GUNNEDAH
NSW
FRIDAY 13
AUGUST 2021

GRAINS RESEARCH UPDATE

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GRDC 2021 Grains Research Update Welcome

Welcome.

We at the GRDC understand how challenging the past year has been for all Australians, but we also appreciate how well positioned agriculture has been to respond to and work through the restrictions that have come with this global pandemic.

Across many areas of Queensland and New South Wales, an improvement in seasonal conditions has also provided a much-needed reprieve for growers, advisers, agronomists, researchers and those associated with the grains industry.

With that positive change in circumstances comes a thirst for the latest information and advice from grains research and development – we trust that these GRDC Grains Research Updates will help guide your on-farm decisions this season and into the future.

While COVID-19 has forced temporary changes to our traditional Update locations and audience numbers, these events still offer the high quality, seasonally relevant research, development and extension information you have come to depend on.

We would like to take this opportunity to thank our many research partners, who, like growers and advisers, have gone over and above to continue to work in situations constricted by COVID-19 regulations.

Challenging times reinforce the importance of rigorous, innovative research that delivers genuine gains on-farm. For more than a quarter of a century the GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of the industry.

Sharing the results from this research is a key role of the annual Updates, which are the premier event on the northern grains industry calendar and bring together some of Australia’s leading grains research scientists and expert consultants.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers.

For the past five years we have been doing that from regional offices across the country. Through the northern region offices in Wagga Wagga and Toowoomba and a team of staff committed to connecting with industry, we are now more closely linked to industry than ever.

This year we have less people on the ground – as a result of COVID-19 restrictions – but more than ever we are available to listen and engage with you. So if you have concerns, questions or feedback please contact our team directly (details on the back of these proceedings) or email northern@grdc.com.au.

Regards,
Gillian Meppem
Senior Regional Manager – North

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GRDC Grains Research Update GUNNEDAH

Friday 13 August 2021

Gunnedah Shire Band Hall, South St, Gunnedah

Registration: 8:30am for a 9am start, finish 2:50pm

AGENDA

Time	Topic	Speaker(s)
9:00 AM	**GRDC welcome**	
9:10 AM	**Managing crown rot in the farming system** - crop sequence, varieties, agronomy, interactions with common root rot and new seed treatment technology	Steve Simpfendorfer (NSW DPI)
9:50 AM	**Chickpea Ascochyta Update**	Kevin Moore (NSW DPI) & Hayley Wilson (NSW DPI)
10:30 AM	**Morning tea**	
11:00 AM	**Managing mice** • Baiting and management strategies • Population ecology - how long can plagues last and why?	Steve Henry (CSIRO)
11:40 AM	**Canola harvest management**	Maurie Street (Grain Orana Alliance)
12:10 PM	**Lunch**	
1:00 PM	**Managing upper canopy blackleg and sclerotinia in lower and medium rainfall western canola crops**	Maurie Street (Grain Orana Alliance)
1:30 PM	**Summer crop choice in the farming system**	Steve Simpfendorfer (NSW DPI)
2:00 PM	**Early sown sorghum and WUE efficiency**	Loretta Serafin (NSW DPI)
2:30 PM	**Panel discussion: Implications and plans for country that was too wet to sow winter cereal**	Mike Bange (GRDC, facilitator) Peter McKenzie (Agricultural Consulting & Extension Services) Jim Hunt (Hunt Ag Solutions)
2:50 PM	**Close**	

Contents

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Fusarium crown rot seed fungicides: independent field evaluation 2018-2020

Steven Simpfendorfer, NSW DPI Tamworth

Keywords

fungicide seed treatments, yield loss, wheat, barley, durum, disease

GRDC code

DAN00213: Grains Agronomy & Pathology Partnership (GAPP) - A strategic partnership between GRDC and NSW DPI (Project BLG208) and DAN00175: National crown rot epidemiology and management program.

Take home messages

- Current fungicide seed treatments registered for the suppression of Fusarium crown rot (FCR) inconsistently reduce the extent of yield loss from FCR
- Syngenta® experimental (Tymirium™ technology) had consistent and stronger activity on limiting yield loss from FCR
- However, under high infection levels significant yield loss may still occur in drier seasons
- Fungicide seed treatments, including the Syngenta experimental, should not be considered standalone control options for FCR
- Seed treatments should be used as an additional tool within existing integrated disease management strategies for FCR.

Introduction

Fusarium crown rot (FCR), caused predominantly by the fungal pathogen *Fusarium pseudograminearum* (*Fp*), is a major constraint to winter cereal production across Australia. A range of integrated management strategies, including crop rotation, varietal selection, inter-row sowing, sowing time, stubble and fallow management are required to minimise losses. A number of fungicide seed treatments have been registered for the suppression of FCR in recent years with a further product from Syngenta likely to be available to Australian growers prior to sowing in 2023. Although chemical companies conduct their own widespread field evaluation across Australia, growers and their advisers value independent evaluation of the potential relative fit of these fungicide seed treatments within integrated management strategies for FCR.

What we did

A total of 11 replicated plot experiments (generally 2 x 10 m with minimum of 3 replicates) were conducted across NSW from 2018-2020 with one additional field experiment conducted in Victoria (Horsham) and two in WA (Merredin and Wongan Hills) in 2018 only (Table 1). The winter cereal crop and number of varieties differed between experiments with wheat (W), barley (B) and/or durum (D) evaluated in each experiment (Table 1).

Six fungicide seed treatments: Nil, Vibrance® (difenoconazole + metalaxyl-M + sedaxane at 360 mL/ 100 kg seed), Rancona® Dimension (ipconazole + metalaxyl at 320 mL/100 kg seed), EverGol®Energy (prothioconazole + metalaxyl + penflufen at 260 mL/100 kg seed) and Syngenta experimental (Tymirium™ technology based on cyclobutrifluram at 40 and/or 80 g active ingredient/100 kg seed). All fungicide seed treatments were applied in 1 to 3 kg batches using a small seed treating unit to ensure good even coverage of seed.

All field experiments used an inoculated vs uninoculated randomised complete block design with inoculated plots infected by *Fp* inoculum grown on sterilised wheat grain added at 2.0 g/m of row at sowing. This ensures high (>80%) FCR infection in inoculated plots with uninoculated plots only exposed to any background levels of *Fp* inoculum naturally present across a site. This design allows comparison between the yield effects of the various fungicide seed treatments in the presence and absence of FCR. Yield loss from this disease is measured as the difference between inoculated and uninoculated treatments.

What did we find?

Lower levels of in-crop rainfall between March and September generally lowered the yield potential at each site in each season, but also increased the extent of FCR yield loss. This was highlighted in the nil seed treatments where yield loss ranged from 11 to 48% in 2018, 14 to 20% in 2019 and 11 to 37% in 2020 (Table 1).

Table 1. Effect of various fungicide seed treatments on yield loss (%) associated with Fusarium crown rot infection in 14 replicated inoculated vs uninoculated field experiments – 2018 to 2020

Year	Location	Crop[A]	Rainfall[B] (mm)	Yield[c] (t/ha)	%Yield loss from Fusarium crown rot[D]					
					Nil	Vibrance	Rancona Dimension	EverGol Energy	Syngenta 40 gai[E]	Syngenta 80 gai[E]
2018	Merriwagga, NSW	2W	63	1.44	44	nd[F]	nd	32	25	18
	Mallowa, NSW	2W	73	1.73	48	nd	nd	nd	26	24
	Gilgandra, NSW	2W	93	2.14	42	35	27	28	16	9
	Merredin, WA	2W	182	2.66	35	nd	nd	nd	23	13
	Horsham, Vic	2W	185	2.56	21	nd	nd	nd	+2[I]	+5
	Wongan Hills, WA	2W	291	3.27	11	nd	nd	nd	1	0
2019	Gulargambone, NSW	W/B	141	3.12	20	2	5	9	-[G]	+2
	Narrabri, NSW	W/B	200[H]	4.01	14	10	9	7	-[G]	6
2020	Boomi, NSW	3W/D	202	4.91	37	nd	28	nd	24	18
	Gurley, NSW	W/B	234	6.50	13	nd	nd	nd	-	1
	Rowena, NSW	W/B	247	6.21	12	7	nd	4	-	2
	Trangie, NSW	3W/D	412	4.13	26	20	23	19	4	2
	Gilgandra, NSW	3W/D	420	4.07	12	6	7	7	3	0
	Armatree, NSW	3W/D	425	4.37	11	nd	nd	7	3	+1

[A] Winter crop type variety numbers where W = wheat variety, B = barley variety and D = durum variety.

[B] Rainfall in-crop from March to September at each site. Critical time for fungicide uptake off seed and expression of FCR.

[C] Yield in uninoculated treatment (average of varieties) with nil seed treatment.

[D] Average percentage yield loss from FCR for each seed treatment (averaged across varieties) compared with the uninoculated/nil seed treatment.

[E] gai = grams of active ingredient.

[F] nd = no difference, %yield loss from FCR with fungicide seed treatment not significantly different from the nil seed treatment. Values only presented when reduction in %yield loss from FCR significantly lower than the nil seed treatment.

[G] 40 gai treatment not included at these sites.

[H] Included two irrigations at GS30 and GS39 of 40 mm and 30 mm respectively due to drought conditions.

[I] Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (i.e. the treatment reduced impact from both the added FCR inoculum as well as natural background levels of fusarium present at that site.)

Vibrance and Rancona Dimension significantly reduced the extent of yield loss from FCR in 6 of 14 experiments whilst EverGol Energy reduced FCR yield loss in 8 of 14 field trials (Table 1). However, the Syngenta experimental product significantly reduced yield loss from FCR in 10 of 10 trials at the 40 gai rate and 14 of 14 field experiments at the 80 gai rate (Table 1). The reduction in yield loss was also generally stronger with this product compared with the other fungicide seed treatments and better at the 80 gai than 40 gai rate (Table 1).

Significant yield loss (9 to 26%) still occurred with the Syngenta experimental treatment at generally drier sites which exacerbated yield loss from FCR (>35% in nil seed treatment). However, the 80 gai rate at these 'disease conducive sites', still at least halved the extent of yield loss compared with the nil seed treatment (Table 1). At wetter sites where yield loss from FCR was lower (<26%) the Syngenta experimental reduced the extent of yield loss to <6% with a yield increase at some sites due to reduced impact from background levels of FCR infection (Table 1). Moisture stress during grain filling is known to exacerbate yield loss from FCR and favour the growth of *Fp* within the base of infected plants. Dry soil conditions around seeding depth throughout the season is also likely to restrict the movement of fungicide actives off the seed coat into surrounding soil and subsequent uptake by root systems. This would reduce movement of the fungicides into the sub-crown internode, crown and tiller bases where FCR infection is concentrated. It is currently not clear whether reduced efficacy under drier conditions may be related to one or both of these factors.

What about durum?

Durum wheat is known to have increased susceptibility to FCR compared with many wheat and barley varieties. Consequently, the increased prevalence of FCR in farming systems with the adoption of conservation cropping practices, including retention of cereal stubble, has seen durum removed from rotations due to this increased disease risk. The durum variety DBA Lillaroiⓓ was compared with three bread wheat varieties at four sites in 2020 (Table 2).

Table 2. Effect of Syngenta experimental seed treatment at two rates on the extent of yield loss[A] (%) from Fusarium crown rot in three bread wheat (W) and one durum (D) variety at three sites in 2020

Variety	Boomi 2020			Trangie 2020			Gilgandra 2020			Armatree 2020		
	Nil[B]	Syngenta 40 gai	Syngenta 80 gai	Nil	Syngenta 40 gai	Syngenta 80 gai	Nil	Syngenta 40 gai	Syngenta 80 gai	Nil	Syngenta 40 gai	Syngenta 80 gai
Lancerⓓ (W)	29	23	20	30	10	8	13	2	0	9	4	+7[C]
Mitchⓓ (W)	39	18	11	13	+2	+5	9	2	1	5	0	0
Trojanⓓ (W)	34	22	18	20	4	2	12	1	0	14	2	2
Lillaroiⓓ (D)	48	32	24	45	11	6	16	5	+2	14	6	+2

[A] Average percentage yield loss from FCR for each seed treatment compared with the uninoculated/nil seed treatment for that variety.

[B] Nil = no seed treatment.

[C] Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (i.e. the treatment reduced impact from both the added FCR inoculum as well as natural background levels of fusarium present at that site).

The extent of yield loss from FCR with nil seed treatment was generally higher in the durum variety (14 to 48%) compared with the three bread wheat varieties (5 to 39%). With the exception of the Boomi site, the wheat variety Mitchⓓ tended to have reduced yield loss from FCR compared with the other entries (Table 2). Yield loss from FCR was reduced with the Syngenta experimental in both the bread wheat and durum varieties (Table 2). Even in the higher loss site at Boomi in 2020, the 80 gai rate halved the extent of yield loss in the durum variety Lillaroiⓓ with better efficacy in the other three sites.

Conclusions

Current fungicide seed treatments registered for the suppression of FCR can inconsistently reduce the extent of yield loss from this disease. The Syngenta experimental (Tymirium technology) appears to have more consistent and stronger activity on limiting yield loss from FCR. However, under high infection levels, as created with artificial inoculation in these experiments, significant yield loss may still occur, particularly in drier seasons. Dry soil conditions around seeding depth throughout a season may reduce the uptake of fungicide actives applied to the seed coat. Drier seasons also exacerbate FCR expression which would place additional pressure on fungicide seed treatments. Consequently, fungicide seed treatments, including the Syngenta experimental, should not be considered standalone control options for FCR. Rather, they should be used as an additional tool within existing integrated disease management strategies for FCR.

Acknowledgements

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Fungicide resistance in wheat powdery mildew across NSW and northern Victoria in 2020

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[2] Centre for Crop Disease Management, Curtin University Perth

Keywords

fungicide resistance, reduced sensitivity, disease, varietal resistance, management

GRDC code

DAN00213: Grains Agronomy & Pathology Partnership (GAPP) - A strategic partnership between GRDC and NSW DPI (Project BLG208) and CUR1905-001SAX

Take home messages

- The wheat powdery mildew pathogen has a very high risk of developing fungicide resistance
- Resistance to Group 11 (QoI) fungicides has been detected across most of the southern growing region and was detected in parts of NSW in 2020
- Widespread resistance or reduced sensitivity to Group 3 DMIs is considered an extremely high risk and a DMI ‘gateway’ mutation was detected at very high frequency across NSW and northern Victoria in 2020
- Careful use and rotation of available fungicide actives will help control the spread of resistance in wheat powdery mildew
- Agronomic practices that minimise disease pressure reduce the need to apply fungicides
- Good management will help protect the long-term efficacy of current fungicides.

Introduction

A key challenge in 2020 winter cropping season was the level of wheat powdery mildew (WPM), caused by *Blumeria graminis* f. sp. *tritici* (*Bgt*), across much of NSW and northern Victoria. High mineralised soil nitrogen levels following 2-3 years of drought favoured thick canopies and elevated leaf nitrate levels which favour WPM infection. WPM infections progressed into heads late in the season in some regions. Infection occurred in a range of bread wheat and durum varieties, especially Scepterᶲ and Vixenᶲ (Table 1) which are susceptible-very susceptible (SVS) to WPM and grown widely across the affected regions. WPM occurred predominantly in high-value, irrigated cropping regions, which create ideal conditions for disease development but was also prevalent in a number of dryland crops in the wet 2020 season. There were concerns around fungicide management with less than desirable control achieved. Factors contributing included:

- potentially reduced fungicide sensitivity and/or resistance in the pathogen,
- application timing - i.e., too much time between stripe rust fungicide timings to cope with the quicker cycle time and rapid infection that occurs with WPM and/or,
- spray coverage, especially of heads, which are a horizontal target.

Many crops had 2-4 in-crop fungicide applications during the season, yet WPM continued to progress. *Bgt* has a remarkable ability to adapt to fungicide treatments, which makes this pathogen a high resistance risk for the development of fungicide resistance.

In response, a collaboration with the Centre for Crop Disease Management (CCDM) based at Curtin University in WA was rapidly established to collect and analyse WPM samples for levels of fungicide resistance.

Wheat powdery mildew is favoured by susceptible wheat varieties growing in mild and humid weather (15° to 22°C, relative humidity > 70%), with a dense crop canopy, high nitrogen levels, good soil moisture profiles and extended periods of damp, humid conditions under the canopy. *Bgt* survives on wheat stubble and volunteer wheat plants. Spores can be spread to crops by the wind over moderate distances (kilometres). The pathogen is crop specific and only infects wheat, not barley or other grain crops.

What we did

WPM samples were collected by collaborating agronomists, sent to Tamworth for processing to help ensure viability in transit and sent to CCDM for molecular analysis of frequency of mutations for DMI (F136 'gateway' mutation, triazoles) and QoI (A143 mutation, strobilurins) resistance within the WPM population in each sample. Nineteen viable WPM samples were analysed by CCDM from across NSW and northern Victoria, with sample distribution being; NE Vic (4), SE NSW (5), SW NSW (8), NE NSW (1) and NW NSW (1)(Table 1). Further laboratory and glasshouse testing is continuing with CCDM to determine the relative sensitivity of these WPM populations to various DMI actives.

What we found

The F136 mutation, also known as a 'gateway', has been previously associated with reduced sensitivity to some DMI (Group 3, triazole) fungicides. This mutation is normally found together with other mutations that are ultimately responsible for the resistant phenotype observed in the field. Once the frequency of the F136 and other mutations in a WPM pathogen population reach moderate levels, then reduced sensitivity to DMI fungicides is possible under field conditions. Very high frequencies may result in resistance to WPM and spray failure under field conditions with some DMI actives. The F136 'gateway' mutation itself does not necessarily mean field failure. It is however an initial warning that issues with continued DMI fungicide use exist. Field efficacy of DMI fungicides in the presence of this 'gateway mutation', can vary considerably with individual DMI actives, depending on what other mutations exist once this 'gateway' mutation occurs within a WPM population.

All 19 NSW/Vic WPM samples had a F136 frequency of between 62 to 100% (Table 1). Such a high frequency of DMI resistance across NSW/Vic was surprising but not unexpected given the lack of field control in these crops in 2020. A lower frequency of the QoI A143 muttaion was detected which ranged from 51 to 98% (Table 1). Presence of this mutation in the WPM pathogen population is associated with complete resistance to strobilurin fungicides (e.g., azoxystrobin) and can become ineffective under field conditions at frequencies above 50%. This is alarming, as four of the WPM pathogen populations appear to have dual resistance to DMI (Group 3) and QoI (Group 11) modes of action (MOA). The strobilurins are known to rapidly succumb to fungicide resistance, which is why they are always mixed with another MOA fungicide group (usually DMIs, Group 3). The high frequency of DMI F136 in NSW/Vic WPM pathogen populations is likely increasing the rate of selection for QoI resistance.

A concerning aspect in relationship to the QoI A143 resistance gene, is that it confers cross resistance to all fungicides within the group 11 mode of action group (strobilurins).

Table 1. Location of 19 wheat powdery mildew samples collected across NSW in 2020 and frequency of DMI (triazole) gateway and QoI (strobilurin) mutations

Location	State	Variety	DMI F136	QoI A143
Katamatite	NE Vic	Scepterᶲ	100%	90%
Katamatite	NE Vic	Scepterᶲ	100%	90%
Cobram	NE Vic	Scepterᶲ	100%	46%
Cobram	NE Vic	Scepterᶲ	100%	28%
Balldale	SE NSW	Scepterᶲ	100%	98%
Walbundrie	SE NSW	Scepterᶲ	100%	5%
Rennie	SE NSW	Suntopᶲ	85%	27%
Rennie	SE NSW	Scepterᶲ	85%	20%
Deniliquin	SW NSW	Scepterᶲ	99%	35%
Deniliquin	SW NSW	Scepterᶲ	99%	20%
Deniliquin	SW NSW	Scepterᶲ	83%	20%
Jerilderie	SE NSW	Scepterᶲ	100%	37%
Hillston	SW NSW	Vittaroiᶲ	96%	21%
Hillston	SW NSW	Vixenᶲ	94%	3%
Hillston	SW NSW	Vixenᶲ	85%	6%
Yenda	SW NSW	Cobraᶲ	100%	44%
Yenda	SW NSW	Vixenᶲ	100%	12%
Edgeroi	NE NSW	Lillaroiᶲ	82%	29%
Wee Waa	NW NSW	Bindaroiᶲ	62%	51%

Fungicide resistance terminology

To address the ‘shades of grey’ surrounding fungicide resistance and how it is expressed as a field fungicide failure, some very specific terminology has been developed.

When a pathogen is effectively controlled by a fungicide, it is defined as sensitive to that fungicide. As fungicide resistance develops, that sensitive status can change to:

- **Reduced sensitivity**
  When a fungicide application does not work optimally but does not completely fail.

  This may not be noticeable at field level, or the grower may find previously experienced levels of control require higher chemical concentrations up to the maximum label rate. Reduced sensitivity must be confirmed through specialised laboratory testing.

- **Resistance**
  When a fungicide fails to provide disease control in the field at the maximum label rate.

  Resistance must be confirmed by laboratory testing and be clearly linked to a loss of control when using the fungicide correctly in the field.
- **Lab detection**
  A measurable loss of sensitivity can often be detected in laboratory *in vitro* tests before or independent of any loss of fungicide efficacy in the field. Laboratory testing can indicate a high risk of resistance or reduced sensitivity developing in the field.

The Australian grains crop protection market is dominated by only three major mode of action (MoA) groups to combat diseases of grain crops; the DMIs (Group 3), SDHIs (Group 7) and strobilurins (or quinone outside inhibitors, QoIs, Group 11). Having so few MoA groups available for use increases the risk of fungicide resistance developing, as growers have very few alternatives to rotate in order to reduce selection pressure for these fungicide groups.

With two of the three fungicide MoA groups now compromised in some paddocks in New South Wales and Victoria, all growers and advisers need to take care to implement fungicide resistance management strategies to maximise their chances of effective and long-term disease control.

The Australian Fungicide Resistance Extension Network (AFREN), a GRDC investment, suggests an integrated approach tailored to local growing conditions. AFREN has identified the following five key actions, “The Fungicide Resistance Five”, to help growers maintain control over fungicide resistance, regardless of their crop or growing region:

1. Avoid susceptible crop varieties
2. Rotate crops – use time and distance to reduce disease carry-over
3. Use non-chemical control methods to reduce disease pressure
4. Spray only if necessary and apply strategically
5. Rotate and mix fungicides/MoA groups.

Managing fungicide resistance

It is important to recognise that fungicide use and the development of fungicide resistance, is a numbers game. That is, as the pathogen population increases, so does the likelihood and frequency of naturally resistant strains being present. A compromised fungicide will only control susceptible individuals while the resistant strains within the population continue to flourish.

As a result, it is best if fungicides are used infrequently and against small pathogen populations. That way, only a smaller number of resistant individuals will be present to survive the fungicide application, with many of these remaining vulnerable to other competitive pressures in the agro-ecosystem.

Keeping the pathogen population low can be achieved by taking all possible agronomic steps to minimise disease pressure and by applying fungicide at the first sign of infection once the crop has reached key growth stages. In cereals, the leaves that contribute most to crop yield are not present until growth stage 30 (GS30/start of stem elongation.) Foliar fungicides applied prior to this are more often than not a waste of money and unnecessarily place at risk the longevity of our cost-effective fungicide resources by applying an unneeded selection pressure on fungal pathogens for resistance.

Integrated management strategies

Management practices to help reduce disease pressure and spread include:

- **Planting less susceptible wheat varieties**
  Any level of genetic resistance to WPM slows the rate of pathogen and disease development within a crop and reduces the reliance on fungicides to manage the disease. Avoid growing SVS and VS wheat varieties in disease-prone areas.

- **Inoculum management**
  Killing volunteer wheat plants during fallow periods and reducing infected wheat stubble loads will reduce the volume of spores spreading into an adjacent or subsequent wheat crop.

- **Practicing good crop rotation**
  A program of crop rotation creates a dynamic host environment that helps reduce inoculum levels from year to year. Rotating non-susceptible wheat varieties can also provide a more dynamic host environment, forcing the pathogen to adapt rather than prosper.

- **Disease levels can be higher with early planting**
  Later planting can delay plant growth until after the initial warm and damp period of early winter that favours WPM. This is important as infection of young plants can lead to increased losses at maturity. Later sown crops also tend to develop smaller canopies which are less conducive to powdery mildew infection. However, delayed sowing can have an associated cost of reduced yield potential in some environments which should be carefully considered by growers.

- **Careful nitrogen management**
  As excess nitrogen favours disease development, nitrogen application should be budgeted to measured soil N levels and target yield so as to be optimised to suit the growing purpose.

- **Encouraging air circulation**
  Actions that help increase airflow into the crop canopy can help lower the relative humidity. This can include wider row spacing, reduced plant populations (note yield potential should still be maximised). In mixed farming systems grazing by livestock can be used to reduce and open up the early season crop canopy, with potential to reduce the level of disease inoculum present at commencement of stem elongation when the ‘money leaves’ start to appear.

Fungicide recommendations for wheat

Planning of fungicide rotations needs to consider all fungal pathogens that may be present in the crop. Otherwise the fungicide treatment for one pathogen may select for resistance in another. For example, whilst there is little evidence of the development of fungicide resistance in rust populations globally, growing S-VS rust varieties means the only control option is fungicides. This can potentially have off-target selection pressure on the development of other fungal pathogens such as *Bgt* which is very prone to developing fungicide resistance.

Careful fungicide use will minimise the risk of fungicide resistance developing in WPM in Australia and help ensure the longevity of fungicides.

Advice to NSW and Victorian wheat growers includes:

- **Avoid using Group 11** fungicides in areas where resistance to QoIs has been reported.

- **Minimise** use of the **Group 3** fungicides that are known to have compromised resistance.
- **Monitor Group 3** fungicides closely, especially where the gateway mutation has been detected.
- **Rotate Group 3** fungicide actives within and across seasons. In other words, do not use the same Group 3 product twice in succession.
- **Avoid** more than three applications of fungicides containing a **Group 3** active in a growing season.
- **Group 11** fungicides should be used as a preventive, rather than for curative control and should be rotated with effective **Group 3** products.
- **Avoid** applying **Group 7** and **Group 11** products more than once per growing season, either alone or in mixtures. This includes in-furrow or seed treatments, as well as subsequent foliar sprays. Combined seed and in-furrow treatments count as one application.

Growers and agronomists who suspect DMI reduced sensitivity or resistance should contact the CCDM's Fungicide Resistance Group at frg@curtin.edu.au. Alternatively, contact a local regional plant pathologist or fungicide resistance expert to discuss the situation. A list of contacts is on the AFREN website at grdc.com.au/afren.

Further information on fungicide resistance and its management in Australian grains crops is available at the AFREN website at grdc.com.au/afren.

Conclusions

NSW and Victorian growers need to be aware that issues with fungicide resistance already exist with WPM which could result in reduced fungicide sensitivity or potentially spray failures with DMI (triazoles) and QoI (strobilurin) fungicides. Further testing by CCDM is ongoing as to the level of reduced sensitivity to different DMI actives in these WPM pathogen populations, which will be communicated to growers and their advisers. Fungicide resistance is real and needs to be managed using an integrated approach to limit further development of fungicide resistance within WPM pathogen populations and in other at-risk fungal pathogens (e.g., net-blotches in barley and yellow spot or Septoria tritici blotch in wheat).

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ⓓ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Chickpea Ascochyta update

Kevin Moore and Hayley Wilson, NSW DPI

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Notes

Reducing the impact of mice at critical times of the year

Steve Henry, CSIRO

Key words

mouse plague, monitor stubbles, baiting, residual food

GRDC code

CSP1806-017RTX - Improved surveillance and management options for mice in crops
CSP1804-012RTX - Determining the effectiveness of zinc phosphide rodenticide bait

Take home message

- There is 3 weeks difference between a few mice and a big problem
- Reduce background or residual food to give mice the best chance of finding the bait
- Understand what is happening in your paddocks at critical times of the year for mice and be prepared to bait
- Monitor the effectiveness of your baiting activities.

Mice have been in high numbers in cropping and grazing systems since the start of spring 2020. Northern NSW and parts of southern Queensland have been particularly heavily impacted by the outbreak. Damage has been high in some areas with total losses of some summer crops reported, and loss and contamination of grain and fodder storages.

Mouse numbers are currently highly variable with reports of high numbers through some parts of the northern cropping zone. However, mouse activity has diminished in some areas with the onset of winter and the associated cessation of breeding. This is not cause for complacency, with the likelihood of an average or better than average winter crop, conditions will be favourable for mouse breeding in early spring.

Understanding the level of overwinter survival is critical to reduce mouse damage in the spring of 2021 and ongoing impacts in the summer and autumn of 2022.

Monitoring crops through winter will be critically important to understand mouse numbers. This knowledge will inform baiting activities to minimise damage in winter crops as they ripen in the spring and in the preparation for sowing summer crops in the northern part of the cropping zone and irrigated summer crops in the south.

Stubbles have potential to hide the signs of mouse activity. Walking multiple, 100 metre long by 1 metre wide transects to count active burrows is the best way to get an average estimate of active burrows per 100 square metres. Burrows per 100 square metres can then be multiplied to give burrows per hectare. Rules of thumb can then be applied to estimate of the number of mice per hectare.

Understanding the number of mice per hectare in combination with the rate of reproduction is important to understand the potential for population increase. Many grain producers would assume that they don't have a significant problem if they had 200 mice per hectare but if 100 of those mice give birth to six offspring every 3 weeks, 200 mice become a big problem very quickly.

These dramatic rates of increase, mean that understanding the number of mice in paddocks at the start of the breeding season in early spring as winter crops mature, and in the lead up to sowing, is vital to reducing the potential for damage at these critical times of the year.

In the lead up to sowing, management of residual food is important to improve the chance of effective bait application. Zinc phosphide bait (ZnP) is spread at 1 kilogram per hectare or 22,000 grains per hectare, which equates to three grains per square metre. Pre- and post-harvest grain losses result in significant supply of food for mice. Anecdotal reports of one tonne per hectare loss are not uncommon, resulting in 2,200 grains per square metre. If this residual food is present when bait is spread, it can be difficult for mice to find the bait, and the overall uptake of the bait could be reduced.

Through the stubble phase it is important to reduce the amount of residual food to enhance bait detection and uptake. Spraying out germinations reduces food and conserves soil moisture. If livestock are part of the farming system, use sheep to graze stubbles.

The results of recent laboratory studies undertaken by CSIRO in response to farmers concerns about the effectiveness of ZnP have led to the approval of an emergency permit for the manufacture, supply and use of ZnP bait with a mixing rate of 50 g ZnP/kg of bait. Field trials of this new formulation of bait undertaken in cropping systems near Parkes in central NSW have resulted in promising outcomes of the efficacy of the new bait formulation.

Monitoring stubbles and crops to understand mouse populations and timely action to control mice at critical stages of the stubble and the developing crop are critical to minimising the impact of mice.

Acknowledgements

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Was canola fungicide investment justified in low and medium rainfall environments in 2020?

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[1] Brill Ag
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Key words

canola, fungicide, Sclerotinia, upper canopy blackleg, Alternaria black spot, powdery mildew

GRDC codes

GOA2006-001RTX

Take home messages

- Return on investment was strong in only two of five trials, with both these trials being in the south and having higher levels of upper canopy blackleg (branch infection) as well as some Sclerotinia. Best return was from a single fungicide spray at 30% bloom stage
- Application at the recommended timings (30% and 50% bloom) were more likely to result in a yield benefit than an early application (10% bloom)
- Reduction in disease infection did not necessarily result in a positive grain yield response, similarly a positive grain yield response did not always increase profitability
- Overall, with modest yield responses in a high production year, money may be better invested in inputs with a more reliable return on investment.

Introduction

Application of fungicide to manage disease in canola, especially Sclerotinia and upper canopy blackleg (UCB) is a common practice in the higher rainfall, eastern and southern areas of the GRDC Northern Region, but there is little data on the cost-effectiveness in low and medium rainfall zones. In mid to late winter 2020 canola crops had high yield potential across much of the GRDC Northern Region. With forecasts for further rainfall for the spring period, many growers and advisors were considering the need for fungicide in areas where application is not common.

In response Grain Orana Alliance (GOA) and Brill Ag established five canola fungicide response trials through southern and central NSW to determine the response to fungicide in low and medium rainfall environments in a high yield potential season. The trials tested several fungicide products and their timing. The trials were assessed for the common diseases Sclerotinia and UCB as well as the less common diseases Alternaria black spot and powdery mildew that were also present at most sites. This paper outlines the key findings on the effectiveness of fungicide to control each disease as well as the grain yield response from fungicide control and the economics of their application.

Methodology

Trial sites were geographically spread to represent a range of climates and farming systems (Table 1). Trials were a randomised complete block design with four replicates for each treatment. Each trial was sprayed with a ute-mounted boom spray onto existing commercially grown and managed crops to ensure that the canopy remained intact, minimising open space for air to circulate which may have suppressed disease development. The sprayed plots were usually 40-50 m² in size with a smaller area of approximately 15-20 m² harvested with a small plot harvester when the crop was ripe (direct head) to minimise any potential influence from neighbouring treatments. All other crop husbandry prior to applications were completed by the grower.

Table 1. Site description for five canola fungicide response trials conducted in NSW, 2020.

Location	Region	Average annual rainfall	Average growing season rainfall	Variety
Ganmain	Eastern Riverina	475 mm	280 mm	HyTTec® Trophy
Kamarah	Northern Riverina	440 mm	220 mm	Pioneer® 44Y90 CL
Temora	South-west slopes	520 mm	310 mm	Pioneer® 45Y91 CL
Warren	Central-west plains	510 mm	210 mm	HyTTec® Trophy
Wellington	Central-west slopes	580 mm	300 mm	Victory® V75-03CL

Four products were used with multiple combinations of timings and rates (Table 2).

Table 2. Description of fungicide products used in five canola fungicide response trials conducted in NSW, 2020.

Trade Name	Active Ingredient 1	Group	Active Ingredient 2	Group
Aviator Xpro®	Prothioconazole	3	Bixafen	7
Miravis® Star**	Pydiflumetofen	7	Fludioxonil	12
Prosaro®	Prothioconazole	3	Tebuconazole	3
Veritas®	Tebuconazole	3	Azoxystrobin	11

***Miravis Star was applied under a research permit . It is currently under evaluation with APVMA.*

There were three application timings targeted at 10, 30 and 50% bloom (30 and 50% bloom only at Kamarah and Warren). The 30 and 50% timings are commonly suggested timings, with the 10% bloom timing added to reflect grower practice at those sites. Treatments at individual sites are shown in Tables 4-8 later in the paper. These spray timings are overlaid on daily rainfall in Figure 1. After good rains in early to mid-August at all sites, rainfall during the late winter/early spring period was generally below average.

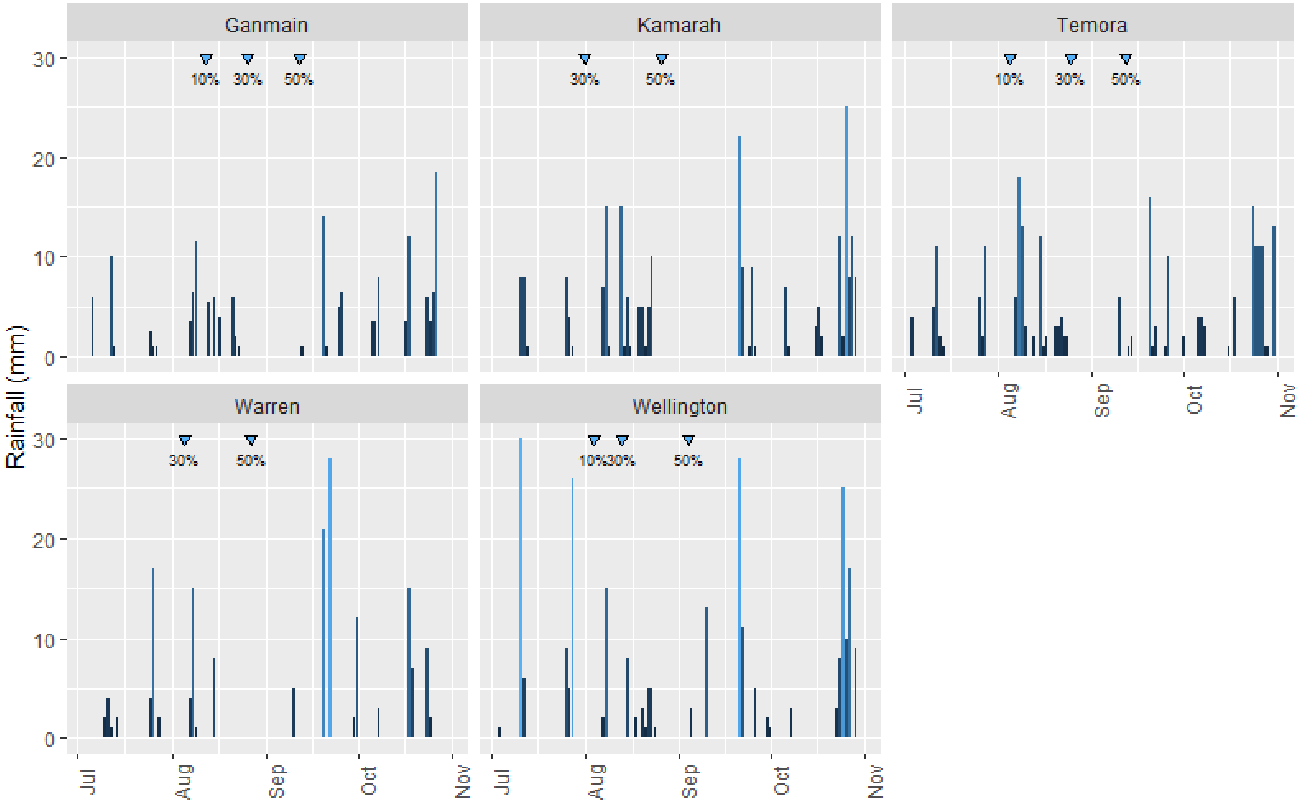

Figure 1. Daily rainfall received (vertical columns) and spray timings (inverted triangles) for five canola fungicide response trials conducted in NSW, 2020. Timings are bloom stage timing, e.g., 10% is 10% bloom stage.

Disease assessment

Diseases prevalence was assessed at one timing, targeted around 60-80 seed colour change (windrowing stage) with the methodologies detailed below.

Sclerotinia – two random sample areas of 1 m^2 were assessed in each plot, with the number of plants with Sclerotinia (basal, main stem and branch) counted along with the total number of plants in the assessment area to determine infection rates.

Upper canopy blackleg – a 0-4 score was allocated for the same two locations that were assessed for Sclerotinia:

- 0 = no infection observed
- 0.5 = at least one lesion found
- 1 = lesions present
- 2 = lesions common
- 3 = lesions common causing damage
- 4 = lesions common causing branch death

Alternaria black spot – the upper canopy blackleg scoring system was adapted for Alternaria with some minor tweaks:

- 0 = no infection observed
- 0.5 = at least one lesion found
- 1 = lesions present
- 2 = lesions common with 1-5% of pod/stem area infected

- 3 = lesions common with 5-15% of pod/stem area infected and low-level early pod senescence.
- 4 = lesions common with >15% of pod/stem area infected and high level of early pod senescence.

Powdery mildew – an assessment was made of the proportion of stem area infected with powdery mildew (two locations per plot as per Sclerotinia).

The trial results were analysed by ANOVA with 95% confidence level. Results are detailed in Tables four to eight below.

Results

Sclerotinia petal testing

Petal samples from 12 flowers from untreated areas were sent to the CCDM for determining the level of Sclerotinia present at each site. Sclerotinia was confirmed as present on petals at each of the five sites, with 100% of petals infected at Ganmain and Temora and down to 55% of petals infected at Wellington.

Table 3. Canola Sclerotinia petal infection rates at from five canola fungicide response trials conducted in NSW 2020.

Site	**Petals infected (%)**
Ganmain	100
Kamarah	78
Temora	100
Warren	87
Wellington	55

Geographic disease distribution

The highest levels of Sclerotinia infections were at the most south-eastern site Temora, where canola intensity and canopy moisture levels favoured disease development (Figure 2). There was no broader Sclerotinia infection of plants at Warren, despite petal tests confirming Sclerotinia as present at the site. Upper canopy blackleg (UCB) on branches ranged from only trace levels at the north-western site at Warren, to high levels of infection likely causing yield loss at the southern sites at Kamarah and Temora. Powdery mildew and Alternaria black spot (on pods) was most severe in the northern trials.

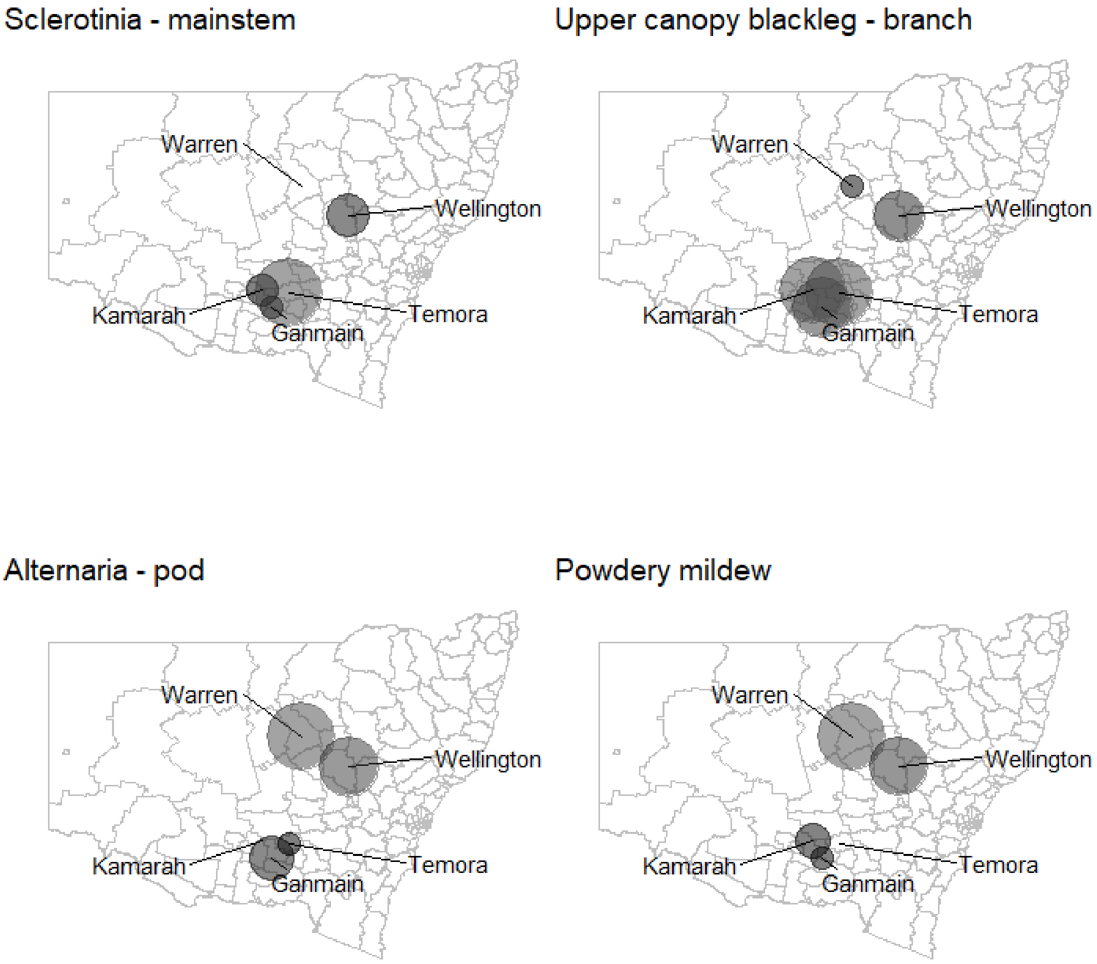

Figure 2. Severity of the diseases Sclerotinia stem rot (main stem), upper canopy blackleg (branch), Alternaria (pod) and powdery mildew across five canola fungicide response trials in NSW in 2020. Larger circles represent greater infection levels (data presented from untreated control). Data presented is dimensionless and no comparison can be made across diseases.

Ganmain

There was no grain yield response to the various fungicide treatments tested at Ganmain.

There was some reduction in Sclerotinia, UCB (branch), powdery mildew and Alternaria incidence, but disease levels were generally low. All fungicide treatments at the 30 and 50% bloom stage reduced Sclerotinia incidence compared to the untreated, but the 10% bloom fungicide treatment (Aviator Xpro only) did not reduce incidence. UCB (branch) was present but not at levels that would impact grain yield (rating of less than 2). Some reduction in incidence was achieved with single applications at 10 and 30% bloom applications of Aviator Xpro, second applications did not reduce incidence further than single spray treatments. A single application of Miravis Star at 30% also reduced incidence. Alternaria on pods was also common but not consequential, with incidence reduced by 50% bloom applications of Aviator Xpro. Powdery mildew was present at low levels, but disease incidence reduced further wherever Prosaro was applied at 50% bloom.

The Ganmain crop was HyTTec Trophy which has effective major gene (Group ABD) resistance to blackleg which may have reduced the severity of UCB infection. Although incidence on branches was easy to find, it was generally not at levels that would impact grain yield. There was only low level of blackleg on pods (data not shown). A further factor that reduced infection risk of this crop was that it flowered the latest of all the crops, with most (30-50% bloom) of the flowering period coinciding with a dry four-week period in late winter/early spring. For the period 1 July to 31 October, Ganmain had the least rainfall (160 mm) of the five sites.

Table 4. Canola grain yield, quality and disease response to fungicide in a crop of HyTTec Trophy at Ganmain 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UC BL Br.	Alt. pod	PM (%)
Aviator Xpro 650 mL/ha 10%	2.47	44.2	5.7	0.6	1.4	2.5	10
Aviator Xpro 650 mL/ha 30%	2.59	43.5	0.3	0	1.4	2.1	5.4
Prosaro 450 mL/ha 30%	2.56	42.9	0.3	0	1.7	2.5	2.9
Miravis Star 30%	2.61	43.9	0.5	0	1.4	2	5
Aviator Xpro 650 mL/ha 10% + Prosaro 450 mL/ha 50%	2.48	44	0.8	0	1.7	2.4	2.7
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	2.56	43.5	0.6	0	1.4	2.4	1.2
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	2.61	43.4	0	0	1.9	2.2	1.5
Aviator Xpro 550 mL/ha 30% + Aviator 550 mL/ha 50%	2.52	43.6	0	0	1.4	1.5	5.6
Aviator Xpro 650 mL/ha 50%	2.53	43.9	0.6	0.3	1.7	1.9	4.5
Prosaro 450 mL/ha 50%	2.47	43.8	0.3	0	2.1	2.8	1.6
Untreated	2.49	42.9	3.3	1.8	2.2	2.8	9.1
l.s.d. (*p<0.05*)	n.s.	1	1.2	0.5	0.8	0.5	3.2

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper canopy blackleg branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Kamarah

There was a positive grain yield response (up to 0.4 t/ha) to all single-spray treatments at Kamarah except Prosaro at 50% bloom. There was no additional benefit of two-spray strategies over one fungicide spray.

Sclerotinia (main stem) infection was low, but all treatments reduced the incidence of the disease except the single applications of Prosaro (both 30 and 50% bloom) or Aviator Xpro at 50% bloom. Fungicide application at 30% bloom (except Veritas) reduced UCB (branch) infection, from levels that would likely reduce yield in the untreated control. All fungicide treatments provided some (but not complete) reduction in the incidence of powdery mildew.

The period between 30 and 50% bloom was relatively wet at Kamarah which may have partly contributed to higher branch blackleg infection than Ganmain. A further contributing factor is that the cultivar 44Y90 CL, despite having effective crown canker resistance, does not have effective major gene resistance.

Table 5. Canola grain yield, quality, and disease response to fungicide in a crop of 44Y90 CL at Kamarah 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UCI Br.	Alt. pod	PM (%)
Aviator Xpro 650 mL/ha 30%	2.87	42.7	0	0	1.9		4.1
Prosaro 450 mL/ha 30%	2.89	43.3	0	0	2.2		5
Veritas 1 L/ha 30%	2.71	42.3	0.5	0	3.1		8.6
Miravis Star 30%	2.70	42.7	0	0	1.9		4.9
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	2.78	42.5	0	0	1.5		3.2
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	2.70	43.1	0	0	2		4.9
Aviator Xpro 550 mL/ha 30% + Aviator 550 mL/ha 50%	2.75	42.7	0	0	1.6		3.4
Aviator Xpro 650 mL/ha 50%	2.74	42.6	4.4	0.6	2.8		7.5
Prosaro 450 mL/ha 50%	2.67	42.6	3.4	0	2.6		7.4
Untreated	2.49	42.7	2.8	0	3.4		15
l.s.d. (*p<0.05)*	0.20	1	1.1	0.5	0.6		4.2

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper canopy blackleg branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Temora

There was a positive grain yield response of up to 0.6 t/ha at Temora. Aviator at 10 and 30% bloom but not 50% bloom improved yields as did Miravis Star at 30% bloom. Prosaro at 30% did not increase yield but did at 50% bloom. Most (but not all) two-spray treatments improved yield.

Sclerotinia infection was highest of all five sites at Temora, but still only a moderate infection level of 12.2% of main stems infected where no fungicide was applied. Aviator Xpro at 10 and 50% bloom, and Veritas at 30% bloom did not reduce Sclerotinia incidence. Aviator Xpro at 10% followed by Prosaro at 50% bloom did not improve yield. Application of Aviator Xpro at 10 and 30%, Miravis Star at 30% bloom and all the two spray strategies reduced UCB (branch), but the best treatment still only reduced the score to a range from 1.5 to 2.1. Application of Prosaro and Veritas at 30% bloom and Prosaro and Aviator Xpro at 50% bloom did not reduce branch blackleg. Miravis Star at 30%, Aviator Xpro followed by Aviator Xpro (30 and 50% bloom) or Prosaro or Aviator Xpro at 50% bloom reduced Alternaria incidence on the pods but did not give full control.

A two-spray strategy generally provided good reductions of both Sclerotinia and blackleg, but no two-spray treatment resulted in higher grain yield than a single application of Aviator Xpro at 30% bloom.

Table 6. Canola grain yield, quality, and disease response to fungicide in a crop of 45Y91 CL at Temora 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UCI Br.	Alt. pod	PM (%)
Aviator Xpro 650mL/ha 10%	3.50	43.2	13.8	1.5	1.5	2	*Nil*
Aviator Xpro 650 mL/ha 30%	3.73	43.5	3.1	1.5	2.1	1.9	*Nil*
Prosaro 450 mL/ha 30%	3.37	43.6	2.6	0.3	2.9	2.1	*Nil*
Veritas 1 L/ha 30%	3.45	42.9	9.9	2	2.9	2.1	*Nil*
Miravis Star 30%	3.58	43.2	2.3	0	2.1	1.4	*Nil*
Aviator Xpro 650 mL/ha 10% + Prosaro 450 mL/ha 50%	3.73	42.6	6.1	0.3	1.7	1.9	*Nil*
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	3.46	43.1	1	0	1.9	1.6	*Nil*
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	3.70	43.5	1	0	2.1	1.8	*Nil*
Aviator Xpro 550 mL/ha 30% + Aviator 550 mL/ha 50%	3.71	43	1.3	0.3	2	1.6	*Nil*
Aviator Xpro 650 mL/ha 50%	3.45	43.1	7.4	0.8	2.6	1.2	*Nil*
Prosaro 450 mL/ha 50%	3.62	43.6	4.6	0.8	3.3	2.1	*Nil*
Untreated	3.07	43.7	12.2	3.6	3.1	2.4	*Nil*
l.s.d. (*p<0.05*)	0.44	0.8	6.3	1.7	0.7	0.7	n.s.

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper canopy blackleg branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Warren

No fungicide treatments resulted in a significant increase in grain yield.

There was no Sclerotinia infection at Warren and low (inconsequential) levels of upper canopy blackleg. The main diseases apparent were powdery mildew and Alternaria infection on pods and stems. Powdery mildew infection was the highest of all five sites, with 67% of stem/branch area infected with powdery mildew by crop maturity (windrow timing) in the untreated control. Fungicide treatments with Prosaro applied at 50% bloom reduced powdery mildew incidence to close to very low levels with no benefit to yields (Prosaro does not claim control of powdery mildew in canola on its label). Alternaria infection on pods was high with only two-spray fungicide treatments providing a small level of control. The Warren site also had high levels of Alternaria on stems/branches, with all fungicide treatments giving some reduction in incidence (data not shown). Unlike branch blackleg observed at other sites, Alternaria did not manifest into cankers that eventually resulted in branch death but were usually superficial. It is difficult to ascertain if Alternaria infection on pods had any effect on grain yield, as no fungicide treatment resulted in clean pods. It is likely that fungicide would need to be applied when all pods are formed (e.g., end of flowering) to achieve good control of Alternaria, but all fungicide products need to be applied by the 50% bloom stage.

Table 7. Canola grain yield, quality, and disease response to fungicide in a crop of HyTTec Trophy at Warren 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UCl Br.	Alt. pod	PM (%)
Aviator Xpro 650 mL/ha 30%	3.72	41.3	*Nil*	*Nil*	0	3.6	19.5
Aviator Xpro 800 mL/ha 30%	3.60	41.1			0	3.6	17.1
Prosaro 450 mL/ha 30%	3.52	41			0	4	17.7
Veritas 1 L/ha 30%	3.39	40.2			0	3.6	20.6
Miravis Star 30%	3.56	40			0	4	43.1
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	3.70	39.6			0	3	2.5
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	3.75	40.6			0	4	5.3
Aviator Xpro 650 mL/ha 50%	3.43	40.9			0.2	3.2	16.9
Prosaro 450 mL/ha 50%	3.47	40.5			0.2	3.6	5.8
Untreated	3.43	40.5			0.2	4	67.4
l.s.d. (*p<0.05*)	0.35	1.6	*n.s.*	*n.s.*	*0.1*	0.4	14.8

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper Canopy Blackleg Branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Wellington

There was a positive (0.2-0.3 t/ha) grain yield response for two of two-spray fungicide treatments, but no single-spray treatments increased yield. Sclerotinia infection levels were low and upper canopy blackleg infection levels were moderate at Wellington. All fungicide treatments except Prosaro and Veritas at 30% bloom provided control of Sclerotinia and upper canopy blackleg branch incidence. Powdery mildew incidence was moderate with best control where Prosaro was applied at the 50% bloom stage. Alternaria infection levels in the untreated control were high on pods (score of 3.9) and stems (score of 4, data not shown for stems) with best reductions from the single Aviator Xpro 50% bloom application (score of 1.4). Fungicide application did a better job of reducing Alternaria on the stems than on pods, again due to the inability to spray fungicide beyond 50% bloom stage to protect all pods. The large differences between Alternaria scores on the stems did not manifest into major differences in grain yield, indicating that Alternaria may have only been superficial.

Table 8. Canola grain yield, quality and disease response to fungicide in a crop of Victory V75-03CL at Wellington 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UCI Br.	Alt. pod	PM (%)
Aviator Xpro 650mL/ha 10%	3.78	43.1	1.1	0	0.7	3.4	24.4
Aviator Xpro 650 mL/ha 30%	3.71	42.9	0.6	0	0.7	3.5	21
Aviator Xpro 800 mL/ha 30%	3.75	43.4	0.4	0.4	0.9	3.1	15.9
Prosaro 450 mL/ha 30%	3.51	43	5.8	0.3	1.9	3.6	15.2
Veritas 1 L/ha 30%	3.62	43.1	3.5	3.3	1.4	3.6	18.2
Aviator Xpro 650 mL/ha 10% + Prosaro 450 mL/ha 50%	3.90	43.3	0	0	0.4	3.3	4.4
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	3.77	42.7	0.5	0	0.7	3.4	8.2
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	3.81	43.2	0.8	0.3	0.7	3.2	5.2
Aviator Xpro 650 mL/ha 50%	3.76	43.7	1.1	0	1.1	2.1	12.5
Prosaro 450 mL/ha 50%	3.77	42.5	0.9	0.4	0.8	3	6.1
Untreated	3.64	43	4	1.7	1.9	3.9	18.8
l.s.d. (*p<0.05*)	0.17	0.9	2	2.2	0.6	0.6	8.7

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper Canopy Blackleg Branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Fungicide economics

To determine the economic benefit of the fungicide treatments, grain yield was multiplied by price (allowing for oil increments) and costs of fungicide product and application costs were subtracted. This partial gross margin was then analysed as a variate in the same way that grain yield was analysed (Miravis Star was not included in the economic analysis as it has not yet commercially available).

We assumed a price of:

- $550/tonne for canola (+/- 1.5% for each 1% oil above or below 42%)
- $54.50/L Aviator Xpro
- $74.50/L Prosaro
- $21/L Veritas
- $13/ha application cost

At Ganmain there was no (statistical) difference in the partial gross margin (gross income less treatment and application costs) of any treatment compared to the untreated control. There was a higher partial gross margin at Kamarah only from the application of both Aviator Xpro and Prosaro at 30% bloom. At Temora, the highest partial gross margin was from a single spray of Aviator Xpro at 30% bloom. At both Warren and Wellington, there was no economic benefit of any fungicide treatment compared to the untreated control.

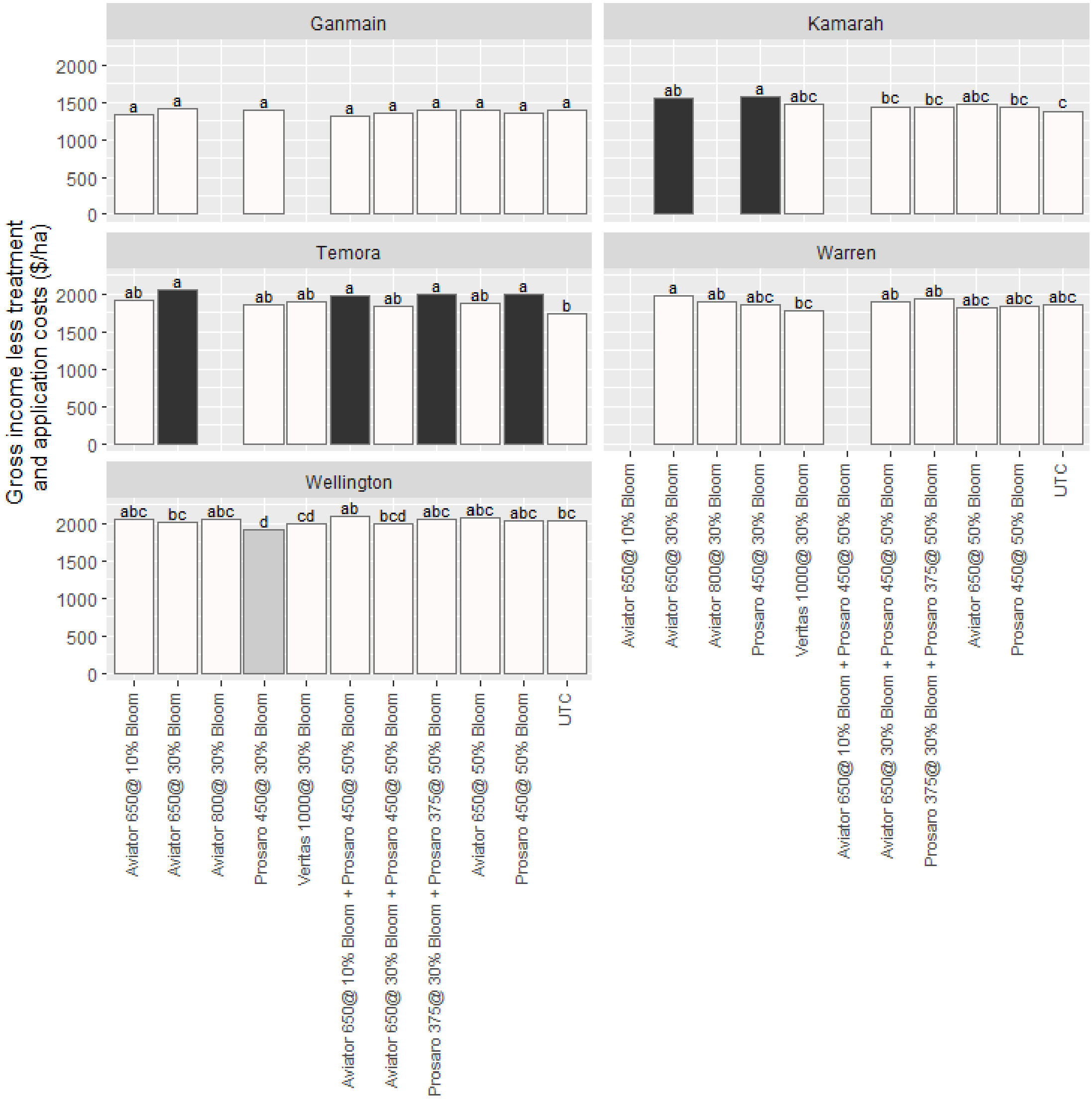

Figure 3. Partial gross margin (gross income less fungicide product and application costs) of fungicide treatments across five sites in NSW in 2020. Treatments with the same letter are not significantly different at p=0.05. Treatments in black are significantly higher than untreated control (UTC) and treatments in grey are significantly lower than UTC.

Discussion and conclusion

Many southern and central NSW canola crops in low-medium rainfall zones had a foliar fungicide applied to them in 2020. The primary driver was protection from Sclerotinia stem rot predicted by a wet first half to the cropping year leading to higher yield potential and medium-term forecasts predicting above average rain through spring. The secondary concern was UCB, especially in southern regions. The presence of Sclerotinia spores was confirmed by petal testing at all trial sites and blackleg was observed at all sites. Despite presence of these diseases at all sites, improvements in grain yield were not common or consistent and economic benefits from fungicide were evident at only two sites.

Petal testing indicated that Sclerotinia inoculum was present at all sites. That visual inspections at Warren and Wellington did not find any apothecia would tend to indicate that infections may have come from neighbouring paddocks. On the other hand, the presence of inoculum was not a good predictor of the ensuing levels of infection.

At all sites, a period of dry weather was experienced through late August and early September which may have limited the development of Sclerotinia in the canopy, however, all sites received good rainfall thorough the early flowering period and again during the late flowering period at most sites.

However, Sclerotinia and blackleg were not the only diseases present in these trials and, although separate assessments were made on the impact of fungicide treatment on the multiple diseases present, it is impossible to attribute yield response (where observed) to any one disease. Yield responses may have been due to reduction in infection of one or more diseases.

Sclerotinia and blackleg were at low levels in the two northern trials (Warren and Wellington) whereas powdery mildew and Alternaria infection were relatively high but spraying fungicide did not provide an economic benefit at these two sites. (None of the products tested have label claims for these two diseases in canola).

Some reduction in Alternaria was achieved with fungicides but it was difficult to ascertain the level of yield loss as even a two-spray strategy was not enough to fully protect pods. The latest spray timing on label is 50% bloom and at this stage only 20-30% of pods have formed. Powdery mildew was a talking point at windrowing time in many crops in the central-west. We found good reductions in in symptoms where Prosaro was applied at 50% bloom yet there did not appear to be significant yield losses even at high levels of infection. Prosaro does not have a label claim for control of powdery mildew in canola.

There was a more compelling case for the economic benefit of fungicides in two of the three southern sites, but not with all treatments. Both responsive sites (Kamarah and Temora) were in cultivars without effective major gene resistance to blackleg, so yield response may have been due to upper canopy blackleg (branch) infection as well as Sclerotinia (especially at Temora). A single spray of Aviator Xpro at 30% bloom provided the most consistent economic benefit in the two responsive southern sites, at Temora returning a net $323/ha net advantage over the untreated.

Overall, despite the presence of several diseases including Sclerotinia and UCB and high yield potential, positive responses to fungicide applications were not universal across sites. In hindsight the dryer conditions in late Autumn to early Spring may have limited disease progression and hence reduced the necessity for fungicides. However, as fungicides are prophylactic, growers and advisors can only work with the information they had at the time.

Many growers and advisors saw the application of fungicide as an insurance policy rather than as an investment and were comfortable knowing they had some of the best crops they had ever grown protected from the potential negative yield effects of key fungal diseases. There are several other ‘investments’ that could be made into a canola crop where returns are more predictable (such as nitrogen) and ideally the investments that give a reliable return should be addressed before spending more money on ‘insurance’.

However, given that 2020 was such a good season with very high yield potential, and that economic benefits were not always present, should give growers the confidence that in seasons with only ‘average’ grain yield potential, expenditure on fungicide may not be justified and money may be better invested elsewhere.

Management factors that growers can implement in 2021 to reduce fungicide requirement during the flowering period include:

- Select cultivars with effective major gene blackleg resistance. Monitor updates to the GRDC Blackleg Management Guide to guide decision making

- Match phenology and sowing date so that crops do not flower too early. Early flowering will usually result in greater exposure to disease - especially upper canopy blackleg
- Closely monitor short-term forecasts as diseases require moisture for infection
- Consider using some of the decision support tools that may quantify the risks of canola diseases and the need for fungicide applications. Download the SclerotiniaCM and BlacklegCM decision support Apps for your tablet or iPad device
- Avoid sowing canola in or near paddocks that have had high levels of disease infection recently
- When a fungicide is required, apply at the correct time (~30% bloom) and with good coverage to avoid needing a second fungicide.

By reducing the need for fungicide, growers may be able to invest in other inputs where higher returns are guaranteed.

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2021 Rethink your approach to canola harvesting to optimise crop performance.

Maurie Street and Ben O’Brien, Grain Orana Alliance

Keywords

canola, windrowing, direct heading, desiccation, pod shatter

GRDC project code

GOA00002

Take home messages

- Timing of windrowing of canola can have a huge impact on profitability through its influence on yield and oil%
- Profit could be reduced by up to $50/day for every day that crops are windrowed before they are ready
- The window for windrowing on time is relatively small so it is difficult to logistically windrow all crops in the ideal period
- Direct heading of canola is a viable and comparable alternative to well-timed windrowing and can outperform windrowed crops
- In contrast, the window for direct heading crops to maximise yield and profit may be much larger than the window to windrow crops for optimum yields
- Desiccation, other than that for weed control, in most cases will not significantly speed up crop maturity.

Background

Windrowing of canola in the central west of NSW has been the traditional approach adopted by most growers. Survey data collected in 2017 by Grain Orana Alliance (GOA), a GRDC Grower Solutions Group, indicated that a decade ago, between 65% - 80% of canola growers were exclusively windrowing (GOA, 2019).

In 2009 GOA was asked to investigate if windrow timing (WRT) was impacting canola performance, specifically the oil percentage of harvested grain. In response, GOA established two trials in 2009 that compared different windrow timings. In both trials, the early windrowing resulted in significant yield penalties of up to 0.5t/ha, but only low levels of impact on oil content.

The outcomes from these two trials inspired subsequent trials undertaken by GOA, not only investigating the impact of WRT, but investigating the fit of direct heading, the use of desiccants, the use of PodCeal™, the impacts of delays in direct heading and Podguard™ technology.

In response to the work undertaken by GOA, more in-depth studies were undertaken by NSW DPI under the GRDC ‘Optimised Canola Profitability Project’ (CSP00187). These confirmed GOA’s findings and developed new guidelines and resources for optimum windrowing timing.

GOA has previously presented and published on these topics. Detailed presentations and papers can be found on either the GRDC or the GOA websites. This paper summarises the key findings and presents a case for growers to reconsider how they might approach harvesting canola in the future.

What is the ideal windrowing timing?

WRT is the stage of crop maturity when the crop is cut and placed into windrows to dry and be later harvested when the grain has dried down to a deliverable moisture content (DMC) of 8%. The crop stage is identified by the percentage of the seed that has changed colour. For example, the previously accepted recommendation for the timing of canola windrowing was -

> "Windrowing should commence when 40-60% seed in the middle third of the main stem has changed colour from green to brown, black or red" (Carmody, 2009).

The changing colour is an indicator of those seeds reaching physiological maturity. At this point seed has reached its full potential in terms of seed size and oil content. Prior to this the seed is still growing (increasing in size) which is contributing to increasing yields and oil content. The recommendation of 40%-60% colour change infers that only 40-60% of the seed in the referenced part of the crop is mature and reached its full size. Immature seed at the time of windrowing will have any further growth or accumulation of oil stopped abruptly which will forgo potential further increases in yield or oil%. Windrow too early and yield and oil% will be forgone, with later timings giving the crop more time to realise its full yield potential.

However, what also occurs as the crop matures is an increase in brittleness. The process of windrowing can be aggressive and often results in seeds being lost from pods, ultimately ending up on the ground and reducing harvested yield.

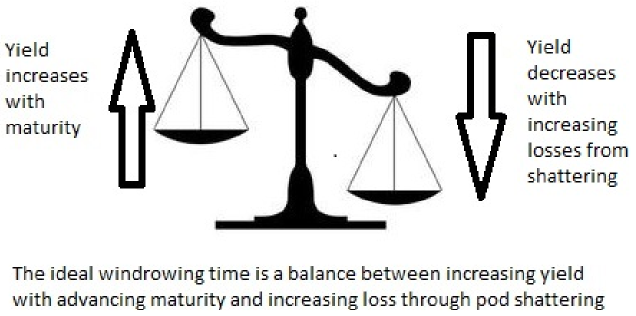

Figure 1. Illustration of the balance needed between increasing yields and increasing potential losses with advancing maturity.

Ideal WRT should aim to maximise the increasing crop yield but not be too late as to reduce harvestable yield by shattering out canola either before but more likely during the windrowing process.

So what did GOA find?

Large scale replicated field trials run by GOA showed that WRT could have an impact on oil% but it was often quite small. The effect of WRT on crop yield however was often much larger, both in magnitude and economic impact. One of the first trials undertaken by GOA at Coonamble in 2009 showed that delaying WRT from 10% seed colour change (SCC) to 70% SCC, or eight days, yields increased by 500kg/ha. The increase represented a 30% yield improvement and at current canola prices, assuming $650/t ex farm (Newcastle port price less freight, July 2021), this would be worth $325/ha.

More recent (2015, 2016 & 2017) trials by NSW DPI under the GRDC co-funded 'Optimised Canola Profitability Project', have looked more closely at the impact WRT can have on yields and oil%. This work has shown in some cases that yield impacts were even greater than those seen in GOA's trials. One trial at Trangie in 2016 showed a 48% yield loss when the crop was windrowed at 6% SCC as opposed to ~60% SCC. At Edgeroi 2016 a 55% (~1.3 t/ha) yield loss from windrowing 8-10 days earlier than the peak yield was measured. Tamworth 2016 showed a potential yield loss of 1.2 t/ha or 32% from premature windowing. (Graham et al, 2018).

The consistent message from both GOA and NSW DPI is that WRT earlier than the current recommended timings of 40-60% SCC, has consistently resulted in significant yield penalties.

The trials have also demonstrated the potential to increase yields further by delaying WRT past the old, recommended timings. The GOA trial at Coonamble showed a further 16% increase in yield (280kg/ha) from only a five-day delay in WRT from 50% SCC to 70% SCC (Street, 2014). Delaying WRT at Trangie in 2016 from ~60% SCC to the 100% SCC increased yields by a further ~800kg/ha (Graham et al, 2018. Several other trials also support these findings, where delaying WRT past 60% SCC increased yields. This outcome is not unexpected given that up to 100% SCC some immature seeds within the crop are still developing and so could still contribute to yield. The question remains however, at what point do the losses from pod or seed shatter negate any further increases in yield?

So, what has changed and why does later windrowing perform so much better?

Plant populations have generally reduced over the years. Street (2014) suggested that with lower plant populations, proportionally less yield is carried by the main stem where we assess windrow timing. Graham (2018) confirmed that greater than ~70% of the crop yield may be carried on branches as opposed to the mainstem and that more importantly, the stems were less mature than the mainstem. As such, estimating crop maturity based on the mainstem also overestimated average crop maturity. Windrowing crops based on mainstem maturity meant that much of the crop was immature and still had substantial yield potential unrealised if windrowed then.

Varieties have also evolved. Variety trials are seldom if ever windrowed but direct headed. Varieties susceptible to pod shatter would likely experience a higher level of yield loss compared to other more resilient varieties, thus reducing the likelihood that any such varieties would progress to commercialisation against other varieties that are more resistant to pod shattering.

This also suggests that varieties of 20-30 years ago may have been more likely to shatter at earlier level of SCC ,tipping the scale towards an earlier windrowing time than it would be with today's varieties.

So when should I windrow?

As an outcome of this work new recommendations have been put forward to target the optimal windrow timing for canola, with two key changes:

1. Crop maturity should be based on the whole crop not just the mainstem
2. The optimum SCC has also moved later from 40-60% to 60-80%.

The current recommended timing is:

'Crops should be windrowed when 60-80% of the seed sampled from the middle third of the mainstem and the branches has changed colour from green to red, brown or black.'

A kit has recently been released 'Canola - Windrow on Time, Reap the Rewards' which details more the methodology to assess SCC and some illustrative references to help determine the level of SCC in your crops. An online version is available at-https://grdc.com.au/canola-windrow-on-time,-reap-the-rewards?utm_source=website&utm_medium=short_url&utm_term=&utm_content=Canola%20%E2%80%93%20Windrow%20on%20time,%20reap%20the%20rewards

What has also been demonstrated is the rapid rate at which seed colour change can occur. Results from a NSW DPI trial in 2017 demonstrated that seed colour change went from 29% to 90% in only a 5-day period. In GOA's 2010 trial at Coonamble, SCC went from 10% to 70% in just eight days and the trial at Warren in 2010 matured from 40% to 95% SCC in seven days. These results demonstrate that to windrow at the optimum timing of 60-80% SCC would only be a fraction of these times. As such, the window to windrow at an optimum crop stage can be very small.

Given the yield and financial impact that premature windrowing has, optimising yields in windrowed crops over a large area can be extremely difficult to achieve in practice. The fact that much of the canola crop, both the individual growers' and the districts', will require windrowing in the same small window, increases the difficulty in getting a windrower when needed.

How late is too late to windrow?

GOA undertook four trials that investigated the effects of delaying WRT past the previous timing recommendations. These trials used commercial windrowers and headers and reported harvested yields. They consider the potential losses from delayed windrowing through shattering; however, they are not quantified. In these trials there was no measurable decline in harvested yields even where WRT was delayed up to 95% SCC on the main stem. This is not to say that delayed WRT did not result in small increases in pod shattering, but any losses were compensated by increases in yields from other more immature parts of the plant.

In one trial however there was a measured a downturn in yield of 250 kg/ha as a result from a delayed WRT. However, the delay was measured as 7 days after 100% SCC and so represented an extreme case of late windrowing. This demonstrates that you can windrow too late and if growers are unable to windrow by the later stage of 80% seed colour change (whole plant) and/or significant pod shattering is likely during windrowing, leaving the crop to direct head may be a better choice.

Is direct heading a viable alternative to windrowing?

GOA has run several trials which have shown that yields from direct headed situations have generally matched the yields of a **well-timed** windrowing. However, when compared to that of an ill-timed windrowing i.e. too early or too late, direct heading outperformed the windrowed treatment.

Direct heading has often been made out to be very risky and not worth considering. Stories of very small harvesting windows before pod shattering occurs, increased exposure to weather damage, reductions in harvesting hours, delays to harvest commencement and slow harvest rates are common, however many such stories are not well founded.

Delayed direct heading and pod shattering

Results of a trial conducted in 2013 (Figure 2), demonstrated that the yields were stable in a standing direct headed crop and did not decline for two weeks after the first harvesting opportunity (Day 0). At this point there was a weather event resulting in a yield decline, after which the yield plateaued again. This suggests that in this situation, yield decline when harvesting is delayed tends to be stepped rather than linear and that shattering yield losses are most likely a function of weather extremes, which are fortunately infrequent but also unfortunately unpredictable.

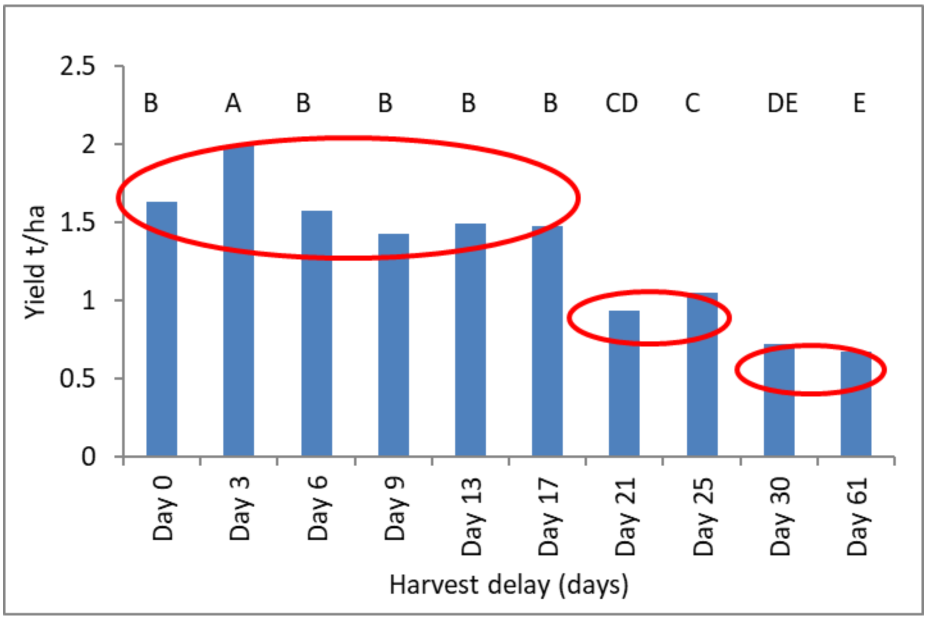

Figure 2. Harvested grain yields in response to delay in direct heading from the first harvest timing 'day 0'- Wellington 2013

PodGuard™ Canola promises of enhanced shatter tolerance

A unique genetic trait 'PodGuard™' has been bred into selected canola varieties which has increased tolerance to shattering. This trait may allow growers to either delay WRT until later stages of crop maturity to capture higher yields or allow growers to have confidence that pre-harvest shattering will be minimised in crops left to direct head.

GOA in conjunction with Bayer tested shattering tolerance of a PodGuard™ variety against a non PodGuard™ variety in a trial conducted in 2015. A severe shattering event was simulated consisting of dragging a two-inch steel pipe twice through the podding zone at harvest (i.e. 100% maturity) for a normal and delayed harvest timing.

At the first harvest timing (H1) without the simulated shattering event, the yields of the two varieties were comparable. However, when the simulated shattering was applied only the yield of the non Podguard™ variety 45Y25 was impacted, with yield reduced by around 600 kg/ha (~25%). Delaying harvest by 14 days (H2) resulted in no statistically significant yield decline in the PodGuard™ variety however the yield of the 45Y25 was reduced by ~500 kg/ha. Combining the simulated shattering event with the delay in harvest, the 45Y25 suffered around a further 500 kg/ha yield loss, while the PodGuard™ variety experienced no loss of yield, see Figure 3.

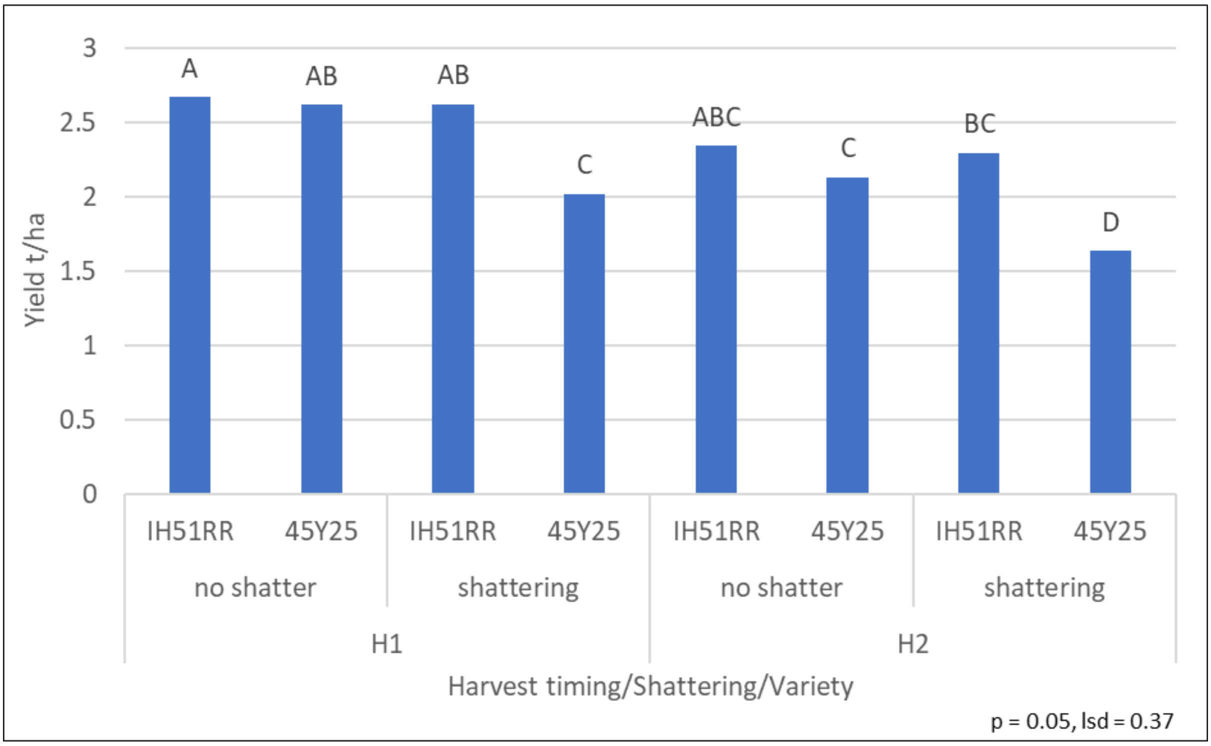

Figure 3. Harvested yield in response to harvest timing and simulated shattering by variety- Wellington 2015. H1 is harvested 'on time', H2 harvested with a 14-day delay. IH51RR contains PodGuard technology, 45Y25 does not.

During this trial, measurements were made to quantify the source and timing of the losses encountered. Details of these are covered in the full trial report on the GOA website which can be found at www.grainorana.com.au/documents?download=39

In summary, the PodGuard™ variety IH51RR has shown good potential to resist shattering from delays in direct heading or severe shattering events such as high winds or hail but worth also noting that although the 45Y25 suffered some yield loss from delays to harvest, it was not a complete disaster.

GRDC have also produced a 'Direct Heading Factsheet' that can be found at www.grdc.com.au/GRDC-FS-Direct-Heading-Canola

This factsheet examines many of the pros and cons and suggests that on top of yield advantages, farmers should also consider the additional benefits including the elimination of windrowing costs, applicability for heavy lodged crops that cannot be windrowed and for lighter crops where small windrows may be unstable in windy conditions.

However, it should be noted that windrowed crops are not immune to the impacts of adverse weather. Windrows, particularly those in light crops are highly susceptible to wind movement and subsequent yield loss. Hail can also impact windrows, as it can a standing crop, but in both cases, these are an insurable risk. Wet weather may also see some differences in grain quality. Anecdotally windrowed crops will stay wetter for longer after rain, delaying harvest and prolonging the risk of sprouting. This could lead to lower test weights and yields along with longer delays in recommencing harvesting.

How does timing of harvest vary between direct headed or windrowed crops and will desiccation help alleviate any differences?

One common concern for growers when considering direct heading is the perceived delay in the commencement of harvesting. It is thought that compared to windrowed crops, crops left for direct heading take a week or longer to dry down to acceptable grain moisture content before harvesting can commence.

One option to potentially manage this issue in direct headed crops is to apply a desiccant to the crop ahead of harvest to speed up the ripening process. Reglone™ has been registered for this purpose for some time, but its cost, difficulties in application and perceived unreliability often deters many from its use.

More recently glyphosate formulations such as Weedmaster™ DST marketed by Nufarm has been registered for use in canola for pre-harvest application. While the main label claim is for pre-harvest weed control, it also registered as a 'harvest aid', suggesting that it may also speed up the ripening process.

Over three years GOA has run four trials investigating the relative effectiveness of Weedmaster DST and Reglone, in reducing grain moisture content (GMC) to facilitate earlier harvesting. The key findings from this work were that Reglone, when applied to canola, showed some limited advantage in bringing GMC down quicker than natural ripening. In two of the 4 trials, there was no advantage to using Reglone (Geurie 2014 and Wellington 2015). At Wellington in 2013 the Reglone treatment would have allowed harvest to start approximately five days earlier. At Coolah in 2014, Reglone may have allowed an earlier harvest, but all treatments including the untreated was below 8% GMC within one more day and so offered little benefit.

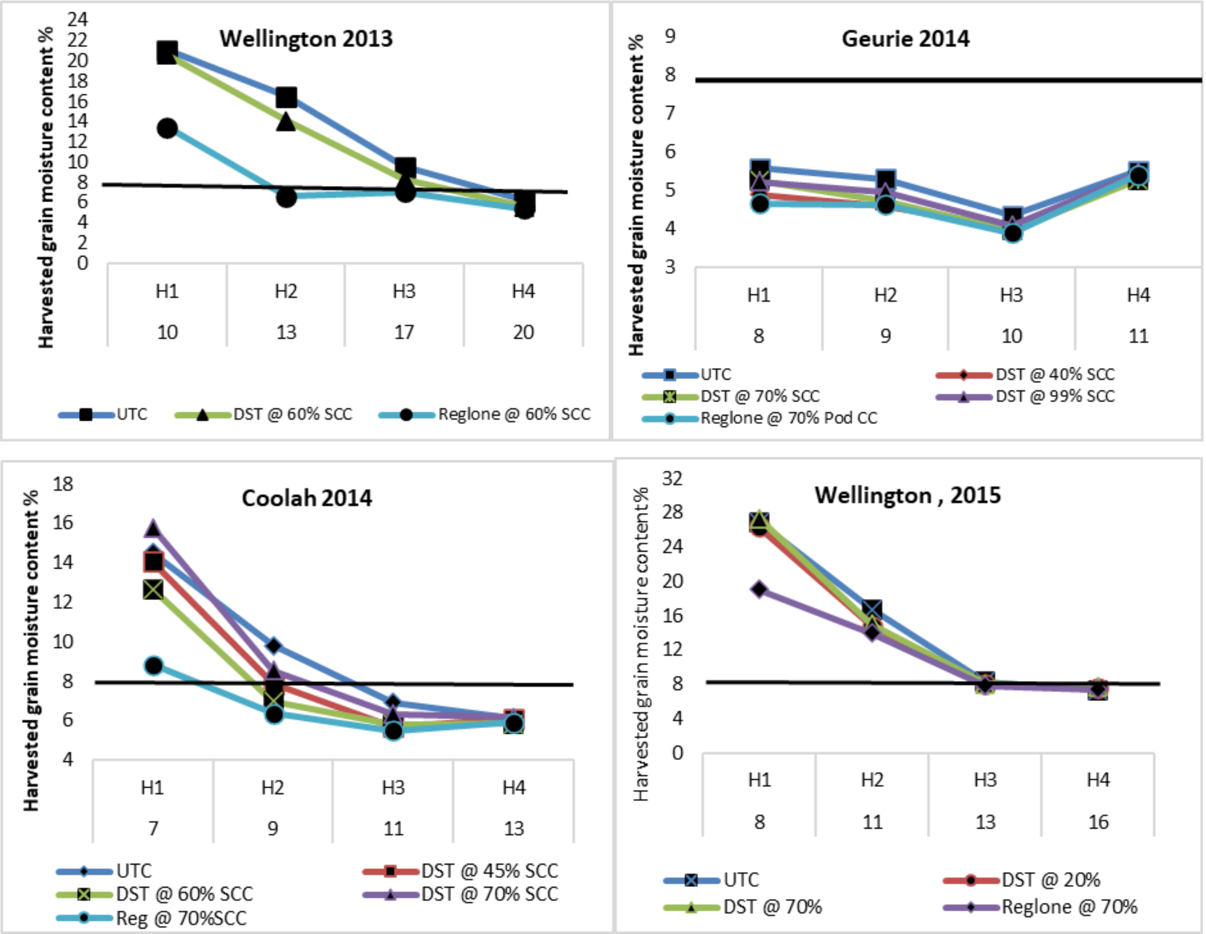

Figure 4. Harvested grain moisture contents in response to application of Reglone (REG) or Weedmaster DST (DST) at differing levels of seed colour change. As assessed at four different harvest timings (H1, H2, H3, H4). Numbers under the harvest timings indicate the number of days since the Reglone application (~70% SCC).

Weedmaster DST applied pre-harvest also showed little practical benefit at bringing harvest forward with no significant difference in GMC at any harvest timing between any DST treatment and the untreated crop.

Further details of the trials can be found at
http://www.grainorana.com.au/documents?download=49

An interesting observation in these trials was the rate at which the crops ripened without any desiccation and the relevance this may have to potential time differences between harvesting of a windrowed crop and direct headed one. Reglone in the trials detailed above was applied at ~70% SCC and considering the new windrowing recommendations, this crop stage is within an optimal WRT. It can be seen in the graphs above the time it takes the untreated crops to dry down to 8% GMC in relation to 70% SCC.

Both Wellington trials took only 13 or 17 days for the untreated canola crop to reach 8% moisture, but in 2014, Geurie reached 8% moisture in under 8 days and Coolah within 10 days. Typical district experience would suggest windrows often cure for at least 10-14 days most years and thus suggest the time to harvest a direct headed crop would be within days of one that is windrowed and not weeks as often thought could be the case.

The view of longer delays to this may be brought about though early windrowing. The earlier a crop is windrowed, the sooner it is dry enough to harvest relative to a crop left standing to ripen naturally. It could be suggested that in many cases if growers do experience lengthy delays in commencement of direct heading in comparison to similar ones around, it could indicate windrowing has commenced too early, which we now know could be incurring significant yield penalties. Looking at this from the other way, is that if growers adopt the later WRT, the difference between harvesting of windrowed crops and direct headed crops is likely to be less than previously experienced.

Windrowing allows me to get started on harvest earlier so as not to interfere with harvesting of my other crops.

Many growers argue their preference for windrowing canola as it hastens harvesting. However, as evidenced above, the difference may not be as large as some think if windrowing at the correct timings. Windrowing may offer several days which may be useful, but for many, this may still not be enough. If growers choose to windrow early to result in more available days to complete harvesting, it should be remembered this could come at a significant cost. Numerous trials have shown that premature windrowing could be costing growers up to $50/ha/day.

This issue may be magnified in crops with mixed maturities due to uneven establishment or major soil type changes etc. There is no debate that windrowing crops with significant maturity differences will allow harvest of the greener areas sooner than if left for direct heading. However, it is worth the grower considering the relative proportions of each maturity, and to which the windrow timing be set on. But the green areas may well be the highest yielding areas of the paddock and windrowing those areas early to suit the more advanced low yield areas may seem counterproductive. Setting windrowing to the greener parts of the paddock may risk shattering during windrowing in the more mature parts. It could be argued that there is no right time to windrow a crop with significant areas of contrasting maturity. If the areas are less balanced it will become an easier question to answer, but it will always be a compromise for some part of the crop.

Growers are often concerned that delays in canola harvest will impact on traditional wheat harvest periods, increasing harvest downgrade risks in wheat. Worth noting that windrowing early to accommodate an earlier start to wheat harvest will almost certainly incur a loss, while a weather downgrade to wheat may not even occur. It is also worth considering crop values. Canola in 2021 is twice the price of wheat and more than three times the price of barley. It could also be suggested that crop harvest order should not need to be set in stone. Traditionally canola has been harvested ahead of barley and wheat, but there is no issue with harvesting barley ahead of canola.

Pulling it all together

Windrowing will remain popular with many growers for several reasons, however growers should strive to windrow to the new recommended timings of 60-80% SCC across the whole crop. Failure to do so could result in significant yield penalties and with current pricing of canola, this can amount to a significant financial penalty. Windrowing crops in the optimal window, which can be quite small, can be logistically difficult and some growers may need to sacrifice yields by starting windrowing of large areas earlier, but again this can be at an additional cost in lost income.

Direct heading of canola is a worthy alternative to windrowing and much of the negative connotations of the past are not as common as often thought. Direct heading will allow for the whole crop to reach its full potential yield and oil%, and trial work suggests that it will yield as well as a correctly timed windrowed crop. If the alternate is to windrow too early or too late because of weather complications or availability of a windrower, direct heading may be the best option.

Concern over rapid yield loss with delays to direct heading have not really been demonstrated in trial work or with commercial experience, which has shown yields to be often quite stable post crop maturity. With ever improving varieties or PodGuard varieties, concerns could be even further allayed.

Time differences between windrowed and direct headed crops may also not be as different as thought, provided windrowing of crops is done at the latest recommended timing. If growers choose to windrow early to finish early, that decision will come at a significant price paid in terms of decreased yield and oil%.

GOA's trial work on desiccation products has shown little advantage in terms of closing the gap on harvest timing, with Reglone, while not consistent, performing better that Weedmaster DST but overall neither achieving practically useful results.

Useful resources

GRDC Grow Notes- Canola: https://grdc.com.au/resources-and-publications/grownotes

Direct heading factsheet: www.grdc.com.au/GRDC-FS-Direct-Heading-Canola

Canola best practice management guide for south-eastern Australia: https://grdc.com.au/resources-and-publications/all-publications/publications/2009/08/canola-best-practice-management-guide-for-southeastern-australia

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Summer crop choice in northern farming systems – impacts on root lesion nematode, charcoal rot, AMF and winter cereal crop pathogen levels

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Key words

pathogens, PREDICTA®B, disease risk, crop rotation, break crop, Fusarium crown rot

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Take home messages

- Summer crop choices are complex and should include consideration of their relative impact on pathogens and beneficial soil biota such as arbuscular mycorrhizae fungi (AMF)
- Mungbean resulted in the greatest increase in AMF populations but also elevated disease risk for charcoal rot and the root lesion nematode (*Pratylenchus thornei*) compared with sorghum, cotton, maize, sunflower and millet
- Summer crops generally reduced Fusarium crown rot risk for following winter cereal crops but variation appeared to exist in their relative effectiveness
- Maize, cotton, sorghum and mungbean appear to be potential alternate hosts for the winter cereal pathogen *Bipolaris sorokiniana* (common root rot), while sunflower does not appear to be a host
- Quantification of individual summer crop choices on pathogen levels has highlighted potential areas requiring further detailed investigation to improve management of these biotic constraints across northern farming systems.

Introduction

Crop choice decisions often involve trade-offs between different aspects of farming systems. In particular, crop choice should consider the need to maintain residue cover, soil water and nutrient availability, and managing pathogen inoculum loads using non-host crops to avoid or reduce risk of problematic diseases (e.g. Fusarium crown rot). This is increasingly challenging as many cropping systems face evolving diseases and weed threats. Hence, understanding how different crops impact on these aspects is critical.

With limited winter rotation crop options in the northern grains' region, summer crops offer advantages as break crops within cropping sequences. Incorporating a mix of summer and winter crops allows variation in herbicide and weed management options, often also serving as disease breaks within the system. For example, sorghum is known to be resistant to the root lesion nematode *Pratylenchus thornei* (*Pt*), allowing soil populations to decline. However, the increasing use of summer crops in many regions, has seen an increase in the frequency of other diseases (e.g. charcoal rot caused by the fungus *Macrophomina phaseolina*). Similarly, using long fallows to transition from summer to winter crop phases can induce low levels of beneficial arbuscular mycorrhizae fungi (AMF) populations associated with long-fallow disorder. In this paper, we interrogate the data collected from northern farming systems research sites over the past 6 years to examine how different summer crop options impact on levels of both pathogen and AMF populations within farming systems.

What was done?

Seven research sites were established in 2015 to test a range of different farming systems in different environments across northern NSW, southern and central Qld. Over the life of the project, the team has sampled and analysed soil (0-30 cm) using the PreDicta® B quantitative PCR (qPCR) DNA analysis to examine how pathogens and other soil biology have varied over a range of crop sequences. A specific PreDicta® B test panel targeted at quantifying a wide range of pathogens important to the northern grains region has been used throughout the project. Here we have looked specifically at the impact of summer crops grown in these crop sequences to calculate the extent of change in DNA populations of pathogens and AMF associated with crop choices. It should be noted that populations are what have naturally developed within each system at the various sites and were not artificially inoculated.

Data from site-crop combinations where a particular pathogen or AMF was not present or below testing detection limits was excluded, as this does not provide a useful indication of the propensity of a crop choice to impact a particular pathogen or AMF population. PreDicta®B data from soil samples collected at sowing and after harvest of each summer crop were used to calculate relative changes or multiplication factor for populations over their growing season for the various summer crop rotation options. This multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0) in pathogen levels following growth of different summer crops.

What did we find?

Root lesion nematodes

Root lesion nematodes (RLN, *Pratylenchus* spp.) are microscopic plant parasites which feed on crop roots. Two important species are known to infect crops in eastern Australia, namely *Pratylenchus thornei* (*Pt*) and *P. neglectus* (*Pn*). *Pt* is known to be the more important species in higher clay content soils in northern NSW and Southern Qld while *Pn* is generally more prevalent in lighter soil types in south-eastern Australia. *Pn* generally feeds and causes root damage in the top 15 cm of soil whilst *Pt* can feed and damage roots down the entire soil profile. Root damage restricts water and nutrient uptake from the soil causing yield loss in intolerant winter cereal and chickpea varieties. Only *Pt* densities were prevalent at high enough densities across northern farming system sites to examine the effect of summer crop options on soil *Pt* populations.

Summer crops are known to vary in their susceptibility to *Pt* with sorghum, cotton, millet and sunflower considered moderately resistant-resistant (MR-R). Maize is considered susceptible-MR (S-MR) whilst mungbean is S-MRMS (GRDC root lesion nematode fact sheet - https://grdc.com.au/__data/assets/pdf_file/0031/385627/GRDC_FS_RootLeNematodesNorth_190213.pdf). The range in resistance ratings can relate to differences between varieties. Our results support these general findings. Mungbean resulted in the highest average increase in *Pt* populations, whilst sorghum favoured the lowest population increases (Table 1).

Table 1. Effect of summer crop choice on *Pratylenchus thornei* soil populations

	Sorghum	**Mungbean**	**Cotton**	**Maize**	**Sunflower**	**Millet**
Multiplication factor*	1.4	8.3	3.2	2.0	3.4	5.0
Range	0.2 - 6.6	4.0 - 21.3	0.8 - 13.7	1.4 - 2.8	3.2 - 3.7	4.0 - 6.0
No. observations	31	20	10	5	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Charcoal rot (Macrophomina phaseolina)

Charcoal rot, caused by the fungus *Macrophomina phaseolina*, is primarily a disease of summer crops including sorghum, maize, cotton, mungbean and sunflower in northern NSW and Qld. Infection causes light brown lesions on crowns and roots and results in increased lodging and/or premature plant death when stress associated with dry weather occurs late in the growing season. *M. phaseolina* has a wide host range of more than 500 weed and crop species including winter cereals.

Table 2. Effect of summer crop choice on *Macrophomina phaseolina* (charcoal rot) soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	9.5	150.0	20.8	7.2	28.9	3.9
Range	1 - 27	5 - 1191	1 - 117	4 - 11	6 - 50	2 - 6
No. observations	23	23	9	4	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

All six of the summer crops grown increased average *M. phaseolina* populations by between 3.9 to 150.0 times demonstrating the known wide host range of this fungal pathogen (Table 2). However, considerable differences were evident between the various summer crop options with mungbean elevating populations 5 to 40 times more than the other crops (Table 2).

Arbuscular mycorrhizae fungi (AMF)

AMF colonise roots of host plants and develop a hyphal network in soil which reputedly assists the plant to access phosphorus and zinc. Low levels of AMF have been associated with long fallow disorder in dependent summer (cotton, sunflower, mungbean and maize) and winter crops (linseed, chickpea and faba beans). Although wheat and barley are considered to be low and very low AMF dependent crops respectively, they are hosts and are generally recommended as crops to grow prior to sowing more AMF dependent crop species, in order to elevate AMF populations.

There are two PreDicta® B qPCR DNA assays for AMF with combined results from both assays presented. It is important to remember that in contrast to all the other pathogen assays outlined, AMF is a beneficial fungus, so higher multiplication factors are good within a farming system context.

Table 3. Effect of summer crop choice on arbuscular mycorrhizae fungi (AMF) soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	3.5	26.8	10.7	5.7	12.0	7.2
Range	0.4 - 12.4	2.2 - 61.5	1.8 - 32.0	3.4 - 8.0	6.3 - 17.6	6.5 - 7.9
No. observations	41	22	10	4	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Mungbean resulted in the highest average increase in AMF populations, whilst sorghum was the lowest (Table 3). Interestingly, even though millet was grown as a short cover crop twice within these farming systems, it resulted in around a 7-fold increase in AMF populations. Hence, millet may be a good option for restoring ground cover over summer and AMF populations which both decline following extended dry conditions.

Fusarium crown rot (Fusarium spp.)

Two PreDicta® B qPCR DNA assays detect genetic variants of *Fusarium pseudograminearum* with a separate third combined test detecting *F. culmorum* or *F. graminearum*. All three *Fusarium* species cause basal infection of winter cereal stems resulting in Fusarium crown rot and the expression of whiteheads when heat and/or moisture stress occurs during grain filling. Fusarium crown rot has increased in northern farming systems with the adoption of conservation cropping practices which include the retention of standing winter cereal stubble. Yield impacts however are sometimes offset by the higher levels of plant available water often available to the plant during grain fill in such systems when compared to tilled systems. The *Fusarium* spp. which cause this disease can survive 3-4 years within winter cereal stubble depending on the rate of decomposition of these residues. Recent research from PhD student Toni Petronaitis has also highlighted that inoculum levels can increase during fallow and non-host crop periods, with saprophytic vertical growth of the pathogen inside standing stubble under wet conditions. Inoculum within standing winter cereal stubble can then potentially be redistributed across a paddock with shorter harvest heights of break crops such as chickpeas. Hence, changes in Fusarium crown rot DNA levels may not represent actual hosting of the pathogen, rather they potentially include inoculum dynamics associated with saprophytic growth and/or redistribution of winter cereal stubble inoculum during harvest. DNA data for all three tests were combined for this interpretation to provide an overall level of *Fusarium* spp. DNA.

Table 4. Effect of summer crop choice on *Fusarium* spp. (Fusarium crown rot) soil populations

	Sorghum	**Mungbean**	**Cotton**	**Maize**	**Sunflower**	**Millet**
Multiplication factor*	1.7	2.9	0.4	0.5	-	-
Range	0.03 - 10.3	0.4 - 9.7	0.1 - 1.0	0.2 - 0.8	-	-
No. observations	19	8	3	2	-	-

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Limited observations were available to support conclusions on the relative effect of summer crops on *Fusarium* spp. associated with Fusarium crown rot. However, cotton and maize appeared most effective at reducing inoculum loads (Table 4). Results were more variable with sorghum and mungbean, but both generally reduced or only moderately increased Fusarium crown rot inoculum levels. Inoculum dynamics associated with saprophytic growth of *Fusarium* spp., potential redistribution during harvest of summer and winter break crops and the role of grass weed hosts appears worthy of further investigation to improve management of this disease across farming systems.

Common root rot (Bipolaris sorokiniana)

Bipolaris primarily infects the sub-crown internode of winter cereal crops causing dark brown to black discolouration of this tissue referred to as the disease ‘common root rot’. Common root rot reduces the efficiency of the primary root system in susceptible wheat and barley varieties resulting in reduced tillering and general ill-thrift in infected crops. This disease has increased in prevalence across the northern region over the last decade with the increased adoption of earlier and deeper sowing of winter cereals which exacerbates infection. There is little information on the effect of summer crop options on *B. sorokiniana* levels within Australian farming systems. One international study from Pakistan determined that millet, sorghum, mungbean and maize were hosts of *B. sorokiniana*, whilst sunflowers were a non-host (Iftikhar et al. 2009). Similar research has not been conducted in Australia.

Table 5. Effect of summer crop choice on *Bipolaris sorokiniana* (common root rot) soil populations

	Sorghum	**Mungbean**	**Cotton**	**Maize**	**Sunflower**	**Millet**
Multiplication factor*	3.9	2.6	6.8	7.4	0.04	-
Range	0.5 - 9.6	0.3 - 9.3	0.3 - 12.0	na	na	-
No. observations	12	6	3	1	1	-

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Although limited observations were available to support conclusions on the relative effect of summer crops on *B. sorokiniana* populations, the data appears to support the only previous study of host range from Pakistan (Iftikhar et al. 2009). Mungbean, sorghum and maize appeared to generally increase populations, whilst sunflower considerably decreased levels of this pathogen (Table 5). Cotton, which was not included in the Pakistan study, also appears to generally increase *B.*

sorokiniana soil populations (Table 5). These results indicate that the role of summer crops need to be considered when managing common root rot in northern farming systems. Further research is required to confirm the relative host range of this increasingly important pathogen.

What does it all mean?

Summer crop choice remains a complex balancing act but this research has highlighted some of the impacts on pathogen and AMF populations. For example, mungbean had the largest increase in beneficial AMF levels but had the negatives of elevating charcoal rot and *Pt* risk compared with the other summer crop options examined. Mungbean also did not appear to be as effective at reducing Fusarium crown rot risk for subsequent winter cereal crops compared with other summer crop options where data was available. The underlying reasons behind these apparent differences requires further investigation of Fusarium crown rot inoculum dynamics with a farming systems context.

These northern farming systems experiments have further highlighted the potential differential role of summer crop species as alternate hosts of the common root rot pathogen *Bipolaris sorokiniana*, supporting an overseas study. The use of qPCR within these experiments is unique in that it allows the relative changes in pathogen or AMF levels associated with various summer and/or winter crop choices to be quantified. This is more valuable than simple presence/absence data, in that it allows growers and their advisers to understand and manage potential changes in disease risk within their paddocks to limit impacts on profitability.

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Early sown sorghum and water productivity on the Liverpool Plains, NSW

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Key words

sorghum, early sowing, water use, water productivity

GRDC code

UOQ 1808-001RTX Optimising sorghum agronomy

Take home message

- The potential benefits of early sown sorghum include but are not limited to:

  - Improved grain yields due to reduced risk of crop exposure to heat and moisture stresses at flowering and grainfill periods

  - Increased water productivity (kg grain sorghum/ha/mm water used)

  - Improved grain quality as demonstrated by reduced screenings when compared to the normal sowing time and

  - Increased chance of double cropping with a winter crop as the harvesting time is moved forward
- Planting into cold soils e.g. ~ 12° C, can reduce establishment of early sown sorghum
- The grain yield of early sown sorghum is comparable or above grain yields of normal sowing times
- Early sowing alters the crop growth pattern, water use and time to flowering, leading to reduced risk of crop exposure to heat and moisture stress at critical stages (i.e. flowering and grain fill periods)
- Early sowing improved water productivity of dryland sorghum in the 2018-19 season. But in the 2019-20 season, water productivity declined as plant population increased for both very early (winter) and early (spring) sowing times. This suggests the need for a longer-term evaluation into the effect of sowing times and plant density on water productivity
- Additional trial data generated in 2020-21 and to be collected in 2021-22 will improve understanding of crop water productivity in early sowing for a range of hybrids.

Across sites analysis 2018-2020

The optimising sorghum yield project has just completed its third year of trials across seven production zones from Emerald, central QLD, to the Darling and Western downs in southern QLD, and Mungindi, Moree and the Liverpool Plains in NSW.

The focus of the trial series is on adaptation of sorghum to early sowing and managing the associated risks and benefits of this practice. These trials used three sowing times (very early/TOS1, early/TOS2 and a normal planting time/TOS3); four plant populations (3,6,9 and 12 plants/m^2), and a range of commercial sorghum hybrids (a minimum of 6) at each site in each season. The sowing dates for TOS1,2 and 3 are determined by the soil temperature (~12°C for TOS1; 14°C for TOS2, and 16-18°C for TOS3).

The results of 2018-19 and 2019-20) trials from14 sites show consistent and interesting responses across regions as summarised below:

The main driver for uniform crop emergence is the quality of seed batch (germination and vigour) (irrespective of the hybrid). This presents a management challenge, as there is no commercial seed testing method available for seed companies or farmers to reliably predict the likely seed establishment rate.

Early sowing (at ~ 12°C soil temperature) has been possible with little to no frost damage for 2018-2020 seasons. The reduced seed emergence and establishment with earlier sowing (Figure 1) means more seed must be sown to achieve the same plant population as for a normal sowing time.

The early sown crops grow under cooler temperatures and a lower photothermal quotient. This has resulted in more tillers and longer vegetative and panicle growth stages. As a result, it takes more days to reach 50% flowering when compared to a normal sowing time.

However, potential yield loss from a longer vegetative duration is offset by a reduced risk of heat and water stress at flowering, which occurred earlier in December instead of late December / early January at Breeza.

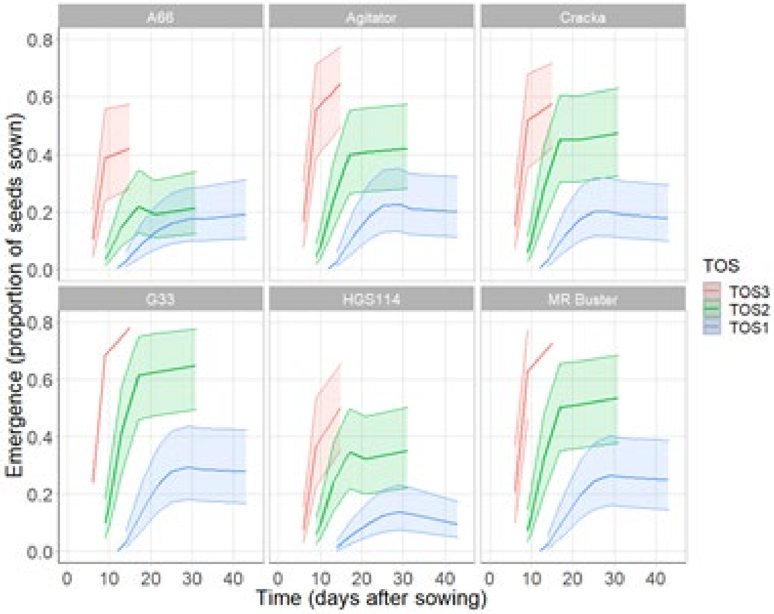

Figure 1. Predicted means (lines) and 95% confidence interval (shading) for the effect of time of sowing (TOS) on sorghum emergence dynamics (Nangwee, 2020-21 data set)

Grain yield of the very early and early sowing times were similar or higher than the normal sowing times (Figure 2). The added benefit of these earlier sowing times is the increased chance of double cropping with a winter crop as the harvesting time is moved forward.

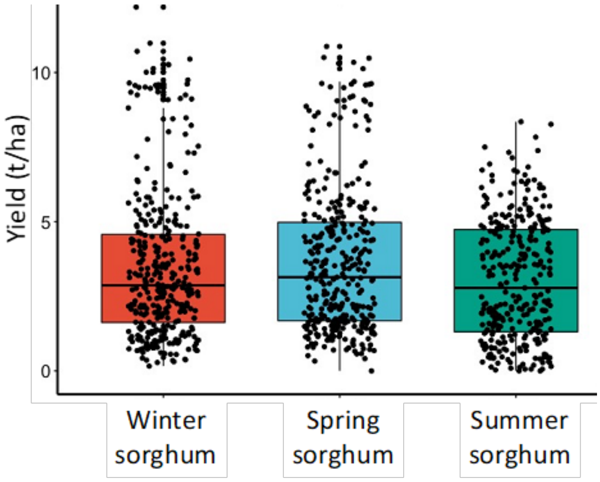

Figure 2. Treatment yields for the sowing times in winter (TOS 1), spring (TOS 2) and summer (TOS 3)

There was a large variation in yield measured (~66%) across all treatment combinations; hybrids (G), planting times and plant populations (M) (n=3,072), indicating that informing optimum Genetics x Management for each system is critical to maximising crop performance (Figure 3).

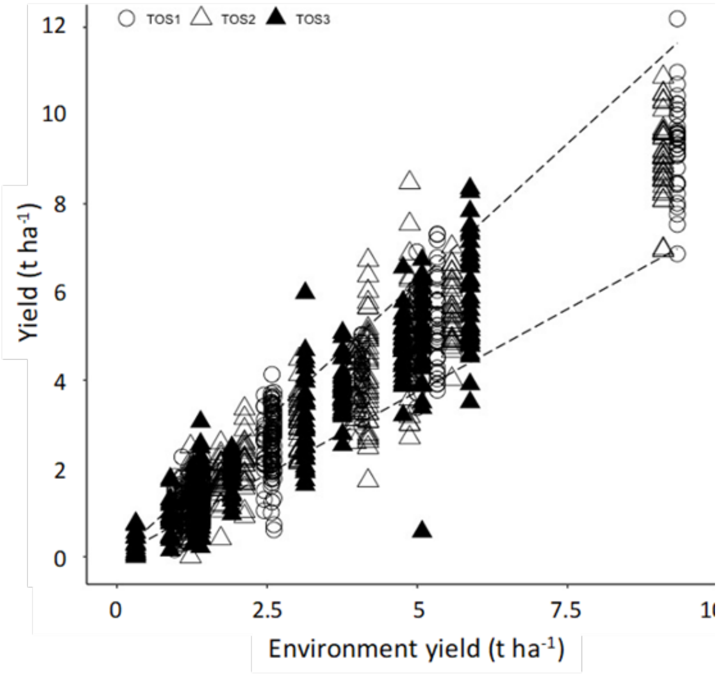

Figure 3. Grain yield as a function of the environment yield (average treatment yields for each site x season x time of sowing) for 2018-2020 with different time of sowing. Open circle indicates very early (TOS 1), open triangles early (TOS2) and closed triangle normal (TOS3).

Additional benefits from early sowing include improved grain quality as indicated by less screenings (Figure 4).

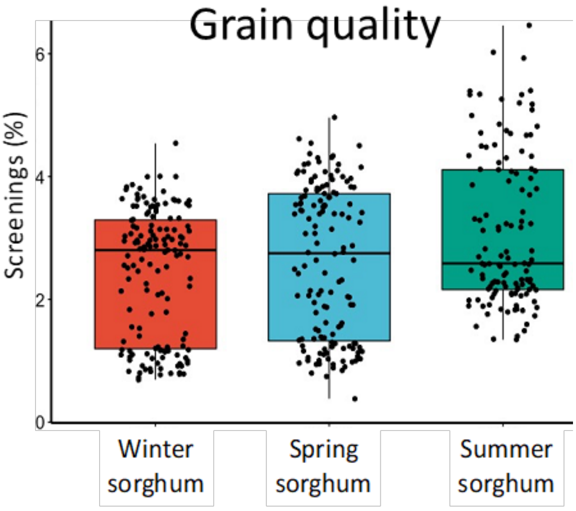

Figure 4. Observed screenings for sowing times in winter (TOS 1), spring (TOS 2) and summer (TOS 3).

Breeza 2020-21 dryland trial results

The 2020-21 dryland trials were conducted at the Liverpool Plains Field Station (Breeza), using three sowing times, four plant populations and 10 hybrids (Table 1).

Table 1. Sowing dates, target populations and hybrids for the trials in 2020/21 season at Breeza.

Sowing date	Soil temperature (7 days post sowing at 8 am)	Target plant population (plants/m^2)	Hybrids
TOS 1 - 16th Sep	16.2	3 6 9 12	A66, A75, Agitator, Cracka, G33, HGS114, MR Taurus, MR Bazley, MR Buster, Sentinel IG
TOS 2 - 6th Oct	19.4		
TOS 3 - 3rd Nov	20.1		

Plant establishment

Plant establishment percentages were good across all sowing times (>60%) (Figure 5) at 22—29 DAS. This is most likely due to the unusually warm soil temperatures (i.e. averaged 16.2 °C for the 7 days post sowing for TOS1). Significant differences occurred between hybrids, which was correlated to the seed germination and vigour (data not shown).

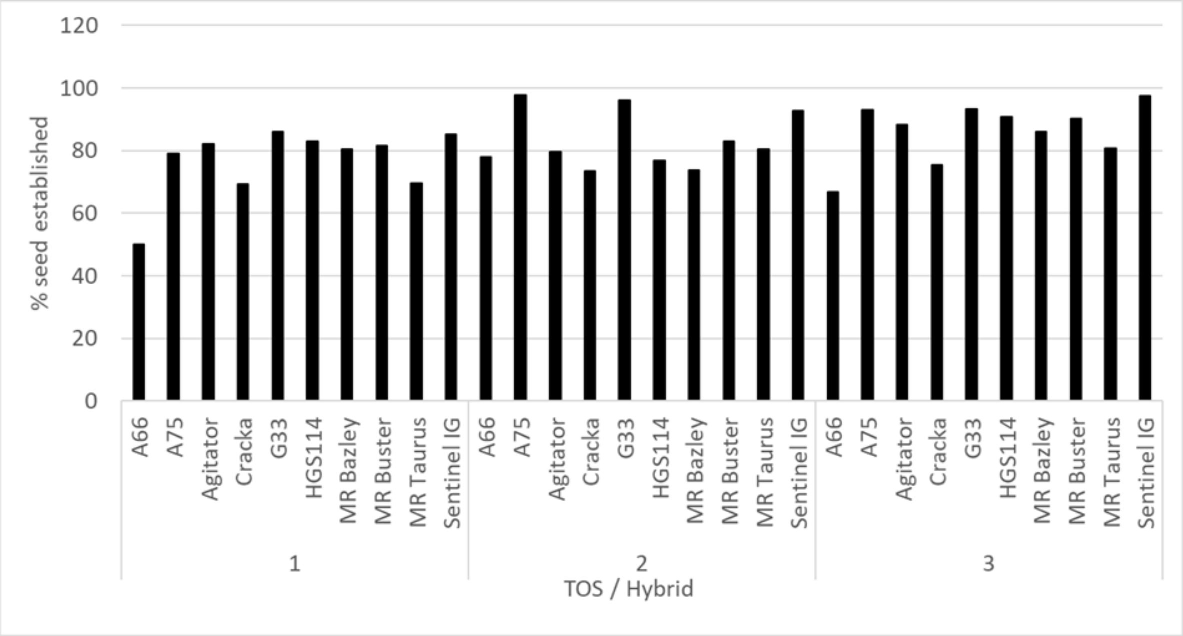

Figure 5. Plant establishment (% of seeds emerged from seeds sown) at 29 DAS -TOS 1, 22 DAS -TOS 2 & 3.

Grain yield

The average grain yield of the site was 4.57 t/ha (at 13.5% moisture). Time of sowing alone did not have a significant impact on yield but there as an interaction with hybrids. Yields for most hybrids were higher from the early (TOS 2) and normal sowing times (TOS 3), but this pattern was not consistent for all hybrids. For example, Sentinel IG produced higher yields from TOS 1 and 2, compared to the normal sowing time (TOS3) (Figure 6).

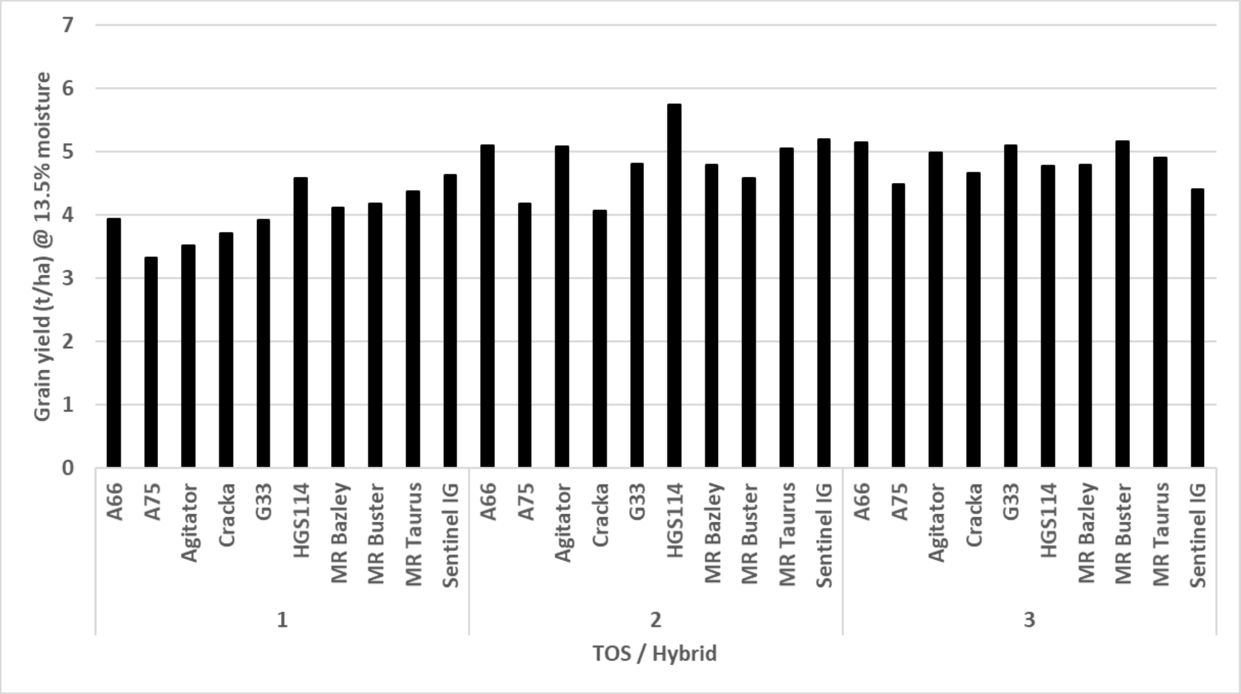

Figure 6. Grain yields at 13.5% moisture content across TOS and Hybrid at Breeza 2020-21 season.

There was also a significant interaction between hybrids and plant population.

Grain yields increased as plant population increased, with an interaction between hybrids. The highest yielding treatments were HGS114 and Sentinel IG at 12 plants/m^2 and MR Taurus at 6 plants/m^2 (Figure 7).

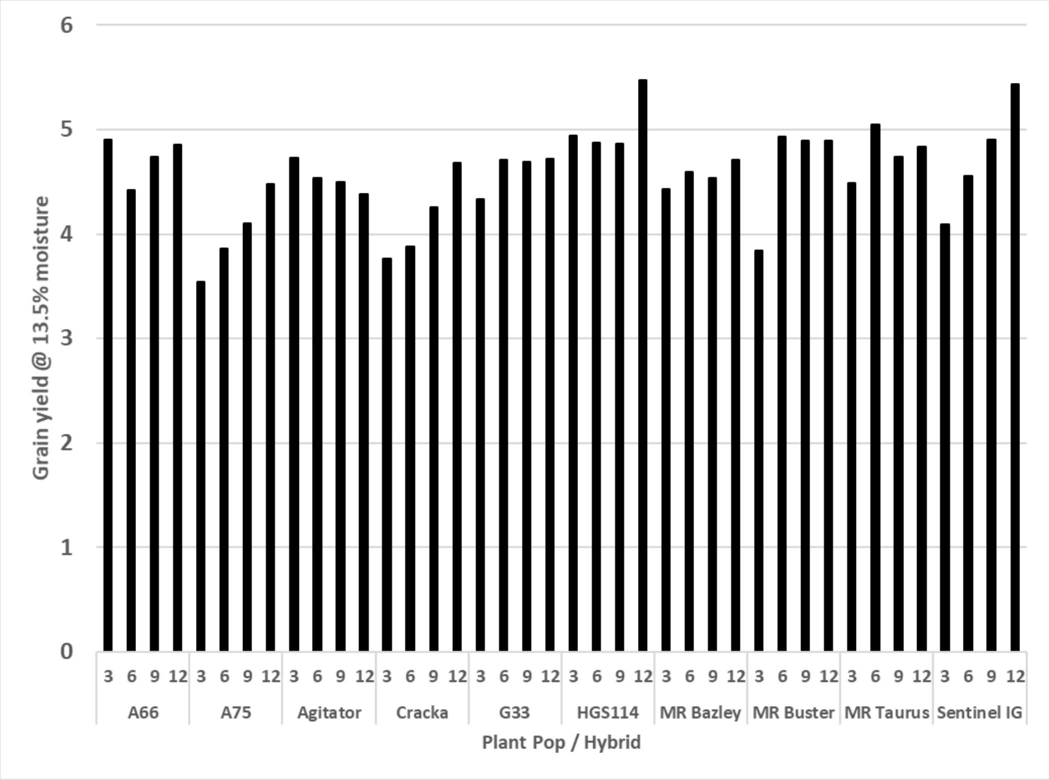

Figure 7. Grain yields at 13.5% moisture content across hybrid and plant population

Grain quality

The average grain protein contents for this season were 11.9% and it was affected by plant population and TOS (Table 2). Within TOS 1, grain protein contents declined as plant population increased, but differences were not always significant (Table 2). In contrast there was no difference in protein for populations in TOS 2.

Table 2. Time of sowing (TOS) and target plant population effect on grain protein %

	Population (plants/m^2)			
TOS	3	6	9	12
1	12.21%$_{a}$	12.18%$_{abc}$	11.93%$_{de}$	11.78%$_{e}$
2	11.87%$_{e}$	11.7%$_{e}$	11.81%$_{de}$	11.72%$_{e}$
3	11.94%$_{acde}$	11.88%$_{de}$	12.07%$_{abcd}$	12.21%$_{ab}$

The average screenings were 4.7% across all treatments which is within the limits for the receival standard ‘Sorghum 1’. There was an interaction between TOS and hybrid for screenings (Figure 8). Screenings in general were higher in TOS 3 and was particularly higher for hybrids Agitator, MR Bazley and Sentinel IG. MR Buster was the only hybrid with no significant impact on screenings between sowing times

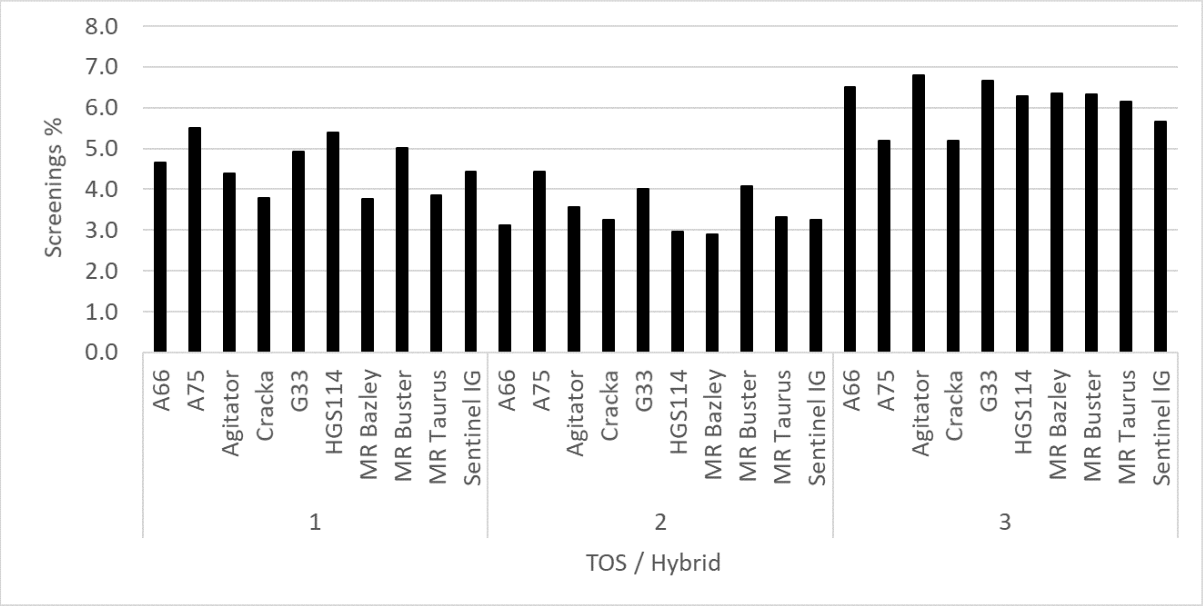

Figure 8. Screenings % at Breeza 20-21 across times of sowing and hybrid

Grain test weights were on average 67 kg/hL, which was below the 71 kg/hL Grain Trade Australia receival standard for Sorghum 1, but acceptable for Sorghum 2 (>62 kg/hL). Like screenings, there was a significant interaction between hybrid and TOS (data not shown). Test weights were higher from TOS 2.

Water productivity in early sown sorghum

Water use and more specifically, efficient use of water by the crops or 'water productivity', are critical to sorghum crop success in the western zone. The higher water productivity, the more kilograms of grain is produced for each millimetre of water used by the crop.

Sowing sorghum into cooler soil affects plant development by extending the vegetative phase or number of growing days required to reach flowering. However, as temperatures are lower during this vegetative phase (August – October), the crop water demand/use is also lower, leaving more available water in the soil profile for the grain fill period. APSIM simulations of total crop water use for 8 trial sites between central QLD and the Liverpool Plains NSW in the 2018-19 season (Figure 9), showed increased water use during the grain filling stage in the early sown sorghum (TOS 1 and TOS2), compared to the normal sowing time (TOS 3).

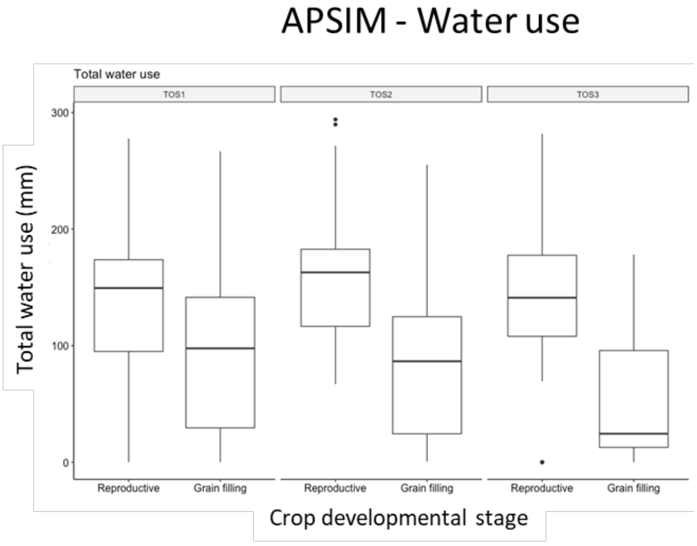

Figure 9. APSIM simulated water use (mm) between floral initiation and flowering (reproductive) and after flowering (grain filling) periods for all the treatments and sites trialled during the first season of trials.

Water productivity of dryland and irrigated sorghum under three sowing times at Breeza in the 2018-20 seasons

In 2018-19 and 2020-21 trials seasons, crop water use was monitored from dryland and irrigated treatments that also incorporated plant population density in two sorghum hybrids, at Breeza, Liverpool Plains NSW. To assess water use patterns across the three sowing times, profile soil water was monitored to a depth of 180 cm using a neutron moisture meter (NMM), from selected plots at strategic times of crop development. NMM readings were taken from all MR Buster and Agitator plots with populations of 30 and 120 plants/m^2, as well from the MR Buster 6 plants/m^2 plots to provide a commercial standard comparison. These measurements were conducted at emergence, 6 leaf, flag leaf, flowering and physiological maturity.

The NMM readings were used to estimate total crop water use (in mm), water use efficiency which is expressed as water productivity, and biomass water ratio expressed as transpiration efficiency. Water productivity (WP) is the measure of the amount of grain yield produced per mm of water used (kg grain/ha/mm water). The water biomass ratio (BWR) or transpiration efficiency is used to measure the amount of above ground biomass produced per unit of water used (kg dry matter/ha/mm water).

Dryland trials

For the 2018-19 season, the water productivity of dryland sorghum was higher in TOS 1 and TOS 2 when crops were sown into cooler soil temperatures (11.2 and 10.3 °C, respectively) compared to the normal sowing time (TOS 3, sown at soil temperature of 18.8 °C) (Table 3). There was no difference in water productivity between plant populations or hybrids in this season or significant interaction effects.

Table 3. Water productivity (kg/ha/mm) of dryland sorghum grown at Breeza 2018-19 (averaged across populations and hybrids).

Sowing time	**Water productivity (kg biomass/ha/mm)**
Very early (TOS 1)	6.51_a
Early (TOS 2)	5.68_a
Normal (TOS 3)	2.44_b

L.S.D: 2.25

In the 2019-20 season, there was an interaction between sowing time and plant population. Water productivity declined as plant population increased for both TOS 1 and 2, (soil temperature at sowing of 12.1 and 17.8 °C, respectively) (Figure 10). There was no difference in water productivity between populations for TOS 3 which was sown into higher soil temperatures (21.2 °C). MR Buster had a higher water productivity than Agitator in this season.

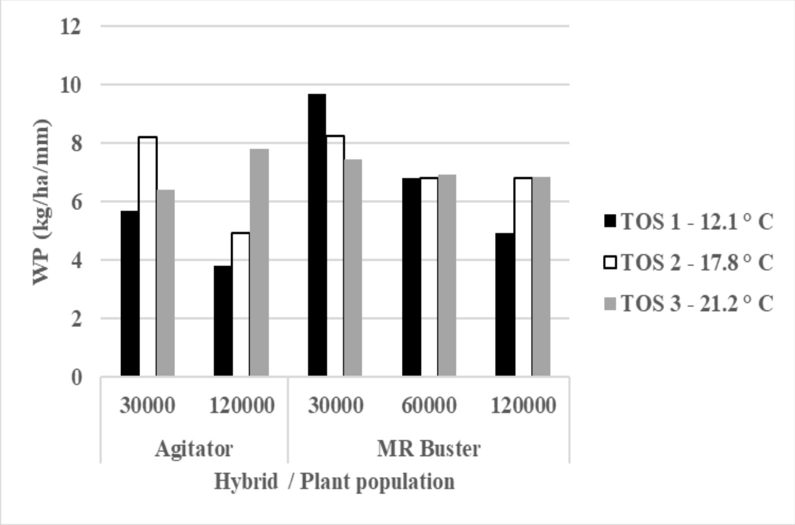

Figure 10. Water productivity response to varying sowing time at Breeza for 2019-20 season (LSD = 2.61 kg/ha/mm)

Irrigated trial

The irrigated trial was sown on 2 m raised beds and was flood irrigated pre-sowing. Three in-crop irrigations were applied at; 6 leaf stage, flag leaf emergence and flowering. The very early and early sowing times used significantly more water than the normal sowing time, by 100-110 mm, leading to a higher biomass water ratio on later sowing (Table 4). There was no interaction effect between treatments on water use and biomass water ratio. These patterns of water use or biomass water ratio did not translate into water productivity. The average water productivity of irrigated sorghum (8.8 kg/ha/mm) was higher than the dryland sorghum, but was not significantly different between time of sowing, hybrid or plant populations.

Table 4. Water use, biomass water ratio (BWR) across sowing times at Breeza irrigated trial in 2018-19

Sowing time	Total water use (mm)	Biomass water ratio (kg DM/mm)
Very early (TOS 1) - 3rd Sept	576_a	14.83
Early (TOS 2) – 18th Sept	589_a	17.99
Normal (TOS 3) – 16th Oct	475_b	21.71

Plant population had a significant impact on total water use, with higher populations using more water (516 mm for 3 plants/m^2 and 578 mm for 12 plants/ m^2). The biomass water ratio of MR Buster (19.23 kg DM/mm), was also higher than Agitator (17.12 kg DM/mm). However, the water productivity between these hybrids was not different.

Conclusions

The potential benefits of early sown sorghum include but are not limited to improved grain yield due to reduced risks of crop exposure to heat and moisture stresses at flowering and grain fill periods; increased water productivity (kg grain sorghum/mm water used); improved grain quality as indicated by reduced screenings; and increased chance of double cropping with a winter crop as the harvesting time is moved forward.

Early sown sorghum could reduce establishment when planted into cold soils (e.g. ~ 12° C). But increasing planting population can help offset this impact. When considering planting population, it is important to note that there is a high correlation between establishment and seed lot quality.

The variable responses of water productivity over 2018-19 and 2019-20 seasons, suggest the need for a longer-term evaluation into the effect of sowing times and plant density on water productivity. To improve understanding of water productivity of early sown sorghum, additional data has been collected in the 2020-21 season and will continue in the 2021-2022 season.

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Panel discussion: Implications and plans for country that was too wet to sow winter cereal

Notes

Practical management of fall armyworm

Graham Boulton, Black Earth Agronomy

Key words

fall armyworm, management, 2020, *Spodoptera frugiperda*

Take home message

Chemical control alone will not be enough to manage this pest in the long term

Introduction

This presentation is based on the practical experiences of the staff of the Black Earth Agronomy group in managing fall armyworm (*Spodoptera frugiperda*) in the Burdekin region of North Queensland and on the Darling Downs since March 2020.

The 2020 experiences

In January 2020, the Director General of DAF advised that fall armyworm (FAW) had arrived in Queensland across the Torres Strait.

In late April 2020, one of our clients planted a small block (10ha) of maize corn at Mona Park near Clare in the Burdekin Region. This field proved to be where my company started its education in dealing with fall armyworm.

At the time, no-one could tell us what strain of fall armyworm we were dealing with, or what insecticide resistance genes the FAW population was carrying.

In the beginning, we couldn't understand where all the fall armyworm larvae were coming from. We could find low numbers of egg rafts generating 2-3 larvae per plant distributed across a field. Then we discovered that the fall armyworm larvae were hatching in the egg rafts and then 'ballooning' or 'parachuting' in the breeze to colonize other plants. You only need one egg raft in 10 metres of row to produce a significant infestation of fall armyworm larvae per plant.

An application with deltamethrin to the Mona Park block at the 3-4 leaf stage killed the cluster caterpillars (*Spodoptera litura*) present in the crop but left the fall armyworm in the whorl behind. We realised that the plant stand of the crop was at risk and applied Altacor (PER89366). Acceptable levels of control were achieved to preserve the plant stand.

Critical early stage of development in maize

Based on regular and thorough scouting, we gained confidence in what was working and what was not in the Mona Park block and other early planted corn fields in the district.

In maize crops in the Burdekin in 2020, we settled on a strategy which included the following spray program to get the crop through to the 6 true leaf stage:-

1) Steward® (PER89530) The indoxacarb application was often mixed with a post-emergent herbicide for broadleaf weed control at the 2.5 to 3 true leaf stage. By trial and error, we found that indoxacarb was not effective in controlling FAW larvae if rain or irrigation fell 1-2 days after application. My current recommendation is to avoid using indoxacarb if rain is forecast in the 5 days following the spray.
2) Altacor (PER89366) (if deemed necessary by crop monitoring).

In some maize crops, we applied only one insecticide spray during the early stage of crop development because the FAW moths did not ‘find’ the corn field until it was already at the 4-5 true leaf stage. If crop monitoring indicated that two insecticide applications were required, they often occurred 7-10 days apart during the 2 to 5 true leaf growth stage.

On some farms, we were able to achieve acceptable levels of control with *Bacillus thuringiensis* (Bt) sprays until the third week of May 2020. By this time, the FAW population in the Burdekin and Bowen Regions was increasing exponentially. It reached the point where we were not confident that we would obtain acceptable levels of control using Bt. Consequently, we switched to conventional chemistry.

Cost savings can be made by applying the insecticide in a 50% band over the row, particularly when the crop is 2-4 true leaves.

Once the maize crop had reached 6-7 true leaves, we felt that the plant stand was not at risk. We decided to stop spraying and monitor the FAW larval population and the leaf damage that ensued. The leaf damage caused by large FAW grubs in the whorl from 6 true leaves up to tassel emergence can make the crop appear very ’mauled’ but I don’t believe that significant yield reductions resulted from this vegetative damage in 2020.

Critical late stage of corn development

By the time that *‘most’* maize fields had tasselled, all the FAW larvae had gone to ground to pupate.

I was relieved that I did not have to recommend another spray to control FAW and Helicoverpa larvae moving down from the tassels to attack the developing cobs.

When the kernels had coloured and were midway through the soft dough stage, I thought that my job was done with FAW. Little did I know! There were large FAW and Helicoverpa in the tips of a high percentage of the cobs.

It is commonplace to find Helicoverpa going through their life cycle from eggs laid in the silks to large larvae in the tips before going to ground to pupate.

What wasn’t expected was the behaviour of very small and small FAW larvae crawling beneath several layers of husk from the tips to midway down the cobs in most of the corn paddocks.

Several test strips were initiated using Altacor (PER89366) and Steward (PER89530) applied by air. The crops were too tall for most ground rigs. As you would expect, control of FAW larvae under the husk was not effective.

The FAW larvae proceeded to grow through to their final instar, feeding on the kernels midway down the cob length. At this late instar stage, they chewed exit holes through the husks to go to ground to pupate. This left many cobs with 2-3 large ’bullet holes’ or damage that I describe as body grub damage. The risk of crop failure from aflatoxins and cob rots was very real and some growers prepared to harvest at high moisture rather than allow the crop to experience a rainfall event. Fortunately, it was a very dry finish and all crops were harvested successfully.

One interesting observation was that on three farms (6% of the total maize area under our supervision in 2020), the incidence of body grub damage was minimal. These farms were aerially sprayed with Altacor (PER89366) at tasselling/early silking because the crops were uneven and medium to large FAW larvae were still present when the tassel emerged.

This tassel spray is now standard practice for Black Earth Agronomy **whether or not** there are FAW larvae present at tasselling until research or experience proves otherwise.

Subterranean behaviour

In some corn and soybean plantings, we found that FAW can behave like cutworm.

Case 1

Once volunteers from a previous crop of soybeans had been sprayed out, we discovered that large FAW can quite happily survive under the soybean trash layer for some time before attacking corn plants at the 1-2 true leaf stage. In this case, chlorpyrifos was applied in the late afternoon to control ’cutworm’ and the crop damage subsided.

Case 2

This subterranean ’cutworm’ behaviour was replicated in an August planted crop of soybeans. The grower had a few scattered grass weeds (feathertop Rhodes, crowsfoot and summer grass) in the field where he intended to plant winter soybeans. The grower worked the ground with discs before hilling up and pre-watering.

After a week, small weeds which had germinated were sprayed with glyphosate prior to planting. Before the crop emerged, the field was sprayed with paraquat and metolachlor before flushing the field again to ensure an even crop emergence and survival of the inoculant for successful nodulation. The crop emerged very well.

At the one trifoliate leaf stage, we noted that the soybean seedlings were being attacked above and below ground level. We could find no larvae on the leaves and stems so we proceeded to dig underneath the crop row. There we found large FAW larvae down to 5cm deep in the soil profile.

These larvae were chewing through the base of the seedings below ground level. In the evening, the larvae were feeding on the leaves and stems above ground. We applied deltamethrin because chlorpyrifos is not registered for ’cutworm’ in soybeans. Either the deltamethrin was effective OR the large FAW pupated soon after application, but crop damage subsided quickly and an acceptable plant stand was achieved.

Case 3

In 2021, we have seen a repeat of this behaviour where FAW larvae have infested grass seedlings in the fallow prior to sowing corn. The grasses were sprayed out prior to planting but the larvae seem to be able to survive in the soil until the crop emerges.

Other potential host crops

For those sorghum crops planted in the Burdekin in January-March 2020, we found very few FAW larvae infesting the crops grown on our client’s properties.

Similarly for Panorama Millet planted in July or Shirohie Millet planted in August 2020.

We have anecdotal evidence that FAW have caused significant leaf damage in forage sorghum around Gumlu.

FAW larvae have also penetrated capsicum bells without leaving obvious points of entry. It is disconcerting when ‘unblemished’ fruit reach the markets containing FAW larvae!

Negligible numbers of FAW larvae have been found in green beans, mungbeans or soybeans in the Burdekin.

The 2021 experiences

Corn

Due to the price of corn falling to $280 per tonne in the Burdekin, most growers have decided not to grow corn this winter, especially when the cost of production has increased significantly due to fall armyworm. An increased level of crop monitoring by the grower or his consultant is also required to manage the pest.

In 2021, we have chosen not to recommend Altacor (PER89366) in the early growth stages of corn to reduce our reliance on this valuable insecticide group.

We now suggest that our clients use emamectin benzoate (PER89371) instead.

This season, we only have 3 blocks of popcorn (Var. R502 Butterfly) which were planted in early April. To date, we have sprayed the crop 3 times for FAW, twice with emamectin benzoate (PER89371) at the 2-5 true leaf stage and once with Altacor (PER89366) at tasselling. Emamectin benzoate (PER89371) was chosen at the early stages because the weather was rainy and unpredictable. The grower also used QM FAW/methomyl (PER89279) to attract and kill the FAW moths.

Sorghum

One of the neighbouring farms in the Burdekin planted large areas of grain sorghum during the wet season (January-March 2021). The neighbour said that he did not treat any of his sorghum for fall armyworm.

In some blocks, he estimates that crop losses of 50% have occurred in both dryland and irrigated sorghum blocks due to FAW damage. In these cases, high numbers of FAW larvae were present during the late vegetative phase which led to significant damage by large FAW larvae to the developing head in the boot.

In a telephone hook-up last year, I was advised that this type of damage had been observed in grain sorghum crops grown in Texas in the USA (Anthony Hawes *pers.com*). The USA experience suggested that the FAW larvae hidden by the leaves surrounding the developing head in the boot cannot be killed by insecticide sprays. Consequently, you would have to recognise that you had a developing problem with FAW numbers **before** the crop reached the boot stage.

What larval sizes and numbers constitute a spray threshold in vegetative sorghum?

We did not observe this type of head damage in the mid-January planted sorghum on our clients' properties on the Central Darling Downs this season. The FAW larval population remained low throughout the crop's growth and development.

A similar circumstance exists in corn. We have found that you cannot kill FAW larvae feeding on the developing tassel in the whorl until the tassel emerges from the surrounding sheath of leaves. The timing of a spray can be very difficult to determine if a crop is uneven in tassel emergence.

Area wide management

Without doing a statistical analysis of our scouting records, it was apparent to the staff of Black Earth Agronomy that if you fail to control a significant population of FAW larvae in a crop on your farm or on a neighbouring block in your local district, you can generate your own FAW plague or pandemic.

It becomes a numbers game.

In a highly susceptible crop such as corn, you are in big strife if you start to find 2 egg rafts per metre of row in a crop at the 2 true leaf stage. This equates to 200-400 eggs per metre.

This situation requires repeated sprays to reach the 6 true leaf stage. Even then, you may finish up with one large FAW larva buried deep down in the whorl of every plant, which you cannot control with insecticide. Without disease or parasitism, this has the potential to produce 13,333 moths per ha which begin another cycle in the later stages of the crop or migrate to your neighbour's susceptible crop.

Trichogramma

We have tried releasing *Trichogramma pretiosum* which you can buy commercially. We can definitely 'see' a high number of parasitised Helicoverpa eggs in the field but we haven't seen FAW egg rafts which have been significantly parasitised. The staff of Black Earth Agronomy have also caged FAW egg rafts together with commercially reared *T. pretiosum* but have ended up with a cage full of FAW hatchlings! We have not counted the number of eggs in the FAW egg rafts or the number of larvae that actually hatched so we do not have an accurate measurement of the level of parasitism. Melina Miles, DAF Entomologist in Toowoomba, and Siva Subramaniam, the DAF Entomologist in Bowen, might have more accurate numbers from their research in controlled, laboratory environments.

Other pests and diseases of fall armyworm

High levels of parasitism by a parasitic wasp called *Cotesia ruficrus* were recorded in maize crops monitored by Steve and Anna Madden, agricultural consultants in Northern NSW, in the spring of 2020. It is uncertain whether this parasitic wasp species would be a suitable candidate for mass rearing in a commercial insectary. This could be a research project for an aspiring entomologist or entrepreneur?

Fawligen (Permit No. PER90820) is a virus preparation which infects and kills small FAW larvae. To date, Black Earth agronomists have not trialled Fawligen as a 'stand-alone' product against FAW in corn in the Burdekin. It has been used as a mixing partner with conventional insecticides to lower the potential for the development of insecticide resistance. We have felt that the FAW pressure in the corn has been too high and the prevailing minimum temperatures too low to risk a stand-alone application of Fawligen.

Metarhizium (formerly known as Nomuraea) is a fungi genus that has shown that it can kill FAW in NQ. Occasionally, we have come across FAW larvae which have been infected by a local species of Metarhizium in maize crops but the incidence is very low. In the Giru district in the Burdekin, Metarhizium was responsible for the death of a significant number of cluster caterpillars (*Spodoptera litura*) in soybean crops at the end of summer in 2021. I understand that commercial preparations of Metarhizium could become available in Australia in the next few years.

Attract and kill technologies

This technology offers a lot of potential to reduce the FAW moth population on a farm and would be the core of an area wide management plan where susceptible crops are grown.

Magnet® was developed 18-19 years ago as a feeding attractant for Helicoverpa moths which were killed by an insecticide added to the mix. The Magnet/insecticide mix is applied in a very coarse spray to the crop row at a pre-determined interval (36 or 72 metres).

In the winter of 2020, all the Magnet supplies in Australia were sent to the Ord river irrigation area to aid in protecting the seed corn and sorghum production areas.

AgBitech were able to import the active ingredients to make and distribute another batch of Magnet by the end of August 2020.

Magnet (PER89398) was applied commercially to sweetcorn crops in the Bowen and Burdekin regions in the spring and early summer of 2020. Dead Helicoverpa and FAW moths could be found at the base of the corn rows the day after application. The overall effect of applying Magnet to reduce the incidence and distribution of FAW across the farming enterprise was inconclusive in 2020.

In an experiment, Black Earth staff discovered that a large number of moths of various species including FAW could be caught in pheromone bucket traps where the pheromone lure was replaced with a Magnet lure. This experiment was conducted adjacent to a field where poor control of FAW larvae had been achieved. The aim of the experiment was to determine how attractive Magnet was to FAW moths rather than as a tool to reduce the moth population in a particular area of the field.

New attractant products are being developed to target fall armyworm moths. These include Smartgreen Biosciences QM FAW and Organic Crop Protectants ACTTRA FAW.

More trial work needs to be conducted to determine which attractant works best on FAW moths and to quantify the benefits of suppressing moth numbers across a farming district. Quantifying the effect of attract and kill technology is a difficult task.

Different attractant products applied to different fields in a district might be more beneficial than relying on one attractant?

More research needs to be conducted on insecticides to mix with the moth attractants.

The moth attractants do attract a whole range of insect species including beneficials such as lady beetles. Having broad spectrum insecticides such as methomyl as the mixing partner may be useful in the short term. In the future, we need more specific adulticides which target the pest species and conserve the majority of the beneficial insects.

The development of Bt cotton technology and nuclear polyhedrosis virus (NPV) for controlling Helicoverpa in grain sorghum was fundamental to the Area Wide Management of Helicoverpa in the mixed cropping systems on the Darling Downs.

It will take a mixture of different technologies to manage FAW in the future.

Ultimately, developing an Area Wide Management Plan for FAW and assessing its success or failure might be the best course of action. Over time, the diseases, predators and parasites in the local environment might adapt to the availability of the new food resource and assist us in managing the pest.

One thing I am sure of is that we can’t rely on chemical control to manage this pest in the long term.

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Rob Stockham & Sons, Giru
Mark Vass, Home Hill
Aaron Linton, Home Hill

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Grain storage, what's new: managing large flat-bottom silos; grain protectants; storing pulses; resistance update

Philip Burrill, Greg Daglish, Manoj Nayak, Raj Jagadeesan, Department of Agriculture and Fisheries, Queensland

Key words

monitoring stored grain, large grain silos, grain protectant insecticides, storing pulses, phosphine insect resistance, grain pest control

GRDC codes

PRB2011-001SAX, DAQ1906-00RTX

Take home message

- Regular monthly monitoring of stored grain and keeping records for both small and large capacity silos is critical for successful grain quality results and storage pest control
- Carefully check the design and build quality of any monitoring equipment before purchase and instalment in silos. Grain temperature and equilibrium relative humidity (ERH) information is valuable but requires robust sensors, carefully placed
- Monitoring of fumigation gas levels in large silos and storages such as grain bunkers and sheds helps to check if grain pests have had the required dose over time to achieve effective control.
- Talk with potential grain buyers and seek advice prior to applying grain protectant treatments. Each year restrictions change with respect to acceptance of insecticide residues in both domestic and export markets
- Storage pests can develop resistance to fumigants and grain protectants. Growers should be alert to this threat and ensure that phosphine fumigations are conducted to the highest standard and choose effective grain protectant combinations
- Effective management of insect pests of stored pulses is possible using an integrated approach: pest monitoring, aeration cooling and phosphine fumigation.

Managing large flat-bottom silos – grain quality & pests

- There has been widespread investment in large flat-bottom silos by many grain growers as part of on-farm storage facilities. While large capacity (600 – 2000 tonnes), flat-bottom silos are a cost-effective on-farm storage method, they currently have a significant downside. The silo design makes it difficult to carry out effective checks for storage pests and storage conditions, such as grain temperature and moisture content.
- Regular monitoring is critical to ensure grain quality is maintained and pests are controlled in a timely manner. In addition, an efficient method for monitoring gas levels at a number of locations in a large silo during a fumigation would also be beneficial.
- While there are grain storage monitoring systems available from the USA and Canada, most have design issues that currently make them unsuitable for the majority of silos / storages in Australia.

Figure 1. A farm storage facility with ten large flat-bottom silos, each with 1500 tonnes capacity (photo DAF Qld)

Figure 2. Cable or canister monitoring systems can be located inside a silo to monitor grain temperature, humidity or gases

Things to consider when assessing storage monitoring systems

- Measuring both grain temperature and equilibrium relative humidity (ERH) is valuable as it provides information on storage conditions, grain moisture content and providing insight as to how active insect pests are, if present
- Tests following phosphine fumigation have shown that sensors inside a silo designed to measure humidity in grain can be permanently damaged by phosphine gas during a standard fumigation
- Sensor location inside a silo is critical. If sensors are too close to silo walls, readings may be influenced by excessive grain trash or external temperatures i.e. sun or shade on walls
- Some sensors may be difficult to install in silos and to access later if they require maintenance
- Grain storage sensors and cables are in a hostile environment with dust, heat, moisture and significant physical stresses when the silo is filled, emptied and as grain settles during storage
- Sensor's build quality, lifespan and long-term accuracy will be important for each parameter i.e. grain temperature, humidity and in some cases gas concentration measurements

- Reliable communication of data between the internal storage sensors and external reading / recording devices will be required.

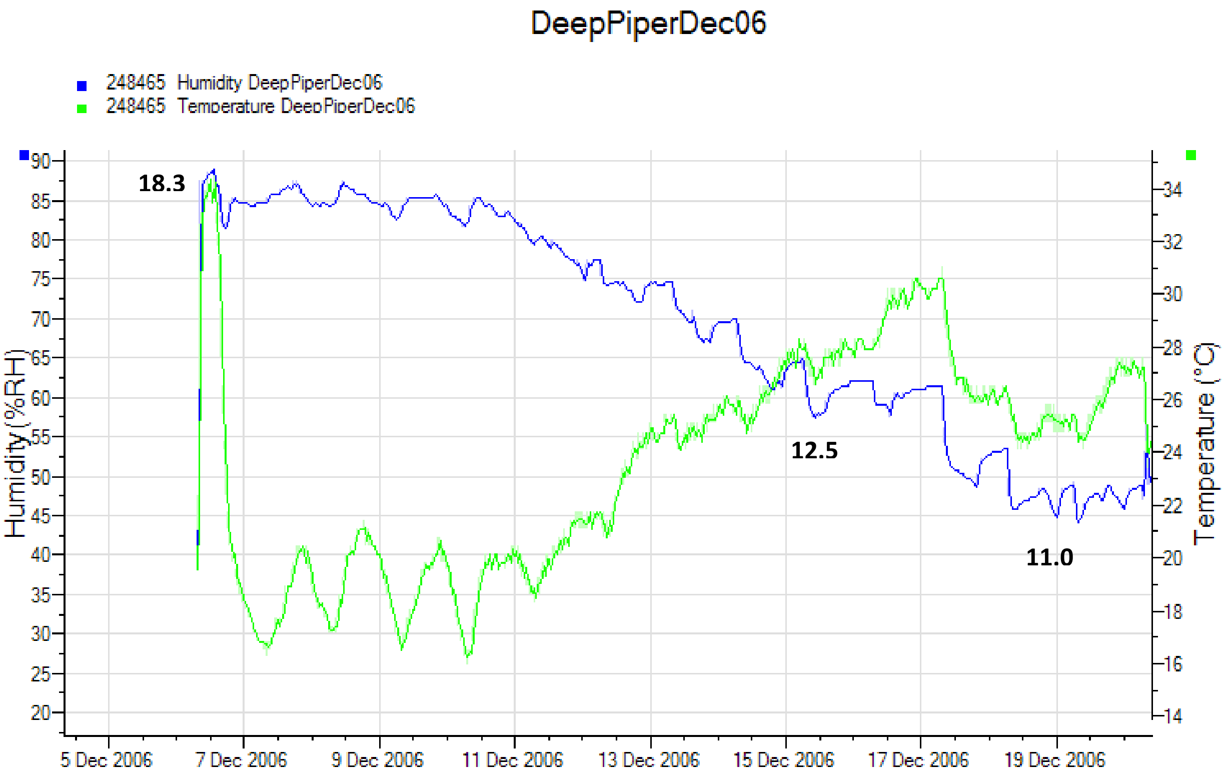

Figure 3. Sensors in the lower half of a 60 tonne aeration drying silo measured both wheat temperature and equilibrium relative humidity (ERH). Using this information wheat moisture contents (18.3%, 12,5%, 11.0%) can be determined using a wheat ERH chart. The silo was fitted with a 7.5 kW fan delivering an airflow rate of 27 L/s/t for 238 hours to reduce moisture content from 18.3% to 11.0%

Pest detection and fumigation

Timely pest detection in stored grain is critical to ensure grain is ready for sale, meeting the 'nil live stored grain insects' delivery standard. Early detection of pests is also important to ensure significant grain losses and grain quality damage does not occur.

While it is relatively easy to sample grain and check for pests in small cone-based silos, it is difficult to check for storage pests in large flat-bottom silos with limited access to sample grain at the base and top of silos. Currently there appears to be very few commercial products offered to resolve this pest detection issue for large silos.

Unfortunately, this can lead to the practice of 'calendar based' regular fumigations of large silos. Silos are fumigated with no knowledge of either pest numbers or pest species present. Any grain stored for 12 – 18 months plus, may then receive multiple fumigations, some of which may not have been required. This is when the risk of development of insect pest resistance to fumigation products like phosphine increases substantially.

Measuring gas concentrations during fumigation at a number of locations inside large silos or other large capacity storage types like grain bunkers or sheds is important. For any fumigation to be effective at controlling storage pests, the insects need to be exposed to a given gas concentration ('C'), for a specified length of time '(T)'.

If this ‘C x T’ exposure requirement is not met throughout all parts of the storage during the fumigation, survival of various insect life cycle stages (eggs, larvae, pupae, adults) is likely. Live adult insect pests will quickly reappear in the grain within days or weeks.

Along with not killing the pests, poor fumigation can also lead to selection and development of resistant insect populations.

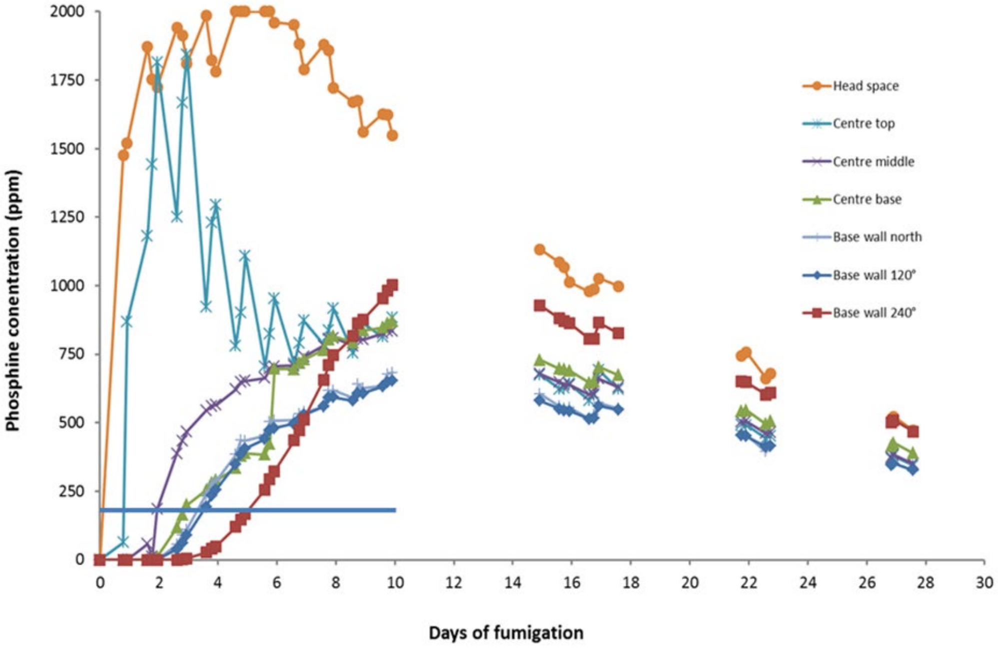

Figure 4. Phosphine gas concentrations at 7 locations in a silo fumigating 1420 t of wheat. Phosphine blankets were placed in the silo headspace with no gas recirculation. It took 5 days before all grain at the silo base reached at least 200 ppm gas concentration.

Potential future ideas for grain & pest monitoring equipment

- Development of grain storage humidity sensors that are not damaged by phosphine fumigations would add significant value to the current commercial grain moisture cables or canisters (e.g. OPI® moisture cable)
- Developing a new storage cable designed to included both temperature sensors plus 3 or 4 air sample lines to sample air at various heights within the storage could provide multiple measurement functions e.g., equilibrium relative humidity (ERH), fumigation gas levels and detection of insect pest pheromones
- Fitting small ports through the silo wall next to silo ladder landings provides access for 1.0 to 1.5 meter-long grain probes. These 6 mm diameter stainless steel probes are currently available (Graintec Scientific™) to measure grain temperature and to take air samples for a range of functions.

Grain protectant treatments update

Warning: Grain protectant notes below do not apply to the grains industry in Western Australia where their use is restricted. In all cases, product labels are to be used to determine correct use patterns.

Grain protectant sprays – a useful tool for storage management

Strategic use of grain protectant insecticides is only one of five key strategies to maintain grain quality and achieve reliable pest control results. Combined, they form the foundation of successful grain storage. Good results with on-farm grain storage is crucial in the long term for a producer to build a reputation as a reliable supplier of quality grain with no pest problems. Key aspects of successful grain storage are:

1. **Aeration**: correctly designed and managed, it provides cool grain temperatures and uniform grain moisture conditions. Aeration reduces problems with moulds and insect pests in storage, plus maintains grain quality attributes such as germination, pulse seed colour, oil quality and flour quality.
2. **Hygiene**: is crucial in keeping background pest numbers to a minimum and reducing the risk of grain contamination.
3. **Monitoring**: monthly checking of grain in storage for insect pests (sieving / trapping) as well as checking grain quality and temperature. Record these details, including any grain treatments applied.
4. **Fumigation**: in Australia we now only have gases (fumigation) to deal with insect pest infestations in stored grain. To achieve effective fumigations the storage/silo must be sealable – gas-tight (AS2628) to hold the gas concentration for the required time.
5. **Grain protectants**: used on specific parcels of grain like planting seed held on farm, or bulk grain where potential grain buyers have agreed to its use in accordance with the currently registered label, grain protectant sprays provide another line of defence against storage pests in specific situations.

Use of grain protectants on cereal grains for both domestic and export markets is becoming increasingly difficult. Acceptance of insecticide chemical residues on grain, even at extremely low levels, has changed significantly in the last few years. It is important that growers always check with potential grain buyers before using grain protectants.

The Manildra Group™ is a recent example of a large tonnage, Australian wheat buyer who has been required to move to pesticide residue free (PRF) grain due to a number of European and Asian countries banning residues of commonly used grain protectant chemicals such as chlorpyrifos-methyl.

When to use grain protectants

- Typically, protectant sprays are applied to clean cereal grain at harvest time as grain is augered into storages, providing storage pest protection for 3 to 9 months. Protectants are effective at controlling insects as they invade or emerge from eggs within grain during storage
- Grain protectant sprays are not to be used to disinfest grain. When live storage pest insects are detected, fumigation in a sealable silo is required for effective control
- With many domestic and export markets seeking grain supplies which are ‘pesticide residue free’ (PRF), always talk to potential grain buyers / traders prior to applying grain protectant sprays
- The general rule is that NO protectant sprays can be applied to pulses and oilseeds. Always check labels.

Common 'on-farm' uses for grain protectants (always read and follow directions for use on the registered label before using)

- Planting seed held on-farm – wheat, barley, oats
- Grain held for an extended time in non-sealable storages (not suited for fumigation) and the grain buyer has agreed to grain protectant use that is in line with directions for use on the registered product label.
- Grain held on-farm as feed for livestock with agreement from livestock agent or buyer and is in line with directions for use on the registered product label.

Grain protectant choices

Examples of two products, which include a partner product, to control the main storage pest species:

1. **Conserve® Plus Grain Protector** – active ingredient: 100 g/L spinosad, 100 g/L s-methoprene. Used in combination with a compatible organophosphate (OP) product such as chlorpyrifos-methyl (e.g. Diplomat 500 EC), or fenitrothion

   For label and details on product use, see: Conserve® Plus Grain Protectant | Corteva Agriscience (https://www.corteva.com.au/products-and-solutions/crop-protection/conserve-plus.html)

Key recommendations

- Always add the OP partner to Conserve Plus so rice and maize weevil (*Sitophilus* spp.) is controlled.
- Spray equipment calibration and application care are critical to achieve correct dose and uniform coverage on grain.
- If treated grain is exposed to light, for example a semi open grain shed, cover the grain surface with a tarp or 80 - 90% shade cloth. Sunlight breaks down Conserve Plus over time
- Take care to read notes on the web site (above) and seek advice when purchasing Conserve Plus.

2. **K-Obiol® EC Combi**, synergised grain protectant – active ingredient: 50 g/L deltamethrin, 400 g/L piperonyl butoxide. Used in combination with an organophosphate (OP) partner e.g. chlorpyrifos-methyl or fenitrothion.

   For label and details on product use, see: https://www.environmentalscience.bayer.com.au/K-Obiol/About%20K-Obiol

Key recommendations

- To control rice, maize and granary weevils (*Sitophilus spp.*) add a recommended partner (e.g. OP) to the tank mix.
- To ensure effective pest control and that MRLs are not exceeded, calibrate spray equipment and aim for even treatment / coverage on grain.
- Grower users are required to complete a brief (approx. 60 minutes) online training course to be an 'approved user' prior to purchase of K-Obiol® EC Combi. See above web site.

Insecticide resistance management

If possible, aim to rotate chemical active ingredients for storage pest control at your storage facility. As an example, two years use of Conserve Plus™ product combination, followed by one or two years of K-Obiol® EC Combi.

Please read and follow all label recommendations and ensure that the product is registered for use in your state prior to application of any product.

Application of grain protectants

Grain protectant application requires care to achieve the correct dose and uniform grain coverage. This leads to effective pest control results and ensures MRL's are not exceeded. See Figure 5 below.

- Auger's grain transfer rate. Ensure you have good understanding of the grain flow rate (tonnes per hour) for the particular height the auger will be operating at
- Calibrate your spray application unit with water and check appropriate nozzles and spray pressure are used to achieve the required application of 1 litre of spray mixture per tonne of grain.

Figure 5. Spray application equipment designed for good coverage by applying treatment at two points in the auger

Grain pest resistance update – phosphine and grain protectants

Phosphine resistance

Phosphine fumigation is the most commonly used method used by growers and other grain handlers to disinfest grain. Over recent decades there has been a steady increase in both the prevalence and strength of phosphine resistance in various insect pests of stored grain. Despite these trends, phosphine fumigation remains effective against resistant pests except for one species.

The strongest level of phosphine resistance occurs in the rusty grain beetle (*Cryptolestes ferrugineus*) . This tiny beetle is one of several species of flat grain beetles (*Cryptolestes* species) found on farms (Figure 6). Although not normally the most common pest on farms, the presence of strongly resistant rusty grain beetles will threaten fumigation success, even in well-sealed silos.

GRDC has supported phosphine resistance monitoring for many years, as well as research on managing resistant pests. Our testing procedure allows us to categorise populations as susceptible, weakly resistant or strongly resistant, based on the presence of survivors in laboratory tests. Table 1 shows the results of recent resistance testing of pest populations collected from farms located in the GRDC northern region. The results show that phosphine resistance is common. Concerningly, half of the rusty grain beetle populations were categorised as strongly resistant.

Table 1. Phosphine resistance testing of grain beetle populations collected from farms in the GRDC northern region (2020-2021).

Pests	Number of populations		
	Susceptible	Weak resistance	Strong resistance
Lesser grain borer (*Rhyzopertha dominica*)	0	43	21
Rust-red flour beetle (*Tribolium castaneum*)	12	49	15
Rice weevil (*Sitophilus oryzae*)	1	10	0
Saw-toothed grain beetle (*Oryzaephilus surinamensis*)	0	6	0
Flat grain beetles (*Cryptolestes* species)*	0	12	6

* There are several *Cryptolestes* species, but only rusty grain beetle (*Cryptolestes ferrugineus*) has been shown to develop strong resistance.

Two phosphine fumigation trials conducted at Warwick in February 2017 show how difficult it is to control strongly resistant rusty grain beetles compared with strongly resistant populations of other pests. Silos containing wheat were fumigated according to the registered label for fumigations using aluminium phosphide tablets, with one trial lasting 7 days and the other 10 days. Cages of pests were placed in the silo at three depths (top, middle and bottom) to evaluate fumigation success. The species tested were the rusty grain beetle, the lesser grain borer, the rust-red flour beetle, the rice weevil and the saw-toothed grain beetle. The cages contained all life stages (eggs, larvae, pupae and adults) because phosphine tolerance can vary between life stages.

All species except for the rusty grain beetle were controlled in both the standard 7-day fumigation and the extended 10-day fumigation. The resistant rusty grain beetles were much harder to control (Table 2). As is often observed, the highest average phosphine concentrations were in the upper part of the silo and the lowest in the lower part of the silo. In the 7-day fumigation, there was a high level of population suppression (99.7%) of the rusty grain beetle in the top and middle cages but suppression was negligible (8.6%) in the bottom cages. Efficacy was better in the extended 10-day fumigation with high levels of suppression (99.4-100%) at all three levels of the silo. Similar average phosphine concentrations were achieved in the two fumigations but the extra 3 days made the 10-day fumigation much more effective against the strongly resistant rusty grain beetles.

Table 2. Phosphine efficacy against strongly phosphine resistant infestations of rusty grain beetle (*Cryptolestes ferrugineus*) in sealable silos (46.5 cubic metre volume)

Measurement	Cage location in silo	Fumigation trial	
		7-day	10-day
Average concentration (ppm)	Top	1368	1232
	Middle	936	899
	Bottom	577	628
Infestation suppression (%)	Top	99.7	100
	Middle	99.7	100
	Bottom	8.6	99.4

Figure 6. Flat grain beetles, *Cryptolestes* spp.

Grain protectant resistance

Grain protectant insecticides are used by many growers and other grain handlers where storage structures cannot be sealed well enough for fumigation. There has been a long history of stored grain pests developing resistance to protectants. GRDC has supported protectant resistance monitoring for many years, as well as research on managing resistant pests.

A study is under way testing grain pests to some commonly used protectants. Table 3 shows some preliminary results. As mentioned earlier, no single grain protectant will control all species or all resistant types within a species, so combinations of two or three protectants are needed. This is reenforced by these results.

Chlorpyrifos-methyl is an old organophosphate protectant that targets rust-red flour beetles and rice weevils. There was no evidence of resistance in either species.

S-methoprene is an insect growth regulator that targets lesser grain borers and several other pests. Resistance was first detected in lesser grain borers in the 1990s, so its lack of control of the lesser grain borer populations tested is not surprising. The poor control of rice weevils is expected – not because of resistance but an innate tolerance. S- methoprene controlled about half of the rust-red flour beetle populations and this could be because of resistance or a degree of innate tolerance.

Spinosad was registered for control of lesser grain borers but combined treatments were tested because spinosad is no longer available as a stand-alone treatment. The results for the spinosad combination treatments show how combinations can overcome various protectant resistances to maximise the breadth of pest coverage.

Table 3. Number of populations of lesser grain borer (*Rhyzopertha dominica*; LGB), rust-red flour beetle (*Tribolium castaneum*; RRFB) and rice weevil (*Sitophilus oryzae*; RW) controlled by grain protectant treatments.

Treatment (ppm)	Pest		
Number of populations tested for each pest (n)	LGB (n =7)	RRFB (n = 12)	RW (n = 5)
Chlorpyrifos-methyl (10)	0	12	5
S-methoprene (0.6)	0	5	0
S-methoprene (1) + spinosad (1)	7	12	0
Chlorpyrifos-methyl (10) + s-methoprene (1) + spinosad (1)	7	12	5

Successful storage of pulses

Managing pests of stored pulses

The pulse industry is growing rapidly in the GRDC northern region and the Queensland Government has recently supported a project on effective management practices for pests of stored pulses, especially mungbeans and chickpeas. A lot of research has been done overseas but this has limited relevance to Australia, because of the focus on cowpeas and subsistence agriculture.

Recent farm sampling in the GRDC northern region shows that infested mungbeans and chickpeas can contain pests normally associated with stored cereals, as well as the cowpea weevil (*Callosobruchus maculatus,* also known as bruchids), which is the major pest of stored pulses (Table 4). The cereal pests are probably not causing much damage to pulses, but their presence will negate their insect-free status. Cowpea weevil adults do not feed but the larvae cause major damage as they develop inside individual pulse seeds, and newly developed adults emerge from large exit holes in the pulse seeds (Figure 7).

Cowpea weevils are good fliers. Although the cowpea weevil is a serious pest of stored pulses, overseas studies show that it can infest the cowpea crop before harvest. For cowpeas at least and potentially other pulses, infestation can be caried over from the field and into storages. Pre-harvest infestation is rare in most pests of stored cereals, except for the maize weevil (*Sitophilus zeamais*).

Table 4. Detections of insect pests in infested mungbeans and chickpeas collected from farms in the GRDC northern region.

Pests	Mungbeans (8 samples)	Chickpeas (27 samples)
Cowpea weevil (*Callosobruchus maculatus*)	5	4
Lesser grain borer (*Rhyzopertha dominica*)	5	14
Rust-red flour beetle (*Tribolium castaneum*)	6	26
Rice weevil (*Sitophilus oryzae*)	0	6
Saw-toothed grain beetle (*Oryzaephilus surinamensis*)	0	2
Flat grain beetles (*Cryptolestes* species)	0	4

Figure 7. The distinctive large white eggs and round exit holes of the cowpea weevil (*Callosobruchus maculatus*) on mungbeans. The eggs are white because the larvae have hatched and burrowed into the mungbeans. (Source: QDAF)

Pest monitoring

As with stored cereals, regular monthly inspections and sampling of stored pulses is essential to check both grain quality and for the presence of pests. Sieving of pulse samples from the top and bottom of storages is useful for early detection, as is trapping with probe or pitfall traps placed in the grain surface. Newly laid cowpea weevil eggs are hard to see but are white after the larvae hatch and burrow into the seeds. Adult cowpea weevils are easy to see, as are the large exit holes in the seeds.

Aeration cooling

Population growth of insects is strongly dependent on temperature and aeration cooling has long been promoted as a chemical-free means of reducing infestation levels in stored cereals. Similarly, aeration cooling can be used to reduce infestation levels in cowpea weevils. Figures 8 and 9 show the impact of temperature on generation time and multiplication rate per generation in this pest. The temperature at which population growth was zero was estimated to be 17˚C using these results.

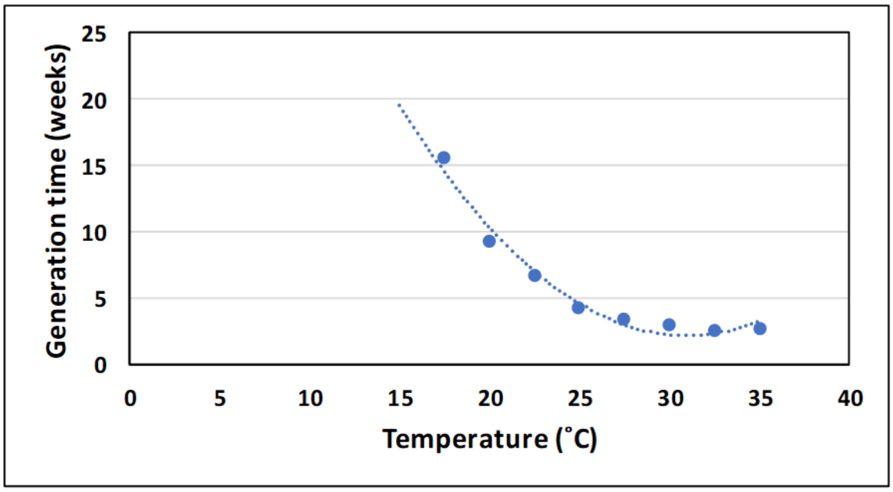

Figure 8. Effect of temperature on generation time of the cowpea weevil (*Callosobruchus maculatus*) in mungbean.

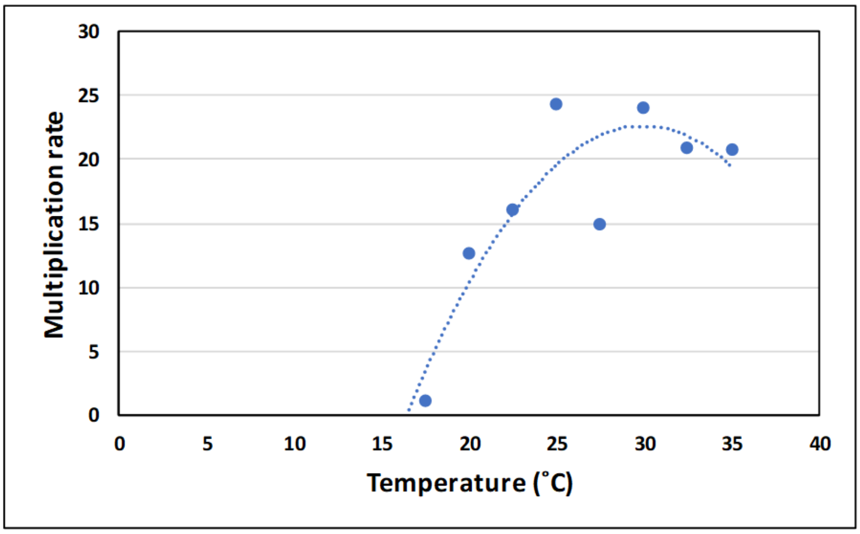

Figure 9. Effect of temperature on multiplication rate of the cowpea weevil (*Callosobruchus maculatus*) in mungbean.

Phosphine fumigation

Phosphine fumigation can be used by growers and other grain handlers to disinfest pulses and there is no evidence to date of resistance in the cowpea weevil. Because of a lack of information on the efficacy of phosphine against cowpea weevils, laboratory fumigations and silo-scale fumigations were conducted.

Phosphine efficacy against other pests is known to be affected by concentration and time. Therefore, this was investigated in the laboratory using fixed concentrations and exposure periods. Cages of pests were placed in the silo at several depths to evaluate fumigation success against cowpea weevil infestations. Mixed-age infestations containing all life stages (eggs, larvae, pupae and adults) were used because phosphine tolerance in other species can vary between life stages.

Table 5 shows that both higher phosphine concentrations and longer exposure periods increase phosphine efficacy against cowpea weevils. Some variation in tolerance to phosphine was evident between different test populations, but concentrations of 360-720 ppm for 7 days would result in high levels of infestation suppression.

Table 5. Phosphine efficacy against infestations of cowpea weevils (*Callosobruchus maculatus*) in laboratory fumigations.

Exposure (days)	Concentration (ppm)	Infestation suppression (%)		
		Mungbeans	Chickpeas (Desi)	Chickpeas (Kabuli)
1	360	54.7-86.8	87.8-99.2	96.8-100
	720	69.0-88.3	98.1-99.0	100
4	360	90.0-99.6	85.5-100	100
	720	99.8-100	99.8-100	97.1-100
7	360	99.8-100	100	100
	720	99.5-99.7	100	100

Two phosphine fumigation trials were conducted at Warwick on mungbeans (March 2019) and chickpeas (March 2021). Silos containing mungbeans or chickpeas were fumigated according to the registered label for fumigations using aluminium phosphide tablets. Cages were placed in the silo at several depths to evaluate fumigation success against cowpea weevil infestations. The cages contained all life stages (eggs, larvae, pupae and adults) because phosphine tolerance in other species can vary between life stages.

The results show that phosphine fumigation conducted according to the registered label resulted in high levels of suppression of cowpea weevil infestations (Table 6).

Table 6. Phosphine efficacy against infestations of cowpea weevils (*Callosobruchus maculatus*) in 7-day fumigations of sealable silos (11.1 cubic metre volume)

Measurement	Cage location in silo	Fumigation trial	
		Mungbeans	Chickpeas
Average concentration (ppm)	Top	1040	1187
	Middle	945	1199
	Bottom	909	1213
Infestation suppression (%)*	Top	99.8-100	100
	Middle	99.9-100	100
	Bottom	100	100

Diatomaceous earth (DE)

Diatomaceous earth (DE) can be used as a structural treatment as part of storage hygiene. Treating empty storages will control cereal pests sheltering in cracks and crevices. Field trials on structural treatments are difficult so DE efficacy against the cowpea weevil was investigated in the laboratory.

Concrete and stainless-steel surfaces were treated with a commercial DE product (Dryacide®) at the rate of 2 g/m^2 and held at either 25˚C and 55% RH or 30˚C and 70% RH. Efficacy was determined after 0 and 3 months by adding adults and monitoring mortality for up to 7 days. High levels of mortality occurred on treated concrete and steel within 7 days of exposure (Table 7).

Table 7. Mortality of cowpea weevils (*Callosobruchus maculatus*) exposed to surfaces treated with diatomaceous earth (DE) at 2 g/m^2.

Surface	Assessment	Storage conditions	
		25˚C and 55% RH	30˚C and 70% RH
Concrete	0 months	100% by 2 days	99.2% by 7 days
	3 months	100% by 2 days	99.2% by 7 days
Steel	0 months	100% by 2 days	100% by 7 days
	3 months	92.9% by 7 days	97.9% by 7 days

A new publication on pulse storage will be released in the second half of 2021. The publication “Best management practices for storage of pulses” will be published by Queensland’s Department of Agriculture and Fisheries. It documents further research and management details to add to the pulse storage data included above. It provides the pulse industry in Australia with a valuable pulse storage management reference guide for the future.

Further information

GRDC fact sheet – Vigilant monitoring protects grain assets Vigilant Monitoring Protects Grain Assets | Stored Grain | Information Hub for Grain Storage, Quality Control, Insect & Pest Management

GRDC booklet – Fumigating with phosphine other fumigants and controlled atmospheres http://storedgrain.com.au/fumigating-with-phosphine-and-ca/

GRDC fact sheet – Pressure testing sealable silos - http://storedgrain.com.au/pressure-testing/

GRDC video – Fumigation recirculation http://storedgrain.com.au/fumigation-recirculation/

Corteva agriscience - Conserve Plus™ Grain Protector Conserve® Plus Grain Protectant | Corteva Agriscience

BAYER CropScience - K-Obiol® EC Combi https://www.environmentalscience.bayer.com.au/K-Obiol/About%20K-Obiol

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Weed recognition technologies: development and opportunity for Australian grain production

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Key words

weed recognition, machine learning, ML, site-specific weed control, SSWC

GRDC codes

UOS2002-003, UOS1806-002AWX

Take home messages

- Visual spectrum weed images can be used to develop highly accurate weed recognition algorithms
- The ready availability of low-cost digital camera and processor technologies has created the opportunity for superior weed recognition capability
- Accuracy of recognition algorithms continues to improve, increasing the opportunity for precise weed detection and identification in Australian cropping systems
- Currently there is a lack of suitably collected and annotated weed image datasets that encompass the diversity of crop and weed species, as well as the complexity of the Australian grain production environment.

Background

Site-specific weed control (SSWC) involves the specific targeting of weeds with control treatments creating the potential to substantially reduce weed control inputs in low weed density situations. The availability of low-cost, durable processors and digital cameras, combined with increasingly accurate recognition technologies, has enabled highly accurate weed recognition capability for fallow and in-crop scenarios. Globally there is currently considerable research and development activities aimed at delivering SSWC across a range of production systems. Australian grain producers lead the world in the use of SSWC in fallow systems and their positive experiences have created the opportunity to fill a demand for the use of this approach for in-crop weed control.

Reflectance-based weed detection

In the 1980s and 1990s the development of technologies that allowed the detection of living plants led to the introduction of SSWC treatments for fallow weed control (Haggar *et al.* 1983; Felton 1990; Visser and Timmermans 1996). The weed detection systems used were based on a relatively simple process of using spectral filters and photodiode sensors to detect growing (green) plant tissue. As all living plants present in fallows are considered weeds, the reflection of near infrared light (NIR) by the chlorophyll in living plants enables the discrimination between these plants and the background soil or crop residues (Visser and Timmermans 1996). With the use of additional light sources, these weed detection systems can be used in a range of light conditions, including at night.

In Australia, reflectance-based weed sensing systems have been in use for over two decades in spot-spraying systems that are now widely adopted by Australian growers for fallow weed control (McCarthy *et al.* 2010). The application of herbicide in spot-spraying treatments can effectively control fallow weeds with substantially reduced amounts of herbicide. The substantial savings in weed control costs through the use of SSWC treatments has created opportunity to use more expensive herbicide treatments and non-chemical methods for the management of herbicide resistant weed problems (Walsh *et al.* 2020).

Camera-based weed detection

The expanded use of digital cameras and machine learning (ML) algorithms for image-based weed recognition in combination with smaller more powerful processors has enabled the development of field-scale and real-time SSWC for in-crop scenarios. The Raspberry Pi is an example of a low-cost single board computer that was developed as a teaching resource to promote computer science in schools. When coupled with a digital camera, the Raspberry Pi has many uses in simple computer vision related tasks, including fallow weed detection scenarios. SSWC systems for real-time use have been developed previously using Raspberry Pi computers for plant feature-based weed detection (Sujaritha *et al.* 2017; Tufail *et al.* 2021). Recent work has focussed on promoting to the Australian weed control community, the accessibility and availability of these technologies for construction of fallow weed detection. At present, although these camera-based weed detection systems are less-expensive, provide greater development opportunity and potentially more effective than current reflectance-based sensors, their use has been limited.

Development of machine learning (ML) based in-crop weed recognition for Australian grain production

Accurate recognition of commonly occurring weeds in Australian grain crops requires a highly sophisticated approach that can manage the complexities of crop-weed scenarios. The substantial benefits to using SSWC for fallow weed control has created a demand for the introduction of this approach for in-crop weed control across the cropping regions. The development of accurate weed recognition systems in horticultural crops is more easily achievable, with highly structured and predictable planting arrangements with slow travel speeds and consistent backgrounds. By contrast, the differences between crop and weed appearances are less pronounced in large-scale grain production systems, increasing the difficulty of developing reliable SSWC. Dense crop coverage in grain production systems exacerbates this challenge as large amounts of visual clutter makes it difficult to distinguish individual plants. Reflectance and simple image-based weed detection methods (e.g. colour thresholds and leaf edge detection) developed for fallow SSWC are not capable of dealing with this complexity. The substantial advance that a ML approach offers is the ability to reliably differentiate between weed and crop plants potentially to the point of identifying plant species. This opens a whole new application domain for in-crop SSWC. The use of digitally collected imagery has been identified as an approach that collects the type and quantity of data that allows for accurate discrimination between crop and weed plants (Thompson *et al.* 1991; M. Woebbecke *et al.* 1995). Imaging sensors, such as the standard digital camera, provide richer data streams with three channels (red, green and blue [RGB] images) of spatial and spectral intensity information. The richer data collected by these systems can be used for machine learning (ML) approaches that develop accurate weed recognition algorithms (Wang *et al.* 2019). With the promise of highly accurate (99%) in-crop weed recognition, there is now considerable research towards developing SSWC opportunities in cropping systems. These efforts are now resulting in commercial availability of detection systems for in-crop SSWC.

Recent examples of weed recognition algorithm development for Australian grain cropping

As part of a recently completed project ‘Machine Learning for weed recognition’, with GRDC investment weed recognition algorithms were developed for annual ryegrass (*Lolium rigidum*) and turnip weed (*Rapistrum rugosum*) plants present in wheat and chickpea crops. The weed recognition context evaluated was the early post-emergence stage where crop canopies are open, and weeds are readily visible in images collected from above. Using digital cameras mounted at a set height above the crop canopy, images of wheat and chickpea crops were collected in Narrabri and Cobbitty

(NSW) during the winter growing seasons of 2019 and 2020. This image dataset was collected over two growing seasons and covers variable background and lighting conditions as well as different crop and weed growth stages. To prepare the image dataset so that it can be used to develop and train ML recognition algorithms, annual ryegrass and turnip weed plants in images were manually annotated with bounding boxes using ’Labelbox’ image annotation software (Figure 1).

Figure 1. Sample bounding box annotations. Top row (red boxes): annual ryegrass (*Lolium rigidum*). Bottom row (green boxes): turnip weed (*Rapistrum rugosum*).

A range of convolutional neural network (CNN) architectures are freely available to use in developing object recognition tasks. These architectures are being continually challenged and improved by the machine learning community. To evaluate weed recognition capability, two recently developed ML architectures, YOLOv5 (June 2020) and EfficientDet (June 2020) as well as the more 'classical' architecture, Faster R-CNN (2015) were trained on the annual ryegrass and turnip weed dataset to develop recognition algorithms. To determine whether the background (crop type) of the images had an impact on weed recognition, the 2000 image dataset was split into three scenarios. In scenario one, only images of weeds in wheat were used for training (~1300) and testing (~300). In scenario two, only images of weeds in chickpea were used for training (~200) and testing (~50). In scenario three, the datasets were combined - images of weeds in both wheat and chickpea were used for training (~1500) and testing (~350).

The precision for all classes (wheat, chickpeas, annual ryegrass, turnip weed and background) reaches up to 0.3 for the YOLOv5-S algorithm (Table 1). This is much lower than the standard of 0.5 achieved by this algorithm on urban image datasets, clearly indicating the difficulty of weed recognition in cropping systems. There was consistently higher accuracy in the recognition of turnip weed (~0.6) than annual ryegrass (~0.08) for all ML architectures across all three crop scenarios. Superior accuracy in recognition of the broadleaf weed (turnip weed) in comparison to the grass weed (annual ryegrass) is an indication of the respective challenges for these weed types. Broadleaf weeds have a very different and distinct phenotype when compared to a cereal grain crop. This makes identifying them a simpler task for both human experts and ML algorithms. Conversely, grass weeds can be nearly indistinguishable from the crop and even pose a difficult challenge for human experts when annotating the data. Recognition of turnip weed was substantially more accurate in wheat (0.6) than in chickpea (0.1) crops, potentially reflecting the influence on accuracy of differences in plant morphologies between the crop and weed species, but also that there was a smaller chickpea data set.

Table 1. Summary of precision results for YOLO v5 XL, YOLOv5 S, EfficientDet-D4 and Faster R-CNN ResNet-50 deep learning architectures. Each model was trained on three scenarios, weeds in wheat, weeds in chickpea and weeds in both wheat and chickpea. Cells coloured dark grey indicate best performance with progressively lighter grey shading highlighting reducing precision. White cells coloured red indicate poorest performance.

Context	**Algorithm**	**Approx. parameters (M)**	**Rank**	**All**	**Annual ryegrass**	**Turnip weed**
Ryegrass and *turnip weed* in **wheat**	YOLOv5 XL	87.7	2	0.28	0.079	0.640
	Faster R-CNN ResNet-50	41.5	4	0.178	0.048	0.471
	EfficientDet-D4	19.5	5	0.184	0.024	0.506
	YOLOv5 S	7.3	1	0.300	0.080	0.600
Ryegrass and *turnip weed* in **chickpea**	YOLOv5 XL	87.7	1	0.136	0.036	0.116
	Faster R-CNN ResNet-50	41.5	4	0.058	0.010	0.034
	EfficientDet-D4	19.5	5	0.055	0.011	0.015
	YOLOv5 S	7.3	2	0.130	0.050	0.084
Ryegrass and *turnip weed* in **wheat** and **chickpea**	YOLOv5 XL	87.7	2	0.288	0.069	0.577
	Faster R-CNN ResNet-50	41.5	5	0.139	0.023	0.330
	EfficientDet-D4	19.5	4	0.169	0.020	0.437
	YOLOv5 S	7.3	1	0.310	0.076	0.590

In a recently completed ‘Intelligent Robotic Non-Chemical Weeding project which was part of a GRDC Innovation Program, ML based weed recognition algorithms were developed for turnip weed and annual ryegrass plants present in wheat and chickpea crops during the late-post emergence stage. Weed images were collected by a camera contained within a shroud with a constant light source (Figure 2). The shroud allowed images to be collected of weeds present beneath the crop canopy in a consistent light environment.

The collected images were subsequently labelled using a labour-intensive, pixel-wise annotation process for a more precise algorithm that returns detections at the pixel-level rather than the previous bounding box level. The algorithms from this approach resulted in high levels of weed recognition precision for turnip weed 0.75 and annual ryegrass 0.65 in wheat (Figure 3). These substantially, higher levels of precision compared to the early post-emergence results are likely due to a combination of factors. These include the use of a more precise pixel-wise annotation technique compared to the bounding box approach, consistent lighting used in the collection of all weed images with these images taken in the same field. Essentially the more accurate weed recognition algorithm developed for the late post-emergence scenario was based on a more specific and precise weed image dataset.

Figure 2. Autonomous platform with suspended shroud containing a digital image collection system and a constant light source.

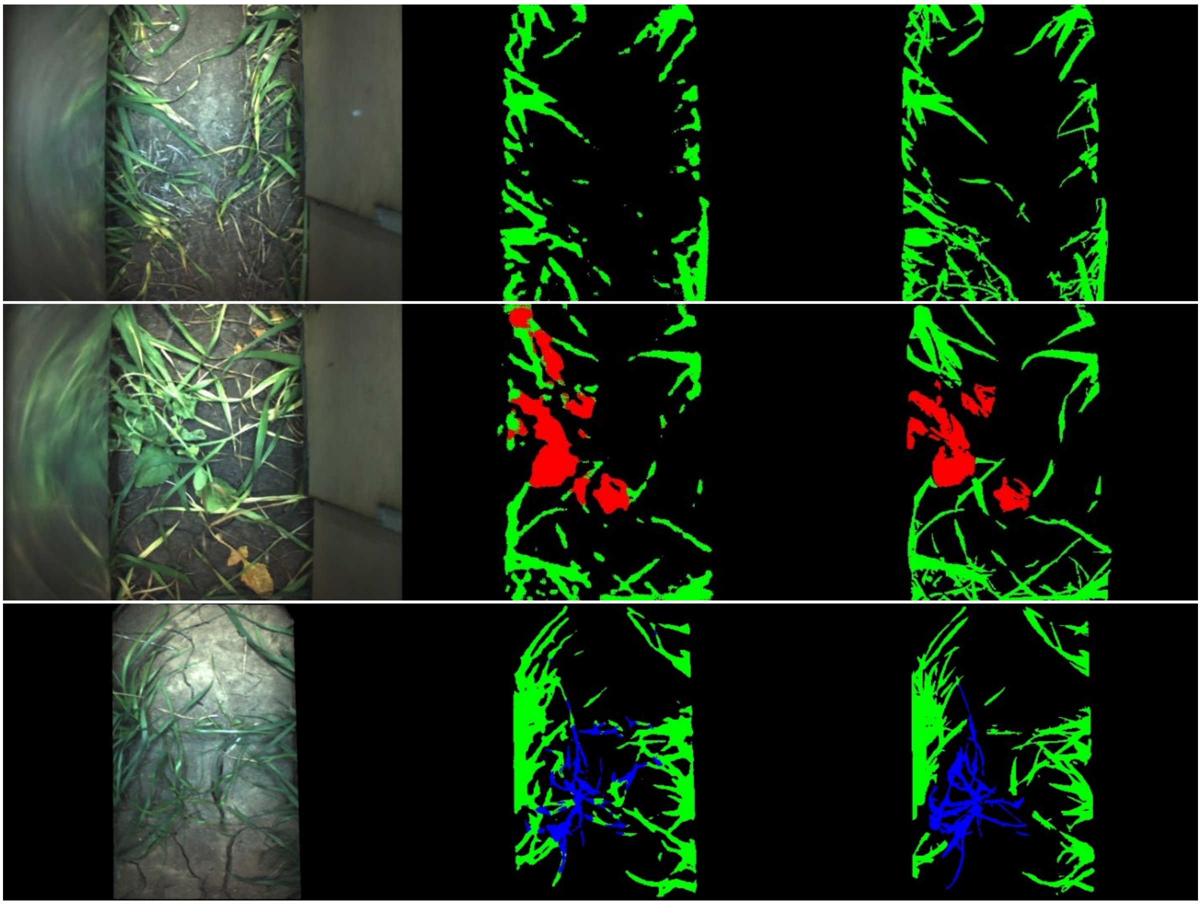

Figure 3. Sample images of image segmentation. Each row is a different example. Images from the left to right columns are: the input RGB image, segmentation results from the ML algorithm, and pixelwise manually segmented 'ground-truth' training data. In the segmented images, green pixels are wheat, red pixels are broadleaf weed, and blue pixels are ryegrass weed.

Summary

The development of weed recognition technologies for SSWC is now focused on the use of ML approaches that will enable accurate detection and identification of weeds in fallows and crops. As well as high potential accuracy, the focus on this approach is being driven by recent ML developments and the low-cost and ready availability of suitable digital cameras and processors. Camera based systems that use algorithms for fallow weed detection have proven high levels of accuracy that are similar if not better than the current reflectance based sensing systems. Increasing interest in the development of in-crop SSWC has resulted in a focus on more sophisticated weed recognition systems for use in both crop and fallow situations. Future SSWC in Australian grain production will be driven by highly accurate ML developed weed recognition algorithms. At present though there is a need to define the weed image dataset requirements, image annotation processes and appropriate ML architectures that are required to enable this opportunity.

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