FAR00002

Improved fungicide use for cereal rust control

PROJECT DETAILS

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Summary

This project was set up to generate a database and knowledge on integrated fungicide management (IFM) strategies combining the performance of new fungicides with partial genetic resistance based on adult plant resistance (APR) to cereal rusts.

Research was conducted in the field using commercial and near isogenic lines (NILs) and under controlled environment conditions. Data on the performance of a range of fungicides against all three rust species was produced, including curative activity under controlled conditions. Reports have been produced and presentations made showing the optimum strategies to integrate these fungicides when genetic resistance is based on increasing levels of APR.

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Conclusions

Field Research

Combining known APR genes Yr18 and Yr29, whether in commercial wheat varieties or in NILs of Avocet, offers greater genetic resistance against stripe rust than where the single APR genes were the basis of resistance. Greater resistance is manifest as a reduction in the leaf area sporulating in the upper canopy (flag leaf) and as a reduction in the overall chlorosis on the leaf due to the disease. This reduction in damage was found to be progressively stronger moving from flag-3 up to the flag leaf compared to more susceptible varieties or NILs.

Greater genetic resistance (where APR genes Yr18 and Yr29 are known to be present), whether in commercial varieties rated as moderately resistant to moderately susceptible (MR-MS) (Elmore CL Plus⦸) or in a NIL, combining the two genes has significant impacts on fungicide timing and economics. Often the superior resistance made foliar fungicide application uneconomic.Where it did not, the effect of the resistance was such that there was little difference in yield response whether fungicide was applied at early stem elongation (GS31-32) or later in stem elongation at flag leaf emergence (FLE) (GS39) following an early infection (GS31).

Where small economic yield increases (0-0.6t/ha) were observed in MR-MS or NILs (Yr18 and Yr29), it was found that control of head infection was incomplete and that there was a loss of flag leaf green leaf area of up to 20% during grain fill. These small economic responses to fungicide in this more resistant germplasm were more likely to be observed where yield potential exceeded 4t/ha. Where varieties were rated MS or where NILs were protected by a single APR gene, it was found that a second fungicide was economic following early infection (if conditions remained conducive) since active sporulation and chlorosis frequently increased in the upper canopy.

Stripe rust head infection can be controlled in the field if fungicide is applied prophylactically at ear emergence (GS59), though the control of the disease is less effective than applications made to the foliage (typically 65%-75% control). The head emergence timing is generally applied too late to prevent infection of the key top three leaves in the canopy unless the onset of infection is post flag leaf.

None of the new fungicide mixtures containing newer succinate dehydrogenase inhibitors (SDHIs) or QoIs was significantly superior to epoxiconazole# when compared in the field on stripe rust, however against leaf rust there was some evidence tebuconazole# was weaker than many of the newer fungicide mixtures. There was insufficient natural infection of stem rust in field work to examine efficacy in the field.

Controlled environment studies

Controlled environment studies at constant temperatures of 20°C-23°C in the glasshouse illustrated good control (90%-99% control) when rusts (stripe, leaf and stem) were targeted one day before or three days after infection. Fungicidal control declines when applications are made seven days (70%-90% control) and 11 days (50% control) post infection. This decline in activity is due to increased leaf damage as a result of chlorosis. The curative activity of newer fungicide applications tested in

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the laboratory was in general no better than the epoxiconazole control. Since disease development and crop development are temperature driven, curative activity is better established in thermal time (to be further investigated).

Recommendations

Growers and advisers are recommended to consider foliar fungicides as the last line of defence after other aspects of an integrated disease management (IDM) program have been considered, most importantly looking at incorporating cereal varieties that have at least a MS (or better) rating against rust diseases. These varieties are likely to have some degree of APR to protect them.

When using foliar fungicides, applications should be made to control rust on the top three to four leaves of the crop canopy (from the base flag-3, flag-2, flag-1 and flag leaf).This is particularly the case with stripe rust and leaf rust. Applications should be targeted at the key leaf layer to be protected before the leaf is visually infected. For early disease onset, apply fungicides at first to second node (GS31-32) to protect flag-2 and flag-3 against rust infection and between flag visible to full emergence (GS37-39) to protect flag-1 and flag leaf. Generally, stripe rust infections occur earlier than leaf rust infection so flag leaf fungicides tend to be more effective against leaf rust in wheat.

With stem rust infections which occur later in the season, foliar fungicide applications need to be timed at head emergence (GS51-59) to protect the flag leaf, flag leaf sheath and head from infection since the disease is less problematic in the lower canopy.

If with MS or S varieties, protection from stripe rust head infection is required, fungicide applications need to be made at ear emergence (GS59). Do not delay applications as fungicides will not control head infection once it can be observed in the glumes.

With more resistant varieties (MR-MS) possessing greater APR protection, fungicide timing for stripe rust control has a wider window, since early sprays give good control of infection on the lower leaves and the upper leaves exhibit stronger APR protection. However, equally the prevention of chlorosis of the upper leaves with a single fungicide in these circumstances gave equal yield increases due to the prevention of upper canopy chlorosis.

In terms of product choice, mixtures containing QoIs (strobilurins) and SDHIs mixed with epoxiconazole[#] are likely to be more effective than tebuconazole[#] for leaf rust control and on occasions stripe rust control, but generally epoxiconazole on its own is equally effective to the newer mixtures. From a fungicide resistance standpoint, do not apply the same fungicide product repeatedly. Use newer mixtures with more than one mode of action to combat rusts and alternation of triazoles and triazole mixtures with good activity against rusts.

Do not depend on the curative activity of foliar fungicides to control cereal rusts as all fungicides are better protectants than eradicants.

Outcomes

Economic benefits
Genetic resistance based on an increasing number of APR genes was shown to reduce upper canopy rust sporulation and leaf chlorosis, however the control of upper leaf chlorosis and head infection was not complete.

Research illustrated that the yield and economic benefits of fungicide application against cereal rusts was marginal when varieties were rated MR-MS or against stripe rust where varieties were protected by two APR genes Yr18 and Yr29. With this intermediate level of resistance, it was shown that where responses did occur, the timing of application in the GS30-39 window was more flexible, meaning that there was only a need for a single fungicide. Following inoculation, at the same time it was shown that stripe rust infection continues to increase on upper canopy leaves in MS rated varieties making second fungicide applications economic.This was not the case with MR-MS fungicide application where APR effectively curtailed rust development.

There was little evidence against cereal rusts to suggest that yield and economic benefits of newer fungicide mixtures containing SDHIs and QoIs (strobilurins) were any greater than the straight triazole, epoxiconazole[#], although benefits were observed over tebuconazole[#], particularly with leaf rust and stem rust.

Controlled glasshouse studies which enabled the research team to define the rust infection period illustrated that fungicide application of triazoles, such as epoxiconazole, gave their most effective control of all three cereal rusts when applied one day before or three days after infection. At seven days after infection, the influence of the products, while still effective (70%-90% control) would not prevent chlorosis associated with the disease. There was again no significant difference in curative activity noted between products carrying newer fungicide modes of action compared to epoxiconazole alone.

The work illustrated that fungicides could be used prophylactically to control head infection of stem rust or stripe rust in wheat, but that agrichemical protection was not as effective as increasing the genetic resistance in the variety being protected. The head wash fungicide timing could not be depended upon to give optimum economic responses unless the onset of infection was later in the season, since the timing did not protect the key canopy leaves. The timing was more effective with stem rust where the head, flag leaf sheath and peduncle more commonly carry the infection.

Environmental benefits
The partial, more durable nature of genetic resistance conferred by APR genes has been proven to result in lower fungicide usage, which both benefits the grower (less need for spraying operations) and the environment (less pressure on non-target organisms in the soil or on the plant) and reduces the opportunities of fungicide resistance development in other foliar diseases that have higher risks of resistance development than rust pathogens.

Achievement/Benefit

This project was instigated following the 2010 GRDC review of the Australian Cereal Rust Control Program (ACRCP), which concluded that there would be benefits in adding a new component of Integrated Fungicide Management (IFM) to the research program of the ACRCP.

The IFM research theme led by FAR was set up to enhance, complement and protect new sources of genetic resistance provided by the breeders, particularly APR, where resistance to cereal rusts is more durable but not complete in the same way that major gene resistance provides rust control. The importance of this investment is reflected in annual losses to cereal rusts of approximately $147 million with a potential loss (if left uncontrolled) of $1,669 million and an investment of $187 million on fungicides to combat foliar diseases (Murray & Brennan 2009).

The IFM project had three distinct objectives:
1. To increase the understanding of how new fungicides, with new modes of action, can be used to enhance the effectiveness of APR for the control of cereal rusts in new varieties.
2. To optimise the timing of new fungicide actives and formulations for the control of cereal rusts in commercially available wheat varieties.
3. To provide stewardship information on fungicide management on known genetic backgrounds to breeders.

To address these objectives, a series of field experiments were set up to optimise the timing of fungicides with different modes of action applied to varieties and NILs with known genetic backgrounds in terms of APR genes. These experiments were conducted with rust inoculation and irrigation at the Plant Breeding Institute (PBI) at Cobbitty and with natural infection and under dryland conditions in the regions. Over the course of the project, new fungicide performance featuring QoI (strobilurins) and SDHI mixtures were evaluated against **d**e**m**ethylation inhibitors (DMI) controls (triazoles - principally epoxiconazole[#]). The majority of field trial results related to stripe rust.

To better understand the properties of fungicides in terms of protectant and curative activity, a range of fungicides were tested in the glasshouse against stripe, leaf and stem rusts. Methodology was developed using a spray cabinet, inoculation chambers and glasshouse sub-unit cubicles.

Early achievements in 2012-2013 were clarifying the correct methodology for both field and controlled environment experimentation. Setting up large plot fungicide trials taken to grain yield had never been a core component of work at PBI Cobbitty (the Institute having previously only conducted work on small screening plots). The controlled environment studies developed methodologies that proved that cross contamination (due to DMI vapour activity) in the glasshouse cubicles was not the issue in running these experiments.

Field research

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i) Fungicide timing on varieties of intermediate genetic resistance to cereal rusts.
Using fungicides as the final part of an IDM approach (after genetic resistance and cultural control have been considered) revealed that the key timings to consider foliar fungicide application for stripe rust and leaf rust was during the stem elongation period (GS30-39), since timings in this period protect the top four leaves in the canopy. The exception to this was when the onset of rust infection occurred very late (a result that occurred in 2016), where rust control is required on the head or when stem rust is the principal target for the fungicide. In these cases, fungicides applied at head emergence GS59 were effective. Fungicide application at this timing has less economic value when rust infection occurs pre-FLE (GS39).

Fungicides applied at early stem elongation GS30-32 give good protection of the lower canopy leaves, particularly flag-2 (F-2) and flag-3 (F-3) (the lowest of the top four canopy leaves), whilst fungicides applied at FLE GS39 give good control of disease in the flag leaf and the leaf below, F-1. The specific need for fungicide application at these timings will depend on time of disease onset, variety resistance and whether at sowing measures have been used. In MS varieties, early fungicides applied at GS30-32 or at sowing do not prevent reinfection on the upper canopy leaves if conditions for disease remain conducive, potentially resulting in the need for further fungicide application at flag leaf. Adopting varieties with greater genetic resistance such as (MR-MS rated varieties) rarely results in more than one fungicide being economic and allows greater flexibility in fungicide timing during the stem elongation period (GS30-39), if disease infection is noted. Earlier sprays in this window are more effective on F-2 and F-3 rust infection that is expressing itself prior to APR being fully active, while later timed sprays in the window are more effective at preventing chlorosis associated with rust that is not fully controlled by APR.

Foliar fungicides were noted to be less effective applied to leaves that were not emerged at the time of application or that are already visibly infected. Later fungicide sprays applied prophylactically at full head emergence (GS59) will give partial control (50%-75%) of stripe rust head infection, but in most cases are applied too late to protect the important top three leaves in the canopy. Greater reduction in head infection can be achieved by adopting a higher stripe rust resistance rating, for example MR-MS as opposed to MS, rather than applying a foliar fungicide. With reference to newer fungicides, it was noted that greater genetic resistance gives less opportunity for products with better efficacy against the disease to express their benefits, since the overall response to fungicide is itself smaller.

There was no significant evidence that newer fungicide mixtures containing strobilurins and SDHIs gave superior yield responses than commonly used triazoles, such as epoxiconazole and tebuconazole[#], when tested for stripe rust control in MS, MR-MS and MR rated varieties. There was some evidence that tebuconazole was less effective than epoxiconazole with leaf rust and stem rust infection.

At a yield potential of 4t-6t/ha, stripe rust chlorosis covering up to 10% of the flag leaf at the start of grain fill did not produce economic returns from fungicides, despite control of the chlorosis associated with the disease. There was no significant evidence to suggest that newer fungicides based on triazoles mixed with QoIs or SDHIs changed the key development timings for fungicide application compared to triazoles alone. However, the time of disease onset in the canopy and the level of APR resistance did influence the optimum fungicide timings irrespective of mode of action.

ii) Influence of APR genes on rust development and the need for fungicide (using commercial and NILs).

Field research using varieties and NILs incorporating combinations of APR genes in more resistant varieties reduced both the overall chlorosis caused by rust infection and the area of leaf actively producing rust spores. Fungicide application was largely uneconomic and non-significant when a variety was protected by two APR genes (Yr18, Yr29) as yield increases were small. Where responses in these varieties were economic, there was little difference in fungicide timing between GS31 and GS39, indicating greater flexibility in making fungicide decisions with these varieties. The economic benefits of newer fungicides containing QoIs (strobilurins) and SDHIs were no greater than fungicide programs based on the straight triazole epoxiconazole. Overall yield increases to stripe rust control of between 0% and 90% obtained were dependent on the level of APR protection in the NILs. From the reductions in chlorosis achieved with increasing numbers of APR genes, it is estimated that there is an 8%-9% yield increase from fungicide application for every 10% decrease in flag leaf chlorosis observed at grain fill.

iii) Controlled environment studies examining rust infection.
Individual strobilurins and SDHIs have variable systemic properties conferring variable levels of curative activity, but they are excellent protectant fungicides. In Australia they are only provided to broadacre growers as mixtures with DMIs. From the project, it can be concluded that irrespective of fungicide or disease treated, fungicides are much more effective applied as protectants before infection is evident in the leaf, than used as curative applications.

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In recent glasshouse studies using defined infection events, foliar fungicides applied one day before or three days after infection gave 90%-99% control of cereal rust species (stripe, leaf and stem rusts of wheat). However, rust control declined to 70%-90% control when application was delayed until seven days post infection and to approx. 50% when delayed until 11 days after infection. Applications made eleven days after infection, whilst giving some control of sporulation on the leaf, do not prevent significant damage to the leaf through the effects of chlorosis associated with the disease. The triazole epoxiconazole gave very effective control of all three cereal rusts, stripe, leaf and stem, and the addition of a strobilurin to epoxiconazole or the use of newer fungicides (some yet to be commercially released) did not significantly improve control in comparison to epoxiconazole.

These results underpin the principal achievements of the project which have been to define how increased genetic resistance delivered through APR genes influences the rust control, yield responses and economic benefit of foliar fungicides. It illustrated that the curative activity of fungicides including new product mixtures containing strobilurins and SDHIs is limited and that to ensure the best results with these products, fungicides have to be applied to leaf tissue as protectant. Importantly, the work has shown that even with newer fungicides, if rust resistance is increased to MR-MS, then economic responses to fungicides become marginal. Where disease pressure is high and economic responses have been achieved, no more than one fungicide is required and the greater genetic resistance allows much greater flexibility in product choice and timing as the yield differences created are much smaller.

Research results were conveyed to the wider industry at the GRDC Updates in 2016-2017, IFM workshops (2017) and research reports were available for breeders, researchers and advisers through the project's website www.integratedfungicidemanagement.com (2012-2017).

Other Research

The principal research opportunities that developed over the term of the project were to determine how the barley APR genes Rph20, Rph23 and Rph24 for leaf rust (*Puccinia hordei*) protection influence fungicide response and to assess how this relationship is influenced by temperature since the expression of Rph20 is known to be influenced by temperature. Since barley generally receives more fungicide than wheat and is commonly treated with two fungicide applications, the impact of leaf rust APR could have larger effects than in wheat in terms of management strategy.

In addition, to verify whether the curative activity of fungicide is better described in thermal time as opposed to calendar date, since initial work in the glasshouse was conducted at constant temperatures of 20°C-23°C . Running experiments at different temperatures under controlled conditions would give more accurate knowledge for the field. Initial work on stripe, leaf and stem rusts indicated a curative activity of approx. 140-160 growing degree days (7 days at 20°C-23°C constant). Glasshouse studies at different temperatures would help to determine whether cooler conditions would mean that fungicide activity was slower or that the number of curative calendar days was increased. For example, if curative activity was 160 growing degree days at a mean temperature of 15°C, the number of days of curative activity would be 10-11 days.

In order to address these opportunities, new research themes would be based on three objectives:

1. To increase the understanding of how SDHI (FRAC group 7) and QoI (FRAC group 11) fungicides mixed with triazoles can be used to enhance the effectiveness of APR for the control of leaf rust in barley and stem rust in new wheat varieties (no field work component on stem rust was achieved in phase one of the IFM component of the ACRCP).
2. To understand the influence of temperature in the interaction between the APR rust resistance genes Rph20, Rph23 and Rph24 and fungicide application in barley. This would optimise the timing of fungicide actives and formulations for the control of leaf rust in commercially available barley varieties carrying different combinations of Rph20, Rph23 and Rph24.
3. To provide stewardship information on fungicide management for barley with known genetic backgrounds to breeders and the wider industry.

Intellectual Property Summary

NILs were multiplied up for research purposes only. This NIL material is acknowledged to belong to PBI Cobbitty. There are no strategies undertaken or plans to facilitate the protection and or commercialisation of the project outputs as it is not applicable.

Collaboration Organisations

This project has linked to research on fungicide effects (timings, products and rates) being undertaken by the Foundation of Arable Research (FAR) in New Zealand (NZ) and by NIAB TAG in the UK. Earlier product approval and similar issues with cereal rusts in wheat (except stem rust) have assisted with knowledge of active ingredient strengths and weaknesses.

The informal collaboration was with Patrick Stephenson and Richard Overthrow NIAB TAG, as well as Jim Orson, also NIAB TAG, prior to his retirement in 2015.

In NZ, the primary contact has been with Rob Craigie, FAR NZ's Cereal Research Manager who controls research investments in the cereal disease management portfolio.

Collaboration Details

This collaboration has taken the form of an informal data exchange where research data on rust management strategies has been discussed with key research agronomists in these organisations. Research has not been undertaken using common protocols or experimental treatment lists in this case.

Additional Information

Attachments

1. FAR Australia 2014 Field Trials Report.

2. FAR Australia 2015 Field Trials Report.

3. Adelaide Update paper - Septoria fungicide update and latest developments in rust management.

4. Wagga Wagga Update paper - Septoria fungicide update and latest developments in rust management.

5. FAR Australia 2016 Field Trials Report.

6. FAR Australia Controlled Environment Studies Report 2014-2016.

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