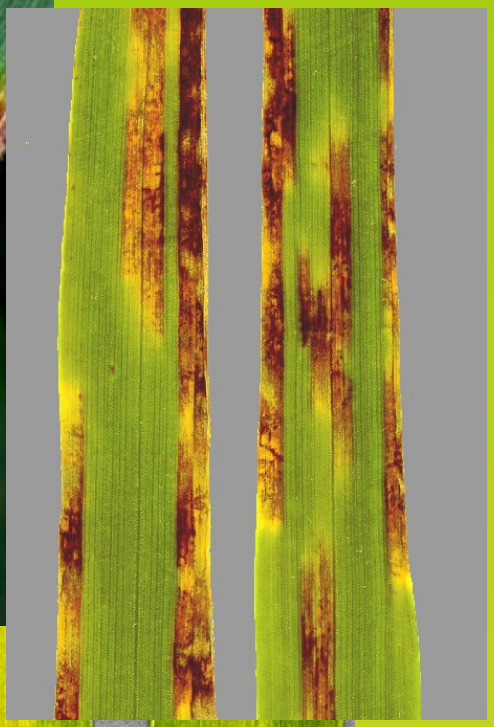
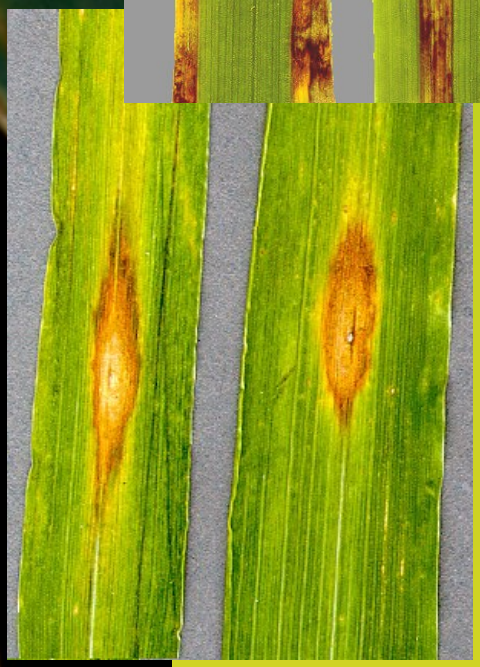
Fungicide Resistance Management in Cereals

FRAG - UK





2015 Edition

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Fungicide Resistance Management in Cereals

Introduction

Fungicides, in combination with exploitation of resistant varieties and other agronomic and cultural techniques, will be the mainstay of cereal disease control for the foreseeable future and so must be protected from the threat of resistance.

Applying appropriate products at the right time and at the right dose is critical for good disease control. Poor field performance can often be attributed to cutting recommended rates of use, or to poor or mistimed application, rather than resistance. The risk of development of resistance is linked to a number of factors including the specific mode of action (MOA) of the fungicide, the biology of the target pathogen and the level of exposure of the pathogen to the fungicide. Resistance management is vital to maintain effective control whilst minimising over-exposure of the pathogen and reducing the risk of resistance developing.

This publication incorporates the many developments that have occurred in recent years, in particular, fungicides representing a number of new groups have been registered, which offer a greater opportunity to minimise the risk of resistance developing.

Resistance terminology

Resistance occurs when a pathogen becomes so insensitive to a fungicide that the fungicide's field performance is impaired. Resistance can arise rapidly and completely so that disease control is lost in a single step. More commonly, resistance develops gradually so that the pathogen becomes progressively less sensitive. When this happens there is usually no initial detectable loss of control.

Laboratory testing can reveal a number of things about fungal strains isolated from the field. They can tell us about the genetic make-up of the isolate and how it has changed (mutated) by comparison with sensitive "wild-type" isolates from many years ago (so called 'base-line' sensitivity). Growth tests on laboratory media with different doses of fungicide can show how sensitive that isolate is compared with the wild type. Where selection has taken place, it is often very difficult to find any 'wild type' isolates because such isolates are very sensitive to fungicides and have been removed from the population by frequent fungicide use. The isolates that remain are less sensitive than the wild type – often by a large factor – up to 1000 times less sensitive in lab tests, These isolates may only be slightly less sensitive in practical terms and still controlled in the field by robust fungicide programmes or they may be highly resistant, leading to field control failure.

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 once it has occurred.

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 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 number of applications.

Septoria leaf spot

Mycosphaerella graminicola / Septoria tritici

Introduction

Mycosphaerella graminicola (*Septoria tritici, Zymoseptoria 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, *M. graminicola* developed resistance to benzimidazole fungicides (MBCs). Isolates resistant 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 with notable increases in the frequency of resistant isolates occurring during 2003 and 2004. Since then, the sensitivity of Septoria to the DMIs has continued to decline and field performance, particularly at reduced doses, has deteriorated further. Several azoles, primarily epoxiconazole and prothioconazole, continue to provide good control at full label doses.

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, some of which affect the sensitivity of *M. graminicola* to particular azole fungicides, while others have no measurable impact on sensitivity.

- Use in mixture with fungicides with good efficacy e.g. SDHI or chlorothalonil. Use at an effective dose to ensure a high level of disease control.
- Do not use DMIs alone. Alternate or mix fungicides with different modes of action in repeat spray programmes if possible.
- 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 spot

Mycosphaerella graminicola / Septoria tritici

Fungicide Groups

Resistance risk	Suggested use
Quinone outside inhibitors (QoIs) - Strobilurins	
Due to prevalence of the G143A mutation within the population, resistant isolates of *M. graminicola* are widespread at high levels throughout the UK. Despite this, QoIs still give some control and yield responses are still evident.	• 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. • Useful in programmes for their 'greening effect' and for control of rusts.
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 *M. graminicola* as part of an anti-resistance strategy when mixed with DMIs, SDHIs or QoIs, particularly at protectant spray timings.	• Apply preventatively in tank mix with DMIs, SDHIs and QoIs. • Use as part of an anti-resistance strategy with DMIs, SDHIs and QoIs. • 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, SDHIs and QoIs. • Use appropriate doses to ensure protection of the partner fungicide.
Succinate-dehydrogenase inhibitors (SDHI)	
Field isolates with several target site mutations conferring reduced sensitivity were identified in Europe in 2012-2014. Many of the identified mutations have low to moderate resistance factors for commercially available SDHIs and the frequency of the resistant mutations remains low. Field performance remains high. In the UK cereal market SDHI fungicides are currently limited to two applications per season and are recommended in mixtures or formulated with other fungicides. The resistance risk in *M. graminicola* is considered to be moderate/high.	• Useful as partner for DMI fungicides giving broad-spectrum disease control. • Different mode of action offers improved anti-resistance management strategies. • Always apply in mixture with other fungicide groups. • Ensure that the statutory limit of two foliar sprays containing SDHI fungicides is not exceeded.
Phthalimide	
Folpet is a multi-site fungicide with protectant activity. This makes it a useful partner against *M. graminicola* as part of an anti-resistance strategy when mixed with DMIs, SDHIs or QoIs, particularly at early (GS31-32) spray timings.	• Apply preventatively in tank mix with DMIs, SDHIs and QoIs. • 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 resistant 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 against mildew. • 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 where an alternative mode of action mildewicide is required.
Amidoxines	
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 against mildew. • 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.	• Moderately curative for mildew when applied during the latent phase. • 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.

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 resistant isolates 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*) and Septoria (*Septoria tritici*) in Europe but field performance remains high.
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 azole fungicides so resistance risk is considered to be moderate.

- Useful as partner for DMI fungicides giving broad-spectrum disease control.
- Always apply in mixture with other fungicide groups.
- Limit the number of foliar applications of SDHI fungicides to the statutory limit of two.

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.

Disease pressure on susceptible varieties can lead to intensive use of fungicides which can impact on the resistance risk of other pathogens such as *Septoria 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 repeat spray programmes if possible. • Minimise selection pressure frpm DMIs on *Septoria 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 (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*) and Septoria (*Septoria tritici*) in Europe but field performance remains high.

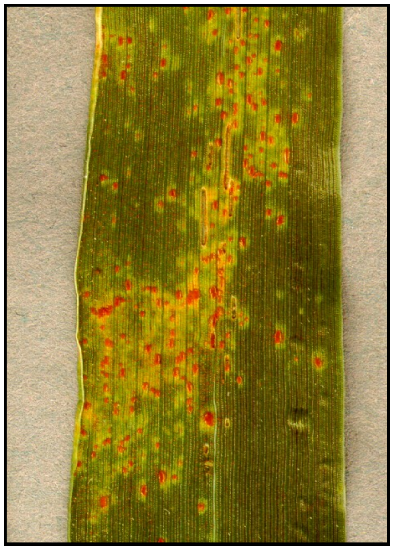
There are no reports of mutations affecting performance of SDHIs against yellow rust. In the UK cereal market SDHI fungicides are currently recommended in mixtures or formulated with azole fungicides so resistance risk is considered to be moderate.

- Useful as partner for DMI fungicides giving broad-spectrum disease control.
- Always apply in mixture with other fungicide groups.
- Limit the number of foliar applications of SDHI fungicides to the statutory limit of two.

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 relatively minor 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 markedly in the last few years Tan spot was the second most common foliar disease in the 2014 national survey, affecting 15% of crops (although disease severity was very 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, which results in lower levels of resistance expression compared to the G143A mutation (which has now also been found within the pathogen population). Resistant isolates have been identified in a number of countries across 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 repeat 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, resistant isolates 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.	• 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

Net blotch occurs sporadically depending on location and seasonal weather.
Incidence and severity of net blotch has declined in winter barley in recent years and 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.
Whilst no recent data are available, 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.

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 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	
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 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.
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.

Net blotch

Pyrenophora teres / Drechslera teres

Fungicide Groups

Resistance risk | **Suggested use**

Succinate-dehydrogenase inhibitors (SDHI)

Isolates of *Pyrenophora teres* with slightly reduced sensitivity were found in northern Germany in 2012 but the resistance factor was low and field performance was not affected. In 2012 two isolates of net blotch were detected in Germany with sensitivities outside the base-line. Resistance factors in both cases 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. In 2014, more isolates were detected with reduced sensitivity, carrying different mutations in France, Italy, Germany and UK.

Several SDH mutations have now been found in *Pyreno-phora teres*. In recent testing the resistance factors were low for B-H277Y, D-D124E, D-D145G and moderate for C-G79R, C-H134R, C-S135R, C-N75S, C-R64K, D-H134R, C-K49E. The predominant mutation was C-G79R

Field performance remains high.

In the UK cereal market SDHI fungicides are generally recommended in mixtures or formulated with azole fungicides but resistance risk is considered to be moderate/high.

- Useful as partner for DMI fungicides giving broad-spectrum disease control.
- Always apply in mixture with other effective fungicide groups.
- Ensure that the statutory limit of two foliar sprays containing SDHI fungicides is not exceeded.

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 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 but recent surveys have not found further cases. There are reports of isolates from Ireland carrying the G143A mutation. However, 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 (SDHI)	
In the UK cereal market SDHI fungicides are currently recommended in mixtures or formulated with azole fungicides so resistance risk is considered to be moderate.	• Different mode of action offers improved *Rhynchosporium* control over partner triazole alone. • Always use in mixture with an effective fungicide with an alternative mode of action. • Limit the number of foliar applications of SDHI fungicides to the statutory limit of two.
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 triazoles, 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 QoIs.

Fungicide Groups

Resistance risk	Suggested use
Sterol demethylation inhibitors (DMIs) – Triazoles	
Little evidence to date of reductions in sensitivity to the more active triazoles with some fungicides (e.g. prothioconazole) showing good activity.	• Use a triazole 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 (pre – GS32) timings.

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. The product has now been used for several years on UK cereals.	• 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 (SDHI)	
In the UK cereal market SDHI fungicides are generally recommended in mixtures or formulated with azole fungicides so resistance risk is considered to be moderate.	• Use of boscalid at early gives good eyespot control in wheat and barley. • Always apply with an effective mixture partner. • Limit the number of foliar applications of SDHI fungicides to the statutory limit of two.
Aryl-phenyl-ketone	
Risk is currently unknown.	• Metrafenone can give useful eyespot control • Low doses used for mildew control may not be sufficient for effective eyespot control. • Good 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 in efficacy. Sensitivity to DMIs is variable and many older azoles are very limited in their efficacy. Chlorothalonil provides protectant activity but has limited efficacy on the systemic component of the infection. SDHI fungicides show good efficacy and must be stewarded carefully to maintain efficacy.

Fungicide Groups

Resistance risk	Suggested use

Sterol demethylation inhibitors (DMIs) – Triazoles

Sensitivity testing is limited but Ramularia is closely related to *Septoria tritici* and shows similar issues with reduced sensitivity to older DMIs. Field efficacy of prothioconazole remains good but performance with older DMI products is often poor. Epoxiconazole is also effective especially when applied in mixture with SDHIs.

- 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.
- Base treatments on effective DMI products.
- Use in mixture with fungicides with good efficacy e.g. SDHI or chlorothalonil.
- Apply fungicides at a timing that allows for maximum protectant activity – this is prior to heading and spot 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.
- Do not apply more than two applications of QoI containing fungicides.

Succinate-dehydrogenase inhibitors (SDHI)

Isolates with reduced sensitivity to SDHIs have been reported but no target site mutations have been identified.
This group of fungicides shows good efficacy against Ramularia but are at risk so should be very carefully stewarded to maintain efficacy.
The risk of resistance development is high

- Always apply with an effective DMI mixing partner.
- The rate of the effective mixing partner should be sufficient to match the efficacy of the SDHI component.
- Limit the number of foliar applications of SDHI fungicides to the statutory limit of two.

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, SDHIs and SDHIs

Microdochium

Microdochium nivale and M. majus

Introduction

There are many species of *Fusarium* that affect cereals. These fungi form a complex of diseases on seeds, seedlings and adult plants. The seed-borne *Microdochium* (formerly considered as *Fusarium nivale*) now known to consist of 2 species - *M. majus* and *M. nivale* is usually included in this group of fungi.

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) – Triazoles	
There are no reports of resistance to DMI fungicides in *Microdochium* spp. but the 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 Fenbuconazole Fluquinconazole Flutriafol Ipconazole Metconazole Propiconazole Prothioconazole Tebuconazole Triadimenol
Amines (Morpholines) (SBI: Class II)	5	Morpholine Piperidine Spiroketalamine	Fenpropimorph Fenpropidin Spiroxamine
Succinate-dehydrogenase inhibitors (SDHI)	7	Oxathiin carboxamide	Carboxin
		Pyridine carboxamide	Boscalid
		Pyrazole carboxamide	Bixafen Fluxapyroxad Isopyrazam Penthiopyrad
QoI-fungicides (Quinone-outside Inhibitors)	11	Oxazolidinedione Strobilurin	Famoxadone Azoxystrobin Dimoxystrobin 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
PP-fungicides (Phenylpyrroles)	12	Phenylpyrrole	Fludioxonil

Fungicide Groups for disease control in wheat

Fungicide Groups	FRAC Code	Chemical Families	Common name of active substance
Dicarboximides	2	Dicarboximide	Iprodione
Benzo-thiadiazole BTH	P1	Benzothiadiazole	Acibenzolar-S-methyl
MBC-fungicides (Methyl Benzimidazole Carbamates)	1	Benzimidazole	Carbendazim
			Fuberidazole
		Thiophanate	Thiophanate-methyl
Amidoxines	U6	Phenyl-acetamide	Cyflufenamid
Aryl-phenyl-ketones	U8	Aryl-phenyl-ketone	Metrafenone Pyriofenone
Inorganics - carbonates	NC	Inorganic	Potassium hydrogen carbonate
Inorganics - copper	M1	Copper	Cupric ammonium carbonate
Inorganics - sulphur	M2	Sulphur	Sulphur
Dithiocarbamates and relatives	M3	Dithiocarbamate	Mancozeb Maneb Thiram Ziram
Phthalimide	M4	Folpet	Folpet
Chloronitriles (phthalonitriles)	M5	Phthalonitrile	Chlorothalonil
Guanidines	M7	Guanidine	Guazatine

For a constantly updated on-line version of this table, see http://frag.csl.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 Fluquinconazole Flutriafol Ipconazole Metconazole Propiconazole Prothioconazole Tebuconazole Triadimenol Triticonazole
Amines (Morpholines) (SBI: Class II)	5	Morpholine Piperidine Spiroketalamine	Fenpropimorph Fenpropidin Spiroxamine
Succinate-dehydrogenase inhibitors (SDHI)	7	Oxathiin carboxamide	Carboxin
		Pyridine carboxamide	Boscalid
		Pyrazole carboxamide	Bixafen Fluxapyroxad Isopyrazam Penthiopyrad
QoI-fungicides (Quinone-outside Inhibitors)	11	Oxazolidinedione Strobilurin	Famoxadone 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
PP-fungicides (Phenylpyrroles)	12	Phenylpyrrole	Fludioxonil
Dicarboximides	2	Dicarboximide	Iprodione

Fungicide Groups for disease control in barley

Fungicide Groups	FRAC Code	Chemical Families	Common name of active substance
MBC-fungicides (Methyl Benzimidazole Carbamates)	1	Benzimidazole	Carbendazim Fuberidazole
Benzotriazines	35	Benzotriazine	Triazoxide
Amidoxines	U6	Phenyl-acetamide	Cyflufenamid
Aryl-phenyl-ketones	U8	Aryl-phenyl-ketone	Metrafenone
Inorganics - carbonates	NC	Inorganic	Potassium hydrogen carbonate
Inorganics - copper (different salts)	M1	Copper	Cupric ammonium carbonate
Inorganics - sulphur	M2	Sulphur	Sulphur
Dithiocarbamates and relatives	M3	Dithiocarbamate	Mancozeb Maneb Thiram Ziram
Phthalimides	M4	Folpet	Folpet
Chloronitriles (phthalonitriles)	M5	Phthalonitrile	Chlorothalonil
Guanidines	M7	Guanidine	Guazatine

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

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This leaflet and further information on resistance are available at http://www.pesticides.gov.uk/rags.asp?id=644

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