

CASE STUDY: INDUSTRY RESPONSE TO THE LUPIN ANTHRACNOSE INCURSION IN WESTERN AUSTRALIA

Greg Shea¹, Geoff Thomas¹, Bevan Buirchell¹, Moin Salam¹, Simon McKirdy²
and Mark Sweetingham¹

¹Department of Agriculture and Food, Western Australia

²CRC for National Plant Biosecurity

Corresponding author: gshea@agric.wa.gov.au

ABSTRACT

Anthracnose in lupins, caused by *Colletotrichum lupini*, was first detected in commercial crops in Western Australia (WA) in 1996. This incursion of an exotic plant pathogen into Australia constituted a major biosecurity threat to the local lupin industry. The disease caught the industry unawares with the majority of cultivars at that time being susceptible and there were major issues with local plant pathologists and lupin agronomists having very little exposure to diagnosis and management of this disease. In 1997, the first major breakthrough was made when resistance to anthracnose was confirmed in several breeding lines and commercial cultivars of narrow-leafed lupins (*Lupinus angustifolius*), and landraces of *Lupinus albus*. These findings led to the release of cultivars with elevated levels of resistance to the disease. Important information on relative yield loss, critical seed infection levels, fungicide seed treatment and geographical risk factors have also been discovered through applied research leading to use of seed testing and registered fungicides for the control of early infection.

In addition, a spatio-temporal model was developed to simulate the spread of anthracnose initiated by infected seed and other sources. The modelling has contributed to the formulation of strategies for management of lupin anthracnose. An extension campaign through field days, seminars and regular media exposure promoted the management package developed from the research.

KEY WORDS

lupin, fungicide, cultivar, resistance, spatio-temporal model

INTRODUCTION

Anthracnose is a serious disease of lupins caused by the fungus *Colletotrichum lupini* (Bondar) Nirenberg, Feiler & Hagendorn. It is present in almost every country where lupins are grown and is considered the most important disease of lupins in Europe, North America and South America.

Lupin anthracnose was detected in *L. albus* in the Chapman Valley east of Geraldton, and east Mingenew areas on the 5 September 1996. Infected crops were subsequently found on over 40 properties in the northern and north-eastern grainbelt in 1996. Agriculture Western Australia, now the Department of Agriculture and Food, Western Australia (DAFWA), with strong industry support, delineated the extent of the infestation and took action to stop further spread. Infected crops were confirmed on 133 properties. An estimated 40,000 hectares of crop lupin and 5,000 ha of sandplain lupin (*Lupinus cosentinii*) pastures were affected by the end of the 1996 growing season. The infection was most widespread in *L. albus* which later proved to be the most susceptible species. A moratorium was placed on *albus* lupin production until 1998 to reduce the risk of an epidemic of the disease. A code of conduct for the growing of *albus* lupin was implemented after the moratorium was lifted as a risk management strategy.

Lupin growers in WA are renowned for their innovative approach and willingness to adopt new and improved methods. Biosecurity, however, was not a strong industry-wide focus at the time, and free entry of lupin seed from overseas had been able to occur unhindered before quarantine restrictions finally came into force in 1996. Adoption of fungicide seed dressing and resistant cultivars was rapid once presented to industry.

DAFWA initially identified the extent of the disease incursion through wide spread survey. The initial containment campaign involved the destruction of standing crops. After it became clear that total eradication was not economically feasible, the campaign moved into a disease management phase. Industry was able to respond by utilising resources provided through grower funded industry grants to carry out the necessary research and development. Notable was the commitment shown by agribusiness and private agronomists in surveillance for the disease in the early stages of the campaign. These agronomists also took a key role in extending the latest findings to growers in a timely manner, especially when there was a great deal of anxiety in the industry.

The research centred on screening for available resistance, immediate management through development of fungicide seed dressing and seed testing and understanding epidemiology, inoculum thresholds and their relationship to yield losses.

This paper outlines generally the industry response, (grower, agribusiness and research) following the incursion of anthracnose in WA, and the research and development activity carried out in WA.

SEED TESTING

To reduce the spread of this disease a mechanism to determine the infection status of seed was required. This test needed to be able to test representative seed samples at a high level of sensitivity in a timely fashion. At the time, a lupin seed assessment service was available through the DAFWA which included a test for cucumber mosaic virus (CMV) status. As such, the industry was already aware of the benefits of this type of testing.

A Polymerase Chain Reaction (PCR) test, based on research carried out at the Centre for Legumes in Mediterranean Agriculture and the State Agricultural Biotechnology Centre, became available to growers. This test was capable of detecting one infected seed in 10,000. The test was improved over time to become quantitative, providing an estimation of the seed infection level based on the quantity of *C. lupini* DNA present in the sample. It was widely useful to growers in high risk areas, particularly prior to the wide scale release of resistant cultivars. Over the time, with greater understanding of the disease and greater deployment of resistant cultivars, seed testing became widely utilised as a tool for seed certification, for local seed supply and interstate and international seed biosecurity.

RESISTANT CULTIVAR DEPLOYMENT

At the time of the anthracnose incursion most narrow-leafed lupins were rated 'moderately susceptible' (MS) or worse. The newly released cv. Kalya was rated as 'intermediate-moderately resistant' (I-MR). All albus lupin and yellow lupin cultivars were rated 'very susceptible' (VS) or 'susceptible' (S). Field and glasshouse screening soon identified good resistance in narrow-leafed lupin (cv. Wonga and cv. Tanjil) (Cowling *et al.* 2000).

The release and uptake of these cultivars coincided with an extremely high level of anthracnose infection in 1999, (due to conducive seasonal conditions) and highlighted the benefits associated with using resistant cultivars. Tanjil had the added benefit of low CMV seed transmission which also helped in the Northern Agricultural Region where lupin crops were particularly prone to both anthracnose and CMV. Unfortunately, Tanjil had poor tolerance to the herbicide Metribuzin, which meant growers had fewer weed control options. The yield of Tanjil was better than older cultivars but

not as high as the cv. Quilinoch which unfortunately had an anthracnose rating of 'very susceptible' (VS). Development of resistant types continued using marker assisted technology (Yang *et al.* 2007) and intensive disease screening nurseries. With the 2005 release of the moderately resistant, Metribuzin tolerant and higher yielding cultivar Mandelup, the area sown to Tanjil reduced. Tanjil is still sown in the highest anthracnose risk areas of the state.

The albus industry has not recovered from the incursion and remains very small in WA. Most of the albus lupin grain production in Australia currently occurs in NSW which has 'area freedom' from anthracnose ('area freedom' is declared where a defined survey fails to detect the presence of the disease). Improvements in anthracnose resistance through breeding and selection led to the release of cv. Andromeda. Andromeda has gained some support in the industry which has seen some renewed interest in albus lupin production.

Breeding and selection in yellow lupin has produced genotypes with improved levels of resistance, but as yet cultivars have not been released.

FUNGICIDE SEED DRESSING

The seed borne nature of lupin anthracnose required that effective fungicides were identified for use as seed dressings to reduce transfer of infection from seed to seedling. Within Western Australia, use of seed dressing fungicides for lupin production was already well established through the use of iprodione and procymidone to manage brown spot (caused by *Pleiochaeta setosa*). Apart from these two chemicals, no other fungicides were registered for use on lupins in Australia. International research indicated that a number of fungicides had some activity, with a mixture of carbendazim + iprodione registered in a number of countries. In Australia temporary permits for the use of products containing carbendazim, thiabendazole and thiram were obtained for the 1997 and 1998 seasons. Full product registrations were being obtained while experiments were carried out to confirm their efficacy under WA conditions.

A combination of experimental approaches were carried out, including direct *in vitro* screening for activity against *C. lupini*, glasshouse and small plot experiments to assess systemic activity, and glasshouse, small plot and field experiments using infected seed to assess reduction of seed transmission (Thomas and Sweetingham, 2000a, 2003). A summary is presented in Table 1.

Both thiram and fluquinconazole were highly effective *in vitro* and reduced seed transmission of infection in field experiments. Fluquinconazole exhibited systemic protection, more so in *L. albus* than in *L. angustifolius* but it was not likely to be commercialised for use in lupins at the time. At the rate

effective for control of brown spot, procymidone and particularly iprodione reduced transmission of seed borne anthracnose infection, however both were more effective when combined with thiram. Both were more effective when used at higher rates but the cost associated with higher rates when compared to effective rates of thiram is prohibitive. Thiram, fluquinconazole and carbendazim are all ineffective as seed treatments for control of brown spot and therefore to provide control of both brown spot and anthracnose, mixtures

with either iprodione or procymidone are required. As a result of this research, thiram, which is relatively low cost and compatible with both iprodione and procymidone, was registered for reduction of seed transmission of seed borne anthracnose. Treatment combinations reduce anthracnose transmission by 75–85% providing subsequent yield responses. This treatment has been widely adopted by lupin growers, particularly in the higher risk northern agricultural region.

Table 1. Effect of fungicide seed treatments on anthracnose infection of seedlings grown from infected seed of *L. angustifolius* (cv. Gungurru) under glasshouse conditions assessed 3 weeks after sowing; *L. angustifolius* (cv. Myallie) at Badgingarra assessed 5 weeks after sowing; and *L. albus* (cv. Kiev Mutant) at Geraldton and Mingenew assessed 7 weeks after sowing (Thomas and Sweetingham, 2003).

Fungicide (g ai/kg seed)	Plants infected (% [#])			
	Glasshouse	Badgingarra	Mingenew	Geraldton
untreated	8.5 ^{a##}	4.8 ^a	38.6 ^a	47.6 ^a
iprodione (0.25)	5.7 ^{ab}	1.8 ^c	33.1 ^a	30.5 ^{ab}
procymidone (0.25)	–	3.4 ^b	–	–
thiram (1.0)	0.4 ^c	1.0 ^d	–	–
carbendazim (0.5)	2.7 ^{bc}	–	–	–
iprodione (0.25) + carbendazim (0.5)	0.9 ^c	–	6.4 ^b	8.9 ^c
iprodione (0.25) + thiram (1.0)	–	0.5 ^c	7.1 ^b	7.0 ^c
procymidone (0.25) + thiram (1.0)	–	0.9 ^{dc}	13.7 ^b	20.8 ^{bc}
iprodione (0.25) + fluquinconazole (0.5)	–	–	3.4 ^b	7.3 ^c

[#] Back transformed values from angular transformation used for statistical analysis.

^{##} Different letters following data indicate significant difference at that site.

NON-CHEMICAL SEED TREATMENTS

Apart from the use of fungicide, considerable interest was raised in the use of long term storage or high temperature treatment of seed to reduce anthracnose infection. Long term storage of seed reduces infection levels and elevating temperatures from 10°C to 30°C hastens the decline of infection. Six months storage at 30°C almost eliminates infection (Thomas and Sweetingham 2000c).

Higher temperature treatment over shorter periods also reduced seed infection. Exposure of seed to temperatures from 60°C to 70°C for periods of 1–7 days reduces transmission of infection with minimal impact on establishment (Thomas and Adcock, 2004). However, neither short term or long term seed storage or thermotherapy can be guaranteed to totally eliminate seed infection.

Due to the lack of practicality and lack of complete control of infection, non chemical seed treatments for Lupin anthracnose were not adopted by industry.

FOLIAR FUNGICIDE

Despite the adoption of resistant cultivars and seed dressing fungicides, anthracnose remains a lupin production issue and can cause yield losses. Yield losses

are particularly significant in the high–medium rainfall areas of the northern agricultural zone as a result of warmer winter temperatures and the widespread presence of anthracnose susceptible sandplain lupins which act as a reservoir for the disease. In addition, although cultivars such as cv. Tanjil show good resistance in the stems and petioles, the young flower tissue is still susceptible.

A range of fungicides were evaluated in both glasshouse and field experiments (Thomas *et al.*, 2008). Results are summarised in Table 2. Glasshouse investigation identified a range of products that reduced disease severity including chlorothalonil, mancozeb, azoxystrobin and tebuconazole. Field application of azoxystrobin, mancozeb or chlorothalonil during flowering and podding reduced incidence of anthracnose infection on pods and increased yield in moderately susceptible, moderately resistant and resistant cultivars. Timing was found to be important with application prior to, but close to, the time of infection being most effective. This research indicates that the use of foliar fungicides for anthracnose control is a viable management option in high anthracnose risk areas of WA. Mancozeb is currently registered and permits for chlorothalonil were granted for this purpose.

Table 2. Effect of anthracnose foliar fungicide application on anthracnose infection and grain yield of *Lupinus angustifolius* (cvs Kalya and Tanjil) at Badgingarra (Thomas *et al.* 2008).

Treatment	Number of pods [#] (pods/plant)	Pod infection (% pods)	Grain yield (t ha ⁻¹)
Unsprayed	6.3	20.8	1.29
Fungicide sprayed*	10.3	10.5	1.83
LSD (<i>P</i> = 0.05)	1.3	3.1	0.15

- Bravo Fungicide® (chlorothalonil 720 g/L) @ 1.5 L/ha.

SEED INFECTION THRESHOLDS AND YIELD LOSS STUDIES

A program involving over 20 field experiments was carried out across the WA grain belt looking at how levels of anthracnose inoculum, environment and cultivar resistance affected anthracnose infection and grain yield.

Anthracnose infection and yield loss is significantly related to seasonal rainfall and cultivar resistance (Fig. 1). Yield loss is greatest in higher rainfall environments as the more frequent rainfall allows more infection events and therefore increases anthracnose infection. Resistant cultivars have lower yield loss under higher disease pressure (due to high rainfall) however as disease pressure decreases with decreasing rainfall, the advantage from resistant cultivars is reduced (Burchell *et al.* 2006; Thomas and Sweetingham, 2004).

Resistant cultivars can tolerate higher levels of infected seed than susceptible cultivars before significant yield loss occurs (Fig. 2) (Thomas and Sweetingham, 2000a). Yield losses can still occur in resistant cultivars, particularly from pod infection. Pods and flowers of resistant cultivars are more susceptible to infection than stem tissue (Thomas and Sweetingham, 2000a). Higher seed infection levels can be tolerated in lower rainfall environments than high rainfall environments. Predictive yield loss tables were produced incorporating rainfall, cultivar and inoculum level (seed infection) (Thomas, 2002). This allowed growers to interpret risks associated with seed infection levels determined through seed testing.

GEOGRAPHICAL RISK FACTORS

Climatic factors impact on anthracnose disease expression. Controlled environment studies showed that the latent period was shorter and disease incidence and severity greater as temperatures rose from 12°C to 26°C. Also, resistance in cultivars such as Wonga was less effective at higher temperatures. As already outlined, disease incidence and severity is greater in higher rainfall environments.

Wild sandplain lupins are endemic in pastures and roadsides in the northern agricultural region of WA and are susceptible to anthracnose. As such, they act as a reservoir for the fungus and a source of infection annually. Regional risk across WA was characterised using climatic and prevalence of sandplain lupins (Thomas, 2003). Risk was greatest in the high rainfall northern grainbelt, where winter temperatures are warmest and sandplain lupins were abundant.

DISEASE MODELLING

Within a few years of the incursion in 1996 in WA, researchers had made significant progress in relation to pathogen behaviour, epidemiology and fungicide control measures based on a series of field and controlled environment experiments. To enable disease risk predictions and control recommendations to be made across a wider set of environments and scenarios a simulation model ('AnthracnoseTracer') was developed.

AnthracnoseTracer simulates the spread of anthracnose in a lupin paddock over space and time. Diseased seed and/or infected sandplain lupins can be

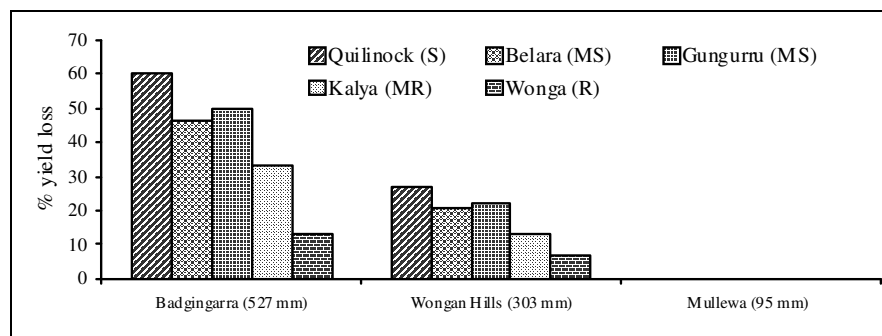


Fig. 1. Percentage yield losses from 0.5% infected plants across cultivars at three sites with different rainfall (Thomas and Sweetingham, 2000b).

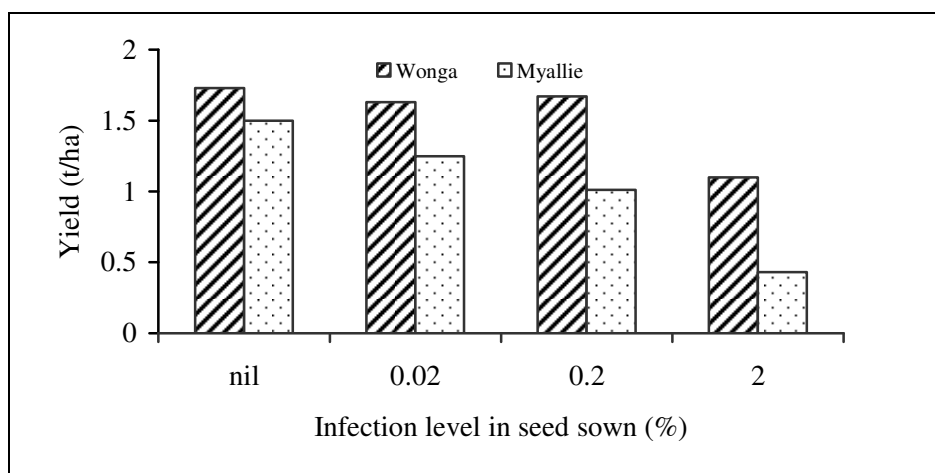


Fig. 2. Impact of inoculum level and cultivar resistance on lupin yield (Thomas and Sweetingham, 2000b).

considered as the primary source of infection. The model considered the number of wet-hours in a day as the most important weather variable for disease spread, while the rainfall intensity (splash distance) and wind (intensity and direction) dictated where *C. lupini* spores could be dispersed. The disease status was described as the percent loss of healthy (uninfected) lupin growing points in each 1 m² segment of a paddock, after accounting for the compensatory growth. For the details of the model, refer to Diggle *et al.* (2002).

The model was applied to quantify the effect of seed infection levels on the disease epidemic and final level of anthracnose infection in the crop and the impact on production. For example, based on rainfall and temperature in Geraldton in 1998, the model showed that 1 in 10,000 seed infection in cv. Myallie could produce over 15% yield loss; 1 in 640,000 infection would have caused only a 0.03% loss; whereas a 1 in 1,000 could cause total (100%) crop loss. Of course, a more resistant cultivar such as cv. Wonga, in the same location and season, slowed the disease epidemic to a considerable extent (e.g. < 1% loss with 1 in 10,000 seed infection compared to 15% loss with cv. Myallie). The model showed that the presence of infected sandplain lupins on the fenceline around a paddock, especially in the up-wind direction, could negate the benefits of using clean seed. A 1 m wide infected blue lupin fenceline, 10 m away from the paddock in the upwind direction, could cause about 1% loss in cv. Wonga, 6% in cv. Belara and 9% in cv. Myallie (in the Geraldton 1998 season).

The model was also applied to see how seasonal and regional differences could affect disease development. For example, in the Geraldton area, the model predicted a 10% loss in 1999 in the cv. Belara with 1 in 10,000 seed infection compared to a < 1% loss in 2000 with the same cultivar and seed infection level. There had been an expectation that anthracnose was a more serious threat to production of lupins in high rainfall than in low rainfall environments. The model quantified the extent

of this difference and allowed agronomists to provide growers with an assessment of the risk of losses in different cultivars in different regions. For example, in the high rainfall area, and in the absence of blue lupins, susceptible cultivars were suggested as an option for sowing if levels of seed infection are known to be below 0.01%. On the other hand, unless the seed infection level was > 1%, then susceptible cultivars could be grown in the low rainfall regions. Such information was invaluable where farm managers needed to interpret seed testing results for level of anthracnose infection.

The model was also capable of accounting for the control of the disease by using fungicide seed dressing and was used to simulate the effectiveness of post-emergent fungicide application which was useful to assist in determining the most effective timing strategy for economic control.

LUPIN TRADE

Lupin anthracnose was also detected in parts of South Australia (SA) and was found in ornamental *Lupinus polyphyllus* in an alpine nature reserve in 1996 in New South Wales (NSW) (Lindbeck, 1998). It is a testament to good biosecurity practises that anthracnose has been kept out of lupin cropping regions of Victoria and NSW. The flip-side of this has been the difficulties faced by compound feed manufacturers in eastern Australia from accessing lupins from WA. This has been an important issue in recent years when drought in eastern Australia has created a feed shortage. Seed testing and grain movement protocols have enabled shipment of some grain. An important distinction should be made for movement of lupin kernels. For while this material could carry trace quantities of the *C. lupini* pathogen, it cannot transmit the disease to germinating seedlings as is the case with viable seed.

COMMUNICATION WITH INDUSTRY

The management package extended to the WA lupin industry was:

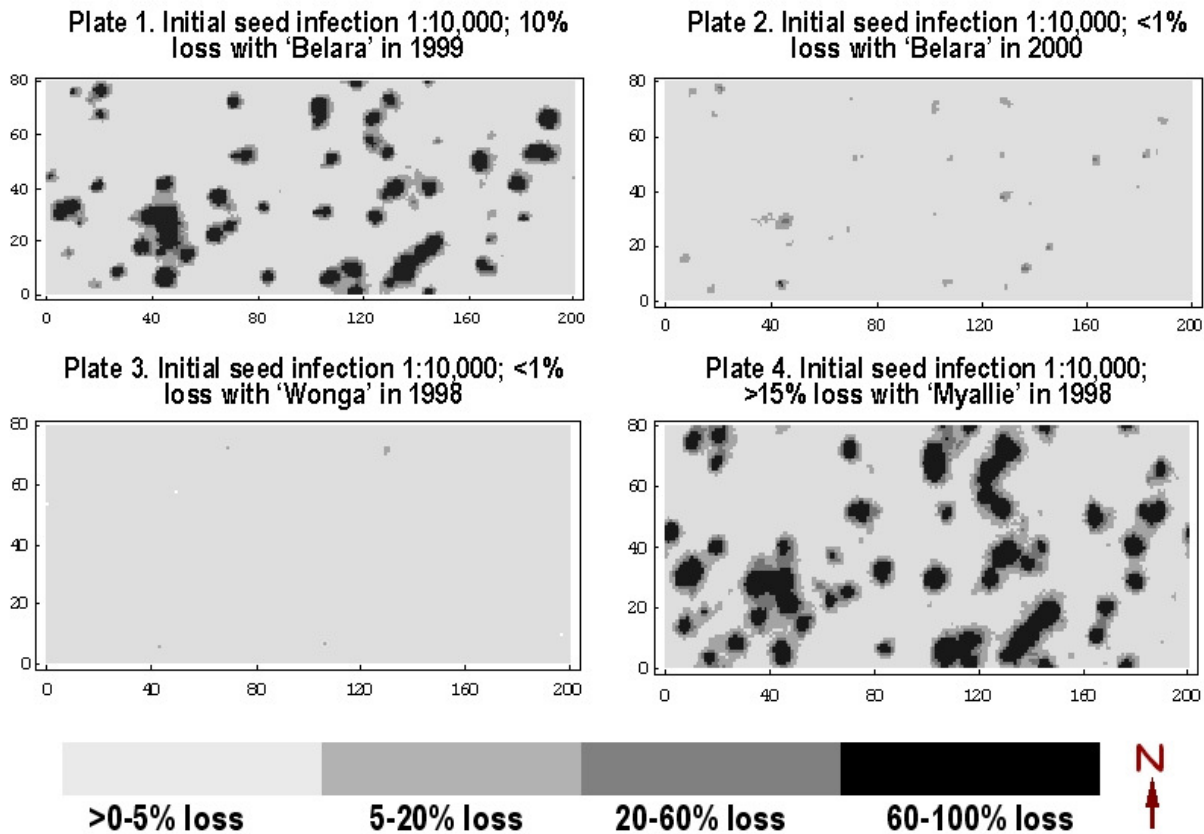


Fig. 3. Spread of anthracnose in lupin, simulated by the model AnthracnoseTracer, at the end of the growing season showing cultivar and seasonal difference in disease outbreak in Geraldton, Western Australia. Shading indicates percent loss of healthy growing points (gp) in each 1 m² subunit area of the paddock.

Planting low risk seed. A seed source should be selected with the lowest anthracnose infection available. Seed should be graded to remove the smaller infected seeds. The seed test was made available and information on safe thresholds was provided based on cultivar and regional environment.

Fungicide seed treatment. Thiram was the recommended fungicide mixed with a dicarboximide for brown spot control. Seed dressing fungicide was strongly recommended in all parts of the State.

Crop rotation. Lupins were not recommended to be sown back onto the previous season's lupin stubble. A single year break is sufficient for stubble borne spores to break down.

Reducing reservoirs of infection. It was recommended that sandplain lupins on fencelines and roadways be controlled. To be effective, these needed to be sprayed out early in the seedling stage before the disease has a chance to multiply and spread. Volunteer lupins in cereal and canola crops in paddocks that will be sown to lupins the following season were also recommended to be sprayed out.

Machinery hygiene. Experience from the initial incursion showed that there was potential for clean seed to be contaminated with infected material during harvest and grading. Also, there was potential for spraying rigs

to spread disease within and between paddocks. Biosecurity measures were recommended to reduce this risk.

Cultivars. Cvs Tanjil and Wonga were the most resistant followed by the cvs Mandelup, Coromup and then Kalya. The cvs Kiev Mutant, Wodjil, Pootalong, Myallie or Tallerack were not recommended in higher risk situations.

There was a concerted effort by all involved to ensure reliable, credible and consistent information was made available. The maintenance of information flow reduced the uncertainty amongst growers and stifled the opportunity for misinformation from less reliable sources. The DAFWA and Grains Research and Development Corporation sponsored annual Agribusiness Crop Update Conference was a very useful vehicle for disseminating information along with other seminars, Grower Field Days, media interviews, Farmnotes and web-based information. The Grains Research Committee funded a project to extend information to growers via on-farm demonstrations which helped ensure rapid adoption of the management package.

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LITERATURE CITED

- Buirchell, B.J., M.W. Sweetingham and G.J. Thomas. 2006. Cultivar, environment and inoculum source influence the development of lupin anthracnose. In 'México, where old and new world lupins meet. Proceedings of the 11th International Lupin Conference, Guadalajara, Jalisco, Mexico, 4–9 May 2005. pp. 128–130.
- Cowling, W.A., B.J. Buirchell, M.W. Sweetingham, H. Yang, G. Thomas, D.J. Luckett, A.G.P. Brown and J. Hamblin. Anthracnose resistance in lupins – an innovative Australian research effort 1996–1998. IN Lupin, an ancient crop for the new millennium: Proceedings of the 9th International Lupin Conference, Klink/Muritz, Germany, 20–24 June 1999, 2000, pp. 60–62.
- Diggle, A.J., M.U. Salam, G.J. Thomas, H.A. Yang, M. O'Connell and M.W. Sweetingham. 2002. Anthracnose Tracer: A spatio-temporal model for simulating the spread of anthracnose in a lupin field. *Phytopathology* 92: 1110–1121.
- Lindbeck, K.D., G.M. Murray, A. Nikandrow, M. Priest and B.C. Dominiak. Survey for anthracnose caused by *Colletotrichum gloeosporioides* in crop lupins (*Lupinus angustifolius*, *L. albus*) and ornamental lupins (*L. polyphyllus*) in New South Wales. *Australasian Plant Pathology*, 1998, 27: 259–262.
- Thomas, G. 2003. Lupin anthracnose – identification and management. *Farmnote* No. 15/2003.
- Thomas, G.J. 2002. Estimated yield losses in lupin cultivars from sowing anthracnose infected seed. In '2002 Lupin Update'. *Agribusiness Crop Update*, Sheraton Hotel, Perth, Western Australia, 20–21 February 2002 (Ed. A. McLarty).
- Thomas, G.J. and K.G. Adcock. 2004. Exposure to dry heat reduces anthracnose infection of lupin seed. *Australasian Plant Pathology* 33: 537–540.
- Thomas, G.J. and M.W. Sweetingham. 2000a. Fungicide seed dressings for lupin anthracnose. In 'Lupin, an ancient crop for the new millennium: Proceedings of the 9th International Lupin Conference, Klink/Muritz, Germany, 20–24 June, 1999' (International Lupin Association: Canterbury, New Zealand).
- Thomas, G.J. and M.W. Sweetingham. 2000b. Lupin anthracnose – 2000 update. IN '2000 Lupin Update'. *Agribusiness Crop Update*, Rendezvous Observation City Hotel, Perth, 17–18 February, 2000 (Ed. B. O'Neill).
- Thomas, G.J. and M.W. Sweetingham. 2000c. Storage effects on *C. gloeosporioides* infection levels in lupin seed. In 'Lupin, an ancient crop for the new millennium: Proceedings of the 9th International Lupin Conference, Klink/Muritz, Germany, 20–24 June, 1999' (International Lupin Association: Canterbury, New Zealand). pp. 33–36.
- Thomas, G.J. and M.W. Sweetingham. 2003. Fungicide seed treatments reduce seed transmission and severity of lupin anthracnose caused by *Colletotrichum gloeosporioides*. *Australasian Plant Pathology* 32: 39–46.
- Thomas, G.J. and M.W. Sweetingham. 2004. Cultivar and environment influence the development of lupin anthracnose caused by *Colletotrichum lupini*. *Australasian Plant Pathology* 33: 571–577.
- Thomas, G.J., M.W. Sweetingham and K.G. Adcock. 2008. Application of fungicides to reduce yield loss in anthracnose-infected lupins. *Crop Protection* 27: 1071–1077.
- Yang, H., D. Renshaw, G. Thomas, B. Buirchell and M. Sweetingham. 2007. A strategy to develop molecular markers applicable to a wide range of crosses for marker assisted selection in plant breeding: a case study on anthracnose disease resistance in lupin (*Lupinus angustifolius* L.). *Molecular Breeding*, 21: 473–483.