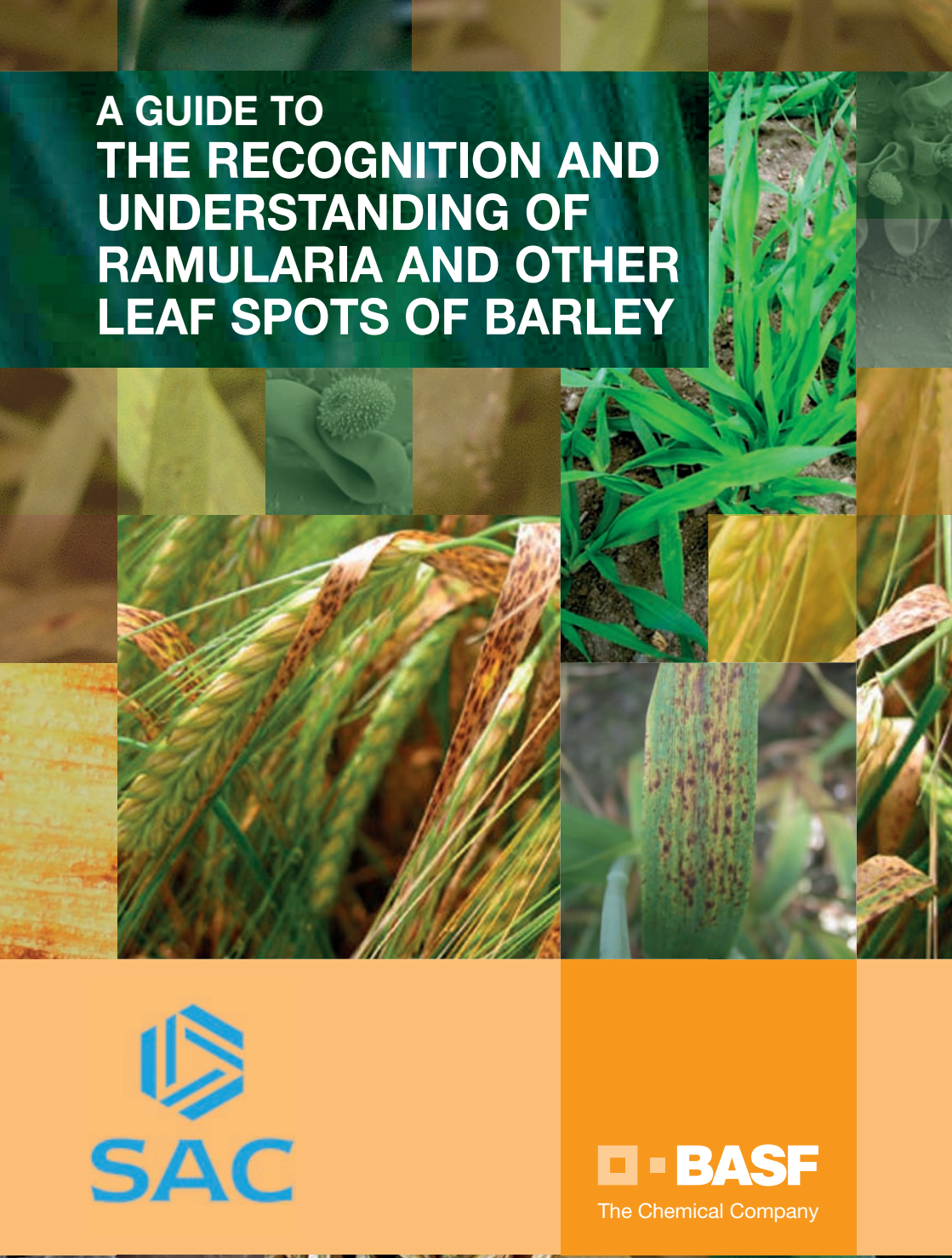
A GUIDE TO THE RECOGNITION AND UNDERSTANDING OF RAMULARIA AND OTHER LEAF SPOTS OF BARLEY



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Introduction

Ramularia, or more fully ramularia leaf spot, is the common name for the barley disease caused by the fungus *Ramularia collo-cygni*.

The disease was first recorded in 1893, but it is only in the last 15 years that it has become recognised as an economically important disease both in Europe, Argentina and New Zealand. The disease is however more widespread and in some regions remains under reported, since ramularia leaf spot symptoms are easily mistaken for other more common diseases or misidentified as physiological leaf spots.

In some areas it is has become one of the key diseases threatening barley and therefore should be a key consideration when planning fungicide programmes. Nevertheless, there remains some confusion regarding its identification, particularly in areas where it currently occurs infrequently.

The primary motivation for producing this guide is therefore to help with identification. The inclusion of photographs of 'spots' produced by a range of other factors will further help to distinguish ramularia in the field.

Information on the background biology of this important disease is also included, which will add interest, as well as an appreciation of how best to approach its control.

There is still more to learn about the epidemiology of ramularia leaf spot, but some advice is given on the current integrated control measures which can be taken to help limit the loss in yield and quality caused by ramularia, as well as physiological leaf spots.

The production of this guide was a team effort bringing together the authors Simon Oxley, Neil Havis and Andy Evans of SAC together with Steve Waterhouse and Lindy Tonguç of BASF who edited and formatted it. The publication was funded by BASF and SAC. We hope you find it interesting and informative.

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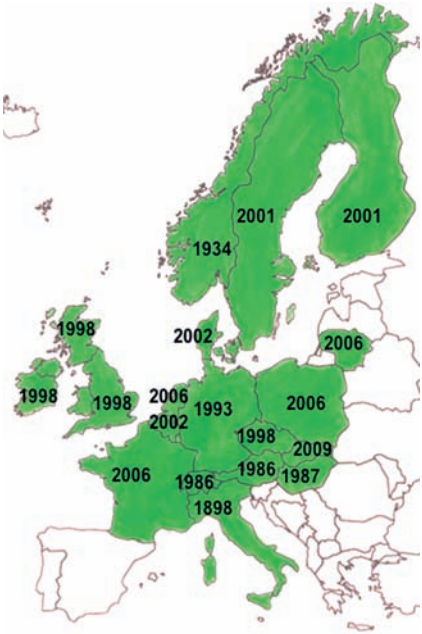
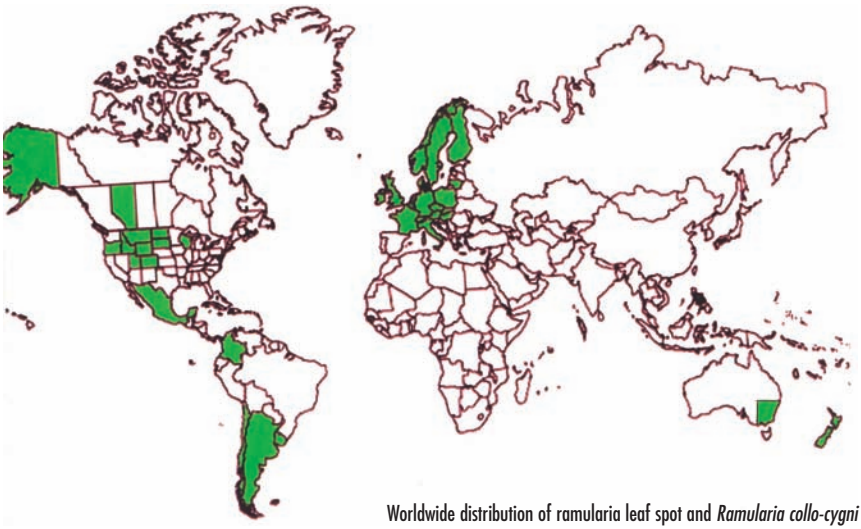
Ramularia leaf spot distribution

Ramularia leaf spot caused by the fungus *Ramularia collo-cygni* is recognised as an economically important disease of barley in Europe, South America and New Zealand. The fungus has been reported on other grass species and also on maize and is likely to be more widely distributed in regions where barley is not grown or where ramularia leaf spot is not recognised to be a serious threat to barley.

The disease has been reported throughout Europe and these maps show the countries where ramularia leaf spot was first reported on barley in Europe and throughout the world.



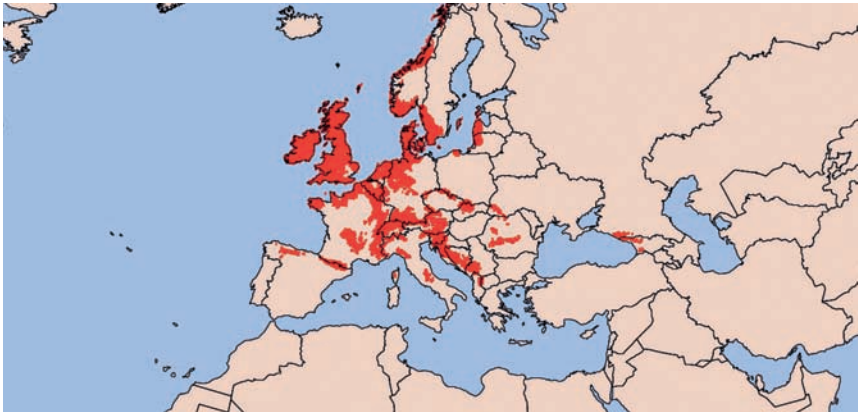
First reported outbreaks of ramularia leaf spot in Europe



Worldwide distribution of ramularia leaf spot and *Ramularia collo-cygni*

The potential distribution of the disease has been mapped using climate matching software. These maps are based on the optimum weather conditions for Scotland, where the disease is established as an important economic disease.

It shows the potential for the disease to become established in most European countries including countries around the Black Sea where no official outbreaks have been confirmed.

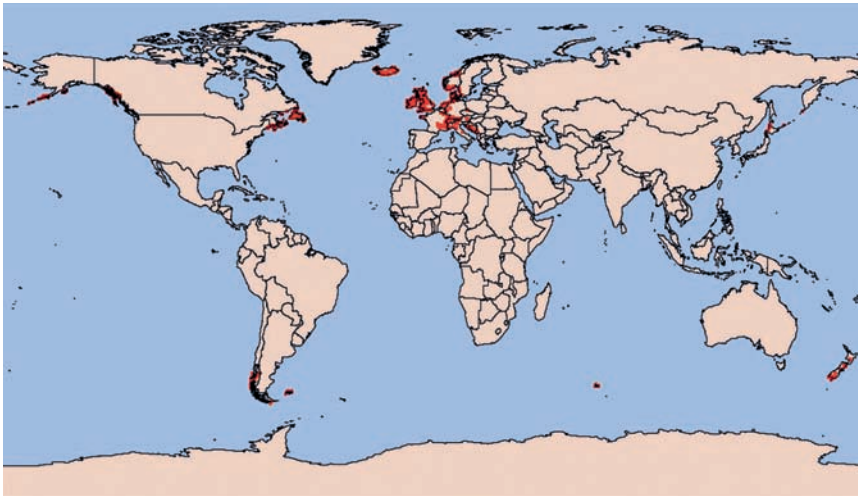


Regions in Europe where weather conditions are suitable for ramularia leaf spot

In the southern hemisphere, New Zealand is at risk from ramularia leaf spot and the disease is well established in that region. The disease has also been reported in the New South Wales region of Australia.

Regions in Australia & New Zealand where weather conditions are suitable for ramularia leaf spot

The world map based on the potential distribution of the disease shows the greatest risk from ramularia leaf spot to be Europe, New Zealand, Argentina and the east and west coast of Canada. This distribution links well with known outbreaks, but the disease is more widespread in North and South America suggesting the pathogen can adapt to different climates.



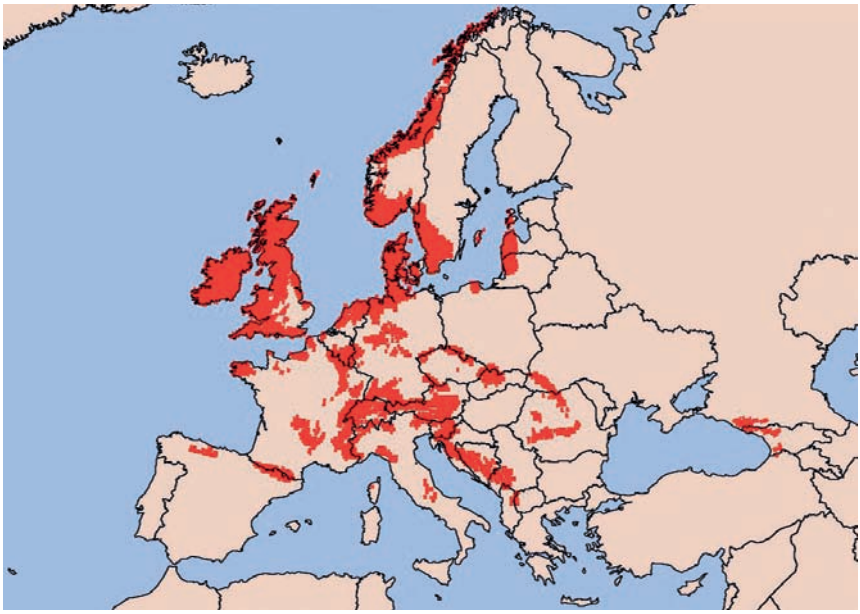
Regions where weather conditions are suitable for ramularia leaf spot

Since seed movement is an important method of spreading the fungus, there is a real threat that ramularia leaf spot will become endemic in these regions if barley is grown.

If new populations of the fungus develop which enable the fungus to adapt to new environments, the regions where the disease could become economically important will increase further.

Future projection of risk in Europe from ramularia leaf spot

Using a climate change forecast based on medium greenhouse gas emissions, the disease has the potential to remain a problem in the same countries in 2050, but the distribution within those countries can change. A greater threat will come from changes in the pathogen, which could lead to new races developing which can adapt to climate change or enable the disease to spread to other barley growing regions.



Projected distribution of ramularia leaf spot in 2050

What are the symptoms of ramularia leaf spot on barley leaves?

Early stages

At the earliest stage of symptom development, small brown irregular "pepper spots" appear on the leaf. These are just visible to the naked eye.

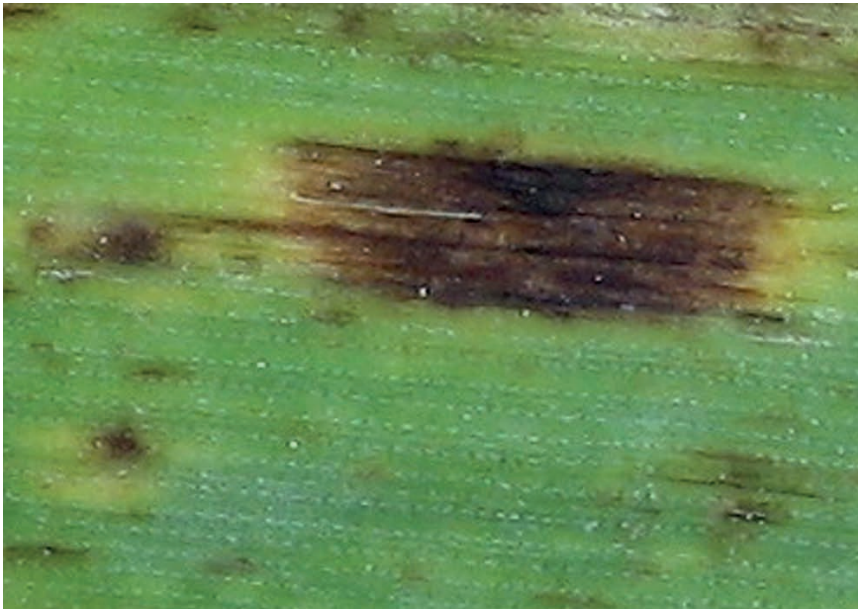
At this very early stage, the symptoms can be indistinguishable from physiological leaf spots caused by high light. However, ramularia leaf spots will be visible on both sides of the leaf, unlike physiological leaf spots which are more superficial and only visible on the side of the leaf exposed to the light.

Intermediate stage

The early "pepper spot" symptom of ramularia quickly develops into typical ramularia leaf spot lesions. Look for rectangular dark brown lesions typically 2 mm x 0.5 mm in size. They have straight longitudinal sides where the lesions are defined by the leaf ridges. The shorter sides of the lesions are more irregular. At the centre of the brown lesions there is the darker brown centre where the original "pepper spot" symptom occurred. The whole brown rectangular lesion is surrounded by a yellow (or chlorotic) halo. This in turn is surrounded by a normal green leaf at this intermediate stage.

Distinctive features of ramularia leaf spot lesions are that they are easily seen both on the upper and lower surface of the leaf and the longitudinal edges of the brown lesion remain enclosed by the leaf ridges.

Pepper spot symptom of ramularia leaf spot alongside distinctive rectangular symptoms.



Pepper spot symptom of ramularia leaf spot alongside distinctive rectangular symptoms.

Pepper spot symptom of ramularia leaf spot alongside distinctive rectangular symptoms.

Classic ramularia leaf spot symptoms surrounded by pepper spot symptoms

Classic ramularia leaf spot lesions on upper side on leaf

Classic ramularia leaf spot symptoms on underside of the same leaf

Later stage

The rectangular lesions remain visible on the upper and lower side of the leaf but the leaf dies back rapidly losing all its green leaf initially turning yellow (chlorotic) before dying back completely. This die-back usually starts to occur at the leaf tip. On the underside of the dead leaf, translucent spores of *Ramularia collo-cygni* develop in lines coming out from the leaf pores (stomata). These spores are not associated with the dark rectangular lesions which will still be visible on the dead leaves. The translucent spores can be seen using a magnifying hand lens or occasionally by the naked eye. Wet conditions late in the season can lead to a red colouration around ramularia leaf spot lesions on dead leaves.

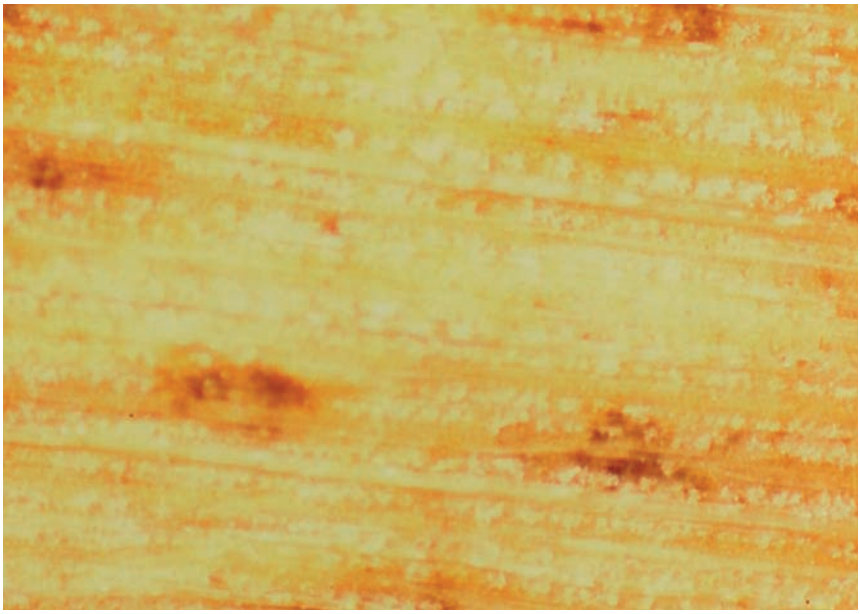
Later stage of ramularia leaf spot

Later stage of ramularia leaf spot on the underside of the same leaf

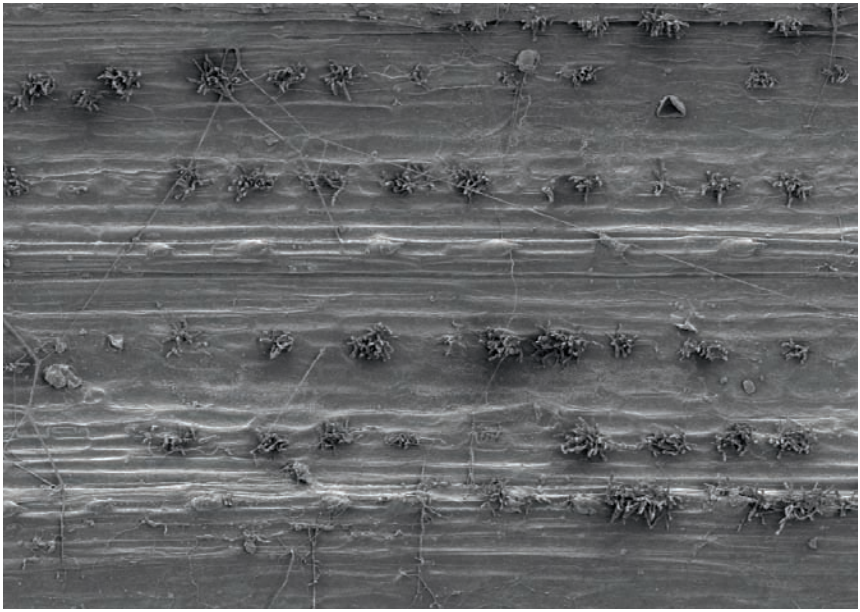
Later stage of ramularia leaf spot showing loss of green leaf area at leaf tip

Extensive ramularia leaf spot symptoms on leaf surrounded by dead leaf

Extensive ramularia leaf spot symptoms on leaf surrounded by dead leaf



Spores of *Ramularia collo-cygni* on the underside of a barley leaf



Spores of *Ramularia collo-cygni* on the underside of a barley leaf (Scanning electron micrograph)

Ramularia leaf spot symptoms on stems and awns

Ramularia leaf spot lesions also appear on the awns and leaf sheaths on barley stems. The dark brown rectangular lesions are small when compared to leaf symptoms, but they also comprise dark brown rectangular flecks surrounded by a yellow halo. The lesions continue to remain visible after the awns and leaf sheaths have died-back.

Ramularia leaf spot on flag leaf and leaf sheath

Early stage of ramularia leaf spot on flag leaf surrounded by green leaf

Later stage of ramularia leaf spot on flag leaf with no green leaf remaining

Ramularia leaf spot symptoms on flag leaf and awns

Ramularia leaf spot on seed

It is uncommon to recognise typical ramularia leaf spot lesions on the seed. Seed is however an important source of infection of *Ramularia collo-cygni*.

Ramularia collo-cygni is deep seated in the seed and cannot be identified visually

When do symptoms of ramularia leaf spot appear in crops?

Tillering growth stages to flag leaf emergence.

At tillering growth stages (GS25-30), ramularia leaf spot symptoms can develop on lower leaves which are dying back naturally or as a consequence of crop stresses caused by either nutritional deficiencies (i.e. low nitrogen), weather (i.e. frosts) or leaf scorch from the application of agronomic inputs. It is unusual to see ramularia leaf spot symptoms develop on newly emerged leaves and the leaves of healthy unstressed crops.

Post ear emergence

When crops start to flower (GS61-69), ramularia leaf spot symptoms can start to appear on the top leaves. Exposure to sunlight is an important stress factor which leads to symptoms developing hence the incidence of ramularia leaf spot is higher on the top two leaves.

Varieties which have an upright growth habit and crops which have low plant populations can show more symptoms lower down the canopy, primarily due to increased light. Thicker crops and varieties with prostrate leaves or ears can show fewer symptoms where the upper leaves, ears and awns provide shade to the lower canopy.

The process of flowering is also an important natural stress factor where the plant mobilises nutrient reserves away from the leaves in order to provide greater resources for ear and grain development.

Crops which have limited fertiliser inputs (i.e. crops grown for low nitrogen malting barley) will show ramularia leaf spot symptoms earlier than feed barley crops where nitrogen is less limiting.

Early maturing varieties will also show symptoms earlier than later maturing varieties.

Flowering is an important natural stress factor which leads to development of ramularia leaf spot symptoms

Disease lifecycle

The causal fungus of ramularia leaf spot (*Ramularia collo-cygni*) was first reported in 1893 in Italy. The fungus has also been called *Ophiocladium hordei*, *Ovularia hordei* and *Ramularia hordeicola* in scientific literature. More recent work would suggest the fungus is a *Mycosphaerella* species. Although the name of the causal fungus is likely to continue to change, the common name of the disease is now recognised as ramularia leaf spot.

Source of infection

One of the sources of infection for ramularia leaf spot is the seed. This can not be identified visually, but its presence can be confirmed using molecular diagnostic tests. In regions where the disease is not common, seed is likely to be an important source of the disease. Movement of seed is therefore a potential method to spread *Ramularia collo-cygni* populations into new regions. Furthermore, populations which may be more aggressive pathogens or which may be resistant to fungicides could also be spread through seed movement. Although the testing of seed for *Ramularia collo-cygni* is not required as a statutory seed test, methods exist which can identify the fungus in seed.

Other sources of infection include airborne spores coming from barley volunteers and grasses. A second fungal body known as asteromella also exists in stubble. The importance of this stage in subsequent infection and the production of new fungal populations are under investigation.

Asymptomatic or invisible phase

When seedlings start to emerge, *Ramularia collo-cygni* fungus will grow inside the plant and move into new leaves as they develop. The plants will however show no visible disease symptoms of ramularia leaf spot. During this phase of the disease the fungus co-exists with the plant host as an endophyte. The impact the fungus has on the plant during this symptomless phase is unknown. The existence of endophytes is common in nature, particularly in grasses and indeed, endophytes have been shown to be beneficial to the host plant in some situations.

Symptomatic or visible phase

When leaves start to die-back either as a consequence of natural ageing, weather or nutritional stresses, changes occur in the fungus within the leaf, leading to the production of plant toxins, identified as rubellins, which contribute to symptom development. Rubellins belong to a group of closely related anthraquinoid metabolites (rubellin A, B, C and D). Rubellin D is closely linked to the formation of typical ramularia leaf spot symptoms and later to leaf death as it spreads out from the initial source of infection to the rest of the leaf. The overall result of rubellin D formation by the fungus is extensive and premature leaf death. Although there is more fungus inside the lower leaves compared to the upper leaves, more symptoms appear at the top of the crop canopy. This occurs because the rubellin D produced by the fungus is activated by light to trigger the production of reactive oxygen species. Plants grown under shading are known to produce fewer ramularia leaf spot symptoms than plants grown in natural light. Restricting light will however reduce both crop yield and grain quality.

Spore dispersal

Leaf wetness is an important factor in spore dispersal and the infection of barley from airborne spores. The duration of leaf wetness in the spring is linked to the severity of ramularia leaf spot symptoms which occur after flowering. This observation can be used as a method to forecast the potential risk of ramularia leaf spot.

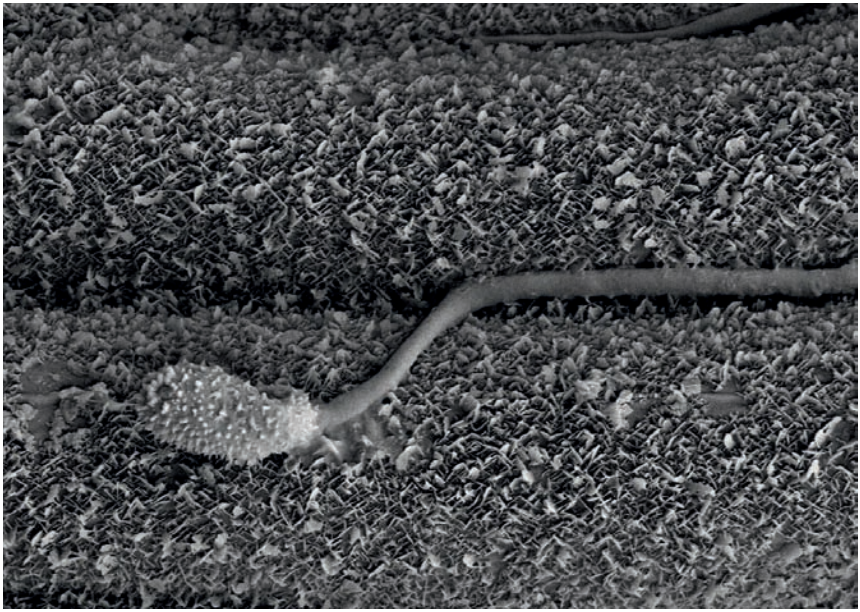
Leaf wetness is important for infection and can be used to forecast disease risk

Water logging is an important stress factor for ramularia leaf spot

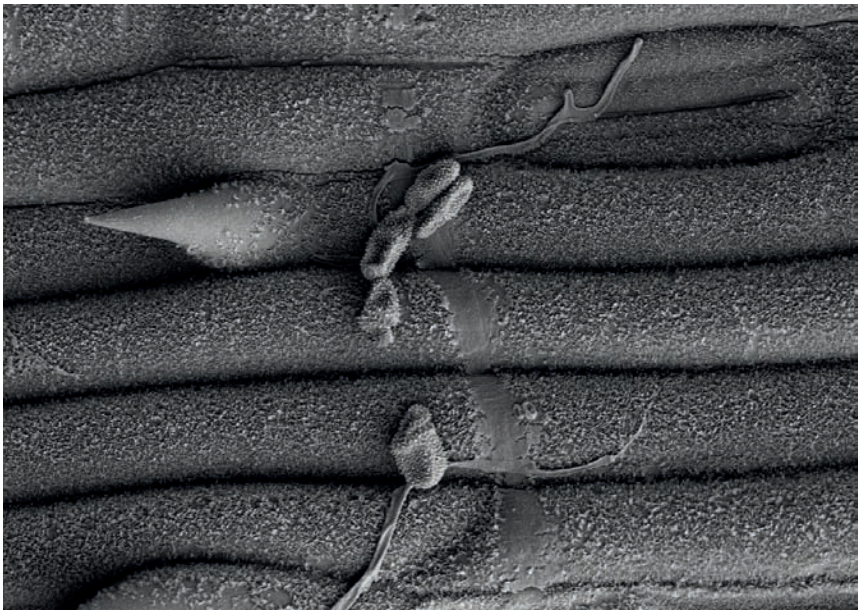
Secondary infections during the season

When ramularia leaf spot symptoms are present in a crop, secondary infections can occur as spores are dispersed from infected leaves. Airborne dispersal of *Ramularia collo-cygni* spores is reliant on leaf wetness. This is more important than rainfall. Spores are dispersed into the air 24-48 hours after a prolonged period of leaf wetness of several hours. These airborne spores can lead to secondary infection of leaves and they infect leaves through leaf pores (stomata). The dispersed spores are also likely to colonise barley heads and awns and also grasses which are known to be a secondary host for the disease. It is not known if barley seed is infected primarily by the airborne spores or infected by the fungus developing inside the plants.

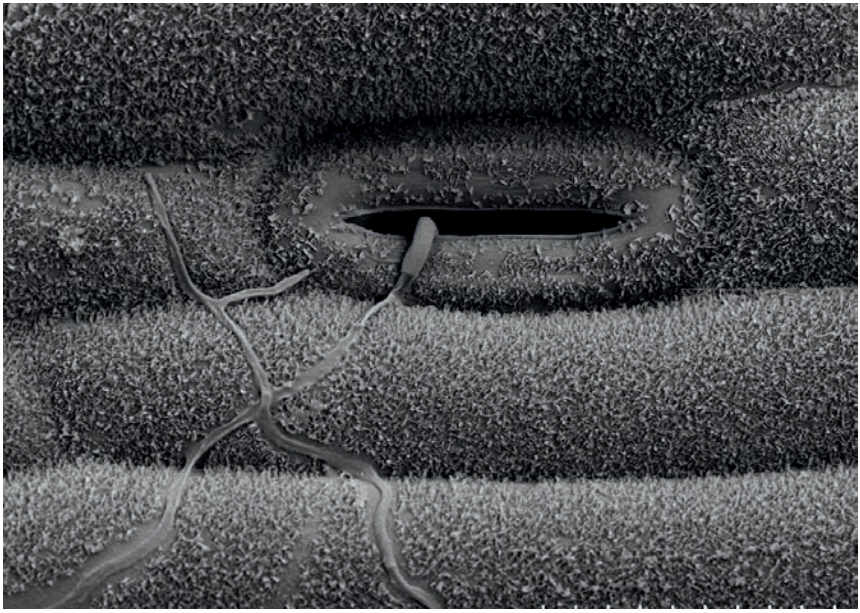
Secondary infection of leaves from airborne spores



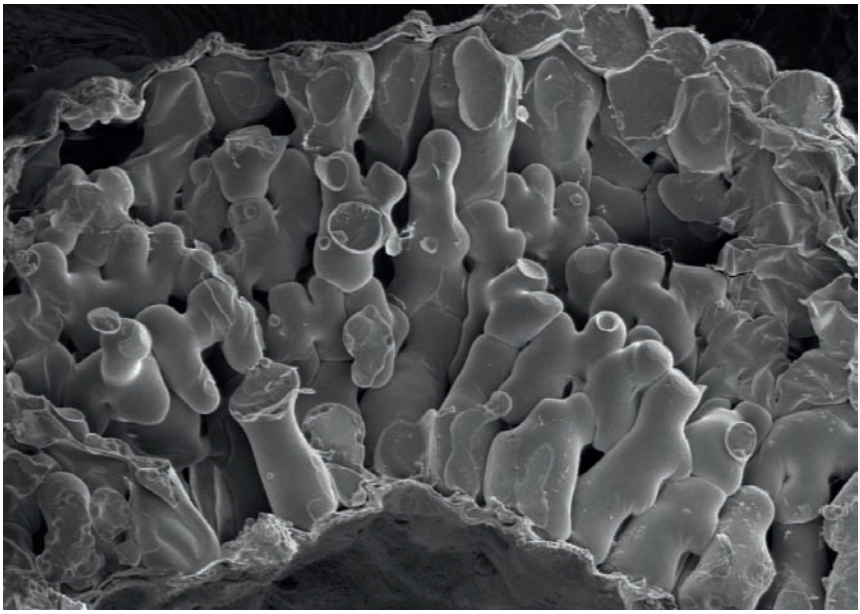
Spore of *Ramularia collo-cygni* growing on leaf surface



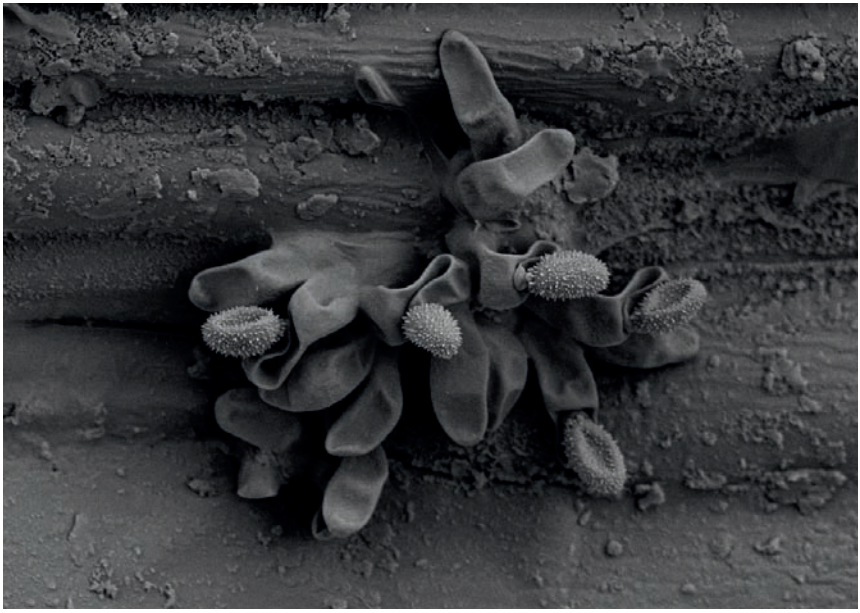
Infection of barley by *Ramularia collo-cygni* through stomata (leaf pore)



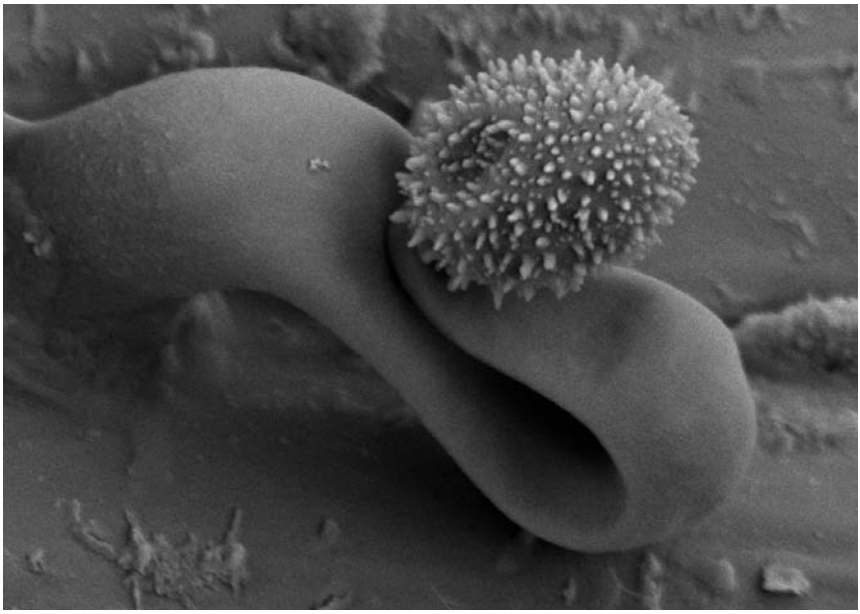
Infection of barley by *Ramularia collo-cygni* through stomata (leaf pore)



Cross section of Ramularia leaf spot symptoms



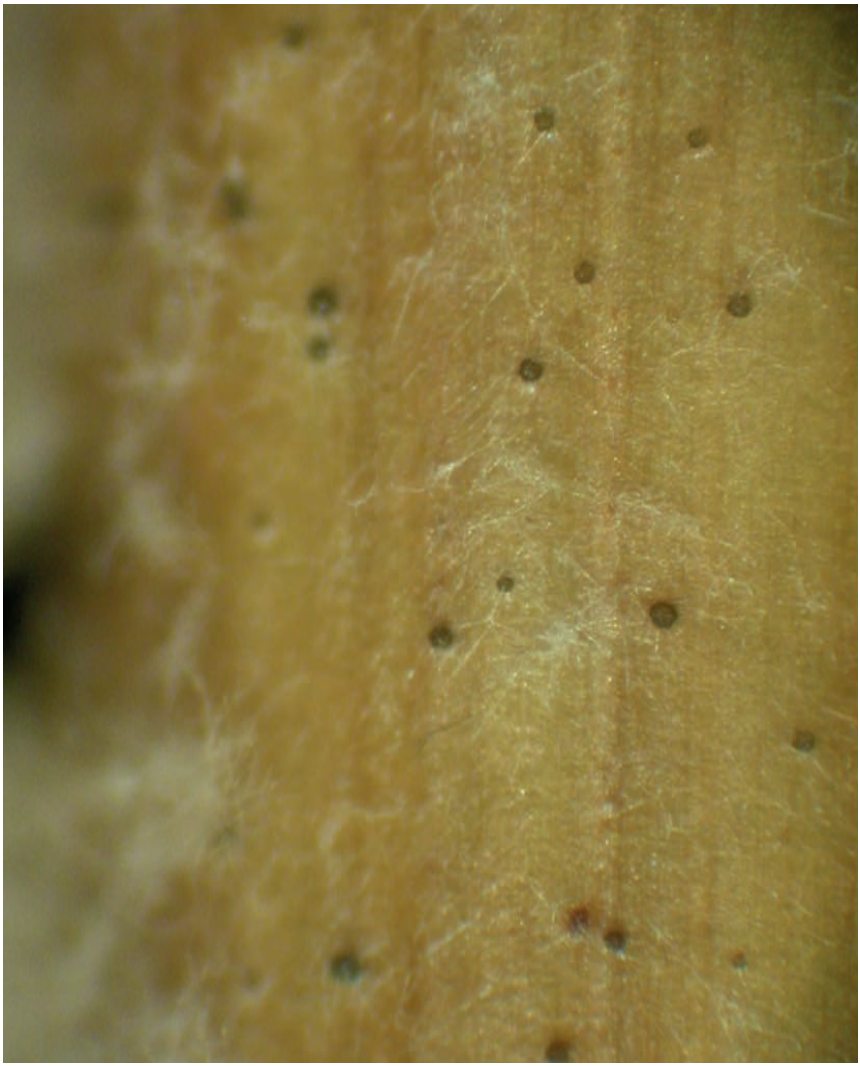
Clusters of *Ramularia collo-cygni* spores on leaf surface



Ramularia collo cygni spore on distinctive curved conidiophore

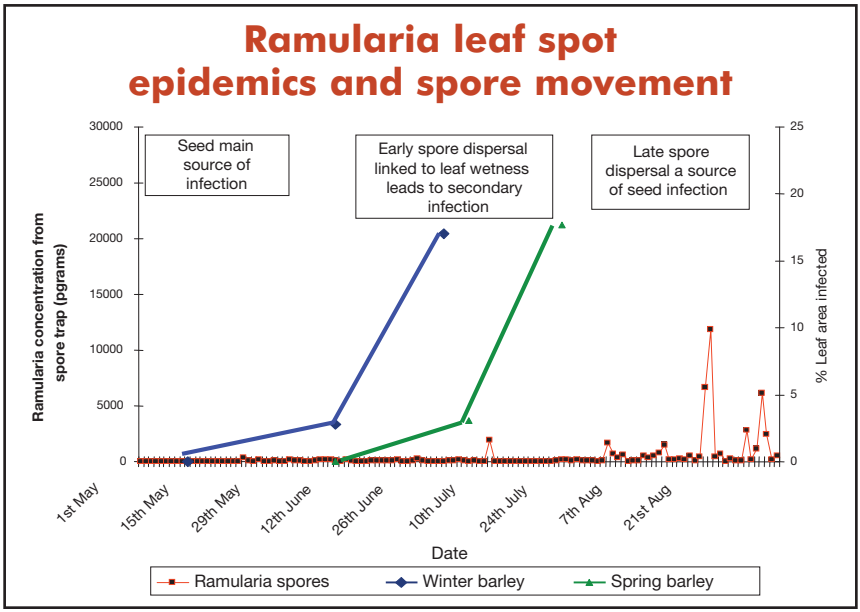
Asteromella production

Ramularia collo-cygni produces a second type of spore known as asteromella. They develop late in the season on straw. The importance of this second spore body on the disease epidemic is not fully understood, but they are a potential source of secondary spores in stubble which can infect the following barley crop. They are also a potential method for the pathogen to reproduce sexually leading to the formation of new races which may adapt to changes in climate and fungicide usage.

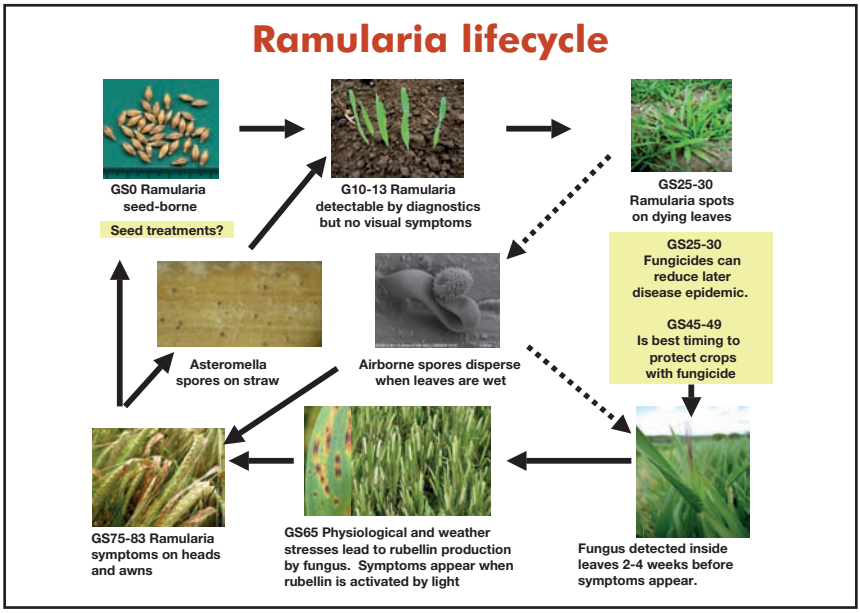


Ramularia collo-cygni second spore body (asteromella) on straw

The disease lifecycle of *Ramularia collo-cygni* is summarised in the next two figures. Current information suggests ramularia leaf spot is a polycyclic disease with seed as a primary source of infection and airborne spores creating further infections when the leaves are wet.



Ramularia leaf spot epidemics and spore movement



Ramularia lifecycle

Control measures for ramularia leaf spot

Varietal resistance

Varieties differ in their susceptibility to ramularia leaf spot symptoms. In the UK spring barley varieties which show low levels of ramularia leaf spot include Decanter, Belgravia and NFC-Tipple High levels of *Ramularia collo-cygni* fungus can be found in the seed and developing leaves of the variety Decanter. The mechanism for resistance may therefore be a matter of the host plant being able to tolerate or break down the rubellin toxins produced by the fungus. Spring barley varieties which are most susceptible include Cocktail, Optic and Forensic. Yield losses associated with the disease can be as high as 1.0 tonne per hectare. In resistant varieties, yield losses are 0.1-0.2 tonnes per hectare. Average yield losses in Scotland for spring barley are 0.4 tonnes per hectare which equates to a loss of £10 million per year.

Winter barley varieties also show different levels of resistance or tolerance to ramularia leaf spot. The malting barley variety Pearl exhibits low levels of symptoms whilst Flagon and Cassata are more susceptible. The feed barley variety Retriever can also be classified as susceptible.

Seed health and seed treatments

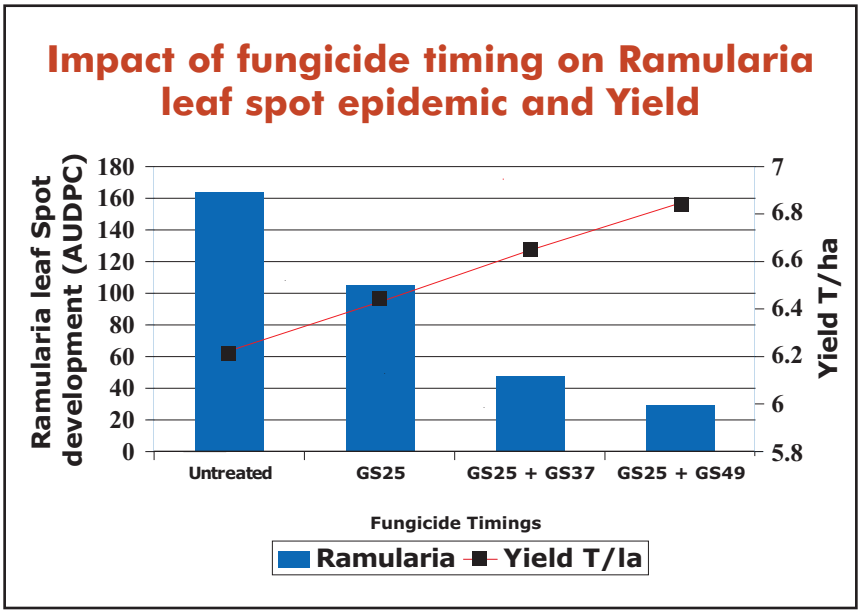
It is advisable to sow seed with low levels of contamination of *Ramularia collo-cygni*, particularly in regions where the disease is not a major threat, since seed transmission is a real risk for spreading this disease. However finding seed which is completely free from the pathogen is rare, even in the east of England where the disease is not perceived to be a major disease threat. Choosing seed stocks with less than 1pg of DNA per 100ng of total DNA in regions where the disease has yet to become established is recommended in the absence of effective seed treatments.

Although seed is an important source of infection, currently available seed treatments have little impact on the fungus.

Foliar fungicide treatments

Fungicide timing

The optimum timing to protect barley from ramularia leaf spot is before leaf spot symptoms are visible on the upper leaves. This usually occurs after the crop has flowered. The timing of the treatment is likely to be compromised by the latest application timing of fungicides, since most fungicides cannot be applied to malting barley crops when the ear has emerged. Awns visible growth stage (GS49) is therefore the optimum timing to protect the crop.



Area Under Disease Progress Curve and Yield

Earlier treatments applied at tillering or stem extension growth stages can have some influence on the eventual disease epidemic, but they are insufficient to provide effective reduction of ramularia leaf spot symptoms. These earlier timings are however important to protect crops from other barley diseases including powdery mildew, net blotch, rusts and rhynchosporium.

For low input crops on resistant varieties where a single treatment is typically applied, then a treatment at flag leaf emergence (GS39) is a compromise to eradicate early disease and protect the crop from ramularia leaf spot. In regions where rhynchosporium and ramularia are common, two applications of fungicides are required for effective disease control.

Once symptoms have started to develop in a crop, no fungicide will provide effective control.

GS25-30 treatment has some influence on later disease epidemic

GS49 treatment is optimum timing to protect crop from ramularia leaf spot

Fungicide choice

It is recommended that a combination of at least two fungicides which both have activity against ramularia leaf spot is applied at the optimum timing of awns visible growth stage (GS49). This will achieve the best reduction in ramularia leaf spot and the most cost effective yield response, whilst minimising the risk of fungicide resistance developing.

Triazole fungicides epoxiconazole or prothioconazole both show good activity against ramularia leaf spot.

Succinate dehydrogenase inhibitor fungicides (SDHIs) are also very effective. Current examples include boscalid, which is co-formulated with epoxiconazole (Tracker®) and isopyrazam which is co-formulated with cyprodinil. New fungicides in this group are expected to be launched over the next few years.

Chlorothalonil provides effective protection against ramularia leaf spot and also prolongs green leaf area. Since it has multisite modes of action, it remains an important component of a fungicide mixture to control the disease and reduce the risk of fungicide resistance developing.

	Ramularia leaf spot
Strobilurins	
azoxystrobin	-
picoxystrobin	-
pyraclostrobin	-
trifloxystrobin	-
Triazoles	
epoxiconazole	* *
prothioconazole	* * *
Other straight ais	
chlorothalonil	* * *
cyprodinil	*
Mixtures	
azoxystrobin + chlorothalonil	* * *
epoxiconazole + boscalid	* * *
isopyrazam + cyprodinil	* * *
prothioconazole + fluoxastrobin	* * *

* * * *	Excellent protection
* * *	Good protection
* *	Moderate protection
*	Low protection
-	No protection

Fungicide resistance

As with most diseases, ramularia leaf spot is not exempt from the risk of resistance to fungicides. Analysis of samples of *Ramularia collo-cygni* taken from around Europe show that resistance to strobilurin fungicides (Quinone outside Inhibitors), is widespread and they should not be relied upon to deliver control of ramularia leaf spot (e.g. azoxystrobin, fluoxastrobin, pyraclostrobin, trifloxystrobin, picoxystrobin). These fungicides may however be required in a fungicide mixture to control other biotic diseases including net blotch and brown rust.

Resistance to *Ramularia collo-cygni* has not been found in other groups of fungicides, but the use of combinations of active ingredients is a wise precaution against its development.

Physiological leaf spots

Physiological leaf spots or abiotic leaf spots are common terms used to describe leaf spots for which there is no obvious association with a disease and their cause is not fully understood. Environmental conditions which may trigger physiological leaf spots include extremes of light, temperature, nutritional deficiencies or toxicity, pollutants and other crop stresses. Since ramularia leaf spot develops as a consequence of stresses on plants, it is common for ramularia leaf spot symptoms to develop alongside physiological leaf spots and for physiological leaf spots to be mistaken for ramularia leaf spots.

Symptoms

What are the symptoms of physiological leaf spots on barley leaves?

Physiological leaf spots caused by light stress

Early stages of physiological leaf spots caused by light stress include small brown "pepper spots" surrounded by a yellow halo. Symptoms are visible on the part of leaves exposed to light. These spots can superficially resemble the early stages of ramularia leaf spot and it is normal for them to occur on the same leaf as ramularia leaf spots. Physiological leaf spots will be clearly visible on the side of the leaf exposed to the light, but shaded parts of the leaf including the underside of the leaf may appear normal.

Effect of variety

Symptoms of physiological leaf spots vary depending upon the variety. In some varieties they develop into regular brown spots or streaks which are confined by leaf veins and which are surrounded by a yellow halo. In others, they form brown irregular spots which are not confined by the leaf veins and which do not have a yellow halo.

The reason why some varieties exhibit more physiological leaf spots than others is thought to be due to differences in the ability of a variety to produce superoxide dismutase enzyme. This enzyme produces antioxidants which absorb the harmful effects of superoxides, produced inside the plant as a consequence of prolonged exposure to sunlight.

Early development of physiological leaf spots

Intermediate development of physiological leaf spots

Advanced development of physiological of spots

Physiological leaf spots on winter barley variety Amarena

Physiological leaf spots on the spring barley variety Spire

Physiological leaf spots on the spring barley variety Century

Interaction between ramularia leaf spot and physiological leaf spots

Ramularia leaf spot symptoms and physiological leaf spots regularly occur at the same time, causing challenges in identification of the primary cause. Since the rubellin D produced by *Ramularia collo-cygni* activates reactive oxygen species, its presence can produce both ramularia leaf spot symptoms and also activate the production of physiological leaf spots.

The severity and combination of symptoms of the complex is dependent on the susceptibility of a variety to physiological leaf spots. In the 1980s, selecting against physiological leaf spots was not a high priority. The spring barley variety Chariot is an example of a variety which regularly developed physiological leaf spot symptoms. These were seen as a typical characteristic of the variety and were deemed to be unimportant. When ramularia leaf spot was initially recognised as a serious problem in the 1980's, symptoms were regularly assumed to be of physiological origin in Germany and the UK. By contrast, in Norway, breeders screened out barley varieties which showed extensive physiological leaf spots. This meant commercial varieties grown in Norway tended to show typical ramularia leaf spot symptoms and physiological leaf spots were mostly absent.

The spring barley variety Chariot exhibits effective resistance to powdery mildew but it is susceptible to ramularia leaf spot. Since the introduction of commercial varieties with the mildew resistance gene *mlo* coincided with an increase in ramularia leaf spot, it was suggested at the time that there was a linkage between *mlo* and ramularia leaf spot. This was shown not to be the case and the presence of *mlo* gene reduced the level of ramularia leaf spot, but did lead to an increase in physiological leaf spots.

Commercial spring varieties introduced in the last ten years in the UK, including varieties the *mlo* genes for mildew resistance now show fewer physiological leaf spot symptoms compared to varieties used in the 1990s.

Physiological leaf spots on spring barley variety Chariot

Combination of ramularia leaf spot and physiological leaf spots

Physiological leaf spots and pollen scorch

A common name sometimes used to describe unknown leaf spots is "pollen scorch". Pollen can be associated with leaf spots, but this would be expected since many physiological leaf spots and ramularia leaf spots occur on the top leaves after flowering, when pollen is likely to be seen on affected leaves. Although there is little evidence to suggest that pollen on the leaf surface is a direct cause of these leaf spots, extensive leaf scorch can be associated with pollen on the leaf surface, particularly following wet spells of weather when pollen sticks to the leaves. In these situations, the growth of saprophytic fungi, bacteria and yeasts (microflora) on the leaf surface use pollen as an additional food source growing rapidly on the leaf surface.

These microflora may cause leaves to die-back earlier than normal. Leaf surfaces are however complex environments for a wide range of mircroflora. Some of these are known to prevent infection from known plant diseases whilst others may enhance disease. Plant defence mechanisms can also respond to the presence of some of these leaf surface microflora causing localised leaf death in response to a potential attack by them. The application of fungicides will influence the leaf surface microflora populations and different varieties will also have different populations of leaf surface organisms.

Physiological leaf spots in response to disease attack

For several years, plant breeders have used effective resistance genes known as *mlo* genes to breed varieties with resistance to powdery mildew. Some of these varieties will induce a hypersensitive reaction when powdery mildew spores attack the plant leading to distinct leaf spots commonly known as target spots.

Distinctive leaf spots associated with mildew infection on mildew resistant varieties

Powdery mildew is generally absent from these lesions, but irregular brown spots can develop around powdery mildew lesions on susceptible varieties. Fungal growth is usually associated with these lesions, but in some cases it can be absent where the mildew fungus has died off.

Leaf spots associated with powdery mildew infection on some barley varieties

Control of physiological leaf spot

Keeping crops free from stress is the key to minimising the impact of physiological leaf spots. Some things can be done to minimise stress including variety choice, nutrition and also choice of fungicides Stresses from extreme weather events including frost, waterlogging, drought or prolonged sunshine are more challenging to manage.

Variety

Since some varieties are more susceptible to producing physiological leaf spots than others, varietal choice is one method to minimise their impact. In recent years, plant breeders have made advances in breeding varieties which are less susceptible to producing leaf spots.

Nutrition

Crops should be adequately provided with nutrition from macro nutrients including nitrogen, potassium and phosphorus and micronutrients in particular manganese which can cause stress when plants are deficient.

Nitrogen is most likely to be limiting in varieties grown for malting markets which require grain with a low nitrogen level (1.4%). Growers should therefore be aware that crops grown for these markets are at a greater risk from physiological leaf spots.

Manganese deficiency is a common nutritional disorder in barley grown on soils with a pH greater than 6.0. Deficiency symptoms include the development of brown linear flecks on leaves which can be indistinguishable from some physiological leaf spots. Since manganese is an important component of many plant enzymes, deficient plants are likely to be more susceptible to the development of physiological leaf spots as the plants ability to produce superoxide dismutase enzymes will be reduced. Protection against manganese deficiency is through the use of seed and foliar manganese treatments. Soil applications are unlikely to be effective since soil levels are likely to be high, but the availability of soil manganese is limited at high soil pH.

Manganese deficiency symptoms on barley

Magnesium deficiency is more likely to occur in acid soils since soil magnesium is less available to the crop at low soil pH. Leaves of plants affected by magnesium deficiency are likely to show necrotic leaf spots on the leaf margins. The underlying soil pH can be corrected using magnesian limestone. Where a foliar treatment is required, magnesium sulphate can be applied.

Magnesium deficiency symptoms on barley

Activity of fungicides against physiological leaf spots

Some strobilurins can reduce the effect of physiological leaf spots. Research has shown that pyraclostrobin improves the ability of the crop to tolerate stress. This activity is due to its direct effect on levels of the enzyme superoxide dismutase which breaks down damaging compounds in the leaf produced in response to stress, including high light intensity. Increased levels of superoxide dismutase activity have been measured following treatment with pyraclostrobin, which then gives the plant a level of protection against stress within the plant.

Other fungicides can produce similar effects, but it is unknown if this is due to a direct effect from the fungicide or in response to anti-oxidant components in the formulated products.

	Ramularia leaf spot	Physiological leaf spot
Strobilurins		
azoxystrobin	-	* *
picoxystrobin	-	-
pyraclostrobin	-	* * *
trifloxystrobin	-	-
Triazoles		
epoxiconazole	* *	* *
prothioconazole	* * *	* * * *
Other straight ais		
chlorothalonil	* * *	* * * *
cyprodinil	*	* *
Mixtures		
azoxystrobin + chlorothalonil	* * *	* * * *
epoxiconazole + boscalid	* * *	* * * *
isopyrazam + cyprodinil	* * *	* * * *
prothioconazole + fluoxastrobin	* * *	* * * *

* * * *	Excellent protection
* * *	Good protection
* *	Moderate protection
*	Low protection
-	No protection

Fungal diseases causing symptoms similar to ramularia leaf spots

Net blotch *(Pyrenophora teres)* and spot form of net blotch *(Pyrenophora teres f maculata)*

Net blotch is a common disease of barley whose symptoms can be easily mistaken for ramularia leaf spot. Net blotch produces dark brown lesions on a leaf which can be associated with leaf yellowing. In its most typical form, the lesions have a netted appearance. And lesions are not contained by the leaf ridges.

The spot form of net blotch produces smaller lesions that are very similar to ramularia leaf spot. Ramularia leaf spot lesions tend to be more rectangular with straight longitudinal sides to the lesion than the spot form of net blotch. Net blotch symptoms are typically longer and more irregular than ramularia leaf spot. It is possible for the two diseases to be present on the same leaf in which case a more detailed microscopical analysis would be required to differentiate the two diseases.

Net blotch symptoms on barley

Spot form of net blotch lesions on barley

Pyrenophora leaf stripe *(Pyrenophora graminea)*

Pyrenophora leaf stripe is a seed-borne disease which produces longitudinal yellow and brown stripes on a leaf. Since the disease is seed borne, the stripes will originate from the base of the leaf. These symptoms are more likely to be mistaken for physiological leaf spots which can occur in stripes on some varieties.

Pyrenophora leaf stripe on barley

Halo spot *(Selenophoma donacis)*

Halo spot is a leaf spotting disease of barley which produces small irregular pale lesions on a leaf with a defined dark brown margin. This disease is generally uncommon but can develop on the upper leaves in a wet season when it can be confused with ramularia leaf spot or rhynchosporium secalis

Halo spot caused by *Selenophoma donacis* on barley

Septoria nodorum

Septoria nodorum produces oval shaped brown lesions on a leaf surrounded by a yellow halo. The lesions are not confined by the leaf ridges unlike ramularia leaf spots. Septoria nodorum symptoms are more common on the lower leaves and develop up the leaf canopy. This is in contrast to ramularia leaf spot which is typically more common on the upper leaves.

Septoria nodorum lesions on barley

Glossary

Abiotic leaf spots – leaf spots caused by physical stress including light, weather and chemical

Asymptomatic – causal fungus present in plants but not expressing symptoms of ramularia leaf spot

Endophyte – fungus or bacteria living inside the plant without causing any visible symptoms

Mlo **-** mildew resistance genes in barley

Pathogen – an organism that causes disease

Polycyclic epidemic – a disease which once established will spread further if weather conditions are suitable

Physiological leaf spots – leaf spots caused by physical stress including light, weather and chemical

Ramularia collo-cygni **–** causal fungus of Ramularia leaf spot

Ramularia leaf spot – common name for the disease caused by *Ramularia collo-cygni*

Stomata – pores on the leaf

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Outside Back Cover picture: shows artificially coloured image of Ramularia collo-cygni spore on distinctive curved conidiophore.

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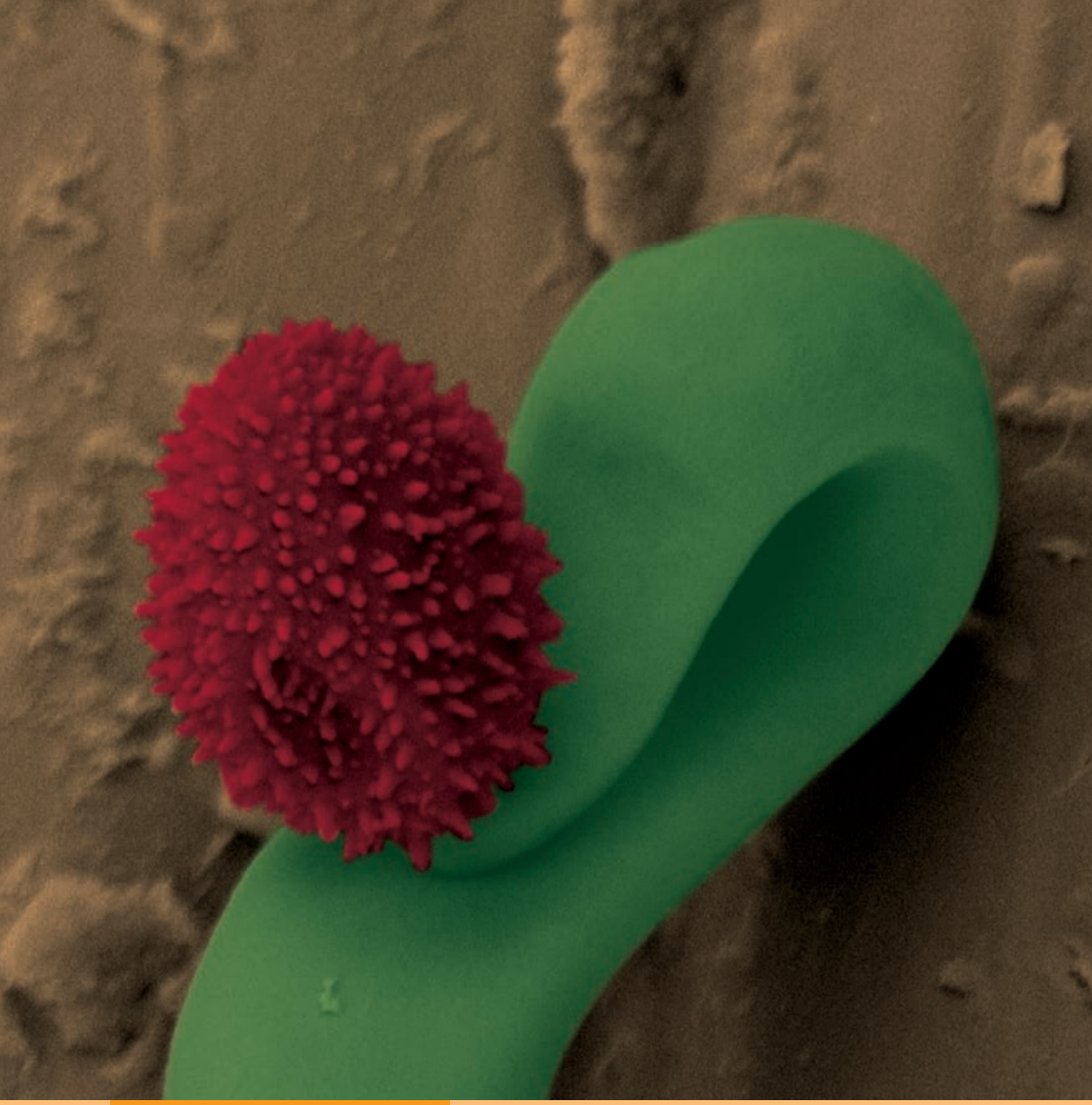

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