INDUSTRY BIOSECURITY PLAN
FOR THE GRAINS INDUSTRY

Threat specific contingency plan

Barley stripe rust

(*Puccinia striiformis* f. sp. *hordei*)

Prepared by Colin Wellings

and Plant Health Australia

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Plant Health AUSTRALIA

GRDC Grains Research & Development Corporation

CRC PLANT biosecurity

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Further information

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

Address:	Suite 5, FECCA House 4 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**

1 Purpose of this document

This contingency plan was developed to provide an overview of the Australian grains industry"s preparedness for an incursion of Barley stripe rust (*Puccinia striiformis* f. sp. *hordei*) and/or its derivatives. This document contains background information on the pest biology, diagnostic and surveillance activities in place to respond to an incursion, as well as possible control measures and management strategies. The information contained within this document is designed to:

1. **Aid in an eradication or containment attempt** by providing guidelines for steps to be undertaken and considered when developing a Response Plan to this pest. Any Response Plan developed using information in whole or in part from this contingency plan must follow procedures as set out in PLANTPLAN (Plant Health Australia, 2009) and be endorsed by the National Management Group prior to implementation.
2. **Effectively manage** the pest and minimise the disruption to agricultural industries following entry and establishment, should eradication be deemed not feasible.

2 Eradication or containment decision matrix

Eradication of Barley stripe rust (*Puccinia striiformis* f. sp. *hordei*) would only be technically feasible if the rust is detected while still contained within a very small area and the spore load was light. Determination of the extent of the incursion should be completed quickly and commence as soon as there is a reasonable suspicion of the presence of Barley stripe rust, without waiting for confirmation, as any delay may be critical in allowing further spread.

While it is possible an initial detection maybe contained within an area small enough and/or isolated enough that eradication is considered feasible, past experience in the detection and monitoring of exotic cereal rust pathogen isolates have shown that in reality eradication is unlikely to work. With current surveillance protocols, the threshold of detection of new rust isolates is such that by the time a new pathogen has been detected and diagnosis confirmed, it has already spread over significant distances. Stripe rust of wheat was detected in Australia in 1979, and this example is instructive in this context. The initial detection of this pathogen and its subsequent spread and establishment were well documented by O"Brien *et al.* (1980) and Wellings (2007). The disease was first reported on 25 October 1979 near Charlton and Dooen (Victoria), and had been observed 3 days earlier at Darlington Point (NSW). Detailed surveys established that by November 16, the disease was already well established in commercial wheat crops throughout the Mallee and Wimmera, as well as south of Hamilton and near Geelong (O"Brien *et al.*, 1980). At the time, it was suggested that the pathogen would not be able to survive the non-cropping harsh Australian summer; however, it has managed to do so every summer since, often surviving in more than one location (Wellings, 2007).

No specific eradication matrix has been determined for Barley stripe rust; however the general decision process as outlined in Figure 1 should be followed in determining if an incursion of this pest will be eradicated or managed/contained. The final decision between eradication and management will be made through the National Management Group (NMG).

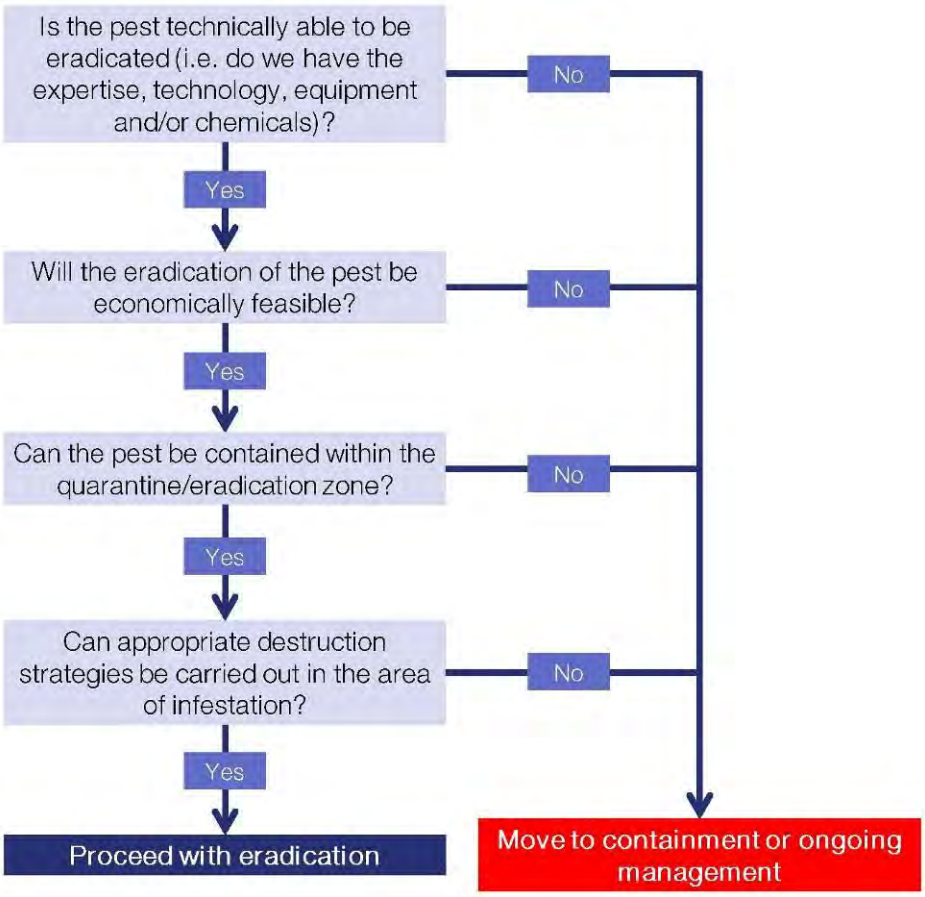

Figure 1. Decision outline for the response to an exotic pest incursion

3 Pest information/status

3.1 Pest details

Scientific name	*Puccinia striiformis* Westend f. sp. *hordei* Erikkson & Henning
Common names	Barley stripe rust, barley yellow rust, glume rust

3.1.1 Background

Rust fungi are plant pathogens that pose a significant biosecurity threat because they can travel large distances, build up rapidly, evolve new variants readily and those that attack economically important plant species are frequently very damaging. The ability of rust pathogens to spread and build up rapidly also makes them extremely difficult to eradicate once introduced.

Australia faces threats not only from exotic rust species, but also from exotic isolates of endemic rust species. Long-term (80+ years) national studies of cereal rust pathogens conducted at the University of Sydney have documented 10 incursions of new races of endemic rust pathogens as well as two incursions of new cereal rusts (Table 1). The rate of exotic cereal rust incursions has increased steadily since 1925 when these surveys began. Rust introductions have had serious implications for Australia's plant-based industries, and in the cereal industry have hindered attempts to control rust by genetic resistance. Barley stripe rust (*Puccinia striiformis* f. sp. *hordei*; *Psh*) is a major current threat to the Australian cereal industries. Overseas tests of Australian barley germplasm have shown that about 80% of current cultivars and advanced breeding lines are susceptible to stripe rust (Wellings *et al.* 2000b).

Table 1. Documented incursions of exotic cereal rust pathogens in Australia

Disease (Pathogen)	Year	Origin	Reference
New introductions of endemic cereal rusts			
1. Wheat stem rust (*P. graminis* f. sp. *tritici*)	1925	?	Waterhouse (1952)
2. Wheat stem rust (*P. graminis* f. sp. *tritici*)	1954	Africa?	Luig (1977)
3. Wheat stem rust (*P. graminis* f. sp. *tritici*)	1969	Africa?	Watson and de Sousa (1982)
4. Wheat stem rust (*P. graminis* f. sp. *tritici*)	1969	Africa?	Watson and de Sousa (1982)
5. Wheat leaf rust (*P. triticina*)	1981	?	Luig *et al.* (1985)
6. Wheat leaf rust (*P. triticina*)	1984	?	Park *et al.* (1995)
7. Wheat leaf rust (*P. triticina*)	1996	?	Park and Burdon (1992)
8. Wheat stripe rust (*P. striiformis*)	2002	USA?	Wellings *et al.* (2003)
Newly introduced cereal rust pathogens			
9. Wheat stripe rust (*P. striiformis*)	1979	France?	Wellings *et al.* (1987)
10. Barley grass stripe rust (*P. striiformis*)	1998	?	Wellings *et al.* (2000a)

Rust diseases have caused sporadic crop losses in most barley producing regions of the world. Stripe rust, caused by *P. striiformis*, exists in several biological forms (*formae speciales*) that vary in host range between, and within genera and species of the Gramineae family (Stubbs, 1985). Background detail on *formae speciales* of the stripe rust pathogen current and exotic to Australia is provided in Section 9.5, Appendix 5. Wheat stripe rust, *P. striiformis* f. sp*. tritici* (*Pst*), may cause a low level of infection on barley, but does not cause significant damage to commercial barley crops. However, susceptible barley cultivars can lose approximately 10% of yield due to barley grass stripe rust caused by *P. striiformis* f. sp. *pseudo-hordei* (*Psp-h*) (Wellings *et al.*, 2000a).

Barley stripe rust (caused by *P. striiformis* f.sp. *hordei, Psh*) is not present in Australia, but has caused significant problems in winter barley production in Europe, the UK, the Netherlands (Stubbs, 1985), Colombia, South America (Dubin and Stubbs, 1986), Mexico and the USA (Marshall and Sutton, 1995). Since 1991, barley stripe rust has quickly spread and become established in the south-central and western USA and is now the most important disease of barley in western USA (Line, 2002; Chen, 2004). Infection with *Psh* reduces yields (approaching 70% in USA) and grain quality. Damage to barley depends on the growth stage when rust develops, with early infections causing the most damage.

Using a set of 11 differential barley genotypes, 69 races *of Psh* have been identified in the United States (Chen, 2004). Since 1998 certain races have become predominant but because of non race-specific resistance, selection pressure has been low and the rust population still consists of numerous races (Chen, 2004). In Europe, there has been less race diversity identified with race 24 being predominant in the 1980s (Stubbs, 1985; Dubin and Stubbs, 1986).

3.1.2 Life cycle and morphology

Puccinia striiformis is a macrocyclic rust with the life cycle consisting of all five possible spore stages: pycniospores, aeciospores, urediospores, teliospores, and basidiospores. The urediospores complete multiple asexual cycles throughout the winter cereal growing season, with these cycles causing the principle damage to cereal crops (Figure 2). The sexual stage of *Pst* has recently been demonstrated to occur on several *Berberis* species in the USA (Yue Jin *et al*., 2010). It is anticipated that *Psh* will also have a complete life cycle, although this has not been demonstrated to date. However the sexual cycle is not expected to have a role for *P striiformis* under Australian conditions as *Berberis* is rare.

The urediospores are macroscopically yellow to orange in colour, resulting from orange cytoplasm and hyaline cell walls; globose to ellipsoid, 25-30 by 12-24 μm with small echinulate spines and scattered indistinct germ pores (Mulder and Booth, 1971). Albino spore coloured isolates have rarely been recovered (Wellings, unpublished). Teliospores may form under conditions of heavy inoculum pressure at the end of the growth cycle of the host. Teliospores are brown, two-celled with smooth walls, 30-70 by 16-25 μm (Mulder and Booth, 1971). Teliospores germinate to form basidiospores, but these have no known host for infection to occur.

Spores infect leaves and spikelets then develop sporulating pustules in rows of varying lengths giving the appearance of narrow yellow stripes (Figure 3 A and Figure 4). On seedling leaves and highly susceptible adult plant leaves, striping is not evident and instead infection covers the leaves in a random fashion. In heavy epidemics the fungus may also affect leaf sheaths and heads (Figure 4 B; Adams, 1997; Wellings, 2009).

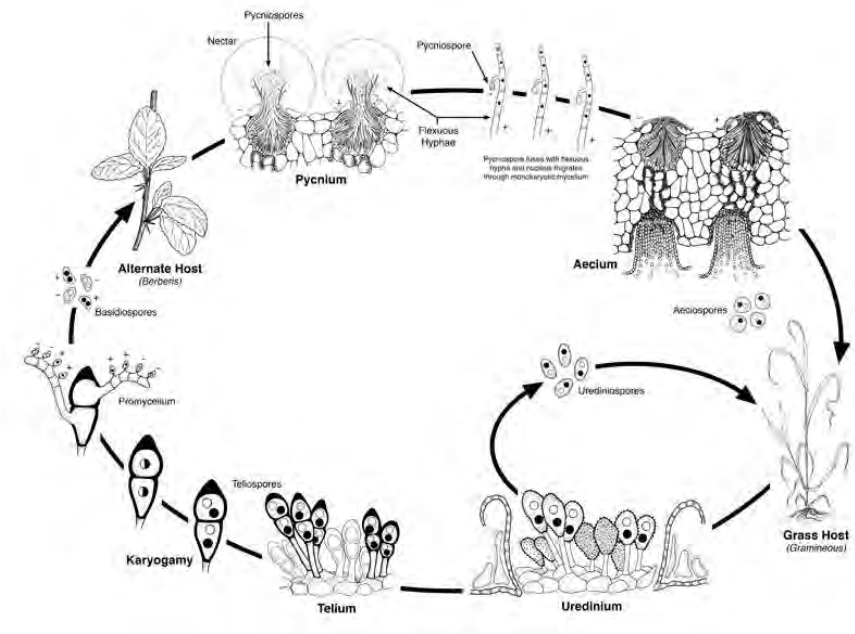

Figure 2. The complete life cycle of a typical cereal rust. *Puccinia striiformis* has recently been found to have a complete life cycle including the sexual stages on *Berberis* species in the USA. (Diagram source: Leonard and Szabo, 2005)

A **B** **C**

Figure 3 A Barley stripe rust urediospores presenting on the leaf surface, giving the appearance of yellow stripes. **B** Wheat stripe rust urediospores infecting glumes. **C** Infection foci (hot-spots) in the field. (source: Colin Wellings – colin.wellings@sydney.edu.au)

As the rust is an obligate pathogen, it must reside within a living host for survival between seasons on volunteer wheat, barley and possibly some wild grasses (Adams, 1997) although evidence for the role of the latter is lacking. In Australia, conditions are suitable for stripe rust development between April and December and in most years infestations can be observed in crops by September. The amount of over-summering rust available for the following year depends on the amount of volunteer plants,

which in turn is a function of moisture over the summer months. Only one infected leaf per 30 hectares of regrowth needs to survive the summer to produce severe rust infections the following winter (Hollaway, 2009).

Rust spores are spread by wind to initiate and spread infections. *Pst* spores, and by implication *Psh,* germinate over 6-8 hours in conditions of high humidity and temperatures between 5 and 15°C, with the optimum temperature for the germination of urediospores at 10-12°C. Infections result from urediospores producing adhesion pads to maintain contact with the host cuticle, and a germ-tube that grows across the leaf surface prior to entering the leaf via stomata. An infection peg forms through the stomatal pore giving rise to a sub-stomatal vesicle from which infection hyphae develop that branch out and can infect the whole of the leaf tissue. The optimum temperature for development of stripe rust in plants is 13-18°C. Under optimum conditions, the time from inoculation to sporulation is 12-14 days (Line, 2002; Davis and Jackson, 2002). Late in the summer, telia develop as linear black pustules on the leaf, leaf sheaths and glumes.

Figure 4. Barley stripe rust symptoms, including yellow spores appearing on leaves (source: Colin Wellings – colin.wellings@sydney.edu.au)

3.2 Affected Hosts

3.2.1 Host range

The primary host of Barley stripe rust is spring barley, *Hordeum vulgare*, with certain races of rust surviving on wild barley species such as *H. jubatum* (foxtail barley) and *H. leporinum, H. glaucum, H. murinum* (barley grass complex) (Marshall and Sutton, 1995) (Table 2).

Table 2. Host range of *P. striiformis* f. sp. *hordei*

Major host	*Hordeum vulgare* (barley)
Minor hosts	*H. jubatum* (foxtail barley) , *H. leporinum, H. glaucum, H. marinum* (barley grasses)

3.3 Geographic distribution

3.3.1 Current distribution

Barley stripe rust is widespread, having been detected throughout Asia, Africa, Europe and the Americas (Table 3), however it is currently absent from Australia.

Table 3. World distribution of *P. striiformis* f. sp. *hordei*

Countries	Reference
Asia	Stubbs (1985)
Canada	Stubbs (1985)
Central Africa	Referenced in Chen *et al.* (1995)
Central America	Referenced in Chen *et al.* (1995)
China	Referenced in Chen *et al.* (1995)
Europe	Stubbs (1985)
India	Nagarajan and Joshi (1985)
Japan	Stubbs (1985)
Nepal	Referenced in Chen *et al.* (1995)
North America	Marshall and Sutton (1995)
South America	Dubin and Stubbs (1984)

3.3.2 Potential distribution in Australia

Should Barley stripe rust enter and establish in Australia, it has the potential to infect barley throughout all Australian growing regions (Figure 5). Traditional summer rainfall with opportunities for rust to survive over summer would suggest that the northern region of eastern Australia may be more vulnerable to barley stripe rust. However, it can be anticipated that impacts of the pest would occur in all Australian barley growing regions.

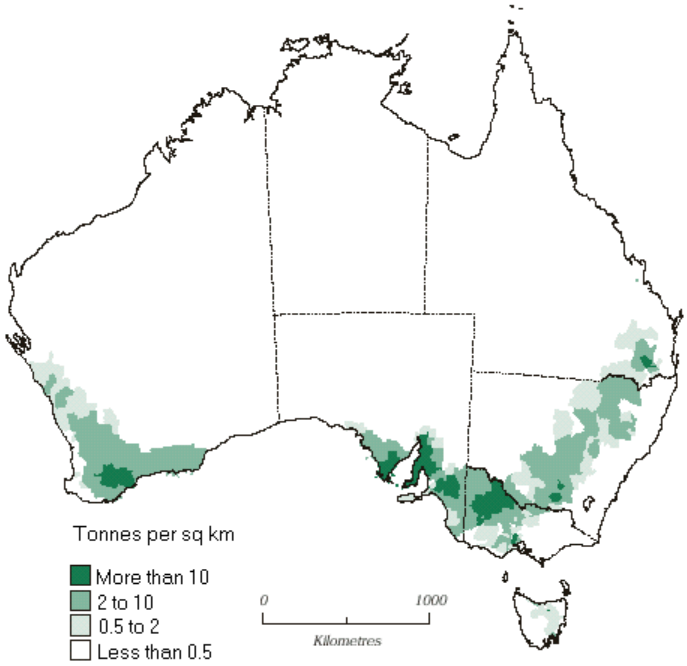

Figure 5. Barley production distribution in Australia (Source: ABS Year Book Australia 2003, Agricultural Crops)

3.4 Symptoms

3.4.1 Plant parts affected

Psh primarily attacks the leaves but in heavy infestations may also affect leaf sheaths and heads (see Figure 3 and Figure 4). *Psh* is not seed borne.

The primary symptom of stripe rust is the appearance of yellow orange pustules (uredia) which are generally arranged in stripes along upper leaf surfaces (Figure 3A). Glumes also can be infected (Figure 3B). Stripe rust symptoms usually appear earlier in the season than other wheat rusts because the fungus develops at temperatures lower than the other cereal rust fungi. As plants mature and temperatures increase, the pustules turn dark and shiny as teliospores are formed. These spores do not play a role in disease development or survival (Davis and Jackson, 2002). Rust infections reduce plant vigour and root growth, increase water loss and decrease the amount of photosynthate available for grain filling, resulting in reductions in the number and weight of kernels (Davis and Jackson, 2002; **www.ipmcenters.org**).

On seedling leaves and susceptible adult plant leaves, striping is not evident with the infection seen in a random fashion across the leaves. Initially stripe rust is distinguished from stem and leaf rusts based on colour, position and pattern of infection (Table 4).

Table 4. Differences in spore colour, position of infection and pustule pattern between the cereal rust diseases

Rust	Colour	Position	Pattern
Stripe	Yellow	Upper leaf surfaces	Striped pustules
Stem	Dark brown	Leaves, leaf sheaths, stems and heads	Large pustules
Leaf	Mid to light brown	Upper leaf surfaces and leaf sheaths	Scattered pustules

Under severe infection conditions (high inoculum load, ideal climatic conditions and susceptible varieties) infection of the floral structures of wheat may occur (Figure 3B). Infection occurs at flowering in wheat and triticale when glumes are open; spores later become noticeable on the inside surface of glumes adjacent to the developing seed. It is unlikely that head infection will be observed in barley as flowering occurs inside the boot and glumes do not generally open.

3.5 Pest risk analysis

3.5.1 Entry pathways for exotic rust pathogens

Rating: Medium

The increasing frequency of travel between Australia and countries where the pathogen exists, together with the ability of the spores to be carried on contaminated clothing for considerable periods of time (Wellings *et al.,* 1987; 2000a) provides a potential pathway for pathogen entry. Long distance natural spread of pathogen spores on wind currents provides an additional possibility for incursion, although this is considered to be less likely compared to movement by international travellers.

3.5.2 Spread potential

Rating: High

Previous experience has shown that the cereal rust fungi have tremendous potential for spread once introduced to a new region. The spread potential of Barley stripe rust is high as spores are spread large distances on wind currents. Barley stripe rust in South America migrated from Colombia to Chile over a period of only a few years as a result of wind dispersal (Dubin and Stubbs, 1986). Intercontinental air travel on contaminated clothing from Europe has been predicted to be the pathway pattern of *Psh* on barley in Columbia.

Examples exist in Australia of the pathogens causing wheat stem rust (Zwer *et al.,* 1992), wheat leaf rust (Park *et al.*, 1995) and wheat stripe rust (Wellings, 2007) being dispersed across the Australian continent in as little as 12 months, and in many cases with subsequent dispersal to New Zealand (Wellings, 2007). These situations demonstrate quite clearly that once the threshold of detection is reached, eradication of rust diseases is not likely to be effective.

3.5.3 Establishment potential

Rating: High

Establishment potential is considered to be high as:

- Other *forma specialis* of *P. striiformis* have already entered and established successfully in Australia on other host species.
- Current commercial barley cultivars in Australia are highly susceptible to Barley stripe rust.
- Climatic conditions between regions where similar forms of stripe rust already occur in Australia are similar.

3.5.4 Economic impact

Rating: Extreme

Barley stripe rust epidemics have the potential to cause large economic losses. The disease has the potential to greatly affect the barley industry in Australia in a similar manner to the Wheat stripe rust incursions of 1979 and 2002. Australian barley varieties have little resistance to Barley stripe rust and an incursion is likely to develop into an epidemic. Trials of Australian barley varieties held at CIMMYT (in Mexico) indicate that current cultivars are vulnerable to *Psh* (Wellings *et al.*, 2003). In the US, losses up to 70% of barley yield are estimated due to Barley stripe rust infection (Dubin and Stubbs, 1986).

Conservative estimates of fungicide costs for control of the new pathotype of Wheat stripe rust in Australia in 2004 was $90 million. In this case, genetic resistance was still effective, as compared to Barley stripe rust incursions where there is expected to be limited genetic resistance available in commercial barley cultivars. The estimated potential cost to the Australian barley industry to uncontrolled epidemics of barley leaf rust and stem rust is over $100 million (Murray and Brennan, 2009). These figures provide a benchmark for the potential impact of Barley stripe rust in Australia.

Barley stripe rust has the potential to infect all barley producing areas of Australia.

3.5.5 Environmental impact

Rating: Negligible

There is no potential to degrade the environment or otherwise alter the ecosystem by affecting species composition or reducing the longevity or competitiveness of wild hosts.

3.5.6 Social impact

Rating: Medium

The reduction in the value of production would be expected to cause moderate social impact with significant losses to local barley producers and processors (livestock feed, malt producers) as well as flow on effects to the broader community.

3.5.7 Overall risk

Rating: High

The overall risk rating was calculated by combining the entry, establishment and spread potentials and the economic impact using the risk assessment framework applied in Industry Biosecurity Plans. A complete protocol can be found on the PHA website[1].

4 Surveillance

4.1 Overview of surveillance systems for cereal rust in Australia

The importance of maintaining vigilance for exotic pathogens within the grains industry becomes clear when past experience with Wheat stripe rust in Australia demonstrated that losses could have been minimised had industry been aware of exotic pest threats and their identification.

Annual surveys of rust diseases in winter cereal crops and pathotype analyses have been conducted on a continuous basis at the University of Sydney since the early 1900s. Surveys typically involve random inspections of crops and roadside self sown cereals and weed species, along with experimental plots, and are conducted by staff of the Australian Cereal Rust Control Program (ACRCP) at the University of Sydney and state based cereal pathologists, cereal breeders, extension staff and cereal growers.

4.2 What additional surveillance is required to successfully detect Barley stripe rust?

The annual surveillance activities undertaken by the ACRCP (i.e. surveying the presence/absence of rust diseases and pathotype analyses) use standard methods that are well established and have proven successful in the timely detection of exotic rust incursions. Experience with this system has shown that the systemic deployment of trap plots to supplement information gained from commercial crops and experimental plots adds very little information, and that the effort involved in establishing such a system does not justify the minimal increase in resolution of detection. While it could be argued that more extensive crop inspections could lead to earlier detection, the benefit from doing so is by no means clear.

4.3 Delimiting survey and epidemiology study

4.3.1 Sampling method

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

[1] Available from **www.planthealthaustralia.com.au/go/phau/biosecurity/general-biosecurity-information**

Crop surveys should be based on at least 100 plants examined at random for symptoms typical of stripe rust. However, preference may be given to symptomatic plants in fields where the disease incidence is low. Samples should be initially collected over a representative area of the infected crop to determine the pathogen distribution. The disease may appear as circular patches within the crop (often referred to as „hot spots") depending on the source of the pathogen inoculum (Figure 3 C). It is important to note the distribution of disease in the initial crop inspections, as this will indicate whether the pathogen has arrived as a spore shower from adjacent areas, or introduced by human movement on contaminated clothing.

Samples should be collected from plants that represent a range of symptoms observed in the infected crop. Preferably enough material should be collected to allow for immediate processing and retention of a portion that can be placed into long term storage as a reference herbarium specimen.

Samples should be treated in a manner that allows them to arrive at the laboratory in a timely and well-preserved state. Infected leaves should be folded once on top of themselves and placed in a paper envelope; 6-10 leaves showing symptoms will be sufficient for dispatch. Do not use plastic bags or envelopes lined with plastic materials; leaf samples collected in plastic will deteriorate rapidly and spores will germinate prior to processing, thus rendering the sample non-viable. Sample envelopes should be clearly labelled with date of collection, location (GPS co-ordinates; farm identification, distance to nearest town, etc.), crop variety if known, and collector details. Urgent samples for initial diagnosis should then be dispatched by overnight courier services to the appropriate testing facility. Survey samples can be stored in a refrigerator for several days prior to posting.

Upon receival, specimens will be recorded and examined for symptoms, and spores removed for immediate processing to determine identity using microscope examination of pathogen morphology and molecular diagnostics. Spores will also be transferred to susceptible seedlings in order to establish infection and multiply inoculum for pathogen and pathotype identification. Inoculum can be stored as dried spores in microfuge tubes in a -80°C freezer, or in liquid nitrogen (-170°C) for long term preservation. Infected plant tissue to be used for PCR analysis can also be placed in a -80°C freezer and stored for an indefinite period under these conditions without damaging fungal DNA.

Any personnel collecting samples for assessment should notify the diagnostic laboratory prior to submitting samples to ensure expertise is available to undertake the diagnosis. General protocols for collecting and dispatching samples are available within Appendix 3 of PLANTPLAN (Plant Health Australia, 2009).

A large number of samples may be collected and it is vital that a system of sample identification is determined early in the procedure to allow for rapid sample processing and accurate recording and reporting of results. Follow up samples will be forwarded to the nominated diagnostic laboratories for processing.

4.3.2 Epidemiological study

The number of infected plants within a crop will depend on the amount of inoculum available and whether conditions have been favourable for the pathogen to spread from the initial foci.

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:

- Recent and anticipated weather patterns that may give potential leads for investigating the source of initial inoculum and the potential direction of further disease spread.

- The proximity of other susceptible crops to the initial infected crop. This will include the growers" crops and those on neighbouring properties. Alternative and wild host species should also be considered if in proximity.
- What machinery or vehicles have been in the infected crop.
- The extent of human movements in the infected crop. A possible link to recent overseas travel or visitors from other regions should also be considered.

4.3.3 Models of spread potential

No specific models have been developed for Barley stripe rust. However, the following points on the mechanism of spread should be considered:

- Local and regional dispersal through fungal spore movement is the major pathway for pathogen spread. Long distance movement of spores occurs predominately by wind and to a lesser extent by contaminated machinery, equipment, and clothing.
- Within a crop the spores are usually dispersed relatively short distances in cool conditions with high moisture, *ie* typical of winter and early spring. Under these conditions, spores collect in masses that fall out of the air quickly and so travel relatively short distances. These conditions lead to the development of foci of infection, *ie* hot spots seen in crops.
- As temperatures increase, the atmosphere has less humidity and canopies become more open, spores disaggregate and become capable of spreading over longer distances.

4.3.4 Pest Free Area guidelines

The establishment and maintenance of Pest Free Areas (PFAs) would be a resource-intensive process, especially as other *forma specialis o*f the pathogen already occur within Australia and the pathogen can be easily spread by wind currents. Prior to development of a PFA due consideration should be given to alternative methods (e.g. treatments or enclosed quarantine) that achieve an equivalent biosecurity outcome. A benefit-cost analysis is useful for this purpose.

Additional information is provided by the IPPC (1995) in Requirements for the Establishment of PFA. This standard describes the requirements for the establishment and use of PFAs as a risk management option for phytosanitary certification of plants and plant products. Establishment of maintenance of a PFA can vary according 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).

Points to consider are:

- Design of a statistical delimiting field survey for symptoms on host plants.
- Plant sampling should be based on at least 100 plants taken at random per crop.
- Preliminary diagnosis can be based on host species, leaf symptoms and fungal morphology.
- Cereal rust pathotypes can only be identified by using seedling based greenhouse host assays which take a minimum of 3 weeks.
- Surveys should also consider alternative host plants.

5 Diagnostic information

5.1 Current diagnostics for Barley stripe rust

Guidelines for the identification of *P. striiformis* can be found in the „Barley stripe rust national diagnostic protocol[2]" (Spackman, 2005). The document contains methodology for PCR diagnostics, enabling identification of the casual pathogen *P. striiformis* from other common foliar pathogens that attack barley together with potentially confounding *formae speciales* of *P. striiformis.*

A summary of the diagnostic process for *Psh* is shown below:

- Following preliminary examination of the infected plant for the presence of stripe rust in the field, laboratory diagnosis would be a two-stage process.
    - PCR test to distinguish the infection from the other endemic species.
    - Test on differentials to confirm the PCR test.
- The PCR test would be done first to give a rapid result that can be acted on immediately as the differential test takes a number of weeks to complete.
- The primary test would require sample processing in a specialised laboratory capable of molecular techniques.
- The differential test and pathogenicity survey would be conducted by an experienced plant pathologist at the University of Sydney"s Plant Breeding Institute (PBI) at Cobbitty. PBI have undertaken national pathogenicity surveys for all cereal rust pathogens since the early 1900s, and continue to do so with Grains Research and Development Corporation (GRDC) and university funding.
- The barley cultivar differentials test differentiates *Psh* from other rust species and allows a determination of pathotype. Providing a good rust sample is received, the differential tests can be completed within three weeks. However this period of time for positive diagnosis is likely to be too long if eradication or containment were to be considered.

6 Control methods

If Barley stripe rust became established in grain growing regions of Australia, there are a number of control options that would be available to producers, including:

- **Seed treatment with fungicides** may delay the onset of an epidemic by preventing early build up of the disease on seedlings (Brown *et al.,* 2001).
- Use of **resistant cultivars**. These are limited at present and no malting barleys with resistance to *Psh* have been developed in the US (Chen, 2004). Current work in Australia is using offshore field testing and molecular markers to develop resistant varieties as a pre-emptive control strategy (Wellings *et al.,* 2003; Cakir *et al.,* 2003).
- Use of **cultural control** methods to limit inoculum build-up, such as reducing the green bridge.

[2] Document can be downloaded from the Pest Information Document Database (**www.planthealthaustralia.com.au/pidd**).

- **Spraying with a foliar fungicide** using a range of alternative triazole fungicides that would be expected to give excellent control.

6.1 Breeding for resistance

The development of cereal plants containing rust resistance genes has limited the impact of many rust diseases affecting the Australian grains industry and has historically been the major approach to achieving national disease control. The use of this approach for barley production has resulted in a decline in the incidence of barley stripe rust in many countries where the pathogen is present, with many resistant varieties showing no significant yield loss. For example, yield losses of up to 72% occurred in the USA in 1995 (Marshall and Sutton, 1995), but through the development of host-resistance yield losses have been reduced to 12-20% (Chen, 2004). In recent years, US state-wide losses have been lower as highly susceptible cultivars are rarely grown. However, severe barley stripe rust still appears in test plots on susceptible lines and is a continuing threat.

When field testing of Australian barley commenced at CIMMYT, Mexico, more than 80% of current varieties were determined to be very susceptible to Barley stripe rust (Wellings and Park, 2003). This information became the basis for testing larger breeding and mapping populations from Australian breeding programs in an attempt to identify resistance in genotypes adapted to Australian regional conditions. Funding from GRDC provides the opportunity to establish annual disease screening nurseries at Toluca, Mexico. Data flows back to Australian barley breeders, who have the opportunity to advance material to commercial release with resistance to barley stripe rust. With offshore testing and the availability of molecular markers to select resistance genes (Cakir *et al*., 2003) pre-emptive breeding is being initiated to give Australian barley varieties protection from stripe rust incursions.

6.2 Chemical management

Foliar and seed fungicides are commonly used in Australian cereal production to limit the impact of rusts and other fungal diseases where host-plant resistance is not sufficient. For example, in 2008 $40-50 million was spent on fungicidal control of Wheat stripe rust in NSW alone. Fungicides have also been used to control leaf rust in wheat in Australia particularly during epidemics experienced in WA in 1992 and again in 1999.

If barley stripe rust were to become established in Australia, fungicides currently used for the control of wheat stripe rust would be the anticipated chemicals of choice. Some of these fungicides are also effective against other forms of rust, such as stem and leaf rust. Lists of these chemicals, their registration status and further information can be obtained from the relevant state government department (Table 5).

Any chemicals used for the eradication or control of barley stripe rust in Australia must be registered for use through the Australian Pesticides and Veterinary Medicines Authority (APVMA). In the event of a barley stripe rust incursion, emergency permits for application on barley will need to be sought as a matter of urgency. For information regarding this process visit the APVMA website (**www.apvma.gov.au**).

Table 5. State government information regarding cereal production, including chemical control

State	Website listing cereal rust fungicide information
NSW	**www.dpi.nsw.gov.au/agriculture/field/field-crops/winter-cereals**
QLD	**www.dpi.qld.gov.au/26_3394.htm**
SA	**www.pir.sa.gov.au/grains**
VIC	**www.dpi.vic.gov.au/DPI/nrenfa.nsf/FID/-8724DFCE872B08DACA256C7800193FFB?OpenDocument**
WA	**www.agric.wa.gov.au/PC_92220.html?s=1841233945**

A potential issue with fungicidal control of the cereal rusts is the single mode of action represented amongst the group of currently registered products. While there are examples of some fungal plant pathogens developing insensitivities to fungicides, there are no verified reports of a cereal rust pathogen developing insensitivity to a Group C (DMI inhibiting) fungicide.

An issue associated with fungicidal control of rust diseases in broad-acre crops like wheat and barley in Australia has been product supply. Predicting requirement in a given year is very difficult and chemical suppliers do not like to maintain large inventories of active ingredient as a contingency strategy. With this in view, it can be anticipated that there may be logistical issues in obtaining sufficient fungicide to address the needs of an incursion of barley stripe rust in Australia.

6.3 Cultural control

Barley stripe rust is an obligate pathogen, and therefore requires living host material (the „green bridge") between seasons to maintain viable inoculum. The pathogen can over-summer on volunteer barley and some wild grasses (Adams, 1997). Implementing cultural methods to reduce the „green bridge" may reduce the initial spore load for the next cropping season, and thus delay disease onset and reduce the incidence of disease symptoms in the crop.

7 Course of action

The information presented within this section is relevant only if eradication or containment of Barley stripe rust will be attempted. This decision will be made by the NMG (see Section 2). Should the response to an incursion be the ongoing management of the pest with no attempt at containment, the required information can be found in the above sections.

7.1 Infected crop destruction strategy

7.1.1 Destruction protocols

- Disposable equipment, infected plant material or soil should be disposed of by autoclaving, high temperature incineration or deep burial.
- Any equipment removed from the site for disposal should be double-bagged.

7.1.2 Decontamination protocols

Machinery, equipment and vehicles in contact with infected plant material or soil, or present 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 bleach (1% available chlorine) solution in a designated wash down area. 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 (see Appendix 18 of PLANTPLAN 2009).
- Disposable overalls and rubber boots should be worn when handling infected soil or plant material in the field. Boots, clothes and shoes 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 infected plant material or soil should be washed.

7.1.3 Priorities

- Confirm the presence of the pest.
- Prevent movement of vehicles and equipment through affected areas.
- Prioritise eradication/decontamination of infected host material.
- Determine the extent of infection through survey and plant material/personnel movement trace back.

7.1.4 Plants, by-products and waste processing

- Infected plant material should be destroyed by (enclosed) high temperature incineration, autoclaving or deep burial (in a non-cropping area).
- As the fungus can be mechanically transmitted on clothing, crops destroyed with herbicide and or fungicide should be ploughed in.

7.1.5 Disposal issues

- Particular care must be taken to minimize the transfer of plant material and contaminated clothing from the area.

- No particular issues with resistance of disease to chemicals or physical treatments are known to exist.

7.2 Quarantine and movement controls

7.2.1 Quarantine priorities

- Plant material at the site of infection to be subject to movement restrictions.
- Machinery, equipment, vehicles and disposable equipment in contact with infected plant material or soil to be subject to movement restrictions.
- Wind-borne inoculum can escape from rust infested crops, therefore the establishment of a quarantine area may be impractical.

7.2.2 Movement control for people, plant material and machinery

Once symptoms of barley stripe rust are observed the pathogen is usually well established in the crop and eradication will be difficult. Therefore, any zoning, quarantine or movement controls will usually pertain to containment and management.

Movement of people, vehicle and machinery, from and to affected farms, must be controlled to ensure that spore inoculum is not moved off-farm on clothing, footwear, vehicles or machinery. This can be achieved through:

- Signage to indicate quarantine area and/or restricted movement in these zones.
- Fenced, barricaded or locked entry to quarantine areas.
- Movement of equipment, machinery, plant material or soil by permit only.
- Clothing and footwear worn at the infected site should either be double-bagged prior to removal for decontamination or should not leave the farm until thoroughly disinfected, washed and cleaned.
- Hay, stubble or trash must not be removed from the site.
- All machinery and equipment should be thoroughly cleaned down with a pressure cleaner prior to leaving the affected farm. The clean down procedure should be carried out on a hard surface, preferably a designated wash-down area, to avoid mud being re-collected from the affected site onto the machine.

7.3 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 infected property to other infected properties. This will be determined by the NMG during the production of the Response Plan. Further information on quarantine zones in an Emergency Plant Pest incursion can be found in PLANTPLAN, Appendix 10 (Plant Health Australia, 2009). These zones are outlined below.

7.3.1 Destruction zone

If destruction of hosts is considered, the entire crop should be destroyed after the level 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 contiguous areas of management if spread is likely to have occurred prior to detection.

If the movement of air-borne inoculum to adjacent crops appears likely, they will also need to be destroyed.

7.3.2 Quarantine zone

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

7.3.3 Buffer zone

A Buffer zone may or may not be required depending on 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.

7.3.4 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.

7.3.5 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.

7.4 Decontamination and farm clean up

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

7.4.1 Decontamination procedures

General guidelines for decontamination and clean up:

- Keep traffic out of affected area and minimize it in adjacent areas.
- Adopt best-practice farm hygiene procedures to retard the spread of the pest between fields and adjacent farms.
- Machinery, equipment, vehicles in contact with infected plant material or soil or present within the Quarantine Area, should be washed to remove soil and plant material using high pressure water or scrubbing with products such as a detergent, farm degreaser or a 1% bleach solution in a designated wash down area. Plant material should be destroyed using herbicide. Only recommended materials are to be used when conducting decontamination procedures, and should be applied according to the product label.

Refer to PLANTPLAN (Plant Health Australia, 2009) for further information.

7.4.2 General safety precautions

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

7.5 Surveillance and tracing

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

7.5.2 Survey regions

Establish survey regions around the surveillance priorities identified above. These regions will be generated based on the zoning requirements (see Section 7.3), and prioritised based on their potential likelihood to currently have or receive an incursion of this pest. Surveillance activities within these regions will either allow for the area to be declared pest free and maintain access and market access requirements or establish the impact and spread of the incursion to allow for effective control and containment measures to be carried out.

Steps outlined in Table 6 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 6. Phases to be covered in a survey plan

Phase 1	Identify properties that fall within the buffer zone around the infested premise Complete preliminary surveillance to determine ownership, property details, production dynamics and tracings information (this may be an ongoing action)
Phase 2	Preliminary survey of host crops in properties in buffer zone establishing points of pest detection
Phase 3	Surveillance of an intensive nature, to support control and containment activities around points of pest detection
Phase 4	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 infested 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 disease. Pathways to be considered are: • 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 growing media/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	Surveillance of production and retail nurseries, gardens and public land where plants known to be hosts of pathogen are being grown
Phase 6	Agreed area freedom maintenance, pest control and containment

7.5.3 Post-containment surveillance

The period of pest freedom sufficient to indicate that containment of the pest has been achieved will be determined by a number of factors, including cropping conditions, the level of infection and the control measures applied. As a guide, the following activities should be carried out following the containment of the pest:

- Establishment of sentinel plants around the site of infection but outside the containment zone.
- Sentinel plants should remain in place and inspected on a fortnightly basis for a further six weeks and then on a monthly basis.
- Surveys comprising plant sampling for and testing for barley stripe rust to be undertaken for a minimum of 12 months after containment has been achieved.

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9 Appendices

9.1 Appendix 1. Standard diagnostic protocols

For a range of specifically designed procedures for the emergency response to a pest incursion refer to PLANTPLAN (Plant Health Australia, 2009).

9.2 Appendix 2. Experts, resources and facilities

The following tables provide lists of experts (Table 7) and diagnostic facilities (Table 8) for use in professional diagnosis and advisory services in the case of an incursion.

Table 7. Experts in Barley stripe rust diagnosis

Expert	State	Details
Dr Merrin Spackman (PCR)	Vic	DPI Victoria 110 Natimuk Rd Horsham 3400 Ph: (03) 5362 2111
Dr Colin Wellings (pathogen biology and symptomatology, pathotype analysis)	NSW	University of Sydney Plant Breeding Institute Cobbitty Private bag 4011 Narellan NSW 2567 Ph: (02) 9351 8826

Table 8. Diagnostic service facilities in Australia

Facility	State	Details
DPI Victoria Knoxfield Centre	Vic	621 Burwood Highway Knoxfield VIC 3684 Ph: (03) 9210 9222 Fax: (03) 9800 3521
DPI Victoria Horsham Centre	Vic	Natimuk Rd Horsham VIC 3400 Ph: (03) 5362 2111 Fax: (03) 5362 2187
Industry & Investment NSW Elizabeth Macarthur Agricultural Institute	NSW	Woodbridge Road Menangle NSW 2568 PMB 8 Camden NSW 2570 Ph: (02) 4640 6333 Fax: (02) 4640 6300
Industry & Investment NSW Tamworth Agricultural Institute	NSW	4 Marsden Park Road Calala NSW 2340 Ph: (02) 6763 1100 Fax: (02) 6763 1222
Industry & Investment NSW Wagga Wagga Agricultural Institute	NSW	Pine Gully Road Wagga Wagga NSW 2650 Ph: (02) 6938 1999 Fax: (02) 6938 1809
SARDI Plant Research Centre Waite Research Precinct	SA	Hartley Grove Urrbrae 5064 South Australia Ph: (08) 8303 9400 Fax: (08) 8303 9403
Grow Help Australia	QLD	Entomology Building 80 Meiers Road Indooroopilly QLD 4068 Ph: (07) 3896 9668 Fax: (07) 3896 9446
DAFWA (AGWEST) Plant Laboratories	WA	3 Baron-Hay Court South Perth WA 6151 Ph: (08) 9368 3721 Fax: (08) 9474 2658

9.3 Appendix 3. Communications strategy

A general Communications Strategy is provided in PLANTPLAN (Plant Health Australia, 2009).

9.4 Appendix 4. Market access impacts

Within the AQIS PHYTO database, no countries appear to have a specific statement regarding area freedom from *Puccinia striiformis* f. sp. *hordei* and/or its derivatives (December 2009). Should barley stripe rust be detected or become established in Australia, some countries may require specific declaration. Latest information can be found within PHYTO, using an Advanced search "Search all text" for *Puccinia striiformis* f. sp. *hordei* and/or its derivatives.

9.5 Appendix 5. Overview of barley stripe rust diseases

A number of cereal rusts have the ability to infect and negatively impact barley under Australian environmental conditions, including wheat stem rust, barley leaf rust and barley grass stripe rust. A number of stripe rust variants are already present in the country, while others have so far remained exotic. The information provided below is a brief overview of these pathogens. See Section 8 for references.

9.5.1 Wheat stripe rust (*Puccinia striiformis* f. sp. *tritici* [*Pst*])

Pst was first detected in Australia in 1979 (O"Brien *et al.,* 1980) and has become endemic in the eastern cereal growing regions. The annual cereal rust survey has monitored the adaptation and evolution of *Pst* from a founder pathotype through single step mutation (Wellings and McIntosh, 1990; Wellings, 2007). Several of these pathotype mutants became dominant in the pathogen population through selective advantage, and caused considerable crop losses to the wheat industry during the early to mid 1980s and more recently from 2002 (Wellings, 2007).

Although the predominant host of *Pst* has been wheat, a noticeable increase in frequency of isolates recovered from wild *Hordeum* species stimulated an investigation of the evolutionary development of *Pst* on this host. Observations indicated that isolates of standard *Pst* pathotypes showed further differential variation on clones of *H. glaucum* and *H. leporinum* (Wellings *et al.,* 2000a). However, it was concluded that pathotype evolution within *Pst* on the weedy *Hordeum* species was independent from, and therefore likely to have little impact on, that occurring on wheat. It was concluded that while *Pst* can cause stripe rust on rare genotypes of cultivated barley, it is not considered to be a threat to production (Wellings, 2007).

9.5.2 Cocksfoot stripe rust (*P. striiformis* f. sp. *dactylidis* [*Psd*])

Stripe rust infecting cocksfoot (*Dactylis glomerata*) was originally described as morphologically distinctive in urediospore size and therefore ascribed the status of variety within *P. striiformis* (Manners, 1960). Although *Psd* was described in New Zealand in 1975 (Latch, 1976), the first report of *Psd* in Australia was not until 1979 (Wellings, 2007) and perhaps it was not by chance that it was contemporaneous with the first detection of *Pst*. It is therefore possible that this disease was present, but undetected, in Australia for some time. It remains a sporadic disease in isolated naturalised

communities of cocksfoot that occur along roadsides and in pasture situations in the cooler highlands and slopes of eastern Australia. *Psd* has not been detected in Western Australia (Wellings, 2007).

9.5.3 Barley grass stripe rust (*P. striiformis* f. sp. *pseudo-hordei* [*Psp-h*])

A new form of *P. striiformis* was detected in Australia in 1998 and described by Wellings *et al.* (2000a). The pathogen, commonly referred to as barley grass stripe rust (BGYR), was observed to cause disease on certain barley cultivars and barley breeding lines naturally infected in the field (Wellings *et al.* 2000b). BGYR was closely associated with weedy *Hordeum* species, showed broad avirulence on standard wheat differential testers with the exception of Chinese 166 (carrying Yr1) and appeared to contrast at one isozyme locus with *Pst*. Further studies demonstrated unique molecular phenotypes of BGYR isolates compared to a collection of Australian *Pst* pathotypes (Keiper *et al.,* 2003), and so provided more evidence for the unique grouping of BGYR as a new *forma specialis* within *P. striiformis* (Wellings, 2007).

9.5.4 Stripe rust on Kentucky bluegrass (*P. striiformis* f. sp. *poae* [*Psp*])

Psp was described as the pathogen causing stripe rust of Kentucky bluegrass (*Poa pratensis*) in the USA. Temperature optima for urediospore germination (12-18°C) and the close association between pathogen isolates and the host suggest that this is a distinctive *forma specialis*, although the geographic distribution outside the USA remains unclear. *Psp* has not been reported in Australia.

9.5.5 Barley stripe rust (*P. striiformis* f. sp. *hordei* [*Psh*])

Isolates of the stripe rust pathogen, which demonstrated adaptation to cultivated barley, were described as *Psh* by European workers in the late nineteenth century (Eriksson, 1894). Barley stripe rust has caused significant problems in winter barley production, particularly in the UK and the Netherlands in the 1960s (Stubbs, personal communication). More recently, the introduction and spread of *Psh* Race 24 in Colombia, South America, in 1975, and its adaptation and spread throughout South America in the 1980s caused considerable crop losses (Dubin and Stubbs, 1984). The disease subsequently spread northward into Mexico, Texas and western USA resulting in seasonal epidemics and significant economic losses (Marshall and Sutton, 1995). *Psh* has not been reported in Australia.