FUNGICIDE RESISTANCE MANAGEMENT IN AUSTRALIAN GRAIN CROPS

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Citation
Ireland, K. B., Beard, C., Cameron, J., Chang, S., Davidson, J., Dodhia, K. N., Garrard, T. A., Hills, A. L., Hollaway, G., Jayasena, K. W., Kiss, L., Mair, W., Marcroft, S. J., McLean, M. S., Milgate, A., Poole, N., Simpfendorfer, S., Snyman, L., Thomas, G. J., Wallwork, H., Van de Wouw, A. P., Zulak, K. G. & Lopez-Ruiz, F. J. 2021. *Fungicide resistance management in Australian grain crops*. Grains Research and Development Corporation, Australia.

ISBN: 978-1-922342-17-1

GRDC Project Codes
CUR1905-001SAX, CUR00016, CUR00023, UM00051, DJP1907-004RTX, DAW1907-001RTX, DAW1907-002RTX and DAN00177.

Contact Us
afren@curtin.edu.au
grdc.com.au/afren

REGIONAL FUNGICIDE RESISTANCE PLANT PATHOLOGISTS & EXPERTS / AUTHORS

AFREN extension coordinator – National
Dr Kylie Ireland (Nov 2020 - March 2021) - CCDM, Curtin University, Perth, WA (current address DPIRD, South Perth, WA) - afren@curtin.edu.au

Fungicide resistance – National
Dr Fran Lopez-Ruiz – CCDM, Curtin University, Perth, WA - fran.lopezruiz@curtin.edu.au

Canola - National
Dr Steve Marcroft – Marcroft Grains Pathology - steve@grainspathology.com.au
Dr Angela Van de Wouw – University of Melbourne - apvdw2@unimelb.edu.au

Grains agronomy & crop protection R&D – National
Nick Poole – FAR Australia, Bannockburn, Vic - Nick.Poole@faraustralia.com.au

Northern region - NSW
Dr Steven Simpfendorfer – NSW DPI, Tamworth, NSW - steven.simpfendorfer@dpi.nsw.gov.au
Dr Andrew Milgate – NSW DPI, Wagga Wagga, NSW - andrew.milgate@dpi.nsw.gov.au

Northern region - Qld
Prof. Levente Kiss – Centre for Crop Health, USQ, Toowoomba, Qld -levente.kiss@usq.edu.au
Dr Lisle Snyman - Queensland Department of Agriculture and Fisheries, Warwick, Qld - lisle.snyman@daf.qld.gov.au

Southern region – SA
Dr Jenny Davidson – SARDI, Adelaide, SA - jenny.davidson@sa.gov.au
Dr Tara Garrard – SARDI, Adelaide, SA - tara.garrard@sa.gov.au
Dr Hugh Wallwork – SARDI, Adelaide, SA - hugh.wallwork@sa.gov.au

Southern region - Victoria
Dr Grant Hollaway – Agriculture Victoria, Horsham, Vic - grant.hollaway@agriculture.vic.gov.au
Dr Mark McLean – Agriculture Victoria, Horsham, Vic - mark.s.mclean@agriculture.vic.gov.au

Western region – WA
Geoff Thomas – DPIRD, South Perth, WA - geoff.j.thomas@dpird.wa.gov.au
Ciara Beard – DPIRD, Geraldton, WA – ciara.beard@dpird.wa.gov.au
Dr Kith Jayasena – DPIRD, Albany, WA – kithsiri.jayasena@dpird.wa.gov.au
Andrea Hills – DPIRD, Esperance, WA – andrea.hills@dpird.gov.au

Acknowledgements
This guide has been produced as part of GRDC investment CUR1905-001SAX – Australian Fungicide Resistance Extension Network (AFREN): fungicide resistance management targeted at regional level.

The guide was compiled by Kylie Ireland from the Centre for Crop and Disease Management (CCDM) at Curtin University, in collaboration with the aforementioned authors and incorporating input from additional AFREN team members from the CCDM (Katherine Zulak, Wesley Mair, Kejal Dodhia and Steven Chang) and Independent Consultants Australia Network (ICAN) (John Cameron). The guide was edited and formatted for publishing by AgCommunicators (Bridget Penna and David Foxx). The guide was designed by Jane McLean Design. The guide incorporates significant feedback from CropLife Australia (Katie Asplin, Leanne Forsyth and the Expert Committee on Fungicide Resistance (ECFR) and the GRDC (Randall Wilksch, Friday Obanor and Gordon Cumming), for which we are grateful as it has improved the Guide to the benefit of Australian growers.

Many thanks to those who laid the groundwork for fungicide resistance research in Australian grain crops not listed above, including Richard Oliver and Madeline Tucker, and all current and past staff of the fungicide resistance group at the CCDM. We also acknowledge the contribution of Hayley Wilson, Kim Plummer and James Hunt from La Trobe University for clarification of the status of net blotch resistance in Victoria. Research on canola blackleg resistance that informs the blackleg section of this guide was supported by an ARC linkage grant (project number LP170100548) funded by the Australian government. Finally, thank you to the many grains growers and advisers who have contributed time, knowledge and experience to guiding our understanding of fungicide resistance in Australian grain crops – the context you provide helps us deliver the best materials we can, to help Aussie growers thrive in these uncertain times.

AFREN

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 agronomists across Australia.

Supported by the Grains Research and Development Corporation (GRDC), AFREN aims to raise awareness of the nature and importance of fungicide resistance management, provide clarity on the key elements driving the development and persistence of fungicide resistance in the Australian grains industry, and outline management strategies that can be implemented to mitigate and prevent current and future impacts of fungicide resistance.

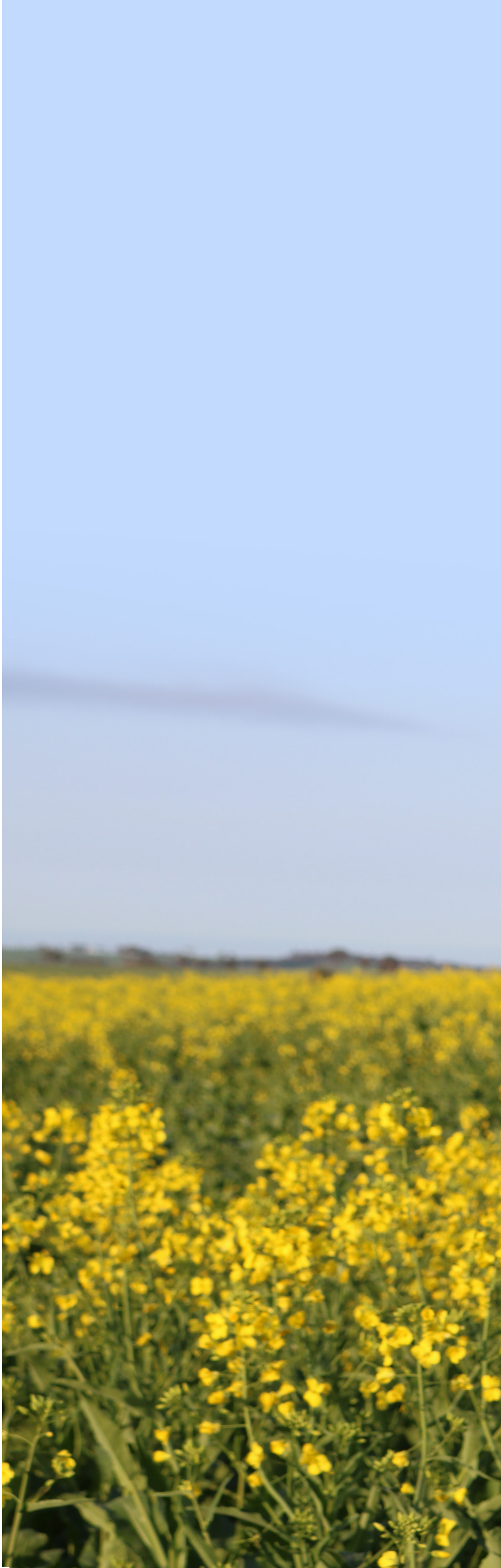
The core AFREN team includes regional plant pathologists and fungicide resistance experts from the Centre for Crop and Disease Management (CCDM) at Curtin University, Agriculture Victoria (AgVic), Centre for Crop Health (CCH) at the University of Southern Queensland, the Department of Primary Industries and Regional Development (DPIRD) in Western Australia, Field Applied Research (FAR) Australia, Marcroft Grains Pathology, New South Wales Department of Primary Industries (NSW DPI), Queensland Department of Agriculture and Fisheries, the South Australian Research and Development Institute (SARDI) and the University of Melbourne. This core team works closely with peak industry bodies such as the GRDC and CropLife Australia, as well as communication and extension specialists from AgCommunicators and the Independent Consultants Australia Network (ICAN), to ensure AFREN extension is relevant and effective.

Growers, agronomists, plant pathologists or other stakeholders with an interest in fungicide resistance are invited to connect with the network by registering online at grdc.com.au/AFREN, following #AFREN and @theGRDC on Twitter, or emailing afren@curtin.edu.au.

AFREN Partners

AFREN is supported by the Grains Research and Development Corporation (GRDC) in partnership with:

Contents



Introduction

Fungicide resistance is a serious and increasing problem in cropping systems worldwide. Fungicides are an important component of integrated disease management strategies for the protection of crops from the impacts of fungal diseases. However, as their use has increased, the effectiveness of some fungicides has been reduced by the development of fungicide resistant pathogen populations. Without intervention, more fungicides are likely to become ineffective.

To extend the effective life of fungicides, anti-resistance strategies need to be implemented that:

- Incorporate a range of integrated disease management (IDM) strategies. IDM can extend the effective life of available fungicide chemistries, reduce crop inputs and support sustainable farming practices.
- Consider the impacts of local crop practices, pathogen diversity and environmental conditions.
- Take place as early as possible. Action is most effective when taken as soon as fungicides are introduced to the market and before any shifts in pathogen sensitivity are detected, though some strategies also work at a later stage.

This Guide has been developed by the Australian Fungicide Resistance Extension Network (AFREN), in collaboration and consultation 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 growers to extend the effective life of fungicides. Regional and disease-specific strategies are provided, along with general advice.

The intent of this Guide is to provide best practice management advice to reduce the emergence and/or impact of pathogen resistance to any chemical fungicides. The advice given is intended to complement the recommendations already provided on fungicide labels and by CropLife Australia, providing growers and advisers with best management advice and principles upon which to build their own disease management strategies.

While every effort has been made to ensure the scientific accuracy and currency of all information and recommendations, understanding of fungicide resistance is constantly developing and readers are advised to seek up-to-date and further information regarding fungicide resistance at the AFREN grdc.com.au/AFREN, CCDM Fungicide Resistance Group ccdm.com.au/frg and CropLife Australia croplife.org.au websites. Current information on registered fungicides can be found on the Australian Pesticides and Veterinary Medicines Authority (APVMA) website at apvma.gov.au.

What is fungicide resistance?

Fungicide resistance occurs when a previously effective fungicide fails to control a disease, despite being applied correctly. It is a preventable issue that can arise when fungi are exposed repeatedly to the same fungicide or fungicide actives from the same chemical Mode of Action (MoA) group. It can become a major constraint to good disease control, especially where no alternative fungicide or effective host-plant resistance is available.

Fungicide resistance terminology

Sensitive

Fungi are considered sensitive when they are killed by a fungicide at recommended label rates.

Reduced sensitivity

Fungi are considered as having reduced sensitivity to a fungicide when a fungicide application does not work optimally, but does not completely fail. In most cases, this would be related to small reductions in product performance, which may not be noticeable at the field level. In some cases, growers may find that they need to apply the maximum label rates of the fungicide to obtain the previously experienced level of control. Reduced sensitivity needs to be confirmed through specialised laboratory testing.

Resistant

Resistance occurs when the fungicide fails to provide an acceptable level of control of the target pathogen in the field at maximum label rates. Resistance needs to be confirmed with laboratory testing, and be clearly linked with an unacceptable loss of disease control when using the fungicide correctly in the field.

Lab detection

Measurable differences in the sensitivity to the fungicide when the fungus is tested *in vitro* using tests recognised by the scientific community and/or detection of known or novel molecular mechanisms (e.g. genetic mutation, changes in target gene expression, etc.) of a fungal isolate. These changes can often be detected in the laboratory before any loss of fungicide efficacy is detected in the field. Lab detections are used to confirm reports of field resistance or reduced sensitivity, or to indicate the potential for resistance or reduced sensitivity to develop. For further detail, see Appendix A: Fungicide resistance in the lab.

Why might a fungicide application fail?

A range of on-farm practices can potentially affect the efficacy of fungicide applications in several different ways, irrespective of the presence or absence of fungicide resistance.

Reasons for fungicide failure may include:

- poor application of foliar fungicide due to operator error or incorrect sprayer calibration,
- unsuitable weather during or immediately after spraying (i.e. excessive wind or rain),
- poor application timing,
- poor application coverage,
- antagonistic tank mixes,
- ineffective rates,
- faulty product,
- excessive inoculum (disease) pressure, or
- choice of a poor efficacy fungicide for the target pathogen.

Many of these factors can also affect the efficacy of seed and in-furrow fungicide treatments. Dry soil conditions and/or other factors that restrict root growth may reduce the efficacy of seed and in-furrow fungicides by restricting root uptake and redistribution of the active throughout the plant. Wet soil conditions and excessive rainfall may also reduce the efficacy of seed and in-furrow treatments, by moving the active constituents out of the root zone and further down the soil profile.

Importantly, fungicides have a specific spectrum of activity. Use of a fungicide that is not effective on the target pathogen or applying the fungicide sub-optimally may fail to provide effective disease control, with no link to fungicide resistance.

Given the above, it is important to keep good records, monitor crops and have samples tested if you suspect fungicide resistance, so that you can adapt your management strategies in a timely and effective manner.

Responsible use of fungicides – labels and MRLs

Growers are required to comply with all label directions when using fungicides. It is the responsibility of growers and advisers to ensure that any fungicide to be applied to a crop is registered for that purpose, or that permits are current, and that all withholding periods are followed. Current information on registered and permitted fungicides can be found on the APVMA website at apvma.gov.au.

The use of fungicides in accordance with the registered label may lead to the presence of finite (measurable) residues in both grain and forage. Different market destinations may have differing maximum residue levels (MRLs) or import tolerances compared to those set in Australia by the APVMA.

There is a need for more awareness by growers and advisers of the impact of chemical use on market access. Growers and their advisers should talk to their storage agent and/or marketer with regards to any specific market or contract requirements.

How does fungicide resistance develop?

Fungicide resistance usually develops following the repeated use of fungicides with the same mode of action for disease control. In any fungal population there are likely to be individuals that have natural resistance and are less susceptible to fungicides, even before chemicals are applied. This resistance arises through mutations (random changes in the genetic structure of the pathogen). If resistant individuals are then repeatedly exposed to the same fungicide, they may be selected for, increasing their frequency in the fungal population (Figure 1).

Continued use of the same fungicide or fungicides from the same Mode of Action (MoA) group can result in a significant build-up of resistant individuals in the fungal population – to the point where that product, or other products from the same MoA group, have reduced efficacy or are no longer effective. In some cases, removal of the selection pressure can result in the fungal population regaining its sensitivity to the fungicide or MoA group, but this is not always the case.

The risk of developing fungicide resistance varies between different MoA groups, different fungal pathogens and different environments. Consequently, specific strategies are recommended for those situations considered to carry the highest risk.

For more information on these high risk situations, see the fungicide resistance risk factors section at the start of this Guide.

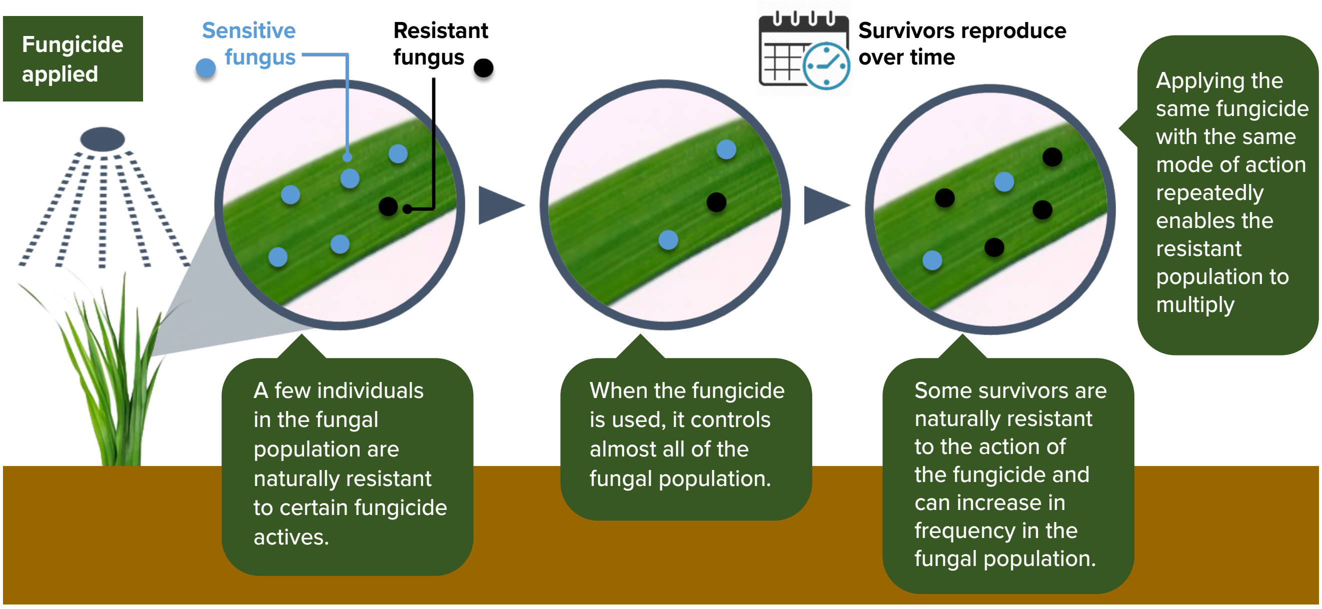


Figure 1. Fungicide resistance evolution. Modified from CropLife Australia Fungicide Resistance Management Fact Sheet – https://www.croplife.org.au/resources/programs/resistance-management/fact-sheet-fungicide-resistance/

Fungicide groups - Modes of Action (MoA)

Different numbers are used to distinguish fungicide groups according to their biochemical Mode of Action (MoA). When a pathogen develops resistance to a fungicide, all other fungicides within the same fungicide MoA group are often at risk of having reduced sensitivity or resistance develop.

More than 200 fungicides, within 57 MoA groups, are approved worldwide for the control of fungal pathogens in agriculture. However, very few of these MoA groups are registered for use to combat pathogens of grain crops in Australia, and only a handful of these dominate the market. Having so few MoA groups available for use increases the risk of fungicide resistance developing, as growers have very few alternatives to rotate with, in order to reduce selection pressure on these fungicide MoA groups.

Dominant MoA groups registered for diseases of Australian grain crops:

Group 3 - Azoles/demethylase inhibitors (DMIs).
Common actives: cyproconazole, epoxiconazole, flutriafol, tebuconazole, propiconazole, prothioconazole, triadimefon.
Registered: canola, cereals and pulses. The predominant group, they have been generally cheap and effective against a broad range of diseases in various crops for many years.
Risk of resistance development: moderate.

Group 7 - Succinate dehydrogenase inhibitors (SDHIs).
Common actives: bixafen, fluxapyroxad, penflufen.
Registered: canola, cereals and pulses. Commonly used as a seed dressing, and as a mixing partner in some foliar formulations. There are distinct differences in disease spectrum and systemic movement of these fungicide actives within plants within this group.
Risk of resistance development: moderate to high.

Group 11 - Strobilurins/quinone outside inhibitors (QoIs).
Common actives: azoxystrobin, pyraclostrobin.
Registered: canola, cereals and pulses. Used as a mixing partner in some foliar and in-furrow formulations.
Risk of resistance development: high.

Other MoA groups registered for diseases of Australian grain crops:

Group 1 - Methyl benzimidazole carbamates (MBCs).
Common actives: carbendazim, thiabendazole. Registered: pulses. Risk of resistance development: high.

Group 2 - Dicarboximides/MAP-kinase inhibitors.
Common active: iprodione. Registered: canola (not for blackleg) and pulses (excl. chickpeas). Risk of resistance development: moderate.

Group 4 - Phenylamides/PAA.
Common active: metalaxyl. Registered: most crops. Used as a mixing partner in seed treatments and in-furrow applications to target oomycetes (e.g. *Phytophthora* spp., *Pythium* spp.). Risk of resistance development: high.

Group 5 - Amines/Morpholines.
Common active: spiroxamine. Registered: barley. Risk of resistance development: low to moderate.

Group 12 - Phenylpyrroles/PP fungicides.
Common active: fludioxonil. Registered: canola, maize, peanut and sorghum. Risk of resistance development: low to moderate.

Group 13 - Aza-napthalene.
Common active: quinoxyfen. Registered: barley. Risk of resistance development: moderate.

Group 14 - Aromatic hydrocarbons and heteroaromatics.
Common active: quintozene. Registered: peanut (soil-borne fungi). Risk of resistance development: low to moderate.

Group 33 - Phosphonates.
Common active: phosphorous acid. Registered: barley, canola and wheat. Principally used for the control of oomycetes (e.g. *Phytophthora* spp., *Pythium* spp.). Risk of resistance development: low.

M1-M5 - Multi-site activity.
Common actives: chlorothalonil, copper, mancozeb, sulphur. Registered: predominantly pulses. Good rotation and mixing partner options for managing fungicide resistance. Risk of resistance development: low.

Note: Fungicides are registered on a state/territory, crop, target pathogen, formulation and application rate basis. Current information on registered fungicides and their use can be found on the APVMA website at apvma.gov.au.

Risk of resistance development indicated above is based on global experience and assessments by the Fungicide Resistance Action Committee (FRAC). See the fungicide resistance risk factors section at the front of this Guide for more information.

Further information on MoA groups and risk of resistance development can be found on the FRAC website at frac.info.

Pathogen or Disease?

These terms can sometimes be interchanged, however, it is helpful to think of the **pathogen** as the organism that causes the damage and the **disease** as the symptoms of the pathogen.

In scientific terms:

A PATHOGEN is an organism e.g. plant parasitic fungus, bacterium or nematode, that infects a plant to cause disease.

INOCULUM is the part of the pathogen that resides in the soil or on seed or foliage and can infect plants.

The DISEASE is the expression of symptoms that negatively affect the yield and/or quality of a crop, e.g. the symptoms caused by the pathogen.

For example, the pathogen *Leptosphaeria maculans* causes the disease canola blackleg. The spores of *Leptosphaeria maculans* survive in the stubble of canola, which can be the inoculum source for disease outbreaks at the start of the next season.

Fungicide resistance risk factors

Fungicide resistance is a numbers game – higher disease pressure increases the probability of a pathogen population developing fungicide resistance.

Higher disease pressure means larger pathogen populations. The larger the size of the pathogen population, the higher the likelihood of fungicide resistant individuals developing within that population due to random mutations. Then, the more fungicide applications that are required to control the disease, the higher the probability of selecting for survival of these fungicide resistant individuals within the pathogen population.

Higher disease pressure is associated with factors such as: favourable weather conditions for disease development, sub-optimal agronomic practices (e.g. lack of crop rotation, use of susceptible crop varieties or presence of green bridges or stubble which harbour spores from the last season), and inherent characteristics of the fungi themselves (e.g. rapid life cycle, short latent periods).

The risk of fungicide resistance is greatest in pathogens with short life cycles, where there is a lack of useful resistance in the dominant varieties, and when fungicides within a single mode of action (MoA) group are used repeatedly.

Fungicide resistance risk factors

high risk | moderate to high risk | moderate risk | low risk

Fungicide risk

Of the three principal MoAs used regularly to combat grain diseases in Australia:

Group 11 (Strobilurins/QoIs, e.g. azoxystrobin) have the highest risk of pathogen resistance development, especially for the pathogens responsible for septoria tritici blotch in wheat, and powdery mildews in barley and wheat.

Resistance can result from a single-gene mutation in these pathogens, and this resistance can spread quickly and cause field failures. Usually, when resistance to an active within Group 11 is detected, other actives within the group are likewise compromised (i.e. cross-resistance).

Group 7 (SDHIs, e.g. fluxapyroxad) have a moderate to high risk of resistance development, especially for the pathogens responsible for net form net blotch (NFNB) and ramularia leaf spot in barley and septoria tritici blotch in wheat.

Resistance can result from single or multiple-gene mutations in the pathogen, which can spread quickly and cause field failures. Depending on the mutation, when resistance to a Group 7 fungicide is detected, other Group 7 fungicides may or may not be compromised, to differing extents (i.e. moderate to high cross-resistance).

Group 3 (DMIs, e.g. tebuconazole) have a moderate risk of pathogen resistance development. However, recent developments in Western Australia have challenged this view. The shift in pathogen sensitivity to Group 3 fungicides has usually been a gradual process, where an incomplete form of resistance slowly builds and can take years to develop (i.e. reduced sensitivity toward resistant). In Western Australia however, a highly virulent genotype of barley powdery mildew, resistant to the Group 3 fungicide tebuconazole, came to dominate the fungal population over a short period of time in 2010, devastating crops and highlighting that Group 3 fungicide resistance may develop more rapidly under conducive conditions and in relation to specific interactions between certain active compounds and specific pathogens.

Depending on the mutation in the pathogen, when resistance to a Group 3 fungicide is detected, other fungicides within Group 3 may or may not be compromised, to differing extents (i.e. low to moderate cross-resistance). For this reason, it may be possible to rotate use of different active compounds of Group 3 fungicides, though limits on the total number of applications, and taking care to not apply them consecutively, is then needed to manage the risk of fungicide resistance developing for these actives. While AFREN recommend the rotation of Group 3 active compounds throughout a season to manage Group 3 resistance development, this position is not currently supported by CropLife Australia or FRAC (frac.info) (see the Group 3 rotation box item in the General fungicide resistance management guidelines section).

Global experience further indicates the following:

Group 1 (MBCs, e.g. carbendazim) have a high inherent risk of pathogen resistance developing. Resistance can result from single-gene mutations in the pathogen. Usually, when resistance to an active within Group 1 is detected, other actives within the group are likewise compromised (i.e. cross-resistance).

Group 1 resistant strains of *Botrytis* species from crops other than grains have been widely reported, including evidence demonstrating no impaired fitness compared to sensitive field strains.

Group 2 (dicarboxamides, e.g. iprodione) have a low to moderate risk of pathogen resistance developing.

Group 2 resistant strains of *Botrytis* species from crops other than grains have been widely reported.

Pathogen/disease risk

Grain diseases known to have a risk of developing fungicide resistance include the following:

CEREALS

Barley and wheat powdery mildew (caused by *Blumeria graminis* f. sp. *hordei* and f. sp. *tritici*) have an inherently high resistance risk because of their remarkable ability to adapt to fungicide treatments.

Resistance and **reduced sensitivity** have been reported in Western Australia for **Group 3** fungicides for barley powdery mildew and **resistance** for **Group 11** fungicides for wheat powdery mildew in New South Wales, South Australia, Tasmania and Victoria. The detection in Australia of **resistance** and a collection of mutations linked to a **gateway mutation** for **Group 3** resistance in wheat powdery mildew indicates an ongoing need for vigilance for this group of fungicides.

Resistance to Group 11 fungicides has been reported in Europe and New Zealand, and reduced sensitivity to Group 3 fungicides has been reported in Europe and China for both pathogens. In Europe, barley powdery mildew has additionally developed resistance to Group 5 morpholine and Group 13 Aza-napthalene fungicides, and reduced sensitivity has been detected in the lab to the Group 50 fungicide metrafenone, with no impact on field performance detected.

Net blotches
(caused by *Pyrenophora teres* f. *maculata* and f. *teres*).

Resistance and **reduced sensitivity** have been reported for **Group 3** fungicides for both spot form net blotch (SFNB, *P. teres* f. *maculata*) and net form net blotch (NFNB, *P. teres* f. *teres*) in Western Australia. **Reduced sensitivity** for **Group 3** fungicides for both SFNB and NFNB has also been reported in South Australia, and to a lesser extent in Victoria. **Resistance** and **reduced sensitivity** of NFNB to **Group 7** fungicides has been reported in South Australia. **Resistance** and **reduced sensitivity** of SFNB to **Group 7** fungicides has been reported in Western Australia. Cases of NFNB and SFNB **dual reduced sensitivity/resistance** to **Group 3** and **Group 7** have also been confirmed in the laboratory from South Australia and Western Australia, respectively.

Reduced sensitivity to Group 3, 7 and 11 fungicides are reported from Europe. Resistance to Group 3 fungicides is reported from New Zealand. Reduced sensitivity to Group 3 and 11 fungicides has also been reported from Canada.

Ramularia leaf spot (caused by *Ramularia collo-cygni*).

Resistance to Group 1, 3, 7 and 11 fungicides has been reported in Europe. Resistance to Group 7 and 11, and reduced sensitivity to Group 3 fungicides has been reported from New Zealand.

Septoria tritici blotch (caused by *Zymoseptoria tritici*).

Reduced sensitivity to **Group 3** fungicides has been reported in New South Wales, South Australia, Tasmania and Victoria.

Resistance to Group 1 and 11, as well as reduced sensitivity to some Group 3 and 7 fungicides, has been reported in Europe. Resistance to Group 11 and reduced sensitivity to some Group 3 and 7 fungicides has also been reported in New Zealand.

Septoria nodorum blotch
(caused by *Parastagonospora nodorum*).

Reduced sensitivity to Group 3 fungicides has been reported in China and Europe. Resistance to Group 11 fungicides has also been reported in Sweden and most recently (2020) in the USA.

Barley scald (caused by *Rhynchosporium commune*).

Resistance to Group 1 fungicides is common and widespread in the UK and reduced sensitivity has been detected for Group 3 and 11 fungicides in Europe.

Eyespot (caused by *Oculimacula yallundae*).

Resistance to Group 1 fungicides has been reported in New Zealand. Reduced sensitivity to the Group 3 fungicide prochloraz has been reported in France.

Tan spot / Yellow leaf spot of wheat
(caused by *Pyrenophora tritici-repentis*).

Resistance to Group 3 and reduced sensitivity to Group 11 fungicides has been reported in Europe.

Smuts (caused by *Ustilago* spp.).
Cereal smuts are considered to be at a low risk of developing resistance to fungicides. However, resistance to the Group 7 fungicides carboxin and fenfuram has been reported for loose smut of barley (caused by *Ustilago nuda*) in Europe.

CANOLA

Blackleg (caused by *Leptosphaeria maculans*).

Reduced sensitivity has been reported in Australia for **Group 3** fungicides for populations from New South Wales, South Australia, Victoria and Western Australia. **Lab detections** of target site mutations, which confer fungicide resistance to **Group 2** fungicides (not registered for blackleg), have also been recorded in Western Australia. While no Group 2 fungicides are registered for use on *L. maculans* in Australia, use of Group 2 fungicides registered to target other fungi may select for resistant individuals of *L. maculans* through non-target selection.

Sclerotinia stem rot
(caused by *Sclerotinia sclerotiorum*).

Resistance to Group 1 and reduced sensitivity to Group 2 and 7 fungicides has been detected in France, and reduced sensitivity has been detected throughout Europe.

Note: No groups of fungicides have completely gone out of use because of resistance. Resistance of pathogen populations often decreases if use of the at-risk fungicide is reduced or stopped, allowing growers to manage and extend the life of many chemistries.

PULSES

Ascochyta blights
(caused by *Ascochyta lentis* (syn: *Didymella lentis*).)

Lab detections of target site mutations known to confer resistance to the **Group 1** fungicide carbendazim, and associated discriminatory dose responses, have been detected for ascochyta blight of lentil isolates (*A. lentis*) from South Australia. The field implication of these detections is unclear. While carbendazim is not registered or considered efficacious for control of ascochyta blight, cross-resistance is common amongst Group 1 fungicides and care should be taken when considering Group 1 fungicides to control *A. lentis* in the future.

Resistance to Group 11 fungicides has been detected in chickpea ascochyta blight (caused by *Ascochyta rabiei* (syn: *Didymella rabiei*)) in Canada since the 1990s, and in the USA since the mid-2000s. Reduced sensitivity of field pea ascochyta blight (caused by *Didymella pinodes* (syn: *Ascochyta pinodes, Mycosphaerella pinodes, Peyronellaea pinodes*) to Group 11 fungicides has also been detected in Canada.

***Botrytis* spp.** (e.g. *Botrytis cinerea*).

Lab detections of a target site mutation known to confer resistance to the **Group 1** fungicide carbendazim, and associated discriminatory dose responses, have been detected for a botrytis grey mould of chickpeas isolate (*B. cinerea*) from South Australia. The field implication of this detection is unclear. Cross-resistance is common amongst Group 1 fungicides and care should be taken when considering Group 1 fungicides to control *B. cinerea* in pulses in the future.

Resistance, and cases of dual and multiple resistance and reduced sensitivities, to Groups 1, 2, 7, 9, 11, 12 and 17 fungicides, have been reported globally for *Botrytis* spp. across many crops. Studies in other crops in Europe show that Group 1 resistant strains of *B. cinerea* appear to have no impaired fitness compared to sensitive field strains, and have been shown to persist in populations, even after use of the fungicide has ceased.

Downy mildew (caused by *Peronospora viciae*).

Resistance to Group 4 fungicides has been detected in peas in New Zealand.

Agronomic risk

ENVIRONMENTAL

Environmental conditions conducive to disease development naturally increase disease pressure, and therefore the risk of fungicide resistance developing, where fungicides are used.

Given that moisture is a significant limiting factor for the growth and spread of most plant pathogens, rainfall is closely linked to the natural risk of fungicide resistance developing in an area.

- **High rainfall** areas are at most risk of fungicide resistance developing as disease pressure can be highest in these areas. Crop growth can be markedly higher in these areas, resulting in closed canopies that increase disease incidence via microclimates of increased moisture. Closed canopies can also make it more difficult to attain the required level of spray coverage throughout the crop canopy. Longer-season high rainfall zones (e.g. Tasmania, southern Victoria) assume additional risk, as more fungicides are typically applied to afford protection across the longer growing season.
- **Moderate rainfall** areas have a moderate to high risk of fungicide resistance developing. The risk is greatest during periods of increased rainfall and prolonged moisture.
- **Low rainfall** areas have the lowest risk of fungicide resistance developing as disease pressure is often lower and terminal drought often causes the crop to dry off before disease impacts are fully expressed.

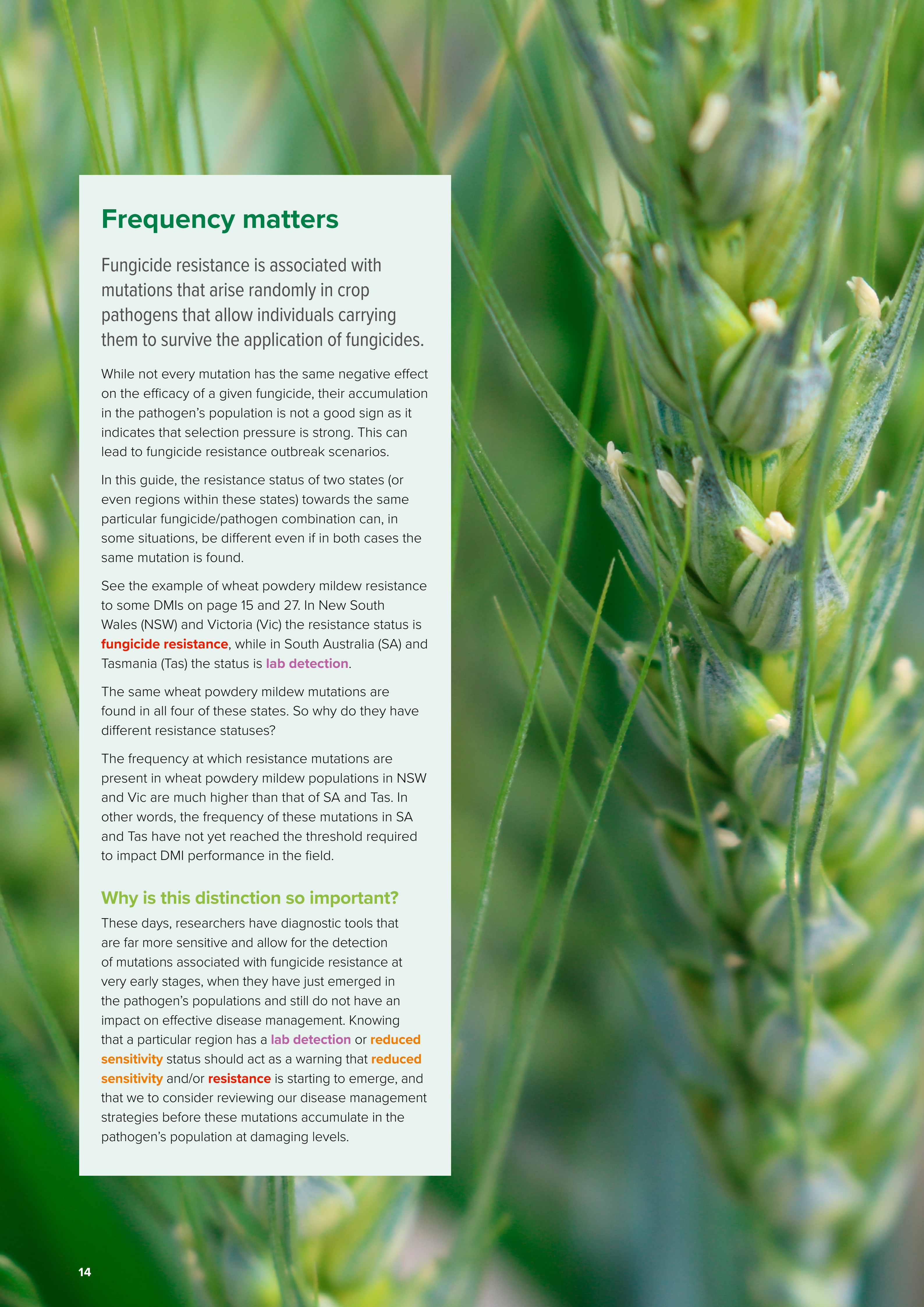
AGRONOMIC PRACTICES

Agronomic practices have the greatest impact on the risk of fungicide resistance developing, and growers have the power to moderate or change these practices. In the absence of fungicides, fungicide resistance cannot develop to damaging levels, and where disease pressure is reduced, fungicide resistance develops slower. The degree of risk different agronomic practices pose will differ across crops and diseases.

Agronomic practices likely to increase fungicide resistance development risk include:

- **Repeated use of the same fungicide** active or MoA group against the same pathogen in the same growing season. Each application provides the opportunity for selection of resistant individuals in the population. There is also a risk that repeated use of the same fungicide on the same paddock/farm over seasons could also contribute to fungicide resistance through selection of resistant individuals in non-target pathogen populations.
- **Cropping susceptible varieties**. Choosing susceptible varieties increases disease pressure as the pathogen has a suitable host to build up larger populations on. This may mean that growers then use more fungicide, compounding the risk.

- **Allowing crops to become heavily infected**. The greater the pathogen population, the greater the chance of fungicide resistant individuals being selected when fungicides are applied.
- **Poor crop rotation**. Planting the same crop or another crop susceptible to the same pathogen(s) as the prior crop for more than one season usually increases the disease pressure of multiple pathogens within those crops. This may also allow for carry-over of resistant individuals of a pathogen within a population.
- **Poor stubble management**. Where infected stubble or plant residues are retained or crops are grown not far from the previous season's stubble of the same crop, pathogens are likely to survive, which increases disease pressure and selection for resistance in following crops. This is likely to occur through increased fungicide use to control disease and potential carry-over of resistant individuals of a pathogen within a population.



Frequency matters

Fungicide resistance is associated with mutations that arise randomly in crop pathogens that allow individuals carrying them to survive the application of fungicides.

While not every mutation has the same negative effect on the efficacy of a given fungicide, their accumulation in the pathogen's population is not a good sign as it indicates that selection pressure is strong. This can lead to fungicide resistance outbreak scenarios.

In this guide, the resistance status of two states (or even regions within these states) towards the same particular fungicide/pathogen combination can, in some situations, be different even if in both cases the same mutation is found.

See the example of wheat powdery mildew resistance to some DMIs on page 15 and 27. In New South Wales (NSW) and Victoria (Vic) the resistance status is **fungicide resistance**, while in South Australia (SA) and Tasmania (Tas) the status is **lab detection**.

The same wheat powdery mildew mutations are found in all four of these states. So why do they have different resistance statuses?

The frequency at which resistance mutations are present in wheat powdery mildew populations in NSW and Vic are much higher than that of SA and Tas. In other words, the frequency of these mutations in SA and Tas have not yet reached the threshold required to impact DMI performance in the field.

Why is this distinction so important?

These days, researchers have diagnostic tools that are far more sensitive and allow for the detection of mutations associated with fungicide resistance at very early stages, when they have just emerged in the pathogen's populations and still do not have an impact on effective disease management. Knowing that a particular region has a **lab detection** or **reduced sensitivity** status should act as a warning that **reduced sensitivity** and/or **resistance** is starting to emerge, and that we to consider reviewing our disease management strategies before these mutations accumulate in the pathogen's population at damaging levels.

Fungicide resistance in pathogens of Australian grain crops

Multiple cases of fungicide resistance and reduced sensitivity have been identified in pathogens of Australian grain crops since 2010 (Table 1). More cases are expected to arise as survey and detection techniques become more sophisticated and widely adopted across regions, and fungicide use continues.

Table 1. Confirmed records of fungicide resistance in diseases of Australian grain crops. Red ✖ = resistance, orange # = reduced sensitivity, and purple □ = lab detections. See detail of detections, by active constituent, in each crop disease section. Farm-level or regional risk may vary greatly from the state level results presented here. Please note, this information is current as at 1 March 2021 and is subject to change. Updated information will be available at grdc.com.au/AFREN.

Fungicide Group	Compounds affected	Resistance Status						Industry implications
		NSW	Qld	SA	Tas	Vic	WA	
Barley								
Barley powdery mildew - caused by *Blumeria graminis* f. sp. *hordei*								
3 (DMI)	Tebuconazole, propiconazole, flutriafol	□	□		□	□	✖ #	Field resistance and reduced sensitivity to some Group 3 fungicides.
Net form net blotch (NFNB) - caused by *Pyrenophora teres* f. *teres*								
3	Tebuconazole, propiconazole, prothioconazole, epoxiconazole			#		#	✖ #	Field resistance and reduced sensitivity to some Group 3 fungicides
7 (SDHI)	Fluxapyroxad			✖ #				Field resistance to fluxapyroxad.
3 + 7	Tebuconazole (3), fluxapyroxad (7)			✖ #				Risk of field resistance and reduced sensitivity to both Group 3 and Group 7 fungicides due to the existence of double mutants.
Spot form net blotch (SFNB) - caused by *Pyrenophora teres* f. *maculata*								
3	Tebuconazole, propiconazole, prothioconazole, epoxiconazole					□	✖ #	Field resistance and reduced sensitivity to some Group 3 fungicides.
7	Fluxapyroxad						✖ #	Field resistance and reduced sensitivity to Group 7 fungicides.
3 + 7	Tebuconazole (3), fluxapyroxad (7)						□	Risk of field resistance and reduced sensitivity to both Group 3 and Group 7 fungicides due to the existence of double mutants.
Hybrid net/spot form net blotch – caused by *Pyrenophora teres* f. *teres* x f. *maculata*								
3	Tebuconazole, propiconazole, epoxiconazole						✖	Field resistance to some Group 3 fungicides.
Wheat								
Septoria tritici blotch - caused by *Zymoseptoria tritici*								
3	Flutriafol, propiconazole, tebuconazole, triadimenol epoxiconazole, cyproconazole	#		#	#	#		Reduced sensitivity to some Group 3 fungicides.
Wheat powdery mildew - caused by *Blumeria graminis* f. sp. *tritici*								
3	Propiconazole, tebuconazole	✖		□	□	✖		Field resistance to some Group 3 fungicides in NSW and Vic. Gateway mutation detected in all other states except for Qld and WA. The gateway mutation does not reduce the efficacy of the fungicide but is the first step towards resistance evolving.
11 (QoI)	All group 11	✖		✖	✖	✖		Field resistance to all Group 11 fungicides.
Canola								
Blackleg - caused by *Leptosphaeria maculans*								
3	Flutriafol, fluquinconazole, prothioconazole, tebuconazole	#		#		#	#	Field implication unclear. High likelihood of reduced sensitivity and/or resistance developing.

General fungicide resistance management guidelines

Resistance is a numbers game, and the only viable option to slow it down is to limit the size of pathogen populations (see the fungicide resistance risk factors section at the start of this Guide). This can be done by implementing an integrated disease management (IDM) strategy tailored to specific growing conditions and pathogens prevalent in particular local regions, to reduce disease pressure and reliance on fungicide application.

Fungicides are just one component of an effective IDM strategy (Figure 2). To maintain their effectiveness for as long as possible, AFREN recommends that growers:

AVOID SUSCEPTIBLE CROP VARIETIES

- The use of less susceptible crop varieties can reduce the need for fungicide inputs.

ROTATE CROPS – USE TIME AND DISTANCE TO REDUCE DISEASE CARRY-OVER

- Rotate crops to help break the disease cycle. Extend rotations and distance stubble, crops and susceptible varieties to reduce disease carry-over and spread.

USE NON-CHEMICAL CONTROL METHODS TO REDUCE DISEASE PRESSURE

- Invest in clean seed. Do not use seed from heavily infected crops.
- Manage the green bridge – destroy volunteer crop plants and alternate hosts prior to sowing.
- Remove or reduce stubble to minimise carry-over of stubble-borne pathogens.

SPRAY ONLY IF NECESSARY AND APPLY STRATEGICALLY

- Only apply if necessary and limit applications. Fungicide use may not be economical or necessary in low disease pressure scenarios.
- Get a good diagnosis in order to avoid unnecessary application for abiotic issues such as physiological spotting or yellowing, herbicide damage or nutrition or non-fungal diseases such as viruses or bacterial infections.
- Use an effective seed dressing for early crop protection, especially in high disease pressure scenarios or to reduce the spread of seed-borne pathogens.
- If conditions are highly conducive for disease development, apply fungicides as early as possible after symptoms develop or preventatively (for contact fungicides), based on assessment of local weather and disease pressure conditions.
- Carefully consider your need to apply fungicides to heavily infected crops. If you do, be strategic and try to select a fungicide for which little or no resistance has been reported in your state. It is simply a numbers game. The larger the pathogen population, the larger the number of resistant individuals that you could select for when a fungicide is applied.
- Always follow the label. Use the registered rates.
- Where reduced sensitivity or resistance has developed, minimise and if possible, avoid the use of affected fungicides and their mode of action groups.

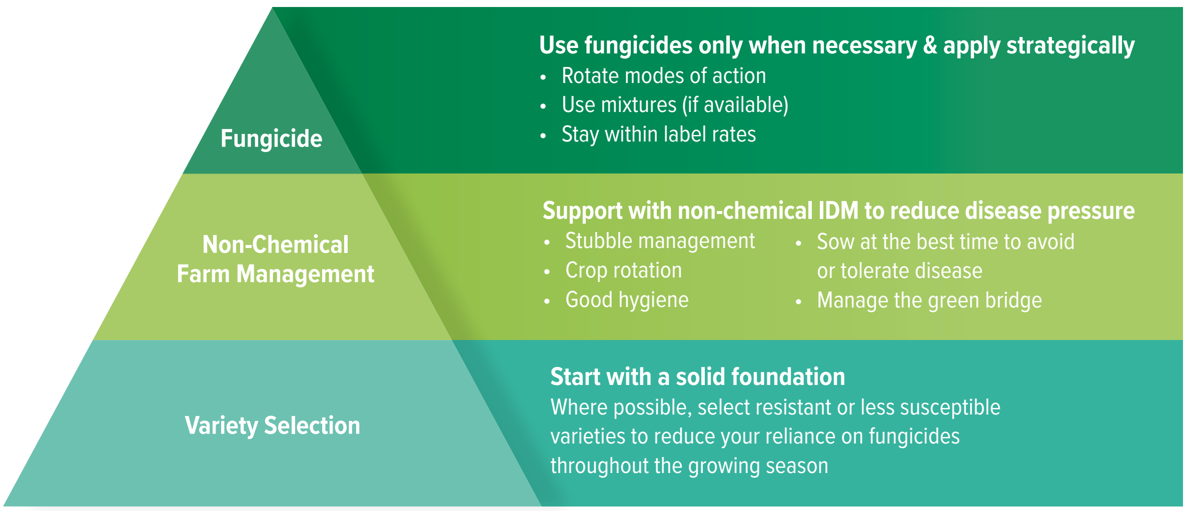


Figure 2. Fungicide resistance management. Growers should seek to provide a strong and reliable foundation of resistant or less susceptible crop varieties, supported by non-chemical integrated disease management that can be complemented by strategic and responsible use of fungicides.

ROTATE AND MIX FUNGICIDE MODE OF ACTION (MoA) GROUPS

- Avoid using the same fungicide active more than once in a growing season.
- Avoid applying the same fungicide active consecutively, even if in different mixtures or products, both within and across seasons.
- Use mixtures with different MoA groups whenever possible, especially if disease pressure is high. Ensure effective registered rates of each fungicide active are maintained in mixtures for each target pathogen and disease pressure scenario.
- Rotate MoA groups as much as possible in a fungicide control program, both within and across seasons.
- Rotate Group 3 fungicide actives where more than one is required in a growing season. Avoid applying only Group 3 fungicides, even over consecutive growing seasons, for the same target pathogen.
- Avoid applying Group 7 and Group 11 fungicide actives more than once in a growing season. They must always be in a co-formulation or in mixture with a registered mixing partner with a different mode of action. This mixing partner should ideally be one for which the target pathogen has no (or less) known reduced sensitivity or resistance.

MONITOR REGULARLY FOR DISEASE

- Inspect crops for plant disease symptoms. Use regional disease guides e.g. GRDC GrowNotes, Ute or Pocket guides and apps, and crop disease updates to identify when and where to look for crop disease – or reach out to agronomists, advisers or regional state pathologists for assistance. Reassess a couple of weeks after fungicide application to assess fungicide efficacy.
- Have samples tested if resistance is suspected, so that crop diseases can be quickly and effectively managed. Contact a local regional plant pathologist or fungicide resistance expert to discuss the situation (listed at the front of this Guide). Alternatively, contact the Fungicide Resistance Group at the Centre for Crop and Disease Management directly via frg@curtin.edu.au to arrange for testing.

Rotation of Group 3 fungicides

AFREN recommends that when more than one application of a Group 3 fungicide is required within and across growing seasons, that effective (both efficacy and resistance status) registered actives are rotated. A maximum of three applications per season are recommended, whether as a solo active or in a mixture. AFREN recommends these applications should be of a different active within the registered Group 3 fungicides for the target pathogen (i.e. do not use the same Group 3 active consecutively and avoid using the same Group 3 active more than once per season).

This recommendation differs from the CropLife and FRAC (frac.info) resistance management strategies. CropLife Australia have raised concerns that this could encourage development of resistance mutations common to multiple Group 3 fungicides, as has occurred for the septoria tritici blotch pathogen *Zymoseptoria tritici* in Europe. Both AFREN and CropLife Australia agree that to reduce selection pressure on Group 3 resistance, a more sustainable practice is to include multiple modes of action within a fungicide programme.

Given the early stage of Group 3 resistance development in Australia, AFREN considers that the benefits of rotating Group 3 fungicide actives in Australian grains outweigh the potential risks associated with such a practice.

Should the situation change, AFREN will update recommendations swiftly to ensure Australian grain growers can continue to manage fungicide resistance most effectively for Australian conditions.

If resistance to Group 3 fungicides is suspected, both CropLife and AFREN recommend growers to reduce total applications of Group 3 fungicides.

Note: This guide provides tailored advice to grain growers on tackling fungicide resistance in Australia. These general guidelines, along with specific IDM strategies in grower guides and as advised by agronomists and regional plant pathologists, can be applied to all crops in the absence of any formal detections of fungicide resistance, to reduce the chances of resistance developing.

Fungicide resistance management guidelines – Barley

Fungicides - current field performance

	Group 3 (DMI) e.g. epoxiconazole, flutriafol, propiconazole, tebuconazole						Group 7 (SDHI) e.g. fluxapyroxad, bixafen						Group 11 (QoI) e.g. azoxystrobin, pyraclostrobin					
	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA
Barley powdery mildew	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Net form net blotch	✓	✓	=	✓	=	×	✓	✓	⊗	✓	✓	✓	✓	✓	✓	✓	✓	✓
Spot form net blotch	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	⊗	✓	✓	✓	✓	✓	✓
Barley scald	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Barley leaf rust	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ramularia leaf spot	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	NR	NR	NR	NR	NR	NR

Note – Status of active compounds within each MoA group detailed in each disease section. Farm-level or regional field performance may vary to that recorded here. Not all active constituents/products in each MoA group are registered for use on the target pathogens indicated in each region. It is the responsibility of growers and advisers to ensure that the fungicide is registered, or that permits are current, for their target pathogen, crop and region. Current information on registered and permitted fungicides can be found on the APVMA website at apvma.gov.au.

✓	Active
=	Some active compounds compromised – be selective based on the resistance profile of specific farms or growing regions
×	Reduced sensitivity or resistance to some or all active compounds – avoid if possible, or use only in a mixture
⊗	Resistance to most or all active compounds – avoid entirely if possible
NR	Not registered for this disease.

Any fungicide application should consider the susceptibility of the variety being treated to the target pathogen, as fewer fungicide applications will likely be required for less susceptible varieties, dependent upon local conditions.

For additional fungicide applications for any crop (even across seasons if only one application required within a growing season), growers should rotate and mix their fungicide actives and MoA groups, using fungicide resistance management principles to reduce pressure on any one individual fungicide or fungicide group.

Barley powdery mildew

Caused by *Blumeria graminis* f. sp. *hordei*

Introduction

Barley powdery mildew is an important disease of barley, especially in the western and northern regions. It is also potentially very damaging in the southern region in conducive seasons. Severe infections can occur in winter during both early and later stages of crop growth and can cause significant yield loss in crops with high yield potential. Barley powdery mildew is typically favoured by susceptible hosts, mild and humid weather (15-22°C, Relative Humidity (RH) > 70%), dense crop canopies, higher nitrogen levels, good soil moisture profiles, and extended periods of humid and damp canopies. The pathogen survives on barley stubble and volunteer barley plants, from which spores can spread by wind. Note that barley and wheat powdery mildew are caused by different sub-species, so are crop specific.

Resistance status

Resistance – **Group 3 (DMI)** fungicide tebuconazole in Western Australia.

Reduced sensitivity – **Group 3** fungicides propiconazole and flutriafol in Western Australia.

Lab detection – **Group 3** fungicides in New South Wales, Queensland, Tasmania, Victoria and Western Australia.

A highly virulent tebuconazole-resistant barley powdery mildew population was detected in Western Australia in 2010. The emergence of this resistance was linked to the widespread planting of susceptible varieties and repeated use of Group 3 fungicides. The outbreak has largely been managed through the planting of less susceptible varieties and timely applications of effective fungicides. Target-site mutations in the pathogen associated with reduced sensitivity and resistance elsewhere have been reported in all other states except for South Australia, but these have not been associated with any reduced sensitivity or resistance in the field to date.

Resistance management strategy

IDM

A typical IDM strategy for barley powdery mildew should consider:

- Crop rotation. **Avoid** barley on barley.
- Control of green bridge volunteers.
- Planting less susceptible barley varieties. Avoid SVS and VS varieties in disease-prone areas.
- Time of sowing. Early sowing can favour disease development and increase losses.
- Grazing of early sown barley to reduce disease pressure.
- Careful nitrogen management, optimised to suit growing purpose.
- A region-wide approach. Resistant powdery mildew can spread easily. Talk to your neighbours, and work toward an integrated, area-wide management strategy.

FUNGICIDE USE & ROTATION

- **Minimise** use **of Group 3** fungicides known to have compromised efficacy due to resistance.
- **Rotate Group 3** fungicide actives within and across seasons.
- **Group 11** fungicides should be used as preventive rather than curative control; rotate with effective **Group 3** products.
- **Avoid** applying more than one application per growing season of **Group 7** and **11** containing products. This includes foliar sprays as well as in-furrow or seed treatments that have activity on foliar diseases. Combinations of in-furrow and seed treatment are counted as one application.
- **Do not** apply more than two applications per growing season of **Group 5, 7**, **11** or **13** containing products.
- **Avoid** applying more than two applications per growing season of **Group 3** containing products.
- **Do not** apply consecutive applications of **Groups 7** and **11** containing products. This includes in-furrow i.e. If a **Group 11 + 4** fungicide has been used in-furrow at planting, the first foliar fungicide spray must not contain a **Group 11** fungicide.
- Use **Group 13** products in mixture with an effective partner or rotate with fungicides of a different activity group. Always apply in mixture with a curative fungicide where disease is established. Where applied alone, only use as a protectant (preventative) treatment.

REGIONAL ADVICE

WEST: Do not use tebuconazole-based fungicides to control barley powdery mildew; they are no longer effective in Western Australia.

Net form net blotch (NFNB)

Caused by *Pyrenophora teres* f. *teres*

Introduction

Net form net blotch (NFNB) is an important disease of barley across all growing regions, especially in medium to high rainfall zones of South Australia and Western Australia. It is particularly damaging in wetter years, in systems with high inclusion of susceptible barley in rotations, and where barley is sown into barley stubble. Severe infections can cause 20-50% yield loss and significant reduction in grain quality. NFNB is typically favoured by susceptible hosts, early sowing, mild weather (15-25°C) and extended periods of leaf wetness. It survives between seasons on stubble, volunteer plants and seed.

Resistance status

Resistance – **Group 3 (DMI)** fungicides propiconazole and tebuconazole in the Esperance and Kwinana West port zones, Western Australia.

Resistance – **Group 7 (SDHI)** fungicide fluxapyroxad on the Yorke and Eyre Peninsulas and Kybybolite region, South Australia.

Reduced sensitivity – **Group 3** fungicides epoxiconazole, propiconazole, prothioconazole and tebuconazole in South Australia and Western Australia, and tebuconazole and propiconazole in Victoria.

Reduced sensitivity – **Group 7** fungicide fluxapyroxad in South Australia.

Dual resistance/**reduced sensitivity** – both **reduced sensitivity** to the **Group 3** fungicide tebuconazole and **resistance** to the **Group 7** fungicide fluxapyroxad on the Yorke Peninsula, South Australia.

Isolates of NFNB have been detected with reduced sensitivity and resistance to several Group 3 fungicides in Western Australia since 2013. NFNB isolates with reduced sensitivity were first detected in the Albany port zone (Kojonup) in 2013, and subsequently throughout the Kwinana West, Esperance and Albany port zones. Resistant isolates have been found in the Esperance (Scaddan) and Kwinana West (Dandaragan) port zones from 2017 onwards. NFNB isolates with resistance to the Group 7 fungicide fluxapyroxad were detected on the Yorke Peninsula in South Australia in 2019, associated with continuous barley and repeated use of fluxapyroxad across the region. In 2020, resistance to Group 7 fungicides was also detected in the south-eastern region of Kybybolite and on the Eyre Peninsula in South Australia, from samples collected in 2019. Further testing of isolates from the Yorke Peninsula region detected reduced sensitivity to the Group 3 fungicide tebuconazole, with some isolates being also resistant to the Group 7 fungicide fluxapyroxad (i.e. dual reduced sensitivity/resistance). Resistance to the Group 3 fungicides tebuconazole and propiconazole was also detected in isolates from the Wimmera region of Victoria in 2019.

Resistance management strategy

IDM

A typical IDM strategy for NFNB should consider:

- Crop rotation and stubble management. **Avoid** barley on barley.
- Planting less susceptible varieties. Avoid SVS and VS varieties in disease-prone areas.
- Time of sowing. Early sowing can favour disease development and increase losses.

FUNGICIDE USE & ROTATION

- **Minimise** the use of **Group 7** fungicides (seed treatments and foliar sprays). In areas where resistance to this group of fungicides has been reported, **do not** use **Group 7** fungicides for NFNB control.
- **Avoid** applying more than one application per growing season of **Group 7** and **11** containing products. Combinations of in-furrow and seed treatment are counted as one application.
- **Minimise** use of **Group 3** fungicides that are known to have compromised resistance status. Avoid using tebuconazole, propiconazole and epoxiconazole as stand-alone products in barley for any disease, as a way of avoiding indirect selection for fungicide resistance.
- **Rotate Group 3** fungicide actives within and across seasons.
- **Avoid** applying more than three applications containing **Group 3** fungicides per growing season. If possible, **reduce** this to one or two applications in regions where **Group 3** resistance has been reported.

Spot form net blotch (SFNB)

Caused by *Pyrenophora teres* f. *maculata*

Introduction

Spot form net blotch (SFNB) is an important disease of barley across all growing regions. It is particularly damaging in wetter years in the southern regions, in early sown crops, in systems with high inclusion of barley in rotations, and where barley is sown into barley stubble. Severe infections can cause 10-45% yield loss and significant reduction in grain quality. SFNB is typically favoured by susceptible hosts, mild weather (15-25°C) and extended periods of leaf wetness. It survives between seasons on stubble.

Resistance status

Resistance – **Group 3 (DMI)** fungicides epoxiconazole, propiconazole and tebuconazole in the Albany and Esperance port zones of Western Australia.

Resistance – **Group 7 (SDHI)** fungicide fluxapyroxad in the Kwinana West port zone of Western Australia.

Reduced sensitivity – **Group 3** fungicides epoxiconazole, propiconazole, prothioconazole and tebuconazole in Western Australia.

Reduced sensitivity – **Group 7** fungicide fluxapyroxad in the Kwinana West port zone of Western Australia.

Reduced sensitivity – **Group 3** fungicide tebuconazole in South Australia and Victoria.

Lab detection – **dual reduced sensitivity** to both the **Group 3** fungicide tebuconazole and **Group 7** fungicide fluxapyroxad in the Kwinana West port zone of Western Australia.

Isolates of SFNB have been detected with reduced sensitivity and resistance to several Group 3 fungicides since 2016 and 2017, respectively, and reduced sensitivity and resistance to the Group 7 fungicide fluxapyroxad since 2020, in Western Australia. Reduced sensitivity to Group 3 fungicides has been detected in the Esperance (Coomalbidgup, Gibson and Munglinup) and Kwinana West (Pithara) port zones from 2016 onwards, and resistance has been found in the Albany (Amelup, Broomehill, Frankland, Green Range, South Stirling, Takalarup and Wellstead) and Esperance (Gibson and Dalyup) port zones since 2017. Reduced sensitivity to the Group 3 fungicide tebuconazole has been detected only recently in South Australia and Victoria from isolates collected in 2011 and 2014, respectively. However, no impacts on fungicide performance in the field have been reported in these areas to date and thus field implications remain unclear. Resistance to the Group 7 fungicide fluxapyroxad was detected near Cunderdin, in the Kwinana West port zone, in 2020, associated with continuous barley and repeated use of fluxapyroxad. Further testing of isolates from this Cunderdin region detected reduced sensitivity to the Group 3 tebuconazole, with some isolates being also resistant to the Group 7 fungicide fluxapyroxad (i.e. dual reduced sensitivity/resistance), though field implications of this finding remain unclear.

Resistance management strategy

IDM

A typical IDM strategy for SFNB should consider:

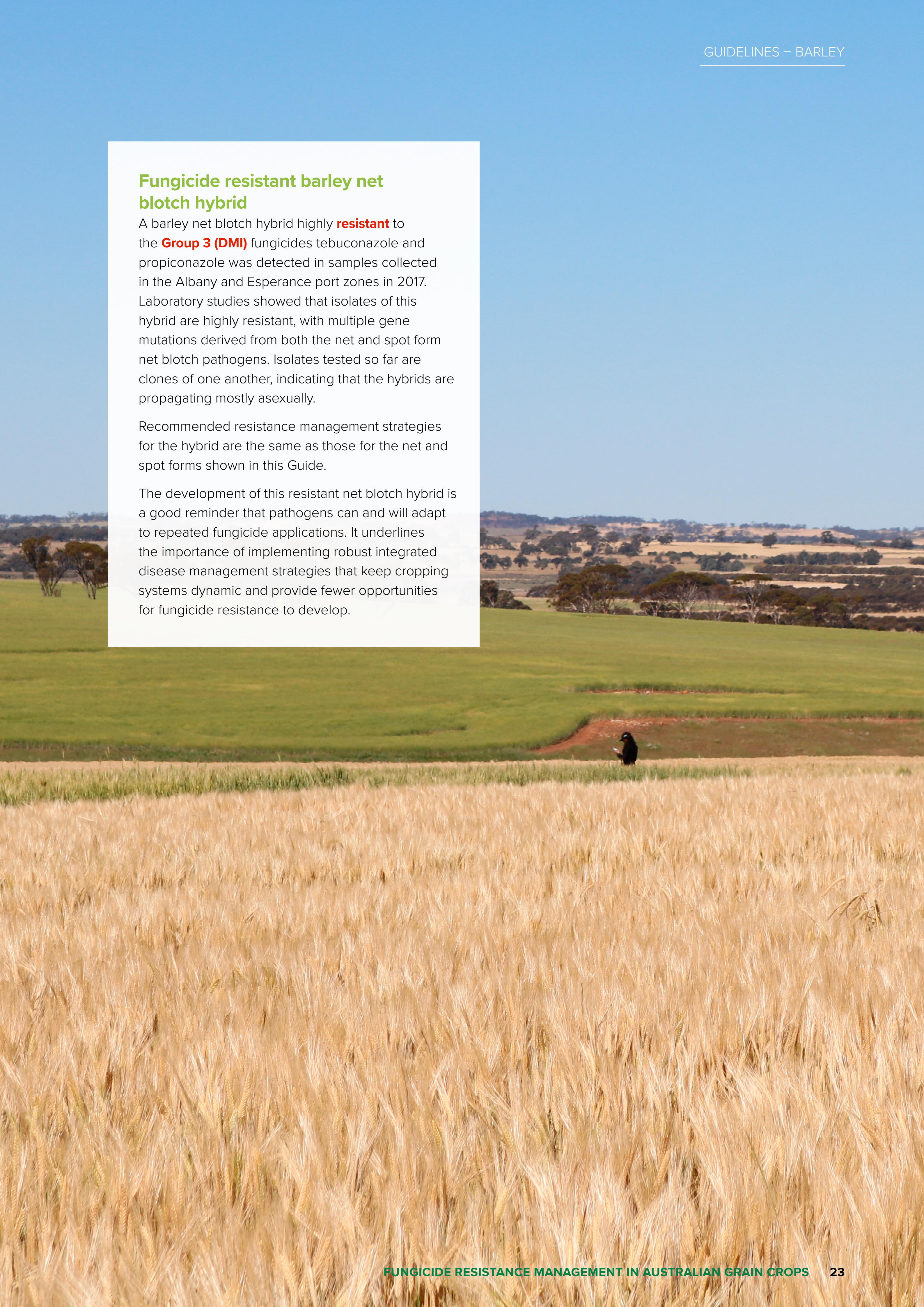
- Crop rotation and stubble management. **Avoid** barley on barley.
- Planting less susceptible varieties. Avoid S and VS varieties in disease-prone areas.
- Time of sowing. Early sowing can favour disease development and increase losses.

FUNGICIDE USE & ROTATION

- **Minimise** the use of **Group 7** fungicides (seed treatments and foliar sprays). In areas where resistance to this group of fungicides has been reported, **do not** use **Group 7** fungicides for SFNB control.
- **Avoid** applying more than one application per growing season of **Group 7** and **11** containing products. Combinations of in-furrow and seed treatment are counted as one application.
- **Minimise** use of **Group 3** fungicides that are known to have compromised resistance status. Avoid using tebuconazole, propiconazole and epoxiconazole as a stand-alone products in barley for any disease, as a way of avoiding indirect fungicide resistance selection.
- **Rotate Group 3** fungicide actives within and across seasons.
- **Avoid** applying more than three applications containing **Group 3** fungicides per growing season. If possible, **reduce** this to one or two applications in regions where **Group 3** resistance has been reported.

REGIONAL ADVICE

WEST: Avoid using tebuconazole or propiconazole as stand-alone products in barley for any disease - this will only select for further development of resistance.



Fungicide resistant barley net blotch hybrid

A barley net blotch hybrid highly **resistant** to the **Group 3 (DMI)** fungicides tebuconazole and propiconazole was detected in samples collected in the Albany and Esperance port zones in 2017. Laboratory studies showed that isolates of this hybrid are highly resistant, with multiple gene mutations derived from both the net and spot form net blotch pathogens. Isolates tested so far are clones of one another, indicating that the hybrids are propagating mostly asexually.

Recommended resistance management strategies for the hybrid are the same as those for the net and spot forms shown in this Guide.

The development of this resistant net blotch hybrid is a good reminder that pathogens can and will adapt to repeated fungicide applications. It underlines the importance of implementing robust integrated disease management strategies that keep cropping systems dynamic and provide fewer opportunities for fungicide resistance to develop.

Fungicide resistance management guidelines – Wheat

Fungicides - current field performance

	Group 3 (DMI) e.g. epoxiconazole, flutriafol, propiconazole, tebuconazole						Group 7 (SDHI) e.g. fluxapyroxad						Group 11 (QoI) e.g. azoxystrobin, pyraclastrobin					
	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA
Wheat powdery mildew	×	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	⊗	✓	⊗	⊗	⊗	✓
Septoria tritici blotch	=	✓	=	=	=	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Septoria nodorum blotch	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Leaf rust	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Stripe rust	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Stem rust	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tan spot (yellow spot)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Eyespot	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	NR	NR	NR	NR	NR	NR

Note – Status of active compounds within each MoA group detailed in each disease section. Farm-level or regional field performance may vary to that recorded here. Not all active constituents/products in each MoA group are registered for use on the target pathogens indicated in each region. It is the responsibility of growers and advisers to ensure that the fungicide is registered, or that permits are current, for their target pathogen, crop and region. Current information on registered and permitted fungicides can be found on the APVMA website at apvma.gov.au.

✓	Active
=	Some active compounds compromised – be selective based on the resistance profile of specific farms or growing regions
×	Reduced sensitivity or resistance to some or all active compounds – avoid if possible, or use only in mixture
⊗	Resistance to most or all active compounds – avoid entirely if possible
NR	Not registered for this pathogen.

Any fungicide application should consider the susceptibility of the variety being treated to the target pathogen, as fewer fungicide applications will likely be required for less susceptible varieties, dependent upon local conditions.

For additional fungicide applications for any crop (even across seasons if only one application required within a growing season), growers should rotate and mix their fungicide actives and MoA groups, using fungicide resistance management principles to reduce pressure on any one individual fungicide or fungicide group.

Septoria tritici blotch

Caused by *Zymoseptoria tritici*

Introduction

Septoria tritici blotch is an important disease of wheat, particularly in high rainfall areas of the southern region. It is more common in early sown crops and in wet springs, and is typically favoured by stubble retention, susceptible cultivars, cool, wet weather (15-20°C, RH > 70%), dense crop canopies and extended periods of leaf wetness or dew. It can cause up to 20% yield loss annually, and much more (>50%) in conducive years. It survives on stubble.


PHOTO: Andrew Milgate, NSW DPI

Resistance status

Reduced sensitivity – Group 3 (DMI) fungicides cyproconazole, epoxiconazole, flutriafol, propiconazole, tebuconazole and triadimenol in New South Wales, South Australia, Tasmania and Victoria.

Isolates of septoria tritici blotch showing reduced sensitivity to Group 3 fungicides were first detected in Victoria and Tasmania in 2011, and New South Wales and South Australia in 2014. Tasmania was found to have the highest levels of reduced sensitivity when compared to Victoria and South Australia. In Tasmania, triadimefon and cyproconazole may be less effective control options. Field data indicates that cyproconazole is not compromised in the high rainfall zones of South Australia and Victoria at this time. All triazoles are affected to some extent. Tebuconazole, propiconazole and flutriafol have reduced efficacy, but they will still provide some control of disease. Epoxiconazole and fluquinconazole, however, remain highly effective at label rates.

Resistance management strategy

IDM

A typical IDM strategy for septoria tritici blotch should consider:

- Crop rotation and stubble management. **Do not** sow wheat into wheat stubble.
- Planting less susceptible varieties. Avoid S and VS varieties in disease-prone areas.
- Grazing of early sown wheat to reduce disease pressure.
- Time of sowing. Early sowing can favour disease development and increase losses.

FUNGICIDE USE & ROTATION

- **Minimise** use of **Group 3** fungicides known to have compromised resistance status.
- **Rotate Group 3** fungicide actives within and across seasons.
- **Group 11** containing fungicides should be used as preventive rather than curative control; **rotate** with effective **Group 3** or **Group 3 + 7** products, ensuring that the product choice is based on a different active constituent to that mixed with the Group 11.
- **Avoid** applying more than one application per growing season of **Group 7** or **11** containing products, whether solo or in mixtures. This includes foliar sprays as well as in-furrow or seed treatments that have activity on foliar diseases. Combinations of in-furrow and seed treatment are counted as one application.
- **Avoid** applying more than three applications containing **Group 3** fungicides per growing season.

Wheat powdery mildew

Caused by *Blumeria graminis* f. sp. *tritici*

Introduction

Wheat powdery mildew is a sporadic and important disease in years with conducive conditions, especially in the southern region. Wheat powdery mildew is typically favoured by susceptible hosts, early sowing, mild and humid weather (15-22°C, RH > 70%), dense crop canopies, good soil moisture profiles, higher nitrogen status and extended periods of humid and damp canopies. It is spread predominantly via wind-borne spores, and survives on stubble and volunteer plants. Note that wheat and barley powdery mildew are caused by different sub-species, so are crop specific.

Resistance status

Resistance – all **Group 11 (QoI)** fungicides in New South Wales, South Australia, Tasmania and Victoria.

Resistance – **Group 3 (DMI)** fungicides propiconazole and tebuconazole in New South Wales and Victoria.

Lab detection – **Group 3** gateway mutation associated with reduced sensitivity detected in New South Wales, South Australia, Tasmania and Victoria.

Group 11-resistant wheat powdery mildew was first detected in samples collected in 2015, following reports of field failures from both Tasmania and Victoria in 2016. It has since been reported in South Australia in 2019 and New South Wales in 2020. The emergence of this resistance is likely linked to the high disease pressure in these high-rainfall growing areas, combined with the repeated use of the limited fungicides that were registered for use against the pathogen at the time – only Group 3 and Group 11 fungicides. Group 3 fungicides are also at a high risk of fungicide resistance developing, as a well-characterised gateway mutation has been detected in New South Wales, South Australia, Victoria and Tasmania from 2015. In 2020, resistance to Group 3 fungicides was detected across multiple paddocks in New South Wales (around Albury, Rennie, Balldale, Deniliquin near the border, and more widely in paddocks near Hillston and Yenda and south-west NSW, plus Edgeroi and Wee Waa in northern NSW) and into the Victorian border region (at Cobram and Katamatite).

Resistance management strategy

IDM

A typical IDM strategy for wheat powdery mildew should consider:

- Crop rotation. **Do not** sow wheat into wheat stubble.
- Control of green bridge volunteers.
- Planting less susceptible varieties. Avoid S and VS varieties in disease-prone areas.
- Time of sowing. Early sowing can favour disease development and increase losses.
- Grazing of early sown wheat to reduce disease pressure.
- Careful nitrogen management, optimised to suit growing purpose.
- A region-wide approach. Resistant powdery mildew can spread easily. Talk to your neighbours, and work toward an integrated, area-wide management strategy.

FUNGICIDE USE & ROTATION

- **Avoid** use of **Group 11** fungicides in areas where resistance to this group of fungicides has been reported.
- **Minimise** use of **Group 3** fungicides known to have compromised resistance status and **monitor Group 3** performance in states where the gateway mutation has been detected.
- **Rotate Group 3** fungicide actives within and across seasons.
- **Group 11** fungicides should be used for preventive rather than curative control; rotate with effective **Group 3** products.
- **Avoid** more than one application per growing season of **Group 7** or **11** containing products, whether solo or in mixtures. This includes foliar sprays as well as in-furrow or seed treatments that have activity on foliar diseases. Combinations of in-furrow and seed treatment are counted as one application.
- **Avoid** applying more than three applications containing **Group 3** fungicides per growing season.

REGIONAL ADVICE

SOUTH: Avoid using Group 11 fungicides to control wheat powdery mildew; they may no longer be effective in growing regions of South Australia, Tasmania and Victoria.

Ensure that Group 3 fungicides used for wheat powdery mildew control are rotated, to extend the life of these chemistries.

NORTH: Avoid using Group 11 fungicides to control wheat powdery mildew; they may no longer be effective in growing regions of New South Wales.

Ensure that Group 3 fungicides used for wheat powdery mildew control are rotated, to extend the life of these chemistries.

Fungicide resistance management guidelines – Canola

Fungicides - current field performance

	Group 3 (DMI)						Group 7 (SDHI)						Group 11 (QoI)					
	e.g. fluquinconazole, flutriafol, tebuconazole						e.g. bixafen						e.g. azoxystrobin					
	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA
Blackleg	=	✓	=	✓	=	=	✓	✓	✓	✓	✓	✓	NR	NR	NR	NR	NR	NR
Sclerotinia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

	Group 2 (dicarboxamides)					
	e.g. iprodione, procymidone					
	NSW	Qld	SA	Tas	Vic	WA
Blackleg	NR	NR	NR	NR	NR	NR
Sclerotinia	✓	✓	✓	✓	✓	✓

Note – Status of active compounds within each MoA group detailed in each disease section. Farm-level or regional field performance may vary to that recorded here. Not all active constituents/products in each MoA group are registered for use on the target pathogens indicated in each region. It is the responsibility of growers and advisers to ensure that the fungicide is registered, or that permits are current, for their target pathogen, crop and region. Current information on registered and permitted fungicides can be found on the APVMA website at apvma.gov.au.

✓	Active
=	Some active compounds compromised – be selective based on the resistance profile of specific farms or growing regions
×	Reduced sensitivity or resistance to some or all active compounds – avoid if possible, or use only in mixture
⊗	Resistance to most or all active compounds – avoid entirely if possible
NR	Not registered for this pathogen.

Plan fungicide rotations for the complete suite of target pathogens

Given that blackleg and sclerotinia are often managed concurrently in canola crops, it is best to consider fungicide rotations for both diseases together when managing for fungicide resistance.

Sclerotinia targeted applications should be applied during flowering of the crop (20%-50%), prior to an infection period. Application of fungicides for sclerotinia may put selection pressure on blackleg populations, and vice-versa applications of fungicides for blackleg may put selection pressure on sclerotinia populations.

This advice applies to any crop where more than one disease is managed concurrently. For example, Septoria nodorum blotch (caused by *Parastagonospora nodorum*), in the Western Region or Septoria tritici blotch (caused by *Zymoseptoria tritici*), in the Southern and Northern regions) and yellow spot (caused by *Pyrenophora tritici-repentis*, Ptr) often co-occur and are managed concurrently in wheat crops across Australia.

For additional fungicide applications for any crop (even across seasons, especially if only one application is required within a growing season), growers should rotate and mix fungicide actives and MoA groups, using fungicide resistance management principles to reduce pressure on any one individual fungicide or fungicide group.

Blackleg

Caused by *Leptosphaeria maculans*

Introduction

Blackleg is the most important and costly disease of canola in Australia and is widespread in all growing regions. Blackleg is typically favoured by high intensity canola plantings, high annual rainfall (> 500 mm), high total rainfall in the three months prior to sowing (Mar-May; > 100 mm), susceptible cultivars, and extended periods of leaf wetness (> 48 h). It can cause yield losses of 50-90% in conducive years. It is a stubble-borne disease and spores are spread from stubble remaining from the previous season.

Resistance status

Reduced sensitivity – **Group 3 (DMI)** fungicides flutriafol, fluquinconazole, prothioconazole and tebuconazole in New South Wales, South Australian, Victorian and Western Australian populations. Confirmed via *in planta* and *in vitro* assays, field implications remain unclear.

Due to the propensity for the blackleg fungus to overcome sources of genetic resistance in the host, and increases in fungicide applications to canola in the past decade, there are concerns that the blackleg fungus may evolve fungicide resistance quite easily. In 2013, research into blackleg fungicide resistance detected isolates with reduced sensitivity to fluquinconazole in *in planta* assays. Since 2014, surveys across canola growing regions using this *in planta* assay have identified isolates with reduced sensitivity to the fungicides fluquinconazole, flutriafol, prothioconazole and tebuconazole. While field implications remain unclear, these results indicate that the risk of blackleg populations developing resistance to a range of Group 3 fungicides is high.

Resistance management strategy

IDM

A typical IDM strategy for blackleg should consider:

- Use of less susceptible varieties. Rotate varieties from different resistance groups as needed (i.e. yield losses indicate resistance genes may be compromised). Monitor crops each year to detect if the fungus has overcome any varietal resistance genes, and plan accordingly.
- Growing canola at least 500 m from the previous season's canola stubble.
- Never sowing a canola crop into last year's canola stubble.
- Consulting the blackleg management guide or BlacklegCM app to determine individual paddock risk for blackleg.

FUNGICIDE USE & ROTATION

- **Minimise** use of **Group 3** fungicides known to have compromised resistance status.
- **Rotate Group 3** fungicide actives within and across seasons.
- **Do not** apply more than two consecutive applications of a **Group 3** fungicide.
- **Avoid** applying more than two applications per growing season of **Group 3** containing products.
- **Avoid** applying more than one application per growing season of **Group 7** containing products. This includes foliar sprays as well as in-furrow or seed treatments that have activity on foliar diseases. Combinations of in-furrow and seed treatment are counted as one application.
- If a **Group 7** seed treatment has been used with cotyledon / first true leaves activity on blackleg (as determined by label claims), the 4-8 leaf fungicide application targeting blackleg should not contain a **Group 7** fungicide.
- **Plan** fungicide rotations for both blackleg and sclerotinia together when managing for fungicide resistance, as these diseases are often managed concurrently.


PHOTO: GRDC

Fungicide resistance management guidelines – Pulses

Fungicides - current field performance

	Group 3 (DMI)						Group 7 (SDHI)						Group 11 (QoI)					
	e.g. fluquinconazole, flutriafol, tebuconazole						e.g. fluxapyroxad						e.g. azoxystrobin					
	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA
Chickpeas																		
Ascochyta blight	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Botrytis grey mould	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lentils																		
Ascochyta blight	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Botrytis grey mould	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

	Group 1 (MBC)						Group 1 (MBC)						Multi-sites (M3, M5)					
	Carbendazim						Thiabendazole						e.g. captan, chlorothalonil, copper, mancozeb, thiram					
	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA
Chickpeas																		
Ascochyta blight	NR	NR	NR	NR	NR	NR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Botrytis grey mould	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lentils																		
Ascochyta blight	NR	NR	NR	NR	NR	NR	✓	✓	=	✓	✓	✓	✓	✓	✓	✓	✓	✓
Botrytis grey mould	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note – Status of active compounds within each MoA group detailed in each disease section. Farm-level or regional field performance may vary to that recorded here. Not all active constituents/products in each MoA group are registered for use on the target pathogens indicated in each region. It is the responsibility of growers and advisers to ensure that the fungicide is registered, or that permits are current, for their target pathogen, crop and region. Current information on registered and permitted fungicides can be found on the APVMA website at apvma.gov.au.

✓	Active
=	Some active compounds compromised – be selective based on the resistance profile of specific farms or growing regions
×	Reduced sensitivity or resistance to some or all active compounds – avoid if possible, or use only in a mixture
⊗	Resistance to most or all active compounds – avoid entirely if possible
NR	Not registered for this pathogen.

FUNGICIDE USE AND ROTATIONS

Across all pulse crops:

- **Minimise** the application of **Group 1** fungicides, preferably to only one use per season (inclusive of seed treatments). While the registered Group 1 fungicide thiabendazole for use in pulses has not specifically been compromised, cross-resistance in Group 1 fungicides is common and should be accounted for in order to reduce risk of fungicide resistance developing.
- **Do not** apply consecutive **Group 1**, **7** or **11** containing fungicide treatments within **or across** seasons. Where seed is retained on farm, the final foliar spray of the previous season should be considered when planning which fungicide group to use in seed treatments and the first foliar application.
- **Avoid** applying more than two applications containing **Group 3** fungicides per growing season (including seed treatments).
- **Avoid** more than one application per growing season of **Group 2, 7** or **11** containing products, whether solo or in mixtures. Combinations of in-furrow and seed treatment are counted as one application.
- **Use multi-site (e.g. M3, M5)** fungicides as rotation and mixing partners to reduce selection pressure on single-site fungicides (i.e. Groups 1, 2, 3, 7 and 11).

For additional fungicide applications for any crop (even across seasons if only one application required within a growing season), growers should continue to rotate and mix fungicide actives and MoA groups, using fungicide resistance management principles to reduce pressure on any one individual fungicide or fungicide group.

Ascochyta blight of lentils

Caused by *Ascochyta lentis* (syn: *Didymella lentis*)

Introduction

Ascochyta blight of lentils is an important disease of lentils in Australia, especially in the key growing areas of the southern region. It can affect all above-ground plant parts from leaves and stems to flowers and pods, and is often inconspicuous, relying on close inspection to detect it. It is favoured by prolonged cool and wet conditions (5-15°C) early in the growing season, and heavy rainfall later in the season to establish pod and seed infections. Unprotected crops can suffer more than 50% yield loss, and in severe cases the crop may drop all of its leaves. It is spread via stubble, self-sown plants and seed.

PHOTO: GRDC

Resistance status

Lab detection – **Group 1** fungicide carbendazim in South Australia.

Ascochyta blight of lentils isolates resistant to the Group 1 fungicide carbendazim were first detected in samples collected in South Australia in 2010 and 2011, and again in field samples collected in 2020. While carbendazim is not registered for control of this disease, the Group 1 fungicide thiabendazole is registered for use in a seed treatment mixture with the multi-site fungicide thiram. Additionally, carbendazim is registered to control botrytis grey mould of lentils (caused by *B. cinerea*), and therefore the ascochyta blight of lentils pathogen may be exposed to this fungicide in the course of a spray program. Research on Group 1 fungicide resistance in lentils, and pulse diseases more generally, is limited. The presence of this resistance in states other than South Australia is unknown. However, resistance to Group 11 fungicides in ascochyta blight has been documented overseas, and a reminder that this fungal pathogen is capable of developing resistance to different fungicides in Australian pulse crops.

Resistance management strategy

IDM

A typical IDM strategy for ascochyta blight should consider:

- Avoiding growing susceptible lentil varieties. Monitor varieties regardless of resistance rating, as resistance breaking fungal isolates may develop quickly in high-intensity, low variety-diversity cropping systems.
- Using a three-year break between lentil crops.
- Sowing at least 250 m from other lentil, faba bean, chickpea or vetch crops or stubble.
- Sowing into standing stubble of a previous cereal crop to protect against rain splash of soilborne spores.
- Sowing at the optimum time, not early.

FUNGICIDE USE & ROTATION

- **Minimise** use of **Group 1** fungicides, preferably to only once per season.
- **Avoid** applying more than two applications containing **Group 3** fungicides in one season (including seed treatment).
- **Avoid** applying more than one application containing **Group 7** or **11** fungicides in one season (including seed treatment).
- **Use multi-site (M3, M5)** fungicides as rotation and mixing partners to reduce selection pressure on single-site fungicides (i.e. Groups 1, 2, 3, 7 and 11).

Botrytis grey mould of chickpeas

Caused by *Botrytis cinerea*

Introduction

Botrytis grey mould is a serious disease of chickpea, especially in the northern growing regions. Prior to the incursion of ascochyta blight, it was considered a major disease of chickpea. It has a wide host range, across grapes and multiple pulse species. This wide host range, combined with its capacity to survive on dead plant material, mean inoculum is rarely limiting and infections can proceed quickly when conditions are favourable. Botrytis grey mould is typically favoured by crops with thick closed canopies that provide conducive temperature and humidity conditions (20-25°C, RH > 90%) for infection. Yield reductions can result via seedling loss due to seed-borne root rot, and infection of stems, flowers, pods and leaves throughout the season. Yield loss in unprotected crops can be as high as 10-25% under conducive conditions and can cause complete crop failure in extreme cases. It is spread predominantly via airborne spores, infected alternate hosts, and contaminated seed, soil and stubble.

Resistance status

Lab detection – **Group 1** fungicide carbendazim in South Australia.

A chickpea botrytis grey mould isolate resistant to the Group 1 fungicide carbendazim was detected amongst samples collected from South Australia in 2003. The isolate was collected from a chickpea field adjacent to a vineyard, so it is quite likely it originated in the grape crop. However, the use of Group 1 fungicides against *Botrytis* species infecting pulses in South Australia has been common practice, using seed dressings containing the Group 1 fungicide thiabendazole in mixture with the multi-site fungicide thiram. Research on Group 1 fungicide resistance in chickpeas, and pathogens of pulses more generally, is limited. The presence of this resistance in states other than South Australia is unknown.

Resistance management strategy

IDM

A typical IDM strategy for botrytis grey mould should consider:

- Planting less susceptible varieties.
- Using clean seed.
- Stubble and green-bridge management.
- Paddock selection. Use a 4-year break between chickpea and other pulse crops and sow at least 500 m from other pulse crops or bean stubble.
- Harvesting as early as possible to minimise infection on seed.

FUNGICIDE USE & ROTATION

- **Minimise** use of **Group 1** fungicides, preferably to only once per season.
- **Avoid** applying more than two applications containing **Group 3** fungicides in one season (including seed treatment).
- **Avoid** applying more than one application containing **Group 7** or **11** fungicides in one season (including seed treatment).
- **Use multi-site (M3, M5)** fungicides as rotation and mixing partners to reduce selection pressure on single-site fungicides (i.e. Groups 1, 2, 3, 7 and 11).

Further information

RESISTANCE & RESISTANCE MANAGEMENT IN AUSTRALIAN GRAIN CROPS

GRDC Groundcover Supplement: **Resistance in Weeds, Pests and Diseases**. Issue 139: March – April 2019. Available at: https://groundcover.grdc.com.au/grdc-groundcover-supplement?supp=resistance-in-weeds,-pest-and-diseases,-march-april-2019

An overview of chemical resistance in weeds, pests and diseases. Largely in laymen's terms, without compromising on depth or quality.

Select articles: available at the above URL

Umina et al. **Your guide to agricultural chemical resistance in a nutshell**.

Young. **Your guide to ag chemical resistance mechanisms in laymen's terms**.

Young. **What drives the pace of resistance development in agricultural chemicals?**

McDonald. **Changing up chemical groups essential to preserve longevity of actives**.

Poole et al. **Label rates for effective control of weeds, pests and diseases**.

Hoffman & Lopez-Ruiz. **Common tactics for managing agricultural chemical resistance**.

Poole et al. **Strategies must differ for weeds, insects and fungal pathogens**.

Oliver. **Overseas fungicide resistance experience guides Australia**.

Van de Wouw. **Fungicide resistance needn't be a blot on the landscape**.

FUNGICIDE RESISTANCE

CropLife Australia **Fungicide Resistance Management Strategies**. Available at: www.croplife.org.au/resources/programs/resistance-management/fungicide-resistance-management-strategies1/fungicide-resistance-management-strategies1-draft/

Australian agro-chemical advice. The peak body for agro-chemical companies in Australia, CropLife Australia publish regularly updated fungicide resistance management strategies for high risk crops, diseases and mode of action chemical groups.

FRAG UK 2020. **Fungicide Resistance Management in Cereals**. Available at: https://ahdb.org.uk/frag-cereals

Explore the UK and European experience of fungicide resistance in cereals. The Fungicide Resistance Action Group – UK (FRAG-UK) is a forum of fungicide resistance experts who publish updated fungicide resistance management strategies for cereals in this guide. Many of the lessons are transferrable, and provide alarming case studies of how widespread and damaging fungicide resistance can be.

Fungicide Resistance Action Committee – www.frac.info

Take a look at the global fungicide resistance experience through the lens of the Fungicide Resistance Action Committee. A specialist technical group of CropLife International, an international trade association of agrochemical companies. They provide a number of educational resources (videos, apps etc.) to assist with effective fungicide resistance outreach, as they work to prolong the effectiveness of fungicides liable to encounter resistance problems and limit crop losses should resistance occur.

Bayer Crop Science Canada **Evaluating the Risk of Fungicide Resistance**. Available at: https://www.cropscience.bayer.ca/-/media/Bayer-CropScience/Country-Canada-Internet/Growers-Tools/About-Fungicide-Resistance.aspx

See how Canadian growers are being advised to assess their risk of fungicide resistance developing on farm. Many of the lessons are transferrable – just remember to take local risks and conditions into account.

Vincelli 2014. **Some Principles of Fungicide Resistance**. University of Kentucky Plant pathology Fact Sheet. Available at: https://plantpathology.ca.uky.edu/files/ppfs-misc-02.pdf

A primer exploring the basic principles of fungicide resistance, in greater detail than that provided in this Guide.

AGRONOMY AND INTEGRATED DISEASE MANAGEMENT

Blackleg Management Guide (GRDC). Available at: https://grdc.com.au/GRDC-FS-BlacklegManagementGuide

Best practice management guide for blackleg of canola. Good variety selection and crop management is the foundation for effective fungicide resistance management, and this is explored specifically for blackleg in this useful publication.

GRDC GrowNotes series - https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy

Explore GRDC resources for a variety of crops. Good variety selection and crop management is the foundation for effective fungicide resistance management, and the GrowNote series offers a plethora of information for you to explore to ensure you're growing the best crop you can.

Pulse Australia fungicide guides. Chickpea and lentil fungicide guides: 2020 season. Available at: http://pulseaus.com.au/growing-pulses/crop-protection-products

Management advice for chickpeas, lentils and many other pulses, updated each season. Good variety selection and crop management is the foundation for effective fungicide resistance management, and the Pulse Australia website offers a plethora of information for you to explore to ensure you're growing the best crop you can.

PHOTO: GRDC

Glossary

Active / Active constituent	The active component of a chemical formulation.
Cross resistance	When the resistance mechanism that makes a pathogen resistant to a fungicide also makes it resistant to others, often those with a similar mode of action.
Demethylase inhibitors (DMIs)	Fungicides of the Group 3 mode of action group. Commonly referred to as azoles. See Fungicide groups - Modes of Action (MoA) for further detail.
Discriminatory dose(s)	Single or multiple dose rates, specific to fungicides and/or fungal species, used in phenotype-based laboratory studies to identify different sensitivity groups (i.e. sensitive, reduced sensitivity or resistant fungal isolates). See fungicide resistance terminology and Appendix A: Fungicide resistance in the lab for further detail.
Disease	The expression of symptoms that negatively affect yield and/or quality of a crop e.g. the symptoms caused by the pathogen.
EC_{50}	The Effective Concentration (EC) of a fungicide that inhibits the growth of a fungus by 50% after a specified exposure time. See Appendix A: Fungicide resistance in the lab for further detail.
Field failure	When a correctly applied fungicide fails to control the target pathogen completely in the field. This is sometimes referred to as *qualitative resistance*. Field failures must be confirmed with laboratory testing, and be clearly linked with a complete loss of disease control when using the fungicide in the field.
Frequency of resistance	The proportion of the population that is resistant in the field.
Gateway mutation	The first genetic mutation in a series of steps needed to allow expression of resistance.
Gene mutation	A permanent alteration in the DNA sequence that makes up a gene.
Gene overexpression	When genes are up-regulated or switched on to produce extra copies of a protein or other substance. When genes are overexpressed this can result in more sites for fungicides to bind to, which can dilute their effect on the target pathogen.
IDM (Integrated Disease Management)	The combined, complementary use of a range of different strategies for the control of crop diseases. This can include deployment of genetic resistance in the host crop, non-chemical cultural/hygiene methods (e.g. crop rotation, stubble management) and the use of fungicides.
Inoculum	Parts of a pathogen that reside in the soil or on seed or foliage and can infect plants.
Isolate	A purified sample of a fungal pathogen.
Lab detection	Shifts in sensitivity to fungicide (i.e. through EC_{50} or discriminatory dose trials) or molecular evidence of resistance mechanism are detected in the laboratory, but may not yet be confirmed in the field. See Fungicide resistance terminology for further detail.
Label rates	Registered application rates listed on a fungicide label. The maximum rate is the highest registered rate, while lower rates refer to label rates that can be used in some situations, such as low disease pressure.
Mixture	The simultaneous combination of two or more fungicides from the same or different modes of action.
Mode of Action (MoA)	The mechanism by which a fungicide kills or suppresses the target fungal pathogen.
Multiple resistance (e.g. dual resistance)	When an organism possesses two or more resistance mechanisms to one or more mode of action groups. For example, dual resistance is when an organism possesses two resistance mechanisms.

Multi-sites	Fungicides that act within the fungus on multiple biochemical pathways or multiple target sites.
Pathogen	An organism e.g. plant parasitic fungus, bacterium or nematode that infects a plant to cause disease.
Quinone outside inhibitors (QoIs)	Fungicides of the Group 11 mode of action group. A synonym for strobilurins. See Fungicide groups - Modes of Action (MoA) for further detail.
Reduced sensitivity	Fungi are considered as having reduced sensitivity to a fungicide when a fungicide application does not work optimally, but does not completely fail. Reduced sensitivity needs to be confirmed in the laboratory. See Fungicide resistance terminology for further detail.
Resistance (general)	When a previously effective fungicide fails to control a fungal pathogen, resulting in reduced sensitivity or field failure. Resistance may be used to define any response by a fungus to a fungicide, which indicates a sensitivity shift, reduced sensitivity or field failure scenario.
Resistance mechanism	The biological process involved in the resistance to a given agricultural chemical. A common resistance mechanism is target site mutation.
Resistance monitoring	To actively survey fungal pathogen populations for sensitivity to a particular fungicide using established laboratory methods.
Resistant (specific terminology, cf. reduced sensitivity)	Resistance occurs when a previously effective fungicide fails to provide an acceptable level of control of the target pathogen in the field at label rates. Resistance needs to be confirmed with laboratory testing, and be clearly linked with an unacceptable loss of disease control when using the fungicide in the field at maximum label rates. See Fungicide resistance terminology for further detail.
Rotate / rotation (of fungicides)	The sequential application of different fungicides, most typically (although not always) with different modes of action. Sometimes referred to as alternation.
SDHIs (succinate dehydrogenase inhibitors)	Fungicides of the Group 7 mode of action group. See Fungicide groups - Modes of Action (MoA) for further detail.
Selection pressure	The evolutionary force that drives the development of resistance within a fungal pathogen (or other organism) population. In the case of fungicide resistance, selection pressure most often refers to the repeated exposure to agricultural chemicals.
Sensitive	Fungi are considered sensitive when they are killed by a fungicide. See Fungicide resistance terminology for further detail.
Sensitivity shift	This terminology is used where published results indicate that there is reduced efficacy of a fungicide, related to fungicide resistance. Whether these shifts indicate a reduced sensitivity or field failure scenario remains unclear. Depending on the nature of the shift in sensitivity, isolates in this guide may be termed to be a lab detection, reduced sensitive or resistant, depending on field results. See Fungicide resistance terminology for further detail.
Single site	An agricultural chemical that targets only one pathway/site of control in an organism.
Strobilurins	Fungicides of the Group 11 mode of action group. A synonym for quinone-outside-inhibitors (QoIs). See Fungicide groups - Modes of Action (MoA) for further detail.
Target site mutation	DNA-level mutation in the target site of the pathogen for a particular chemical compound.

Appendices

Appendix A: Fungicide resistance in the lab

Both traditional culturing and modern molecular methods have enabled researchers to determine levels of pathogen sensitivity to fungicides, and better understand the biochemical and molecular mechanisms driving fungicide resistance. In some cases, this means that researchers are able to detect mutations in fungal DNA before reduced sensitivity or resistance occurs in the field, or to confirm that the failures experienced by growers in the field are in fact related to a distinct mutation (genetic change) in the target fungal pathogen.

EC_{50}

To determine the sensitivity of a fungal isolate, tests are carried out using multiple doses of the fungicide on amended laboratory media, in order to determine an EC_{50} value. The EC_{50} is the effective concentration of a fungicide required to inhibit 50% of the growth of a fungal isolate of the target pathogen, compared to a non-fungicide amended control. EC_{50} values are specific to the fungicide used and the species of target pathogen. Some fungal isolates can have increased EC_{50} values that are still within the normal range of sensitivities of the population, so these are unlikely to affect field performance of the fungicide. Others may have EC_{50} values outside the normal range of sensitivities and if these become frequent in the population, field performance of the fungicide may decrease. If these fungal isolates with reduced sensitivity remain at low levels, they may have no impact on the field performance of the fungicide when used at the recommended label rate.

Discriminatory doses

When the baseline sensitivity of a pathogen population is well-understood, discriminatory doses of fungicides may be employed to determine levels of pathogen sensitivity to fungicides. These may take place *in vitro* on fungicide-amended media, as for EC_{50} studies, or *in planta* on detached foliage or whole plant material. Discriminatory doses can be single or multiple dose rates, specific to the fungicides and/or fungal species, used to identify sensitive, reduced sensitivity or resistant isolates as per the definitions in this Guide. The dose rate(s) used and the reaction criteria of the fungus must be carefully defined through thorough research, and ideally be aligned with field reports of reduced sensitivity and resistance, and registered effective rates of fungicides (particularly relevant to *in planta* studies). Once established, discriminatory dose tests are often far simpler and more rapid than EC_{50} tests. As with the results of EC_{50} tests, it is then the frequency of these isolates identified as reduced sensitive and resistant in the fungal population that affects field performance of a fungicide.

Molecular mechanisms

Resistance can arise via several molecular mechanisms in fungal populations (Table 2). The simplest way is a target site mutation. This is a single or multiple gene mutation in the pathogen at the site targeted by the fungicide. Mutations at the target site interfere with how the fungicide interacts with the target in the fungus.

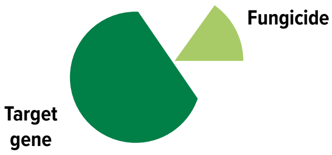
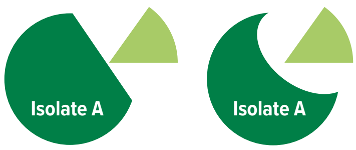
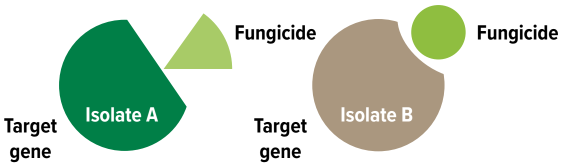
Other mechanisms for resistance can also occur. Target sites may also be over-expressed, or increased in copy number, making it more difficult for the fungicide to control the target pathogen.

Years of research have also uncovered what are referred to as "gateway mutations", mutations that are linked to early changes in the pathogen that correspond with the development of resistance in the longer term.

Fungicide resistance can also occur via detoxification of the fungicide by the fungus, and exclusion or expulsion of the fungicide from fungal cells. These latter two mechanisms have not been detected in any cases of fungicide resistance within the Australian grains industry to date. There are likely still many other resistance mechanisms that remain to be discovered.

The functional result of any detected genetic or molecular change, such as shifts in sensitivity or development of resistance, must always be confirmed through traditional laboratory EC_{50} analysis. Fungal populations can still be sensitive to a fungicide while carrying a genetic change associated with fungicide resistance within their population. When individuals carrying these mutations come to dominate a population, then practical resistance can develop. Resistance must always be confirmed by field observations.

Table 2. Molecular mechanisms of fungicide resistance currently known to occur in pathogens of Australian grain crops. Figures illustrate the relationship between the target gene in the fungus (dark green and grey) and fungicide (light green). Examples of fungicide resistance cases (diseases and fungicide mode of action group) with different levels of sensitivity/resistance are provided in the final column.

Mechanism	Resistance association in Australian grain crop diseases (examples)	
Target-site mutation, single  	**Reduced sensitivity**	Net form net blotch – Group 3 Net form net blotch – Group 7 Septoria tritici blotch – Group 3 Spot form net blotch – Group 3
	Resistant	Net form net blotch – Group 7 Spot form net blotch – Group 7 Wheat powdery mildew – Group 11
Multiple target-site mutations, within an individual isolate  	Single target site, multiple mutations - resistance to single fungicide or fungicide Mode of Action (MoA) group	
	Reduced sensitivity	Septoria tritici blotch – Group 3
	Reduced sensitivity to **Resistant**	Barley powdery mildew – Group 3
Multiple target-site mutations, within a population  	**Multiple target sites - resistance to multiple fungicide classes**	
	Reduced sensitivity to **Resistant**	Net form net blotch – Group 3 and Group 7
Target-site over-expression 	**Reduced sensitivity**	Spot form net blotch – Group 3 Blackleg – Group 3
Mixed mechanisms		
Target-site mutation + gene over-expression 	**Resistant**	Net form net blotch – Group 3 Spot form net blotch – Group 3 Hybrid spot/net form net blotch – Group 3

Fungicide resistance development – single and multi-step processes

Fungicide resistance can arise rapidly or slowly, through single- or multi-step processes at the molecular level (Figure 3), leading to reduced sensitivity or resistance. Single-step development of fungicide resistance is generally associated only with shifts from sensitive to resistant, and single target-site mutations in the fungus, while multi-step resistance is associated with a gradual shift from sensitive, through reduced sensitivity, to resistant as a result of an accumulation of multiple target-site mutations.

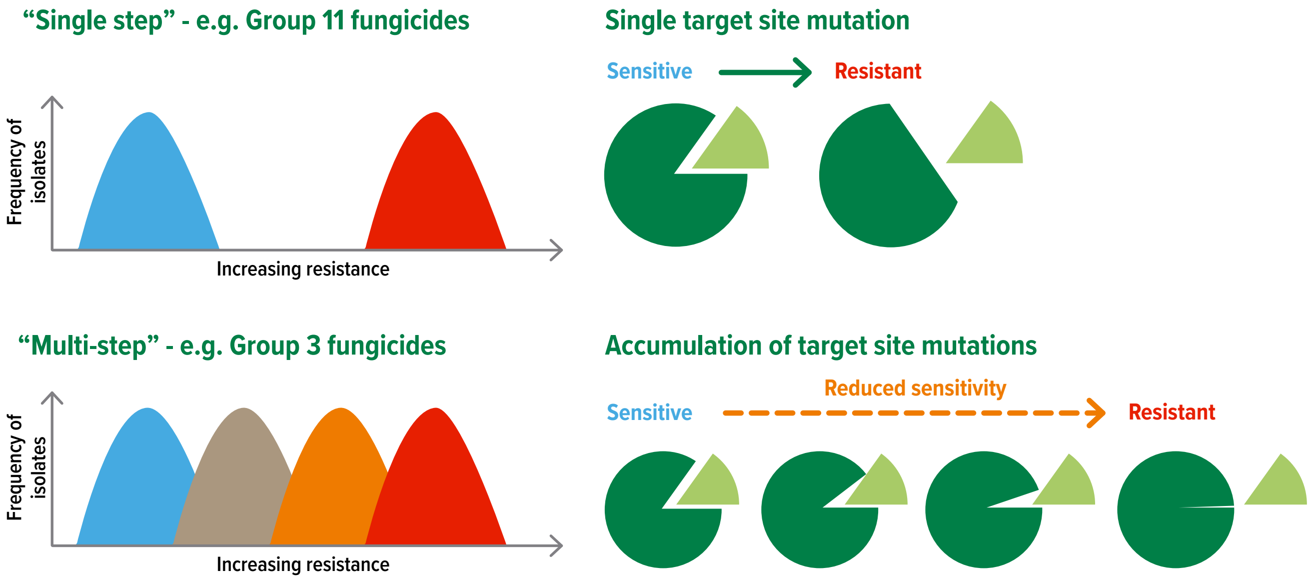


Figure 3. Fungicide resistance can develop through a single-step change, commonly associated with a single target site mutation, or through multiple steps, commonly associated with accumulation of multiple target site mutations. Graphs to the left show hypothetical frequency distributions of resistant isolates[1]. Figures to the right are illustrative of the relationship between the target gene (dark blue) and fungicide (yellow).

[1] Modified from Lucas et al. (2015) and Georgopoulos and Skylakakis (1986). Lucas et al. 2015. In Sariaslani & Gadd (Eds) Advances in Applied Microbiology. 90: 29-92. Georgopoulos & Skylakakis 1986. Crop Protect. 5: 299-305.

Appendix B: Recommended fungicide rotations

All of the following recommendations should consider the susceptibility of the variety being treated to the target pathogen, as fewer fungicide applications will likely be required for less susceptible varieties, dependent upon local conditions.

Recommendations are provided only as a guide, and in good faith, to help guide best management practices. Specific rotation strategies will depend on a range of factors, including the pathogens being targeted and fungicides registered to target those pathogens. Current information on registered fungicides can be found on the APVMA website at apvma.gov.au.

RECOMMENDED FUNGICIDE ROTATIONS - BARLEY

Where options are given, choose only one. If multiple formulations are applied together at the same time (e.g. 4 + 11 as in-furrow applied alongside a 4 + 7 + 3 seed treatment at seeding), consider the rotation options of both. Take into consideration the risk profiles of the fungicide MoAs (as outlined in the Fungicide groups - Modes of Action (MoA) section, p 7) and the general fungicide resistance management guidelines (p 16-17).

Note - Group 5 and 13 foliar fungicides are only registered to target barley powdery mildew.

Options in brackets, such as (7 + 3), indicate care should be taken to minimise use of this fungicide group, in line with the general fungicide resistance management guidelines (p 16-17).

Application stage & Rotation options		**Rotation options for different fungicide MoA groups**						
		A	**B**	**C**	**D**	**E**	**F**	**G**
Seed / in-furrow		None	3	3 + 4	4 + 7* + 3	4 + 11	7*	M3 + 7*
Foliar – spray 1	Option 1	None	None	None	None	None	None	None
	Option 2	3	7 + 3	7 + 3	11 + 3	3	3	3
	Option 3	7 + 3	11 + 3	11 + 3	3	7 + 3	11 + 3	11 + 3
	Option 4	11 + 3	13	3	(7 + 3)	13	(7 + 3)	(7 + 3)
Barley powdery mildew only	Option 5	13	5	13	13	5	13	13
	Option 6	5		5	5		5	5

If additional foliar application(s) required:

Application stage & Rotation options		**Immediately prior application contains**				
		3	7 + 3	11 + 3	5	13
Foliar – spray 2+	Option 1	(7 + 3)	(11 + 3)	(7 + 3)	3	3
	Option 2	(11 + 3)	(3)	(3)	(7 + 3)	(7 + 3)
	Option 3				(11 + 3)	(11 + 3)
Barley powdery mildew only	Option 3	13	13	13	13	5
	Option 4	5	5	5		

* Note – Group 7 actives have differential activity on foliar pathogens (as determined by label claims), and their subsequent use following the use of a Group 7 seed / in-furrow treatment should take this into account.

RECOMMENDED FUNGICIDE ROTATIONS - WHEAT

All of the following recommendations should consider the susceptibility of the variety being treated to the target pathogen, as fewer fungicide applications will likely be required for less susceptible varieties, dependent upon local conditions.

Where options are given, choose only one. If multiple formulations are applied together at the same time (e.g. 4 + 11 as in-furrow applied alongside a 4 + 7 + 3 seed treatment at seeding), consider the rotation options of both. Take into consideration the risk profiles of the fungicide MoAs (as outlined in the Fungicide groups - Modes of Action (MoA) section, p 7) and the general fungicide resistance management guidelines (p 16-17).

Options in brackets, such as (7 + 3), indicate care should be taken to minimise use of this fungicide group, in line with the general fungicide resistance management guidelines (p 16-17).

Application stage & Rotation options		**Rotation options for different fungicide MoA groups**					
		A	**B**	**C**	**D**	**E**	**F**
Seed / in-furrow		None	3	3 + 4	4 + 7* + 3	4 + 11	7*
Foliar – spray 1	Option 1	None	None	None	None	None	None
	Option 2	3	7 + 3	7 + 3	11 + 3	3	3
	Option 3	7 + 3	11 + 3	11 + 3	3	7 + 3	11 + 3
	Option 4	11 + 3		3	(7 + 3)		(7 + 3)

If additional foliar application(s) required:

Application stage & Rotation options		**Immediately prior application contains**		
		3	7 + 3	11 + 3
Foliar – spray 2+	Option 1	(7 + 3)	(11 + 3)	(7 + 3)
	Option 2	(11 + 3)	(3)	(3)

* Note – Group 7 actives have differential activity on foliar pathogens (as determined by label claims), and their subsequent use following the use of a Group 7 seed / in-furrow treatment should take this into account.

RECOMMENDED FUNGICIDE ROTATIONS - CANOLA

All of the following recommendations should consider the susceptibility of the variety being treated to the target pathogen, as fewer fungicide applications will likely be required for less susceptible varieties, dependent upon local conditions.

Where options are given, choose only one.

Options in brackets, such as (7 + 3), indicate care should be taken to minimise use of this fungicide group, in line with the general fungicide resistance management guidelines (p 16-17).

Application stage (Target disease)		**Rotation options for different fungicide MoA groups**											
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
Seed & in-furrow (Blackleg)		None	None	None	None	3	3	3	3	7*	7*	7* + 3	7* + 3
Seedling 4-8 leaf (Blackleg) – spray 1		None	3	7	7 + 3	None	(3)	7	7 + 3	None	3	None	3
20-50% flowering – spray 2 (Sclerotinia)	Option 1	None	None	None	None	None	None	None	None	None	None	None	None
	Option 2	2	2	2	2	2	2	2	2	2	2	2	2
	Option 3	3	(3)	3	3	3		3		3	(3)	3	
	Option 4	7 + 3	7 + 3	(7 + 3)	(7 + 3)	7 + 3		7 + 3		(7 + 3)	(7 + 3)	(7 + 3)	
	Option 5	11 + 3	11 + 3	11 + 3	11 + 3	11 + 3		11 + 3		11 + 3	11 + 3	11 + 3	

If a second application at 50% flowering required:

Rotation options		**Application at 20% flowering – spray 2**			
		2	3	7 + 3	11 + 3
50% flowering – spray 3	Option 1	3	2	2	2
	Option 2	(7 + 3)			
	Option 3	(11 + 3)			

* Note – Group 7 actives have differential activity on foliar pathogens (as determined by label claims), and their subsequent use following the use of a Group 7 seed / in-furrow treatment should take this into account.

Recommendations are modified from the most recent CropLife Australia Fungicide Resistance Management Strategies. Recommendations are provided only as a guide, and in good faith, to help guide best management practices. Specific rotation strategies will depend on a range of factors, including the pathogens being targeted and fungicides registered to target those pathogens. Current information on registered fungicides can be found on the APVMA website at apvma.gov.au.

RECOMMENDED FUNGICIDE ROTATIONS - PULSES

For chickpea and lentil crops:
The following recommendations assume that the chickpea or lentil variety being managed does not have resistance to either ascochyta blight (AB) or botrytis grey mould (BGM).

Where options are given, choose only one.

Options in brackets, such as (1), indicate care should be taken to minimise use of this fungicide group, in line with the general fungicide resistance management guidelines (p 16-17).

CHICKPEAS:

Application stage (target disease) & Rotation options		Rotation options for different fungicide MoA groups					
		A	**B**	**C**	**D**	**E**	**F**
Seed (AB/BGM)		M3	M3	M3	M3 + 1	M3 + 1	M3 + 1
Foliar – spray 1 (AB)		7 + 3	M5	11 + 3	7 + 3	M5	11 + 3
Foliar – spray 2 (AB)	Option 1	M5	7 + 3	M5	M5	7 + 3	M5
	Option 2	11 + 3	11 + 3	7 + 3	11 + 3	11 + 3	7 + 3
	Option 3	M3	M3	M3	M3	M3	M3

Spray 2+, where targeting BGM.

Application stage (target disease) & Rotation options		Immediately prior application contains			
		1	2	7 + 3	M3
Foliar – spray 2+ (BGM)	Option 1	(2)	(1)	(1)	(1)
	Option 2	(7 + 3)	(7 + 3)	(2)	(2)
	Option 3	(M3)	(M3)	(M3)	(7 + 3)

LENTILS:

Application stage (target disease) & Rotation options		Rotation options for different fungicide MoA groups					
		A	**B**	**C**	**D**	**E**	**F**
Seed (AB/BGM)		M3	M3	M3	M3 + 1	M3 + 1	M3 + 1
Foliar – spray 1 (AB) (prior to canopy closure)		M5	7 + 3	11 + 3	M5	7 + 3	11 + 3
Foliar – spray 2 (BGM ± sclerotinia)	Option 1	1	1	1	(1)	(1)	(1)
	Option 2	2	2	2	2	2	2
	Option 3	7 + 3	M3	7 + 3	7 + 3	M3	7 + 3
	Option 4	7		7	7		7
	Option 5	M3		M3	M3		M3

For additional foliar fungicide sprays for any crop, growers should continue to rotate and mix their fungicide actives and MoA, using the fungicide resistance management principles illustrated here, to reduce pressure on any one individual fungicide or fungicide group. Products can be mixed (according to label directions) to control multiple diseases, in which case extra care should be taken to avoid sequential applications of the same fungicide group. Beware that some fungicides may not be registered beyond a particular growth stage (e.g. flowering, podding) of the crop, and rotations should take this into consideration.

GRDC™

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION