Fungal diseases of canola in Australia:

Identification of trends, threats and potential therapies.

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Abstract

Fungal diseases are the major constraint on canola (*Brassica napus*) production in Australia and worldwide. Blackleg (caused by *Leptosphaeria maculans*) and Sclerotinia stem rot (*Sclerotinia sclerotiorum*) are the predominant diseases limiting production but, with increased intensification of production, other diseases previously considered of minor importance and sporadic may be increasing in prevalence. We report on the incidence and severity of four 'minor' diseases of canola in Australia: white leaf spot (caused by *Pseudocercosporella capsellae*), downy mildew (*Peronospora parasitica*), Alternaria leaf and pod spot (*Alternaria brassicae*) and powdery mildew (*Erysiphe cruciferarum*). Diseases were monitored at more than 30 sites across Australia from 2013 to 2015. Regions were identified in which specific diseases are a consistent problem, such as white leaf spot in Hamilton in Victoria. In these regions, control strategies to minimise disease may be required. Varietal differences were observed for some diseases suggesting that resistance to these pathogens is already present in Australian advanced breeding material. Lastly, fungicide applications were shown to control some diseases such as white leaf spot.

Keywords: *Brassicaceae* diseases, disease resistance, oilseed industry, triazole fungicide

Introduction

Fungal diseases are a major constraint to crop production worldwide. Intensification of land use results in large areas of monoculture that can be conducive to fungal infection and subsequent yield-limiting disease. In Australia, canola (*Brassica napus*, oilseed rape) is the third largest grain crop after wheat and barley and is primarily grown as a break crop for wheat. Canola can be sown every three or four years in rotation with cereals, pulses and pastures, but is also commonly grown one in every two years with wheat (Van de Wouw et al. 2016). Since 1990, the canola cropping area has increased from 50,000 ha to 2.7 million ha in 2013-2014 and yield has increased from 78 kt to 3,832 kt (ABARES 2015).

Blackleg disease, caused by the fungal pathogen *Leptosphaeria maculans*, is a major constraint on canola production and as a consequence has been the focus of much research in Australia and worldwide (Fitt et al. 2006; Van de Wouw et al. 2016; Khangura and Barbetti 2001). In Australia, it is estimated that blackleg disease causes 10-15% yield losses annually with up to 90% yield loss in extreme situations (Sprague et al. 2006). The impact of blackleg disease in Australia is minimised through rotation with other crops, avoidance of stubble, application of fungicides and rotation of cultivars that have been bred with different resistance genes (Marcroft et al. 2004; Marcroft et al. 2012b; Van de Wouw et al. 2016). In addition to *L. maculans*, *Sclerotinia sclerotiorum* is problematic in Australia with particular regions experiencing variable levels of disease due to this fungus each year (Hind et al. 2003). Reduced yields caused by Sclerotinia stem rot are as high as 24% in some regions in some years (Kirkegaard et al. 2006; Khangura et al. 2014). Surveys of *S. sclerotiorum* inoculum on petals indicate widespread presence of the pathogen (Sprague and Stewart-Wade 2002; Hind et al. 2003). Sclerotinia stem rot is more complicated to control than blackleg as disease expression occurs under very specific environmental conditions, the pathogen has a very wide host range, a necrotrophic life cycle and forms sclerotia that can survive in the soil for up to 10 years (Bolton et al. 2006; Kabbage et al. 2015).

In Australia, information on the severity and prevalence of fungal diseases of canola other than blackleg and Sclerotinia stem rot is limited. It is not known what impact increased canola intensity and production is having on other fungal diseases. In the current study, we identify four other fungal diseases of canola of wide prevalence across Australia through the analysis of their incidence and severity over a three year period: caused by *Pseudocercosporella capsellae* (white leaf spot), *Peronospora parasitica* (downy mildew), *Alternaria brassicae* (Alternaria leaf/pod spot) and *Erysiphe cruciferarum* (powdery mildew). We identify potential areas of high risk ('hot spots') for these diseases as well as varietal differences and potential fungicide control strategies.

Materials and Methods

To provide the first assessment of the less common fungal diseases affecting the Australian canola industry, a set of field sites in the major canola growing areas of Australia were established and monitored for disease. The same sets of cultivars were used with standard assessments for disease symptoms (Table 1) to ensure similar comparisons across the country, the trials were assessed twice to measure diseases at the early and late stages in canola growth, and the assessments were conducted over three growing seasons to establish long term patterns.

Monitoring sites

In conjunction with the National Variety Trial (NVT) sites across Australia, disease monitoring sites were established each year between 2013 and 2015 (Figure 1). The NVT program is a national program funded by the Australian Grains Research and Development Corporation to compare cultivars and breeding lines with standardised trial management, data generation and collection across Australia (http://www.nvtonline.com.au/). The number of sites monitored for disease each year ranged from 16 to 33. These disease monitoring sites were established primarily to monitor blackleg disease and they contained seven cultivars/advanced breeding lines that represent different blackleg resistance groups (Marcroft et al. 2012a). The cultivars/lines varied each year due to seed availability and were sown in the absence of fungicide. The *B. napus* cultivars/lines used were ATR-Stingray

(all years), CB Telfer (all years), CrusherTT (2013, 2014), Hyola444TT (2013, 2014), ThumperTT (2013, 2014), ATR-Marlin (2014, 2015), T28156 (2014, 2015), Surpass501TT (2013), Hyola650TT (2015), ATR-Gem (2015) and Hyola450TT (2015). A *B. juncea* advanced breeding line, JBOT800407, was also used in 2013. All cultivars were sown in three replicate plots (10m x 1m) with complete randomisation designed using DiGGer software. All sites were monitored for the incidence of canola diseases. Dates of sowing and harvest, monthly rainfall, minimum and maximum temperate are provided for the sites in Supplementary Table 1.

Fungicide control trials

Three trials were established (one each in Victoria, New South Wales and Western Australia) to determine whether current fungicides used to control blackleg disease would also reduce disease severity for white leaf spot and downy mildew. These two diseases were chosen as they are common in most years and are present during the early vegetative growth when fungicides are applied in commercial fields for blackleg control. All trials were sown adjacent to the disease monitoring sites described above, in three replicate plots (10m x 1m in Victoria and 20m x 1.4m in WA), with complete randomisation designed using DiGGer software. Cultivars with triazine tolerance (TT) were used: CrusherTT, CB Telfer, ATR-Stingray, PioneerSturtTT and Hyola559TT. Three fungicide treatments were used; seed dressing (Jockey®, fluquinconazole) only, seed dressing plus foliar fungicide (Prosaro®, mixture of prothioconazole and tebuconazole) applied at the 4-5 leaf stage, or fungicide amended fertilizer (Impact®, flutriafol), as per label recommendations, plus an untreated control.

Data collection and analysis

The monitoring and fungicide trial sites were surveyed twice each year to detect diseases expressed at (1) the rosette vegetative growth stage (primarily for white leaf spot and downy mildew) and (2) adult plant stages (primarily for Alternaria leaf/pod spot and powdery mildew). General disease severity (designated ‘site severity’) was recorded as

absent, present, minor, moderate and severe for each of the four diseases at the sites (Table 1). In addition, a selection of sites at which disease levels were severe was scored in more detail to determine potential genetic differences or efficacy of fungicides. At these sites, disease incidence and/or disease severity was determined. Disease incidence was determined by counting 20 consecutive plants in a plot and recording the number of plants that displayed disease symptoms. These data were collected from a single plot for each cultivar. Secondly, each of the three replicate plots per cultivar was scored for disease severity on a 0-4 scale (Table 1). Average disease severity for each cultivar was then determined from the three replicate plots. Significant differences in disease severity were identified by a one-way analysis of variance after square root transformation of the data. P-values less than 0.05 were considered statistically significant. All data were analysed using GenStat® 16th Edition.

Results

Canola diseases were assessed in trial sites across Australia over three growing seasons. While blackleg (caused by *L. maculans*) and Sclerotinia stem rot (caused by *S. sclerotorium*) were the primary diseases observed in the trials, other diseases were also present. Although some of these diseases were rare, localised or sporadic (such as hypocotyl rot, charcoal rot, club root and turnip yellows virus), four fungal diseases were consistently present in sites across Australia, and were therefore analysed in more detail.

General symptom descriptions

The symptoms of the four diseases are represented in Figure 2. White leaf spot and downy mildew generally occur during the vegetative stages of crop growth, however, white leaf spot can spread up the canopy as plants elongate. White leaf spot lesions occur on the leaves and are greyish-white to brown often with brown margins. In severe situations, complete loss of leaf area resulting in crop failure can occur (Figure 2a and b). Downy mildew lesions are characterised by yellowish-brown discolouration on the upper leaf surface with white mycelial masses on the under surface of the leaf (Figure 2c). Symptoms of this disease are usually restricted to the oldest true leaves, which are in contact with the

soil surface, and in severe situations reduce photosynthetic area resulting in potential yield loss (Figure 2d). Alternaria pod and leaf spot symptoms include dark target-like lesions on the leaves (Figure 2e) and black spots on the pods (Figure 2f). Alternaria pod spot can lead to premature ripening and shattering of pods. Powdery mildew symptoms appear as white powdery spots on leaves (Figure 2g) and stems (Figure 2h) most commonly during pod fill.

White leaf spot

White leaf spot was detected in most of the trial sites assessed in at least one year of the survey, and ranged from 56% incidence in 2013 to 55% in 2015 (Table 2). The highest levels of severity were detected in Victoria, and at one site, Hamilton, the level of disease was moderate to severe each year of the survey thus indicating a hot spot for this disease (Table 3).

In 2013, white leaf spot was detected at all sites in Victoria and disease incidence was determined for three genotypes, two *B. napus* cultivars and a *B. juncea* advanced breeding line. Disease incidence was significantly lower in the *B. juncea* cultivar (14%) compared to the *B. napus* varieties (50% for CrusherTT and 54% for CB Telfer). In 2014, the severity of white leaf spot was determined at Hamilton for all *B. napus* cultivars to detect potential genotypic differences. The level of disease was similar (ranging from 3.7-4.0) in all cultivars with the exception of line T28156, which had significantly less disease (Table 4).

The application of fungicides significantly reduced the level of disease caused by white leaf spot but varied across experiments. At Diggora, Victoria, the application of a seed dressing (Jockey®) and foliar fungicide (Prosaro®) significantly reduced the level of white leaf spot on the three cultivars tested compared to the bare control (Figure 3). At Grenfell, NSW, the combined application of a seed dressing (Jockey®) and fungicide amended fertilizer (Impact®) significantly reduced disease compared to Jockey® alone but the foliar fungicide (Prosaro®) did not significantly reduce disease compared to the seed treatment alone (Figure 4). In addition, without the application of fungicides cultivar Pioneer SturtTT exhibited less disease symptoms than ATR-Gem and Hyola650TT.

Downy mildew

Downy mildew was detected at most sites assessed, with the site incidence ranging from 100% in 2013 to 52% in 2015 (Tables 2 and 3). In 2013, the disease incidence for downy mildew was determined for two *B. napus* cultivars and a *B. juncea* advanced breeding line. As for white leaf spot, the average disease severity of downy mildew was significantly less in *B. juncea* (12%) than the *B. napus* cultivars (64% for CrusherTT and 59% for CB Telfer) for the nine trial sites. Genotypic differences were evident in the *B. napus* cultivars at various sites in 2013. Cultivars ATR-Gem, CB Telfer and ATR-Stingray had consistently less disease than each of the other cultivars (Figure 5). The impact of fungicides to control downy mildew was also determined. Unlike for white leaf spot, the application of the fungicides in these trials did not significantly reduce severity of downy mildew (Table 5).

Alternaria leaf and pod spot

Alternaria leaf/pod spot was a sporadic disease in the 2013-2015 seasons, with site incidence ranging from 9% in 2014 to 48% in 2013 (Table 2) and moderate to severe infection only detected at four sites in 2013 (Table 3). In 2013, disease severity was lower in the *B. juncea* line than the *B. napus* cultivars at two Victorian sites, Hamilton and Streatham. Cultivars Surpass501TT and ThumperTT had less disease at Streatham but this was not consistent with the Hamilton site (Table 6).

Powdery mildew

Powdery mildew was a sporadic disease with incidence ranging from 4% in 2013 to 33% in 2014 (Table 2), with only three sites showing moderate levels, all in 2014 (Tables 2 and 3). In WA, although powdery mildew was not detected at the blackleg monitoring sites, it was widely distributed in the northern and Central Agricultural regions in 2015 (data not shown). In 2014, severity was scored on the *B. napus* genotypes at five sites (1 VIC, 4 SA). Cultivars CrusherTT, ThumperTT and ATR-Marlin showed significantly less disease than the other cultivars (Figure 6).

Discussion

The canola industry in Australia has increased more than 50-fold since 1995, with 2.7 million hectares sown and 3.8 million tonnes production in 2013-2014 (ABARES 2015). A number of microbial diseases affect *B. napus* thereby reducing grain production, and while some diseases are ubiquitous and common, such as blackleg disease, others occur sporadically, are localised to certain regions, or occur in different parts of the landscape where the micro-climate is conducive.

There have been previous estimates of the potential impact of the less common canola diseases in Australia, such as charcoal rot caused by *Macrophomina phaseolina* in Western Australia (Khangura and Aberra 2009) or Sclerotinia stem rot in southern New South Wales (Kirkegaard et al. 2006) and Western Australia (Khangura et al. 2014) but these have been specific to individual regions. Diseases can be influenced by genetic background of the cultivar, climate, management practices and fungicide applications. While localised in reporting, the current distribution and the potential for diseases to spread geographically remains unclear and therefore requires a robust surveillance system. However, a national approach is required to be able to take a systematic analysis of disease incidence, define trends in disease prevalence that may pose a threat to the industry, and identify potential control mechanisms. In this study, these challenges were addressed such that a standard set of *B. napus* cultivars was monitored for disease at 33 sites in three growing seasons. The primary observations were that white leaf spot and downy mildew are common across all canola growing regions of Australia, however in most cases they are present at low levels and unlikely to affect yield.

Some diseases were problematic at specific locations, yet may be targeted by fungicide treatment. For instance, white leaf spot was moderate or severe at Hamilton each year with disease probably resulting in yield loss at this site due to damage to leaf tissue and therefore presumably photosynthesis capability. Data from two field experiments showed that control of white leaf spot can be achieved with fungicides currently used to control blackleg disease, *viz.* Jockey® (seed dressing), Impact® (fungicide amended fertilizer) and Prosaro® (foliar fungicide), although Prosaro® was not effective at Grenfel in 2015. Unlike white leaf

spot, downy mildew was not controlled by Jockey®, Impact® or Prosaro®. These fungicides all belong to the azole class of fungicides that target the product of the *Cyp51* gene, lanosterol 14α-demethlyase (Joseph-Horne and Hollomon 1997). This is consistent with the fact that downy mildew is an oomycete in the Order Peronosporales, a lineage that does not make ergosterol and lacks the *Cyp51* target gene (Haas et al. 2009).

Genetic resistance in crop plants is one of the main strategies to control diseases. In the current survey, varietal differences were detected in all four diseases. An advanced breeding line of *B. juncea* showed significantly less white leaf spot, Alternaria leaf/pod spot and downy mildew than the *B. napus* cultivars. This is consistent with previous studies whereby accessions of *B. juncea* have shown differential reactions to isolates of *P. parasitica* (causing downy mildew), *A. brassicae* (causing Alternaria leaf/pod spot) and *P. capsellae* (causing white leaf spot) (Nashaat and Awasthi 1995; Vishwanath et al. 1999; Gunasinghe et al. 2014). Unfortunately, there is no longer any commercial *B. juncea* cultivars on the market in Australia. However, *B. juncea* has been used in breeding programs for blackleg resistance (Van de Wouw et al. 2016) so it is possible that some of these traits have also been introgressed. Furthermore, within the *B. napus* cultivars and lines tested here, varietal differences were observed for downy mildew, powdery mildew and to a lesser extent white leaf spot. Although more extensive experimental work is required, the differences in cultivars detected in just a small number of genotypes in this study indicate that there may be more substantial resistance sources within current advanced breeding material. Given the sporadic nature of some of these diseases and the low return on investment for breeding companies to develop resistant cultivars, knowledge that there is already some resistance in available germplasm is useful information as an incentive to consider these 'minor' diseases in cultivar selection.

Powdery mildew and Alternaria leaf/pod spot were sporadic diseases in Australia over the three years assessed, and at current levels are unlikely to warrant specific breeding directions or control strategies. However, extremely dry springs in 2014 and 2015 probably constrained the severity of these diseases that traditionally develop late in the season under wetter conditions. Alternaria leaf/pod spot was detected at the greatest number of sites in 2013 when rainfall was greater in the spring.

Canola provides significant break crop benefits to subsequent cereal crops, yet has also become an economically viable crop in its own right. Increased production leads to an environment in which pathogens, which may have been rare, can emerge as major threats to the entire industry across the country particularly if no resistant cultivars are known or the impact of fungicides is untested. Identification of these pathogens can be difficult due to their sporadic nature. This study sets a nation-wide benchmark for how to measure disease severity across a continent, defines the potential disease threats to the canola industry, and provides evidence that commercial fungicides are available that can reduce disease risk for some of these pathogens. While the discoveries provide insight into the diseases that currently reduce the full potential of the Australian canola industry, taking similar experimental approaches around the world would likely be able to provide greater insight into diseases affecting the oilseed industry.

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Table 1 Definitions of severity classes for white leaf spot (caused by *Pseudocercosporella capsellae*), downy mildew (caused by *Peronospora parasitica*), Alternaria leaf and pod spot (caused by *Alternaria brassicae*) and powdery mildew (caused by *Erysiphe cruciferarum*) diseases assessed.

		Definition of severity for each disease			
Severity scores		White leaf spot	Downy mildew	Alternaria leaf/pod spot	Powdery mildew
Absent	0	Disease not observed	Disease not observed	Disease not observed	Disease not observed
Present	1	Few lesions detected	Few lesions detected	Few lesions detected	Single plant displaying symptoms
Minor	2	Lesions common but not on all plants	Lesions common but not on all plants	Lesions common but not on all plants	Small patches of mycelial growth on most plants
Moderate	3	Lesions common on majority of plants	Lesions common on majority of plants	Lesions on majority of plants	Most of the main stem covered with mycelial growth
Severe	4	Leaves dying and lesions present up the canopy	Two oldest leaves dying	Lesions on all plants	Stems/branches and lower leaves covered with mycelial growth

352 **Table 2** Incidences of four fungal diseases of canola across Australia during 2013 to 2015. Values in parentheses represent the number of sites
353 monitored for each disease in a given season.

	Year					
	2013		2014		2015	
Disease	Sites with disease detected	Sites with moderate to severe disease	Sites with disease detected	Sites with moderate to severe disease	Sites with disease detected	Sites with moderate to severe disease
White leaf spot	56% (16)	31% (16)	55% (33)	6% (33)	55% (33)	6% (33)
Downy mildew	100% (16)	31% (16)	58% (33)	19% (33)	52% (33)	0% (33)
Alternaria spot	48% (23)	17% (23)	9% (33)	0% (33)	16% (32)	0% (32)
Powdery mildew	4% (23)	0% (23)	33% (33)	9% (33)	13% (32)	0% (32)

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Table 3 Disease severity for white leaf spot (caused by *Pseudocercosporella capsellae*), downy mildew (caused by *Peronospora parasitica*), Alternaria leaf and pod spot (caused by *Alternaria brassicae*) and powdery mildew (caused by *Erysiphe cruciferarum*) at monitoring sites across Australia between 2013 and 2015. The disease severity is indicated by shading from green (absent) to red (severe).

		Site severity scores[b]											
		White leaf spot			Downy mildew			Alternaria leaf/pod spot			Powdery mildew		
Site[a]	State	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
Streatham (1)	Vic	Minor	Moderate	Minor	Moderate	Absent	Minor	Moderate	Absent	Absent	Absent	Absent	Absent
Hamilton (2)	Vic	Severe	Severe	Moderate	Moderate	Absent	Absent	Severe	Absent	Absent	Absent	Absent	Absent
Minyip (3)	Vic	Minor	Minor	Moderate	Minor	Absent	Present	Absent	Absent	Absent	Absent	Absent	Absent
Kaniva (4)	Vic	Moderate	Minor	Present	Present	Absent	Present	Minor	Absent	Absent	Absent	Absent	Absent
Charlton (5)	Vic	Moderate	Minor	Absent	Present	Minor	Absent	Absent	Absent	No data	Absent	Absent	No data
Yarrawonga (6)	Vic	Minor	Minor	Present	Present	Minor	Present	Absent	Absent	Absent	Absent	Absent	Absent
Wunghnu (7)	Vic	Severe	Minor	Minor	Moderate	Absent	Minor	Present	Absent	Absent	Absent	Moderate	Absent
Diggora (8)	Vic	Severe	Minor	Absent	Moderate	Minor	Absent	Minor	Absent	Absent	Absent	Minor	Absent
Arthurton (9)	SA	No data	Absent	Absent	No data	Absent	Minor	Severe	Absent	Present	Absent	Moderate	Present
Bordertown (10)	SA	No data	Absent	Minor	No data	Absent	Present	Present	Absent	Absent	Absent	Absent	Absent
Mt Hope (11)	SA	No data	Minor	Minor	No data	Minor	Minor	Absent	Absent	Minor	Absent	Absent	Absent
Riverton (12)	SA	No data	Absent	Absent	No data	Absent	Present	Minor	Absent	Absent	Absent	Minor	Minor
Spalding (13)	SA	No data	Minor	Absent	No data	Absent	Minor	Minor	Absent	Absent	Absent	Minor	Minor
Turretfield (14)	SA	No data	Absent	Minor	No data	Absent	Present	Severe	Absent	Minor	Minor	Minor	Minor

Frances (15)	SA	No data	Absent	Present	No data	Absent	Present	No data	Absent	Absent	No data	Moderate	Absent
Yeelanna (16)	SA	No data	Minor	Minor	No data	Minor	Minor	Minor	Absent	Minor	Absent	Absent	Absent
Beckom (17)	NSW	No data	Minor	Minor	No data	Absent	Minor	Absent	Absent	Absent	Absent	Absent	Absent
Cootamundra (18)	NSW	No data	Absent	Minor	No data	Minor	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Cudal (19)	NSW	No data	Minor	Present	No data	Minor	Present	Absent	Present	Absent	Absent	Absent	Absent
Gerogery (20)	NSW	No data	Minor	Minor	No data	Minor	Absent	Absent	Minor	Absent	Absent	Minor	Absent
Grenfell (21)	NSW	No data	Minor	Minor	No data	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Lockhart (22)	NSW	No data	Minor	Minor	No data	Minor	Absent	Absent	Present	Absent	Absent	Minor	Absent
Parkes (23)	NSW	No data	Minor	Minor	No data	Absent	Present	Absent	Absent	Absent	Absent	Minor	Absent
Wagga Wagga (24)	NSW	No data	Minor	Absent	No data	Minor	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Goulburn (25)	NSW	No data	Absent	Absent	No data	Minor	Minor	No data	Absent	Absent	No data	Minor	Absent
Badgingarra (26)	WA	Absent	Absent	Absent	Present	Present	Absent	No data	Absent	Absent	No data	Absent	Absent
Corrigin (27)	WA	Absent	Absent	Absent	Present	Present	Absent	No data	Absent	Absent	No data	Absent	Absent
Gibson (28)	WA	Absent	Absent	Absent	Present	Moderate	Absent	No data	Absent	Absent	No data	Absent	Absent
Katanning (29)	WA	Absent	Absent	Absent	Severe	Moderate	Absent	No data	Absent	Present	No data	Absent	Absent
Kendenup (30)	WA	Present	Absent	Absent	Present	Moderate	Absent	No data	Absent	Absent	No data	Absent	Absent
Kojonup (31)	WA	Absent	Absent	Absent	Present	Moderate	Absent	No data	Absent	Absent	No data	Absent	Absent
South Sterling (32)	WA	Absent	Absent	Absent	Present	Moderate	Absent	No data	Absent	Absent	No data	Absent	Absent
Williams (33)	WA	Present	Absent	Absent	Present	Moderate	Absent	No data	Absent	Absent	No data	Absent	Absent

[a] Numbers in parentheses refer to site locations in Figure 1.

[b] Definitions of disease severity scores are presented in Table 1. No data refers to sites where data were not collected.

360 **Table 4** Average disease severity of white leaf spot on *B. napus* cultivars at Hamilton,
361 Victoria, in 2014. One line, T28156, showed significantly less disease compared to all other
362 cultivars. Plants were assessed at rosette vegetative stage. Data are the average of three
363 replicate plots.

Cultivar	Disease severity (0-4 scale)
CrusherTT	4.0
CB Telfer	4.0
ATR-Stingray	3.7
Hyola444TT	4.0
ThumperTT	4.0
T28156	2.3*
ATR-Marlin	4.0

364 * Represents p-value less than 0.05.

365

Table 5 Disease severity of downy mildew after application of a fungicide at a site in WA. Fungicide application did not significantly reduce downy mildew severity. Plants were assessed at the rosette vegetative growth stage. Data are the average of three replicate plots.

Cultivar	Fungicide application	Infection score (0-4 scale)
CrusherTT	Nil	2.3
	Jockey	3.0
	Jockey+Prosaro	3.3
Hyola559TT	Nil	3.0
	Jockey	3.7
	Jockey+Prosaro	3.3
ATR-Stingray	Nil	2.3
	Jockey	2.7
	Jockey+Prosaro	2.7
PioneerSturtTT	Nil	2.3
	Jockey	3.3
	Jockey+Prosaro	3.3

Table 6 Severity of Alternaria pod or leaf spot at two Victorian sites in 2013. The *B. juncea* advanced breeding line, JBOT800407, showed significantly less disease than all other cultivars at both sites. The level of disease in ThumperTT and Surpass501TT were significantly lower than other cultivars at Streatham but not at Hamilton.

	Disease severity (0-4 scale)	
Cultivar	**Streatham**	**Hamilton**
CrusherTT	3	4
CB Telfer	3	4
ATR-Stingray	3	4
Hyola444TT	3	4
ThumperTT	1*	4
JBOT800407	1*	1*
Surpass501TT	1*	4

* Represents p-value less than 0.05. Data are average of three replicate plots.

Figure legends

Fig. 1 Location of disease monitoring sites across Australia. Numbers refer to locations listed in Table 3.

Fig. 2 Symptoms of four fungal pathogens of *Brassica napus* and *Brassica juncea* in Australia between 2013 to 2015 (excluding *Leptosphaeria maculans* and *Sclerotinia sclerotorium*). White leaf spot (caused by *Pseudocercosporella capsellae*) symptoms visible on the oldest leaf (a) and moving up the canopy of the plant (b). Hyphal growth of downy mildew (caused by *Peronospora parasitica*) on the underside of the oldest leaf (c) as well as yellowing of the oldest leaves across a plot (d). Symptoms caused by *Alternaria brassicae* on a leaf (e) and pods (f). Powdery mildew (caused by *Erysiphe cruciferarum*) symptoms on the stem (g) and leaves (h).

Fig. 3 Effect of fungicide application on the severity of white leaf spot (caused by *Pseudocercosporella capsellae*) at Diggora, Victoria, in 2013. The application of the seed-dressing fungicide, Jockey®, as well as the addition of a foliar fungicide, Prosaro®, significantly reduced disease severity compared to the nil control for all three *B. napus* cultivars screened. Plants were assessed at rosette vegetative growth stage. Data are average of three replicate plots. * Represents p-value less than 0.05.

Fig. 4 The effect of fungicide application on severity of white leaf spot (caused by *Pseudocercosporella capsellae*) at Grenfell, NSW, in 2015. Plants were assessed at the rosette vegetative growth stage. Values are the mean of 4 replicate plots. Mean infection scores followed by the same letter are not significantly different at p=0.05.

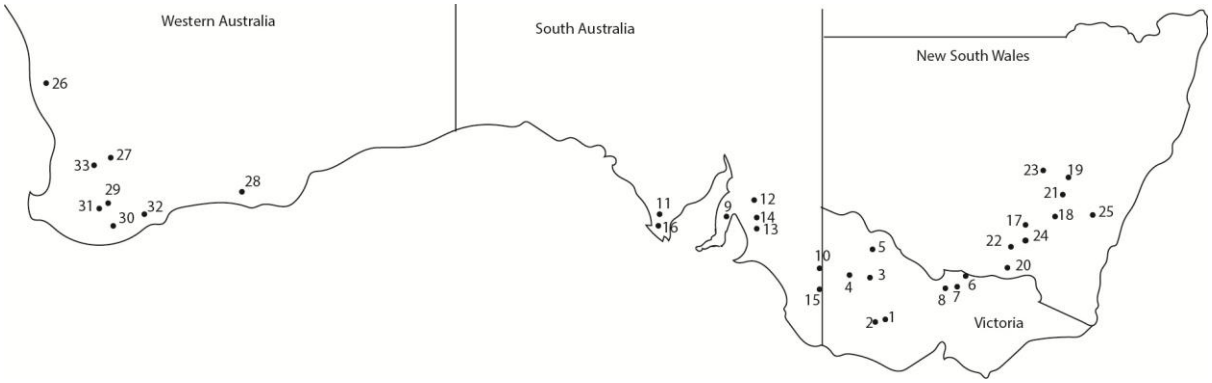
Fig. 5 Severity of downy mildew (caused by *Peronospora parasitica*) at six sites (1 VIC, 2 SA, 3 NSW) in 2013. Cultivars ATR-Gem, CB Telfer and ATR-Stingray had significantly less disease than the remaining three cultivars. Plants were assessed at the rosette vegetative growth

406 stage. Data are average of three replicate plots across 6 sites. * Represents p-value less than
407 0.05.

408

409 **Fig. 6** Severity of powdery mildew (caused by *Erysiphe cruciferarum*) at five sites (4 SA, 1 Vic)
410 in 2014. Cultivars CrusherTT, ThumperTT and ATR-Marlin show significantly less disease than
411 the other cultivars. Plants were assessed at maturity. Data are average of three replicate
412 plots across 6 sites. * Represents p-value less than 0.05.

413


Western Australia
South Australia
New South Wales
Victoria
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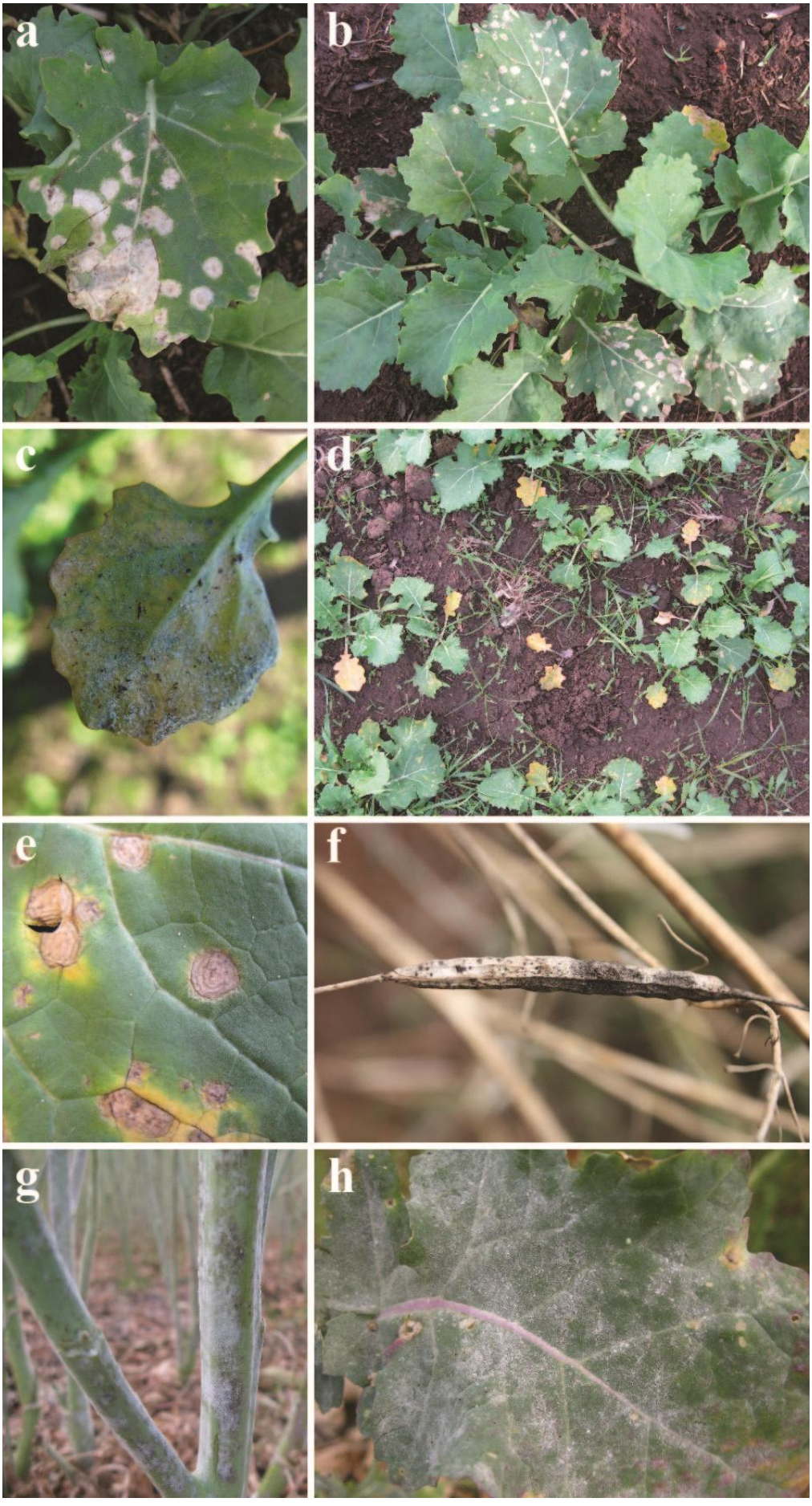

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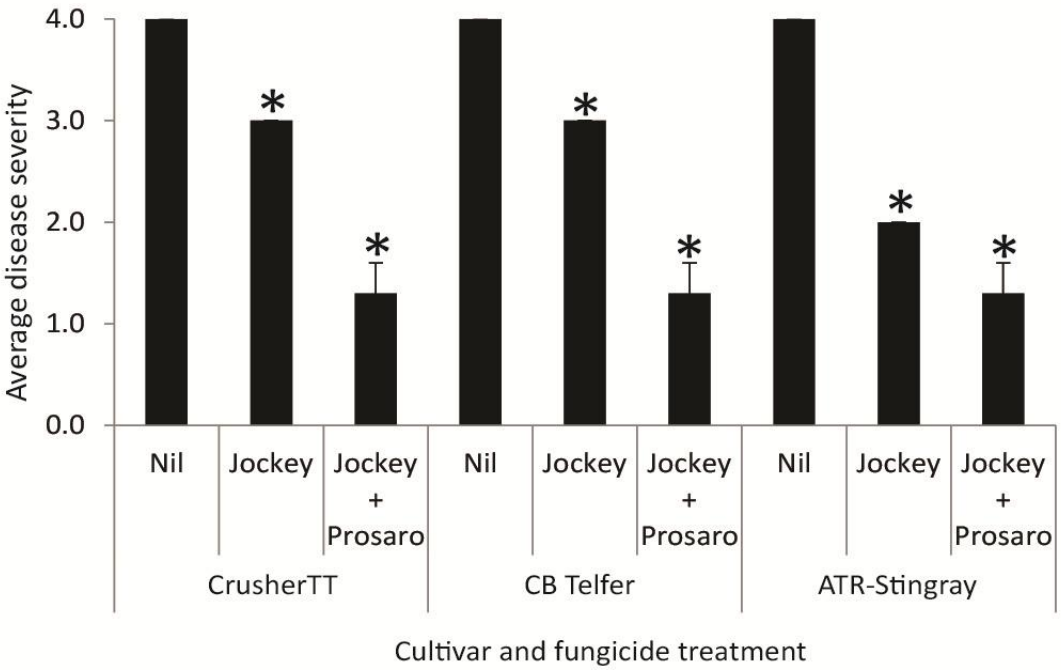
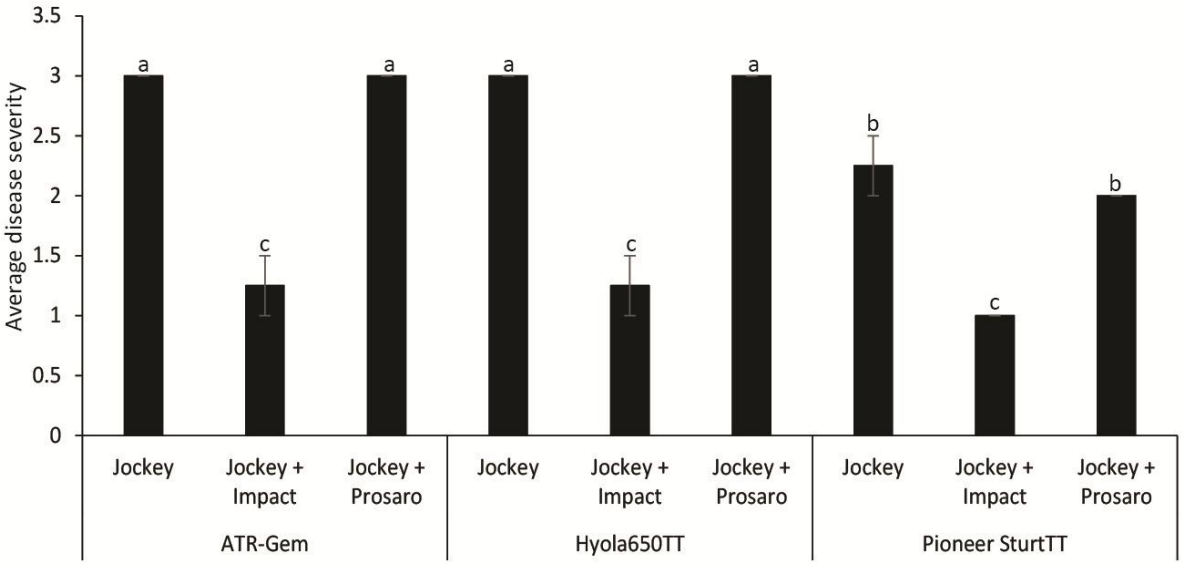

4.0
3.0
2.0
1.0
0.0
Average disease severity
*
Nil
Jockey
Jockey + Prosaro
CrusherTT
CB Telfer
ATR-Stingray
Cultivar and fungicide treatment

418

419


Average disease severity
3.5
3
2.5
2
1.5
1
0.5
0
a
c
a
a
c
a
b
c
b
Jockey
Jockey + Impact
Jockey + Prosaro
Jockey
Jockey + Impact
Jockey + Prosaro
Jockey
Jockey + Impact
Jockey + Prosaro
ATR-Gem
Hyola650TT
Pioneer SturtTT

420

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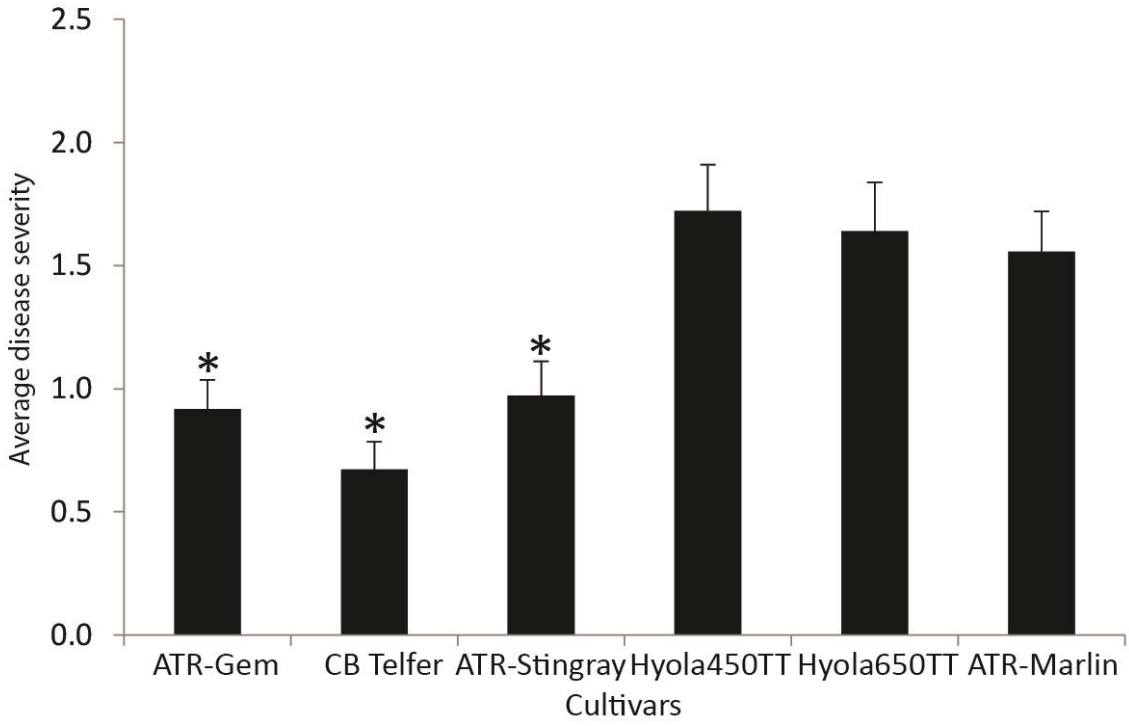
2.5
2.0
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1.0
0.5
0.0
Average disease severity
*
*
*
ATR-Gem
CB Telfer
ATR-Stingray
Hyola450TT
Hyola650TT
ATR-Marlin
Cultivars

422

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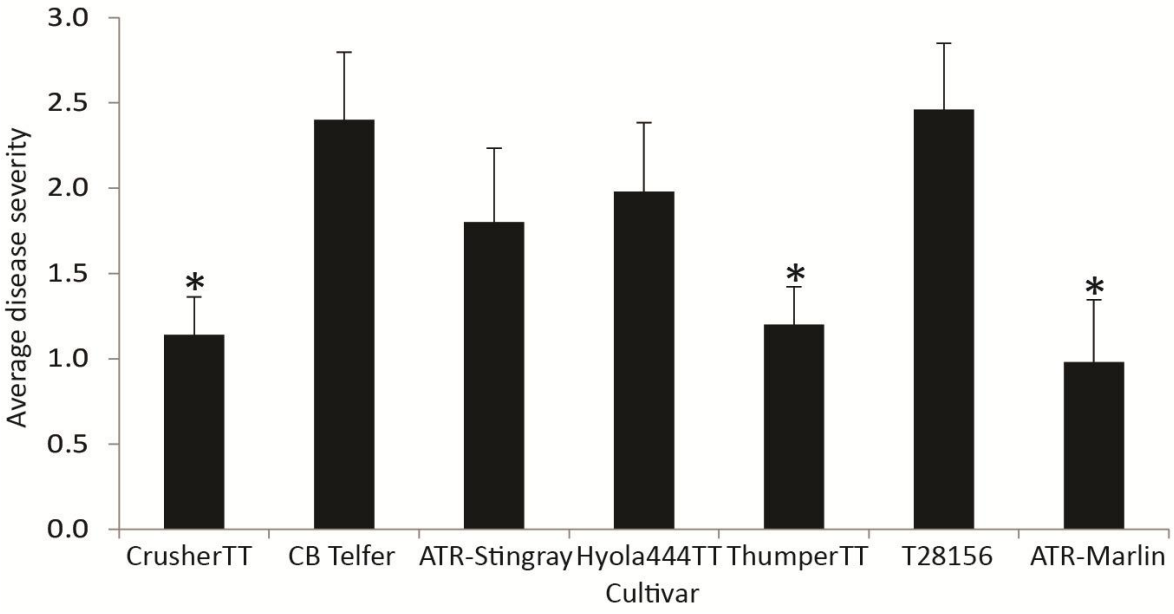
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Average disease severity
*
*
*
CrusherTT
CB Telfer
ATR-Stingray
Hyola444TT
ThumperTT
T28156
ATR-Marlin
Cultivar

424

					Monthly rainfall (mm)												Mean (minimum) temp (°C)											
Year	Site	State	Date Sown	Date harvested	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2013	Streatham	Vic	19-May	17-Dec	0	13.4	4	7.6	36.2	50.4	68.2	73.4	42.4	60	23.4	22.6												
	Hamilton	Vic	15-May	16-Dec	0.4	15.6	14.4	12.6	50.6	72.8	84	114.8	45	82	37.8	28.8												
	Minyip	Vic	23-May		3.6	18.8	4.1	7	27.7	81.2	53	48.8	50.4	37.9	16.6	0												
	Kaniva	Vic	6-May	26-Nov	3	17	2.8	11.4	35.6	130.3	71.4	65.4	42.4	33	8.4	3												
	Charlton	Vic	27-May	3-Dec	7.2	17.6	8.8	4.2	36.2	44	46	47.2	46.1	23.2	7.8	10.2												
	Yarrawonga	Vic	6-May	18-Nov	2.6	30.2	59.6	6.6	29.2	61	38.4	32.6	33	21	16.4	47.2												
	Wunghnu	Vic	3-May	15-Nov	2.2	50	15.6	8.6	37.6	70.2	48.8	30.1	14.2	13.2	21.6	42.6												
	Diggora	Vic	23-May	25-Nov	4	36.1	19.2	1.2	23.4	52.5	56	64.8	38.2	15	10	44												
	Arthurton	SA	2-May	13-Nov	10.2	15.4	16	29.8	50.6	74.8	101.5	52.2	48.8	19.8	3.6	11.8												
	Bordertown	SA	28-May	10-Dec	3	14.8	7	15	46	90	90.8	76	46.8	35.4	11.8	3.8												
	Mt Hope	SA	14-May	5-Nov	9	3.6	13.2	33.2	50.8	95.4	107.4	62.2	48	9	16.8	0												
	Riverton	SA	13-May	15-Nov	4	30	4.4	39	74.4	73.4	67.4	67.6	79.4	27.8	4.6	30.2												
	Spalding	SA	1-May	18-Nov	0	35	5	29.5	48.5	94	71	45.5	24	21.5	5.5	26												
	Turretfield	SA	6-May	5-Nov	8.6	26.2	9	39.2	50.8	66.4	59.6	68.8	35.8	20.8	6.4	25.2												
	Frances	SA	5-Jun		8.6	6.8	7.2	16.4	55	92	99.8	108	76.6	35.4	12.4	12.8												
	Yeelanna	SA	30-Apr	30-Oct	8.2	8.6	48.4	34.2	30	57.8	77	63.4	41	12.4	12	0												
	Beckom	NSW	18-May	7-Nov	5	50	24	4.5	43.5	81	37	30.5	41	12	33	12						5.2	3.7	2.9	4.1	4.3	11.3	
	Cootamundra	NSW	20-May	27-Nov	5	61	48	5	30	78.6	69.2	49	30.4	26	22.2	15						3.6	3.6	3.8	3.4	2.3	7.5	
	Cudal	NSW	25-May	13-Nov	24.4	46.6	80.2	7	24.6	129.8	43.4	31.2	34.4	15	65	47.6						2.2	3.0	2.5	4.4	4.0	11.3	
	Gerogery	NSW	21-Jun	10-Dec	5	26	48	11	112	72	69	63	46	21	11	49						4.5	5.0	5.0	5.3	3.5	6.9	
	Grenfell	NSW	15-May	14-Nov	0	23.5	76	6	23	100	58.5	26.5	38.5	22	29.5	23.5						6.7	2.8	2.2	3.2	3.0	12.2	
	Lockhart	NSW	20-May	15-Nov	16	31	36	6	62.5	52	65.5	33.5	33	0	22.5	30						3.4	4.2	3.7	5.0	3.1	11.2	
	Parkes	NSW	14-May	15-Nov	20	68	16.8	2.5	25.5	143.5	55.5	14	38	6	40	35.5						5.2	3.7	2.2	3.9	4.0	13.6	
	Wagga Wagga	NSW	20-Jun	3-Dec	0	25	20	3	57	65	39	35	47	61	3	19						4.0	3.6	3.4	3.4	2.0	6.6	
	Goulburn	NSW	N/A	N/A																								
	Badgingarra	WA	3-May	6-Nov	26	0.2	48.6	12.2	116	14.4	83.6	117.2	90.4	25	3.2	0.6	18.4	19.5	15.6	16.3	10.4	7.6	6.2	8.3	8.4	9.7	14.0	15.5
	Corrigin	WA	15-May	20-Nov	89.3	0.2	28.5	3.5	53.1	3.3	112.4	53.2	57	23.2	2.9	17.6	17.6	17.2	14.3	14.5	8.4	4.7	3.9	6.9	7.4	8.2	13.8	14.1
	Gibson	WA	5-May	12-Nov	36.6	5.6	137	35.8	78.5	25.8	57	65	66.2	72	12	34.8	16.3	15.1	14.5	14.3	10.8	8.3	7.0	9.1	8.9	9.5	12.3	13.8
	Katanning	WA	23-May	20-Nov	31.2	1.8	66.2	8.9	67	20.3	48.7	64.1	114	28.1	4.2	2.9	14.9	14.5	12.7	13.4	8.9	6.7	5.4	8.1	7.9	7.8	11.7	11.4
	Kendenup	WA	6-Jun	6-Dec	9.8	6.6	56.4	21.4	51	24.8	68.4	81.2	126.8	27.4	15	13.8	14.2	14.4	12.9	13.6	9.1	7.5	6.5	8.5	8.2	8.9	11.8	11.4
	Kojonup	WA	9-May	3-Dec	2.4	1.2	42.7	7.8	63.8	33.4	72.8	115.6	119.4	24.2	14.4	11.6	14.3	14.1	12.2	13.1	8.3	6.2	5.1	7.8	7.9	7.8	11.4	11.0
	South Sterling	WA	5-May	23-Nov	20	3.4	109.1	31.2	50.8	20.4	63	78	118.6	42.1	27.6	20.3	15.1	15.2	13.6	14.3	9.9	8.0	7.3	9.2	8.8	9.4	12.5	12.3
	Williams	WA	7-May	2-Dec	6.1	5.3	47.6	22.4	108.3	16.9	80	84.8	112.9	19.8	20.1	2.6	15.6	15.0	12.6	13.4	7.8	4.8	4.1	7.6	7.7	7.5	12.0	12.2
2014	Streatham	Vic	9-May		17.8	11.8	14.8	63.2	23	69.4	35.6	38.6	28	15	31.4	0												
	Hamilton	Vic	14-May	28-Nov	20.4	17.2	22.2	75	51.2	103.2	73.8	39.4	28.6	18.8	20	0												
	Minyip	Vic	6-May	5-Nov	7.8	12.4	0	52	30.8	32.6	39.1	11.6	19.4	13.1	30.8	0												
	Kaniva	Vic	5-May	11-Nov	10.6	11.6	8.4	42.8	28	53.8	41.4	27.8	17.4	0.8	22.2	0												
	Charlton	Vic	1-May	6-Nov	5.2	8.2	35.8	55.8	23.4	35	23.6	6.8	13	11	41.4	0												
	Yarrawonga	Vic	5-May	20-Nov	39.4	22.6	51.6	111.8	54.6	46.2	22.2	3.6	66.4	15.5	52.8	31.4												
	Wunghnu	Vic	24-Apr	11-Nov	16.4	19.6	34.6	85.4	53	67	26.6	2.8	50	8.6	48.4	17.4												
	Diggora	Vic	7-May	24-Nov	8.8	21.6	31.8	82.4	35.4	90.4	28.1	4.9	85.1	9.4	33.2	0												
	Arthurton	SA	7-May	14-Nov	3.6	67.6	12.4	56.4	38.8	73.8	45	11	19.6	4.4	8.8	6.2												
	Bordertown	SA	15-May	13-Nov	12.4	13.2	9.8	39.6	22.2	67	59.4	27.2	16.2	5.2	20.2	17.6												
	Mt Hope	SA	30-Apr	4-Nov	7.4	65.8	9	25	89.6	124	91.2	13.6	14.8	0.4	5.8	0												
	Riverton	SA	5-May	14-Nov	4.2	83.4	11.8	69.6	68.2	118.8	78.4	18.2	17.4	12.2	34.2	7												
	Spalding	SA	6-May	21-Nov	8	52	4	79	56	111.5	49	15.5	27	4	8.5	25												
	Turretfield	SA	5-May	4-Nov	10.4	77.2	5.6	66.8	36.2	50.6	47.6	13	22	7.8	23.2	10.8												
	Frances	SA	20-May	12-Nov	19.2	23.4	18.2	38	40.4	81.6	56.4	14.4	44.8	8.2	22.6	18												
	Yeelanna	SA	30-Apr	5-Nov	10.4	64.8	4.8	25	88.6	95.6	75.8	12.2	16.8	3.6	10	0												
	Beckom	NSW	16-Apr	3-Nov	31.5	21	62.5	47.5	27	62	20	19.5	30	14	21	-						4.6	1.0	-1.1	1.6	6.2		
	Cootamundra	NSW	24-Apr	19-Nov	18	82.6	123	90	36.6	105	32.8	31.4	38.6	24.6	28	91						4.7	3.0	2.6	3.6	5.3	11.5	
	Cudal	NSW	28-Apr	14-Nov	60	43	147	66.2	37.6	61.8	29.2	18	20.8	73	9.6	-						3.0	0.8	0.2	0.3	2.7	11.9	
	Gerogery	NSW	23-Apr	21-Nov	40	24	32	144	73	65	24	4	57	17	47	-							2.6	-0.2	1.8	4.4	9.5	
	Grenfell	NSW	23-Apr	11-Nov	16	36	113.5	66	34.5	103.5	40.5	29	14.5	30	17	56						3.4	0.8	0.3	0.9	3.1	13.8	
	Lockhart	NSW	22-Apr	6-Nov	21	30.2	41.2	57.6	24.4	61.8	19.8	5.2	34.2	14.6	47.4	-						5.1	2.7	0.6	2.7	6.7		
	Parkes	NSW	24-Apr	12-Nov	138	57	153.8	26.4	43.4	83.4	13.4	27.2	32	32.2	20.2	-							1.7	-0.1	1.8	4.2	16.1	
	Wagga Wagga	NSW	24-Apr	13-Nov	8.5	18	68	63	51	46	18	14	39	22	58	34						4.4	1.3	-1.5	0.0	3.6	11.7	
	Goulburn	NSW	17-Apr	13-Nov	10.4	58.4	78.4	56	26.8	39.4	11.8	116.8	39.6	44.2	12.4	149.8	11.3	12.6	11.6	6.4	2.4	2.5	0.7	-0.7	2.7	4.9	9.4	12.4
	Badgingarra	WA	9-May		8.4	2.2	4.9	43.4	93.4	42.2	130.2	62.8	75.5	11.5	23.2	0	17.4	19.3	17.2	13.8	10.6	7.4	7.1	9.4	10.4	11.1	11.5	14.5
	Corrigin	WA	17-May	8-Nov	4.4	5	2.6	90.6	47.1	25.1	58.8	39.6	27.4	68	28.5	0	17.4	16.1	15.2	11.9	9.9	4.2	5.7	6.3	7.7	10.4	12.1	13.5
	Gibson	WA	14-May	7-Nov	10.8	7.2	6.4	11	40.6	37.6	74.4	34.6	48.8	66.6	56.6	15.6	15.4	15.3	14.2	12.3	11.3	8.5	7.5	7.8	9.2	11.0	12.4	13.1
	Katanning	WA	26-May	26-Nov	0.4	0	2.9	15.5	94.7	34	80.8	64.7	54.3	51	18.3	4.7	14.0	13.3	13.3	11.1	10.2	6.9	6.9	7.1	7.5	9.1	10.1	11.4
	Kendenup	WA	16-May	3-Dec	0.6	10.8	5.6	15.6	100.8	33.8	109.3	38.2	51	84.2	29	16.6	13.6	13.3	13.4	11.3	10.6	8.2	7.4	7.7	8.7	10.2	10.4	11.3
	Kojonup	WA	6-Jun	18-Dec	1	3.4	2.8	12.2	131.7	43	109	55.9	54.4	63	12.5	2.2	13.4	12.9	13.0	10.4	10.0	6.6	6.7	7.0	7.4	8.9	9.5	10.9
	South Sterling	WA	5-Jun		0.5	4.2	6.4	13.3	84.5	34.8	89.3	35.6	47	93.6	56.6	20.4	14.5	14.4	14.1	12.0	11.3	8.8	7.7	7.9	8.8	10.7	11.2	12.1
	Williams	WA	16-May	28-Nov	0.2	0	4.4	21.7	112.3	41.4	111.5	55.8	67.6	22.4	24.6	0.6	14.6	14.4	13.8	10.4	9.5	5.0	6.1	6.6	7.5	9.0	10.0	12.0
2015	Streatham	Vic	1-May		47	11.6	12.2	23	46.4	41.6	45.4	25.8	43.6	4.6	19	4.2												
	Hamilton	Vic	1-May	19-Nov	0	0	30	33	80.6	55.8	64.2	36.2	34.4	13.4	0	0												
	Minyip	Vic	29-Apr	20-Nov	0	0	6.7	18.6	25.6	43	25.1	28	24.6	4.2	0	0												
	Kaniva	Vic	30-Apr	24-Nov	0	0	3.6	20.4	35.8	29	39.4	22.8	30.4	2.8	0	0												
	Charlton	Vic	28-Apr																									
	Yarrawonga	Vic	29-Apr	18-Nov	66.4	51.4	2.4	74.4	20.6	44.2	35.8	46.6	22.8	19.4	67.6	0												
	Wunghnu	Vic	30-Apr	12-Nov	32.6	34.6	3.6	40.8	16.8	42	36.6	30.6	15.4	12.4	68.2	0												
	Diggora	Vic	6-May	13-Nov	48.2	2.6	5.2	32.2	12	26	20.6	22.9	23.2	1.8	29.6	0												
	Arthurton	SA	3-May	17-Nov	48.6	0	4.6	43.6	44	25.2	40.6	59.8	18.2	6.8	27.2	6.4												
	Bordertown	SA	25-May	18-Nov	40.2	3.4	7.2	29.4	67.4	20.6	39.4	32.8	26.2	4.8	19.8	11												
	Mt Hope	SA	28-Apr	9-Nov	10.4	0	2.2	56.6	27.8	24	44	85	45.8	1.2	38	0												
	Riverton	SA	22-Apr	15-Nov	51.5	2	7.5	71.5	59.5	24.5	51	67.5	55.5	12.5	33	3												
	Spalding	SA	28-Apr	20-Nov	56	0	4	103	35	19	38	89	27	14	47	0												
	Turretfield	SA	23-Apr	9-Nov	44.4	0	3.6	44	23.4	22.4	49.6	57.4	28.4	9.2	25.6	13.6												
	Frances	SA	26-May	18-Nov	30.2	1.4	13.2	26.6	53.4	31.2	65	33.6	30.6	4.4	17.6	18												
	Yeelanna	SA	27-Apr	10-Nov	20.6	0	2	55.2	23.7	47	43.7	80.7	42.3	2	22.4	0												
	Beckom	NSW	21-Apr	9-Nov	101.6	42	1	63.4	13	44.6	88.4	74.2	16.8	10.8	87	-						6.0	2.6	2.1	0.7	9.4	14.9	
	Cootamundra	NSW	22-Apr	19-Nov	85.4	29.6	6	64	31	61	91	71	18	23	87	4						6.0	1.8	2.0	0.8	8.7	13.5	
	Cudal	NSW	24-Apr	18-Nov	75.6	14.4	6.6	94.8	33.2	16.6	88.2	44.8	10	17.2	120.6	-						6.0	1.5	2.2	1.3	10.3	15.2	
	Gerogery	NSW	29-Apr	20-Nov	107	62	2	71	30	95	66	77	30	21	57	34						2.1	2.6	3.0	2.6	8.6	14.3	
	Grenfell	NSW	23-Apr	16-Nov	116.1	13.5	13.2	114.4	46.2	30.3	120.7	91.4	7.4	19.4	72.2	-						5.8	1.8	1.7	0.7	8.0	16.0	
	Lockhart	NSW	24-Apr	9-Nov	34	28.5	0	80	17	54	47	76	24	10	73	30.5						2.1	2.7	2.8	2.8	10.6	14.3	
	Parkes	NSW	29-Apr	9-Nov	36.4	126	2	87.6	24	20.6	89.8	56.6	11.2	36	93.4	-						6.2	2.6	1.8	0.5	10.1	15.8	
	Wagga Wagga	NSW	14-May	19-Nov	100	12	0	104	34	45	51.5	81.5	16	21.5	54	3						2.7	3.4	4.0	3.3	10.6	15.6	
	Goulburn	NSW	21-May	2-Dec	118.5	55.8	31.2	86.8	18.6	53.6	59.2	62.6	14	12	35.2	8.8	13.1	12.5	8.5	7.5	3.3	-0.8	-0.7	1.1	1.7	6.6	9.5	9.9
	Badgingarra	WA	11-May	5-Nov	0.6	17.6	39.2	45.4	26.8	66.6	93.8	86.8	17.1	4.4	14.6	4.2	17.4	19.1	16.4	14.3	10.0	9.9	8.3	8.0	8.1	11.1	14.3	15.6
	Corrigin	WA	7-May	3-Nov	1	2.2	29.9	26.4	18.8	27.2	33.5	59.5	14.8	10.6	27.2	15	16.6	18.1	14.7	10.8	6.3	5.9	5.4	5.6	5.1	11.2	13.5	14.5
	Gibson	WA	1-May	3-Nov	5	2.6	43.2	45.6	50	59.2	42.9	80.1	55.3	26	23.4	37.8	14.8	16.6	14.0	11.5	9.0	8.9	7.8	8.0	8.0	12.2	13.6	14.0
	Katanning	WA	5-May	9-Nov	1.1	1.4	19	45.5	28.6	59.2	40	52.2	24.2	19.2	9.9	35.9	14.1	15.8	13.0	10.5	6.8	7.5	6.2	6.0	6.4	10.3	11.8	12.2
	Kendenup	WA	29-Apr		6.4	15.4	24.8	97.2	35.4	47.2	72.6	60	37.6	29.5	10.8	42.6	14.1	15.3	13.2	11.0	7.7	8.5	7.1	7.1	7.7	10.8	11.9	11.9
	Kojonup	WA	29-Apr	4-Dec	1.6	10.2	23.8	73.2	25	43.8	79.8	56.8	48	29	3.4	45.8	13.7	15.2	12.6	9.9	6.3	7.1	5.8	5.9	6.1	9.9	11.4	11.6
	South Sterling	WA	29-Apr	29-Nov	2.1	15.7	26.1	81.1	57.4	46.8	80.4	72.6	44.6	41.8	29.3	39.1	14.8	16.0	13.8	11.4	8.1	8.7	7.7	7.4	8.0	11.2	12.7	12.8
	Williams	WA	29-Apr	3-Dec	15.8	16.4	38.6	44.2	33.7	35.5	34.4	70.1	30.7	12.8	19.2	39.6	14.7	16.2	13.2	10.0	5.4	6.0	5.4	5.3	5.2	9.9	12.0	12.8