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ORIGINAL RESEARCH ARTICLE

Evaluation of economic fungicide strategies for control of ascochyta blight in field pea in southern Australia

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Abstract

The aim of this five-year study was to identify economic fungicide treatments to control ascochyta blight in field pea in southern Australia. Results showed a complex interaction between a number of factors. There were clear patterns in efficacy of different fungicides in controlling disease however grain yield and financial gains were dependent on fungicide costs, seasonal conditions and yield potential. Disease suppression was achieved at early growth stages with fungicides applied as seed dressings or via fluid injection before sowing. Foliar fungicides were applied before or at canopy closure growth stage and early flowering. The foliar fungicides prothioconazole plus bixafen, azoxystrobin plus cyproconazole and pyraclostrobin were economic where grain yield was above 1.6 t ha^{-1} but mancozeb, the traditional protectant fungicide for field pea, was not economic even where disease severity was reduced. Analysis of grain yield responses to ascochyta blight identified three groupings based on maximum grain yield potential and found ascochyta blight had greatest impact on grain yield in higher rainfall and higher yielding situations. In dry growing seasons with yield potential below 1.6 t ha^{-1} the disease had no significant effect on grain yield and no fungicide strategy was economic irrespective of the disease control. A sowing date experiment confirmed that modern semi-leafless 'afila' erect field pea varieties are better suited to the combination of early sowing and economic disease management strategies to maximise grain yield in southern Australia than traditional conventional trailing types and have made redundant the advice to delay sowing as a means to avoid ascochyta blight.

Keywords *Ascochyta* · *Phoma* · Blackspot · Foliar fungicide · Seed dressing

Introduction

Field pea (*Pisum sativum*) is a winter grown crop in southern Australia, and the harvested grain is mainly used for human consumption, with some going to livestock feed. A minor use of the crop is for forage or green/brown manure. The majority of the Australian crop is based on semi-leafless 'afila' plant ideotypes with thick stems and leaves modified into tendrils for better standing ability (GRDC Grownotes 2018a), although before the 2000's it was almost entirely made up of trailing conventional cultivars (McMurray et al. 2011). Australia produced 400,000 tonnes of field pea in 2020 (AEGIC 2020).

Ascochyta blight (synonyms: blackspot, Mycosphaerella blight) of field pea is common worldwide and is the major disease in Australia. It is estimated to regularly cause 25% yield loss with up to 75% yield loss in individual crops (Bretag et al. 1995; McMurray et al. 2011). The causal pathogens are *Didymella pinodes* (syn. *Mycosphaerella pinodes, Peyronellaea pinodes*), *D. pinodella* (syn. *Phoma medicaginis* var. *pinodella, P. pinodella)* and *Ascochyta pisi* (Davidson et al. 2020). In Australia another pathogen *A. koolunga* (syn. *Phoma koolunga*) has been described in this disease complex (Davidson et al. 2009; Hou et al. 2020). Ascospores of *D. pinodes* can be blown several kilometres from infested stubble during autumn and early winter when field pea crops are sown and establishing in Australia, and conidia of all the pathogens are rain-splashed from infested stubble, soil and diseased plants throughout the season (Davidson et al. 2020). A second cycle of ascospores is

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spread by wind and rain during spring at the crop flowering and podding stages (Roger and Tivoli 1996; Bretag et al. 2006). Rain events are important in spreading the spores and the resulting humidity is conducive for infection and increased plant symptoms. No Australian field pea variety has resistance to this disease. A fungicide strategy recommended for ascochyta blight in field pea includes a combination of fungicide seed treatment plus foliar applications of fungicide at 7 to 9 node growth stage (g.s.) and again at early flowering (McMurray et al. 2011), noting that all g.s.in this manuscript refer to the above ground nodes only. The seed treatment and first foliar spray are designed to minimise the establishment of ascochyta blight pathogens in the crop and the later spray is to control infection from the second cycle of ascospores. Field pea growers avoid the use of seed treatments as they can be difficult to handle and can have a deleterious effect on rhizobium inoculant (Rathjen et al. 2020), which is important for nitrogen fixation in grain legume crops.

The role of early infection on the severity of the ascochyta blight epidemic and final disease levels was identified by Salam et al. (2011a, b) and Davidson et al. (2013). Controlling disease on seedlings can be achieved via seed treatments or by foliar fungicides. Studies were designed to compare the efficacy of foliar fungicide sprays at early growth stage (4 node) as an alternative strategy to the fungicide seed dressing or other sowing treatments.

Delayed sowing several weeks past the autumn rains also reduces seedling infection since fewer ascospores are present at the later time (Salam et al. 2011a, b) but this risks grain yield loss from terminal drought (McMurray et al. 2011). This is especially of concern in lower rainfall areas with relatively short growing seasons where much of the Australian field pea crop is sown. Growers need to balance the reduced disease risk associated with delayed sowing against the terminal drought risk. McMurray et al. (2011) identified that grain yield in field pea was optimised in early sown crops combined with strategic fungicides but also concluded that fungicides with greater efficacy than mancozeb were required in these conditions. Since then, alternative fungicides have been registered in Australia for ascochyta blight of field pea including prothioconazole plus bixafen (AviatorXpro®) and azoxystrobin plus tebuconazole (Veritas®).

The aim of this study was to identify economic fungicide treatments in different rainfall regions with new registered products compared to older protective actives, for the control of ascochyta blight in field pea.

Materials and methods

Replicated field experiments were sown following autumn opening rains from late April to late May each year from 2015 to 2019, inclusive, at Hart (-33.75805, 138.42723), a medium rainfall region (mean annual rainfall 404 mm), and Minnipa (-32.83824, 135.15105), a low rainfall region (mean annual rainfall 282 mm). In 2015 a third location was sown at Pinery (-34.30967, 138.46888), a medium rainfall region (mean annual rainfall 422 mm) (rainfall data accessed via Bureau of Meteorology Climate Data Online). Fungicide treatments were randomised within each of the three replicate blocks in each experiment.

The 2017 Hart experiment consisted of two sowing dates, one sown after the opening rains in late April, and the second sown four weeks later in late May. This experiment was a split plot design with sowing date as the main block and fungicide treatments randomised within each sowing date block. Individual plots were 10 m x 1.45–1.65 m in size and plant density was sown at 55 seeds m^2. Trial management represented the local practice for each region with respect to fertiliser, herbicides and insecticide rates and application times. Rhizobium inoculant was not applied as this is the general accepted practice for this region.

The field pea variety PBA Coogee (Pulse Australia 2013) was sown in the field experiments in 2015 and 2016. It is a mid flowering and mid maturing conventional dun dimpled type pea suitable for either grain or forage production. It grows rapidly early on, and produces high early season plant biomass, hence providing a conducive canopy for ascochyta blight. Flowering and pod set is slightly later in the season than modern varieties, making it is more suited to the higher rainfall zones. The variety PBA Oura (Seednet 2011) was sown in the trials in 2017 to 2019. It is a high-yielding early to mid-flowering semi-leafless 'afila' plant type producing dun dimpled seed and relatively high grain yields. This line has broad adaptation and high grain yield potential in short growing seasons, hence is suited to the lower rainfall regions, and also adapted across South Australia (SA) in lower rainfall seasons.

To accelerate disease infection all trials were inoculated with ascochyta blight infested field pea straw after sowing. The straw had been collected from known infested field pea crops or trials after harvest the previous season and stored in ambient conditions until ascospore maturity of *D. pinodes* was forecast using Blackspot Manager (Salam et al. 2011a, b) with the assistance of researchers from Department of Primary Industries and Regional Development (DPIRD) Western Australia. At that point the straw was moved to a dry location under cover to delay release of the ascospores. When experiments were at 1 to 2 node g.s. the straw was broken into small pieces using a hammermill and was

Table 1 Fungicide products used in the trials

Product (and application)	Active ingredients	Rate of application
P-Pickel T® (seed dressing)	360 g L^{-1} thiram plus 200 g L^{-1} thiabendazole	200 ml per 100 kg seed
Systiva® (seed dressing)	333 g L^{-1} fluxapyroxad	150 mL per 100 kg seed
Chlorothalonil720® (foliar)	720 g L^{-1} chlorothalonil	2 L ha^{-1}
AmistarXtra® (foliar)	200 g L^{-1} azoxystrobin plus 80 g L^{-1} cyproconazole	600 mL ha^{-1}
AviatorXpro® (foliar)	150 g L^{-1} prothioconazole plus 75 g L^{-1} bixafen	600 mL ha^{-1}
Cabrio® (foliar)	250 g L^{-1} pyraclostrobin	200 mL ha^{-1}
Mancozeb750WG® (foliar)	750 g kg^{-1} mancozeb	2.5 kg ha^{-1}
Veritas® (foliar)	200 g L^{-1} tebuconazole plus 120 g L^{-1} azoxystrobin	1 L ha^{-1}
Flutriafol250® (fluid injection)	250 g L^{-1} flutriafol	400 mL ha^{-1}
Uniform® (fluid injection)	325 g L^{-1} azoxystrobin plus 125 g L^{-1} metalaxyl	400 mLha^{-1}

then spread evenly over the trial sites, using 2 full bags (90 × 40 cm) of straw per experiment.

Fungicide products are listed in Table 1. In general, trials included (1) seed and or fungicide treatments applied at sowing through fluid injection, (2) foliar fungicides applied between the 4 to 9 node g.s. and (3) foliar fungicides applied at early flowering. All trials included two control treatments; (1) untreated, aimed at achieving maximum disease severity, and (2) the industry standard seed treatment thiram plus thiabendazole (P-Pickel T®) plus fortnightly sprays of chlorothalonil, aimed at maximum control of ascochyta blight disease. The 2015 and 2016 field experiments investigated different fungicide treatments applied at sowing as seed treatment or fluid injection, compared to the seed treatment thiram plus thiabendazole and also compared different foliar treatments applied at 9 node g.s. and at early flowering. The 2016 experiment included two additional foliar treatments with applications starting at 4 node g.s.; (1) prothioconazole plus bixafen (600 mL ha-1) applied at 4 node g.s. plus early flowering plus mancozeb (2.5 Kg ha^{-1}) at mid-flowering, and (2) mancozeb at half rate (1.25 Kg L^{-1}) applied 4 times i.e. 4 node g.s., 13 node g.s., early flowering and mid-flowering. The 2017 experiment investigated the efficacy of the selected foliar treatments across two sowing dates. The 2018 and 2019 trials investigated whether foliar actives applied at the 4 to 5 node g.s. were as effective or better than the thiram plus thiabendazole seed treatment at reducing early disease severity, combined with early flowering foliar treatments to control disease.

Disease assessments were generally conducted six weeks after sowing to assess the effectiveness of seed and sowing fungicide treatments, and again two weeks after the foliar fungicide treatments. Prior to flowering the disease assessments were recorded as the % plant area (leaf and stem) diseased, averaged for 5 plants selected at random per plot. During flowering, for ease of assessment, disease was assessed on 5 plants per plot by placing individual nodes into disease categories of 0%, 1–25%, 26–50%, 51–99%, or 100%. This system was devised as a quick and efficient method to assess multiple plots and trials in a short time period. A Disease Index per plot was calculated by summing the number of nodes per category for the five plants, and multiplying this sum by a weighting factor per category of 0, 1, 3, 6 or 8 respectively. The weighting factors represent the increasing severity of each disease category. This node score was summed for the plot then averaged for the five plants to achieve the Disease Index. This system was first tested in one trial to ensure the resulting data were representative of disease observations in the trial.

Disease Index per plot = $[(0 \text{ x } n^{0}) + (1 \text{ x } n^{1-25}) + (3 \text{ x } n^{26-50}) + (6 \text{ x } n^{51-99}) + (8 \text{ x } n^{100})]/5$.

where n = number of nodes per category, and the superscript denotes the category.

Plots were harvested using an experimental plot harvester and grain yield recorded as kg $plot^{-1}$ and converted to tonnes ha^{-1}. This was achieved by calculating the plot width from row spacing and the number of sown rows adjusted for plot edge effects between adjacent plots (2 spaced rows). The price of the fungicide treatments and grain was sourced from the PIRSA (2021a) Gross Margin Guide. The value of the grain was calculated as \$380 $tonne^{-1}$ multiplied by the yield ha^{-1} and fungicide costs per hectare were subtracted from the grain yield to achieve a harvested grain value.

Disease and yield data were spatially analysed in Genstat 20th Edition using residual maximum likelihood (REML) MetaAnalysis - Automatic Analysis of Series of Trials for multiple sites each season. REML linear mixed models analysis of variance was used to analyse data from single sites including the split plot time of sowing experiment in 2017. Significant differences were based on 95% confidence intervals.

Results

Seasonal effect on disease severity

Winter seasonal conditions in 2015 and 2016 favoured plant growth and disease progression, ascochyta blight symptoms were apparent at all sites, with a maximum Disease Index score above 90 in these two seasons (Tables 2 and

Table 2 Effect of seed treatments and foliar fungicides on ascochyta blight severity in field pea trials at Hart, Pinery and Minnipa in 2015 at 6.5 node growth stage (g.s.) (Hart site only), at 9.5 node g.s. after the first foliar fungicides had been applied, and at mid flowering after the early flowering fungicides had been applied

Treatment	% disease at 6.5 node g.s.	% disease at 9.5 node g.s.	Disease Index at mid flowering	Grain yield t ha^{-1}	Grain value \$ ha^{-1}
	Hart	**3 sites**	**3 sites**	**3 sites**	**3 sites**
Thiram plus thiabendazole[1]	0.0^{a}	23.8^{bc}	88.4^{abc}	1.31^{ab}	\$492^{bc}
Thiram plus thiabendazole + fortnightly chlorothalonil[2]	0.0^{a}	15.5^{ef}	42.0^{e}	1.62^{e}	\$438^{a}
Thiram plus thiabendazole + mancozeb[3]	0.0^{a}*	20.5^{cd}	80.1^{bc}	1.42^{cd}	\$496^{bc}
Thiram plus thiabendazole + prothioconazole plus bixafen[3]	0.5^{a}*	12.8^{f}	50.0^{e}	1.61^{e}	\$537^{d}
Thiram plus thiabendazole + azoxystrobin plus cyproconazole[3]	0.7^{a}*	18.3^{de}	63.8^{d}	1.55^{e}	\$539de
Thiram plus thiabendazole + pyraclostrobin[3]	0.0^{a}*	15.6^{ef}	65.4^{d}	1.57^{e}	\$571^{e}
Flutriafol[4]	8.5^{bc}	18.0^{de}	83.1^{abc}	1.40^{bcd}	\$516^{cd}
Azoxystrobin plus metalaxyl[4]	7.8^{b}	26.3^{ab}	90.3^{a}	1.32^{abc}	\$476^{b}
Untreated	9.8^{c}	28.8^{a}	87.7^{abc}	1.32^{ab}	\$502^{bc}

*No foliar fungicides applied before this disease assessment

[1]Seed treatment; [2]Foliar application; [3]Foliar treatments applied at 9 node growth stage and again at early flowering; [4]Fluid injection fungicides applied at seeding. Annual rainfall Hart = 353 mm, Minnipa = 292 mm, Pinery = 399 mm

Different superscript letters indicate significant differences at 95% confidence intervals

3). In particular, the Minnipa 2016 site had above average rainfall which favoured the development of high disease severity prior to the first foliar applications. At Hart in 2016, while there was low disease severity early in crop development, towards the end of the season a relatively cool and wet spring resulted in prolonged maturation of the crop and increased severity of ascochyta blight symptoms.

The 2017, 2018 and 2019 rainfall totals were below long-term average which was associated with reduced disease severity in these experiments. The maximum Disease Index was progressively lower each season, viz. 69.7, 54.8 and 28.5 in 2017, 2018 and 2019, respectively (Tables 4, 5 and 6). The 2017 season started with a late break in most parts of South Australia and no experiment was sown at Minnipa due to the dry conditions. Early ascochyta blight infection and progression was low at Hart due to an extended dry period during the growing season and non-conducive environmental conditions. However, a high rainfall event occurred in late winter and favoured late disease spread. In 2018 most of the in-crop rainfall fell in mid-winter in August. The sustained dry seasonal conditions influenced crop establishment and reduced the progression of ascochyta blight during the 2018 cropping season at both sites. In 2019 experiments initial disease establishment occurred due to favourable rainfall events in May and June but July to October rainfall totals were below the average resulting in lower than average grain yields for the site. Hot and dry conditions during spring at Hart negatively impacted grain filling and therefore grain yields were lower than average. Extensive dry conditions at Minnipa in 2019 limited disease spread although one large rainfall event (~ 50 mm) in September recovered plant growth and grain yield to some extent at this site.

Comparison of fungicide treatments applied at sowing on disease severity

Small reductions in disease severity compared to the untreated plots were associated with some fungicide treatments applied to seed or at sowing. Thiram plus thiabendazole seed treatment significantly reduced disease below the untreated plots in early assessments (6 to 9.5 node g.s). but by 13 node g.s. disease severity had increased and was similar to the untreated (Tables 2, 3 and 6). The fluid injection treatment, flutriafol, significantly reduced disease below the untreated in 2016 experiments when assessed at 7 node g.s. and also in 2015 experiments when assessed at 9.5 node g.s. but not at the 6.5 node g.s. assessment at Hart in 2015 (Tables 2 and 3). At very early growth stage the plots treated with thiram plus thiabendazole had significantly less disease than those treated with flutriafol, but by 9 node g.s. or later the disease severity was similar or significantly lower in the flutriafol treated plants. The fluid injection treatment azoxystrobin plus metalaxyl reduced disease in the 2015 experiments when assessed at 6 nodes, but not at later assessments, while fluxapyroxad seed treatment did

Table 3 Effect of seed treatments and foliar fungicides on ascochyta blight severity in field pea trials at Hart and Minnipa in 2016 at 7 node growth stage (g.s.) after first foliar fungicides applied at 4 node, at 13 node g.s. after foliar fungicides applied at 9 node g.s., and at mid flowering after the early flowering fungicides had been applied

Treatment	% disease at 7 node g.s. 2 sites	% disease at 13 node g.s. 2 sites	Disease Index at mid flowering 2 sites	Grain yield t ha^{-1} 2 sites	Grain value $ ha^{-1} 2 sites
Thiram plus thiabendazole[1]	20.8[c]	41.1[ef]	89.9[bc]	1.47[ab]	$464[a]
Thiram plus thiabendazole + fortnightly chlorothalonil[2]	14.2[a]	19.3[a]	56.4[a]	1.95[d]	$628[d]
Thiram plus thiabendazole + mancozeb[3]	19.9[bc*]	36.5[de]	90.3[bc]	1.47[ab]	$474[a]
Thiram plus thiabendazole + prothioconazole plus bixafen[3]	19.9[bc*]	35.6 [cd]	82.6[bc]	1.55[bc]	$573[bcd]
Thiram plus thiabendazole + azoxystrobin plus cyproconazole[3]	20.8[bc*]	41.3[ef]	80.7[bc]	1.47[ab]	$568[bcd]
Thiram plus thiabendazole + mancozeb (half rate)[4]	20.5[bc]	39.6[def]	89.1[bc]	1.47[ab]	$531[abc]
Thiram plus thiabendazole + prothioconazole plus bixafen[5] + mancozeb[6]	14.1[a]	30.1[b]	83.2[bc]	1.67[c]	$537[abc]
Flutriafol[7] + prothioconazole plus bixafen[3]	17.8[b*]	30.9[bc]	79.0[b]	1.47[ab]	$587 [cd]
Azoxystrobin plus metalaxyl[7] azoxystrobin plus cyproconazole[3]	24.9[d*]	40.0[def]	85.0[bc]	1.51[abc]	$507[abc]
Flutriafol	19.9[bc]	38.1[def]	91.9[c]	1.47[ab]	$488[a]
Fluxapyroxad[1]	24.3[d]	40.2[def]	80.9[bc]	1.39[ab]	$502[ab]
Untreated	27.0[d]	42.9[f]	84.0[bc]	1.33[a]	$478[a]

[*]No foliar fungicides applied before this disease assessment

[1]Seed treatments; [2]Foliar application; [3]Foliar fungicides applied at 9 node growth stage (g.s.) and again at early flowering; [4]Foliar fungicide applied at 4 node g.s., 13 node g.s., early flowering and mid flowering; [5]Foliar fungicides applied at 4 node g.s. and early flowering; [6]Foliar fungicide applied at mid flowering;[7]Fluid injection fungicides applied at seeding

Annual rainfall Hart = 483 mm, Minnipa = 366 mm. Different superscript letters indicate significant differences at 95% confidence intervals

not reduce disease in any of the experiments (Tables 2 and 3). These three latter treatments are not registered on field pea in Australia and were not included in subsequent experiments. By flowering stage, all fungicide treatments applied at sowing without subsequent foliar fungicide applications had equivalent disease to the untreated plots and no significant yield gains.

Table 4 Effect of seed treatments and foliar fungicides on ascochyta blight severity in field pea trials with two sowing dates at Hart in 2017 at 14 node growth stage (g.s) after the first foliar fungicides had been applied and at mid flowering after the early flowering fungicides had been applied

Treatment	% disease at 14 node g.s.		Disease Index at mid flowering	Grain yield t ha^{-1}		Grain value $ ha^{-1}	
	Sowing 1	**Sowing 2**	**2 sowing dates**	**Sowing 1**	**Sowing 2**	**Sowing 1**	**Sowing 2**
Thiram plus thiabendazole[1] + fortnightly chlorothalonil[2]	0.01[a]	0.4[a]	18.2[a]	3.53[d]	2.29[a]	$1285[e]	$791[a]
Thiram plus thiabendazole + mancozeb[3]	24.3[d]	12.3[bc]	59.6[d]	2.76[b]	2.31[a]	$1070[c]	$889[b]
Thiram plus thiabendazole + prothioconazole plus bixafen[3]	13.8[bc]	11.5[bc]	36.5[b]	3.22[c]	2.33[a]	$1221[de]	$867[b]
Thiram plus thiabendazole + azoxystrobin plus cyproconazole[3]	21.0 [cd]	11.5[bc]	47.0[c]	3.04[c]	2.37[a]	$1174[d]	$906[b]
Thiram plus thiabendazole + prothioconazole plus bixafen[4] + Mancozeb[5]	21.2 [cd]	8.9[ab]	35.5[b]	3.42[d]	2.19[a]	$1285[e]	$793[a]
Untreated	26.5[d]	18.7[bc]	69.6[e]	2.66[b]	2.28[a]	$1062[c]	$910[b]

[1]Seed treatment; [2]Foliar fungicide; [3]Foliar fungicides applied at 9 node g.s. and at early flowering; [4]Foliar fungicide applied at 4 node g.s and early flowering; [5]Foliar fungicide applied at at mid flowering

Annual rainfall Hart = 331 mm. Different superscript letters indicate significant differences at 95% confidence intervals

Table 5 Effect of seed treatments and foliar fungicides on ascochyta blight severity in field pea trials at Hart and Minnipa in 2018 at 7 node growth stage (g.s.) after first foliar fungicides applied at 4 node g.s., and at mid flowering after the early flowering fungicides had been applied

Treatment	% disease at 7 node g.s.	Disease Index at mid flowering	Grain yield t ha^{-1}	Grain value $ ha^{-1}
	Hart	**2 sites**	**2 sites**	**2 sites**
Thiram plus thiabendazole[1] + fortnightly chlorothalonil[2]	1.4[a]	11.6[a]	1.35[a]	$335[a]
Thiram plus thiabendazole + tebuconazole plus azoxystrobin[3]	12.3[e]	41.3[bcd]	1.21[a]	$400[b]
Thiram plus thiabendazole + prothioconazole plus bixafen[3]	8.7[b]	49.6[bcd]	1.35[a]	$442[bc]
Thiram plus thiabendazole + azoxystrobin cyproconazole[3]	12.2[e]	44.0 [cd]	1.28[a]	$438[bc]
Thiram plus thiabendazole + azoxystrobin cyproconazole[3] + mancozeb[4]	9.8[bcd]	42.4[bcd]	1.31[a]	$411[b]
Tebuconazole plus azoxystrobin[3]	11.1[cde]	40.4[bcd]	1.30[a]	$443[bc]
Prothioconazole plus bixafen[3]	8.3[bc]	37.4[b]	1.27[a]	$417[b]
Azoxystrobin cyproconazole[3]	11.3[de]	43.2 [cd]	1.21[a]	$419[b]
Untreated	9.4[bc]	54.8[e]	1.27[a]	$483[c]

[1]Seed treatments;[2]Foliar fungicide; [3]Foliar fungicides at 4 node g.s. and early flowering; [4]Foliar fungicide applied at mid flowering

Annual rainfall Hart = 224 mm, Minnipa = 244 mm. Different superscript letters indicate significant differences at 95% confidence intervals

Comparison of new foliar fungicides on disease severity and yield in 2015 and 2016 trials

The effect of an early foliar fungicide treatment in these experiments was measured at 9.5 or 13 node g.s. when seed dressings or sowing treatments were losing effectiveness (Tables 2 and 3). At this stage a spray of mancozeb significantly reduced disease below the untreated plots in both seasons (20.5% vs. 28.8% plot severity in 2015 and 36.5% vs. 42.9% plot severity in 2016). However, the plots with half rate of this product had similar disease to the untreated at this and subsequent disease assessments (Table 3). Prothioconazole plus bixafen also significantly reduced disease levels below the untreated in both seasons and in 2015, also had significantly less disease at this early growth stage than plants treated with mancozeb. In 2016 the combination of flutriafol fluid injection or thiram plus thiabendazole seed dressing with prothioconazole plus bixafen had similar disease levels indicating no advantage of the fluid injection treatment over the seed dressing when combined with the foliar treatment. The plots with a foliar application of azoxystrobin plus cyproconazole, or pyraclostrobin had disease levels that were equivalent or intermediate between

Table 6 Effect of seed treatments and foliar fungicides on ascochyta blight severity in field pea trials at Hart and Minnipa in 2019 assessed at 7 node growth stage (g.s.) after first foliar fungicides, and at mid flowering after the early flowering fungicides had been applied

Treatment	% disease per plot at 7 node g.s.	Disease Index at mid flowering	Grain yield t ha^{-1}	Grain value $ ha^{-1}
	2 sites	**2 sites**	**2 sites**	**2 sites**
Thiram plus thiabendazole[1] + fortnightly chlorothalonil[2]	12.2[a]	8.9[a]	1.173[abc]	$266[a]
Thiram plus thiabendazole + tebuconazole plus azoxystrobin[3]	12.4[a]	19.2[bc]	1.155[ab]	$380[c]
Thiram plus thiabendazole + prothioconazole plus bixafen[3]	12.3[a]	16.9[b]	1.154[a]	$364[b]
Thiram plus thiabendazole[1] + chlorothalonil[3]	12.3[a]	18.4[b]	1.185[abcd]	$393 [cd]
Tebuconazole plus azoxystrobin[3]	14.0[bc]	25.9[de]	1.190[bcd]	$401[d]
Prothioconazole plus bixafen[3]	13.6[b]	25.9[de]	1.209[d]	$391 [cd]
Chlorothalonil[4]	14.2[c]	25.3[de]	1.184[abcd]	$400[d]
Thiram plus thiabendazole[1]	12.3[a]	28.5[e]	1.159[ab]	$430[e]
Untreated	14.1[c]	27.0[de]	1.164[ab]	$439[e]

[1]Seed treatments; [2]Foliar fungicide; [3]Foliar fungicides applied at 4 node g.s. and early flowering

Annual rainfall Hart = 277 mm, Minnipa = 231 mm. Different superscript letters indicate significant differences at 95% confidence intervals those treated with mancozeb and prothioconazole plus bixafen.

In 2015 the Disease Index was significantly lowest in treatments receiving 2 sprays of prothioconazole plus bixafen and in plants with fortnightly applications of chlorothalonil. Next lowest were plots treated with 2 sprays of azoxystrobin plus cyproconazole or pyraclostrobin while 2 sprays of mancozeb resulted in similar Disease Index to the untreated control (Table 2). In 2016 the fortnightly sprays were the only treatment that had significantly less Disease Index values than the untreated at the flowering stage (Table 3).

In 2015 all the foliar treatments significantly reduced yield losses from disease so that grain yield was 7.5–22.7% above the 1.32 t ha^{-1} mean grain yield in the untreated control. In 2016 the grain yield was significantly 16.5–25.6% above the untreated (1.33 t ha^{-1}) where 2 sprays of prothioconazole plus bixafen with thiram plus thiabendazole or 2 sprays of prothioconazole plus bixafen with thiram plus thiabendazole plus mancozeb had been applied. The fortnightly treatments of chlorothalonil had the greatest effect with grain yield 46.6% higher than the untreated control.

In both seasons the grain value was significantly higher than the untreated control for foliar applications of prothioconazole plus bixafen, azoxystrobin plus cyproconazole or pyraclostrobin combined with thiram plus thiabendazole or flutriafol. None of the other treatments including mancozeb had higher grain value than the untreated control. The inclusion of a third spray (mancozeb) in spring after the prothioconazole plus bixafen applications did not result in higher grain value than the prothioconazole plus bixafen treatment. In 2015 the fortnightly applications of chlorothalonil treatment had significantly less value than the untreated control but grain value was increased by this treatment in 2016 reflecting higher achieved grain yield in this year.

Fungicide treatments at two sowing dates

Disease assessment at 14 node g.s at the first sowing date found neither mancozeb nor azoxystrobin plus cyproconazole significantly reduced disease below the untreated control and only treatments with prothioconazole plus bixafen or fortnightly sprays of chlorothalonil had less disease than the untreated control. At the second sowing date only the fortnightly sprays of chlorothalonil had less disease than the untreated control (Table 4). After the second foliar application at early flowering, all fungicide treatments significantly reduced the Disease Index compared to the untreated control. Lowest disease severity was recorded in treatments with fortnightly sprays of chlorothalonil followed by prothioconazole plus bixafen, then azoxystrobin plus cyproconazole and then mancozeb. A third spray (mancozeb) was applied to treatments that had already received two sprays of prothioconazole plus bixafen but the Disease Index, recorded 18–20 days after the third spray, was not significantly reduced compared to the two sprays of prothioconazole plus bixafen alone. However, at the first sowing date, grain yield was significantly higher in the three spray treatment than the two spray treatment, with yield equivalent to the fortnightly sprays.

In the first sowing date, grain yield was significantly more the untreated control (2.66 t ha^{-1}) by 33% in the fortnightly sprayed treatment, and by 29% in the three spray treatment (Table 4). Two sprays of prothioconazole plus bixafen or azoxystrobin plus cyproconazole resulted in grain yield 21% and 14%, respectively, above the untreated control. Mancozeb had similar yield to the untreated control. In the later sowing date, there was no yield response to fungicides and a grain yield penalty of approximately 1 t ha^{-1} was observed across all treatments compared to the earlier sowing date treatments.

In the first sowing date, the grain value was significantly greater than the untreated control for all treatments except mancozeb which was not significantly different to the untreated control. At the second sowing date there were two treatments that reduced the grain value viz. the fortnightly sprays and the three spray treatment. In this experiment, sowing early without fungicide sprays produced higher grain yields and higher grain values than all later sowing treatments.

Comparison of seed treatment with foliar fungicide at 4 node g.s. 2018 and 2019

In this set of four experiments, treatments included an untreated control thiram plus thiabendazole seed treatment plus foliar fungicides when symptoms first appeared in plots, foliar fungicides applied at 4 node g.s and the fortnightly chlorothalonil (Tables 5 and 6).

In 2018 at Hart disease symptoms were already visible at 4 node g.s. when all plots, other than the untreated, were sprayed with a foliar fungicide. There were no differences in disease severity between untreated control and treatments with or without the seed dressing, except the fortnightly chlorothalonil treatment. The first fortnightly chlorothalonil application was applied before symptoms were apparent and this treatment had the lowest disease scores at this assessment compared to all other treatments. At Minnipa in 2018 the dry conditions at this site caused the disease to progress very slowly and no disease assessment was conducted at the early stage. All plots with foliar fungicide applications had lower Disease Index than the untreated in 2018. The lowest disease score was in the plots sprayed fortnightly with

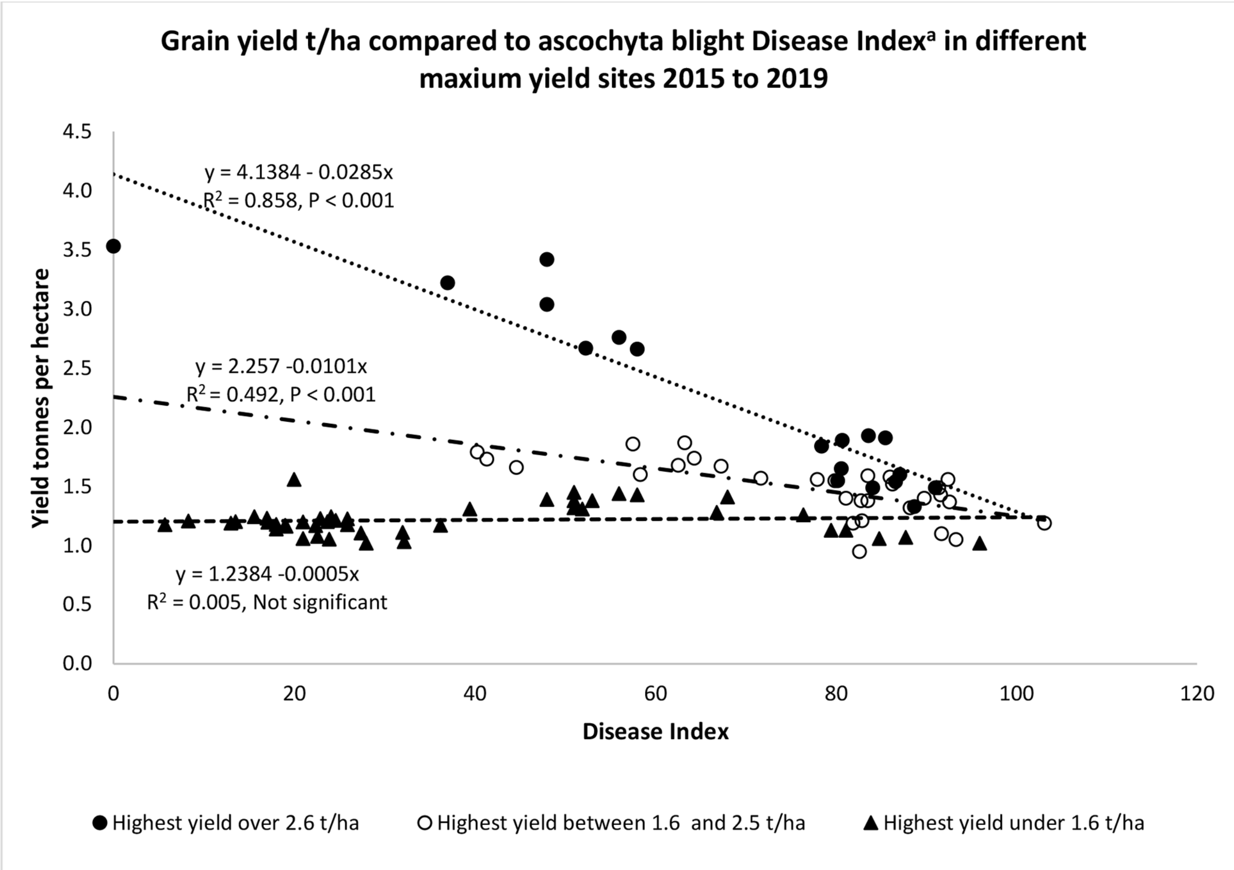

Fig. 1 Average grain yield (t ha^{-1}) plotted against the average Disease Index of ascochyta blight for each site x treatment. Data is presented in three groups (1) Maximum site grain yield > 2.5 t ha^{-1} (Hart 2016 and Hart 2017 first sowing date), (2) Maximum site grain yield between 1.6 and 2.5 t ha^{-1} (Hart 2015, Minnipa 2015 and 2016), and (3) Maximum site grain yield less than 1.6 t ha^{-1} (Pinery 2015, Hart 2017 s sowing date, Hart and Minnipa in 2018 and 2019)

[a]Disease Index per plot = $[(0 \times n^{0}) + (1 \times n^{1\text{–}25}) + (3 \times n^{26\text{–}50}) + (6 \times n^{51\text{–}99}) + (8 \times n^{100})]/5$ where n = number of nodes per disease category, and the superscript denotes the disease category

chlorothalonil and the other foliar treatments had similar Disease Index scores to each other.

In 2019 all plots with the thiram plus thiabendazole seed treatment had significantly less disease than plots without the seed dressing when assessed at 7 node g.s demonstrating that early foliar fungicides were less effective than the seed dressing in controlling disease at this stage. This effect was also detected in the Disease Index assessment that year, where plots without the seed dressing had similar Disease Index to the nil treatment irrespective of the foliar fungicide applications (Table 6).

No significant grain yield gains were associated with the treatments at either site in both years, due to the dry seasonal conditions that limited both the spread of disease and grain yield. Grain value was significantly reduced below the untreated by many of the treatments in these two low rainfall seasons, and no treatments gave an economic advantage over the untreated control.

Grain yield responses and disease severity

Grain yield was graphed against the Disease Index scores for all treatments and trials (Fig. 1). This identified three grain yield response groups to disease severity depending on the maximum grain yield in each trial. In trials with maximum grain yield above 2.5 t ha^{-1} (Hart 2016 and the first sowing date at Hart 2017) grain yield was significantly correlated with Disease Index ($R^2 = 0.858$, $P < 0.001$) and every 10 units in Disease Index reduced grain yield by 285 kg ha^{-1}; Disease Index accounted for 84.9% of variation in yield. The maximum Disease Index in these two high yielding experiments was 91.0 representing a potential yield loss of 2.6 t ha^{-1} valued at \$988 ha^{-1}. In experiments where maximum yield was between 1.6 and 2.5 t/ha (Hart 2015, Minnipa 2015 and 2016), every 10 units in Disease Index reduced yield by 101 kg ha^{-1}. The maximum Disease Index in this group of trials was 103.1 representing a potential yield loss of 1.0 t ha^{-1} valued at \$380 ha^{-1}. Disease Index accounted for 47.3% of variation in yield with $R^2=0.492$, $P<0.001$. In trials where maximum yield was less than 1.6 t ha^{-1} (Pinery 2015, Hart 2017 s sowing date, Hart and Minnipa in 2018 and 2019) grain yield was not correlated with Disease Index ($R^2=0.005$, P = Not significant). The maximum Disease Index in this group of trials was 95.93 representing a potential yield loss of 0.05 t ha^{-1} valued at only \$19 ha^{-1}.

Discussion

Results from this research showed a complex interaction between ascochyta blight of field pea and environment and the corresponding responses in disease control and financial benefit from fungicide application. There were clear patterns in the efficacy of fungicides in controlling disease and improving grain yields, however, financial gain was dependent on fungicide costs, seasonal conditions and grain yield achieved.

The management of ascochyta blight disease in field pea was evaluated under contrasting seasonal conditions which influenced disease severity and grain yield potential and highlighted the difficulties in developing effective and economic disease management strategies for growers in southern Australia. There were significant grain yield losses, over 1 t ha^{-1}, in the absence of fungicides in the high rainfall seasons when disease severity was high. In this situation grain yield was highly correlated with disease. In trials with medium rainfall the grain yield losses were substantially lower, even where disease severity was similar to the high rainfall seasons. In low rainfall trials grain yield was limited by rainfall and disease had no influence on the yield of field pea.

The main foliar fungicides currently registered in Australia for control of ascochyta blight of field pea include various mancozeb products, prothioconazole plus bixafen and tebuconazole plus azoxystrobin. Pyraclostrobin is not registered on field pea in Australia and fungicide resistance to this active has been detected in *D. pinodes* in Canada (Bowness et al. 2016). The previously recommended strategy of using two foliar sprays of mancozeb (McMurray et al. 2011) gave inconsistent disease control in this set of trials and did not protect against grain yield loss in any trial, demonstrating this is an inferior product to the newer (although more expensive) products. Mancozeb is also registered on field pea in Canada where it provided disease control and protection against yield loss in three of eight site-years (Warkentin et al. 2000) and similarly chlorothalonil provided protection against yield loss in one of three years in Canadian field experiments (Xue et al. 2003). Prothioconazole plus bixafen was included in every experiment in the current study and grain yield loss from ascochyta blight was significantly reduced in the 2015, 2016 and 2017 experiments, but not in the two low rainfall years of 2018 and 2019 when grain yield was limited. Tebuconazole plus azoxystrobin was only included in the low rainfall 2018 and 2019 experiments and while efficacy was similar to prothioconazole plus bixafen in three of the four trials, grain yield responses could not be validated for this product.

Ascochyta blight is polycyclic, with conidia splashed up and between plants with each rainfall event, creating a multiplying effect of the disease. Multiple foliar fungicide applications effectively suppress the epidemic but are rarely economic in field pea. Consequently, reducing the early establishment of disease is an important strategy to minimise the epidemic (Davidson et al. 2013). While seed treatment with thiram plus thiabendazole demonstrated some early disease control in the majority of trials, under high disease pressure this product occasionally failed to control disease. The fluid injection of flutriafol at sowing provided some benefit where it was used, but it is not registered on field pea in Australia. The lack of total control of infection from these treatments at the seedling stage highlighted the need for foliar fungicides at early growth stage in high disease risk situations. In this situation, applications of foliar fungicides at 4 node g.s. or before gave greater early disease control than fungicides applied after disease had established. Conversely, this set of trials demonstrated that where early disease severity was low, the first foliar fungicide applications could be delayed until the 7 to 10 node g.s. without risking a severe increase in the epidemic. Understanding the risk of infection combined with an accurate assessment of the disease infection status of the field pea crop at an early growth stage (4 to 7 node g.s.) is important for decisions about the timing of these fungicide applications. The risk from ascospore showers of *D. pinodes* can be determined by the decision support tool 'Blackspot Manager' which forecasts the timing of ascospore release from infested stubbles, provided either on a website or directly to subscribers mobile phone (Salam et al. 2011b). In addition, the risk from soilborne inoculum of ascochyta blight can be determined through using PredictaB® (PIRSA, 2021b). This is a DNA based soil testing service which quantifies soil-borne pathogens based on submitted soil samples from commercial paddocks (Ophel-Keller et al. 2008). Soil tests are available for *D. pinodes* plus *D. pinodella* and for *A. koolunga.* Combining these two systems should assist growers with understanding the risk of early infection and choosing appropriate fungicide timing to minimise the early disease infection. Foliar fungicides at early flowering further suppressed disease in many situations and in seasons with a wet spring a third fungicide spray during podding significantly protected against yield loss from disease, demonstrating the potential benefit of multiple fungicides in wetter seasons with higher yielding crops. Label recommendations in Australia for prothioconazole plus bixafen (AviatorXpro®) only permit two sprays per season, both pre-flowering, and hence a third spray of a product with better efficacy than mancozeb might improve grain yields above those achieved with the combination of prothioconazole plus bixafen and mancozeb in this study.

Despite efficacy, the response from fungicides was often not economic for a number of reasons including the sporadic nature of rainfall in winter and spring in southern Australia that may not coincide with the predetermined two spray strategy, the lack of complete disease control by the fungicides and the varying yield potential among sites and seasons. Only three of the five seasons had trials that demonstrated an economic return from fungicide control of ascochyta blight (2015 to 2017) similar to findings of McMurray et al. (2011) where foliar fungicides were only economic in one of three seasons. In the 2015, 2016 and 2017 trials foliar applications of prothioconazole plus bixafen, azoxystrobin plus cyproconazole and pyraclostrobin were financially beneficial but mancozeb was not. Economic returns from tebuconazole plus azoxystrobin could not be confirmed, however, at two thirds the price of prothioconazole plus bixafen, results indicate that tebuconazole plus azoxystrobin would have been economic to use in the 2015, 2016 and 2017 trials when disease limited grain yield. This may also be a suitable product to include in the three spray strategy in wet springs, as described above.

Low rainfall conditions limited disease and grain yield, and the results from all trials with maximum grain yield of less than 1.6 t ha^{-1} confirmed that fungicide applications for ascochyta blight in field pea are not economic in these situations. However, economic benefits from foliar fungicide applications in higher yielding crops are also not guaranteed. In experiments conducted with foliar applications of mancozeb in 2007 to 2009 (McMurray et al. 2011) financial benefits were achieved in trials with average grain yield of 1.66 t ha^{-1} or above, while the experiments with no financial benefit from fungicides ranged from 0.2 to 2.47 t ha^{-1}. The latter experiments had a much lower disease severity early in the season than the former due to low in-crop rainfall during the vegetative phase, again demonstrating the importance of early disease infection on final severity and grain yield loss. While financial benefits are more likely to occur in the higher rainfall regions, most of the Australian field pea crop is grown in medium or low rainfall regions, with average grain yields of 1.0 to 1.7 t ha^{-1}, respectively (PIRSA 2021a). These average grain yields combined with the grain yield responses identified in this study, suggest the majority of field pea crops in low rainfall regions are unlikely to show a yield response from reduced severity of ascochyta blight through foliar fungicide applications. However, in moderate rainfall regions the grain yield gains from controlling disease could be as much as 1.0 t ha^{-1} in the most severe epidemics and in high rainfall situations the losses could be over 2 t ha^{-1}.

This research also confirmed the established knowledge that delaying sowing 3 to 4 weeks past the first autumn rains minimised early establishment of ascochyta blight on field pea (Bretag et al. 2000, 2006; Davidson et al. 2013; McMurray et al. 2011) through avoidance of the airborne ascospore showers from infested stubble (Salam et al. 2011). However, delayed sowing risks greater yield loss from terminal drought than from ascochyta blight (McMurray et al. 2011). This was demonstrated in the Hart 2017 trial where 31% of grain yield loss occurred through delayed sowing compared to 22% grain yield loss from ascochyta blight in the first time of sowing when no fungicide was applied. Grain yield reduction in the second time of sowing was related to the limited in-season rainfall and a shortened growing season.

The agronomic advice to delay sowing field pea was developed in older conventional field pea types with dense trailing canopies that were prone to lodge mid-season and highly conducive to ascochyta blight (Bretag et al. 2000). Modern semi-leafless ‘afila’ erect field pea varieties combined with shorter growing seasons have made this advice outdated and field pea can be sown early in the season with an economic disease management strategy, provided early sowing does not put the crop at risk of frost damage (Day et al. 2021, GRDC Grownotes 2018b).

Decisions for fungicide sprays to control ascochyta blight in field pea are complex and determined by (1) yield potential above 1.6 t ha^{-1}, (2) fungicide costs, (3) the disease risk at seedling stage, (3) seasonal conditions at early flowering and (4) the yield potential plus seasonal conditions at podding, making them often difficult to implement effectively. These studies indicate a financial risk associated with foliar fungicides for ascochyta blight of field pea especially in low rainfall regions, but efficacy data indicated that the foliar fungicide tebuconazole plus azoxystrobin may be economic in many situations. Further studies are required to validate the role of tebuconazole plus azoxystrobin in economic management of ascochyta blight in field pea, and additional studies may enhance the potential for registration of flutriafol as an alternative sowing treatment for reducing early infection of ascochyta blight. In addition, genetic solutions could focus on seedling resistance as a means of reducing the early establishment of disease instead of whole season resistance which has not been successful in field pea. The combination of seedling resistance and the foliar fungicides strategies presented in this study could minimise epidemics and greatly reduce losses from ascochyta blight.

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Declarations

Conflict of interest The authors declare they have no conflict of interest.

References

AEGIC (2020) Australian Grain note pulses. https://aegic.org.au/wp-content/uploads/2021/03/AEGIC-Grain-Note-pulses_LR-1.pdf (accessed 2/06/2021)

Bowness R, Gossen BD, Chang KF, Goswani R, Willenborg CJ, Holtz M, Strelkov SE (2016) Sensitivity of *Mycosphaerella pinodes* to pyraclostrobin fungicide. Plant Dis 100:192–199. https://doi.org/10.1094/PDIS-03-15-0350-RE

Bretag TW, Keane PJ, Price TV (1995) Effect of ascochyta blight on the grain yield of field peas (*Pisum sativum* L.) grown in southern Australia. Aust J Agric Res 35:531–536. https://doi.org/10.1071/EA9950531

Bretag TW, Keane PJ, Price TV (2000) Effect of sowing date on the severity of ascochyta blight in field pea (*Pisum sativum* L.) grown in the Wimmera region of Victoria. Aust J Exp Agric 40:1113–1119. https://doi.org/10.1071/EA00097

Bretag TW, Keane PJ, Price TV (2006) The epidemiology and control of ascochyta blight of field peas: a review. Aust J Agric Res 57:883–902. https://doi.org/10.1071/AR05222

Bureau of Meteorology (2021) Climate Data Online http://www.bom.gov.au/climate/data/. Accessed 02 June 2021

Davidson JA, Gossen B, Chen W(2020) Ascochyta complex. In: Harveson RM, Pasche JS, Porter L, ChenW, Burrows M (eds.) Compendium of pea diseases and pests, third edition. American Phytopathology Society, Minnesota, USA, pp 30–36

Davidson JA, Wilmshurst CJ, Scott ES, Salam MU (2013) Relationship between ascochyta blight on field pea (*Pisum sativum*) and spore release patterns of *Didymella pinodes* and other causal agents of ascochyta blight. Plant Pathol 62:1258–1270. https://doi.org/10.1111/ppa.12044

Davidson JA, Hartley D, Priest M, Krysinska-Kaczmarek M, Herdina, McKay A, Scott ES (2009) A new species of *Phoma* causes ascochyta blight symptoms on field peas (*Pisum sativum*) in South Australia. Mycologia 101:120–128. https://doi.org/10.3852/07-199

Day S, Roberts P, Gutsche A(2021) Low rainfall pulse production with – one pulse does not fit all. Grains Research Update, Wudinna, South Australia, 27th July, pp 39–46. https://grdc.com.au/__data/assets/pdf_file/0027/448344/GRDC-Wudinna-update-proceedings-2021-Inter.pdf

GRDC Grownotes (2018a) Field Pea Sect. 1 Introduction. **Error! Hyperlink reference not valid**. https://grdc.com.au/__data/assets/pdf_file/0024/366207/GrowNote-Peas-South-1-Introduction.pdf Accessed 08 Sep 2021

GRDC Grownotes (2018b) Field pea Sect. 13 Environmental Issues https://grdc.com.au/__data/assets/pdf_file/0022/366223/GrowNote-Peas-South-13-Environmental-Issues.pdf. Accessed 08 Sept 2021

Hou LW, Groenewald JZ, Pfenning LH, Yarden O, Crous PW, Cai L (2020) The phoma-like dilemma. Stud Mycol 96:309–396. https://doi.org/10.1016/j.simyco.2020.05.001

McMurray LS, Davidson JA, Lines MD, Leonforte A, Salam MU (2011) Combining pathological, agronomic and breeding advances to maximise *Pisum sativum* yields under changing climatic conditions in south eastern Australia. Euphytica 180:69–88. https://doi.org/10.1007/s10681-011-0362-9

Ophel-Keller K, McKay A, Hartley D, Herdina, Curran J (2008) Development of a routine DNA-based testing service for soilborne diseases in Australia. Austral Plant Pathol 37:243–253. https://doi.org/10.1071/AP08029

PIRSA (2021a) Farm gross margin and enterprise planning guide. Rural Solutions South Australia. ISSN – 2207–2357 online. https://www.pir.sa.gov.au/__data/assets/pdf_file/0005/385304/PIRSA_Gross_Margin_Guide_2021.pdf. Accessed 02 June 2021

PIRSA (2021b) Molecular Diagnostics - PredictaB®. https://www.pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b. Accessed 07 June 2021

Pulse A (2013) PBA Coogee 'Dun type' field pea. http://www.pulseaus.com.au/storage/app/media/crops/2013_VMP-Dunfieldpea-PBACoogee.pdf. Accessed 10 June 2021

Rathjen JR, Ryder MH, Riley IT, Lai TV, Denton MD (2020) Impact of seed-applied pesticides on rhizobial survival and legume nodulation. J Appl Microbiol 129:389–399. https://doi.org/10.1111/jam.14602

Roger C, Tivoli B (1996) Spatio-temporal development of pycnidia and perithecia and dissemination of spores of *Mycosphaerella pinodes* on pea (*Pisum sativum*). Plant Pathol 45:518–528

Salam MU, Galloway J, MacLeod WJ, Davidson JA, Seymour M, Pritchard I, Salam KP, Diggle AJ, Maling T (2011a) G1 Blackspot Manager model predicts the maturity and release of ascospores in relation to ascochyta blight on field pea. Australas Plant Pathol 40:621–631. https://doi.org/10.1007/s13313-011-0035-0

Salam MU, MacLeod WJ, Pritchard I, Seymour M, Davidson JA, Salam KP, Galloway J, McMurray LS, Lindbeck KD, Richardson H (2011b) G2 Blackspot Manager model to guide field pea sowing for southern Australia in relation to ascochyta blight disease. Australas Plant Pathol 40:632–639. https://doi.org/10.1007/s13313-011-0044-z

Seednet(2011) PBA Oura Erect 'dun' type field pea https://www.seednet.com.au/sites/seednet/files/2018-07/documents/PBA-Oura-field-pea-factsheet.pdf. Accessed 10 June 2021

Warkentin TD, Xue AG, McAndrew DW (2000) Effect of mancozeb on the control of Mycosphaerella blight of field pea. Can J Plant Pathol 80:403–406. https://doi.org/10.4141/P99-085

Xue AG, Charest J, Davidson CG, McAndrew DW, Bing DJ, Warkentin TD (2003) Response of field pea cultivars to chlorothalonil in the control of Mycosphaerella blight. Can J Sci 83:313–318. https://doi.org/10.4141/P02-046