

**FRAG UK**



# Fungicide Resistance Management in Cereals



**2024**



# Fungicide Resistance Management in Cereals

## CONTENTS

<b>Section</b>	<b>Page</b>
Introduction	3
General resistance management guidelines	4
<b>Individual disease sections:</b>	
Septoria leaf blotch	5
Powdery mildew	7
Brown rust	9
Yellow rust	11
Other cereal rusts	12
Tan spot	13
Net blotch	14
Rhynchosporium	16
Eyespot	18
Ramularia	20
Microdochium spp.	22
Fungicide groups — Wheat	24
Fungicide groups — Barley	26
Acknowledgements	27





# Fungicide Resistance Management in Cereals

## Introduction

Fungicides are essential for the maintenance of healthy crops. However, for some diseases, their effectiveness has been seriously affected by the development of fungicide resistance in target pathogens.

Fungicide treatments are, and are likely to remain, essential for maintaining healthy crops and reliable, high-quality yields. They form a key component of integrated crop management, and their effectiveness must be maintained for as long as possible.

The majority of modern fungicides have single-site modes of action, acting on specific biochemical pathways in the target fungal pathogen. Once a fungicide is used on a pathogen population, individual isolates of the fungal population which have a reduced sensitivity to the fungicide will be selected by repeated use of fungicides with the same mode of action. Multi-site fungicides are less prone to the development of resistance in the target pathogen and these older fungicides still have an important role in the anti-resistance strategy for the more modern, single-site, fungicides.

To determine the sensitivity of a fungal isolate, tests are carried out using a range of doses of the fungicide in order to determine an EC<sub>50</sub> value which is the dose that provides 50% inhibition of the isolate compared to a non-fungicide-amended control. Some isolates can have increased EC<sub>50</sub> values which 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<sub>50</sub> values outside the normal range of sensitivities and these may affect field performance if they become frequent in the population. If these isolates remain at low levels they may have no impact on the field performance of the fungicide when used at commercial doses.

Resistance can arise rapidly and completely so that disease control is lost in a single step, such as the G143A mutation affecting the performance of strobilurin fungicides. More commonly, resistance develops gradually so that the pathogen population becomes progressively less sensitive, such as the development of resistance in *Zymoseptoria tritici* to the azole fungicide group. When resistance develops slowly, with multiple mutations affecting sensitivity, individual isolates may show reduced sensitivity in laboratory tests but there may be no loss of field performance.

To have the greatest impact, anti-resistance strategies need to be implemented as soon as fungicides are introduced to the market, before any shifts in sensitivity are detected.

### FRAG-UK

The Fungicide Resistance Action Group - UK (FRAG-UK) is a forum to look at fungicide resistance issues and to publish information and advice relevant to the UK. The group combines the expertise of industry with the independent sector to produce up-to-date information on the resistance status of important diseases in UK agriculture and to suggest ways of combating resistance.

## General Resistance Management Guidelines

Good resistance management is based on limiting the level of exposure of the target pathogen to the fungicide.

- Fungicide input is only one aspect of crop management and other integrated control measures should always be used, such as disease-free seed lots, good hygiene through disposal of crop debris and control of volunteers which may harbour disease.
- Always aim to select varieties exhibiting a high degree of resistance to diseases known to be prevalent in your area, in addition to the main agronomic factors you desire.
- Avoid growing large areas of any one variety, particularly in areas of high disease risk where the variety is known to be susceptible.
- Only use fungicides in situations where the risk or presence of disease warrants treatment.
- Use a dose that will give effective disease control and which is appropriate for the variety and disease pressure.
- Make full use of effective fungicides with different modes of action in mixtures or as alternate sprays.
- Ensure that mixing partners are used at doses that give similar efficacy and persistence.
- Monitor crops regularly for disease and treat before the infection becomes well established.
- Avoid repeated applications of the same product or mode of action and never exceed the maximum recommended dose or number of applications.

# Septoria leaf blotch

*Zymoseptoria tritici* / *Mycosphaerella graminicola*

## Introduction

*Zymoseptoria tritici* (*Mycosphaerella graminicola*, *Septoria tritici*), is the most important foliar disease of UK winter wheat. Although some newer varieties have good resistance, fungicides continue to be the mainstay of disease control. Rainfall splashes spores from leaf to leaf, although they may also spread to the upper leaves through overlapping contact with the lower canopy.



## Resistance Status

Isolates with reduced sensitivity to QoI fungicides were first detected in 2002 and are now widespread throughout the country at high levels. Sensitivity to older DMIs has declined since the mid 90s and field performance, particularly at reduced doses, has steadily declined. Some older azoles such as prothioconazole, continue to provide some control at full label doses in protectant situations. The more recent azole mefentrifluconazole is currently the most effective.

Several target site mutations affecting sensitivity to SDHIs have been confirmed in recent years. Field performance, particularly of older SDHIs, is now being affected. The new active ingredient fenpicoxamid, with a Qil mode of action, provides effective control particularly in protectant situations.

## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Current evidence shows a significant shift towards reduced sensitivity to DMIs. Field performance from the most effective products has declined in recent years, particularly in eradicant situations. There is now considerable variation in performance of active ingredients in this group and to ensure good performance it is important to select appropriate DMI products and use appropriate rates.

All azoles have the same mode of action inhibiting sterol 14 $\alpha$ -demethylase (CYP51). Consequently it has been assumed that if resistance occurred in a pathogen then all azoles would be equally affected. This is now known not to be true. A large number of mutations in the azole target site protein have now been identified. In addition, alternative (non target site) mechanisms involving overexpression of the target protein or enhanced efflux have been identified in a limited number of isolates.

- Do not use DMIs alone. Always mix azoles with fungicides with different modes of action in repeat spray programmes.
- Use in mixture with fungicides with good efficacy e.g. SDHIs and Qils.
- Use at appropriate doses to ensure effective disease control.
- Azole insensitivity appears to be driven more by application number and less by dose. Resistance risk can therefore be reduced by minimising application number - fewer high dose treatments would be preferable to multiple low doses.
- Because CYP51 mutations affect DMI fungicides in different ways it is theoretically possible that mixtures of azoles could help slow down further shifts in sensitivity. However, the number and complexity of mutations is very dynamic, making it difficult to predict the performance of multiple azole products.

## Fungicide Groups

### Resistance risk

### Suggested use

#### Quinone outside inhibitors (QoIs) - Strobilurins

Due to prevalence of the G143A mutation within the population, isolates of *Z. tritici* with much-reduced sensitivity are widespread at high levels throughout the UK. Despite this, QoIs can sometimes give low levels of control and yield responses are still evident.

- Do not rely on QoI fungicides for septoria control.
- Should always be applied in mixture with a partner from a different cross resistance group.
- Use an application rate of the partner appropriate for disease control on its own.
- Do not apply more than two sprays of a QoI-containing fungicide to any one crop.

#### Quinone inside inhibitors (Qils)

A new fungicide group for use in cereals. The resistance risk is moderate/high.

- Use as part of an anti-resistance strategy in mixture with DMIs, SDHIs and multi-sites.
- Should always be applied in mixture with a partner from a different cross resistance group.
- Use appropriate doses to ensure protection of the partner fungicide.
- Use only once per season

#### Dithiocarbamates

Mancozeb has been available for many years and there have been no cases of resistance recorded in this pathogen. Considered a low risk group because of its multi-site activity.

- Apply preventatively, in mixture with other fungicide groups.
- Use appropriate doses to ensure protection of the partner fungicide.

#### Succinate-dehydrogenase inhibitors (SDHIs)

In 2012 isolates of *Z. tritici* with slightly reduced sensitivity to SDHIs were found in France and the UK, mainly (C-T79N and C-W80S mutations). Since then, several different target site mutations conferring reduced sensitivity have been identified throughout Europe. Many of the identified mutations have low (e.g. B-T268I, C-N86S and C-R151S) to moderate/high (C-H152R) resistance factors for commercially available SDHIs.

The frequency of the C-H152R mutation remains low in field populations. Isolates with enhanced efflux pump activity as well as double target-site mutations are present at low frequency in some populations.

The resistance risk in *Z. tritici* is considered to be moderate/high.

- Useful as a partner for other fungicide groups giving broad-spectrum disease control.
- SDHIs should be applied in a balanced mixture with at least one fungicide with comparable efficacy against the target pathogens from an alternative mode of action group.
- Follow the statutory requirement to limit the number of applications to two SDHI fungicide-containing sprays per season.

#### Phthalimide

Folpet is a multi-site fungicide with protectant activity. There have been no cases of resistance recorded in this pathogen. Considered a low risk group because of its multi-site activity.

- Apply preventatively in tank mix with other fungicide groups.
- Use appropriate doses to ensure protection of the partner fungicide.



# Powdery mildew

*Blumeria graminis* / *Erysiphe graminis*

## Introduction

Powdery mildew exists as specific strains. Each one can only infect wheat, barley, oats or rye – e.g. *B. graminis* f.sp. *tritici* attacks wheat but not other cereals. Cross-infection can occur between winter and spring-sown varieties of the same cereal species.

## Resistance Status

Cereal mildews have an inherently high resistance risk because of their remarkable ability to adapt to fungicide treatments. Currently, resistance in mildew to QoIs is high across Northern and Western Europe. Following an initial shift towards reduced sensitivity, the sensitivity pattern to the morpholines and DMIs has remained stable for several years. Isolates with reduced sensitivity to metrafenone have been found but field performance remains good. Sulphur products may have a label claim for powdery mildew control. All mildew products should be used in mixture with products showing alternative modes of action.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Intensive use of DMIs has led to significant loss of field performance of many DMIs against cereal mildew. Use in mixtures, or co-formulations, has helped to prevent further erosion of activity. Monitoring data indicate that the situation is stable. Resistance risk remains high.

- Never use DMIs alone or repeatedly for mildew control.
- Always mix with a non-DMI fungicide at effective doses to ensure a high level of disease control.
- Alternate or mix fungicides with different modes of action in repeat spray programmes. Include another mode of action with eradicant activity if mildew already active.

#### Quinone-outside inhibitors (QoIs) – Strobilurins

Resistance in powdery mildew to QoI fungicides is widespread and this group should not be relied upon for control of this disease.

- Do not rely on QoI fungicides for mildew control.

#### Inhibitors of sterol reductase and isomerase – morpholines and spiroketalamines

A shift in sensitivity was recorded in the late 1990s, which led to a decline in field performance in the UK. Since then, the sensitivity pattern has remained stable in all monitored countries. Field performance of products based on fungicides in this group is still good with no reported control failures. The risk of a further shift is moderate.

- Exploit the strong eradicant effect of this group as partners for other groups with limited eradicant activity.
- Always use in mixtures with fungicides with different modes of action.

## Fungicide Groups

### Resistance risk

### Suggested use

#### Anilinopyrimidines

Resistance risk not known but thought to be moderate. Anilinopyrimidines have been used on cereals since 1998 and no shifts in sensitivity have been detected.

- Use early in the spray programme to make the best use of the protectant activity of the fungicide.
- Use with a suitable eradicant partner for established infections.

#### Azanaphthalenes

Proquinazid is an Azanaphthalene fungicide with a spectrum of activity limited to powdery mildew. Low frequencies of *Blumeria graminis* isolates with reduced sensitivity to quinoxifen - another Azanaphthalene - were first detected in 2001. A clear cross-resistance pattern between the two has been demonstrated in some powdery mildews (e.g. *Erysiphe necator*) with less clear cross resistance in *Blumeria graminis*. Resistance risk is moderate to high.

- Apply preventatively, in mixture with other groups of fungicides before mildew is established. Will not control latent or established infections.
- Use with a suitable eradicant partner for established infections.

#### Amidoximes

Resistance risk is currently not known but thought to be moderate.

- Use early in the spray programme to make the best use of the protectant activity of the fungicide .
- Use with a suitable eradicant partner for established infections.

#### Aryl-phenyl-ketones

Isolates with reduced sensitivity to metrafenone have been confirmed but field performance remains good. The resistance risk is thought to be moderate.

- Always use with an eradicant partner where mildew is present.
- Apply with a fungicide offering an alternative mode of action against mildew.

#### Fungicides with multi-site activity – sulphur, dithiocarbamates and potassium salts

There is no evidence of resistance developing and resistance risk is low. They are relatively weak protectants offering alternative modes of action.

- Not reliable for mildew control if applied alone.

#### Succinate-dehydrogenase inhibitors (SDHIs)

Although resistance has been confirmed in other powdery mildew pathogens such as cucurbit powdery mildew (*Podosphaera xanthii*), monitoring programs carried out in 2015 on wheat powdery mildew showed full sensitivity of isolates from several different European countries.

Resistance risk is thought to be moderate to high.

- Although not a primary target for the SDHIs a number of SDHI-containing products are authorised for use against powdery mildew.
- Always use with an eradicant partner where mildew is present.



# Wheat brown rust

*Puccinia triticina*

## Introduction

Brown rust prefers warm temperatures and high humidity. Epidemics can develop quickly under the right conditions although severe attacks do not usually occur until late in the season.

## Resistance Status

Incidence and severity of wheat brown rust has been higher in recent years but performance of the DMIs has been maintained. No failure to control has been reported for the Qols and no resistance has been found to any of the other groups.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Despite good field performance, shifts in the past in sensitivity of brown rust to DMIs indicate that a moderate to low resistance risk still exists. Monitoring data indicate that the situation is stable.

- Always mix with a non-DMI fungicide at effective doses to ensure a high level of disease control.
- Alternate or mix fungicides with different modes of action in repeat spray programmes if possible.

#### Quinone-outside inhibitors (Qols) – Strobilurins

Performance of Qol fungicides against brown rust remains good, particularly in protectant situations. No isolates with reduced sensitivity have been detected in widespread monitoring studies in Europe, confirming the fully sensitive picture.

- Choose products known to be effective as variability in effectiveness of eradicant activity exists across the group.
- Use Qols in combination with an effective partner with a different mode of action.
- Apply no more than two Qol-containing sprays to any crop.

#### Inhibitors of sterol reductase and isomerase – morpholines and spiroketalamines

Little monitoring has been done since work in the early 1990s which showed no evidence of any shift in sensitivity. The risk of resistance developing remains medium to low.

- Use fungicides in this group for their eradicant effect, in mixtures with an effective fungicide with a different mode of action.
- When used in mixture, both partner products should be used at doses effective for disease control.

## Fungicide Groups

### Resistance risk

### Suggested use

#### Succinate-dehydrogenase inhibitors (SDHI)

The mutation C-I87F has been detected showing a low resistance factor but is not thought to impact field efficacy.

In the UK cereal market SDHI fungicides are currently recommended in mixtures or formulated with other fungicides so resistance risk in brown rust is considered to be moderate.

- Useful as partner for DMI and Qil fungicides giving broad-spectrum disease control.
- SDHIs should be applied in a balanced mixture with at least one fungicide with comparable efficacy against the target pathogens from an alternative mode of action group.
- Follow the statutory requirement to limit the number of applications to two SDHI fungicide-containing sprays.

#### Quinone inside inhibitors (Qils)

A new fungicide group for use in cereals. Currently the resistance risk to Qils in cereal rusts remains unknown, but is thought to be moderate to low.

- Should always be applied in mixture with a partner from a different cross resistance group.
- Use only once per season

# Wheat yellow rust

*Puccinia striiformis*

## Introduction

Yellow rust is highly specialised. There are many different 'races', each of which affects a different range of varieties. New races, capable of overcoming varietal resistance, evolve frequently to make previously resistant varieties susceptible. Refer to annual and in-season updates on the resistance status of varieties. Avoid drilling large areas of susceptible varieties to reduce the risk of yellow rust spreading on farm.

## Resistance Status

Incidence and disease pressure has been very high in recent years and performance of DMIs has been maintained. No failure to control has been reported for the Qols and no resistance has yet been found to the morpholines or the SDHIs.

Disease pressure on susceptible varieties can lead to intensive use of fungicides which can impact on the resistance risk of other pathogens such as *Z. tritici*.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Despite good field performance, sensitivity shifts to DMIs in the past indicate that a moderate resistance risk still exists if robust anti-resistance strategies are not adopted. Monitoring data indicate that the situation is stable.

- Always mix with a non-DMI fungicide at effective doses to ensure a high level of disease control.
- Alternate or mix fungicides with different modes of action in spray programmes if possible.
- Minimise selection pressure from DMIs on *Z. tritici* by using other fungicide groups where possible.

#### Inhibitors of sterol reductase and isomerase – morpholines and spiroketalamines

Little monitoring has been done since work in the early 1990s which showed no evidence of any shift in sensitivity. The risk of resistance developing remains medium to low.

- Use fungicides in this group for their eradicant effect, in mixtures with an effective fungicide with a different mode of action.
- When used in mixture, both partner products should be used at doses effective for disease control.

#### Quinone-outside inhibitors (Qols) – Strobilurins

The genetic basis of the resistance to Qol fungicides (G143A) means that the risk of resistance developing in yellow rust is low.

- Qols are largely protectant with limited eradicant activity.
- Use Qols in combination with an effective partner with a different mode of action.
- Apply no more than two Qol-containing sprays to any crop.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Succinate-dehydrogenase inhibitors (SDHIs)

There are no reports of mutations affecting performance of SDHIs against yellow rust.

In the UK cereal market SDHI fungicides are currently recommended in mixtures or formulated with other fungicides so resistance risk is considered to be moderate.

- Useful as partner for other fungicide groups giving broad-spectrum disease control.
- SDHIs should be applied in a balanced mixture with at least one fungicide with comparable efficacy against the target pathogens from an alternative mode of action group.
- Follow the statutory requirement to limit the number of applications to two SDHI fungicide-containing sprays.

#### Quinone inside inhibitors (Qils)

A new fungicide group for use in cereals in 2021. Currently the resistance risk to Qils in cereal rusts remains unknown, but is thought to be moderate to low.

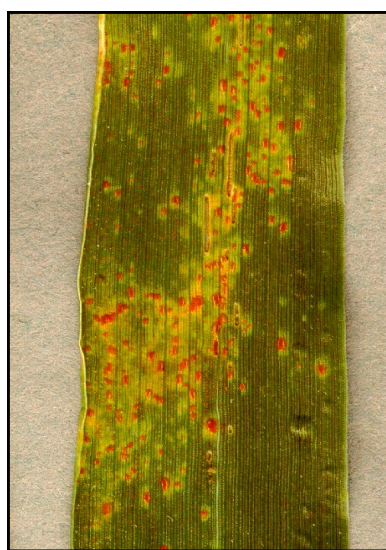
- Should always be applied in mixture with a partner from a different cross resistance group.
- Use only once per season

## Other Cereal Rusts

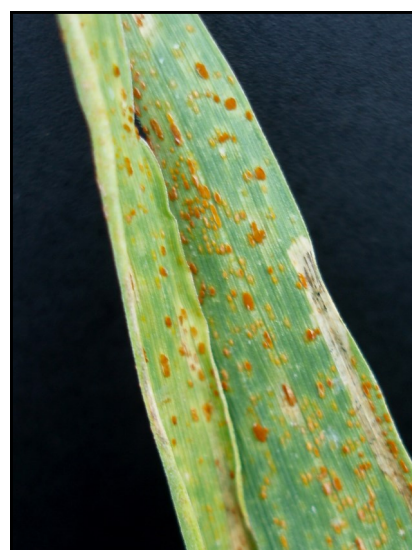
Rust diseases affect all UK cereals. Barley is affected by brown rust (*P. hordei*) and yellow rust (*P. striiformis*). In oats, crown rust (*P. coronata* var. *avenae*) can be highly damaging. The general principles outlined for wheat yellow rust above apply for the control of all rusts, though it is important to ensure the products chosen have approval on these crops.



*Puccinia coronata* (Oats)



*Puccinia hordei* (Barley)



*Puccinia recondita* (Rye)

# Tan spot of wheat (DTR)

*Pyrenophora tritici-repentis* / *Drechslera tritici-repentis*

## Introduction

Until recently, tan spot has been a relatively rare disease in the UK. Caused by *Pyrenophora tritici-repentis*, the disease was first recorded in national surveys in 1987. Incidence of the disease has increased in the last few years. Tan spot was common in 2015 and 2016 although disease severity was generally low. In recent years incidence has been low. There is little information available on varietal resistance in the UK.

## Resistance Status

Decreased sensitivity to QoI fungicides was first detected in Sweden in 2003. The mutation was identified as F129L. Since then, G143A, F129L and G137R mutations have all been detected with G143A the most commonly detected.

Isolates with reduced sensitivity to QoI fungicides have been identified in a number of countries throughout Europe. Field resistance to some DMI fungicides has been recorded but field performance generally remains good.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Reduced sensitivity to some DMI fungicides has been recorded in Europe since 2005 but field performance is still good.

- Always mix with a non-DMI fungicide at effective doses to ensure a high level of disease control.
- Alternate or mix fungicides with different modes of action in spray programmes if possible.

#### Quinone-outside inhibitors (QoIs) – Strobilurins

Resistance to QoI fungicides was detected in 2003. Three mutations (F129L, G137R or G143A) have been found within populations. Initially, isolates with reduced sensitivity carried the F129L mutation, which confers partial rather than full resistance. More recently, isolates carrying all three mutations have been found to be prevalent in the European population. Field performance of QoI fungicides alone is much reduced in the UK.

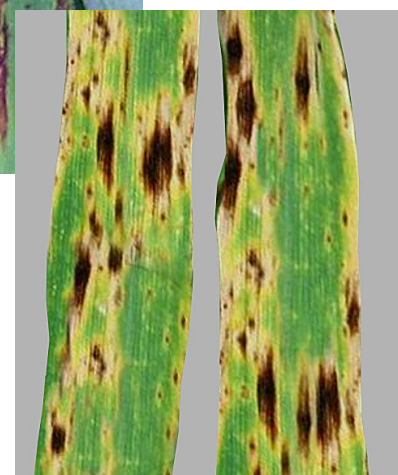
- Only use fungicides in this group in mixtures with an effective product with a different mode of action.
- When used in mixture, both partner products should be used at doses effective for disease control.
- Apply no more than two QoI-containing sprays to any crop.

# Net blotch

*Pyrenophora teres f teres* and *Pyrenophora teres f maculata*

## Introduction

The incidence and severity of net blotch has declined in winter barley in recent years although the spot form (*P.teres f maculata*) of the disease appears to be more common. The disease is rarely important in spring crops. Net blotch can occur on seed. Fungicide timing is usually critical.



## Resistance Status

Control has typically relied on QoIs and DMIs but resistance (F129L) to the QoI group was detected during 2004. A decline in efficacy of the QoIs has been seen in recent years.

Declines in sensitivity of net blotch isolates to DMIs seen in the early 1990s showed no link to reduced field performance. Disease control has remained reliable. Since 2014/15 many isolates have been detected with reduced sensitivity to SDHs. Among the mutations with moderately decreased sensitivity, C-G79R, C-H134R, CN75S and C-S135R are the most frequently detected mutations while the mutation BH277Y was observed to decrease since 2016.

Several SDH mutations have now been found frequently throughout Europe in *Pyrenophora teres* with associated loss of efficacy in field.

## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Though sensitivity to some DMIs has been shown to decline over time, some fluctuations have also been seen between years. In 2017 in France significant shifts in sensitivity of populations were observed. It is thought that sensitivity across Europe is fairly stable. Field performance in recent years has been good with no reported problems.

- Always mix with a non-DMI fungicide at an effective dose to ensure a high level of disease control.
- Alternate or mix fungicides with different modes of action in repeat spray programmes if possible.

#### Quinone-outside inhibitors (QoIs) – Strobilurins

Resistance to QoI fungicides was detected in 2004 and the frequency of the F129L mutation has increased in recent years. The risk of the G143A mutation, which confers complete resistance in other pathogens, occurring in net blotch is low. Isolates carrying the F129L mutation are now common in the UK. Performance of QoI-containing spray programmes against net blotch is now variable.

- Only use fungicides in this group in mixtures with an effective product with a different mode of action.
- When used in mixture, both partner products should be used at doses effective for disease control.
- Apply no more than two QoI-containing sprays to any crop.



# Net blotch

*Pyrenophora teres f. teres* and *Pyrenophora teres f. maculata*

## Fungicide Groups

### Resistance risk

### Suggested use

#### Anilinopyrimidines

Resistance risk unknown but thought to be moderate.  
Some evidence of low frequency of isolates with reduced sensitivity in UK in 2019.

- Use in tank mix with other products as a mixture partner with a different mode of action.

#### Succinate-dehydrogenase inhibitors (SDHIs)

Isolates of *Pyrenophora teres* with slightly reduced sensitivity were found in northern Germany in 2012. Resistance factors were very low. In 2013 isolates of net blotch with mutations conferring reduced sensitivity to SDHI fungicides were commonly detected throughout Europe and the UK. Since 2014, more isolates have been detected with reduced sensitivity, carrying different mutations in many European countries.

Among the frequent mutations with moderately decreased sensitivity, C-G79R, C-H134R, CN75S and C-S135R are the most frequently detected mutations while the mutation BH277Y was observed to decrease since 2016.

SDHIs used alone in trials have shown variable performance since 2016/17 in the UK. In the UK cereal market SDHI fungicides are recommended in mixtures or formulated with other fungicides but resistance risk is considered to be moderate/high.

- Useful as partner for DMI fungicides giving broad-spectrum disease control.
- SDHIs should be applied in a balanced mixture with at least one fungicide with comparable efficacy against the target pathogens from an alternative mode of action group.
- Follow the statutory requirement to limit the number of applications to two SDHI fungicide-containing sprays.

#### Phthalimides

Folpet is a multi-site fungicide with protectant activity. There have been no cases of resistance recorded in this pathogen. Considered a low risk group because of its multi-site activity.

- Apply preventatively in tank mix with other fungicide groups.
- Use appropriate doses to ensure protection of the partner fungicide.

# Rhynchosporium

## *Rhynchosporium commune*

### Introduction

Rhynchosporium, or barley leaf blotch, is a major disease of both winter and spring barley. The disease is spread mainly by rain-splashed spores but can be seed-borne. It is particularly severe in the wetter parts of the UK and coastal areas.

### Resistance Status

Variability in sensitivity to DMIs has been recorded for many years with some of the older actives no longer offering effective control. However, some of the newer products in this group give good control. Recent monitoring showed no shift in sensitivity with good disease control across Europe.

Isolates carrying the G143A mutation have occasionally been confirmed in France and Ireland but field control remains good. Performance of the QoI fungicides in the UK remains good.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Though sensitivity to some DMIs has been shown to decline over time, some fluctuations have also been seen in consecutive years but it is thought that sensitivity across Europe is fairly stable. Field disease control in recent years has been good with no reported problems.

- Always mix with a non-DMI fungicide at effective dose to ensure a high level of disease control.
- Alternate or mix fungicides with different modes of action in repeat spray programmes if possible.

#### Quinone-oxidoreductase inhibitors (QoIs) – Strobilurins

G143A was confirmed at one location in northern France in 2008. In some years since 2008 (e.g. 2012 France, 2014 UK, 2015 Spain), occasionally isolates have been found containing the G143A mutation. The frequency is always very low.

The performance of QoI-containing spray programmes remains good.

The risk of resistance is thought to be moderate.

- Select QoIs showing a high level of control as variability in activity against rhynchosporium exists across the group.

## Fungicide Groups

### Resistance risk

### Suggested use

#### Anilinopyrimidines

Resistance risk unknown but thought to be moderate. There has been no evidence of any changes in sensitivity to date.

- Activity against rhynchosporium makes fungicides in this group a good partner with alternative mode of action for tank mixes with other products.
- Also active against eyespot, mildew and net blotch, but weak against brown rust.

#### Inhibitors of sterol reductase and isomerase — morpholines and spiroketalamines

The risk of resistance is low and there is no evidence of any change in sensitivity.

- Use in mixture with effective fungicides having different modes of action.
- Particularly useful eradicant activity where active disease is present.
- Spiroketalamines are useful partner products with activity against rhynchosporium.

#### Succinate-dehydrogenase inhibitors (SDHIs)

In the UK cereal market SDHI fungicides are currently recommended in mixtures or formulated with other fungicides so resistance risk is considered to be moderate. Single isolates showing slightly decreased sensitivity with no reported reduction in field efficacy have been identified. In some isolates, the mutation *sdh C-N85S* was detected. The population is generally highly sensitive.

- Different mode of action offers improved rhynchosporium control over DMIs alone.
- SDHIs should be applied in a balanced mixture with at least one fungicide with comparable efficacy against the target pathogens from an alternative mode of action group.
- Follow the statutory requirement to limit the number of applications to two SDHI fungicide-containing sprays.

#### Phthalimides

Folpet is a multi-site fungicide with protectant activity. There have been no cases of resistance recorded in this pathogen. Considered a low risk group because of its multi-site activity.

- Apply preventatively in tank mix with other fungicide groups.
- Use appropriate doses to ensure protection of the partner fungicide.



# Eyespot

## *Oculimacula* species

### Introduction

Two species of fungi, *Oculimacula yallundae* and *O. acuformis*, cause eyespot in cereals. Symptoms caused by either species can only be distinguished by laboratory analysis. Both species attack wheat and barley but rye is affected mainly by *O. acuformis*. Most infections on wheat are mixed infections with *O. acuformis* being the more common of the two species

### Resistance Status

Reduced sensitivity to prochloraz has been known in parts of Europe for several years. Several azoles, particularly some of the newer fungicides, show control equivalent to anilinopyrimidines, but cross-resistance is known in this group and strains resistant to some fungicides have been found. There is no evidence of any change in sensitivity to anilinopyrimidines or SDHIs.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Small shifts in sensitivity found in the UK in 2013 and 2014 but little evidence to date of reductions in field performance with the more active DMIs (e.g. prothioconazole).

- Use a DMI with very good eyespot activity if risk of disease is high.
- Apply early in season for best effect.

#### Sterol demethylation inhibitors (DMIs) - Imidazoles

Isolates of the eyespot fungus with reduced sensitivity to prochloraz were found in Northern France in the 1990s. This led to reduced field performance. Only moderate activity against *O. acuformis*.

- Can provide some useful control when applied at early timings (up to GS32).

## Fungicide Groups

### Resistance risk

### Suggested use

#### Anilinopyrimidines

Risk is not known, but thought to be moderate. Although there are reports of reduced sensitivity to cyprodinil in isolates of both *O. yallundae* and *O. acuformis*, there is no evidence of any shifts in field performance.

- Apply early (up to GS32) as a protectant.
- Use at doses appropriate for effective eyespot control.
- Determine precise timing according to disease severity and seasonal weather conditions.
- A good partner with alternate mode of action in tank mix with other products.
- Also active against rhynchosporium, powdery mildew and net blotch, but weak against brown rust.

#### Succinate-dehydrogenase inhibitors (SDHIs)

In the UK cereal market SDHI fungicides are generally recommended in mixtures or formulated with other fungicides so resistance risk is considered to be moderate.

- Use of SDHIs early gives good eyespot control in wheat and barley.
- Always apply with an effective mixture partner.
- Follow the statutory requirement to limit the number of applications to two SDHI fungicide-containing sprays.

#### Aryl-phenyl-ketone (Benzophenone)

Risk is currently unknown.

- Metrafenone can give useful eyespot control
- Low doses used for mildew control may not be sufficient for effective eyespot control.
- Use an effective partner fungicide where powdery mildew is also a problem.

# Ramularia

## *Ramularia collo-cygni*

### Introduction

*Ramularia collo-cygni* causes leaf spot symptoms in winter and spring barley and is problematic throughout the UK. The disease has a complicated life-cycle and is seed, air and trash borne. It is present in a symptomless form from early in plant development and causes losses in green leaf area after flowering when it is triggered into the damaging part of its life-cycle. Although there are differences in varietal tolerance all varieties are relatively susceptible and fungicides are important in limiting leaf area losses and in maintaining yield and quality.

### Resistance Status

Resistance to QoI fungicides occurred in the early 2000s and is now present at high levels with a corresponding loss of efficacy. Target site mutations affecting field performance of SDHIs have been confirmed in Europe since 2016. Marked declines in azole efficacy have been noted at some sites in the UK and Europe since 2017.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

Ramularia is closely related to *Z. tritici* and shows similar issues with reduced sensitivity to older DMIs. Multiple CYP51 mutations have been detected.

Loss of field efficacy of some azoles was noted in Germany in 2016. In 2017 a significant loss of field efficacy was seen in the UK, even with the previously highly-effective prothioconazole. Mefentrifluconazole which was launched in 2020 is still considered to provide effective control.

In 2020 and 2021, isolates were detected showing significant loss of sensitivity. Relevant CYP51-mutations explaining the effects have been identified (I325T, I328L, Y403C/Y405H). Isolates carrying mutations were found at high frequency in the UK.

- Do not use DMIs alone at any point in the spray programme. Ramularia can be present without symptoms from early in plant development and even early sprays can have a selective effect.
- Use in mixture with fungicides with good efficacy.
- Apply fungicides at a timing that allows for maximum protectant activity – this is prior to flowering and symptom development and is usually aimed at booting.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Quinone-outside inhibitors (QoIs) - Strobilurins

The G143A resistance mutation, common to many pathogens, is also the resistance mechanism detected in ramularia. Monitoring shows that close to 100% of the population is affected and QoI fungicides are now largely ineffective in controlling the disease.

- Always apply QoI fungicides in mixture – they remain important for the management of other important barley pathogens such as rhynchosporium or rusts.
- Follow the statutory requirement to limit the number of applications to two QoI fungicide sprays.

#### Succinate-dehydrogenase inhibitors (SDHIs)

This group now shows very variable efficacy against ramularia and is at high risk of further resistance development. Isolates with reduced sensitivity to SDHIs resulting in loss of field performance were confirmed in Europe in 2016 and the UK in 2017. A heterogeneous situation, ranging from low to high (frequency of mutations and sensitivity), was observed in 2021 in France, Germany, Ireland, the Netherlands and the United Kingdom. Significantly decreased sensitivity is mainly associated with the mutations C-G91R, CH146R/L, C-G171D or C-H153R. Additionally, mutations linked to lower resistance factors (C-N87S, B-T267I, B-N224T) were detected. Overall, the previously dominating C-H146R mutation is observed to decrease while CN87S is increasing.

This fungicide group should therefore be very carefully stewarded.

- SDHIs should always be applied in a balanced mixture with at least one fungicide with comparable efficacy against the target pathogens from an alternative mode of action group.
- Follow the statutory requirement to limit the number of applications to two SDHI fungicide-containing sprays.

#### Phthalimides

Folpet is a multi-site fungicide with protectant activity. There have been no cases of resistance recorded in this pathogen. Considered a low risk group because of its multi-site activity.

- Apply preventatively in tank mix with other fungicide groups.
- Use appropriate doses to ensure protection of the partner fungicide.

# Microdochium

*Microdochium nivale* and *M. majus*

## Introduction

The seed-borne fungus *Microdochium* (formerly considered as *Fusarium nivale*) is now known to consist of 2 species - *M. majus* and *M. nivale*.

Both species can colonise the heads of cereals in cool wet summers. They are primarily a threat to winter wheat as they can reduce germination and cause a seedling blight and thinning of plant stand. Staining of nodes and lower leaf sheath also occurs. They do not produce mycotoxins.

## Resistance Status

Of the two species, *M. majus* tends to be the dominant species in Europe. Extensive monitoring in Europe during 2009/10 confirmed resistance in both species due to the G143A mutation in several countries including the UK. Resistance to the MBC fungicides is widespread in Europe.



## Fungicide Groups

### Resistance risk

### Suggested use

#### Sterol demethylation inhibitors (DMIs) – Azoles

There are no reports of resistance to DMI fungicides in *Microdochium* spp. but the range of efficacy between azoles is very variable.

- Ear treatments should be based around effective DMI products.
- Seed-borne *Microdochium* is controlled largely by azole-based seed treatments.

## Fungicide Groups

### Resistance risk

### Suggested use

#### Quinone-outside inhibitors (QoIs) - Strobilurins

The G143A resistance mutation, common to many pathogens, is also present in both *M. nivale* and *M. majus*. Ear sprays based on QoI fungicides are likely to be ineffective in controlling the disease.

- Do not rely on QoI-containing fungicides for control of *Microdochium* on the ear.



# Fungicide Groups for disease control in wheat

Fungicide Groups	FRAC Code	Chemical Families	Common name of active substance
DMI-fungicides (DeMethylation Inhibitors) (SBI: Class I)	3	Imidazole	Prochloraz
		Triazole	Bromuconazole Difenoconazole Flutriafol Mefentrifluconazole Prothioconazole Tebuconazole
Amines (Morpholines) (SBI: Class II)	5	Piperidine Spiroketalamine	Fenpropidin Spiroxamine
Succinate-dehydrogenase inhibitors (SDHIs)	7	Pyridine carboxamide	Boscalid
		Pyridinyl-ethyl- benzamide	Fluopyram
		Pyrazole carboxamide	Isoflucypram Benzovindiflupyr Bixafen Fluxapyroxad Isopyrazam Penthiopyrad
QoI-fungicides (Quinone outside Inhibitors)	11	Strobilurin	Azoxystrobin Fluoxastrobin Pyraclostrobin Trifloxystrobin
Qil-fungicides (Quinone inside Inhibitors)	21	Picolinamide	Fenpicoxamid

# Fungicide Groups for disease control in wheat



Fungicide Groups	FRAC Code	Chemical Families	Common name of active substance
Thiophene-carboxamides	38	Thiophene-carboxamide	Silthiofam
AP-fungicides (Anilino-Pyrimidines)	9	Anilino-pyrimidine	Cyprodinil
Azanaphthalene	13	Quinazolinones	Proquinazid
PP-fungicides (Phenylpyrroles)	12	Phenylpyrrole	Fludioxonil
Phthalimide	M4	Folpet	Folpet
Amidoximes	U6	Phenyl-acetamide	Cyflufenamid
Aryl-phenyl-ketones	50	Aryl-phenyl-ketone	Metrafenone Pyriofenone
Inorganics - sulphur	M2	Sulphur	Sulphur
Dithiocarbamates	M3	Dithiocarbamate	Mancozeb

# Fungicide Groups for disease control in barley

Fungicide Groups	FRAC Code	Chemical Families	Common name of active substance
DMI-fungicides (DeMethylation Inhibitors) (SBI: Class I)	3	Imidazole	Imazalil
		Triazole	Ipconazole Mefentrifluconazole Metconazole Prothioconazole Tebuconazole
Amines (Morpholines) (SBI: Class II)	5	Spiroketalamine	Spiroxamine
Succinate-dehydrogenase inhibitors (SDHIs)	7	Pyridinyl-ethyl- benzamide	Fluopyram
		Pyrazole carboxamide	Benzovindiflupyr Bixafen Fluxapyroxad Isopyrazam Penthiopyrad
QoI-fungicides (Quinone outside Inhibitors)	11	Strobilurin	Azoxystrobin Fluoxastrobin Pyraclostrobin Trifloxystrobin
Thiophene-carboxamides	38	Thiophene- carboxamide	Silthiofam
AP-fungicides (Anilino-Pyrimidines)	9	Anilino-pyrimidine	Cyprodinil
Azanaphthalene	13	Quinazolinones	Proquinazid



# Fungicide Groups for disease control in barley



Fungicide Groups	FRAC Code	Chemical Families	Common name of active substance
PP-fungicides (Phenylpyrroles)	12	Phenylpyrrole	Fludioxonil
Amidoximes	U6	Phenyl-acetamide	Cyflufenamid
Aryl-phenyl-ketones	50	Aryl-phenyl-ketone	Metrafenone
Inorganics - sulphur	M2	Sulphur	Sulphur
Phthalimides	M4	Folpet	Folpet

## Acknowledgements

The authors are grateful to the members of FRAG-UK for comments during the preparation of this edition of the leaflet. For a full list of the FRAG-UK committee members see the FRAG-UK website <https://cereals.ahdb.org.uk/frag>

Whilst this leaflet has been prepared from the best information available, neither the authors, the organisations involved in its production and distribution nor the Fungicide Resistance Action Group - UK shall in any event be liable for any loss, damage or injury howsoever suffered directly or indirectly in relation to the contents or the research on which they are based. Always check the approval status of a product before use

This leaflet and further information on resistance are available at <https://cereals.ahdb.org.uk/frag>

Published February 2024  
© FRAG-UK 2024



Published March 2024  
© FRAG-UK 2024

Fungicide resistance management in cereals