Fungicide Resistance Management in Cereals

FRAG UK

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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 that 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 a very important role in the resistance strategy for the more modern fungicides.

To determine the sensitivity of a fungal isolate, tests are carried out using multiple doses of the fungicide in order to determine an EC50 value, which is the dose that provides 50% inhibition of the isolate compared to a non-fungicide-amended control. Some isolates can have increased EC50 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 EC50 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 that 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 desired.
- 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 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

In the mid 1980s, *Z. tritici* developed resistance to benzimidazole fungicides (MBCs). Isolates with reduced sensitivity to QoI fungicides were first detected in 2002 and are now widespread throughout the country at high levels. Sensitivity to DMIs has declined since the mid 90s and field performance, particularly at reduced doses, has steadily declined. Several azoles, primarily epoxiconazole and prothioconazole, continue to provide good control at full label doses in protectant situations.

Several target site mutations affecting sensitivity to SDHIs have been confirmed in recent years. Some isolates also show enhanced efflux pump activity but field performance of SDHIs remains generally good.

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 still been good in recent years as long as appropriate timings and doses were used. 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.

All azoles have the same mode of action inhibiting sterol 14α-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.

- Use in mixture with fungicides with good efficacy e.g. SDHI or chlorothalonil. Use at high doses dose to ensure effective disease control.
- Do not use DMIs alone. Always mix azoles with fungicides with different modes of action in repeat spray programmes.
- Azole insensitivity appears to be driven more by application number and less so by dose. Resistance risk can therefore be reduced by minimising application number - fewer high dose treatments would be preferable to split 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.

Septoria leaf blotch

Zymoseptoria tritici / Mycosphaerella graminicola

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 still give some control and yield responses are still evident.	• Do not rely on QoI fungicides for septoria control. • Always apply QoI fungicides in mixture with non-cross resistant fungicides. • 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.
Chloronitriles	
Chlorothalonil has been available commercially for many years with no cases of resistance recorded. Its multi-site, protectant activity makes it an ideal partner against *Z. tritici* as part of an anti-resistance strategy when mixed with DMIs, or SDHIs, particularly at protectant spray timings.	• Apply preventatively in tank mix with DMIs and SDHIs. • Use as part of an anti-resistance strategy with DMIs and SDHIs. • Use appropriate doses to ensure protection of the partner fungicide.
Dithiocarbamates	
Mancozeb has also 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 as part of an anti-resistance strategy with DMIs and SDHIs. • 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 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 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 per season.
Phthalimide	
Folpet is a multi-site fungicide with protectant activity. This makes it a useful partner against *Z. tritici* as part of an anti-resistance strategy when mixed with DMIs or SDHIs, particularly at early (GS31-32) spray timings.	• Apply preventatively in tank mix with DMIs and SDHIs. • 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 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 quinoxyfen have been found in Europe with reports of reduced performance. Isolates with reduced sensitivity to metrafenone have been found but field performance remained good. 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.

Powdery mildew

Blumeria graminis / Erysiphe graminis

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	
Quinoxyfen and proquinazid are both Azanaphthalene fungicides with a spectrum of activity limited to powdery mildew. Low frequencies of *Blumeria graminis* isolates with reduced sensitivity to quinoxyfen were first detected in 2001. A clear cross-resistance pattern between quinoxyfen (aryloxyquinoline) and proquinazid (quinazolinone) has been demonstrated in some powdery mildews (e.g. *Erysiphe necator*) with less clear cross resistance in *Blumeria graminis.* For resistance management purposes, quinoxyfen and proquinazid should be managed together. 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. • Due to similarities in biological action between the quinoxyfen and proquinazid, as a precaution the two fungicide groups should not be used together.
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 QoIs and no resistance has been found to any of the other groups. The SDHIs provide useful control.

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 (QoIs) – Strobilurins	
Performance of QoI 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 QoIs in combination with an effective partner with a different mode of action. • Apply no more than two QoI-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.

Wheat brown rust

Puccinia triticina

Fungicide Groups

Resistance risk	Suggested use

Succinate-dehydrogenase inhibitors (SDHI)

Resistance has been confirmed in several non-cereal pathogens (*Alternaria, Botrytis*). Several mutations conferring reduced sensitivity have been found in net blotch (*Pyrenophora teres*), ramularia (*Ramularia collo-cygni*) and septoria (*Z. tritici*) in Europe but field performance remains high, except for ramularia where field performance has been poor at some locations in Europe. There are no reports of mutations affecting performance of SDHIs against brown rust.

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 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.

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 QoIs 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 (QoIs) – Strobilurins

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

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

Wheat yellow rust

Puccinia striiformis

Fungicide Groups

Resistance risk **Suggested use**

Succinate-dehydrogenase inhibitors (SDHIs)

Resistance has been confirmed in several non-cereal pathogens (*Alternaria, Botrytis*). Several mutations conferring reduced sensitivity have been found in net blotch (*Pyrenophora teres*), ramularia (*Ramularia collo-cygni)* and Septoria (*Z. tritici*) in Europe but field performance remains high, except for ramularia, where field performance has been poor at some locations in Europe.

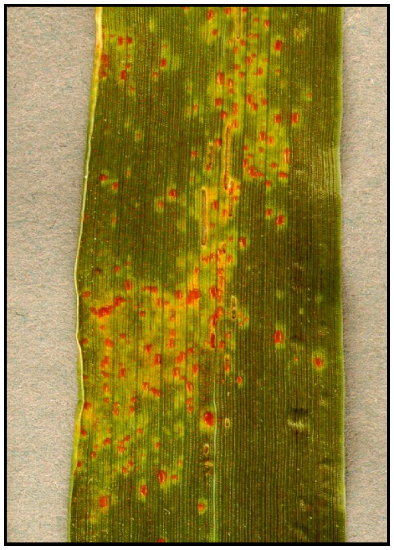
There are no reports of mutations affecting performance of SDHIs against yellow rust. In the UK cereal market SDHI fungicides are currently recommended in mixtures or formulated with other fungicides so resistance risk is considered to be moderate.

- Useful as partner for 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.

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 was recorded in 2005.

Fungicide Groups

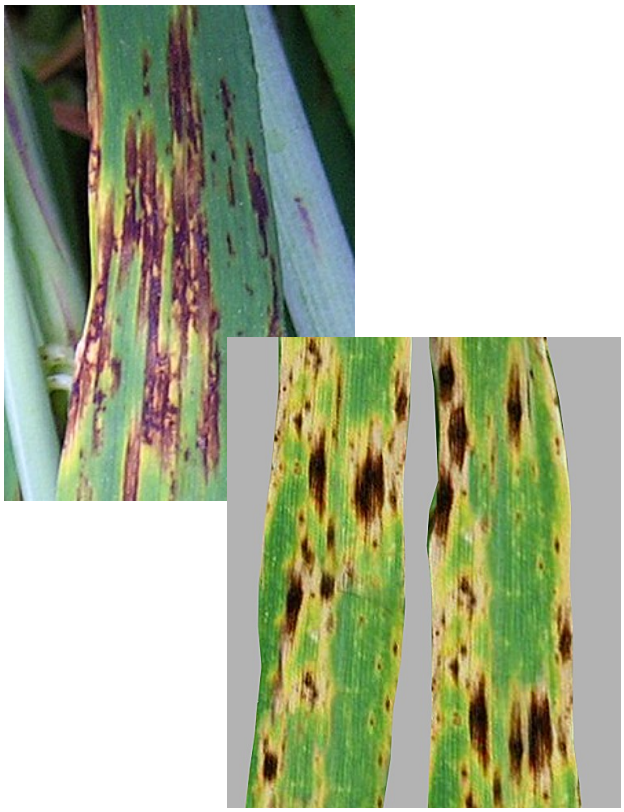
Resistance risk	Suggested use
Sterol demethylation inhibitors (DMIs) – Azoles	
Reduced sensitivity to some DMI fungicides was recorded in Europe in 2005 but field performance is still good.	• Always mix with a non-DMI fungicide at effective doses to ensure a high level of disease control. • Alternate 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. Two mutations (F129L and 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 both F129L and the G143A mutation have now come to dominate the population. Isolates carrying resistance mutations have been found in Sweden, Denmark and Germany. 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 / Drechslera teres

Introduction

The incidence and severity of net blotch has declined in winter barley in recent years although the spot form 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 in France, Italy, Germany and UK with reduced sensitivity to SDHIs. Several target site mutations were found. The predominant mutations were C-G79R, C-H134R, C-S135R and D-H134R. Several SDH mutations have now been found 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 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 mutation has increased in recent years. The mutation causing resistance (F129L) confers partial rather than complete resistance. Isolates carrying this mutation are now common in the UK. Performance of QoI-containing spray programmes against net blotch are 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 / Drechslera teres

Fungicide Groups

Resistance risk	Suggested use

Anilinopyrimidines

Resistance risk unknown but thought to be moderate.

- 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 France, Italy, Germany and UK.

Several SDH mutations have now been found in *Pyrenophora teres*. These include B-H277Y, D-D124E, D-D145G, C-G79R, C-H134R, C-S135R, C-N75S, C-R64K, D-H134R and C-K49E.

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.

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, many of the newer chemicals 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.

Resistance to benzimidazoles (MBCs) is common and widespread in the UK.

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-outside 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.

Rhynchosporium

Rhynchosporium commune

Fungicide Groups

Resistance risk	Suggested use
Chloronitriles	
Because of the multi-site, protectant activity of chlorothalonil, the only member of this group, resistance risk is believed to be low. Chlorothalonil is not effective once an epidemic is established.	• Do not apply alone. • Use as a mixture partner with other fungicides before the onset of serious disease.
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.	• 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 some protectant activity. This makes it a potential partner as part of an anti-resistance strategy when mixed with DMIs.	• Apply preventatively in tank mix with DMIs, SDHIs and QoIs. • 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	
Little evidence to date of reductions in sensitivity to 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).

Eyespot

Oculimacula species

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. Resistance to MBC fungicides has also been detected. Target site mutations affecting field performance of SDHIs have been confirmed in Europe in 2016 and again in 2017/18. Marked declines in azole efficacy were notes at some sites in the UK and Europe in 2017. Chlorothalonil provides good protectant activity and is now an essential component of spray programmes where ramularia is a target.

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 newer 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.

- 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, e.g. chlorothalonil.
- 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.

Ramularia

Ramularia collo-cygni

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. The mutations C-H146R or C-H153R associated with significantly decreased sensitivity were detected in Germany, Ireland, the Netherlands and the UK.

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.

Chloronitriles

Chlorothalonil has no recorded issues with resistance development and has a beneficial protectant effect against air-borne ramularia and also against abiotic spots. It does not target the ramularia that is present systemically within the plant so offers only a partial resistance management strategy. It remains an important mixing partner on barley, for this and other diseases.

- Apply preventatively in tank mix with DMIs and SDHIs

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.

Microdochium

Microdochium nivale and M. majus

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.
MBC-fungicides (Methyl Benzimidazole Carbamates)	
Benzimidazole fungicides became largely ineffective against *Microdochium* spp. in the late 1980s and 1990s owing to the development of widespread resistance.	• Do not rely on MBC fungicides for control of this disease.
Dicarboximides	
Resistance to the dicarboximides was confirmed in the 1990s.	• Do not rely on dicarboximide fungicides for control of this disease.

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	Imazalil Prochloraz
		Triazole	Cyproconazole Difenoconazole Epoxiconazole Flutriafol Ipconazole Metconazole Propiconazole Prothioconazole
Amines (Morpholines) (SBI: Class II)	5	Morpholine Piperidine Spiroketalamine	Fenpropimorph Fenpropidin Spiroxamine
Succinate-dehydrogenase inhibitors (SDHIs)	7	Oxathiin carboxamide	Carboxin
		Pyridine carboxamide	Boscalid
		Pyridinyl-ethyl-benzamide	Fluopyram
		Pyrazole carboxamide	Benzovindiflupyr Bixafen Fluxapyroxad Isopyrazam Penthiopyrad
QoI-fungicides (Quinone-outside Inhibitors)	11	Strobilurin	Azoxystrobin Dimoxystrobin Fluoxastrobin Kresoxim-methyl Picoxystrobin Pyraclostrobin Trifloxystrobin
Thiophene-carboxamides	38	Thiophene-carboxamide	Silthiofam
AP-fungicides (Anilino-Pyrimidines)	9	Anilino-pyrimidine	Cyprodinil

Fungicide Groups for disease control in wheat

Fungicide Groups	FRAC Code	Chemical Families	Common name of active substance
Azanaphthalene	13	Aryloxyquinolines Quinazolinones	Quinoxyfen Proquinazid
PP-fungicides (Phenylpyrroles)	12	Phenylpyrrole	Fludioxonil
MBC-fungicides (Methyl Benzimidazole Carbamates)	1	Thiophanate	Thiophanate-methyl
Amidoximes	U6	Phenyl-acetamide	Cyflufenamid
Aryl-phenyl-ketones	50	Aryl-phenyl-ketone	Metrafenone Pyriofenone
Inorganics - sulphur	M2	Sulphur	Sulphur
Dithiocarbamates	M3	Dithiocarbamate	Mancozeb
Phthalimide	M4	Folpet	Folpet
Chloronitriles (phthalonitriles)	M5	Phthalonitrile	Chlorothalonil

For a constantly updated on-line version of this table, see http://frag.fera.defra.gov.uk/cropspecific.cfm

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 Prochloraz
		Triazole	Cyproconazole Epoxiconazole Flutriafol Ipconazole Metconazole Propiconazole Prothioconazole Tebuconazole
Amines (Morpholines) (SBI: Class II)	5	Morpholine	Fenpropimorph
		Spiroketalamine	Spiroxamine
Succinate-dehydrogenase inhibitors (SDHIs)	7	Oxathiin Carboxamide	Carboxin
		Pyridine carboxamide	Boscalid
		Pyridinyl-ethyl-benzamide	Fluopyram
		Pyrazole carboxamide	Benzovindiflupyr Bixafen Fluxapyroxad Isopyrazam Penthiopyrad
QoI-fungicides (Quinone-outside Inhibitors)	11	Strobilurin	Azoxystrobin Fluoxastrobin Kresoxim-methyl Picoxystrobin Pyraclostrobin Trifloxystrobin
Thiophene-carboxamides	38	Thiophene-carboxamide	Silthiofam
AP-fungicides (Anilino-Pyrimidines)	9	Anilino-pyrimidine	Cyprodinil
Azanaphthalene	13	Aryloxyquinolines Quinazolinones	Quinoxyfen 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
Chloronitriles (phthalonitriles)	M5	Phthalonitrile	Chlorothalonil

For an updated on-line version of this table, see http://frag.fera.defra.gov.uk/cropspecific.cfm

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