“Where we are with Adult Plant Resistance varieties for barley leaf rust - is it worth spraying?”

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Key messages

- Under high leaf rust disease pressure, such as in Albany and Esperance port zones, barley varieties which possess adult plant resistance (APR) genes (*Rph20* and *Rph24*) are likely to benefit from foliar fungicide applications through reduction in disease severity and positive yield responses.
- In high rainfall, long season environments; seed dressing, in-furrow or tillering foliar fungicides are effective against leaf rust but do not provide long enough period of efficacy to protect APR varieties throughout the crop growing season without additional foliar fungicide applications.
- In disease conducive environments varieties with APR against leaf rust such as Flinders or Oxford, will need one or two fungicide sprays, incorporating applications during stem elongation (Z32) to flag leaf (Z39).
- Delayed sowing (e.g. third week of May) reduced leaf rust severity and gave better fungicide responses for managing the disease. Early sown crops (e.g. late April to mid-May) usually need two applications of foliar fungicides.
- Barley varieties which possess APR genes and have leaf rust infection can have leaf flecking, spotting and necrosis rather than typical leaf rust symptoms. Foliar fungicide intervention is still required to prevent the necrosis resulting from APR response to pathogen infection.
- Fungicide products vary in their efficacy in management of barley leaf rust.
- Leaf rust is best managed through an integrated disease management approach, incorporating control of volunteer green bridge, use of varieties with improved resistance, monitoring for disease presence and implementation of well-timed effective foliar fungicides.

Aims

In recent years, leaf rust caused by the fungal pathogen *Puccinia hordei* has been a major constraint for barley production causing reduced yields and grain quality for export markets in the Albany, Esperance and Kwinana port zones of Western Australia (WA). Frequent occurrence of leaf rust infection in the barley crops grown in the southern regions is mainly due to retention of barley regrowth after a wet summer for animal feed in mixed farming systems.

Over the last few years new leaf rust pathotypes (5457P- in 2013, 5457P+ in 2014 and 5656P+ in 2016) have been detected in the southern region of WA, and have been shown to compromise some barley varieties (e.g. Bass, Compass) which possess only *Rph3* (major resistance) gene. Varieties dependent on single major gene resistances (e.g. *Rph3, Rph12, Rph9.am*) are susceptible to being overcome by new virulent pathotypes of the leaf rust pathogen.

Several current barley varieties possess adult plant resistance (APR) genes (e.g. *Rph20* and *Rph24*) that are more durable than their counterpart major gene/s (e.g. *Rph3, Rph12, Rph9.am*). Barley varieties which possess APR genes provide greatest protection against leaf rust pathogens at later growth stages whereas varieties which possess major genes are protected from seedling stage against the pathogens. The APR genes can influence the disease development by lengthening latent periods (the time of fungal spore landing in the leaf to disease symptom development), reducing number and size of pustules and the exhibition of hypersensitive responses in some barley varieties (necrotic flecks without sporulation). The onset of APR resistance against the leaf rust pathogen is governed by the variety the genes are deployed in, the environment the crop is grown in, including temperature, and the disease pressure and can become effective anywhere from early tillering to head emergence. The uncertainty around when the resistance begins in an APR barley variety makes the decision to apply fungicide difficult.

Since the breakdown of the major resistance gene *Rph3*, and lack of availability of barley varieties with other effective major gene resistance, growers currently rely on the use of fungicides on susceptible and APR varieties to manage the disease. Inconsistent performance of APR varieties against leaf rust in Albany and Esperance port zones have raised significant concerns among growers and advisers about factors influencing resistance expression and best fungicide program for optimum disease management.

The aim of this research was to investigate a) the impact of delayed sowing on leaf rust development in some APR varieties; b) requirement for fungicide application to support

APR to leaf rust in two popular barley varieties (Flinders and Oxford); c) efficacy of leaf rust control among different fungicide groups and active ingredients.

Method

Time of sowing

Four barley varieties which possess major genes (ineffective) and APR genes were sown at three sowing dates (27 April, 12 May and 25 May) in 10m X1.54 m plots at Esperance Downs Research Station, Gibson. The trial design was strip plot with four replications. The varieties used and their leaf rust resistance genes present are shown in Table 1.

Table 1. Leaf rust response and disease resistance genotypes of barley varieties used in date of sowing studies at Gibson, fungicide timing studies at North Woogenellup and fungicide efficacy trials at Gnowellen 2017.

Variety	♣Rust responses	Rust resistance genotypes	
		APR gene	Major gene
Flinders	MRMS	*Rph20*	*Rph12+*
Granger	R	*Rph20*	*Rph3+*
LG Maltstar	MS	*Rph20*	*Rph3*
La Trobe	S		*Rph9.am*
Oxford	MR	Rph20 & Rph24	*Rph3*

Note: MR = moderately resistance; MS = moderately susceptible; S= susceptible
+ = indicates the presence of an uncharacterised resistance gene in addition to known genotype

♣ Source 2018 Barley variety sowing guide for Western Australia; protected under the Plant Breeders Rights Act 1994

Fungicide timing

Fungicide timing studies with Flinders (malt) barley

Untreated Flinders barley was sown as a strip at 80kg/ha on 8 May 2017 on to canola stubble using the farmer's air seeder at North Woogenellup. The strip was 13m wide and 100m long and subsequently pegged to create 5m by 10m plots for foliar fungicide spraying. Except for untreated control plots, the middle of the each plot (2m wide and 10m long) was sprayed with fungicide mixture of 75g/L azoxystrobin and 75g/L epoxiconazole (Radial®) at different growth stages commencing from early tillering growth stage Z22, (Zadok's), up to ear emergence complete (Z59) as shown in the Table 4.

Weeds were controlled using knockdown (glyphosate, Ester®, Garlon®, and Ally®) and pre-planting (Logran®,Treflan™, Trilallate 500 EC,and Metolachlor 960) herbicides. Aphids were controlled by using Dominex® at 125mL/ha. Basal MAP-MOP at 100kg/ha was drilled with the seed. N was applied as urea (46% N) at 100kg N/ha.

Foliar and at-seeding fungicide efficacy on Oxford (feed) barley

A series of experiments were conducted in 2017, at Gnowellen on the south coast of WA. Barley variety Oxford was sown at 75kg/ha on 6 June onto 2016 Oxford stubble using a farmer's air seeder. Sakura® at 120g/ha was applied pre-emergence and Tigrex® at 200mL/ha was applied post emergence for weed control. A basal K till Extra at110kg/ha was placed (drilled) with the seed. N was applied as urea (46% N) at 80kg N/ha. Aphids were controlled with Dominex® at 125mL/ha.

At seeding and foliar applied treatments - Three pre-sowing fungicide treatments were tested; Untreated Oxford seed, seed dressing fungicide Systiva® (333g/L fluxapyroxad) at 150mL/100kg seed and Uniform® (322g/L azoxystrobin) and 124g/L metalaxyl-M) applied with fertiliser as an in-furrow treatment. Treatments were sown in alternate 13m wide and 50m long strips which were subsequently pegged to create 13m by 10m plots for foliar fungicide spraying fungicide mixture of 75g/L azoxystrobin and 75g/L epoxiconazole (Radial®) @ 420mL/ha at Z31 & Z45). The trial design was strip plot with 3 replications.

Foliar fungicide products – In 13m wide x 50m long strips of untreated Oxford barley (as above), 5mX10m plots were pegged and the middle 2m width of the each plot sprayed with foliar fungicide. Registered and unregistered foliar fungicide mixtures were applied; application rates and timings are shown in Table 2. Prosaro® was applied as second spray to all the plots at the swollen boot growth stage (Z45) except for untreated control plots.

Disease assessment and harvesting

Diseases developed naturally. Ten plants per plot were selected at random and the percentage leaf area diseased (%LAD) on the three youngest fully emerged leaves was estimated at bi-weekly intervals. GenStat 16th Edition was used to analyse the data. To reduce the variance in the % leaf area diseased, the data was analysed after angular transformation.

Grain yields were measured by machine harvesting grain from the middle 6 rows in December. Subsamples of the harvested grain were collected to measure grain brightness, % grain <2.5mm (known locally as screenings), % protein and hectolitre weight. These latter measurements were undertaken by Co-operative Bulk Handling (CBH) Ltd., Australia.

Table 2. Foliar fungicide products, active ingredients, rates used and growth stage at application at Gnowellen, 2017.

Fungicide	Active constituents	Rate (mL/ha)	Growth stage (Zadok)
Radial®	75g/L azoxystrobin and 75g/L epoxiconazole	420	27, 34
♣Prosaro® 420SC	210g/L prothiconazole and 210g/L tebuconazole	150	31, 45
Tilt® 250EC	250g/L propiconazole and 630g/L hydrocarbon	500	34
Product 1#	75g/L bixafen and 150g/L prothioconazole	500	34
Product 2#	41.6g/L epoxiconazole and 66.6g/L pyraclostrobin and 41.5g/L fluxapyroxad	750	34

♣Prosaro sprayed with 1% v/v Hasten ® Registered trademark
Product 1 and product 2 not registered for this use.

Results

Time of sowing

Table 3. Leaf rust disease severity and yield responses of four barley varieties to different times of sowing and foliar fungicide***** timings at Gibson, 2017.

Variety	Foliar spray timing	Time of sowing					
		% leaf area rusted average Flag -1 to Flag -3 at Grain Filling (19 Sept)			Grain yield (t/ha)		
		TOS 1 (27 April)	TOS 2 (12 May)	TOS 3 (25 May)	TOS 1	TOS 2	TOS 3
Flinders	Nil	91.2	73.1	23.0	3.15	3.29	4.58
	Z31	48.4	33.5	4.8	5.07	5.11	5.71
	Z31 + 3 wks	42.3	24.1	0.0	5.30	5.86	6.04
Granger	Nil	43.0	28.9	9.7	5.55	5.80	5.86
	Z31	28.1	15.4	4.5	5.81	5.96	5.96
	Z31 + 3 wks	27.5	10.9	0.2	5.99	6.24	5.97
Maltstar	Nil	89.0	66.5	21.1	3.51	4.21	4.78
	Z31	36.6	28.5	7.8	5.27	5.83	5.96
	Z31 + 3 wks	39.8	8.9	0.6	5.87	6.75	6.48
LaTrobe	Nil	47.4	30.3	7.6	5.25	5.95	5.88
	Z31	30.7	18.2	3.9	5.70	6.12	6.08
	Z31 + 3 wks	35.4	12.8	0.0	5.73	6.35	6.28
ANOVA		p-value	lsd (5%)		p-value	lsd (5%)	
	TOS	<.001	6.57		0.025	0.41	
	Variety	<.001	3.42		<.001	0.20	
	Foliar Fung	<.001	1.92		<.001	0.14	
	Ffung.V	<.001	4.41		<.001	0.26	
	Var.TOS	<.001	7.18		<.001	0.43	
	Ffung.TOS	<.001	6.75		0.013	0.42	
	V.Ffung.TOS	<.001	8.74		0.279	0.52	

Note: *****Prosaro® 420 SC @ 150 mL/ha with 1% v/v Hasten

Leaf rust dominated this trial, there was very little spot-type net blotch (STNB) present. Disease levels decreased with later times of sowing (TOS) and fungicide applications (Table 3).

Leaf rust appeared at stem elongation (<1% leaf area diseased). Flinders and Maltstar had higher levels of infection than Granger and La Trobe at all stages through to grain filling. Each two week delay in sowing significantly (<0.001) reduced disease levels; and the efficacy of fungicide applications improved with later times of sowing, probably as there was less rust present to control. When sown in late May (TOS 3) disease levels at grain filling were kept sufficiently low (5% leaf area diseased or less) from just one fungicide application at Z31 for the varieties Flinders, Granger and La Trobe. However, at the two earlier times of sowing (which are more common) two fungicide applications were required to control leaf rust levels (Table 3).

There were significant increases in plant establishment by TOS which prevents direct yield comparisons across them. Within each TOS, the grain yield of Maltstar consistently increased with dual fungicide applications, LaTrobe yields did not change with the application of a second fungicide at flag leaf stage and the responses of Flinders and Granger were mixed - only TOS 2 showed any increase in grain yield with a second fungicide. There was a significant effect of fungicide on straw strength with lodging in untreated Flinders and Maltstar not occurring in fungicide treated plots (data not shown). There was no head loss in this trial.

Foliar fungicide improved some grain quality characteristics (data not shown); 2.5mm screenings were reduced with fungicide application at all times of sowing although Granger and LaTrobe had low levels (<5%) while Untreated TOS 1 of Flinders and Maltstar had higher levels (18% and 22%) which decreased with sowing date. Grain brightness improved with later sowing but fungicide had no consistent effect; Flinders was the brightest while Granger the least. Hectolitre weight also increased with date of sowing and fungicide applications in Flinders and Maltstar also resulted in higher test weights. Protein levels decreased with TOS as grain yields increased. Maltstar had notably lower protein levels than other varieties (10.5% vs the trial average of 11.4%).

Fungicide timing studies with Flinders (malt) barley

Table 4. Effects of foliar fungicide spray on leaf rust, and yield and quality on Flinders barley at North Woogenellup, 2017.

Treatments	Z83 (4 Oct) % leaf area diseased (Leaf rust) average Flag to F-2	Yield (t/ha)	Protein (%)	Screenings (% <2.5mm)	Hectolitre Weight (kg/L)	Colour (NIR*)
Untreated	96.2a	2.83a	10.9a	33.7a	61.4a	55a
Radial® @ 420 ml/ha spray at Z22 & Z24	96.0a	3.37b	10.1ab	22.0b	61.8a	55a
Radial® @ 420 ml/ha spray at Z59	65.9b	3.41b	10.4b	9.2c	65.2b	56b
Radial® @ 420 ml/ha spray at Z39 & Z59	44.7c	4.99c	10.3b	10.0c	64.9b	57c
Radial® @ 420 ml/ha spray at Z32 & Z39	38.5c	5.31c	9.5c	6.6c	64.7b	56b
p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
lsd 5%	10.5	0.3	0.4	4	0.8	0.5

Note: values with same letter in each column are not significant at $p = 0.05$ level, NIR*L= near infrared

At the Woogenellup site, net-type net blotch and leaf rust were evident in trace levels on 5 July at the early tillering growth stage (Z21). Net type net blotch did not progress in later growth stages, presumably due to environmental conditions not being conducive for disease development and leaf rust was the main disease at the site. Disease assessments were done at Z21, Z33, Z41 and Z89. At early stem extension growth stage (Z33, 11 Aug), the disease severity on the top three open leaves was 3% on the control (untreated) which was greater than 0.6% on the Z22 (28 June) spray treatment (data not shown). At flag leaf sheath extending (Z41 growth stage, 30 Aug) there were treatment differences between untreated and foliar fungicide applications (data not shown), the leaf rust severity on top open four leaves varied from 40% in the untreated, 19% on multiple spray at Z22 and Z24 and 20% on multiple spray at Z32 and Z39. In addition to sporulating lesions, infection related leaf necrosis was seen at late stem elongation growth stage. At early dough stage (Z83), disease severity on top three leaves varied from 39% (multiple sprays at Z32 and Z39) to 96% (untreated), Table 4. The dual spray treatments incorporating Z39 application (Z32 + Z39 or Z39 + Z59) reduced the leaf rust compared to rest of the treatments. No treatment differences were observed with the untreated and foliar fungicide spray at Z22 and follow up at Z24.

Grain yield varied from 2.8t/ha (untreated) to 5.3t/ha (multiple fungicide sprays at Z32 and Z39), Table 4. The dual spray treatments incorporating Z39 application (Z32 + Z39 or Z39 + Z59) increased the yield by 76% compared to the untreated and approximately 57% compared to the other spray application treatment. Protein varied from 9.5% (multiple sprays at Z32 and Z39) to 10.9% (untreated). Foliar fungicide spray at Z32 with a follow up spray at Z39 reduced protein compared to rest of the treatments and was within the malting grade. Screenings varied from 6.6% (two sprays at Z32 and Z39) to 33.7% (untreated). Foliar fungicide multiple spraying at Z22 and Z24 and the untreated treatment were higher than the other treatments. Hectolitre weight varied from 61.4kg/L to 65.2kg/L and colour 55 to 56 (Table 4). According to the 2017/18 barley receival standards, dual spray treatments incorporating Z39 application (Z32 + Z39 or Z39 + Z59) achieved malt grade however untreated and Z22 & Z24 fungicide treatments did not.

At seeding and foliar applied treatments on Oxford (feed) barley

At the Gnowellen site net-type net blotch and leaf rust were seen early (pre-stem extension), but the predominant disease later in the season was leaf rust. Net-type net blotch was seen in untreated plots at the early tillering growth stage (Z21, 5 July) and leaf rust started to appear at late tillering (Z29, 17 Aug). At mid stem elongation growth stage (Z34, 7 Sept) net-type net blotch severity varied from 0.07% (Systiva) to 0.6% (untreated) on top three leaves and leaf rust varied from 3.1% (Systiva) to 4.9% (untreated). Systiva seed treatment reduced both diseases compared to the in-furrow and untreated treatments (Table 5).

Grain yield varied from 3.3 to 3.4t/ha and treatment differences were not significant (Table 5).

Table 5. Effects of seed dressing and in-furrow fungicides in control of leaf rust and net-type net blotch and yield of Oxford barley, Gnowellen, 2017.

Treatments	% leaf area diseased (open top three leaves) Z34 (7 Sept)		Yield
	net-type net blotch	leaf rust	(t/ha)
Untreated	0.61a	4.9a	3.4
Uniform® @ 300 mL/ha (in-furrow)	0.45a	4.5a	3.35
Systiva® @ 150 mL/100 kg seed	0.07b	3.1b	3.34
p	0.007	0.004	0.967
lsd (5%)	0.38	0.85	ns

Note: values with same letter in each column are not significant at *p* = 0.05 level

Response to foliar fungicide spraying timing on net-type net blotch and leaf rust and yield responses are shown in Table 7. At ear emergence growth stage (Z53), net type net blotch severity on the top four leaves varied from 0.4% (two fungicide spray) to 3.3% (untreated). Fungicide responses were significant compared to untreated control but there was no difference between a single fungicide spray at Z45 and two sprays at Z31 and Z45.

Leaf rust severity varied from 0.4 to 20.5 per cent and applications of fungicide reduced the disease compared to the untreated control, with no difference between one and two spray treatments (Table 6).

Grain yield responses varied from 2.1 to 4.2 t/ha and application of foliar fungicide spraying increased yield by 74% to 100% depending on the timing and number of spray applications(Table 6).

Table 6. Effects of foliar fungicide timing in control of net type net blotch and leaf rust and yield of Oxford barley at Gnowellen, 2017.

Treatments	% leaf area diseased Z59 (10 Oct) average. Flag to Flag-3		Yield
	net-type net blotch	leaf rust	(t/ha)
Untreated	3.3a	20.5a	2.13a
Radial® @ 420 mL/ha at Z45	1.2b	1.0b	3.71b
Radial® @ 420 mL/ha at Z31 & Z45	0.4b	0.4b	4.25b
p	0.017	<0.001	<0.001
lsd (5%)	1.9	2.1	0.558

Note: values with same letter in each column are not significant at *p* = 0.05 level

Interactions between early protection (seeding and in-furrow fungicide) and subsequent post protections (foliar fungicide) against leaf rust were significant (data not shown). Systiva seed dressing provided reduction of leaf rust severity past head emergence (10.5% compared to Untreated 24.7% and Uniform 26.2%), however this was not as effective as either the single or double foliar fungicide application and was not reflected by yield (data not shown).

Efficacy of foliar fungicide products against leaf rust on Oxford barley

Foliar fungicide products containing mixtures of fungicide active ingredients were used to evaluate their performance against leaf rust and results are shown in Table 7. All the fungicide foliar treatments reduced both leaf rust and net-type net blotch and increased the yield by between 40-80% compared to the untreated control.

Table 7. Effects of foliar fungicide sprays on leaf rust severity and grain yield in Oxford barley at Gnowellen, 2017.

Treatments	% leaf area diseased at Z83 (17 Oct) (average. Flag to Flag-2)		Yield
	leaf rust + necrosis	net-type net blotch	(t/ha)
Untreated	54.4a	6.6a	2.93a
Radial® at Z27 &Tilt at Z34 & ♣Prosaro® at Z45 (Control)	5.8b	3.6b	4.57bc
Radial® at Z34 & Prosaro® at Z45	5.7b	5.4b	4.55b
Prosaro® at Z31 & at Z45	5.4b	4.7b	4.12b
Product 2 at Z34 & Prosaro® at Z45	3.5b	1.5b	5.15c
Product 1 at Z34 & Prosaro® at Z45	2.8b	1.3b	5.30c
p	<0.001	0.01	<.001
lsd (5%)	7.26	2.985	0.842

Note: values with same letter in each column not significant at $p = 0.05$ level; ♣Prosaro sprayed with 1% v/v Hasten

Conclusion

Barley leaf rust needs a living host to survive and spread into next season's crop. In a situation where growers are reluctant to control the green bridge, mainly due to relying on the summer regrowth including barley as feed for sheep and cattle, they need to find solutions for barley leaf rust control. Selecting a variety with resistance against a particular disease in an environment which is conducive to develop epidemics is the cheapest option to grow a crop. A particular variety can possess full protection when major genes are present or partial resistance where minor genes are present against the disease.

Since the breakdown of the major gene *Rph3* against leaf rust, growers are relying on barley varieties which possess partial resistance. These varieties (e.g. Granger, Oxford, Maltstar, Flinders) carry either *Rph20* or *Rph24* or both and are less susceptible to leaf rust (range from MS to MR) than varieties without effective major genes or APR genes (e.g. Bass, Compass, Hindmarsh). The onset and efficacy of APR can be variable, depending on the variety the genes are deployed in, the environment the variety is growing in and the disease pressure present. Conventional approaches suggest that use of fungicide to support APR varieties at early growth stages may provide sufficient protection, however variability of response in WA southern regions has created confusion among the growers as to when to spray APR varieties.

Trials conducted in the 2017 season show that despite having APR genes present, several varieties (e.g. Flinders, Oxford, Maltstar) are still significantly affected by leaf rust infection, both as sporulating pustules and as necrosis associated with APR expression. Fungicide application provides substantial reduction in disease severity (and leaf necrosis), retains green leaf area and provides a subsequent yield response in these varieties. Despite having APR, under high disease pressure the optimum timing of fungicide comprised dual applications including incorporating one application around flag leaf-booting. While seed dressing, in-furrow and tillering foliar fungicides all reduced disease pre-flag, the impact of these treatments was not enduring even with the onset of APR.

Integrated disease management (IDM) principles should be used which include green bridge control, varietal selection, time of sowing, seed dressings, in-furrow fungicides and foliar fungicides coupled with careful monitoring of disease progress to optimise management intervention.

Key words

Barley, leaf rust, APR varieties, fungicides

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