matsumoto (2002) that can be used to identify *R. solani* isolates in AG1 (IA, IB, IC and AG2 (2-1 and 2-2) subgroups. These and similar tests could be used for the diagnosis of Banded leaf and sheath spot on suspect material.

5.1.9 Pest risk analysis – Banded leaf and sheath spot

Potential or impact	Rating
Entry potential	HIGH
Establishment potential	MEDIUM
Spread potential	HIGH
Economic impact	HIGH
Overall risk	HIGH

5.1.9.1 ENTRY POTENTIAL

Rating: High

Banded leaf and sheath spot of maize is seed-borne (Ahuja and Payak 1982; DAFF 1999). It is also spread with the movement of infected soil and plant debris (Singh and Shahi 2012; Lin et al., 2008).

This suggests that there is a risk of introducing this pathogen on seeds, plant material and soil from other countries.

Based on this information the entry potential of Banded leaf and sheath spot into Australia is considered to be **High**.

5.1.9.2 ESTABLISHMENT POTENTIAL

Rating: MEDIUM

Establishment of Banded leaf and sheath spot will require access to appropriate hosts and suitable environmental conditions for infection and the survival of the pathogen.

Hosts such as maize and other host plants (as described in Section 5.1.4) are widely planted in Australia. For example more than 422,000 ha of maize was planted in 2011-12 (ABARES 2012).

Singh and Shahi (2012) describe the optimal environmental conditions for the development of Banded leaf and sheath spot as being 28°C with a relative humidity of 88 - 90 % during the first week of infection, development is slow when the relative humidity drops below 70 %. The requirement for high humidity levels means that the pathogen is more likely to develop in coastal areas and/or tropical areas of Australia rather than southern maize production areas such as the NSW Riverina.

Based on the suitability of the climate and the availability of host plants the establishment potential of this pathogen in Australia is considered to be **Medium**.

5.1.9.3 SPREAD POTENTIAL

Rating: High

Banded leaf and sheath spot is spread with the movement of infected soil and plant debris (Singh and Shahi 2012; Lin et al., 2008), irrigation water (Singh and Shahi 2012) and seed (Ahuja and Payak 1982; DAFF 1999). For shorter distances (i.e. between plants) the pathogen is spread by direct contact between infected and non-infected leaves (Singh and Shahi 2012).

Based on this information the potential for spread of Banded leaf and sheath spot following establishment is considered to be **High**.

5.1.9.4 ECONOMIC IMPACT

Rating: High

Banded leaf and sheath spot is considered to be a major pathogen of maize overseas, especially in Asia. This disease has been reported to cause yield losses of 23 - 97 % (Saxena 2010).

Based on the significant losses in yield reported overseas the economic impact of this pathogen is expected to be **High**.

5.1.9.5 OVERALL RISK

Rating: HIGH

Based on the individual ratings above, the combined overall risk is considered to be **High**.

6 Pest management

6.1 Response checklist

The following checklist (Table 4) provides a summary of the response measures to be considered and documented within a Response Plan during an incursion of an exotic necrotrophic foliage affecting pathogen.

Table 4. Checklist of requirements to be identified in a Response Plan

Checklist item	Further information
Destruction methods for plant material, soil and disposable items	Section 7.1.1, 7.1.2
Disposal issues	Section 7.1.3
Quarantine and movement controls	Section 7.3
Decontamination and hygiene	Section 7.5
Diagnostic information	Sections 5.1.8
Surveillance and tracing	Section 7.6
Surveys and epidemiology	Section 6.2
Zoning	Section 7.4
Communication strategy	Section 10.3

A range of specifically designed procedures for the emergency response to a pest incursion and a general communication strategy refer to PLANTPLAN (Plant Health Australia 2013).

6.2 Surveys and epidemiology

Information provided in Sections 6.2.1 to 6.2.3 provides a framework for the development of early detection and delimiting surveys for necrotrophic foliage affecting pathogens.

Personnel should avoid moving any soil and plant material between paddocks and properties. Footwear, tools, equipment and vehicles should be thoroughly washed of soil and plant debris and then sanitised with a registered disinfectant. Extra precautions should be taken when working areas known to be infested by the pathogen.

6.2.1 Technical information for planning surveys

When developing surveys for presence and/or distribution of necrotrophic foliar pathogens, the following characteristics provide the basic epidemiological knowledge to inform the survey strategy:

- Plant material may be asymptomatic, or may not display obvious symptoms at all growth stages. For example Banded leaf and sheath spot generally begins to show visual symptoms between 30 and 50 days after germination (Rai 2012; Singh and Shahi 2012, Patra 2007).

- Host species in Australia are likely to be numerous and widely dispersed and may be present within farm paddocks, as well as home gardens, landscape plantings, nurseries and as weeds.
- The risk of pathogen movement on plant material, machinery, equipment and personal effects is high.
- Some necrotic pathogens can be dispersed via seed or air-borne inoculum. For example: Banded leaf and sheath spot is seed-borne (Ahuja and Payak 1982; DAFF 1999). There is also a suggestion that basidiospores of the teleomorph may spread the pathogen between areas and hosts under ideal conditions (Pascual et al., 2000a).
- Other sources of infection include infected or contaminated crop debris, volunteer plants and alternate host crops.
- Production areas and significant proportions of Australia may have favourable climatic conditions for the pathogens spread and establishment. The area suitable for the pathogen will vary between species and can be estimated based on the known climatic requirements of the specific pathogen.

6.2.2 Surveys for early detection of an incursion

Points to consider in effectively monitoring necrotrophic foliar pathogen populations are:

- Ensure that the laboratory diagnostician has the relevant diagnostic tools and expertise in the specific pathogen to be identified.
- Initial surveys should concentrate on symptomatic plants (i.e. plants showing lesions or spots on their leaves, stems, sheaths, etc., see Section 5.1.7 for symptoms of Banded leaf and sheath spot).
- If pathogens are detected, or suspected, samples of the infected tissue should be collected for further diagnosis.

Points to consider in monitoring infected areas are:

- The host range of the pathogen must be determined and potential hosts grouped into risk categories in order to trace the transmission and expression of the disease (high, medium and low).
- Conditions under which transmission, amplification and expression of the disease occurs must be determined to assess the likelihood of detection and reporting through general surveillance and to assist with the development of protocols for targeted surveillance.
- Potential pathways for distribution of infected or contaminated material must be determined.
- Depending on the pathogen, distribution of the pathogen in the plant may be irregular and the plant material most likely to be infected should be determined for accurate diagnostics.
- Depending on the pathogen, host species in Australia may be numerous, widely dispersed and may be present within farms, nurseries, home gardens, landscape plantings or as weeds.
- Mycologist expertise will be needed to determine diagnostic protocols and sampling requirements including the age of plant material to be sampled, time of year and the potential to bulk samples from plant species or cultivars.

Important points to consider when developing early detection surveys are:

- Awareness information should be targeted at people who are in regular close contact with potential hosts in high risk areas (e.g. farmers, agronomists).
- Systematic and careful inspection of crops is essential to prevent the introduction of a necrotrophic foliar pathogen and limit its spread within and from contaminated areas. Early detection of disease symptoms while the pathogen is present at low levels will provide the best chance of eradication success.
- Personnel involved in surveys must be trained to recognise particular symptoms of the disease and other similar disorders for comparison. This is particularly important for necrotrophic foliar pathogens as visual symptoms often consist of spots and lesions that could be confused with a range of biotic and abiotic factors.

6.2.3 Delimiting surveys in the event of an incursion

Delimiting surveys should comprise local surveys around the area of initial detection concentrating on areas of reduced or unusual crop growth or where disease symptoms are obvious. Symptomatic plants should be tested to confirm the presence of the pathogen followed by random sampling from within the same crop to estimate the disease incidence. Surrounding host crops should then be surveyed to determine the extent of the incursion and to inform further survey work.

If the pathogen can be seed transmitted seed trace-back investigations will indicate how many seed lots and crops will need to be tested. If the seed used has been sown at several sites, delimiting surveys should be conducted at each site.

Delimiting surveys are essential to determine the extent of the incursion and inform the decision-making process. When establishing delimiting surveys the following should be considered:

- The size of the survey area (Figure 9) will depend on the size of the infected area and the severity of the infection. Other influencing factors include; distribution pathways for soil and plant material (including seed, if seed-borne) and potentially the weather patterns experienced during the period prior to detection. Other considerations are; the movement of people, plant material or equipment as a result of trace-forward and trace-back investigations.
- Foliage affecting necrotrophic pathogens may be spread on plant material adhering to machinery, vehicles, livestock or humans.
- All potential host species of the pathogen (see Section 5.1.4) should be surveyed, with particular attention paid to the species in which the pathogen was initially detected.
- Known infected plant material should be collected for ongoing diagnostic purposes (refer to Section 6.2.4).
- If the incursion is in a populated area, publication and distribution of information sheets and appeals for public assistance may be helpful.

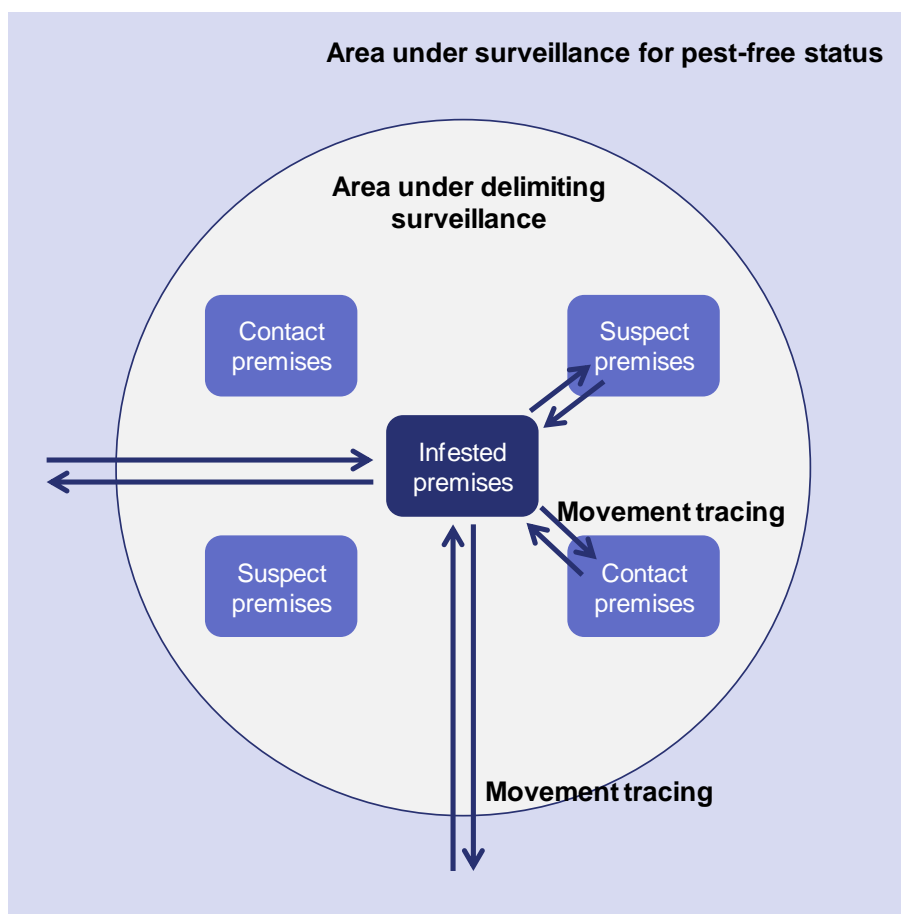


Figure 9. Diagram of a delimiting survey showing surveillance activities from the infested premises

6.2.4 Collection and treatment of samples

Once initial samples have been received and preliminary diagnosis made, follow up samples to confirm identification of the pathogen will be necessary. This will involve sampling directly from the infested crop, and sampling crops over a larger area to determine the extent of disease distribution.

Leaf samples from at least 100 plants should be taken at random from each site being surveyed. The exact number of samples and survey design will depend on the crop and pest being surveyed for and the statistical confidence required. However, preference may be given to symptomatic plants in fields where the disease incidence is low.

All plants should be assessed for the presence of the pathogen's symptoms. See Section 5.1.7 for details of Banded leaf and sheath spot symptoms.

Protocols for the collection, transport and diagnosis of suspect Emergency Plant Pests (EPPs) must follow PLANTPLAN (Plant Health Australia 2013). Any personnel collecting samples for assessment should notify the diagnostic laboratory prior to submitting samples to ensure expertise is available to undertake the diagnosis. A Standard Operating Procedure (SOP) for Collection and transport of EPPs is available as a supporting document of PLANTPLAN (Plant Health Australia, 2013) (www.planthealthaustralia.com.au/wp-content/uploads/2013/12/SOP-Collection-and-transport-of-EPPs.pdf).

The total number of samples collected may run into the hundreds or even thousands. It is vital that a system of sample identification is determined early in the procedure to allow for rapid sample processing and accurate recording of results.

Samples should be initially collected over a representative area of the infected crop to determine the distribution of the pathogen. Plants showing visual symptoms may appear in discrete patches or spread throughout the crop depending on the source of the pathogen.

It is important to note the distribution of disease throughout the crop, as this may indicate whether the pathogens entry and spread was seed-borne, carried on plant material from adjacent paddocks or originated from contaminated machinery or human movement.

It is important that all personnel involved in crop sampling and inspections take all precautions to minimise the risk of disease spread between crops by decontaminating between paddocks.

All sample containers should be clearly labelled with the name, address and contact phone number of both the sending and receiving officers.. Containers should be carefully sealed to prevent loss, contamination or tampering of samples. The Chief Plant Health Manager will select the preferred laboratory. Additional labelling includes the identification of affected plant species/parts, the location of the property/paddock (preferably with a GPS reading) as well as symptoms and an image if available. For further information on the appropriate methods to use, refer to the SOP for the Collection and transport of EPPs, available as a supporting document of PLANTPLAN (Plant Health Australia, 2013) (www.planthealthaustralia.com.au/wp-content/uploads/2013/12/SOP-Collection-and-transport-of-EPPs.pdf).

6.2.4.1 HOW TO TREAT SAMPLES

Samples should be treated in a manner that allows them to arrive at the laboratory in a fresh, well-preserved state. An esky with ice packs or portable fridge should be carried when sampling crops. Samples should be wrapped in damp newspaper, bundled into a plastic bag and clearly labelled. For appropriate labelling and packaging procedures for suspect EPPs consult the SOP for the Collection and transport of EPPs available as a supporting document of PLANTPLAN (Plant Health Australia, 2013) (www.planthealthaustralia.com.au/wp-content/uploads/2013/12/SOP-Collection-and-transport-of-EPPs.pdf).

Samples should be processed as quickly as possible after collection from the field if sub-cultures are to be made from infected tissue. Once removed from the field, fresh plant samples can deteriorate and become contaminated by other mould, fungi and bacteria, which may prevent successful sub-culturing of the pathogen. Sub-culturing should be done within three to four days after collection from the field. Infected plant tissue to be used for PCR analysis can be placed in a -80°C freezer and stored for an indefinite period without damaging fungal DNA.

Long term storage of fungal isolates is possible with plant specimens freeze dried for future reference (without loss of viability) or deep frozen and maintained at -80°C, which can then be used to extract DNA.

6.2.5 Epidemiological study

There are many factors that affect the development of necrotrophic foliar pathogens the field. These include: the presence of virulent strains in the environment, susceptibility of the crop varieties, climatic conditions, irrigated or non-irrigated crops and interactions with other micro-organisms. Inoculum densities are also important as disease symptoms may not be apparent when there are low levels of inoculum.

The number of infected plants within a crop will depend on the source and amount of primary inoculum available and whether environmental conditions have been favourable for the pathogen to spread from the original infection site.

Sampling of crops within a district and beyond will be based upon the origins of the initial suspect sample(s). Factors to consider will be:

- The proximity of other susceptible plants to the initial inoculum source(s), including both the current and previous growing seasons. This will include crops on the infected property and those on neighbouring properties. Alternative hosts should also be considered, including weeds, fodder and garden plants.
- Machinery or vehicles that have been into the known infected area or in close proximity to the source of the pathogen. This is especially important due to the possible movement of contaminated soil on machinery moving between areas.
- The extent of human movement into and around the infected area. A possible link to recent overseas travel or visitors from other regions or the recent importation of plant material, machinery or goods from other regions should also be considered.
- The source of seed and how long that seed has been used by the grower, this is especially important if the pathogen could be dispersed on seed, as is the case for Banded leaf and sheath spot (Ahuja and Payak 1982; DAFF 1999).
- Seed movements and if any other crops have been sown from the same seed source (if the pathogen can be spread with seed).
- The temperature and environmental conditions. Temperature and environmental conditions (e.g. rain fall events, Relative Humidity etc.) affect the severity and spread of the pathogen and therefore need to be considered.

6.2.6 Models of spread potential

No models of spread potential have been developed for Banded leaf and sheath spot of maize. If models were to be developed for this pathogen, or other foliage affecting necrotrophic pathogens, they would need to consider how the pathogen is dispersed (see Section 5.1.3), the potential host range (see Section 5.1.4), host availability and any climatic requirements.

6.2.7 Pest Free Area guidelines

The establishment and maintenance of Pest Free Areas (PFAs) is a resource-intensive process. Prior to development of a PFA consideration should be given to alternative methods (e.g. treatments or enclosed quarantine) that achieve an equivalent biosecurity outcome to a PFA. A benefit-cost analysis is useful for this purpose.

Determination of PFAs should be completed in accordance with the International Standards for Phytosanitary Measures (ISPMs) 8 and 10 (IPPC 1998a, 1999).

Additional information is provided by the IPPC (1995) in Requirements for the Establishment of Pest Free Areas. This standard describes the requirements for the establishment and use of pest free areas as a risk management option for phytosanitary certification of plants and plant products. Establishment and maintenance of a PFA can vary according to the biology of the pest, pest survival potential, means of dispersal, availability of host plants, restrictions on movement of produce, as well as PFA characteristics (size, degree of isolation and ecological conditions).

In the event of an incursion, specific guidelines for surveys and monitoring will be provided by the Consultative Committee on Emergency Plant Pests (CCEPP). General points to consider are:

- Design of a statistical delimiting survey for symptoms on host plants (see Section 6.2 for points to consider in the design).
- Plant sampling should be based on at least 100 plants taken at random per crop.
- Preliminary diagnosis can be based on plant symptoms and fungal morphology.
- PCR methods and diagnostic tools for confirmation of fungal identity.
- Surveys should also consider alternative host plants (see Section 5.1.4) and not be limited to the primary infected host.
- Information (including absence of the pest) should be recorded.

6.3 Availability of control methods

Once introduced and established, these pathogens can survive for extended periods, even in the absence of crop hosts, making eradication a long term process. Ongoing containment procedures to restrict the spread of the pathogen are required.

6.3.1 Priorities

- Confirm the presence of the pest.
- Limit movement of people and prevent movement of vehicles and equipment through affected areas.
- Stop the movement of any plant material, soil or machinery that could be carrying fungal spores from the infected area.
- Determine the strategy for the eradication/decontamination of infected host material.
- Determine the extent of the infestation through survey and plant material trace back and trace forward which would be assessed on a case by case basis and included within the response plan.
- Stop the movement of any seed that may be infected with the pathogen, this is especially important for pathogens that can be spread with seed, such as Banded leaf and sheath spot (Ahuja and Payak 1982; DAFF 1999).

6.3.2 General procedures for control

Control of foliage affecting necrotrophic pathogens is likely to be largely reliant on the use of fungicides, destruction of the host crop and reducing the spread of the pathogen between areas by controlling the movement of people, plant material and machinery. Specific control measures will be determined by the CCEPP, however, general procedures include:

- Keep traffic out of affected areas and minimise movement in adjacent areas.
- Adopt best-practice property hygiene procedures to restrict the spread of the pest between paddocks and adjacent properties.

- After surveys are completed, and permission has been obtained from the Chief Plant Health Manager or the CCEPP, destruction of the infested plant material, including seed (if the pathogen can be dispersed with seed), is an effective control measure.
- Avoid potential host plants in crop rotations, for example if Banded leaf and sheath spot was found maize other susceptible crops should be removed from the crop rotation for a period of time based on the survival ability of the pathogen.
- On-going surveillance of infected and surrounding areas to ensure the pest is eradicated.
- Do not plant seed from infected plants or seed sourced from infected regions, as seeds could be a source of inoculum. For example Banded leaf and sheath spot can be dispersed with seed (Ahuja and Payak 1982; DAFF 1999). If known to be dispersed with seed, seed should be destroyed or treated to avoid spreading the pathogen to new areas.

6.3.3 Control of infected areas

If a small area is found to be infected, such as a small portion of a paddock, mechanically pull out the affected plants, as well as any healthy plants 5 - 10 metres surrounding the infected patch and then burn the plant in the patch. Particular care must be taken to minimize the transfer of infected soil and plant material from the area. Raking and burning the whole field at this stage is NOT an option as this procedure could spread the pathogen.

If a large area is infected, kill any surviving plants in the area, preferably with herbicides (note herbicides have to be registered by the Australian Pesticides and Veterinary Medicines Authority (APVMA) for this purpose prior to use), treat the resulting plant debris with an appropriate fungicide, then burn the crop debris and plough in. Once the dead plants have broken down, sow an alternative non-host crop or pasture to prevent erosion. Particular care must be taken to minimise the transfer of inoculum, plant material or soil from the once infected area.

All equipment used on the site should be thoroughly cleaned down, with products such as a farm degreaser or a 1 % bleach solution and washed down with a pressure cleaner on the affected farm. The clean down procedure should be carried out on a hard surface at a designated wash-down area to avoid recontamination of machinery.

Host plants should not be planted in the infected area for several years; the exact time will depend on the soil life of the inoculum. During this time it is important that volunteer plants are controlled (including along fences and road sides) as such plants could allow the pathogen to persist in the area. Surveys of the surrounding area must continue for some time to ensure that the eradication regime was successful. The exact time that surveys are required will be determined by the expected survival time of inoculum in the absence of host plants.

6.3.4 Weed management

Weeds can serve as alternate hosts of necrotrophic pathogens. If weed species are found to be potential hosts of the pathogen they will also need to be controlled, using a suitable herbicide. Special attention should be paid to weeds along fence lines and road sides adjacent to infected areas or crops as such weeds can act as disease reservoirs.

6.3.5 Chemical control

Chemical controls can be effective in an eradication campaign as these pathogens develop on the leaves and stems of the host where fungicidal sprays can easily come into contact with the pathogen. However in many cases the host plant will also need to be destroyed to ensure total destruction of the pathogen.

Table 5 details the chemicals that have been used to control Banded leaf and sheath spot on maize overseas. However any chemical used in Australia as part of a control or eradication program must be approved for that use by the APVMA before it can be applied.

In general necrotrophic foliar pathogens can be controlled using foliar sprays or by using seed treatments to minimise the damage caused by the pathogen to seedlings. In the case of Banded leaf and sheath spot both foliar and seed treatments have been used to control the pest overseas.

Table 5. Some chemicals used to control of Banded leaf and sheath spot

Chemical	Comments	Reference
<i>Bacillus subtilis</i> BR23 ¹¹	Seed treatments of <i>Bacillus subtilis</i> BR23 were more effective than Captan (applied at 10 g per kg seeds) and Metalaxyl (applied at 10 g per kg seeds) at controlling the pathogen on maize (Muis and Quimio 2006). <i>Bacillus subtilis</i> BR23 was also found to be more effective than Azoxystrobin when applied as a foliar spray (Muis 2007).	Muis and Quimio (2006); Muis (2007)
Captan ¹²	Seed treatments of Captan (applied at 10 g per kg seeds) and Metalaxyl (applied at 10 g per kg seeds) improved yields of infected plants but were not as effective as <i>Bacillus subtilis</i> BR23 at controlling the pathogen on maize (Muis and Quimio 2006). Rai (2012) suggests that Captan controls the pathogen when applied as a seed treatment at a rate of 2.5mg/kg seed.	Muis and Quimio (2006); Rai (2012)
Carbendazim ¹³	Validacin (a.i Validamycin), Bavistin (a.i Carbendazim), Captaf (a.i. Captan), Contaf (a.i Hexaconazole), Rhizolex (a.i Tolclofos methyl), Indofil M-45 (a.i Mancozeb) and Kavach (a.i Chlorpyrifos) were tested by Puzari et al., (1998) for the control of Banded leaf and sheath spot, of these chemicals Validacin (a.i Validamycin), and Bavistin (a.i Carbendazim) were the most effective at controlling the pathogen. Bavistin (a.i Carbendazim) was also the most effective of the seed treatments tested by Rakesh et al., (2011), which included: Bavistin (applied at 2.5 mg/kg of seed), Vitavax (applied at 2.5 mg/kg of seed) and Thiram (applied at 2.5 mg/kg of seed). Carbendazim (0.3 % a.i) and <i>Trichoderma viride</i> (0.4 % a.i) seed treatments were the most effective (in terms of reduced disease severity) of the treatments tested by Rani et al., (2013) for the control of Banded leaf and sheath spot of maize. Benomyl, Thiram, <i>Pseudomonas fluorescens</i> and <i>Bacillus subtilis</i> as seed and soil treatments were also tested. <i>Bacillus subtilis</i> was least effective but still provided some control of the pathogen compared to non-treated plants.	Puzari et al., (1998); Rakesh et al., (2011); Rani et al., (2013)

¹¹ Strain not commercially available overseas or in Australia. other strains available in Australia.

¹² Currently registered for use in Australia but not on maize. No international labels found describing the use of this chemical for the control of the pathogen on maize.

Chemical	Comments	Reference
Metalaxyl ¹⁴	Seed treatments of Captan (applied at 10 g per kg seeds) and Metalaxyl (applied at 10 g per kg seeds) improved yields of infected plants but were not as effective as <i>Bacillus subtilis</i> BR23 at controlling the pathogen on maize (Muis and Quimio 2006).	Muis and Quimio (2006)
Propiconazole ¹⁵	Two sprays of Propiconazole 25 % EC (applied as a solution containing 4 ml of chemical/L water) applied 30 and 40 days after germination reduced the impact of this pathogen.	Saxena (2010)
<i>Pseudomonas fluorescens</i> ¹⁶	Rai (2012) suggest that <i>Pseudomonas fluorescens</i> can be used to control Banded leaf and sheath spot when applied to soil as a solution containing 7 g of a peat based <i>Pseudomonas fluorescens</i> formulation/L of water. The same formulation is also used as a seed dressing at a rate of 16 g/kg seed. Sivakumar and Sharma (2007) used a solution containing the organism was made (containing 1.9*10 ⁷ colony forming units/gram of peat) and applied at a rate of 16 g (i.e. 3.04*10 ⁹ colony forming units)/kg seed, 2.5 kg/ha as an in-furrow application or at a rate of 5 g/L of water as a foliar spray to control Banded leaf and sheath spot.	Rai (2012); Sivakumar and Sharma (2007)
Tolclofos-methyl ¹⁷	Rai (2012) suggests that Rizolex 50WP (Tolclofos methyl) applied as a solution containing 10g Rizolex 50WP/10 L of water applied as an in crop spray to controls the pathogen.	Rai (2012)
<i>Trichoderma viride</i> ¹⁸	Carbendazim (0.3 % a.i) and <i>Trichoderma viride</i> (0.4 % a.i) seed treatments were the most effective (in terms of reduced disease severity) of the treatments tested by Rani et al., (2013) for the control of Banded leaf and sheath spot of maize. Benomyl, Thiram, <i>Pseudomonas fluorescens</i> and <i>Bacillus subtilis</i> as seed and soil treatments were also tested. <i>Bacillus subtilis</i> was least effective but still provided some control of the pathogen compared to non-treated plants.	Rani et al., (2013)

¹³ No international label was found describing this chemicals use for the contrl of the pest. the chemical is also used in Australia but not on maize.

¹⁴ Currently registered for use in Australia on maize. No international labels found specifying this chemicals use for the control of the pathogen on maize.

¹⁵ The chemical is currently labelled for use in Australia but not for use on maize crops. No labels found describing the control of the pathogen on maize overseas.

¹⁶ No overseas labels found describing this chemicals use for the control of the pathogen. Not used in Australia.

¹⁷Tolclofos-methyl is used in Australia to control *R. solani* on cotton and potato. Active ingredient is not currently used in Australia on maize. No overseas labels found describing this chemicals use for the control of the pathogen.

¹⁸ Not used in Australia. No overseas labels found describing this chemicals use for the control of the pathogen.

Chemical	Comments	Reference
Validamycin ¹⁹	<p>Rai (2012) suggests that Validamycin provides control of the pathogen when applied as an in crop spray at a rate of 2.7ml of chemical/L water to the lower parts of the plant.</p> <p>Validacin (a.i Validamycin), Bavistin (a.i Carbendazim), Captaf (a.i. Captan), Contaf (a.i Hexaconazole), Rhizolex (a.i Tolclofos methyl), Indofil M-45 (a.i Mancozeb) and kavach (a.i Chlorpyrifos) were tested by Puzari et al., (1998) for the control of Banded leaf and sheath spot, of these chemicals Validacin (a.i Validamycin) and Bavistin (a.i Carbendazim) were the most effective of the chemicals tested.</p>	<p>Rai (2012); Puzari et al., (1998)</p>

6.3.6 Cultural Control

Cultural controls can be used to control necrotrophic foliar pathogens. Effective cultural controls include:

- Crop rotations that do not include susceptible host plants can be a viable option during eradication efforts, especially if the pathogen's inoculum is short lived. Crop rotation can also be used for long-term management of the pest if eradication is not feasible. Overseas, crop rotations for two to three years have been shown to reduce the severity Banded leaf and sheath spot. (Saxena 2010).
- The use of disease free seed is another cultural control practice that can be used to minimise the further introduction of seed-borne necrotrophic pathogens.
- Altering sowing times and/or the maturity of the crop variety sown (so that the host is not at its most vulnerable growth stage at the same time that the pathogen is at its most effective) can also help manage the impact of some pathogens.
- Cultivating or burning the paddock may help reduce inoculum load for pathogens that overwinter in crop debris (such as Banded leaf and sheath spot). However such practices are at odds with no-till and minimal-tillage practices that are widely practiced in Australia. This trade off must be considered before implementing such practices.

6.3.7 Host-Plant Resistance

The development of resistant varieties of host plants offers a low cost method of managing the impact of foliage affecting necrotrophic pathogens.

Several papers have been written in recent years evaluating maize varieties for resistance to Banded leaf and sheath spot (Madhavi et al., 2012; Garg et al., 2007; Bhavana and Gadag 2009; Hooda et al., 2012). To date several varieties have been identified as showing some level of tolerance to the pathogen. This suggests that there is a possibility of managing the disease with resistant varieties in the event of an incursion of this pathogen.

¹⁹ Validamycin is not used in Australia. No overseas labels specifying the use of this chemical for the control of the pathogen on maize were found.

6.3.8 Biological control

The use of biological control of necrotrophic foliar pathogens is not a common practice. However some work has been carried out looking at the biological control of foliage affecting necrotrophic pathogens on grain crops. For example Sivakumar and Sharma (2007); Muis and Quimio (2006) and others have studied the biological control of Banded leaf and sheath spot and identified some organisms that are antagonistic towards the pathogen (Table 6).

Table 6 Organisms found to be antagonistic towards Banded leaf and sheath spot

Biological control	Life form of biological control agent	Reference
<i>Bacillus subtilis</i> BR23	Gram-positive bacteria	Muis and Quimio (2006)
<i>Pseudomonas fluorescens</i> PF-1 ²⁰	Gram negative bacteria	Sivakumar and Sharma (2007)
<i>Rhizoctonia</i> sp. isolate Rhv7	Basidiomycota fungus	Pascual et al., (2000b)

7 Course of action – eradication methods

Additional information is provided by the IPPC (1998b) in Guidelines for Pest Eradication Programmes. This standard describes the components of a pest eradication programme which can lead to the establishment or re-establishment of pest absence in an area. A pest eradication programme may be developed as an emergency response measure to prevent establishment and/or spread of a pest following its recent entry (re-establish a pest free area) or a measure to eliminate an established pest (establish a pest free area). The eradication process involves three main activities: surveillance, containment, and treatment and/or control measures.

7.1 Destruction strategy

7.1.1 Destruction protocols

- No plant material should be removed from the infested area unless part of the disposal or sampling procedure.
- Infected crops should be destroyed by the application of a herbicide (and fungicide if a suitable chemical is available for controlling the pathogen in question) followed by burning and ploughing. Care must be taken to minimise the spread of soil and plant debris from the site during this process.
- Disposable equipment, infected plant material or soil should be disposed of by autoclaving, high temperature incineration or deep burial (preferably on site).
- Any plant material or equipment removed from the site for disposal should be securely contained.

²⁰ Sivakumar and Sharma (2007) used a solution containing the organism was made (containing 1.9×10^7 colony forming units/gram of peat) and applied at a rate of 16 g (i.e. 3.04×10^9 colony forming units)/kg seed, 2.5 kg (4.75×10^{10} colony forming units)/ha as an in-furrow application or at a rate of 5 g (9.5×10^7 colony forming units)/L of water as a foliar spray to control Banded leaf and sheath spot.

- All vehicles and farm machinery that enter the infected field should be thoroughly washed, preferably using a detergent, farm degreaser or a 1 % (available chlorine) bleach solution.

7.1.2 Decontamination protocols

If decontamination procedures are required, machinery, equipment and vehicles in contact with infected plant material or soil or working within the Quarantine Area, should be washed to remove soil and plant material using high pressure water or scrubbing with products such as a farm degreaser or a 1 % bleach solution in a designated wash down area. Disinfection and decontamination guidelines are available as a supporting document of PLANTPLAN (Plant Health Australia, 2013) (www.planthealthaustralia.com.au/wp-content/uploads/2013/12/Guidelines-Disinfection-and-decontamination.pdf).

General guidelines for wash down areas are as follows:

- Located away from crops or sensitive vegetation.
- Readily accessible with clear signage.
- Access to fresh water and power.
- Mud free, including entry and exit points (e.g. gravel, concrete or rubber matting).
- Gently sloped to drain effluent away.
- Effluent must not enter water courses or water bodies.
- Allow adequate space to move larger vehicles.
- Away from hazards such as power lines.
- Waste water, soil or plant residues should be contained
- Disposable overalls and rubber boots should be worn when handling infected soil or plant material in the field. Footwear and clothes in contact with infected soil or plant material should be disinfected at the site or double-bagged to remove for cleaning.
- Skin and hair in contact with infested plant material or soil should be washed.

In the event of an incursion of a necrotrophic foliar pathogen, additional or modified procedures may be required for the destruction of the pathogen. Any sterilisation procedure must be approved for use in the endorsed Response Plan.

7.1.3 Plants, by-products and waste disposal

- Seeds harvested from infected plants and any soil or infected plant material removed from the infected site should be destroyed by (enclosed) high temperature incineration, autoclaving or deep burial (in a non-cropping area).
- Infested paddocks should remain free of susceptible host plants (including weeds, alternative hosts and volunteer plants) (see Section 5.1.4 for a list of the hosts of Banded leaf and sheath spot) until the area has been shown to be free from the pathogen. The exact period of time that the infested area should remain free of host plants will be determined by the survival ability of the pathogen's spores.

- Many pathogens have been shown to express resistance/tolerance to specific fungicides. In the event of a pest incursion this information needs to be considered when selecting chemicals to use for the eradication of the pathogen.

7.2 Containment strategies

For some exotic pest incursions where eradication is considered impractical, containment of the pathogen may be attempted to prevent or minimise its spread and impact on other areas. The decision to eradicate or contain the pathogen will be made by the National Management Group based on scientific and economic advice.

7.3 Quarantine and movement controls

Consult PLANTPLAN (Plant Health Australia 2013) for further administrative details and procedures.

7.3.1 Quarantine priorities

- Plant material (including seed if the pathogen is known to be spread with seed, as is the case for Banded leaf and sheath spot) and soil at the site of infestation to be subject to movement restrictions as such material could potentially spread the pathogen to new areas.
- Machinery, equipment, vehicles and disposable equipment in contact with infested plant material or soil, or present in close proximity to the site of infestation to be subject to movement restrictions.
- Harvesting of infected crops should be prevented as the dust created during harvesting can, in some instances, contain fungal spores and therefore spread the disease to neighbouring areas.

7.3.2 Movement controls

If Restricted or Quarantine Areas are practical, movement of equipment or machinery should be restricted and movement into the area only allowed by permit.

Movement of people, vehicles and machinery, to and from affected farms, must be controlled to ensure that infected soil or plant debris (including seed) is not moved between properties. This can be achieved through the following; however specific measures must be endorsed in the Response Plan:

- Signage to indicate quarantine area and restricted movement into and within these zones.
- Fenced, barricaded or locked entry to quarantine areas.
- Movement of equipment, machinery, plant material or soil by permit only. Therefore, all non-essential operations in the area or on the property should cease.
- Where no dwellings are located within these areas, strong movement controls should be enforced.

- Where dwellings and places of business are included within the Restricted and Control Areas movement restrictions are more difficult to enforce, however limitation of contact with infested plants should be enforced.
- Clothing and footwear worn at the infected site should either be decontaminated or should not leave the farm until thoroughly disinfected, washed and cleaned.
- Residents should be advised on measures to minimise the inadvertent transport of fungal spores from the infested area to unaffected areas.
- Plant material or plant products, including seed, must not be removed from the site unless part of an approved disposal or sampling procedure.
- All machinery and equipment should be thoroughly cleaned down with a high pressure cleaner (see Section 7.1.2) or scrubbed with products such as a farm degreaser or a 1 % bleach (available chlorine) solution, prior to leaving the affected area. Seed from the affected site should not be used for planting new crops, feeding stock or for human consumption.
- Hay, stubble or trash should not be removed from the site, as these materials could inadvertently spread inoculum.

7.4 Zoning

The size of each quarantine area will be determined by a number of factors, including the location of the incursion, biology of the pest, climatic conditions and the proximity of the infested property to other infested properties. This will be determined by the Response Agency during initial containment efforts and during the development of the Response Plan. Further information on quarantine zones in an Emergency Plant Pest (EPP) incursion can be found in Section 4.1.4 of PLANTPLAN (Plant Health Australia 2013). These zones are outlined below and in Figure 10.

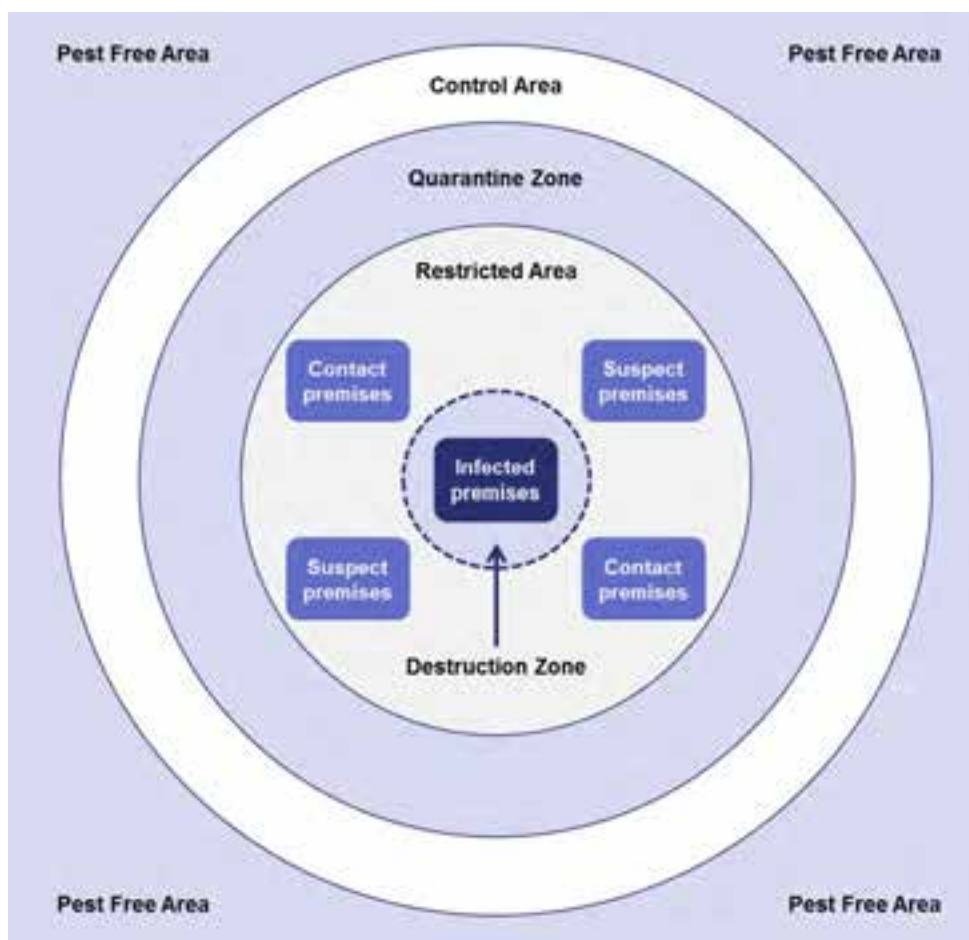


Figure 10. Schematic diagram of quarantine zones used during an EPP incursion (not drawn to scale)

7.4.1 Destruction Zone

The size of the destruction zone (i.e. zone in which the pest and all host material is destroyed) will depend on the ability of the pathogen to spread, distribution of the pathogen (as determined by delimiting surveys), time of season and other factors which may contribute to the pathogens natural or assisted spread.

If destruction of hosts is considered, the entire crop should be destroyed after the extent of infection has been established. The delimiting survey will determine whether or not neighbouring host crops are infected and need to be destroyed.

The Destruction Zone will usually be the entire crop but may be the entire farm or infected areas of management if spread is likely to have occurred prior to detection.

If the movement of the pest to adjacent crops appears likely, they will also need to be destroyed.

Particular care needs to be taken to ensure that plant material or soil is not moved into surrounding areas. Where possible, destruction should take place in dry conditions to limit the movement of mud, plant material and water between areas.

7.4.2 Quarantine Zone

The Quarantine Zone is defined as the area where voluntary or compulsory restraints are in place for the affected property or properties. These restraints may include restrictions or movement controls for the removal of plants, people, soil or contaminated equipment from an infected property.

7.4.3 Buffer Zone

A Buffer Zone may be required depending on the scale and nature of the incident. It is defined as the area in which the pest does not occur but where movement controls or restrictions for removal of plants, people, soil or equipment from this area are still deemed necessary. The Buffer Zone may enclose an infested area (and is therefore part of the Control Area) or may be adjacent to an infested area.

7.4.4 Restricted Area

The Restricted Area is defined as the zone immediately around the infected premises and suspected infected premises. The Restricted Area is established following initial surveys that confirm the presence of the pest. The Restricted Area will be subject to intense surveillance and movement control with movement out of the Restricted Area to be prohibited and movement into the Restricted Area to occur by permit only. Multiple Restricted Areas may be required within a Control Area.

7.4.5 Control Area

The Control Area is defined as all areas affected within the incursion. The Control Area comprises the Restricted Area, all infected premises and all suspected infected premises and will be defined as the minimum area necessary to prevent spread of the pest from the Quarantine Zone. The Control Area will also be used to regulate movement of all susceptible plant species to allow trace back, trace forward and epidemiological studies to be completed.

7.5 Decontamination and hygiene

Decontaminant practices are aimed at eliminating the pathogen thus preventing its spread to other areas.

7.5.1 Decontamination procedures

General guidelines for decontamination and clean up:

- Refer to Disinfection and decontamination guidelines available as a supporting document of PLANTPLAN (Plant Health Australia, 2013) (www.planthealthaustralia.com.au/wp-content/uploads/2013/12/Guidelines-Disinfection-and-decontamination.pdf).
- Keep traffic out of affected area and minimise it in adjacent areas.
- Adopt best-practice property hygiene procedures to retard the spread of the pathogen between fields and adjacent properties.

- Machinery, equipment and vehicles in contact with infested or infected plant material or soil present within the Quarantine Zone, should be washed to remove soil and plant material using high pressure water or scrubbing with products such as a degreaser or a bleach solution in a designated wash down area as described in Section 7.1.2.
- Only recommended materials are to be used when conducting decontamination procedures, and should be applied according to the product label.
- Infested plant material should be disposed of by autoclaving, high temperature (enclosed) incineration or deep burial (on site).

7.5.2 General safety precautions

For any chemicals used in the decontamination, follow all safety procedures listed within each MSDS.

7.6 Surveillance and tracing

7.6.1 Surveillance

Detection and delimiting surveys are required to delimit the extent of the outbreak, ensuring areas free of the pest retain market access and appropriate quarantine zones are established.

Initial surveillance priorities include the following:

- Surveying all host growing properties and businesses in the pest quarantine area.
- Surveying all properties and businesses identified in trace-forward or trace-back analysis as being at risk.
- Surveying all host growing properties and businesses that are reliant on trade with interstate or international markets which may be sensitive to the presence of the pathogen.
- Surveying other host growing properties and backyards.

7.6.2 Survey regions

Establish survey regions around the surveillance priorities identified above. These regions will be generated based on the zoning requirements (see Section 7.4), and prioritised based on their potential likelihood of being infected. Surveillance activities within these regions will either allow for the area to be declared pest free or will help determine the extent of the incursion to allow for further containment measures. Detailed information regarding surveys for necrotrophic foliar pathogen infected plant material have been outlined elsewhere in this plan (refer to Section 6.2).

Steps outlined in Table 7 form a basis for a survey plan. Although categorised in stages, some stages may be undertaken concurrently based on available skill sets, resources and priorities.

Table 7. Phases to be covered in a survey plan

Phase 1	<ul style="list-style-type: none"> Identify properties that fall within the buffer zone around the infected premise. Complete preliminary surveillance to determine ownership, property details, production dynamics and tracings information (this may be an ongoing action).
Phase 2	<ul style="list-style-type: none"> Preliminary survey of host crops on properties in buffer zone establishing points of pathogen detection.
Phase 3	<ul style="list-style-type: none"> Surveillance of an intensive nature, to support control and containment activities around points of pathogen detection.
Phase 4	<ul style="list-style-type: none"> Surveillance of contact premises. A contact premise is a property containing susceptible host plants, which are known to have been in direct or indirect contact with an infected premises or infected plants. Contact premises may be determined through tracking movement of materials from the property that may provide a viable pathway for spread of the pathogen. Pathways to be considered are: <ul style="list-style-type: none"> Items of equipment and machinery which have been shared between properties including bins, containers, irrigation lines, vehicles and equipment. The producer and retailer of infected material, if this is suspected to be the source of the outbreak. Labour and other personnel that have moved from infected, contact and suspect premises to unaffected properties (other growers, tradesmen, visitors, salesmen, crop scouts, harvesters and possibly beekeepers). Movement of plant material and soil from controlled and restricted areas. Storm and rain events and the direction of prevailing winds that result in air-borne dispersal of the pathogen during these weather events.
Phase 5	<ul style="list-style-type: none"> Surveillance of farms, gardens and public land where plants known to be hosts of the pathogen are being grown.
Phase 6	<ul style="list-style-type: none"> Agreed area freedom maintenance, post-control and containment.

7.6.3 Post-eradication surveillance

The period of pest freedom sufficient to indicate that eradication of the pest has been achieved will be determined by a number of factors, including growth conditions, the previous level of infection, the control measures applied and the pests biology.

Specific methods to confirm the eradication of foliage affecting necrotrophic pathogens may include:

- Establishment and monitoring of sentinel plants at the site of infection.
- Sentinel plants should remain in place and inspected on a fortnightly basis for a further 6 weeks and then on a monthly basis.
- If symptoms or pathogen are detected, samples are to be collected and stored and plants destroyed.
- Surveys comprising of host plant sampling for the pathogen should be undertaken for a minimum of three years after eradication has been achieved (or as endorsed by the CCEPP). Note that the biology of the pathogen will dictate the minimum number of years that surveys need to be undertaken, i.e. if inoculum is long lived the surveys will need to continue for a longer period of time.

8 Technical debrief and analysis for stand down

Refer to PLANTPLAN (Plant Health Australia 2013) for further details

The emergency response is considered to be ended when either:

- Eradication has been deemed successful by the lead agency, with agreement by the Consultative Committee on Emergency Plant Pests and the Domestic Quarantine and Market Access Working Group
- Eradication has been deemed impractical and procedures for long-term management of the disease risk have been implemented

A final report should be completed by the lead agency and the handling of the incident reviewed.

Eradication will be deemed impractical if, at any stage, the results of the delimiting surveys lead to a decision to move to containment/control.

9 References

Agricultural and Resource Economics and Sciences (ABARES) (2012) Agricultural commodity statistics 2012, Australian Bureau of Agricultural and Resource Economics and Sciences, December, Canberra. Available from:

www.daff.gov.au/abares/publications_remote_content/publication_topics/agricultural?sq_content_src=%2BdXJsPWh0dHAIM0EIMkYIMkYxNDMuMTg4LjE3LjIwJTJGYW5yZGwIMkZEQUZGU2VydmIjZSUyRmRpc3BsYXkucGhwJTNGZmlkJTNEcGJfYWdjc3RkOWFiY2MwMDIyMDEyXzEyYS54bWwmYWxsPTE%3D.

Ahuja SC and Payak MM (1982) Symptoms and signs of Banded leaf and sheath blight of maize. *Phytoparasitica* 10: 41-49.

Australian Bureau of Statistics (ABS) (2007) 1301.0 – Year book Australia, the Australian wheat industry, ABS, Canberra. Available from:

www.abs.gov.au/ausstats/abs@.nsf/Previousproducts/1301.0Feature%20Article212006?opendocument&tabname=Summary&prodno=1301.0&issue=2006&num=&view.

Bhadauria V, Banniza S, Vandenberg A, Selvaraj G, Wei Y (2011) EST mining identifies proteins putatively secreted by the anthracnose pathogen *Colletotrichum truncatum*. *BMC Genetics* 12: 327-343.

Bhavana P and Gadag RN (2009) Evaluation of maize genotypes for resistance to Banded leaf and sheath blight. *Annals of Plant Protection Sciences* 17: 498-499.

Carling DE, Rothrock CS, MacNish GC, Sweetingham MW, Brainard KA, Winters SW (1994) Characterization of anastomosis group 11 (AG-11) of *Rhizoctonia solani*. *Phytopathology* 84: 1387-1393.

Cubeta MA, Vilgalys R (1997) Population biology of the *Rhizoctonia solani* complex. *Phytopathology* 87: 480-484.

Custers JHHV, Harrison SJ, Sela-Burlage MB, Van Deventer E, Lageweg W, Howe PW, Van der Meijns PJ, Ponstein AS, Simons BH, Melchers LS, Stuiver MH (2004) Isolation and characterisation of a class of carbohydrate oxidases from higher plants, with a role in active defence. *The Plant Journal* 39: 147-160.

Department of Agriculture, Fisheries and Forestry (DAFF) (1999) Pathogen Risks Associated with Bulk Maize Imports to Australia from the United States of America. A report by Technical Working Group 1. Department of Agriculture, Fisheries and Forestry. Canberra, available from: www.daff.gov.au/__data/assets/pdf_file/0013/21901/TWGP_3.pdf.

de Milliano WAJ (1992) Sorghum diseases in southern Africa. Pg 9-19 *In*: de Milliano WAJ, Frederiksen RA, Bengston GD (eds) (1992) Sorghum and millets diseases: a second world review. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

De Vleeschauwer D, Cornelis P, Hofte M (2006) Redox-active pyocyanin secreted by *Pseudomonas aeruginosa* 7NSK2 triggers systemic resistance to *Magnaporthe grisea* but enhances *Rhizoctonia solani* susceptibility in rice. *Molecular Plant-Microbe Interactions* 19: 1406-1419.

Farr, D.F., Bills, G.F., Chamuris, G.P., and Rossman, A.Y. (1989). Fungi on Plants and Plant Products in the United States. The American Phytopathological Society, Minnesota. 1252 pp. says not in USA.

Garg A, Prasanna BM, Sharma RC, Rathore RS, Saxena SC, Chauhan SVS (2007) Identification of resistance sources to Banded leaf and sheath blight (*Rhizoctonia solani* f. sp. *sasakii*) in maize. *Indian Phytopathology* 60: 162-166.

Glazebrook J (2005) Contrasting mechanisms of defence against biotrophic and necrotrophic pathogens. *Annual Reviews of Phytopathology* 43: 205-227.

Gonzalez Garcia V, Portal Onco MA, Rubio Susan V (2006) Review, Biology and Systematics of the form genus *Rhizoctonia*. *Spanish Journal of Agricultural Research* 4: 55-79.

González-Vera AD, Bernardes-de-Assis J, Zala M, McDonald BA, Correa-Victoria F, Graterol-Matute EJ, Ceresini PC (2010) Divergence between sympatric rice- and maize-infecting populations of *Rhizoctonia solani* AG-1 IA from Latin America. *Phytopathology* 100:172-182.

Hartman GL, Sinclair JB, Rupe JC (1999) Compendium of soybean diseases 4th edition. American Phytopathological Society Press, St. Paul, Minnesota.

Hooda KS, Sekhar JC, Karjagi CG, Kumar S, Pandurange Gowda KT, Sreeramsetty TA, Sharma SS, Kaur H, Gogoi R, Reddy RR, Kumar P, Singh A, Devlash RK, Chandrashekara C (2012) Identifying sources of multiple disease resistance in maize. *Maize Journal* 1: 82-84.

IPPC (1995) Requirements for the Establishment of Pest Free Areas. International Standards for Phytosanitary Measures (ISPM) No. 4.

IPPC (1998a) Determination of pest free status in an area. International Standards for Phytosanitary Measures (ISPM) No. 8.

IPPC (1998b) Guidelines for Pest Eradication Programmes. International Standards for Phytosanitary Measures (ISPM) No. 9.

IPPC (1999) Requirements for the establishment of pest free places for production and pest free production sites (ISPM) No.10.

Kimigafukuro T (1992) Sorghum and sorghum diseases in Japan. Pg 31-34 *In*: de Milliano WAJ, Frederiksen RA and Bengston CD (eds) (1992) Sorghum and millets diseases: a second world review. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Khan MSA, Ramsey MD, Cocchiere R, Infantino A, Porta-Puglia A, Bouznad Z, Scott ES (1999) Ascochyta blight of chickpea in Australia: Identification, pathogenicity and mating type. *Plant Pathology* 48: 230-234.

- Khodayari M, Safaie N, Shamsbakhsh M (2009) Genetic diversity of Iranian AG1-IA isolates of *Rhizoctonia solani*, the cause of Rice sheath blight, using morphological and molecular markers. *Journal of Phytopathology* 157: 708-714.
- Kumar CSKV and Rao AS (1979) Production of phytotoxic substances by *Alternaria triticina*. *Canadian Journal of Botany* 57: 1255–1258.
- Laluk K and Mengiste T (2010) Necrotroph attacks on plants: wanton destruction or covert extortion? The Arabidopsis Book 1-34. American Society of Plant Biologists. Available from: www.ncbi.nlm.nih.gov/pmc/articles/PMC3244965/pdf/tab.0136.pdf.
- Lee GB, Hartman GL (1996) Reactions of *Glycines* species and other legumes to *Septoria glycines*. *Plant Disease* 80: 90-94.
- Lin HJ, Tan DF, Zhang ZM, Lan H, Gao SB, Rong TZ and Pan GT (2008) Analysis of digenic epistatic and QTL × environment interactions for resistance to Banded leaf and sheath blight in maize (*Zea mays*). *International Journal of Agriculture and Biology* 10: 605–11.
- Luck J, Spackman M, Freeman A, Trebicki P, Griffiths W, Finlay K, Chakraborty S (2011) Climate change and diseases of food crops. *Plant Pathology* 60: 113-121.
- Madhavi M, Reddy PN, Reddy RR, Sudarshan MR (2012) Evaluation of maize genotypes against Banded leaf and sheath blight disease incited by *Rhizoctonia solani* f. sp. *sasakii* (Kuhn) Exner. *The Journal of Research ANGRAU*. 60: 20-24.
- Mamgain A, Roychowdhury R, Tah J (2013) *Alternaria* pathogenicity and its strategic controls *Research Journal of Biology* 1: 1-9.
- Mathre DE (1997) Compendium of barley diseases 2nd edition. American Phytopathological Society (APS) press. St. Paul, Minnesota.
- Matsumoto M (2002) Trials of direct detection and identification of *Rhizoctonia solani* AG 1 and AG 2 subgroups using specifically primed PCR analysis. *Mycoscience* 43: 185-189.
- Muis A (2007) Evaluation of *Bacillus subtilis* BR23 applied as a spray suspension against Banded leaf and sheath blight (*Rhizoctonia solani* Khun) in corn. In: Prosiding Seminar Ilmiah dan Pertemuan Tahunan PEI dan PFI XVIII Komda Sul-Sel, 2007. Pp 28-34.
- Muis A and Quimio AJ (2006) Biological control of Banded leaf and sheath blight disease (*Rhizoctonia solani* KUHN) in corn with formulated *Bacillus subtilis* BR23. *Indonesian Journal of Agricultural Science* 7: 1-7.
- Murray GM and Plant Health Australia (2009a) Threat Specific Contingency Plan: Leaf spot of field peas *Alternaria humicola*. Plant Health Australia, Canberra, ACT.
- Murray GM and Plant Health Australia (2009b) Threat Specific Contingency Plan: Leaf blight of wheat *Alternaria triticina*. Plant Health Australia, Canberra, ACT.
- Oliver RP and Ipcho SVS (2004) *Arabidopsis* pathology breathes new life into the necrotrophs – vs. – biotrophs classification of fungal pathogens. *Molecular Plant Pathology* 5: 347-352.
- Pande S, Siddique KHM, Kishore GK, Bayaa B, Gaur PM, Gowda CLL, Bretag TW, Crouch JH (2005) Ascochyta blight of chickpea (*Cicer arietinum* L.): a review of biology, pathogenicity, and disease management. *Australian Journal of Agricultural Research* 56: 317-332.
- Pascual CB, Raymundo AD, Hyakumachi M (2000b) Efficacy of hypovirulent binucleate *Rhizoctonia* sp. to control Banded leaf and sheath blight in corn. *Journal of General Plant Pathology* 66: 95-102.

- Pascual CB, Toda T, Raymondo AD, Hyakumachi M (2000a) Characterization by conventional techniques and PCR of *Rhizoctonia solani* isolates causing Banded leaf sheath blight in maize. *Plant Pathology* 49: 108-118.
- Patra DK (2007) Occurrence of Banded leaf and sheath blight diseases of maize in West Bengal. *Journal of Mycopathological Research* 45: 137-138.
- Perello AE and Morerio MV (2003) Occurrence of *Ascochyta hordei* wheat (*Triticum aestivum*) leaves in Argentina. *Australasian Plant Pathology* 32: 565-566.
- Plant Health Australia (2013) PLANTPLAN: Australian Emergency Plant Pest Response Plan. Version 1.0. Plant Health Australia, Canberra ACT.
- Plant Health Australia (2009-review 2014) Industry Biosecurity Plan for the Grains Industry (version 3.0-under review), Plant Health Australia. Canberra, ACT.
- Puzari KC, Saikia UN, Bhattacharyya A (1998) Management of Banded leaf and sheath blight of maize with chemicals. *Indian Phytopathology* 51: 78-80.
- Rai D (2012) Foliar diseases of maize and their management. *International Journal of Plant Protection* 5: 449-452.
- Rakesh D, Guleria SK, Thakur DR (2011) Evaluation of seed dressing fungicides for the management of Banded leaf and sheath blight of maize. *Plant Disease Research* 26: 169-169.
- Rani DV, Reddy NP, Devi UG (2013) Management of maize Banded leaf and sheath blight with fungicides and biocontrol agents. *Annals of Biological Research* 4: 179-184.
- Saxena SC (2010) Integrated management of foliar diseases of maize. In: Plant Pathology In Practice pg 238-243, G.B. Pant University of Agriculture & Technology. Available from: www.gbpuat.ac.in/23%20CAFT%20Proceeding.pdf#page=248.
- Saxena SC (2002) Bio-intensive integrated diseases management of Banded leaf and sheath blight of maize. In: Srinivasan G, Zaidi PH, Prasanna BM, Gonzalez F, Lesnick K (eds) Proceedings of the 8th Asian regional maize workshop, Bangkok, Thailand: August 5-8, 2002.
- Saville RJ, Gosman N, Burt CJ, Makepeace J, Steed A, Corbitt M, Chandler E, Brown JKM, Boulton MI, Nicholson P (2011) The 'Green revolution' dwarfing genes play a role in disease resistance in *Triticum aestivum* and *Hordium vulgare*. *Journal of Experimental Botany* 63: 1271-1283.
- Saylor RJ and Yang Y (2007) Detection and quantification of *Rhizoctonia solani* AG-1 IA, the rice sheath blight pathogen, in rice using Real-Time PCR. *Plant Disease* 91: 1663-1668.
- Singh K, Nizam S, Sinha M, Verma PK (2012) Comparative transcriptome analysis of the necrotrophic fungus *Ascochyta rabiei* during oxidative stress: insight for fungal survival in the host plant. *PLoS ONE* 7: e33128. doi:10.1371/journal.pone.0033128.
- Singh A and Shahi JP (2012) Banded leaf and sheath blight: an emerging disease of maize (*Zea mays* L.) *Maydica* 57: 215-219.
- Sivakumar G and Sharma RC (2007) Management of Banded leaf and sheath blight of maize using *Pseudomonas fluorescens*. *SAARC Journal of Agriculture*. 5: 79-85.
- Sumner DR and Minton NA (1989) Crop losses in corn induced by *Rhizoctonia solani* AG-2-2 and nematodes. *Phytopathology* 79: 934-941.
- Trivedi A and Rathore RS (2006) New grass hosts for Banded leaf and sheath blight of maize. *Indian Phytopathology* 59: 253-254.
- Whipps JM and Lewis DH (1981) Transport of host assimilates to the pathogen pp 47-84. In: Ayres PG (ed) Effects of Disease on the physiology of the growing plant. Cambridge University Press.

White DG (1999) Compendium of corn diseases, 3rd edition. American Phytopathological Society (APS) Press. St. Paul, Minnesota.

Williams RJ, Frederiksen RA, Girard JC (1978) Sorghum and pearl millet disease identification handbook. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Hyderabad, India.

Wolpert TJ, Dunkle LD, Ciuffetti LM (2002) Host-selective toxins and avirulence determinants: what's in a name? *Annual Review Phytopathology* 40: 251-285.

Yang GH, Conner RL, Chen YY, Chen JY, Wang YG (2008) Frequency and pathogenicity distribution of *Rhizoctonia* spp. causing sheath blight on rice and Banded leaf disease on maize in Yunnan, China. *Journal of Plant Pathology* 90: 387-392.

10 Appendices

10.1 Appendix 1: Standard diagnostic protocols

For a range of specifically designed procedures for the emergency response to a pest incursion refer to Plant Health Australia's PLANTPLAN (www.planthealthaustralia.com.au/plantplan).

10.2 Appendix 2: Resources and facilities

Formal diagnostic services for plant pests in Australia are delivered through a network of facilities located in every state and territory. These services are provided by a range of agencies, including state and territory governments, the Australian Government, commercial and private diagnostic laboratories, museums, CSIRO and universities. A current listing of these facilities can be found at www.npbdn.net.au/resource-hub/directories/laboratory-directory

The national network is supported by the Subcommittee on Plant Health Diagnostic Standards (SPHDS), which was established to improve the quality and reliability of plant pest diagnostics in Australia. SPHDS also manages the production of National Diagnostic Protocols.

For more information on the diagnostic services, or to identify an appropriate facility to undertake specific pest diagnostic services, refer to www.npbdn.net.au or contact the SPHDS Executive Officer on SPHDS@daff.gov.au

10.3 Appendix 3: Communications strategy

A general Communications Strategy is provided in Section 4.1.5 of PLANTPLAN (Plant Health Australia, 2013).

10.4 Appendix 4: Market access impacts

Within the Department of Agriculture Manual of Importing Country Requirements (MICO_R) database (www.daff.gov.au/micor/plants/) export of some material may require an additional declaration regarding freedom from the pathogen. Should exotic foliage affecting necrotrophic pathogens be detected or become established in Australia, some countries may require specific declarations. Latest information can be found within MICO_R, using a search for the particular pathogen (note as many fungal pathogens have scientific names for both their teleomorph (sexual) and anamorph (asexual) life stages both names should be searched for in the database).

The Department of Agriculture MICO_R database was searched in December 2013 for current trade restrictions relating to Banded leaf and sheath spot of maize. No countries were identified on the Department of Agriculture MICO_R database as having trade restrictions regarding Banded leaf and sheath spot, however China does have some restrictions relating to the presence of *R. solani* on canola and rice.