GUIDE

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FUNGICIDE RESISTANCE MANAGEMENT IN AUSTRALIAN GRAIN CROPS

Best practice strategies from the Australian Fungicide Resistance Extension Network (AFREN)

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Thank you to the many grain 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.

COVER: A close-up of wheat heads in a crop.
PHOTO: Rebecca Barr

Disclaimer: This guide advises on best management practices to manage the impacts and reduce the emergence of fungicide resistance in the Australian grains industry. All crop protection fungicide products must be handled and applied strictly as specified on the product label or APVMA permits.

Resistance management strategies related to fungicide use in this guide do not replace product labels. They are a guide only and do not endorse particular products, groups of products or cultural methods in terms of their performance. Current information on registered fungicides can be found on the APVMA website (apvma.gov.au).

The information given in this guide is provided in good faith and without any liability for loss or damage suffered as a result of its application and use. While every effort has been made to ensure the scientific accuracy and currency of all information and recommendations, our 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/fungicide-resistance/) and CropLife Australia (croplife.org.au) websites. Advice given in this guide is valid as at 1 January 2026.

Australian Fungicide Resistance Extension Network (AFREN)

The Australian Fungicide Resistance Extension Network (AFREN) is a collaboration between 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 and Regional Development (NSW DPIRD), Queensland Department of Primary Industries (Qld DPI), the South Australian Research and Development Institute (SARDI), the University of Sydney and the University of Melbourne. This core team collaborates closely with leading industry bodies like GRDC and CropLife Australia. Additionally, they work with communication and extension specialists from AgCommunicators and the Independent Consultants Australia Network (ICAN) to ensure AFREN's outreach 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 visiting grdc.com.au/afren or following #AFREN and @theGRDC on X.

Photo: Evan Collis Photography

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Contents

Photo: GRDC

Introduction

Fungicide resistance is a serious and increasing problem in cropping systems worldwide. Fungicides are an important component of integrated management strategies aimed at the protection of crops from the impacts of fungal diseases. However, as their use has increased, the effectiveness of some fungicides has been compromised 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 available 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 development and/or impact of pathogen resistance to 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 from AFREN (afren.com.au), CCDM Fungicide Resistance Group (ccdm.com.au/fungicide-resistance/) 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 (apvma.gov.au).

Introduction to fungicide resistance

Photo: CCDM

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 fungicide group. It can become a major constraint to disease control, especially where no alternative fungicide or effective host-plant resistance is available. In this guide we refer to the following terms when discussing fungicide resistance:

Fungicide resistance terminology

Sensitivity

Sensitivity in fungal pathogens refers to the susceptibility of a fungus to a particular fungicide. A sensitive pathogen is effectively controlled or inhibited by the fungicide at recommended doses, meaning the fungicide can prevent the growth and spread of the pathogen.

Reduced sensitivity

Fungi are considered to have reduced sensitivity to a fungicide when the application does not work optimally but does not completely fail. This occurs when the fungicide provides less control of the target fungal pathogen in the field than it once did, even when applied at recommended rates. In the field, an increased frequency of individuals with reduced sensitivity within the fungal population indicates that a growing portion is less affected by the fungicide. This change can be a precursor to resistance and must be confirmed through monitoring and specialised laboratory testing.

Resistance

Resistance occurs when the fungicide fails to provide an acceptable level of control of the target pathogen in the field, even at maximum label rates. A high frequency of resistant individuals within the fungal population indicates that a significant portion is unaffected by the fungicide, rendering the application ineffective. Confirmation of resistance requires laboratory testing and clear evidence of field failure.

Laboratory detection

A laboratory detection relates to measurable differences of a fungal isolate's sensitivity to a fungicide in scientifically recognised *in vitro* tests, or the detection of a mutation in a fungal isolate that may result in fungicide resistance. These changes can often be detected in the laboratory before any loss of fungicide efficacy is detected in the field. Laboratory 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 laboratory.

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 a foliar fungicide due to operator error or incorrect sprayer calibration
- unsuitable weather during or immediately after spraying (for example, excessive wind or rain)
- poor application timing
- poor application coverage
- antagonistic tank mixes (for example, with in-crop herbicides)
- ineffective rates
- faulty product
- excessive inoculum (disease) pressure
- choice of a low-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 limiting root uptake and distribution 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 fungicide actives further down the soil profile, out of the root zone.

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 fungicide application 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 (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 around fungicide usage.

How does fungicide resistance develop?

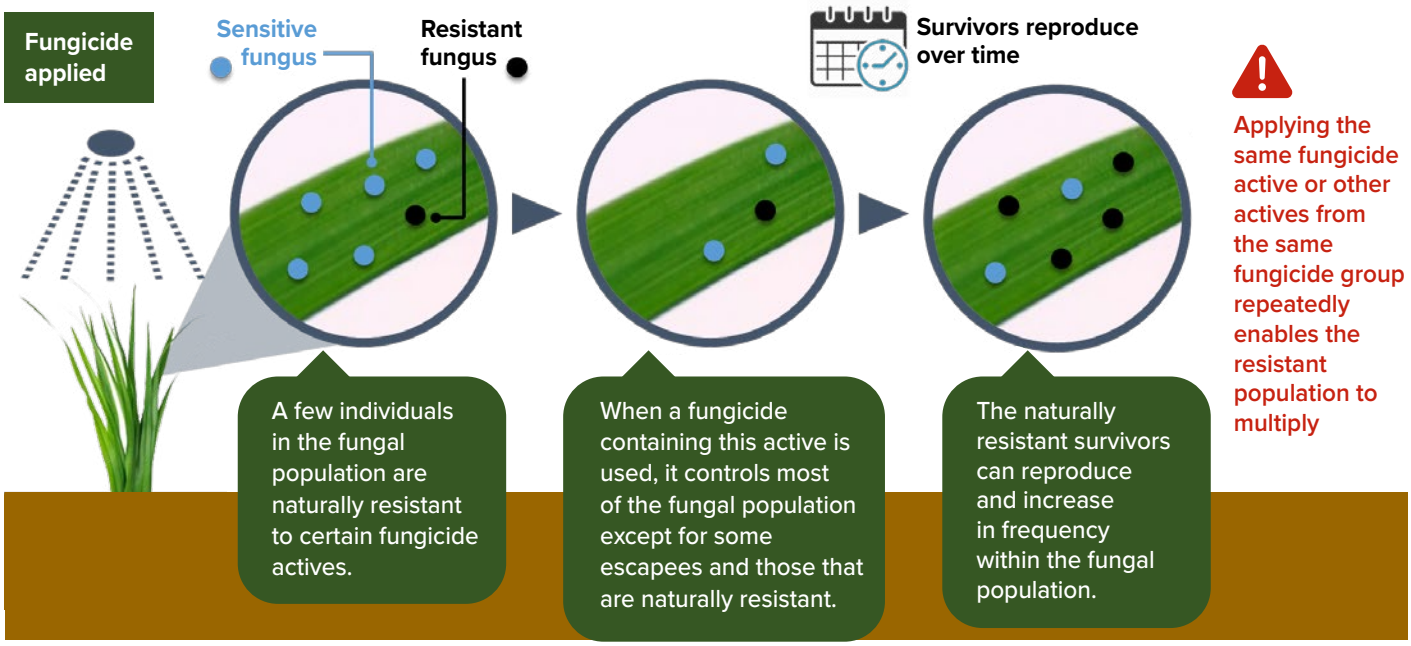
Fungicide resistance usually develops following the repeated use of the same fungicide active or other actives within the same fungicide group for disease control. In any fungal population there are likely to be resistant individuals that are less sensitive to fungicides, even before these are applied. If resistant individuals are then repeatedly exposed to the same fungicide group, fungicide selection pressure may increase their frequency in the fungal population (Figure 1).

Continued use of the same fungicide active or other actives from the same fungicide group can result in the selection and subsequent significant build-up of resistant individuals in the fungal population – to the point where that fungicide active, or other actives from the same fungicide 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, but this is not always the case.

The risk of developing fungicide resistance varies between different fungicide 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 on pages 13–17.

Figure 1: Fungicide resistance selection



Source: Modified from CropLife Australia Fungicide Resistance Management fact sheet (croplife.org.au/resources/programs/resistance-management/fact-sheet-fungicide-resistance/)

Fungicide groups

Different numbers are used to distinguish fungicide groups according to their biochemical action. The numbers were assigned according to the order of introduction to the market. When a pathogen develops resistance to a fungicide, all other fungicide actives within the same fungicide group are often at risk of having reduced sensitivity or resistance develop.

More than 200 fungicides, within 52 fungicide groups, are approved worldwide for the control of fungal pathogens in agriculture. This does not include host-plant defence inducers, chemical multi-site inhibitors, any chemicals with an unknown biochemical action or resistance risk, or biologicals with multiple biochemical actions. Very few fungicide 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 fungicide 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.

Dominant fungicide 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. Commonly used as seed dressing, foliar applications and in-furrow. **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. This is a very diverse group and there are distinct differences in disease spectrum and systemic movement of these fungicide actives within plants. **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. Strobilurins are effective against a broad range of pathogens, and their systemicity varies from local translaminar to upward movement with some actives having vapour activity. **Risk of resistance development:** high.

Other fungicide 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 (excluding chickpeas). **Risk of resistance development:** moderate to high.

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 (for example, *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 (for example, *Phytophthora* spp., *Pythium* spp.). **Risk of resistance development:** low.

M1-M5 – Multi-site activity
Common actives: chlorothalonil, copper, mancozeb, sulphur. **Registered:** pulses. Good rotation and mixing partner options for managing fungicide resistance. **Risk of resistance development:** very 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 (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 on page 13–17 for more information.

Further information on fungicide groups and risk of resistance development can be found on the FRAC website (frac.info).

Pathogen or disease?

A PATHOGEN is an organism, for example, fungus, bacterium or nematode, that infects a plant causing a disease.

INOCULUM is the part of the pathogen, for example, fungal spores or hyphae, that resides in the soil, within crop residues 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, that is, the symptoms caused by the pathogen.

For example, the pathogen *Leptosphaeria maculans* causes the disease blackleg of canola. The spores of *Leptosphaeria maculans* survive within the stubble of canola, which is 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 conditiions for disease development
- sub-optimal agronomic practices, for example, short rotations, varietal susceptibility and planting susceptible varieties in high-risk seasons
- higher intensity agronomic practices, for example, irrigation with higher N inputs, thicker canopies providing more conducive conditions for some leaf diseases
- the presence of green bridges or stubble which can harbour pathogens from the last season
- inherent characteristics of the fungi themselves, for example, 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 grown within a region, and when actives within a single fungicide group are used repeatedly.

Photo: CCDM

Fungicide resistance risk factors

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

Fungicide risk

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

Group 11 QoIs/Strobilurins (for example, 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 can spread quickly causing field failures. Usually, when resistance to an active within Group 11 is detected, other actives within the group are likewise compromised (that is, high cross-resistance).

Group 7 SDHIs (for example, bixafen, fluxapyroxad) have a moderate to high risk of resistance development, especially for the pathogens responsible for net form net blotch (NFNB), 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 (that is, moderate to high cross-resistance).

Group 3 DMIs (for example, propiconazole, tebuconazole) have a moderate risk of pathogen resistance development. The shift towards pathogen resistance to Group 3 fungicides is usually a gradual process, where an incomplete form of resistance slowly builds, taking years to develop into resistance. However, there have been reports in New Zealand and Australia of field failure due to resistance to specific DMI fungicides in net blotch diseases, challenging this view.

In Western Australia, 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 in 2010. This fungicide resistance outbreak devastated crops, highlighting that Group 3 fungicide resistance may develop more rapidly under conducive conditions and in relation to specific interactions between certain fungicide actives 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 (that is, moderate cross-resistance). For this reason, it may be possible to rotate use of different fungicide actives 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 recommends the rotation of Group 3 fungicide actives 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 on page 22).

Global experience further indicates the following:

Group 1 MBCs (for example, 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 (that is, high 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 (for example, iprodione) have a moderate to high 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 hordei* and *Blumeria graminis*). Mildew pathogens have an inherently high resistance risk. A rapid life cycle, continual high spore production and high genetic diversity results in a remarkable ability to adapt to fungicide treatments. Fungicide resistance and reduced sensitivity to the powdery mildews are present in Australia (Table 1).

In Europe, barley powdery mildew has additionally developed resistance to Group 5 morpholine and Group 13 aza-napthalene fungicides. There have also been laboratory detections of reduced sensitivity to the Group 50 fungicide metrafenone.

Barley net blotches (caused by *Pyrenophora teres* f. *maculata* and f. *teres*). Similarly to powdery mildew pathogens, net blotch pathogens have an inherently high resistance risk. Fungicide resistance and reduced sensitivity or laboratory detections of mutations conferring resistance to all the registered fungicides used to control barley net blotches are present in different areas around Australia (Table 1). This now includes the widely reported F129L mutation, known to reduce the effectiveness of Group 11 fungicides.

Ramularia leaf spot (caused by *Ramularia collo-cygni*). There is a high risk of fungicide resistance developing in *Ramularia* populations. No instances have been reported in Australia; however, resistance to Group 1, 3, 7 and 11 fungicides has been reported in Europe and resistance to Group 7 and 11, and reduced sensitivity to Group 3 fungicides have been reported in New Zealand.

Septoria tritici blotch (caused by *Zymoseptoria tritici*). There is a moderate to high risk of resistance developing in *Zymoseptoria* populations. Reduced sensitivity to Group 3 fungicides is present in Australia (Table 1). Mutations associated with resistance to Group 11 fungicides in Europe and New Zealand are the same as those present in Australian *Zymoseptoria tritici* isolates but are not currently associated with reports of field failure in Australia. Reduced sensitivity to Group 7 fungicides is also present in Europe and New Zealand.

Septoria nodorum blotch (caused by *Parastagonospora nodorum*). Fungicide resistance risk is moderate for *P. nodorum*; no resistance or reduced sensitivity currently exists in Australia. Resistance to Group 11 fungicides has been reported in the USA and Sweden. Reduced sensitivity to Group 3 fungicides is present in China and Europe.

Barley scald (caused by *Rhynchosporium commune*). In Australia there are no instances of fungicide resistance in *Rhynchosporium* populations, and the pathogen risk is moderate. However, 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*). This pathogen has a moderate resistance risk. No instances of resistance or reduced sensitivity are present in Australia. Resistance to Group 1 fungicides has been reported in New Zealand and in Europe. 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*). *Pyrenophora triticii-repentis* has a moderate resistance risk. No instances of resistance or reduced sensitivity have been found in Australia. Resistance to Group 3 and reduced sensitivity to Group 11 fungicides have been reported in Europe.

Rusts (*Puccinia* spp.). Despite the high sporulation rates of rust species, the resistance risk is moderate. In Australia, Group 3 target-site mutations have been detected in the laboratory in isolates of *Puccinia hordei*, which causes barley leaf rust (Table 1), but the field implication of this is unclear. Apart from an instance in Brazil of a decline in the field performance of DMIs against the Asian soybean rust, few agronomically important cases are known internationally. Reduced sensitivity to Group 3 fungicides was reported in Europe for *P. triticina* and *P. striiformis*, but these situations have largely stabilised and the risk is still considered low to moderate in the region. Target gene mutations have also been detected in New Zealand, but no evidence of reduced sensitivity or field resistance to Group 3 fungicides has been detected.

In Australia, research by the University of Sydney has demonstrated important changes in the sensitivity to Group 3 fungicides in the barley and wheat leaf rust pathogens, in particular to tebuconazole, prothioconazole, propiconazole and triadimenol. Tebuconazole is not registered for the control of leaf rust in barley, but it is registered for scald and mildew control in barley and for rust diseases in wheat and oats. Consideration of non-target selection in the use of Group 3 fungicides is important as the use of tebuconazole for the control of these diseases can select for resistance to other DMIs in rust pathogens through off-target selection.

Smuts (caused by *Ustilago* spp.). Cereal smut pathogens are considered at 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. No resistance or reduced sensitivity is currently present in Australia.

Photo: Brad Collis

CANOLA

Blackleg (caused by *Leptosphaeria maculans*). This major canola pathogen has a moderate risk of developing fungicide resistance. Reduced sensitivity to Group 3 fungicides is present in Australia, as it is in Europe; as well as laboratory-detected mutations linked to Group 7 and Group 12 fungicide resistance (Table 1). Although Group 2 fungicides are not registered for control of blackleg, target-site mutations conferring fungicide resistance to Group 2 fungicides have been detected in the laboratory. Use of Group 2 fungicides registered to control other fungi may select for resistant individuals of *L. maculans* through off-target selection.

Sclerotinia stem rot (caused by *Sclerotinia sclerotiorum*). The other major canola pathogen also has a moderate fungicide resistance risk. No resistance to any fungicide group has been reported for Sclerotinia in Australia. Instances of resistance and/or reduced sensitivity to Group 1, 2 and 7 fungicides have been documented in Europe.

PULSES

Ascochyta blight of lentils (caused by *Ascochyta lentis* (syn: *Didymella lentis*)). *Ascochyta* species have a high resistance risk. In Australia, resistance to all Group 1 fungicides by *A. lentis* has been detected in the laboratory (Table 1), but field resistance or reduced sensitivity has not been reported.

Resistance to Group 11 fungicides in chickpea Ascochyta blight (caused by *Ascochyta rabiei* (syn: *Didymella rabiei*)) has been present 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 grey mould and chocolate spot (caused by *Botrytis cinerea and B. fabae*). *Botrytis* species have a high resistance risk. Target-site mutations known to confer resistance to all Group 1 fungicide actives have been detected in *Botrytis cinerea* in Australia, but resistance or reduced sensitivity have not been recorded. Cross-resistance is common among Group 1 fungicides and care should be taken when considering Group 1 fungicides to control *B. cinerea* in pulses.

Resistance, and cases of dual and multiple resistance and reduced sensitivities to fungicide Groups 1, 2, 7, 9, 11, 12 and 17 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.

Mungbean powdery mildew (caused by *Podosphaera xanthii* and *Erysiphe vignae*). As with the barley and wheat powdery mildew pathogens, the mungbean powdery mildews also have a high inherent resistance risk. Field resistance to Group 3 fungicides and reduced sensitivity to Group 11 fungicides has been confirmed in Australia (Table 1). Currently, only Groups 3 and 11 fungicides (namely, tebuconazole and azoxystrobin) are registered for the control of mungbean powdery mildew, so it is imperative that other disease management strategies are implemented to limit the impact of this emerging threat.

Downy mildew of peas (caused by *Peronospora viciae*). This pathogen has a moderate resistance risk. It has not been associated with any fungicide resistance or reduced sensitivity in Australia. Resistance to Group 4 fungicides has been detected in field pea in New Zealand.

Agronomic risk

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. When disease pressure is reduced by employing integrated disease management practices, less fungicide applications are required and 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 other actives from the same fungicide 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. For example, spraying to control wheat stripe rust could select for resistance in wheat powdery mildew in the same crop.
- **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 apply more fungicides, 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 carryover 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 fungicide resistance in following crops. This is likely to occur through increased fungicide use to control disease and potential carryover of resistant individuals selected in previous seasons.
- **Seed health.** Consider the risk of seed-borne infection. If seed is suspected to be infected with seed-borne pathogens such as NFNB, seed dressings and/or in-furrow treatments should be used. Avoid moving infected seed between regions where resistance has been detected.

Photo: GRDC

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 risk of fungicide resistance developing in an area.

High-rainfall areas and irrigated systems 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 create microclimates with prolonged periods of leaf wetness and/or high humidity. This is conducive to infection by various fungal pathogens, increasing disease incidence. Closed canopies can also make it more difficult to attain the required level of fungicide spray penetration and coverage, especially to lower leaves and stems. Longer-season high-rainfall zones (for example, Tasmania, southern Victoria, south-west WA) 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 in susceptible varieties or with crop canopies requiring repeated fungicide applications in one season to control disease development.

In addition to this, the repeated use of the same effective active in moderate-rainfall areas over several seasons has led to the rapid selection of resistance that, in some cases, has been faster than in high-rainfall areas.

Low-rainfall areas have the lowest risk of fungicide resistance developing as disease pressure is lower and terminal drought often causes the crop to dry off before disease impacts are fully expressed. Hence, the need to apply fungicides within a season is reduced.

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 for a fungicide/pathogen combination can be different between different states of Australia (or even between regions within the states) despite the presence of the same mutation. For example (see Table 1), mutations for resistance and reduced sensitivity to SDHIs in NFNB are present in all grain-growing states except Tasmania. However, resistance and reduced sensitivity have only been confirmed in SA, Vic and WA. In NSW and Qld, the same mutations have been detected, so why do they have different resistance statuses?

The frequency of these resistance mutations in NFNB in SA, Vic and WA is much higher than in NSW and Qld. In other words, these mutations have not yet reached a significant threshold required to impact SDHI fungicide efficacy.

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 need to consider reviewing our disease management strategies before these mutations accumulate in the pathogen's population at damaging levels.

Photo: CCDM

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 (Table 1). By definition (see terminology page 8) these field observations must be supported by fungicide resistance testing of pathogens in the laboratory. Testing occurs either when observations of less disease control or field failure of a fungicide prompt growers and agronomists to seek clarification of fungicide resistance from pathologists. Alternatively, researchers will perform surveys or routine screening irrespective of observations of sub-optimal disease control.

Laboratory assessment involves genetic or phenotypic testing or both. Genetic testing of fungal isolates will assess for the presence of mutations in the target genes of fungicide actives that can result in resistance to a fungicide. Phenotypic testing assesses measurable differences of a fungal isolate's sensitivity to a fungicide active in scientifically recognised *in vitro* tests. (See Appendix A for more information). These laboratory detections can confirm reports of resistance or reduced sensitivity in the field or alert stakeholders to the potential for fungicide resistance or reduced sensitivity developing.

As fungicide use continues, and survey and detection techniques become more sophisticated and widely adopted across regions, the industry can expect more cases of resistance and reduced sensitivity.

Table 1: Known fungicide resistance status in pathogens of Australian grain crops (current as of January 2026, subject to change). Updated information is available online (afren.com.au). Farm-level or regional risk may vary greatly from the statewide results presented here

- = **resistance.** Reports of field failure associated with detected mutations or with *in vitro* tests confirming resistance.
- = **reduced sensitivity.** Reports of sub-optimal fungicide effectiveness in the field associated with detected mutations or with in-vitro tests confirming reduced sensitivity.
- [1] = mutations detected known to be related to **resistance** or *in vitro* tests indicating resistance, but not yet definitively associated with field reports in this state.
- [1] = mutations detected known to be related to reduced sensitivity or *in vitro* tests indicating **reduced sensitivity**, but not yet definitively associated with field reports in this state.
- = **laboratory detection.** Mutations detected with unknown effect, mutations detected with potential to compromise some fungicides, or *in planta* assays showing a reduction in fungicide sensitivity, but with no reports of reduced effectiveness or failure in the field.
- = pathogens are not routinely tested, or the pathogen is not considered a current threat in this state.

[1]Presence of a mutation(s) or *in vitro* assessment indicating resistance or reduced sensitivity indicate potential for resistance to develop in the field when there is fungicide selection pressure. *Different species of fungal pathogens vary in their propensity to evolve fungicide resistance (see the fungicide resistance risk factors section page 13–17).*

Fungicide group	Actives affected	NSW	Qld	SA	Tas	Vic	WA	Industry implications
BARLEY								
Barley powdery mildew – caused by *Blumeria hordei*								
3 (DMI)	Tebuconazole, Propiconazole, Flutriafol	▢	▢	▢	▢	▢	■ ●	WA – DMI fungicides are no longer effective or are under threat in areas of the state. All other states – The same mutations conferring resistance in WA have been detected. There is a high likelihood of DMI field failure developing. There is a high likelihood of reduced sensitivity and resistance developing.
Net form net blotch – caused by *Pyrenophora teres* f. *teres*								
3	Propiconazole, Prothioconazole, Epoxiconazole	●	●	■ ●	○	■ ●	■ ●	SA, Vic and WA – DMI fungicides are no longer effective or are under threat in areas of the state NSW and Qld – There is a high likelihood of resistance developing and potential for field failure.
7 (SDHI)	Fluxapyroxad, Bixafen	▢ ○	▢ ○	■ ●	○	■ ●	■ ●	SA, Vic and WA – SDHI fungicides are no longer effective or are under threat in areas of the state. NSW and Qld – There is a high likelihood of reduced sensitivity and resistance developing.

Continued next page

Table 1: Known fungicide resistance status in pathogens of Australian grain crops (current as of January 2026, subject to change) cont.

Fungicide group	Actives affected	NSW	Qld	SA	Tas	Vic	WA	Industry implications
BARLEY cont.								
Net form net blotch – caused by *Pyrenophora teres* f. *teres* cont.								
11 (QoI)	Azoxystrobin		○	○	○			Qld and SA – QoI fungicides are under threat in areas of the state.
3 + 7 **Double mutants**	Propiconazole, Prothioconazole, Epoxiconazole, Fluxapyroxad (7)			■ ●	○	■ ●	■ ●	SA, Vic and WA – Fungal isolates with dual resistance to both selected DMI fungicides and SDHI fungicides indicate that mixtures of these fungicide groups may not be effective.
3 + 11 **Double mutants**	Propiconazole, Prothioconazole, Epoxiconazole, Azoxystrobin (11)				○		□	WA – Fungal isolates with dual resistance to DMI and QoI indicate that DMI fungicides applied individually or DMI-QoI mixtures of these two fungicide groups may not be effective.
3 + 7 + 11 **Triple mutants**	Propiconazole (3), Prothioconazole (3), Epoxiconazole (3), Fluxapyroxad (7), Azoxystrobin (11)			■	○	□	■	SA, Vic and WA – Detection of fungal isolates with triple resistance to all registered fungicide actives indicate that fungicides applied individually or in mixtures may not be effective in areas of these states.
Spot form net blotch – caused by *Pyrenophora teres* f. *maculata*								
3	Propiconazole, Prothioconazole, Epoxiconazole	○	■	○	○	□ ●	■ ●	Qld and WA – DMI fungicides are no longer effective or are under threat in areas of the state. Vic – The same mutations conferring resistance in WA have been detected. There is a high likelihood of DMI field failure and resistance developing. NSW and SA – There is a high likelihood of reduced sensitivity and resistance developing.
7	Fluxapyroxad, Bixafen	○	○		○		■ ●	WA – SDHI fungicides are no longer effective or are under threat in areas of the state. NSW and Qld – There is a high likelihood of reduced sensitivity and resistance developing.
3 + 7	Propiconazole (3), Prothioconazole, Epoxiconazole, Fluxapyroxad (7)				○		■ ●	WA – Fungal isolates with dual resistance to both selected DMI fungicides and SDHI fungicides indicate that fungicide mixtures may not be effective.
11	Azoxystrobin			○	○			SA – There is a high likelihood of reduced sensitivity and resistance developing, and a high likelihood of QoI field failure.
Barley leaf rust – caused by *Puccinia hordei*								
3	Tebuconazole, Difenoconazole, Propiconazole, Prothioconazole, Epoxiconazole	▲	▲	▲	▲	▲	▲	All states – Potential for reduced sensitivity developing under high disease pressure and fungicide selection pressure.
WHEAT								
Wheat powdery mildew – caused by *Blumeria graminis*								
3	Tebuconazole, Propiconazole, Prothioconazole	■	■	■	■	■	▲	All states except WA – Some DMI fungicides are no longer effective or are under threat in areas of these states. WA – A gateway mutation has been detected, the first in a series of mutations leading to resistance expression. There is a high likelihood of reduced sensitivity and resistance developing.
11	Azoxystrobin, Pyraclostrobin	■	■	■	■	■		All states except WA – QoI fungicides are no longer effective or are under threat in areas of the state.

Continued next page

Table 1: Known fungicide resistance status in pathogens of Australian grain crops (current as of January 2026, subject to change) cont.

Fungicide group	Actives affected	NSW	Qld	SA	Tas	Vic	WA	Industry implications
WHEAT cont.								
Septoria tritici blotch – caused by *Zymoseptoria tritici*								
3	Tebuconazole, Propiconazole, Flutriafol, Triadimenol, Epoxiconazole, Cyproconazole	●	◎	●	●	●	◎	NSW, SA, Tas, Vic – There is a high likelihood of resistance developing and potential for field failure.
11	Azoxystrobin, Pyraclostrobin		◎	▢	▢	▢	◎	SA, Tas and Vic – There is a high likelihood of QoI field failure developing. There is a high likelihood of reduced sensitivity and resistance developing.
CANOLA								
Blackleg – caused by *Leptosphaeria maculans*								
3	Tebuconazole, Flutriafol, Fluquinconazole, Prothioconazole	●		●		●	●	NSW, SA, Vic and WA – There is a high likelihood of resistance developing and potential for field failure.
7	Pydiflumetofen, Fluopyram, Fluxapyroxad, Bixafen			▲				SA – Potential for reduced sensitivity developing under high disease pressure and fungicide selection pressure.
12 (PP)	Fludioxonil			▲				SA – Potential for reduced sensitivity developing under high disease pressure and fungicide selection pressure.
PULSES								
Ascochyta blight of lentils – caused by *Ascochyta lentis*								
1 (MBC)	All Group 1 actives			▢				SA – There is a high likelihood of field failure developing. There is a high likelihood of reduced sensitivity and resistance developing.
Botrytis grey mould of chickpea – caused by *Botrytis cinerea*								
1	All Group 1 actives			▲				SA – Potential for reduced sensitivity developing under high disease pressure and fungicide selection pressure.
Mungbean powdery mildew – caused by *Podosphaera xanthii* and *Erisyphe vignae*								
3	Tebuconazole		●					Qld – There is a high likelihood of resistance developing and potential for field failure.
11	Azoxystrobin		▢ ●					Qld – There is a high likelihood of field failure and resistance developing.

General fungicide resistance management guidelines

Fungicide resistance is a numbers game, and the only viable option to slow it down is to limit the size of pathogen populations and/or the number of fungicide applications (see the fungicide resistance risk factors section page 13–17). This can be achieved by implementing an integrated disease management (IDM) strategy that is tailored to the specific growing conditions and locally prevalent pathogens, to reduce disease pressure and minimise reliance on fungicide.

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

Avoid susceptible crop varieties

- **Sow less-susceptible varieties**. Avoid SVS and VS varieties in disease-prone areas. Consult your local crop sowing guide for suitable varieties. The use of less-susceptible crop varieties can **reduce the need for fungicide inputs**.

Rotate crops and varieties – use time and distance to reduce disease carryover

- **Rotate crops** to help break the disease cycle. Rotate with crops not affected by the disease of concern to reduce disease carryover and increase time for inoculum to break down.
- **Rotate different resistant varieties** to slow down pathogen populations overcoming varietal resistance. Monitor each year to detect if the fungus has overcome any varietal resistance and plan accordingly in subsequent seasons. Yield losses may indicate varietal resistance is compromised.

Use non-chemical control methods to reduce disease pressure

- **Remove or reduce stubble loads** to minimise carryover of stubble-borne pathogens.
- **Eliminate the green bridge.** Destroy volunteer crop plants and other hosts at least four weeks prior to sowing.
- **Invest in clean seed**. Do not use seed from crops that are heavily infected with seed-borne pathogens. If seed is suspected to be infected, seed dressings and/or in-furrow treatments should be used. Avoid moving infected seed from regions where fungicide resistance has been detected.
- **Adjust time of sowing** in seasons with a high disease risk to avoid the highest peak of pathogen abundance. Early sowing generally favours disease development and increased losses.

Spray only if necessary and apply strategically

- **Ensure correct diagnosis** to avoid unnecessary fungicide application for non-disease issues such as abiotic stresses (for example, physiological spotting, herbicide damage or nutritional deficiencies) or non-fungal diseases (that is, viruses or bacterial infections).
- **Limit fungicide applications**. Fungicide use may not be economical or necessary in low disease pressure scenarios.
- **Use an effective seed dressing** for early crop protection, especially in high disease pressure scenarios, or to reduce infection by 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.
- **If crops are heavily infected**, carefully consider your need to apply fungicides. If you do, be strategic and try to select a fungicide for which little or no fungicide 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 application rates.
- **Where reduced sensitivity or resistance has developed,** minimise and if possible, avoid the use of affected fungicide groups.

Rotate and mix fungicide groups

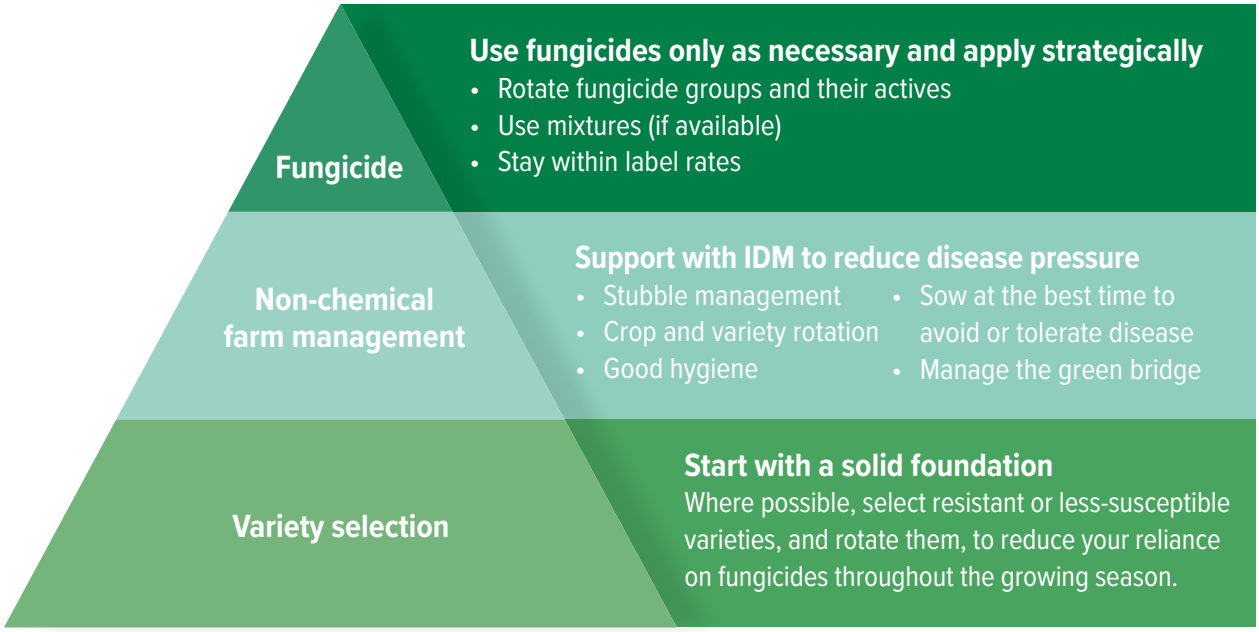
- **Rotate fungicide groups and use mixtures** to reduce fungicide selection pressure.
- **Take care** that each active is applied at the effective registered rate for the target pathogen and disease scenario.
- **Consider** not using any fungicides as stand-alone products for any disease, as a way of 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 season. If possible, **reduce** this **to two** applications in regions where **Group 3** resistance has been reported.
- **Do not use** the same **Group 3** fungicide active **consecutively**.

- **Avoid** using the same **Group 3** fungicide active more than **once per season**. This includes in-furrow or seed treatments that have activity on foliar diseases. Combinations of in-furrow and seed treatment are counted as one application.
- **Group 7 and 11** fungicides must always be in a **co-formulation or in mixture** with a registered mixing partner from a different fungicide group. This mixing partner should ideally be one for which the target pathogen has no (or less) known reduced sensitivity or resistance.
- **Avoid using more than one** application per growing season of **Group 7 and 11** containing fungicides. This includes 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 use more than two** applications per growing season of **Group 7 or 11** containing fungicides.
- **Do not use Groups 7 or 11** containing fungicides **consecutively**.
- **Group 11** containing fungicides should be used as **preventive rather than curative** control.

Monitor regularly for disease

- **Inspect crops for plant disease symptoms.** Use regional disease guides, for example, GRDC fact sheets, 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 treatment 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.

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



Managing Group 3 fungicide resistance

Fungicide resistance to a Group 3 fungicide does not automatically compromise the effectiveness of other fungicides within the same group. Depending on the specific mutation in the pathogen, there may be varying levels of cross-resistance between different active ingredients. Hence, rotating among different Group 3 fungicide actives may be a useful strategy to reduce the risk of fungicide resistance development.

To reduce the risk of fungicide resistance and maintain Group 3 efficacy, AFREN recommends rotating effective registered actives for the target disease, when more than one application is required. Rotation should be within and across growing seasons, with a maximum of three applications per season, either alone or in mixtures. This means avoiding consecutive or repeated use of the same Group 3 active within a season or across seasons.

This recommendation differs from the CropLife and FRAC (frac.info) resistance management strategies. The intention is to aid in managing the rapid selection of Group 3 fungicide resistance that has been observed in several major grain pathogens in Australia.

Both AFREN and CropLife Australia agree that to reduce Group 3 fungicide selection pressure, a more sustainable practice is to include multiple fungicide groups within a spraying program. If resistance to Group 3 fungicides is suspected, both CropLife and AFREN recommend growers reduce total applications of Group 3 fungicides.

General fungicide resistance management in pulses

Pulses are a mainstream part of Australian cropping systems. Their role in crop rotation, soil health and sustainable agriculture is increasingly recognised, alongside their economic value in global markets. However, as the area under pulse cultivation expands, the incidence of crop diseases and the risk of fungicide resistance may also rise if not carefully controlled through integrated disease management and fungicide resistance management strategies.

As well as the general fungicide resistance management guidelines, AFREN recommends the following additional general strategies for any pulse crops with these other fungicides registered for control:

- **Use multi-site (M3, M5)** fungicides as rotation and mixing partners to reduce selection pressure on single-site fungicides (that is, Groups 1, 2, 3, 7 and 11).
- **Do not** apply more than one application of **Group 1** containing fungicides.
- **Avoid** applying more than one application per growing season of **Group 5, 12 and 13** containing fungicides. If you need to apply them more than once, do not apply them consecutively.

Consider off-target pathogens

It is important to consider the complete suite of target pathogens in a crop when planning fungicide application. The presence of multiple pathogens means there is a potential for indirect fungicide selection in off-target pathogens within and across growing seasons. Follow the general fungicide resistance management guidelines for rotating and mixing fungicide groups to treat multiple diseases at once. This will reduce the fungicide selection pressure on all pathogens.

For example, if you use a Group 3 fungicide to treat Septoria tritici blotch in wheat and subsequently detect wheat powdery mildew in the same crop, do not use the same Group 3 fungicide in a second spray. Instead apply a fungicide mixture that contains a different fungicide group (Group 7 or 11) with a different Group 3 active. This will reduce fungicide selection pressure on both diseases, particularly if there is known fungicide resistance to Group 3 fungicides in wheat powdery mildew in your area.

As a way of avoiding indirect fungicide resistance selection, AFREN recommends not using any fungicides as stand-alone products for any disease.

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.

Photo: CCDM

Fungicide resistance management guidelines – barley

Fungicides – current field performance quick guide

Only diseases of pathogens known to have fungicide resistance or reduced sensitivity in Australia are listed.

Use fungicides strategically for yield improvement. Always consider your local environmental conditions and the susceptibility of the crop variety to the target pathogen before fungicide application. Fewer fungicide applications will likely be required for less-conducive environmental conditions using less-susceptible varieties.

- ✱ Currently effective. No current reports of reduced fungicide efficacy or fungicide failure. Monitor effectiveness.
- ◆ Performance of some registered fungicide actives is reduced in areas of the state. Be selective based on the resistance profile of your specific farm or growing region.
- ▼ Performance of most registered fungicide actives is reduced in areas of the state. Avoid if possible or use only in a mixture.
- ⃠ Performance is ineffective. These fungicide actives are no longer effective for controlling disease in areas of the state.
- **NR** Not registered for this pathogen.
- – Crop not grown or this disease is not considered a concern in this state.

Table 2.1: Current field performance of fungicide groups registered for disease control in barley

	Group 3 (DMI)						Group 7 (SDHI)						Group 11 (QoI)					
	e.g. epoxiconazole, flutriafol, propiconazole, tebuconazole						e.g. fluxapyroxad, bixafen						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 leaf rust	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱

Disclaimers:
Fungicide performance is current at January 2026 and can change if fungicide resistance spreads. Resistance can spread from local to regional levels, and the status of fungicide actives within each fungicide group can vary by location. Farm-level or regional field performance may vary. Check PRIM (prim.ccdm.com.au/) for up-to-date information in your area.

Not all fungicide actives within a fungicide 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 (apvma.gov.au).

Barley powdery mildew

Caused by *Blumeria 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° C to 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 fungal species.

Resistance in Australia

Resistance and reduced sensitivity to Group 3 fungicides

A highly virulent Group 3 tebuconazole-resistant barley powdery mildew outbreak was reported in **WA** in **2010**. The emergence of this resistance was linked to the widespread planting of susceptible barley varieties and repeated use of the same Group 3 fungicide. 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 have been reported in all other states. Without disease and fungicide resistance management, it is highly likely that reduced sensitivity and resistance to Group 3 fungicides will result.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24), other non-chemical control and fungicide use strategies for barley powdery mildew include:

- Consider **grazing** of early sown barley to reduce disease pressure.
- In seasons with high powdery mildew risk, **optimise nitrogen management** without excessively increasing biomass; dense closed canopies favour disease development and prevent fungicide penetration.

Barley powdery mildew.
Photo: Evan Collis

- Fungicide-resistant powdery mildew can spread easily. Consider talking to your neighbours and work towards an **integrated, area-wide management strategy**.
- **Minimise** the use **of Group 3** fungicides known to have compromised efficacy due to resistance. In WA avoid using Group 3 fungicide tebuconazole to control barley powdery mildew since it has been associated with severe resistance outbreaks.
- **Do not** apply more than two applications per growing season of **Group 5 or 13** containing fungicides.
- If you use two applications of **Groups 5 or 13** containing fungicides, **do not** use them consecutively.
- Ideally use **Group 13** fungicides in a **mixture** with an effective fungicide from a different group. Always apply in a mixture with a curative fungicide where disease is established. Where applied alone, only use as a protectant (preventative) treatment.

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 southern Australia and WA. 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 to 50% yield loss and significant reduction in grain quality. NFNB is typically favoured by susceptible hosts, early sowing, mild weather (15° C to 25° C) and extended periods of leaf wetness. It survives between seasons on stubble, volunteer plants and seed.

Resistance in Australia

Resistance and reduced sensitivity to Group 3 fungicides

In **2013**, **WA** was the first state to record reduced efficacy of Group 3 fungicide tebuconazole against isolates of NFNB from the Albany port zone. Reduced sensitivity to Group 3 fungicides became widespread in WA followed by widespread resistance starting in 2017 in the Kwinana West and Esperance port zones.

In **2019**, reduced sensitivity in the southern agricultural region became evident with the first detection of mutations associated with reduced sensitivity to Group 3 fungicides in samples from the Yorke Peninsula, **SA**. This has since spread to the Limestone Coast and Mid North regions and throughout the Eyre Peninsula.

Also in **2019**, mutations for both reduced sensitivity and resistance from samples in the Wimmera Southern Mallee region in **Vic** were detected, which later spread to the Barwon South-West and Central Highlands regions, affecting the Group 3 fungicide propiconazole.

Resistance has not been reported in NSW or Qld, however reduced sensitivity to Group 3 fungicide propiconazole first occurred in the New England region of **NSW** in **2021**, spreading to the Riverina and Central West regions. In south-east **Qld,** reduced sensitivity to Group 3 fungicides was first confirmed in **2022**.

The first incidence of resistance to Group 3 fungicides in **SA** was reported from samples collected in **2023**. Isolates from these samples were shown to be triple mutants (see 'Double and triple mutants' and 'Developments in net blotch fungicide resistance' box page 29).

Resistance and reduced sensitivity to Group 7 fungicides

In **2019**, reduced sensitivity and resistance in NFNB to Group 7 SDHI fungicides were confirmed in **SA**. Reduced sensitivity was first reported from the Limestone Coast region and on the Eyre Peninsula, later spreading to the Mid North region.

At the same time a resistance outbreak to the Group 7 fungicide fluxapyroxad was confirmed on the Yorke Peninsula. This was associated with continuous cropping using predominantly susceptible barley varieties and repeated use of fluxapyroxad. Resistance to Group 7 fungicides has subsequently been reported in Kybybolite on the Victorian border and the Lock and Streaky Bay areas of the Eyre Peninsula.

Net form net blotch (NFNB).
Photo: Linda Thomson, InterGrain

In **2021**, widespread resistance and reduced sensitivity to fluxapyroxad was confirmed in **Vic**, affecting the Barwon South-West, Central Highlands and Wimmera Southern Mallee regions. Reduced sensitivity has also been confirmed in the Loddon Mallee region in 2023.

Reduced sensitivity and resistance to fluxapyroxad was also reported in **WA** in **2021**, in the Albany port zone. Reduced sensitivity has since been detected in the Esperance and Kwinana West port zones.

Laboratory testing detected mutations associated with reduced sensitivity and resistance in **NSW** in **2021** and 2023 respectively and in **Qld** since **2022**. The mutations in NFNB isolates are present in the Orana and Riverina regions of NSW and Darling Downs in Qld.

Reduced sensitivity to Group 11 fungicides

A mutation known as F129L, widespread in Europe and known to reduce the effectiveness of Group 11 fungicides such as azoxystrobin, was first detected in Australia in **2022** in NFNB isolates from the Yorke Peninsula, **SA**. This heralded the first time that all three fungicide groups available for the control of NFNB were affected by fungicide resistance or reduced sensitivity in Australia.

The mutation does not lead to full QoI resistance in NFNB, leading researchers to believe it was highly probable that the mutation was undetected elsewhere. This was subsequently confirmed by detection of the mutation in NFNB isolates from the Central Highlands region of **Vic** collected in **2023** and laboratory confirmation of these mutations in double and triple NFNB mutants from **SA, Vic** and **WA** (see below and 'Developments in net blotch fungicide resistance' box).

Double and triple mutants

The first laboratory detection of a **double mutant** NFNB isolate with mutations associated with reduced sensitivity to both the Group 3 fungicide tebuconazole and Group 7 fungicide fluxapyroxad, was from the Kwinana West port zone of **WA** in **2020**. Since then, reports of reduced fungicide efficacy and failure associated with double mutants have been found in **SA, Vic** and **WA.**

Following the first laboratory detection in SA in 2022, of the F129L mutation known to be associated with QoI reduced sensitivity in NFNB isolates, this mutation has subsequently been detected in conjunction with mutations for both Group 3 DMI and Group 7 SDHI fungicides within the same isolates. These **triple mutant isolates** from the Yorke Peninsula in **SA** and South Stirling in **WA** were associated with reports of failure to control NFNB disease in the very susceptible barley varieties RGT Planet$^{\Phi}$ and Zena$^{\Phi}$ in **2023**. A single triple mutant isolate was also detected from Streatham **Vic**, though no associated deficiency in fungicide efficacy was reported.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) other non-chemical control and fungicide use strategies for NFNB include:

- If **triple mutants** are present in your area, it is highly likely that fungicide efficacy will be limited. The best line of defence is to **avoid S and VS varieties** of barley.
- **Minimise** use of **Group 3, 7 and 11** fungicides that are known to have compromised efficacy due to resistance.
- **Do not use Group 7** fungicides for NFNB control in paddocks where high levels of resistance to this group of fungicides have been reported.
- **Avoid** use of **Group 11** fungicides for NFNB control in areas where resistance to this group of fungicides has been reported.

Developments in net blotch fungicide resistance

Fungicide-resistant barley net blotch hybrid

A barley net blotch hybrid highly resistant to the Group 3 (DMI) fungicides epoxiconazole and propiconazole was detected in samples collected in the Albany and Esperance port zones of WA in 2017. Laboratory studies showed that hybrids carry 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.

Triple mutant isolates of net form net blotch in barley

NFNB isolates with mutations for resistance and reduced sensitivity to all three registered fungicide groups used for control of NFNB disease (Groups 3, 7 and 11) have been discovered in SA, Vic and WA. Fungicides are highly likely to be severely limited for controlling high disease situations of these NFNB triple mutant populations.

Non-chemical control strategies to limit disease pressure are the best defence against these triple mutants. The two most important strategies are to avoid S and VS barley varieties and rotate crops. Do not plant barley on barley stubble and rotate barley varieties with different resistance statuses to avoid the breakdown of varietal resistance.

Implement robust IDM strategies

These developments in net blotches of barley are 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.

Growers should continue to follow the general recommended fungicide resistance management strategies, and any additional recommendations for NFNB and SFNB, to keep disease and fungicide resistance pressure low to reduce the impact of naturally evolving net blotch populations.

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 where barley is sown into barley stubble. Severe infections can cause 10 to 45% yield loss and significant reduction in grain quality. SFNB is typically favoured by susceptible hosts, mild weather (15° C to 25° C) and extended periods of leaf wetness. It survives between seasons on stubble.

Resistance in Australia

Resistance and reduced sensitivity to Group 3 fungicides

WA was the first state where reduced sensitivity to Group 3 fungicides in SFNB isolates was confirmed. Initial detections occurred in the Kwinana North port zone in **2015**, followed by widespread reduced sensitivity observed across the Esperance, Kwinana West and Kwinana East port zones.

The first cases of resistance to Group 3 fungicides in SFNB were confirmed in the Albany and Esperance port zones of **WA** in **2017**. Widespread fungicide resistance in SFNB is now evident throughout WA growing regions.

Currently **Vic** is the only other state where reduced sensitivity to Group 3 fungicides is confirmed with reduction in Group 3 fungicide efficacy reported in the Wimmera Southern Mallee region against SFNB since **2021**.

Laboratory detections of mutations for reduced sensitivity to Group 3 fungicides in SFNB was first detected in the Mid North region of **SA** in **2022** and in the Riverina, North-West Slopes and New England regions of **NSW** in **2023**.

Laboratory detections of resistance to Group 3 fungicides in SFNB were first detected in isolates from the Wimmera region in **Vic** in **2022** and the Western Downs and Toowoomba regions of **Qld** in **2023**. Isolates were able to grow *in vitro* at the highest discriminatory dose of Group 3 fungicides epoxiconazole and propiconazole.

Resistance and reduced sensitivity to Group 7 fungicides

In **2020**, near Cunderdin in the Kwinana West port zone of **WA**, the first reported cases of resistance and reduced sensitivity to Group 7 fungicides in SFNB were associated with continuous barley and repeated fluxapyroxad use.

Reduced sensitivity to Group 7 fungicides has also been observed in the Western Downs region of **Qld** in **2022**, associated with mutations in SFNB isolates from this area.

Laboratory detections of mutations for reduced sensitivity to Group 7 fungicides were confirmed in SFNB isolates from the North-West Slopes region of **NSW** in **2023**.

Spot form net blotch (SFNB).
Photo: CCDM

Reduced sensitivity to Group 11 fungicides

The F129L mutation known to reduce the effectiveness of Group 11 fungicides such as azoxystrobin was confirmed in **2024** in SFNB isolates from the Yorke Peninsula, **SA**. This is the first detection of a mutation associated with this fungicide group in SFNB isolates in Australia. Reduced fungicide efficacy has currently not been observed.

Double mutants

When resistance to Group 7 fungicide fluxapyroxad was confirmed in Cunderdin, WA in 2020, SFNB isolates from this region were also tested to determine their sensitivity to Group 3 fungicides. Results indicated these isolates had dual reduced sensitivity to Group 3 DMI fungicides and resistance to Group 7 SDHI fungicides. The field implications of this are unclear considering the widespread reduced sensitivity and resistance to Group 3 fungicides since 2015 and 2017, respectively. It is likely that fungicide mixtures of these two groups will not be as effective under high disease pressure scenarios.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) additional fungicide use strategies for SFNB include:

- **Minimise** use of **Group 3 and 7** fungicides that are known to have compromised efficacy due to resistance.
- **Do not use Group 7** fungicides for SFNB control in paddocks where high levels of resistance to this group of fungicides have been reported.

Barley leaf rust

Caused by *Puccinia hordei*

Introduction

The pathogenic fungus that causes barley leaf rust is of concern as it can spread rapidly over vast distances. Rust-infected crops produce billions of microscopic spores that are highly adapted to wind dispersal. Early infections of leaf rust can result in significant yield losses.

Infection is favoured by moist conditions with temperatures around 15° C to 20° C. Crops sown early when nights are still warm are often more severely infected.

Unlike other cereal rust pathogens, in some parts of Australia the barley leaf rust pathogen can survive between seasons by infecting its alternate host, the winter-flowering bulb Star of Bethlehem (*Ornithogalum umbellatum*). Sowing barley into paddocks where Star of Bethlehem is present is not recommended. This plant is a common weed in some areas of the Yorke Peninsula in SA and in Victoria, Tasmania and WA.

Resistance in Australia

Lab detections for changes in sensitivity to Group 3 fungicides
Lab detections of changes in sensitivity to Group 3 fungicide tebuconazole are known to be present in *Puccinia hordei* isolates in all states of Australia. Tebuconazole is not registered for barley leaf rust control. Currently, there have been no known field failures to other Group 3 fungicides used to control barley leaf rust, but consideration needs to be given to the use of Group 3 DMIs as the rust pathogen continues to show an ability to change and adapt.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) other non-chemical control and fungicide use strategies for barley leaf rust include:

- **Eliminate** the green bridge. All volunteer barley and weeds, particularly **Star of Bethlehem**, should be removed at least four weeks before seeding. Rust does not survive on seed, stubble or soil.
- **Minimise** use of **Group 3** fungicides known to have compromised efficacy due to resistance.

Barley leaf rust.
Photo: Evan Collis Photography

Photo: CCDM

Fungicide resistance management guidelines – wheat

Fungicides – current field performance quick guide

Only diseases of pathogens with known mutations conferring fungicide resistance or reduced sensitivity in Australia are listed.

Use fungicides strategically for yield improvement. Always consider your local environmental conditions, and the susceptibility of the crop variety to the target pathogen before fungicide application. Fewer fungicide applications will likely be required for less-conducive environmental conditions using less-susceptible varieties.

- ✱ Currently effective. No current reports of reduced fungicide efficacy or fungicide failure. Monitor effectiveness.
- ◆ Performance of some registered fungicide actives is reduced in areas of the state. Be selective based on the resistance profile of your specific farm or growing region.
- ▼ Performance of most registered fungicide actives is reduced in areas of the state. Avoid if possible or use only in a mixture.
- ⊘ Performance is ineffective. These fungicide actives are no longer effective for controlling disease in areas of the state.
- **NR** Not registered for this pathogen.
- – Crop not grown or this disease is not considered a concern in this state.

Table 2.2: Current field performance of fungicide groups registered for disease control in wheat

	Group 3 (DMI)						Group 7 (SDHI)						Group 11 (QoI)					
	e.g. epoxiconazole, flutriafol, propiconazole, tebuconazole						e.g. fluxapyroxad, bixafen						e.g. azoxystrobin, pyraclostrobin					
	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA	NSW	Qld	SA	Tas	Vic	WA
Wheat powdery mildew	▼	▼	▼	▼	▼	✱	✱	✱	✱	✱	✱	✱	⊘	⊘	⊘	⊘	⊘	✱
Septoria tritici blotch	◆	–	◆	◆	◆	–	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱

Disclaimers:
Fungicide performance is current at January 2026 and can change if fungicide resistance spreads. Resistance can spread from local to regional levels, and the status of fungicide actives within each fungicide group can vary by location. Farm-level or regional field performance may vary. Check PRIM (prim.ccdm.com.au/) for up-to-date information in your area.

Not all fungicide actives within a fungicide 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 (apvma.gov.au).

Wheat powdery mildew

Caused by *Blumeria graminis*

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° C to 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 species, so are crop specific.

Resistance in Australia

Resistance to Group 3 fungicides

First reported in **Tasmania** in **2015**, fungicide resistance in wheat powdery mildew to Group 3 fungicide actives tebuconazole, propiconazole and prothioconazole is widespread in all states of Australia except WA. The first fungicide resistance outbreak occurred in **NSW** and **Vic** in **2020**, where widespread wheat powdery mildew resistance to Group 3 fungicides was reported. This quickly spread to **SA** and southern **Qld**, most likely by wind-borne spores.

In **WA**, a gateway mutation has been detected in laboratory screening of isolates from Esperance in **2024**. This is the first of a series of mutations that are associated with the development of resistance. A gateway mutation does not result in relevant reduced sensitivity or resistance in wheat powdery mildew on its own. However, the presence of these mutations indicates the probability that further mutations resulting in resistance to Group 3 fungicides can develop under high disease pressure and repeated use of the same fungicide group.

This is the same trend that was observed in other states, where emergence of resistance was likely the result of high disease pressure in high-rainfall growing areas, combined with the repeated use of the limited fungicides that were registered for the pathogen at the time – only Group 3 and Group 11 fungicides.

Resistance to Group 11 fungicides

The first lab detection of isolates resistant to Group 11 fungicide actives azoxystrobin and pyraclostrobin was in samples collected from **NSW** in **2015**. Subsequent failure of Group 11 fungicides in **Tas** and **Vic** to control wheat powdery mildew was reported in **2016**. Resistance outbreaks have been reported in NSW, Vic and SA indicating resistance to Group 11 QoI fungicides is now widespread in all states of Australia except WA. No mutations associated with resistance to Group 11 fungicides have been detected in WA.

Wheat powdery mildew.
Photo: CCDM

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) other non-chemical control and fungicide use strategies for wheat powdery mildew include:

- Consider **grazing** of early sown wheat to reduce disease pressure.
- In seasons with high powdery mildew risk, **optimise nitrogen management** without excessively increasing biomass. Dense, closed canopies favour disease development and prevent fungicide penetration.
- **Minimise** use of **Group 3** fungicides known to have compromised efficacy due to resistance.
- **Avoid** use of **Group 11** fungicides in areas where resistance to this group of fungicides has been reported.

Emergency permits for wheat powdery mildew

In 2023, due to a severe outbreak of DMI and QoI resistance in wheat powdery mildew across several regions of the eastern states, three new mildew-specific fungicides – metrafenone (Group 50), quinoxyfen (Group 13) and proquinazid (Group 13) – were approved under an emergency permit for the control of wheat powdery mildew disease. The high specificity of these active ingredients means that they will have a limited impact on other diseases.

The permits for these fungicides have been extended to 31 May 2027 (metrafenone permit number PER93198 and proquinazid PER93216) and 30 June 2027 (quinoxyfen PER93197). Growers are advised to check with APVMA before proceeding.

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° C to 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.

Resistance in Australia

Reduced sensitivity to Group 3 fungicides

Isolates of Septoria tritici blotch showing reduced sensitivity to Group 3 fungicides were first detected in **Tas** and **Vic** in **2011**, and **NSW** and **SA** in **2014**. High levels of reduced sensitivity are currently found across these states.

In Tas, triadimefon and cyproconazole may be less effective control options. Field data indicates that cyproconazole is not compromised in the high-rainfall zones of SA and Vic currently. All triazoles are affected to some extent.

Resistance to Group 11 fungicides

Laboratory detections of target-site mutations for resistance to Group 11 fungicides were first reported in isolates of *Zymoseptoria tritici* from **SA** in **2020** and **Tas** in **2022**. This mutation can be found at high frequencies in Tas, where it is widespread, while in SA it is limited to the south-east region. Field failure is yet to be associated with detected mutations.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) other non-chemical control and fungicide use strategies for Septoria tritici blotch include:

- Consider **grazing** of early sown wheat to reduce disease pressure.
- **Minimise** use of **Group 3** fungicides known to have compromised efficacy due to resistance.

Septoria tritici blotch.
Photo: Andrew Milgate, NSW DPIRD

Photo: GRDC

Fungicide resistance management guidelines – canola

Fungicides – current field performance quick guide

Only diseases of pathogens with known mutations conferring fungicide resistance or reduced sensitivity in Australia are listed.

Use fungicides strategically for yield improvement. Always consider your local environmental conditions and the susceptibility of the crop variety to the target pathogen before fungicide application. Fewer fungicide applications will likely be required for less-conducive environmental conditions using less-susceptible varieties.

- ✱ Currently effective. No current reports of reduced fungicide efficacy or fungicide failure. Monitor effectiveness.
- ◆ Performance of some registered fungicide actives is reduced in areas of the state. Be selective based on the resistance profile of your specific farm or growing region.
- ▼ Performance of most registered fungicide actives is reduced in areas of the state. Avoid if possible or use only in a mixture.
- ⃠ Performance is ineffective. These fungicide actives are no longer effective for controlling disease in areas of the state.
- **NR** Not registered for this pathogen.
- – Crop not grown or this disease is not considered a concern in this state.

Table 2.3: Current field performance of fungicide groups registered for disease control in canola

	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	◆	✱	◆	✱	◆	◆	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱

	Group 12					
	e.g. fludioxonil, phenylpyrrole					
	NSW	Qld	SA	Tas	Vic	WA
Blackleg	✱	✱	✱	✱	✱	✱

Disclaimers:
Fungicide performance is current at January 2026 and can change if fungicide resistance spreads. Resistance can spread from local to regional levels, and the status of fungicide actives within each fungicide group can vary by location. Farm-level or regional field performance may vary.

Not all fungicide actives within a fungicide 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 (apvma.gov.au).

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 (March–May; > 100 mm), susceptible cultivars, and extended periods of leaf wetness (> 48 h). It can cause yield losses of 50 to 90% in conducive years. It is a stubble-borne disease and spores are spread from stubble remaining from the previous season.

When seedlings are infected, the disease progresses from cotyledons and stems into the crown of the plant causing damage within the plant's vascular system, forming crown canker. Infection later in the season, referred to as 'upper canopy infection', results in upper stem lesions, infected branches, flower infection and abortion of complete flower heads, leading to missing pods.

Resistance in Australia

Reduced sensitivity to Group 3 fungicides

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. **Since 2014**, reduced sensitivity to the fungicides fluquinconazole, flutriafol, prothioconazole and tebuconazole has been identified across **all canola growing regions**. The risk of blackleg populations developing resistance to a range of Group 3 fungicides is high.

Reduced sensitivity to Group 7 fungicides

In **2024**, laboratory detection of resistance to Group 7 SDHI fungicides in the blackleg fungus was reported for the first time in samples from the Eyre Peninsula in **SA**. No associated reduction in sensitivity or failure to SDHI fungicides in the field has been documented.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) other non-chemical control and fungicide use strategies for blackleg include:

- Grow canola at least **500 m away** from the previous season's canola **stubble**.
- Be aware that stubble destruction is generally not effective in reducing blackleg infection.

Blackleg fungal infection in canola.
Photo: Steve Marcroft, Marcroft Grains Pathology

- Consult the Blackleg Management Guide, BlacklegCM or UCI BlacklegCM apps to determine individual paddock risk for blackleg (see Further information).
- **Minimise** use of **Group 3** fungicides known to have compromised efficacy due to resistance.
- **Plan** fungicide rotations considering both blackleg and Sclerotinia together to manage fungicide resistance, as these diseases are often managed concurrently. **Consider** not using **Group 3** fungicides as stand-alone products as a way of avoiding indirect selection for fungicide resistance.
- **Avoid** applying more than one application per growing season of **Group 12** containing fungicides. This includes 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 12** containing fungicides.
- If you use two applications of **Group 12** containing fungicides, **do not** use them consecutively.
- **Do not** apply fungicide after 50% bloom.

Photo: CCDM

Fungicide resistance management guidelines – pulses

Fungicides – current field performance quick guide

Only diseases of pathogens with known mutations conferring fungicide resistance or reduced sensitivity in Australia are listed.

Use fungicides strategically for yield improvement. Always consider your local environmental conditions and the susceptibility of the crop variety to the target pathogen before fungicide application. Fewer fungicide applications will likely be required for less-conducive environmental conditions using less-susceptible varieties.

A variety of fungicide groups are registered for control of some or all pulse diseases, including Groups 1, 2, 3, 5, 7, 11, 12, 13 and the multi-site groups M3 and M5. Currently there has been no detection of mutations or reduction in fungicide efficacy in vitro *associated with reduced sensitivity or resistance to any other fungicide group in Australia, other than those listed in the table.*

- ✱ Currently effective. No current reports of reduced fungicide efficacy or fungicide failure. Monitor effectiveness.
- ◆ Performance of some registered fungicide actives is reduced in areas of the state. Be selective based on the resistance profile of your specific farm or growing region.
- ▼ Performance of most registered fungicide actives is reduced in areas of the state. Avoid if possible or use only in a mixture.
- ⊘ Performance is ineffective. These fungicide actives are no longer effective for controlling disease in areas of the state.
- **NR** Not registered for this pathogen.
- – Crop not grown or this disease is not considered a concern in this state.

Table 2.4: Current field performance of fungicide groups registered for disease control in pulses

	Group 3 (DMI)						Group 7 (SDHI)						Group 11 (QoI)					
	e.g. 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
Ascochyta blight of lentils	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱
Botrytis grey mould of chickpea	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱	✱
Mungbean powdery mildew	✱	▼	✱	✱	✱	✱	NR	NR	NR	NR	NR	NR	✱	▼	✱	✱	✱	✱

	Group 1 (MBC)					
	e.g. thiabendazole to carbendazim					
	NSW	Qld	SA	Tas	Vic	WA
Ascochyta blight of lentils	✱	✱	✱	✱	✱	✱
Botrytis grey mould of chickpea	✱	✱	✱	✱	✱	✱
Mungbean powdery mildew	NR	NR	NR	NR	NR	NR

Disclaimers: *Fungicide performance is current at January 2026 and can change if fungicide resistance spreads.*

Resistance can spread from local to regional levels, and the status of fungicide actives within each fungicide group can vary by location. Farm-level or regional field performance may vary.

Not all fungicide actives within a fungicide 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 (apvma.gov.au).

Ascochyta blight of lentils

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

Introduction

Ascochyta blight 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 including leaves, stems and pods, and is often inconspicuous, relying on close inspection to detect it. Ascochyta blight is favoured by prolonged cool and wet conditions (5° C to 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 typically via rain splash surviving on stubble and self-sown plants, and from infected seed.

Resistance in Australia

Resistance to Group 1 fungicides

Ascochyta blight of lentils isolates resistant to the Group 1 fungicide thiabendazole were first detected in lentil samples from **SA** in **2010** and 2011, and again in field samples collected in 2022. Thiabendazole is registered for use in a seed treatment mixture with the multi-site Group M3 fungicide thiram, and currently still effectively controls Ascochyta blight in lentils in SA.

Resistance to Group 11 fungicides in Ascochyta blight has been documented overseas, which is a reminder that this pathogen may be capable of developing resistance to different fungicides in Australian pulse crops.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) other non-chemical control and fungicide use strategies for Ascochyta blight of lentils include:

- Use a minimum **three-year break** between lentil crops. Sowing into standing stubble of a previous cereal crop can protect against rain splash of soil-borne spores.
- **Sow at least 250 m away** from other lentil, faba bean, chickpea or vetch crops, or their stubble.
- **Plant wider rows** (> 66 cm) to encourage airflow and reduce humidity.
- **Be aware** that seed treatments with fungicides will have a deleterious effect on rhizobia.

Ascochyta blight of lentils.
Photo: Rohan Kimber, SARDI

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. It has a wide host range, across a number of horticultural crops and multiple pulse species. This wide host range, combined with its capacity to survive on dead plant material, means 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° C to 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 to 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 in Australia

Resistance to Group 1 fungicides

An isolate of chickpea Botrytis grey mould with a mutation associated with resistance to the Group 1 fungicide thiabendazole was detected amongst samples collected from Kingsford in **SA** in **2003**. The use of Group 1 fungicides against *Botrytis* species infecting pulses in SA has been common practice, including in seed dressings mixed with the multi-site fungicide thiram. The presence of this resistance in states other than SA has not been recorded.

Research on fungicide resistance in pulses is limited. However, research on fungicide resistance in *Botrytis cinerea* infecting horticultural crops has shown extensive resistance to numerous fungicide groups, including groups registered for control in pulses. *Botrytis cinerea*'s wide host range means any resistance in isolates from horticultural crops will exhibit the same resistance in pulses if spores spread between the farming systems.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) other non-chemical control strategies for Botrytis grey mould of chickpeas include:

- Use a minimum **three-year break** between chickpea or other pulse crops.
- **Sow at least 500 m away** from other chickpea or pulse crops, or their stubble.
- **Plant wider rows** (> 66 cm) to encourage airflow and reduce humidity.
- **Be aware** that seed treatments with fungicides will have a deleterious effect on rhizobia.

Botrytis grey mould of chickpeas.
Photo: GRDC

Mungbean powdery mildew

Caused by *Podosphaera xanthii* and *Erysiphe vignae*

Introduction

Powdery mildew is the most common disease of mungbean in all areas of production across Australia. All mungbean cultivars grown in Australia have some degree of susceptibility to powdery mildew. The causal agents infect all green tissues of the crop, and especially the leaves and stems. The pathogens are spread solely by short-lived, airborne spores. The host ranges of the two fungal species that cause powdery mildew on mungbean are not known, but it is likely that they survive on alternative hosts, including weeds, and on volunteer mungbean plants.

The disease is favoured by milder temperatures (22° C to 26° C) and higher humidity values; therefore, it mostly develops at the end of the summer season. The most damaging epidemics are those that start before flowering. Therefore, planting mungbean early in the summer season may help reduce the economic losses caused by powdery mildew. Disease can cause up to 40% yield loss if the epidemic starts before flowering, the environmental conditions are conducive to the disease, and if no management strategies are applied. The disease may also have an impact on crop desiccation.

Resistance in Australia

Reduced sensitivity to Group 3 fungicides

The first Group 3 fungicide target-site mutation in a mungbean powdery mildew isolate of *P. xanthii* was found in experimental plants in **Qld** in **2022**. Reduced sensitivity to Group 3 fungicide tebuconazole was confirmed in replicated field trials in 2023 and 2024 in Formartin, Kingaroy, Kingsthorpe, Toowoomba and Tummaville.

Resistance and reduced sensitivity to Group 11 fungicides

Since **2019**, a well-characterised mutation associated with resistance to Group 11 azoxystrobin has been consistently identified in powdery mildew isolates (both *P. xanthii* and *E. vignae*) from mungbean paddocks across **Qld**. Azoxystrobin is always applied in a mixture with Group 3 fungicide tebuconazole. Reduced sensitivity to this combination was confirmed in the same replicated field trials where reduced sensitivity to tebuconazole alone was detected.

Mungbean powdery mildew.
Photo: Kirsty Owen, University of Southern Queensland

Currently, only Group 3 tebuconazole either alone or in combination with Group 11 azoxystrobin fungicides are registered for the control of mungbean powdery mildew, so it is imperative that other disease management strategies are implemented, to limit the impact of this emerging threat.

Additional resistance management strategies

In addition to the general fungicide resistance management guidelines (page 22–24) other non-chemical control strategies for mungbean powdery mildew include:

- **Sow seed early** in the summer season to ensure flowering occurs before the peak period of pathogen abundance, which typically develops later in summer.

Further information

Resistance and resistance management in Australian grain crops

GRDC Groundcover Supplement: **Fungicide resistance – Navigating the storm**, Issue 168: January–February 2024.
Available at: groundcover.grdc.com.au/grdc-groundcover-supplement?supp=fungicide-resistance---navigating-the-storm,-january-february-2024

GRDC has invested in the Australian Fungicide Resistance Extension Network (AFREN) since 2019, led by Associate Professor Fran Lopez-Ruiz of Curtin University. This Groundcover Supplement showcases the achievements of AFREN thus far and shines a spotlight on new fungicide-related research underway at Curtin University's Centre for Crop and Disease Management (CCDM).

Select articles: available at the above URL

Foxx. **Fungicide resistance – a mounting problem in Australia.**

Knights. **Fungicide resistance in Queensland: be alert.**

Knights. **Knowledge is power when managing fungicide resistance in pulses.**

Krige. **The AFREN creed.**

Lopez-Ruiz. **From the shelf to field failure: factors driving fungicide resistance.**

Pratt and Galloway. **Decision support tools aid disease management decisions.**

Zulak and Knight. **'Next-gen' monitoring improving fungicide resistance detection.**

GRDC Groundcover Supplement: **Resistance in Weeds, Pests and Diseases**, Issue 139: March–April 2019.
Available at: 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

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

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

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

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

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

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

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

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

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

Fungicide resistance

CropLife Australia, **Fungicide resistance management strategies**. Available at: croplife.org.au/resources/programs/resistance-management/

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

FRAG UK 2024 **Fungicide resistance management in cereals**. Available at: 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 transferable, and provide alarming case studies of how widespread and damaging fungicide resistance can be.

Fungicide Resistance Action Committee. Available at: 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 and so on) 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, **Combined fungicide resistance risk**. Available at: cropscience.bayer.ca/articles/2020/combined-fungicide-resistance-risk

See how Canadian growers are being advised to assess their risk of fungicide resistance developing on farm. Many of the lessons are transferable – 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: 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: 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. Available at: 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 GrowNotes series offers a plethora of information for you to explore to ensure you're growing the best crop you can.

Glossary

Active/active constituent	The individual chemical component(s) of a formulation. See also Fungicide active.
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)	Group 3 fungicides. Commonly referred to as azoles. See Fungicide groups 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 (that is, sensitive, reduced sensitivity or resistant fungal isolates). See Fungicide resistance terminology and Appendix A: Fungicide resistance in the laboratory for further detail.
Disease	The expression of symptoms that negatively affect yield and/or quality of a crop, for example, 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 laboratory 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.
Fungicide active	The individual chemical component(s) of a formulation, synonymous with the common name, for example, epoxiconazole, fluxapyroxad or azoxystrobin.
Fungicide group	The different chemical classes, designated by a number indicating the specific site of activity (the target site) that is inhibited in the biochemical process. All fungicide actives in the same group will inhibit the same target site (for example, Group 3 fungicides known as demethylase inhibitors (DMIs) target C14-demethylase to inhibit sterol biosynthesis). See FRAC for more information on different fungicide groups.
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 (for example, 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 (that is, through EC_{50} or discriminatory dose trials) or genetic evidence of resistance mechanisms that 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	The biochemical process that is inhibited by the fungicide (for example, Group 3 fungicides inhibit sterol biosynthesis in pathogen membranes and Groups 7 and 11 both inhibit pathogen respiration). See FRAC for more information on different modes of action.
Multiple resistance (e.g. dual resistance)	When an organism possesses two or more resistance mechanisms to one or more fungicide 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, for example, fungus, bacterium or nematode, that infects a plant to cause disease.
Quinone outside inhibitors (QoIs)	Group 11 fungicides, commonly referred to as strobilurins. See Fungicide groups 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	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. Note: When discussing fungicide resistance, the term 'Resistance' is often used as a broad, general descriptor for any change in sensitivity to a fungicide. This includes situations involving true resistance, reduced sensitivity, or field failure.
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.
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)	Group 7 fungicides. See Fungicide groups 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 laboratory 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	Group 11 fungicides. The common term for quinone outside inhibitors (QoIs). See Fungicide groups 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 laboratory

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 3). 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.

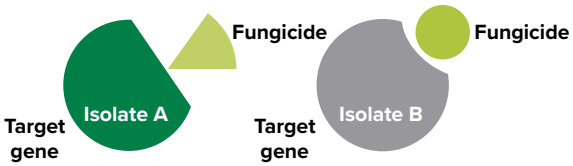
Other mechanisms for resistance can also occur. Target sites may also be overexpressed, or increased in copy number, making it more difficult for the fungicide to control the target pathogen.

Years of research have also uncovered what are referred to as ‘gateway mutations’, which are mutations 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.

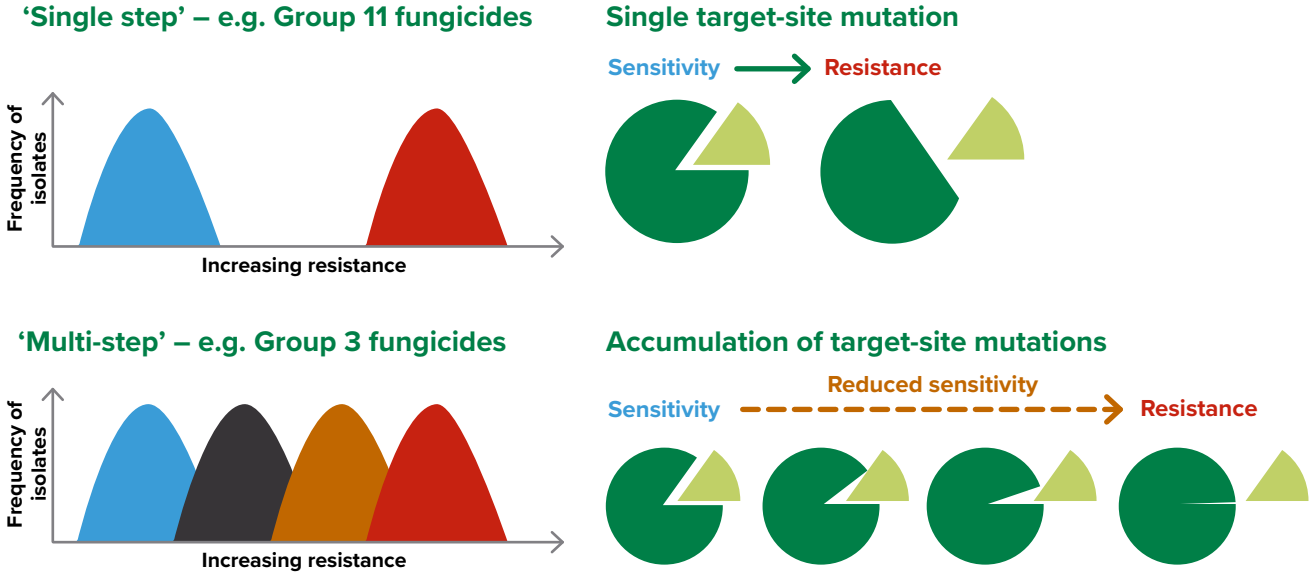
Table 3: Molecular mechanisms of fungicide resistance currently known to occur in pathogens of Australian grain crops. Figures illustrate the relationship between the target gene in the fungus (dark green and grey) and fungicide (light green). Examples of fungicide resistance cases (diseases and fungicide group) with different levels of sensitivity/resistance are provided in the final column

Mechanism	Resistance association in Australian grain crop diseases (examples)	
Single target-site mutation 	**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
	Resistance	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 group	
	Reduced sensitivity	Septoria tritici blotch – Group 3
	Reduced sensitivity to **Resistance**	Barley powdery mildew – Group 3
Multiple target-site mutations, within a population 	Multiple target sites – resistance to multiple fungicide classes	
	Reduced sensitivity to **Resistance**	Net form net blotch – Group 3 and Group 7
Target-site overexpression 	**Reduced sensitivity**	Spot form net blotch – Group 3 Blackleg – Group 3 Wheat powdery mildew – Group 3
Mixed mechanisms		
Target-site mutation + gene overexpression 	**Resistance**	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 green) and fungicide (light green)



[1] Modified from Lucas et al. (2015) and Georgopoulos and Skylakakis (1986). Lucas JA, Hawkins NJ and Fraaije BA (2015) 'The evolution of fungicide resistance', in Sariaslani S and Gadd GM (eds) *Advances in Applied Microbiology*, 90:29–92. Georgopoulos SG and Skylakakis G (1986) 'Genetic variability in the fungi and the problem of fungicide resistance', *Crop Protection*, 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 (apvma.gov.au) and should be consulted for up-to-date information relevant to your specific state.

Recommended fungicide rotations – barley

The fungicide rotation option is determined by choice of fungicide used for seed dressing or in-furrow applications. Once a rotation option is determined, make the first foliar selection from your chosen rotation option irrespective of the disease being treated. If multiple formulations are applied together on seed/in furrow (for example, Group 3 seed treatment applied with Group 4 + 11 in-furrow at seeding), consider the first foliar spray selection of both rotation options.

Take into consideration the risk profiles of the fungicide groups (see fungicide groups section, page 11) and the fungicide resistance management guidelines (general page 22–24, barley page 26–31).

Note: Group 5 fungicide spiroxamine and Group 13 fungicides proquinazid and quinoxyfen are only registered to target barley powdery mildew.

Table 4: Recommended fungicide rotation options for barley crops

Application stage and rotation selections		Fungicide rotation options						
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Seed/in-furrow		None	3^	3^ + 4	4 + 7* + 3^	4 + 11	7*	M3 + 7*
First foliar spray selections	Selection 1	None	None	None	None	None	None	None
	Selection 2	3	7 + 3	3	3	3	3	3
	Selection 3	7 + 3	11 + 3	7 + 3	7 + 3	7 + 3	7 + 3	7 + 3
	Selection 4	11 + 3		11 + 3	11 + 3		11 + 3	11 + 3
For barley powdery mildew only	Selection 5	5	5	5	5	5	5	5
	Selection 6	13	13	13	13	13	13	13

Table 4a: Additional fungicide rotation options for barley crops if required

Application stage and fungicide selections		Immediately prior application contains				
		3^	7 + 3^	11 + 3^	5	13
Second foliar spray selections	Selection 1	7 + 3	11 + 3	3	3	3
	Selection 2	11 + 3	3	7 + 3	7 + 3	7 + 3
	Selection 3				11 + 3	11 + 3
For barley powdery mildew only	Selection 4	5	5	5	13	5
	Selection 5	13	13	13		

^ Avoid using the same Group 3 fungicide active more than once per season; do not use the same Group 3 fungicide active consecutively.

* 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

The fungicide rotation option is determined by choice of fungicide used for seed dressing or in-furrow applications. Once a rotation option is determined, make the first foliar selection from your chosen rotation option irrespective of the disease being treated. If multiple formulations are applied together on seed/in furrow (for example, Group 3 seed treatment applied with Group 4 + 11 in-furrow at seeding), consider the first foliar spray selection of both rotation options.

Take into consideration the risk profiles of the fungicide groups (see fungicide groups section, page 11) and the fungicide resistance management guidelines (general page 22–24, wheat page 33–35).

Note: Group 13 fungicides proquinazid and quinoxyfen and Group 50 fungicide metrafenone are only registered to target wheat powdery mildew.

Table 5: Recommended fungicide rotation options for wheat crops

Application stage and fungicide selections		Fungicide rotation options					
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Seed/in-furrow		None	3^	3^ + 4	4 + 7* + 3^	4 + 11	7*
First foliar spray selections	Selection 1	None	None	None	None	None	None
	Selection 2	3	7 + 3	3	3	3	3
	Selection 3	7 + 3	11 + 3	7 + 3	7 + 3	7 + 3	7 + 3
	Selection 4	11 + 3		11 + 3	11 + 3		11 + 3
For wheat powdery mildew only	Selection 5	13	13	13	13	13	13
	Selection 6	50	50	50	50	50	50

Table 5a: Additional fungicide rotation options for barley crops if required

Application stage and fungicide selections		Immediately prior application contains				
		3^	7 + 3^	11 + 3^	13	50
Second foliar spray selections	Selection 1	7 + 3	3	3	3	3
	Selection 2	11 + 3	11 + 3	7 + 3	7 + 3	7 + 3
	Selection 3				11 + 3	11 + 3
For wheat powdery mildew only	Selection 4	13	13	13	13	3
	Selection 5	50	50	50		

^ Avoid using the same Group 3 fungicide active more than once per season; do not use the same Group 3 fungicide active consecutively.

* 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

The fungicide rotation option is determined by choice of fungicide used for seed dressing or in-furrow applications. Once a rotation option is determined, make the first foliar selection from your chosen rotation option irrespective of the disease being treated. If multiple formulations are applied together on seed/in furrow (for example, Group 3 seed treatment applied with Group 4 + 11 in-furrow at seeding), consider the first foliar spray selection of both rotation options.

Take into consideration the risk profiles of the fungicide groups (see fungicide groups section, page 11) and the fungicide resistance management guidelines (general page 22–24, canola page 37–38).

Consult BlacklegCM or UCI BlacklegCM apps to determine individual paddock risk for blackleg before fungicide application. Do not apply fungicide after 50% bloom.

Table 6: Recommended fungicide rotation options for canola crops

Application stage and fungicide selections		Fungicide rotation options						
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Seed/in-furrow		None	3^	3^ + 4	4 + 7* + 3^	4 + 11	4 + 12	7*
First foliar spray selections#	Selection 1	None	None	None	None	None	None	None
	Selection 2	3	7 + 3	3	3	3	3	3
	Selection 3	7 + 3	11+3	7 + 3	7 + 3	7 + 3	7 + 3	7 + 3
	Selection 4	11 + 3		11 + 3	11 + 3		11 + 3	11 + 3
	Selection 5	7 + 12		7 + 12	7 + 12			7 + 12

Table 6a: Additional fungicide rotation options for canola crops if required

Application stage and fungicide selections		Immediately prior application contains			
		3^	7 + 3^	11 + 3^	7 + 12
Second foliar spray selections#	Selection 1	7 + 3	3	3	3
	Selection 2	11 + 3	11 + 3	7 + 3	11 + 3
	Selection 3	7 + 12			

First foliar spray of canola applied at 4–8 leaf stage will be targeting blackleg crown canker.

Second foliar spray applied at 30% bloom will be targeting blackleg upper canopy infection and/or Sclerotinia, or at 50% bloom will be targeting Sclerotinia.

^ Avoid using the same Group 3 fungicide active more than once per season; do not use the same Group 3 fungicide active consecutively.

* 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 – chickpea

The fungicide rotation option is determined by choice of fungicide used for seed dressing or in-furrow applications. Once a rotation option is determined, make the first foliar selection from your chosen rotation option irrespective of the disease being treated.

Take into consideration the risk profiles of the fungicide groups (see fungicide groups section, page 11) and the fungicide resistance management guidelines (general page 22–24, pulses page 40–43).

Beware that some fungicides may not be registered beyond a particular growth stage (for example, flowering, podding) of the crop, and rotations should take this into consideration. Fungicides 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.

Note: Group 3 + 7 fungicide mixture prothioconazole + bixafen, and Group M5 fungicide chlorothalonil are only registered to target Ascochyta blight in chickpea. Group 1 carbendazim is only registered to target Botrytis grey mould in chickpea.

Table 7: Recommended fungicide rotation options for chickpea crops

Application stage and fungicide selections		Fungicide rotation options	
		Option 1	Option 2
Seed/in-furrow		M3	M3 + 1
First foliar spray selections	Selection 1	7 + 12	7 + 12
	Selection 2	11 + 3	11 + 3
For Ascochyta blight only	Selection 3	7 + 3	7 + 3
	Selection 4	M5	M5
For Botrytis grey mould only	Selection 3	1	

Table 7a: Additional fungicide rotation options for chickpea crops if required

Application stage and fungicide selections		Immediately prior application contains				
		7 + 12	11 + 3	7 + 3	M5	1
Second foliar spray selections[#]	Selection 1	11 + 3	7 + 12	11 + 3	11 + 3	11 + 3
	Selection 2	M3	M3	M3	7 +12	7 + 12
	Selection 3				M3	M3
For Ascochyta blight only	Selection 4	M5	7 + 3	M5	7 + 3	7 + 3
	Selection 5		M5			M5
For Botrytis grey mould only	Selection 4	1	1	1	1	

[#] For subsequent foliar sprays targeting Botrytis grey mould use this table also.

Recommended fungicide rotations – lentil

The fungicide rotation option is determined by choice of fungicide used for seed dressing or in-furrow applications. Once a rotation option is determined, make the first foliar selection from your chosen rotation option irrespective of the disease being treated.

Take into consideration the risk profiles of the fungicide groups (see fungicide groups section, page 11) and the fungicide resistance management guidelines (general page 22–24, pulses page 40–43).

Beware that some fungicides may not be registered beyond a particular growth stage (for example, flowering, podding) of the crop, and rotations should take this into consideration. Fungicides 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.

Note: Group 1 fungicide carbendazim and Group 2 procymidone are only registered to target Botrytis grey mould in lentil.

Table 8: Recommended fungicide rotation options for lentil crops

Application stage and fungicide selections		Fungicide rotation options	
		Option 1	Option 2
Seed/in-furrow		M3	M3 + 1
First foliar spray selections#	Selection 1	1 + 3	1 + 3
	Selection 2	7	7
	Selection 3	7 + 3	7 + 3
	Selection 4	7 + 12	7 + 12
	Selection 5	11 + 3	11 + 3
	Selection 6	M5	M5
For Botrytis grey mould only	Selection 7	1	2
	Selection 8	2	

Table 8a: Additional fungicide rotation options for lentil crops if required

Application stage and fungicide selections		Immediately prior application contains							
		1 + 3	7	7 + 3	7 + 12	11 + 3	M5	1	2
Second foliar spray selections#	Selection 1	7	1 + 3	1 + 3	1 + 3	1 + 3	1 + 3	7	1 + 3
	Selection 2	7 + 3	11 + 3	11 + 3	11 + 3	7 + 3	7 + 3	7 + 3	7
	Selection 3	7 + 12	M5	M5	M5	7 + 12	7 + 12	7 + 12	7 + 3
	Selection 4	11 + 3				M5	11 + 3	11 + 3	7 + 12
	Selection 5	M5						M5	11 + 3
	Selection 6								M5
For Botrytis grey mould only	Selection 7	2	1	1	1	1	1	2	1
	Selection 8		2	2	2	2	2		

First foliar spray of lentil applied prior to canopy closure.

Further information concerning fungal diseases in pulses and fungicide options is available online (extensionaus.com.au/FieldCropDiseasesVic/fungicide-options-in-pulses/). For additional foliar fungicide sprays for any crop, growers should continue to rotate and mix their fungicide actives and groups, using the fungicide resistance management principles illustrated here, to reduce pressure on any one individual fungicide or fungicide group.

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