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GRDC

GROUNDCOVER SUPPLEMENT

FUNGICIDE RESISTANCE – NAVIGATING THE STORM

Curbing the rise of fungicide resistance

By Ruth Peek

■ The 'Green Revolution' and introduction of fungicides, while contributing to a pivotal advancement in grain production, are not without their challenges, foremost among them being the looming threat of fungicide resistance. The drivers of fungicide resistance are complex and can compound each other's effects. Seasons that are conducive to disease are the number one, as dealing with disease pressure requires fungicide application.

Lack of genetic resistance in selected crop varieties, incorrect choice of fungicide, wrong timing of application, overuse of fungicide chemistries and poor integrated disease management can all contribute to an impending fungicide resistance storm. This escalating storm demands a sustainable approach and stewardship of our current limited fungicide modes of action.

Fungicides play a crucial role in integrated disease management strategies aimed at protecting crops from the detrimental effects of fungal diseases. However, as fungicide usage increases it places higher selection pressure on pathogen populations leading to resistance developing faster to key active ingredients.

Fungicide resistance has a financial cost to users and manufacturers and new modes of action are becoming more challenging to discover. Without an industry-wide stewardship program, the likelihood of additional fungicides losing their effectiveness is increasing.

To this end, GRDC has invested in the Australian Fungicide Resistance Extension Network (AFREN) since 2019, led by Associate Professor Fran Lopez-Ruiz of Curtin University. Its mandate is to develop and deliver fungicide management resistance resources for growers and advisers across the country. It brings together regional plant pathologists, fungicide resistance experts and communications and extension specialists.

This *Ground Cover*™ Supplement showcases the achievements of AFREN so far and shines a spotlight on new fungicide resistance-related research underway at Centre for Crop Disease Management (CCDM):

- improved detection of fungicide resistance in grain crops through the use of next-generation monitoring tools that enable agile fungicide resistance management; and
- new technologies such as gene switches and nanobots, which are being added to the arsenal to bring next-level precision to managing diseases.

Together with this cutting-edge research, an update on fungicides available in Australia is provided in this issue along with an update on the status of disease resistance to fungicides across Australia. Additionally, the increasing levels of detected fungicide resistance in Queensland are covered plus the issues that pulse crops in particular face in respect to resistance. Fungicide resistance management resources and digital disease

Photo: Nicole Baxter

Fungicides need to be used judiciously as part of an integrated disease management plan to mitigate escalating fungicide resistance.

monitoring tools developed by pathologists through the leadership of the Western Australian Department of Primary Industries and Regional Development are documented with links for easy access.

Most importantly, the integrated disease management (IDM) framework of AFREN and its call-to-action 'Fungicide Resistance Five' message is included.

The concept of IDM is based on growing resistant varieties and rotating crops. It includes a threshold concept for the application of disease control measures and reduction in the amount and frequency of fungicides applied to an economically and ecologically acceptable level. It also encourages mixing and rotating fungicides with different modes of action. Australian grains research and development will continue to develop genetic and chemical pathogen control measures, assuring the availability of effective combinations of host resistance and fungicides for growers. However, fungicide stewardship is essential to the longevity and sustainability of grain crop disease management. □

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GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

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Photo: Evan Collis

'Spray only if necessary and apply strategically' is one of the key messages from the Australian Fungicide Resistance Extension Network to mitigate fungicide resistance.

Knowledgeable growers – the frontline defence

AFREN's mandate is to help growers and advisers stay informed about the prevalence and management of fungicide resistance in their region

By Bridget Penna

In the absence of new fungicide modes of action or host plant resistance, the first line of defence is knowledge – effective agronomic practices and an informed fungicide strategy that mitigates the risk of fungicide resistance developing.

The team tasked with ensuring Australian grain growers and advisers know how to reduce the emergence and impacts of fungicide resistance is the Australian Fungicide Resistance Extension Network (AFREN).

This national network of plant pathologists, fungicide resistance experts and communication and extension specialists was established with GRDC investment in 2019.

Led by Associate Professor Fran Lopez-Ruiz, initially supported by project coordinator Dr Kylie Ireland and headquartered at the Centre for Crop and Disease Management at Curtin University, AFREN delivered key extension messaging through 2019 and 2022, leading now to a new GRDC-supported project, AFREN 2.

Project partners include Agriculture Victoria, the Centre for Crop Health at the University of Southern Queensland, the Queensland Department of Agriculture and Fisheries, the Western Australian Department of Primary Industries and Regional Development, Field Applied Research Australia, Independent Consultants Australia Network, Marcroft Grains Pathology, the South Australian Research and Development Institute, the University of Sydney, the University of Melbourne and AgCommunicators.

AFREN 2 project coordinator Dr Anna-Sheree Krige says the suite of extension resources and training activities developed through AFREN are increasing growers' and advisers' knowledge of disease and fungicide resistance management.

"A significant achievement has been the delivery of an independent management guide for fungicide resistance to industry in 2021," she says.

"This guide walks users through the dynamics of fungicide resistance and then provides management guidelines for major crops.

"Surveys of 232 participants at AFREN workshops in 2020 and 2022 revealed an increased level of understanding of fungicide resistance from good (64 per cent) to excellent (71 per cent)."

AFREN'S OBJECTIVES

In its first iteration, AFREN engaged experts to develop messaging and management strategies for combating fungicide resistance development in grain crops.

A suite of resources was produced and information was delivered directly to growers and advisers through workshops across Australia. Collectively, these have improved the baseline knowledge and understanding of fungicide resistance development and subsequent management strategies.

AFREN 2's national network will look to build upon the achievements of the initial project by delivering annual fungicide resistance training workshops and ensuring ongoing resources are developed to address management strategies that are crop, disease and region-specific.

"Our partners bring a great diversity in experience and industry knowledge. The new investment ensures this network is maintained, which allows us to continue extending existing and new research information to the industry," Dr Krige says.

"Management practices that reduce disease pressure and the number of fungicide treatments required can reduce the risk of resistance developing. So, by arming growers and advisers with up-to-date management knowledge, we have the potential to reduce the risk of fungicide resistance."

See the following pages for AFREN experts and achievements. □

GRDC Code CUR2302-002RTX

More information:

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Useful resources

AFREN website: afren.com.au

Fungicide Resistance Management Guide: afren.com.au/resources/#management-guide

AFREN – experts, partners, principles and achievements

AFREN MANDATE

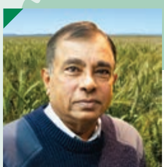
The Australian Fungicide Resistance Extension Network (AFREN) is a collaborative network of Australian grains industry stakeholders with an interest in, and responsibility for, the development and delivery of integrated and regionally specific fungicide resistance extension messages to grain growers and advisers across Australia.

THE AFREN 2 TEAM

WESTERN AUSTRALIA

A Prof Fran Lopez-Ruiz
Program leader

Geoff Thomas
@geoffreyjthomas



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AUSTRALIAN FUNGICIDE RESISTANCE EXTENSION NETWORK

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

Useful resources
AFREN website: afren.com.au
FR Management Guide:
afren.com.au/resources/#management-guide

GRDC Project Code: CUR2302-002RTX

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AFREN PRINCIPLES

The Fungicide Resistance Five provides a creed to follow.

The Fungicide Resistance Five

1. Avoid susceptible crop varieties
2. Rotate crops – use time and distance to reduce disease carryover
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

Growers should seek to provide a strong and reliable foundation of resistant or less susceptible crop varieties, supported by non-chemical integrated disease management that can be complemented by strategic and responsible use of fungicides.

Fungicide

Use fungicides only as necessary and apply strategically
- Rotate modes of action (MOA)
- Use mixtures (if available)
- Stay within label rates

Non-chemical farm management

Support with IDM to reduce disease pressure
- Stubble management
- Crop rotation
- Good hygiene
- Sow at the best time to avoid or tolerate disease
- Manage green bridge

Variety selection

Start with a solid foundation
Where possible, select resistant or less-susceptible varieties to reduce your reliance on fungicides throughout the growing season

NATIONAL COMMUNICATION & EXTENSION

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CANOLA

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IMPACT OF KEY AFREN ENGAGEMENTS SINCE 2019

WORKSHOPS

232 participants at regional workshops

Participants level of understanding good to excellent

64% 2020 ↑ **71%** 2022

Participants modification of disease practice since attending

88% ☑ YES

WEBINARS

Participants in live webinars

147

Increase for belief in positive effect of management practices going forward

31% ↑ 75%

Post-webinar survey results:

Growth in understanding: **77%** (54%)

Concern about fungicide resistance: **46%** (27%)

PODCASTS

11,663
LISTENERS TUNED IN

WEBSITE TRAFFIC*

47%
INCREASE IN USERS

58%
INCREASE IN PAGE VIEWS

*since 2021 reporting period

GROWER AND AGRONOMIST AWARENESS

of fungicide resistance and its impact on crop health

68% 2020

88% 2022

Fungicide resistance – a mounting problem in Australia

Up-to-date fungicide resistance knowledge is key to managing the increasing number of crop diseases developing resistance

By David Foxx

■ No cropping region or state in Australia is free from some degree of fungicide resistance – as reduced sensitivity to a fungicide, fully developed resistance or both. The cases of major concern include barley net blotches in South Australia and Western Australia, Septoria tritici blotch in the southern cropping region, and wheat powdery mildew across SA, New South Wales, Tasmania and Queensland. Other examples exist and there are almost certainly pockets of resistant pathogen populations that are yet to be detected.

Fungicide resistance is an evolutionary process that builds up through the survival and spread of resistant fungi after repeated use of the same fungicide mode of action (Figure 1). Growers should consider all fungal crop diseases as having

FUNGICIDE RESISTANCE TERMINOLOGY

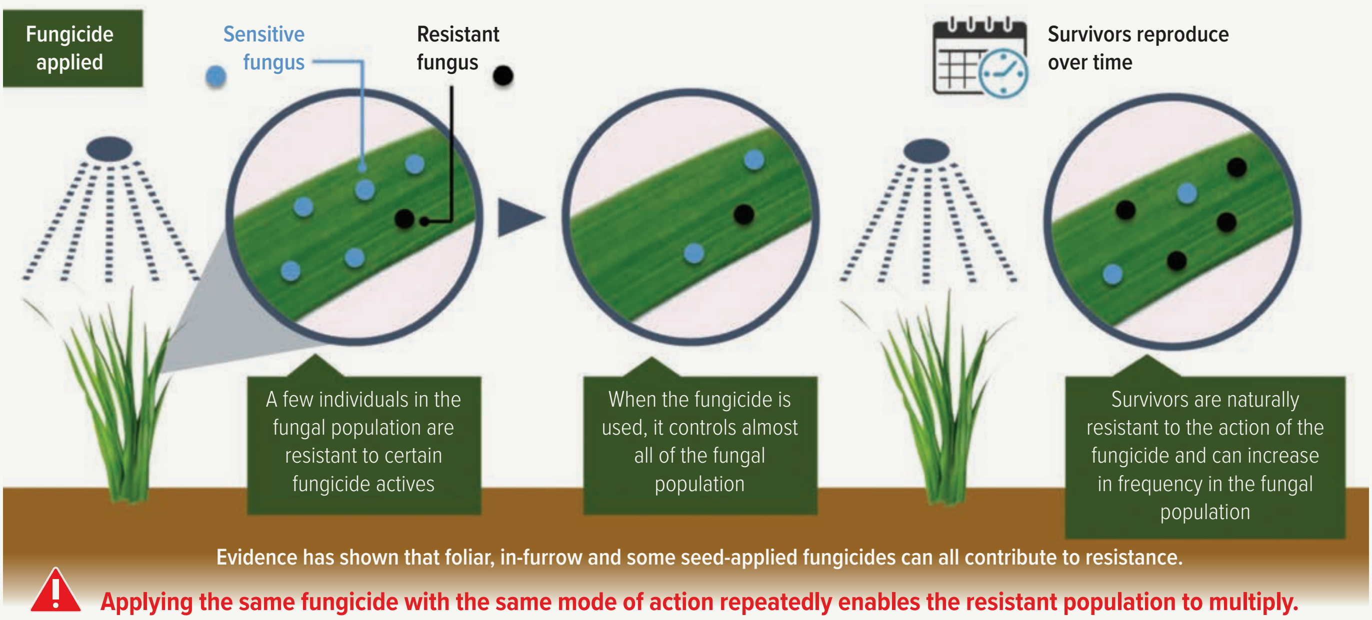
RESISTANCE (R) The fungicide fails to provide disease control in the field at the maximum label rate. Resistance must be confirmed by laboratory testing and clearly linked to a loss of control in the field.

REDUCED SENSITIVITY (RS) A fungicide application does not work optimally but does not completely fail.
Growers may find previously experienced levels of control require higher chemical concentrations up to the maximum label rate. Reduced sensitivity must be confirmed by laboratory testing.

LAB DETECTION (L) Laboratory testing can identify reduced sensitivity or resistance, or even known mutations associated with very small shifts in fungicide sensitivity, before (or independent of) loss of efficacy in the field. This can indicate a greater risk of field failure developing.

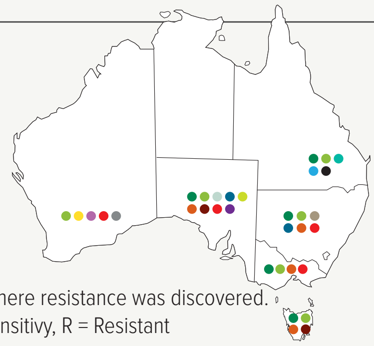
FIELD FAILURE In the context of fungicide resistance this refers to the insufficient control or effectiveness of a fungicide in managing fungal diseases in a field. It occurs when the applied fungicide, which was expected to control or suppress the target pathogens, proves ineffective due to the development of resistance in the fungal population. It indicates that the fungicide is no longer providing the desired level of disease control, leading to potential crop damage, yield and economic losses. AFREN supports monitoring and addressing field failures as crucial components of fungicide resistance management strategies.

Figure 1: Fungicide resistance evolution. Application of fungicides in a cropping system applies selection pressure on pathogens, creating mutations that shift pathogen populations from sensitive to resistant to highly resistant.



Source: Modified from CropLife Australia's Fungicide Resource Management Fact Sheet https://www.croplife.org.au/resources/programs/resistance-management/fact-sheet-fungicide-resistance

Figure 2: Distribution of resistant (R), reduced sensitivity (RS, resistance below the threshold of field failure), and laboratory resistant detections (L) in fungal pathogens to fungicides with distinct modes of action across Australia, as of November 2023.



Dots point to state only, not area where resistance was discovered.
L = Lab detection, RS = Reduced sensitivy, R = Resistant

Disease		Comment
Wheat powdery mildew		R to all Group 11 QoI and R to Group 3 DMI fungicides propiconazole and tebuconazole
Barley powdery mildew		R and RS to Group 3 DMI fungicides tebuconazole, propiconazole and flutriafol in isolates carrying the same L detected mutations in resistant isolates from Western Australia
Barley net form of net blotch		R to group Group 3 DMI fungicides epoxiconazole, propiconazole, prothioconazole and tebuconazole. Mutations associated with R and RS to Group 7 SDHI fungicides L detected. No field failure reported
Barley net form of net blotch		Mutations associated with R and RS to Group 7 SDHI fungicides L detected. No field failure reported
Barley net form of net blotch		R and RS to Group 3 DMI fungicides epoxiconazole, propiconazole, prothioconazole and tebuconazole. Resistance to SDHI fungicides. A mutation associated with RS to Group 11 QoI fungicides has also been L detected. No field failure reported
Barley net form of net blotch		R and RS to Group 3 DMI fungicides propiconazole, prothioconazole and tebuconazole. R to Group 7 SDHI fungicides
Barley spot form net blotch		Mutations associated with R and RS to Group 3 epoxiconazole, propiconazole, prothioconazole and tebuconazole L detected. Mutations associated with R and RS to some Group 7 SDHI fungicides L detected. No field failure reported
Barley spot form net blotch		RS to some Group 3 DMI fungicides including epoxiconazole, propiconazole, prothioconazole and tebuconazole
Barley spot form net blotch		R and RS to Group 3 DMI fungicides propiconazole, prothioconazole and tebuconazole. R and RS to some Group 7 SDHI fungicides
Septoria tritici blotch		RS to Group 3 DMI fungicides cyproconazole, epoxiconazole, flutriafol, propiconazole, tebuconazole and triadimenol
Septoria tritici blotch		A mutation associated with R to Group 11 QoI fungicides has been L detected. No field failure reported
Blackleg of canola		RS to Group 3 DMI fungicides flutriafol, fluquinconazole, prothioconazole and tebuconazole
Blackleg of canola		Mutations associated with R to Group 2 fungicide dicarboximide has been L detected. No field failure reported
Botrytis grey mould of chickpea		A mutation associated with R to Group 1 (MBC) fungicide carbendazim has been L detected. No field failure reported
Ascochyta blight of lentil		A mutation associated with R to Group 1 (MBC) fungicide carbendazim has been L detected. No field failure reported
Mung bean powdery mildew		RS to Group 3 DMI fungicide tebuconazole. Mutations associated with R to Group 11 QoI fungicides has been L detected. No field failure reported

Source: AFREN

Fungicide resistance across Australia

Fungicide resistance is a concern for growers across Australia. Figure 2 shows the diseases of particular concern in each state as determined by laboratory tests and field observations. Growers should always utilise the full suite of preventive and precautionary measures when managing any fungal disease. Extra care should be taken to mix and rotate fungicides if reduced sensitivity has been confirmed in the field or indicated by laboratory tests. When planning a fungicide application, be mindful of any non-target pathogens that might be surviving on the stubble of a previous crop or co-existing with the target pathogen in the current crop. It can be very easy to select resistant strains by killing the susceptible pathogens in these small populations.

the potential to evolve reduced sensitivity and eventual resistance to the available fungicides. By their very nature, single-site fungicides are more vulnerable to the natural mutations that endow pathogen individuals with reduced sensitivity or resistance. In addition to target-site mutations, there are other off-target genetic modifications that can confer resistance to single-site fungicides.

If the mutant strain is selected through repeated applications of fungicides from the compromised mode of action group, it can come to dominate the pathogen population.

The Australian Fungicide Resistance Extension Network (AFREN), with support from GRDC, has been working to help growers and advisers stay informed about the prevalence and management of fungicide resistance in their region since 2019. AFREN advocates responsible fungicide management practices for controlling these naturally occurring resistant individuals within any pathogen population. Resistant fungi can spread widely through windborne spores and movement of infected seed, among other mechanisms, so responsible management might not indemnify one property if poor practices on a neighbouring farm have allowed a resistant strain to proliferate.

A district-wide commitment to discouraging fungicide resistance is recommended. This includes:

- discussing the issue as a community;
- maintaining awareness of the risks, including prevalent diseases and frequently used fungicides;
- monitoring disease pressure each season;
- monitoring fungicide effectiveness and sharing information;
- maintaining a commitment to responsible fungicide application and rotation practices; and
- prioritising agronomic methods to reduce disease pressure and minimise reliance on chemical controls, using the principles outlined in the AFREN Fungicide Resistance Five (see page 23). ☐

GRDC Code CUR2302-002RTX

More information: Dr Anna-Sheree Krige, sheree.krige@curtin.edu.au

Fungicides available for Australian grain crops and their modes of action

By Dr Anna-Sheree Krige

Fungicides play a critical role in safeguarding Australian grain crops, ensuring healthy yields and maintaining food security. As one of the world's leading exporters of grains such as wheat and barley, Australia relies on effective fungicide strategies to combat fungal diseases that can devastate crops.

Fungal diseases such as rusts and net blotches can quickly spread and decimate entire fields. In a country where climate variability is a constant challenge, timely and effective disease management is essential.

This is where correct fungicide application along with best disease management practices are vital to support a successful yield for the grower and ensure the longevity of fungal chemistries.

Fungicides work through various modes of action (MOA) to combat fungal pathogens. These MOA determine how the fungicide interacts with the fungal pathogen and ultimately prevents or manages the disease. Understanding MOAs is crucial for growers and agronomists when selecting and applying fungicides effectively.

Fungicides are categorised according to their MOA and assigned to an internationally determined group number. When a fungal pathogen develops resistance to a particular fungicide, it often puts all other fungicides belonging to the same MOA group at risk of reduced effectiveness or the development of resistance.

Globally, more than 200 fungicides are approved for the management of fungal pathogens in agriculture, classified into 57 different MOA groups. However, in the context of Australian grain crop protection, only a limited number of these MOA groups are registered and a select few dominate the market (Tables 1 and 2).

This limited availability of fungicide groups increases the risk of fungicide resistance emerging because growers have very few alternatives to rotate with, which would otherwise help mitigate the selection pressure on these groups.

While fungicides are invaluable tools for grain crop protection, their overuse or improper application can lead to the development of resistance in fungal populations.

How can we prevent the emergence of fungicide resistance? Simple: stop the fungus from adapting to the treatments applied. This can be achieved by regularly changing the types of fungicide chemistries used, or mixing fungicides from different MOA groups.

Properly implemented fungicide rotations are crucial when incorporating fungicides with specific MOA into disease management programs. It is essential to strictly adhere to fungicide labels and ensure that certain fungicide chemistries are not excessively employed to maintain their long-term effectiveness.

To combat resistance, GRDC supports the operation of the Australian Fungicide Resistance Extension Network (AFREN). This network provides information and support for growers and advisers to manage fungicide resistance. AFREN strongly encourages growers to implement the AFREN Fungicide Resistance Five integrated disease management strategies (see page 23 for further details on each).

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

Table 1: Dominant MOA groups used in Australian grain crops.

Group	Common active ingredient	Target	Registered for use on	Risk of resistance
Group 3 Azoles/demethylase inhibitors (DMIs)	Cyproconazole, epoxiconazole, flutriafol, tebuconazole, propiconazole, prothioconazole, triadimefon	Inhibition of cell membrane synthesis: these fungicides interfere with the production of ergosterol, a vital component of fungal cell membranes. By disrupting the integrity of fungal membranes, sterol inhibitors weaken the pathogen and inhibit its growth.	Canola, cereals and pulses. Used as a seed dressing, and as a mixing partner in some foliar formulations.	Moderate
Group 7 Succinate dehydrogenase inhibitors (SDHIs)	Bixafen, fluxapyroxad, penflufen	Interference with respiration: these fungicides disrupt the energy production process of fungi (also known as respiration), depriving them of essential energy to germinate and grow.	Canola, cereals and pulses. Used as a seed dressing, and as a mixing partner in some foliar formulations.	Moderate to high
Group 11 Strobilurins/quinone outside inhibitors (QoIs)	Azoxystrobin, pyraclostrobin	Interference with respiration: similar to Group 7, QoI fungicides work by inhibiting the fungus' ability to produce energy through normal respiration.	Canola, cereals and pulses. Used as a mixing partner in foliar and in-furrow formulations.	High

Source: Fungicide Resistance Management in Australian Grain Crops, AFREN, afren.com.au/resources

ADDITIONAL INFORMATION

Fungicides are approved based on factors such as state/territory, crop, target pathogen, formulation and application rate. Up-to-date details about registered fungicides and their applications can be accessed through the Australian Pesticides and Veterinary Medicines Authority website at apvma.gov.au.

The mentioned risk of resistance development is determined through global observations and evaluations conducted by the international Fungicide Resistance Action Committee (FRAC). For further insights, refer to the FRAC website at frac.info and refer to page 21 of this Groundcover Supplement for an Australian risk matrix. For an overview of MOA as they relate to the Australian grains industry, visit AFREN.com.au.

Under the 'Resources' tab, locate the Fungicide Resistance Management in Australian Grain Crops guide. ☐

GRDC Code CUR2302-002RTX

More information: Associate Professor Fran Lopez-Ruiz, AFREN project manager and fungicide resistance team leader at the Centre for Crop and Disease Management, Curtin University, fran.lopezruiz@curtin.edu.au

Table 2: Other MOA groups registered for Australian grain crop diseases.

Group	Common active ingredient	Target	Registered for use on	Risk of resistance
Group 1 Methyl benzimidazole carbamates (MBCs)	Carbendazim, thiabendazole	Interference with cell division: cytoskeleton and microtubule arrested; failure in cell division leading to cell death.	Pulses	High
Group 2 Dicarboximides/ MAP-kinase inhibitors	Iprodione	Signal transduction: disruption of osmoregulation and membrane function that inhibit fungal growth.	Canola (not for blackleg) and pulses (excluding chickpeas).	Moderate
Group 4 Phenylamides/PAA	Metalaxyl	Nucleic acid metabolism: disrupt key enzymes needed to construct cell proteins for structure and control. Growth of fungus is slowed down or interrupted.	Most crops. Used as a mixing partner in seed treatments and in-furrow applications to target oomycetes (e.g. *Phytophthora* spp., *Pythium* spp.).	High
Group 5 Amines/morpholines	Spiroxamine	Inhibit metabolism: disrupt the fungal pathogen's ability to generate energy, leading to impaired growth; morpholines target sterol biosynthesis, a component required for cell membrane integrity.	Barley	Low to moderate
Group 12 Phenylpyrroles/ PP fungicides	Fludioxonil	Signal transduction: reduces osmoregulation, preventing fungal growth.	Canola, maize, peanut and sorghum	Low to moderate
Group 13* Azanaphthalene	Quinoxyfen, proquinazid	Signal transduction and cell membrane disruption: inhibit the function of an enzyme that is critical for cell membrane integrity.	Barley, wheat*	Moderate
Group 14 Aromatic hydrocarbons and heteroaromatics	Quintozene	Disruption of lipid synthesis, transport and membrane integrity.	Peanuts (soil-borne fungi)	Low to moderate
Group 33 Phosphonates	Phosphorus acid	Disruption of cell membrane: compromised cell membrane integrity weakens the fungal pathogen, making it more susceptible to environmental stressors.	Barley, canola and wheat. Principally used for the control of oomycetes (e.g. *Phytophthora* spp., *Pythium* spp.).	Low
Group 50* Actin disruption aryl-phenyl-ketones	Metrafenone	Disruption of the cytoskeleton and motor protein: loss of cell integrity and function.	Wheat*	Moderate
M1-M5 Multi-site activity	Chlorothalonil, copper, mancozeb, sulfur	Chemicals with multi-site activity: affect multiple biochemical sites in fungal pathogens.	Predominantly pulses. Good rotation and mixing partner options for managing fungicide resistance.	Low

*Currently only available under a Minor Use Permit for the control of wheat powdery mildew.
PER93197 Legend® (quinoxyfen) permit end date 31 July 2024.
PER93198 Vivando® (metrafenone) permit end date 31 July 2024.
PER93216 Talendo® (proquinazid) permit end date 31 July 2024.

Source: Fungicide Resistance Management in Australian Grain Crops, AFREN, afren.com.au/resources

Fungicide resistance in Queensland: be alert

The detection of fungicide resistance in Queensland highlights the need for industry to be vigilant and access advice

By Dr Sue Knights

■ When the first map of fungicide resistance cases in Australia was compiled in 2016 by the research team at Curtin University's Centre for Crop and Disease Management (CCDM), led by Associate Professor Fran Lopez-Ruiz, Queensland remained a blank region on that map.

However, ever-vigilant cereal pathologist Dr Steven Simpfendorfer from the NSW Department of Primary Industries noticed high levels of powdery mildew on wheat crops in 2022 that had been sprayed against the disease as per industry standards. He sent samples from across Queensland for fungicide resistance testing to the national monitoring program supported by GRDC at CCDM.

Unfortunately, resistance to Group 3 demethylase inhibitor (DMI) fungicides in these wheat samples was detected. Resistance to Group 3 fungicides had previously been documented in barley powdery mildew collected from Queensland fields, although in this case no fungicide control issues were found given the low abundance of the resistant fungal population then.

In addition, complete resistance to Group 11 quinone outside inhibitor (QoI) fungicides was also detected in the state's wheat powdery mildew populations. These were the first documented reports of fungicide resistance in Queensland's grain crops (Figure 1).

Professor Levente Kiss from the University of Southern Queensland (USQ) says disease pressure in crops can vary from season to season and it is necessary for the whole industry to be alert.

"Powdery mildew spreads by wind, and mild weather and damp canopies sometimes favour the development," Professor Kiss says.

"In Queensland we also have a higher mix of summer and winter crops, with the potential for some pathogens, particularly in pulses, to infect diverse crops, so we need to be vigilant year-round."

A pilot project on fungicide resistance, led by USQ's Centre for Crop Health and supported by the Broadacre Cropping Initiative (a partnership between the Queensland Government Department of Agriculture and Fisheries and USQ) has detected the DNA markers of both QoI and DMI resistance in a few samples of mungbean powdery mildew collected from 2019 to 2023 in Queensland.

"No field failures of fungicide have yet been reported; however, this laboratory detection is a red flag because DMIs and QoIs are the only two mode of action groups available for the control of powdery mildews in mungbeans." Professor Kiss says.

"The development of resistance not only threatens effective crop protection, but also reduces the number of modes of action available to growers, contributing to the increase of fungicide resistance risk within those systems."

Due to this growing issue of fungicide resistance to both DMI and QoI fungicides in Queensland – and also in NSW, Victoria, South Australia and Tasmania – the GRDC made a submission to the Australian Pesticides and Veterinary Medicines Authority (APVMA) for three Emergency Use Permits with Grain Producers Australia being the holder of the permits

These permits were for the use of quinoxyfen and proquinazid (Group 13) and metrafenone (Group 50) fungicides for wheat powdery mildew. These two different modes of action have specific activity on mildews.

Professor Kiss, who is also part of AFREN, says these findings emphasise the need for growers to implement integrated management practices when it comes to managing fungal diseases and adhering to the AFREN Fungicide Resistance Five key actions.

"Keeping up with seasonal disease issues is also important, so seek advice from local pathology experts – who you can follow on social media – and further information can be sourced through AFREN." ☐

GRDC Codes CUR2302-002RTX, USQ2202-001RTX

More information: Professor Levente Kiss, levente.kiss@unisq.edu.au

To keep up to date with the latest on fungicide resistance, register online at afren.com.au, follow #AFREN and @theGRDC on X/Twitter, or email afren@curtin.edu.au.

See the map on pages 4–5 for regional AFREN experts.

Figure 1: Map showing the nearest towns to where 10 diseased wheat samples were collected in Queensland.

The orange markers to the east were samples that tested positive for fungicide resistance to Group 11 QoI fungicides. The blue marker is the only sample that tested negative for fungicide resistance against QoI fungicides. All samples tested positive to the mutations associated with resistance to Group 3 DMI fungicides.

Knowledge is power when managing fungicide resistance in pulses

By Dr Sue Knights

Pulse pathologists Dr Joshua Fanning, Agriculture Victoria and Sara Blake, SARDI.

Photo: Luise Fanning

■ Australian pulse production is threatened by the risk of fungicide resistance. Most crop species are susceptible to one or more fungal diseases and although breeding has developed some resistant varieties, there are still susceptible varieties grown that require more-frequent fungicide applications.

Pulse pathologist Sara Blake from the South Australian Research and Development Institute (SARDI) says epidemiological knowledge of each disease-causing fungi is fundamental to disease management.

"Pulse fungal diseases have received comparatively less research compared to cereal and oilseed diseases. This makes these diseases challenging to control and may increase fungicide resistance risk,"she says.

"GRDC has invested to address knowledge gaps through strategic partnerships and national projects to tackle key pulse diseases including recent investments investments focused on epidemiology studies, economic threshold and management of Ascochyta blight and Botrytis diseases in lentil and faba beans," she says.

Agriculture Victoria pulse pathologist Dr Joshua Fanning says that although we do not yet have field-relevant fungicide resistance in pulses, we are at high risk of it developing.

"With all the fungicide options available we need to ensure we maximise their longevity to keep options available for disease control."

PATHOLOGY 101

The risk of developing fungicide resistance in crops depends on three factors: pathogen risk, fungicide risk and agronomic factors.

"It is important to remember that some pathogens can cross pulse species, such as faba beans, vetch and lentils. They are all affected by *Botrytis cinerea* and *B. fabae*, and if grown in high-risk situations it further increases the risk of fungicide resistance developing," Dr Fanning says.

The pulse diseases at highest risk of developing fungicide resistance are Botrytis grey mould in lentils and vetch, chocolate spot in faba beans and Ascochyta blight in lentils and chickpeas.

Generally, growers should be aware of the following issues when it comes to managing these pulse diseases:

- They are polycyclic with short, multiple disease cycles per season and can affect all crop growth stages. This means repeated fungicide applications may be required across the season, which increases selection pressure, potential genetic changes within the pathogen population, and the risk of resistance developing.
- These pathogens are high spore producers, which increases the chance of an insensitive mutant in the population.
- Their wind-dispersed spores enable spread to other plants, crops and regions.
- Most Botrytis and Ascochyta pathogens have a sexual stage in the pathogen life cycle, meaning genetic recombination increases the risk of resistance developing.

"Of the three factors contributing to fungicide resistance risk, the agronomic factors, which also include environmental factors, are arguably the most important," Ms Blake says.

"Wind and rain will influence the disease severity and spread in a local geographic area, so these diseases are community diseases. Without disease pressure, fungicide use is not normally necessary and fungicide resistance risk would be non-existent."

Ms Blake recommends that growers start by choosing pulse varieties with high levels of disease resistance and then test seed for sowing for pathogen infection or contamination, such as sclerotes (fungal resting structures). "Seed testing can inform growers of disease risk. Seed treatment may then be appropriate," she says.

"Fencelines neighbouring the previous year's infested stubble should be scouted for diseased plants and growers should talk to their neighbours about which pulse crop is being grown where, to try and avoid disease spread between adjacent pulse fields."

Dr Fanning says integrated practices are fundamental for disease management in pulses.

"Fungicides are one tool in the kit and only use them as part of an integrated disease management strategy. Timing of application is critical as pulses are indeterminant crops; they will keep growing and can recover from a disease infection."

Ms Blake says local seasonal knowledge is important to support disease management. She encourages growers to follow their regional crop pathologist on X (formerly Twitter) (see pages 4–5). □

GRDC Code CUR2302-002RTX , DJP2304-004RTX, CSP2007-001RTX , DJP2007-001RTX

More information: Sara Blake, sara.blake@sa.gov.au; Joshua Fanning, joshua.fanning@agriculture.vic.gov.au

'Next-gen' monitoring improving fungicide resistance detection

Delivering in-season information for growers on fungicide resistance is key to agile management and will be further enabled with new technology

Kat Zulak and Lina Farfan-Caceres inspecting fungal cultures grown from a grower's paddock sample. This phenotyping will be compared to genotyping analyses using next-gen technologies such as digital PCR and nanopore sequencing to determine fungicide resistance levels of the fungal pathogens.

Photo: Lisa Smith, CCDM

By Dr Kat Zulak and Dr Noel Knight

Like human diseases such as cancer, early detection and monitoring is crucial to keeping crops a step ahead of fungicide resistance.

Achieving this requires continuous monitoring using a combination of sampling, detection and reporting methods that must work efficiently to deliver accurate and timely information to growers to inform practice change (Figure 1).

This system must be dynamic and agile. It must also be able to incorporate emerging technologies from fields such as medicine and environmental science to reduce cost, time and resources while maintaining accuracy.

This task means overcoming technical challenges such as sampling bias, detection accuracy, sensitivity and the development of decision-support tools to link laboratory results to implications in the field.

The mission to continuously improve sampling and detection systems is led by the Centre for Crop and Disease Management (CCDM) at Curtin University in Perth. A key objective is to reduce the economic and food security cost of fungicide resistance in Australia.

SAMPLING

Sampling is the first step in monitoring fungicide resistance in pathogen populations in a crop. Traditionally, the detection of fungicide resistance has relied on growers or advisers observing a decrease in fungicide efficacy. Diseased samples, typically from a few positions in a paddock, are sent to experts to confirm the presence of fungicide resistance.

The quality of the samples can vary depending on the disease, so it is important to consult regional experts. Sampling can also be expanded to examine a larger area of crop along defined transects and include numerous samples. This enables a clearer picture of the frequency of fungicide resistance and how this might affect disease control.

Proactive, regular field sampling is also important to detect resistance before in-crop failure happens. The detection of fungicide resistance can then be made with phenotyping, genotyping or sequencing.

PHENOTYPING

Phenotyping is the foundation of resistance detection. It uses living fungi isolated from diseased plant tissues to test the ability of the fungi to survive different fungicide doses.

Fungi may be generally classified as sensitive (killed by the fungicide), reduced sensitive (survive low doses of fungicide) or resistant (survive high doses of fungicide).

A major benefit comes from the ability to link a phenotype to a mutation, or change associated with fungicide resistance, in the target protein and its gene. This leads to a more precise detection method called genotyping.

GENOTYPING

Once a mutation is linked to fungicide resistance, genotyping tools can be developed to specifically detect those mutations and quantify them in either fungi grown in the laboratory or in diseased leaves from the paddock. This is based on the extraction of DNA from the fungi or leaves. Multiple platforms are available for performing DNA detection; however, the development of high-quality tests is needed. Once developed, these analyses take days rather than weeks, increasing the speed of detection compared with the more time-consuming phenotyping.

For each mutation associated with fungicide resistance, a different test must be designed. These tests are sensitive and specific, which means the frequency of resistance in field populations can be accurately quantified.

However, multiple mutations can be present, which can require many tests to be performed. These tests are also limited to already-described mutations. They do not detect new mutations.

NANOPORE SEQUENCING

To address the issue of multiple mutations to several fungicides, the CCDM has deployed a sequencing assay using the MinION, a small, portable and cost-effective DNA sequencer, enabling on-demand sequencing and mutation detection. This aims to streamline mutation detection and allow targeted genotyping tests to be performed for fungicide resistance frequency analysis.

However, instead of running multiple genotyping assays on each DNA sample, the target genes are directly sequenced using MinION, revealing known and potentially new mutations simultaneously.

If a new mutation has been detected, the process goes back to the traditional phenotyping method to link the mutation to fungicide resistance.

Recently, researchers have used this method to detect mutations directly from infected leaf samples, enabling large-scale mutation profiling from field samples.

WHAT CAN GROWERS DO?

The principles of managing fungicide resistance rely on integrated management practices to disrupt pathogen survival.

This is based on the selection of the most resistant crop variety available, integrated disease management such as stubble reduction, crop rotation and controlling green bridges, and finally the need for fungicide applications, which should be strategic and involve the rotation or mixture of different fungicide groups.

Strategic and effective fungicide applications rely on knowledge of the pathogens in the field and the effect of fungicide resistance on disease control.

As new methods for reporting the presence and frequency of fungicide resistance become available to growers, it will enable more timely and effective management of fungal diseases. □

GRDC Codes
CUR1403-002BLX, CUR2302-002RTX

More information:
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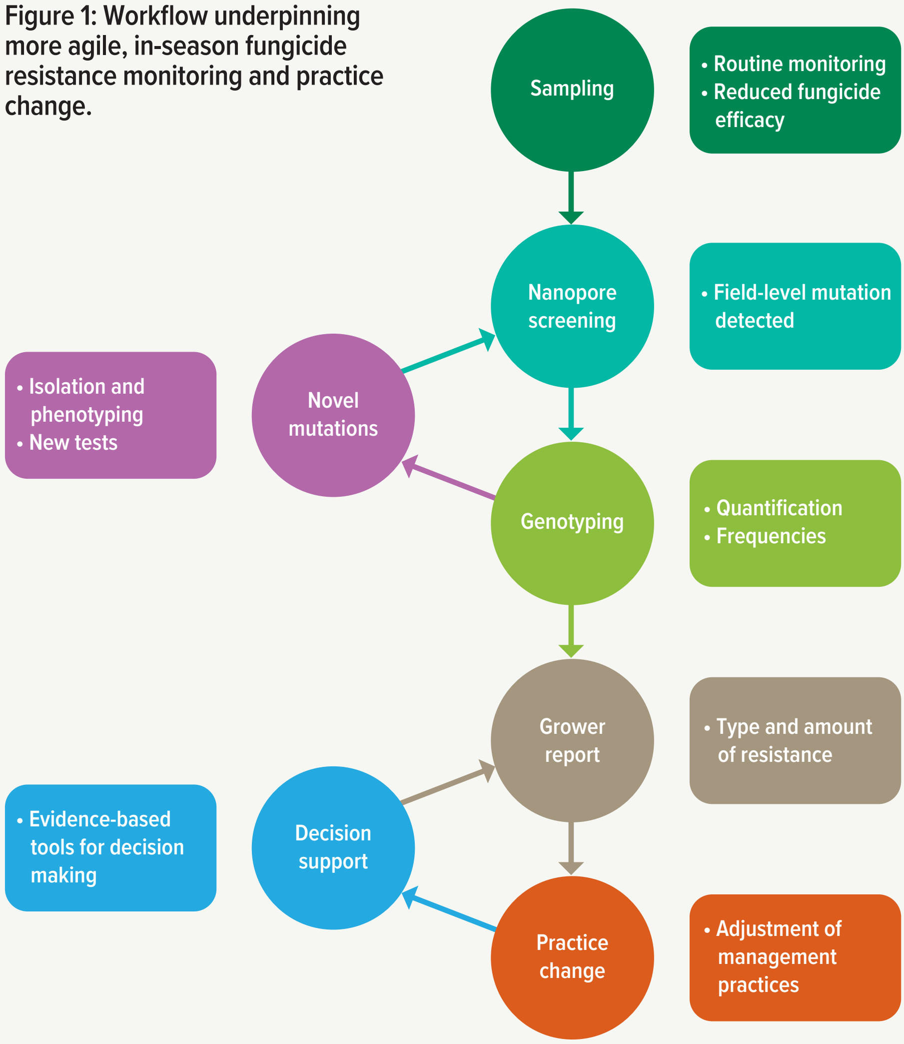
Figure 1: Workflow underpinning more agile, in-season fungicide resistance monitoring and practice change.



Source: Kat Zulak and Noel Knight

Dr Katherine Zulak, Dr Chala Turo and Dr Elizabeth Czislowski (left to right) reviewing long-read sequencing data that can be used to identify new mechanisms of fungicide resistance, including fungicide target gene duplication events.

Photo: CCDM

Tomorrow's fungicides: gene switches and nanobots

New tools and techniques are being added to the fungicide resistance management arsenal

By Dr Elizabeth Czislowski, Dr Chala Turo, Dr Kat Zulak, Anjana Sharma and Associate Professor Fran Lopez-Ruiz

Plant pathogens form intimate relationships with their plant hosts to gain access to resources for their growth and survival, often killing the plant host in the process.

These are complex relationships, with the host and pathogen even undergoing genetic changes as they evolve together and with each trying to survive.

If additional selection pressure is placed on the pathogen in the form of a fungicide, applied to disrupt fungal growth and disease progression, a further level of genetic change can result – that of fungicide resistance.

This dynamic is often likened to an 'arms race' between the plant host and pathogen as both change at the genetic level to outmanoeuvre each other.

To help plants 'outsmart' these pathogens, researchers have increasingly sought to adopt more sophisticated tools to keep ahead of the fungi and to understand the nuances of the plant/pathogen relationship.

Researchers at Curtin University's Centre for Crop and Disease Management (CCDM) with GRDC support are at the forefront of fungicide resistance research.

They are working on two fronts to develop new detection methods for the molecular analysis of fungicide resistance and to investigate the development of novel fungicides.

IDENTIFYING FUNGICIDE RESISTANCE AT WORK

Fungal pathogens can develop resistance to fungicides in a range of ways, with some of these mechanisms being easier to identify than others. Small genetic changes (mutations) in the genes targeted by fungicides are one of the most common mechanisms that lead to resistance.

Another mechanism used by fungi is to 'copy and paste' the fungicide target gene in the genome. By gaining extra copies of the target gene, the fungus can overcome the inhibitory effects of fungicide by simply having more copies of the gene working within the cell, allowing it to outcompete the fungicide.

However, identifying when and how these gene 'copy/paste' events have happened in a fungal genome is difficult. It is hard to determine how frequently this form of fungicide resistance is occurring in a pathogen population and, consequently, how this affects the management of fungicide resistance.

Dr Chala Turo and Dr Kat Zulak are using long-read DNA sequencing technology that allows the sequencing of entire chromosomes. This has been pivotal to identifying 'copy/paste' events that have resulted in very high levels of resistance in fungal pathogens.

The ability to identify these gene duplications increases the ability to monitor pathogen populations for genetic changes. Such changes have already been identified in net blotch pathogen populations and can inform fungicide resistance management practices. Similar research is underway for powdery mildew.

FINDING THE MASTER GENE SWITCH

Within every cell of your body is DNA that gives instructions to the cell on how to make proteins via genes. Each cell has the exact same DNA sequence, but it is the genes that are turned on or off that gives each cell its specific job.

The same is true for fungi. For example, some genes are only turned on when a spore germinates on a leaf and turned off again as the fungus grows. 'Master regulator' genes are important for deciding when whole batches of genes are switched on or off, much like how traffic lights regulate the flow of traffic.

PhD candidate Anjana Sharma has identified a family of master regulator genes that are responsible for controlling dozens of downstream genes in the fungal pathogen *Parastaganospora nodorum* (the causal agent of Septoria nodorum blotch in wheat).

One by one, Ms Sharma is deleting each of these master regulator genes to identify the downstream network of genes that are controlled by these master switches. Ms Sharma is also seeing which of these master regulator genes are critical for the pathogen's survival and ability to cause disease.

This research has the potential to reveal not just one gene, but whole suits of genes that fungi need to survive and cause disease.

Ms Sharma is hoping that future fungicides could be developed with new modes of action to target not only the master regulators but also the important genes that are downstream of the regulators and key to the survival of the pathogen.

NEXT-GEN FUNGICIDES

Can we develop fungicides that are as effective as current chemistries, but have less impact on environmental and human health? This is the question that Dr Elizabeth Czislowski aims to answer with her research at CCDM.

It seems straight out of a sci-fi movie: nanoparticles that are made from folded pieces of DNA that are capable of catching spores before they land on a leaf, or which are programmed to weaken the cell wall of fungal pathogens.

As futuristic as this sounds, it could well come to fruition as a future fungicide technology. While originally designed as an antiviral therapy, researchers at CCDM are exploring whether this nanoparticle technology could be adapted to fight fungal pathogens.

The technology offers many advantages, including being biodegradable and having low or no toxicity to mammalian cells. Ongoing research at CCDM is working to understand the stability of the nanoparticles after coming into contact with fungi and how antifungal properties can be designed into the nanoparticles. Other future technologies being investigated include RNA-based biopesticides designed to specifically turn off fungal genes.

Future fungicides will have to strike a balance between technologies with potent antifungal activity and those with minimal effect on human or environmental health.

To ensure the future of crop production and the security of the world's food supply, these are the types of fungicides that need to be harnessed to manage the continued threat of fungicide resistance. ☐

GRDC Code CUR1403-002BLX

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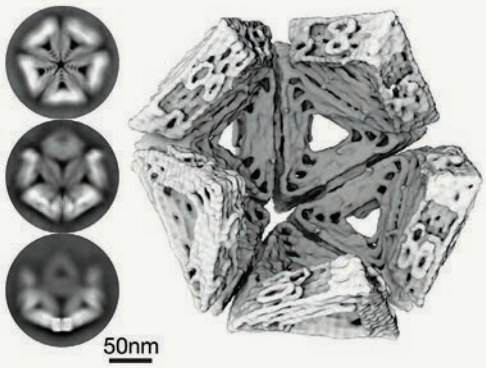


Medical research developed DNA origami therapy for novel antiviral therapy. It is now being explored by CCDM as a new fungicide technology.

Photo: Image provided by J. Kretzmann, University of Western Australia. Reproduced from Sigl, C., Willner, E.M., Engelen, W. et al. Programmable icosahedral shell system for virus trapping. Nat. Mater. 20, 1281–1289 (2021). https://doi.org/10.1038/s41563-021-01020-4

Photo: CCDM

Dr Anjana Sharma working to identify genetic 'master switches' in fungi to develop fungicides with new modes of action.

Preserving our fungicides

Successful stewardship is the key to prolonging the longevity of fungicides and requires collaboration, engagement and support by all stakeholders.

Fungicides belong to a range of essential crop protectant tools that also include insecticides and herbicides.

Fungicides can be classified as contact or systemic. Contact fungicides remain on the plant's surface and are also referred to as protectant or preventative fungicides. Systemic fungicides are absorbed and move variable distances within a plant, they are also known as preventative or curative fungicides. All fungicides are more precisely classified by their mode of action.

Up until the 1940s, disease control relied upon inorganic formulations frequently prepared by farmers. Synthetic chemicals were developed by agrochemical companies after World War II, many were systemic fungicides. Their advantages included reducing application rate, improving selectivity and reducing phytotoxicity. Widespread use of these new fungicides, together with fertilisers,

THE MAKING OF A MODERN CROP PROTECTANT

It can take...

11 YEARS & >US$280M

to develop a new agrochemical[3]

DISCOVERY
- Screening compounds
- Patent application
- Synthesis and testing analogues

SAFETY STUDIES
- Toxicity
- Environmental fate

1 in 140,000 — Probability of finding a new active ingredient[3]

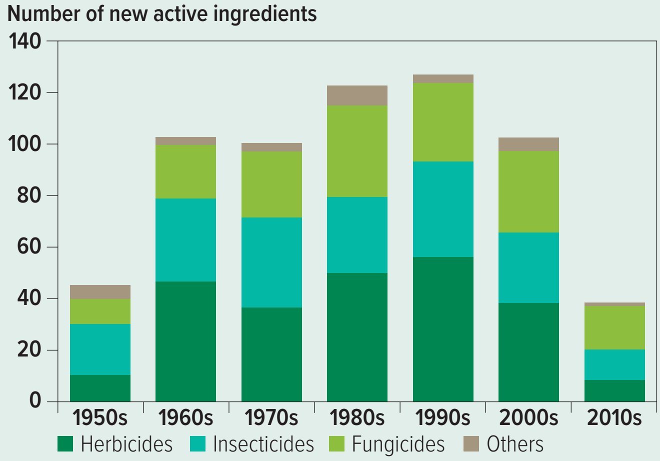
7–10% — Proportion of sales invested by each agrochemical company in R&D[2]

US$100M — Registration-related costs of developing a new active ingredient (doubled from 1995 to 2014)[2]

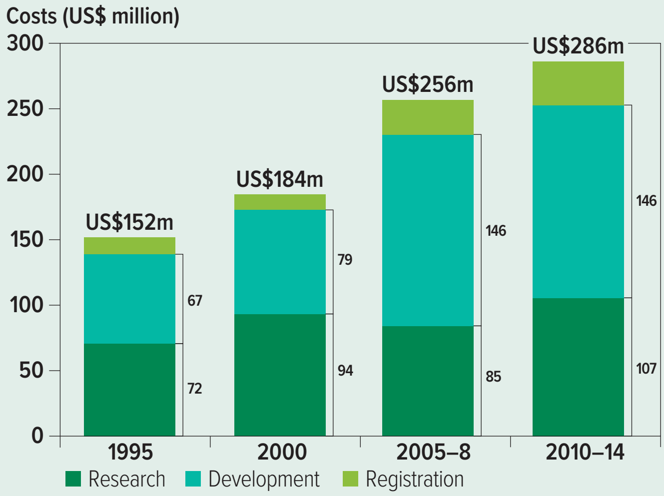
20 years — Length of standard patent, which starts well before commercialisation. After which the chemical becomes generic

$11B p.a. — Value of fungicides to Australian grain crops[3]

Number of new active ingredients introduced per decade 1950–2010.[2]



Change in total and component costs of bringing a new crop protection product to market.[2]

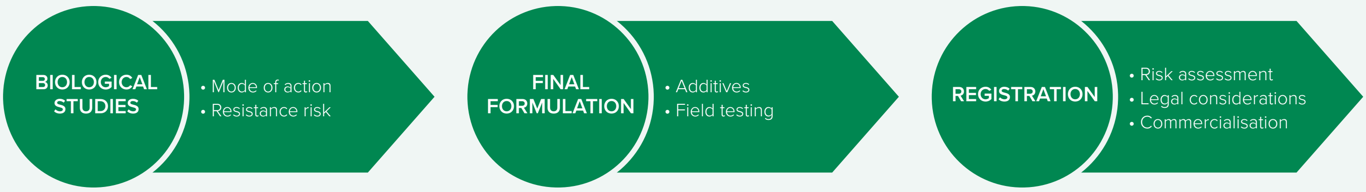


agricultural mechanisation and improved plant genetics, contributed to the success of the Green Revolution.

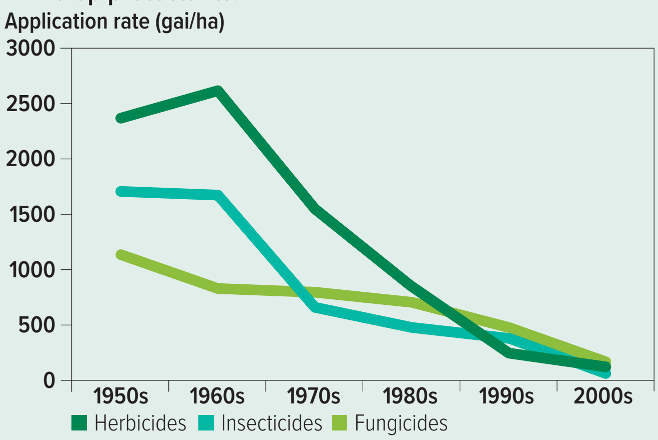
Since the 1970s global agrochemical companies have continued to invest large sums of money in discovering and developing new crop protectants that are more selective for disease, weed and insect control – using a range of modes of action – and possess reduced toxicity profiles and lower environmental impacts. Nonetheless, this task is becoming increasingly challenging, time-consuming and costly.

Paradoxically, as these improvements have ensued for crop protectants, selection pressure through their application has been placed on weeds, pests and diseases and they are developing resistance. Integrated methods of management are endorsed, with protectants as one component.

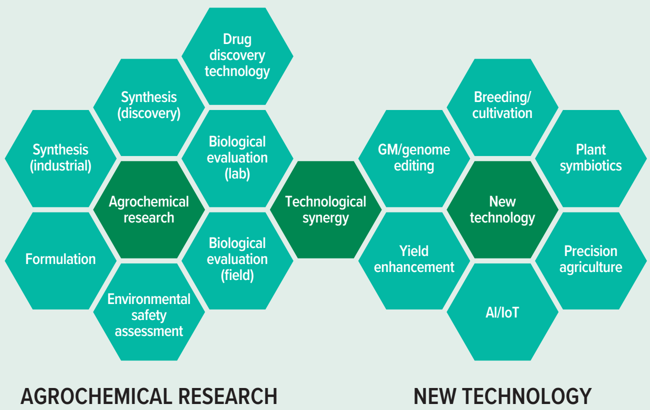
Australian growers require the latest crop protection products and technologies to support robust, sustainable and globally competitive grain production. However, access to these protectants can at times be restrictive as the Australian market is small compared to international markets. Combined, these issues mean the Australian industry needs to adopt best stewardship practices. Through collaboration, engagement and support by all stakeholders, responsible and sustainable use of crop protectants, including fungicides will be ensured to prolong their longevity. □



Improvement in efficacy – average rate of active ingredient application has reduced over time for all crop protectants.[2]



Agrochemical companies are working to improve longevity of chemicals while at the same time investing in new crop protection means.[1]



Number of years between the first synthesis and the first sale of a product – regulatory requirements have had an increasing influence.[2]

1995	2000	2005–08	2010–14
8.3 years	9.1 years	9.8 years	11.3 years

Since 1990, more than 10 agrochemical companies have consolidated to five, due to increasing R&D costs, increasing regulatory demands and business performance.[1]

- BASF
- BAYER
- CHEMCHINA
- CORTEVA
- FMC

RESPONSIBLE USE OF CROP PROTECTANTS

- Comply with all label directions
- Ensure that fungicide is registered or has a permit for the proposed use pattern
- Current label registrations and permits can be found on the Australia Pesticides and Veterinary Medicines Authority website apvma.gov.au

[1] Nishimoto, R (2019) Global trends in the crop protection industry. J. Pest. Sci 44 (3) 141-147
[2] Phillips McDougall (2018) Evolution of the crop protection industry since 1960. Report commissioned by CropLife International
[3] Rainbow, R (2021) The official Australian reference guide for organic, synthetic and biological pesticides CropLife Australia

Photo: CCDM

The Curtin University Centre for Crop and Disease Management (CCDM) team including AFREN project coordinator Dr Anna-Sheree-Krige (centre), research officer Lincoln Harper (L) and program leader Dr Fran Lopez-Ruiz (R) at work testing crop samples for disease and fungicide resistance at the Field Applied Research (FAR) Field Day in Winchelsea, Victoria.

Out and about with AFREN

Advances in portable technology have enabled scientists to test for fungicide resistance onsite, with results available within hours

By Melissa Marino

■ When central Victorian grain grower Ian Martin found brown marks on the leaves of his LRPB Trojan⦶ wheat, he suspected Septoria tritici blotch (STB) had crept into his 2023 crop.

He had planned to sow BigRed⦶ wheat on a 310-hectare outlying block near Mount Beckworth, but after wet weather kept him off his high-rainfall zone plot through April he made the "on-the-run" decision to plant the shorter-season LRPB Trojan⦶ that he had stored for a couple of years instead.

Knowing LRPB Trojan's⦶ susceptibility to STB (and stripe rust), he applied seed dressing penflufen (EverGol® Prime), as well as flutriafol (Impact®) to the fertiliser. But continuing inclement weather delayed the rest of his fungicide regime. Azoxystrobin and epoxiconazole (Tazer® Xpert) were applied later than he would have liked at growth stage 32, and prothioconazole and bixafen (Aviator® Xpro®) 34 to 35 days after that.

So when he saw the invitation to bring a crop sample for testing by the Australian Fungicide Resistance Extension Network (AFREN) team at the Field Applied Research (FAR) field day held at the Victorian Crop Technology Centre in October, he jumped at the opportunity.

Ian's interest was twofold: he wanted to see how his stored grain had held up against potentially evolving pathogens, and also whether he would need to think about changing his approach to fungicides for the remainder of the season and the years ahead.

"Being an older variety, I was interested to see whether it still stacks up, so I thought I'd bring it down to see if there was any disease or resistance and whether I'd need to change any chemistries down the track," he says.

ONSITE TESTING

The fungicide resistance sample testing workshop was one of several AFREN activities that have been bringing technology out of the lab and into the field.

Using state-of-the-art portable technology, AFREN scientists from Curtin University's Centre for Crop and Disease Management (CCDM) test samples onsite, providing insights around disease and fungicide resistance within hours.

AFREN project coordinator Dr Anna-Sheree Krige explains that the portable technology works by comparing DNA extracted from diseased plant samples with markers for particular diseases.

It then produces a digital graph that shows whether the pathogen's DNA contains any mutations that make it less susceptible to fungicides. "With this technology we can detect pathogens, and from those pathogens determine if there are any mutations that are associated with fungicide resistance," Dr Krige says.

BENEFITS OF ENGAGEMENT

Taking the technology into the field is beneficial in several ways, she says.

The practical service to growers not only provides definitive information on whether they have a disease or resistance issue to deal with, but also enables researchers to discover first-hand which diseases and resistance are emerging on the ground in different parts of the country.

The AFREN team also has the opportunity to build awareness of issues and spread the message about how to prevent fungicide resistance, which Dr Krige says is an ongoing duty of AFREN across Australia's cropping regions.

Of notable concern, she says, is resistance against chemistries to control diseases such as net form net blotch (NFNB) in barley across all growing regions and especially South Australian and Western Australian high-rainfall zones; STB in wheat, particularly in the high-rainfall areas of the southern growing region; and wheat powdery mildew (WPM), a disease that emerges in conducive conditions and has been a significant challenge for growers in the southern region in recent years.

"Fungicide resistance is a real problem and we can give growers and agronomists management strategies directly that, if incorporated on a wider scale, will reduce it," she says.

MANAGEMENT STRATEGIES

AFREN, with the support of GRDC, has developed key management strategies to combat fungicide resistance. Coined the 'Fungicide Resistance Five', they begin with building a solid foundation by selecting less-susceptible varieties; continue with management strategies such as crop rotations; and finish with astute fungicide management including strategic application and changing the fungicide group modes of action (MOA) used (see page 8-9).

Dr Krige says that ideally fungicides would be the last option for disease management after crop selection and rotation and other non-chemical strategies.

"Rotating crops and MOA reduces the risk of resistance by helping to ensure the pathogen can't easily adapt to the cropping conditions," she says. "And holding workshops and testing services allows us to see what is happening and spread this messaging directly to try to reduce resistance development in the future."

NEGATIVE AND POSITIVE RESULTS

For Ian Martin, the news was positive – his sample tested negative to STB and therefore showed no signs of fungicide resistance.

This, he says, was a relief and testament to the approach he has taken to his fungicide regime on the advice of FAR managing director Nick Poole, particularly around the timing of applications.

"It's great to see the strategy working," Ian says. He found the information around fungicide MOA and other management strategies provided by AFREN at the field day of significant value. "It's fantastic to be able to talk to the best people in the industry, doing all the hard work behind the scenes, who will give information freely and you can ask them any question you want," he says.

He is also pleased to contribute to the bigger picture of fungicide resistance. While his sample was clear, other testing from the trial site itself turned up some results that showed the implications of resistance.

In some plots where crops were grown under high NFNB pressure to test for the efficacy of particular fungicide strategies, the analysis detected a "high frequency of a mutation conferring SDHI (Group 7) resistance", Dr Krige says. This mutation was found in a trial that had received two Group 3 (DMI) applications, in addition to treatments incorporating SDHI and QoI (Group 11) fungicides. The high level of disease observed after these trial treatments also indicates the potential presence of DMI resistance, which will need to be confirmed with further laboratory testing.

Dr Krige says the presence of this SDHI resistance mutation, verified by further testing at the CCDM laboratories in Western Australia, indicates how vulnerable crops are to diseases when fungicides do not work optimally.

"It shows that fungicide resistance is a very real issue and a very real concern – and proper management practices will be imperative to prevent more cases of fungicide resistance," she says. □

GRDC Code CUR2302-002RTX

More information: Dr Anna-Sheree Krige, sheree.krige@curtin.edu.au

2024 AFREN

Concerned growers and agronomists can reach out to the Fungicide Resistance Group at the Centre for Crop and Disease Management (CCDM) via the email: frg@curtin.edu.au and we will provide instructions on how to send samples to CCDM for fungicide resistance testing.

Further information is available from ccdm.com.au or call us on +61 8 9266 1204

The 2024 AFREN – managing foliar diseases and fungicide resistance workshops:

March 19th and 20th Kadina, SA

June 25th and 26th Wagga Wagga, NSW

June 27th and 28th Dubbo, NSW

July 23rd and 24th Horsham, VIC

July 25th and 26th Melbourne, VIC

More information: For details and registration visit grdc.com.au/events/list

From the shelf to field failure: factors driving fungicide resistance

Factors that combine in time and space to drive fungicide resistance and affect longevity of a fungicide:

- **fungicide mode of action**
- **characteristics of the pathogen**
- **risky agronomic practices**

By Associate Professor Fran Lopez-Ruiz

Growers often ask when a new fungicide will start losing effectiveness due to resistance. This question guides both on-farm disease management and the stewardship strategy for sustainable fungicide use.

To answer this question, it is important to first recognise that the ingredient for resistance already exists in the pathogen population, as pathogen strains carrying mutations that confer fungicide resistance emerge naturally in the field. Second, it is necessary to make a distinction between the time required until fungicide resistance is selected and field failure.

This is because fungicide resistance might already be present in the environment, even before the first use of a fungicide, or selection can occur very rapidly, often within a growing season from its first application. On the other hand, field failure can be a fast or slow process depending on factors such as the fungicide mode of action (MOA), the agronomic practices and the pathogen's life cycle.

Once resistance to a particular fungicide has been selected, pathogen populations resistant to that same fungicide will begin to increase in abundance. However, fungicide performance will not be affected in the field until pathogen populations are dominated by the resistant type.

This means that fungicide lifespan will be shorter or longer depending on the strength and speed of the selection pressure. In other words, when the use of fungicides from the same group is high, selection pressure increases, resulting in a faster accumulation of resistant individuals. Every fungicide is different and, for some of them, such as multi-site fungicides, field failure has never been observed.

FUNGICIDE RESISTANCE DRIVERS

Growers and agronomists need to consider three main factors when they are determining the risk of developing fungicide resistance: the type of fungicide and use pattern; characteristics of the target pathogen; and the specific agronomic practices being used. These factors can then be assigned to the matrix in Table 1 to determine the combined risk of fungicide resistance developing.

Fungicides:

- The repeated use of the same single-site MOA fungicide allows for a faster selection of resistance mutations in the field, since pathogens carrying these mutations have a competitive advantage over sensitive ones. Under this scenario, resistant pathogens will rapidly increase in frequency, becoming the dominant type. For medium-high and high-risk fungicides, such as SDHI and QoI (Groups 7 and 11), only one target site mutation is required for resistance to develop. For medium-risk fungicides, such as DMI (Group 3), several mutations need to occur for resistance to develop and this often takes a longer period (Table 1). For a full review on this topic, see the article on page 6-7.
- Minimal or no rotation of fungicides combined with high-risk agronomic practices increases the likelihood of an even-faster selection and spread of resistance. This has been the case for SDHI fungicides and net blotch diseases of barley, where the lack of chemical and crop rotation and the use of susceptible varieties have led to the fast selection of resistance in medium and high-rainfall zones.

Pathogens:

- **Short life cycle pathogens** – the risk of fungicide resistance evolution increases in pathogens able to produce many offspring rapidly, which often translates into multiple disease cycles in each season, such as wheat powdery mildew. This is exacerbated in paddocks where susceptible varieties are being grown.
- **Sexually reproducing pathogens** – pathogens with a sexual stage in their life cycle have an increased risk of fungicide resistance evolution due to the ability to generate higher variability, such as Septoria tritici in wheat, blackleg in canola and the net blotches in barley.
- **Long-distance dispersing pathogens** – windborne and seed-borne pathogens will have a faster regional impact in terms of resistance

Photo: Péter Kövesi

In agriculture, the environment stands as the uncontrollable variable that thwarts growers at times. Crop selection is within a grower's power, but unpredictable rainfall season to season dictates disease management strategies and can play a part in driving fungicide resistance.

spread than those that are, for example, stubble-borne. However, even stubble-borne pathogens can disseminate over long distances because of plant material movement (transport of hay) and, more locally, the use of contaminated farm machinery across paddocks.

Agronomic practices:

- **Short or no crop rotations** – continuous planting of a particular crop allows for large pathogen populations to build up, especially if the pathogen is stubble-borne. This practice often requires more frequent fungicide applications and higher label rates earlier in the season due to higher disease incidence.
- **Susceptible varieties** – growing susceptible varieties requires more frequent use of fungicides and higher label rates to control bigger disease epidemics. Allowing pathogens to produce large populations increases the risk of faster resistance selection due to mutations arising during pathogen reproduction.
- **Stubble retention** – no-till farming increases the risk of early disease outbreaks due to the accumulation of diseased plant residues from previous seasons that infect the new crop as soon as it emerges. The lack of an adequate stubble management plan is especially relevant for no or short rotation strategies where susceptible varieties are grown (see also above).

By way of example, use Table 1 to determine the combined risk of fungicide resistance developing. If a fungicide from Group 3, which has a medium risk, is applied to manage a high-risk pathogen powdery mildew in a situation deemed a high agronomic risk, the overall risk for fungicide resistance when considering these combined factors is high.

The only factors that a grower cannot control when it comes to managing fungicide resistance are environmental conditions. While a grower can choose where to grow a crop, rainfall each season and across Australia can be quite variable, ranging from drought to waterlogging.

Wetter regions are more conducive to disease development, requiring more frequent fungicide applications. These regions also allow for longer seasons and under these conditions additional fungicide applications are often required. The same applies to wetter seasons. Farm trafficability is a major consideration in very wet seasons as paddock access can be severely affected, which results in delays to fungicide sprays.

Ultimately, the combination of the above factors in time and space drives the speed at which fungicide resistance develops and field failure occurs and, critically, determines whether specific fungicides will be available to the industry in the long run.

FUNGICIDE RESISTANCE MITIGATION

It is well-accepted that integrated disease management practices can slow the selection and increase of fungicide resistance in pathogen populations. As such, any strategy aimed at reducing the frequency or rate of fungicide application required, or that slows the development of pathogen epidemics during the period when fungicide is present, will have a dramatic impact on the speed at which resistance emerges and spreads in the landscape. Careful monitoring of movement of hay and seeds is also useful to limit regional spread of resistance.

Following best disease management and anti-resistance strategies will slow the selection for resistance. These strategies are more effective when implemented early, when the proportion of the pathogen population that is resistant to the fungicide is still small. For this reason, good stewardship of fungicides should consider all resistance risks ahead of the release of a new product and provide management guidelines adapted to the fungicide and the crop and disease targets.

Developed with GRDC support, the AFREN Fungicide Resistance Management in Australian Grain Crops guide (afren.com.au/resources/#management-guide) provides comprehensive advice on best disease and fungicide resistance management practices. ☐

GRDC Code CUR2302-002RTX

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Table 1: Matrix to evaluate the risk of developing fungicide resistance within Australian cropping systems. Plot the pathogen risk against the fungicide risk and agronomic risk to determine the combined risk of developing fungicide resistance.

Fungicide group*	Fungicide resistance risk	Agronomic risk								
		Low	High	Low	High	Low	High	Low	High	
Multi-sites	Low									Combined risk
3, 13, 50	Medium									
2, 7	Medium to high									
1, 4, 11	High									
		Low		Medium		Medium to high		High		Pathogen risk
		Rusts		Scald Yellow spot Sclerotinia Blackleg		Septoria tritici blotch		Powdery mildew Net blotches Ramularia Chocolate spot Ascochyta blight		
		Disease								

* Not all diseases listed as examples may have fungicides registered for their treatment.

Source: Modified from frac.info

Decision support tools aid disease management decisions

By Janette Pratt and Jean Galloway

A suite of decision support tool apps for disease management has been developed to help growers and advisers identify the most effective and financially advantageous strategies for mitigating crop fungal diseases.

These apps have been produced as part of GRDC-supported national disease modelling projects spearheaded by the Western Australian Department of Primary Industries and Regional Development (DPIRD).

Growers and advisers can be confident these tools can help them make disease management decisions as they are specifically tailored for Australian production systems. They have been developed using comprehensive national experimental data and insights from experts in the field.

Users can input their paddock scenarios into the application, enabling them to evaluate the probable, optimal and worst-case outcomes in terms of yield responses and economic returns resulting from various fungicide management options.

Evaluating the likely yield response and economic returns from management options reduces the unnecessary use of fungicides and helps to minimise the development of fungicide resistance.

Available for Android and Apple devices, the apps are easily accessible for use in the field and have options for reports to be emailed directly to the grower's consultant or to experts involved in the development of the tools for further assistance.

The suite of digital disease management tools available includes:

- **BlacklegCM** – blackleg crown canker management in canola. This app provides the latest crown canker resistance ratings for all current canola varieties and allows the user to compare different fungicide options.
- **UCI BlacklegCM** – management of blackleg upper canopy infection in canola. The app takes into account costs, yield benefits, grain price and seasonal conditions when comparing best case, worst case and most likely estimates of financial returns from different management options.
- **SclerotiniaCM** – management of Sclerotinia stem rot in canola. The user can specify individual paddock data as well as recent and expected weather conditions to determine the likely Sclerotinia severity, yield loss and economic return from no fungicide application versus single or multiple foliar fungicide applications.
- **PowderyMildewMBM** – management of powdery mildew in mungbeans. The app takes into account that this disease is highly influenced by seasonal conditions and will give growers and consultants confidence in decisions about whether to invest in spraying for this disease.
- **StripeRustWM** – stripe rust management in wheat crops. The app assesses the probable disease severity, yield loss and economic return across various fungicide strategies, factoring in costs, grain prices and the prevailing seasonal conditions.
- **YellowSpotWM** – management of yellow spot (tan spot) in wheat. The app accounts for the major factors that influence yellow leaf spot severity. The user can specify factors relating to paddock selection, variety, seasonal conditions, prices and management options so that the output relates to their cropping circumstance.

Development and field testing of the apps has been carried out by DPIRD in collaboration with pathology experts from Agriculture Victoria, Marcroft Grains Pathology, the New South Wales Department of Primary Industries, the South Australian Research and Development Institute, Queensland Department of Agriculture and Fisheries, University of Southern Queensland, University of Melbourne and CSIRO. □

GRDC Codes
DAW2112-002RTX, DAW1810-007RTX
More information:
agric.wa.gov.au/appcentre
For suggestions or enquiries about the apps contact DPIRD at CropDiseaseTools@dpird.wa.gov.au

These apps have been produced as part of GRDC-supported national disease modelling projects spearheaded by the Western Australian Department of Primary Industries and Regional Development (DPIRD).

Photo: Steve Collins, DPIRD

A suite of decision support tools is available to assist growers and advisers with fungicide management options for controlling disease in grain crops.

The AFREN creed

Fungicides are just one tool in an integrated plan to manage crop diseases. To mitigate fungicide resistance growers must adhere to the Fungicide Resistance Five developed by AFREN.

Photo: Evan Collis

Following a system of principles or a creed is a formative way to guide business practices and is proving constructive in managing fungicide resistance

By Dr Anna-Sheree Krige

■ Fungicide resistance is a significant threat to Australian grain production, posing a risk to crop health, yields and overall food security.

As fungal pathogens evolve and adapt, the need for effective management strategies is critical to combat the rising incidence of resistance.

THE CHALLENGE OF FUNGICIDE RESISTANCE

Fungicides are valuable tools in protecting grain crops from devastating fungal diseases, contributing to increased yields and quality. However, the intensive and often repeated use of fungicides places selection pressure on fungal populations, which is leading to the development of resistance.

Fungicide resistance occurs when a subset of fungal pathogens survives exposure to fungicides and passes on their resistant traits to subsequent generations. This process, which results in the gradual replacement of the sensitive pathogen population by the fungicide resistant one, reduces the effectiveness of fungicides, leading to decreased disease control and increased likelihood of economic losses.

Fungal diseases including rusts, and Septoria leaf blotch, to name a few, can devastate crop yields, impacting productivity and profitability.

Fungicides are commonly employed to control these diseases, but the rise of resistance jeopardises their long-term efficacy. Therefore, an integrated approach to managing fungal diseases is required, ensuring that fungicides are only a small part of a suite of disease management tools, to secure the future of Australian grain crops.

To address fungicide resistance in Australian grain crops, it is essential to adopt integrated management strategies that reduce selection pressure and enhance disease control. This involves developing an integrated plan of management using several tools, the deployment of the sum of them being more powerful than one individual tool.

The Australian Fungicide Resistance Network (AFREN), with support from GRDC, has developed the five main management strategies to combat resistance (see box).

A COLLABORATIVE APPROACH

Fungicide resistance management is an industry-wide issue requiring a collaborative approach between growers, researchers, industry stakeholders and policymakers.

The purpose of AFREN is to empower Australian grain growers and the wider industry by providing the most up-to-date information on fungicide resistance management through the provision of easily accessible, understandable resources underpinned by the latest science. For more information about AFREN and the resources available, visit afren.com.au. ☐

GRDC Code CUR2302-002RTX

More information: Dr Anna-Sheree Krige, AFREN project coordinator, sheree.krige@curtin.edu.au

Useful resources

AFREN website: afren.com.au

Fungicide Resistance Management Guide: afren.com.au/resources/#management-guide

THE FUNGICIDE RESISTANCE FIVE

START WITH A SOLID FOUNDATION

1. Avoid susceptible crop varieties

- Where possible, select resistant or less-susceptible crop varieties to reduce your reliance on fungicides throughout the growing season.

NON-CHEMICAL FARM MANAGEMENT

2. Rotate crops

- Alternating different crops reduces the build-up of specific pathogen populations, lowering the need for fungicide applications.

3. Reduce disease pressure using non-chemical control methods

- Manage stubble wisely.
- Use time and distance to reduce disease carryover.
- Maintain good hygiene practices.
- Sow at the best time to avoid or minimise disease.
- Regularly scouting fields for disease symptoms and using diagnostic tools enable early detection of potential problems, allowing for targeted fungicide use.

FUNGICIDE MANAGEMENT

4. Strategically apply fungicides

- Spray only if necessary and within label rates. It is crucial to follow recommended dosage rates to maximise fungicide effectiveness and longevity.
- Consider plant development and disease development.
- Applying fungicides at the correct timing based on disease thresholds maximises their efficacy and reduces the need for multiple applications.

5. Rotate and mix fungicides (if available) and rotate mode of actions groups (MOAs)

- Regularly rotating and mixing fungicides with different modes of action prevents the dominance of resistant strains and broadens disease control effectiveness.

AFREN: UPSKILLING THE GRAINS INDUSTRY

AUSTRALIAN FUNGICIDE RESISTANCE EXTENSION NETWORK

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

WHO WE ARE

The **AUSTRALIAN FUNGICIDE RESISTANCE EXTENSION NETWORK (AFREN)** is at the forefront of advancing crop protection in the grains industry. We're here to support you with valuable knowledge, resources and training.

WHAT WE DO

EMPOWER GROWERS AND ADVISORS

AFREN is committed to elevating knowledge and expertise within the grains industry. Our programs and initiatives are designed to enhance skills and understanding of fungicide resistance management.

PROVIDE A SUITE OF RESOURCES AND TRAINING OPTIONS

Benefit from AFREN's educational resources and workshops, focused on the latest advancements and best practices in fungicide resistance management.

PROMOTE INDUSTRY COLLABORATION

Connect with industry experts, growers and advisors to share knowledge and experiences as we aim to combat fungicide resistance effectively.

HOW TO GET INVOLVED WITH AFREN

VISIT OUR WEBSITE Learn more about our mission, informational resources and updates by visiting our website: afren.com.au

AFREN RESOURCES

The ***Fungicide Resistance Management in Australian Crops* guide** was developed by the Australian Fungicide Resistance Extension Network (AFREN), in collaboration with CropLife Australia's Expert Committee on Fungicide Resistance (ECFR) and the Grains Research and Development Corporation (GRDC). It explains what fungicide resistance is, documents cases of fungicide resistance detected in Australia, and suggests best practice fungicide resistance management strategies for Australian grain.

SCAN QR CODE TO VIEW GUIDE

GENERAL FUNGICIDE RESISTANCE

CROP SPECIFIC

DISEASE SPECIFIC

SCAN QR CODE TO VIEW THE FACT SHEETS

PODCASTS

Tune in to our suite of podcasts featuring advice from our leading experts.

VIDEOS

Videos have been produced to help growers understand how fungicide resistance develops and how you can prevent it from becoming an issue in your cropping programs.

WEBINARS

Webinars have been delivered to provide seasonal updates on diseases pressures and fungicide issues.