Wheat and barley disease management guide

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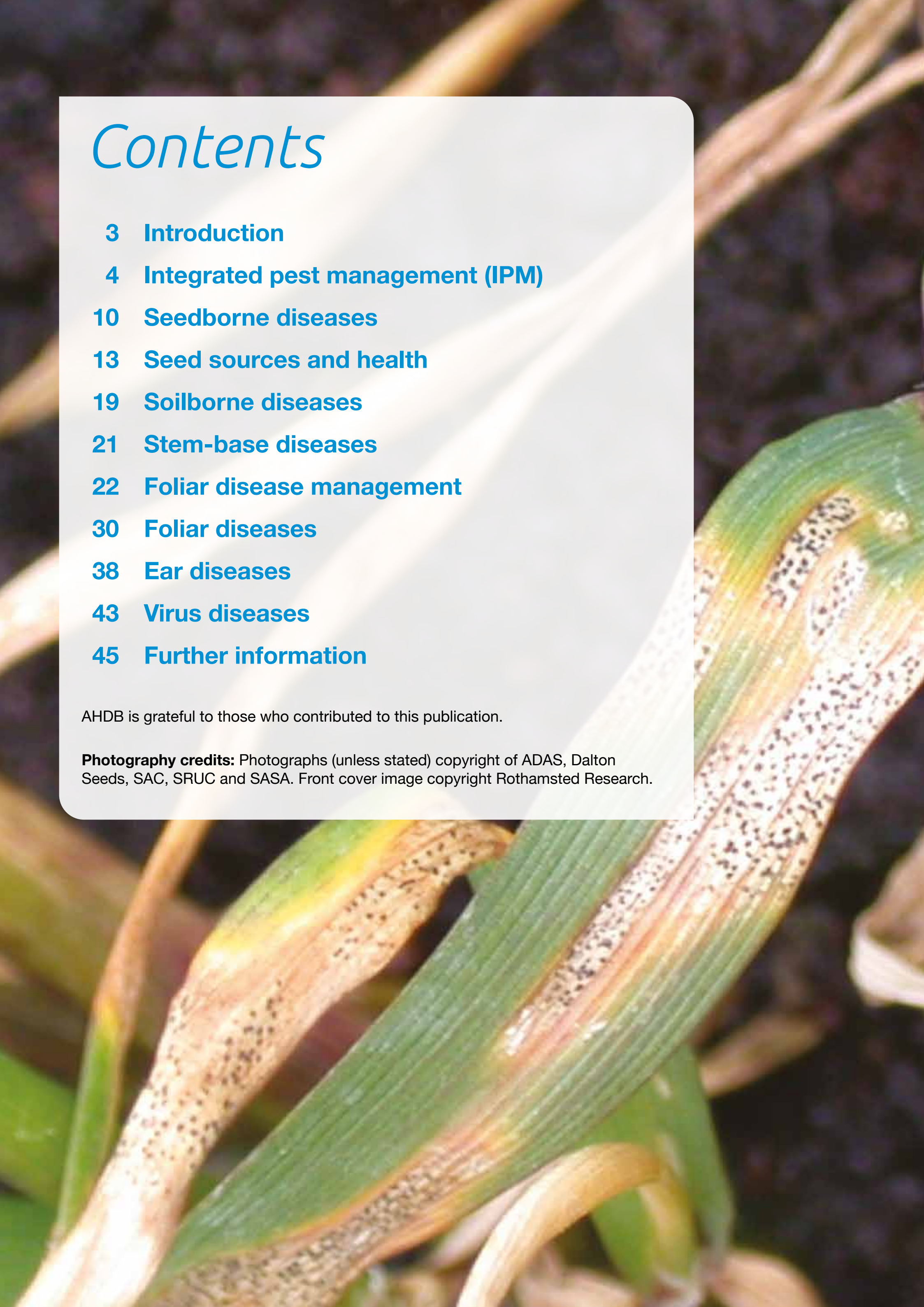
Contents

AHDB is grateful to those who contributed to this publication.



Introduction

The focus of this guide is on the most important diseases of wheat and barley and their reduction through integrated pest management (IPM).

Outlined in the first section are the key options for IPM, which is a central part of cereal agronomy. At the heart of IPM is a well-designed rotation (to minimise disease pressure) and an appropriate variety (to resist the main diseases present).

The guide provides a concise overview of each disease, with a focus on the main risk factors and key management steps.

Disease management programmes that balance non-chemical and chemical options, in the context of fungicide resistance, are summarised, with further details published in the Fungicide programmes for wheat and barley factsheet.

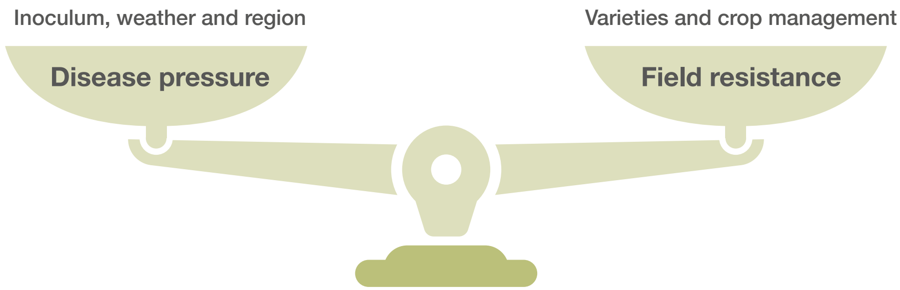


Figure 1. The extent to which disease develops in a crop is a balance between the likelihood of infection (i.e. disease pressure) and the ability of the crop to resist or avoid infection (i.e. field resistance)

Naming of fungal diseases

Agreed by international convention, scientific names of pathogenic fungi can change. For example, *Septoria tritici* was reclassified as *Mycosphaerella graminicola*, then *Zymoseptoria tritici*. Sometimes, however, the original scientific names are widely used to describe the diseases they cause. These common names are not italicised (e.g. septoria tritici).

Access all resources referred to within this guide via **ahdb.org.uk/cereal-dmg**

Integrated pest management

Integrated pest management (IPM) considers all measures that discourage the development of populations of harmful organisms. IPM keeps the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduces or minimises risks to human health and the environment. This section introduces some of the IPM measures available for disease management in cereals.

With various pressures on plant protection products, it may be necessary to accept higher levels of crop diseases in the future.

Rotation

The effect of crop rotation varies between diseases, with a large effect on trashborne disease and a small effect on airborne or seedborne diseases. For trashborne pathogens, the absence of a host crop (or volunteer) reduces the viability of the pathogen. However, if the disease is also seedborne, rotation is only effective if the seed is also clean or treated effectively.

For some diseases (e.g. net blotch), a non-host cereal, such as oats, is an effective break crop. For other diseases (e.g. fusarium), a non-cereal break crop is required to reduce disease risk. As a rule of thumb, a two-year break from a host crop is usually more effective than a one-year break.

However, growing wheat continuously can reduce the risk from take-all because of 'take-all decline'.

For airborne pathogens, infected crops grown in adjacent fields can increase the disease infection risk.

Varietal resistance

Varietal resistance can help reduce the intensity of fungicide programmes. Yield responses to fungicides, between the most and the least resistant varieties, can vary as much as 3 t/ha. A variety with a treated yield benefit of 0.5 t/ha will only justify having the value of 0.5 t/ha of grain spent on it.

Disease-resistant varieties also offer greater flexibility within a spray programme, including the omission of sprays, especially where disease pressure is low. For example, in wheat, a T0 can help insure against a weather-delayed T1 for septoria tritici control. However, there is considerably less need for this practice in a resistant variety because disease progression is much slower. At the T1 timing, varieties with a high septoria tritici disease resistance rating are also unlikely to need a succinate dehydrogenase inhibitor (SDHI) fungicide, especially for later-sown crops (i.e. after late October). Omitting the T0 altogether and the SDHI at T1 not only reduces costs, but also lessens the resistance selection pressure on fungicides.

Figure 2. The AHDB Recommended Lists (RL) provide information on varietal resistance to key cereal diseases

AHDB Recommended Lists (RL) trials assess disease symptom expression in wheat, barley and oat varieties across the UK. In the RL, varietal disease resistance ratings are published on a 1–9 scale, where 1 indicates low resistance and 9 indicates high resistance.

The RL system also compares the yields of varieties grown without fungicides with varieties grown under a robust fungicide programme. Where the treated yields are much higher than the untreated yield, it indicates that a more intensive spray programme may be required to achieve the variety's yield potential.

Historically, good disease resistance was associated with a relatively high yield penalty. However, modern cereal varieties have little or no yield penalty compared with varieties with lower resistance. In wheat, the yield of some resistant varieties is just 5% lower when untreated, compared with yields observed when a robust fungicide programme is applied.

Variety selection

The relative importance of each resistance rating depends on the local disease profile. The AHDB variety selection tool can help you make better variety choices. Use it to calculate an 'agronomic merit' score for each variety. This score takes account of a variety's resistance to key diseases and lodging (instead of looking at each component in isolation). Critically, it also accounts for their relative importance (via the use of weightings).

ahdb.org.uk/vst

United Kingdom Cereal Pathogen Virulence Survey (UKCPVS)

The UKCPVS monitors changes in the pathogen population of cereal rusts and mildews in the UK. It detects new races of disease and warns industry how these might affect currently resistant varieties.

Monitor crops and, if resistance breakdown is suspected, send a leaf sample to the UKCPVS.

ahdb.org.uk/ukcpvs

Types of varietal resistance

Some forms of resistance (race-non-specific/multigene resistance) do not provide complete control. These forms are not subject to sudden failure when the pathogen population changes. This is the main type of resistance available against septoria tritici.

Other forms of resistance (race-specific/single gene resistance) can provide complete protection (resistance ratings of 9). However, in these forms, new races of the fungus may develop that result in sudden loss of control from varietal resistance. This is the main type of resistance available against yellow rust. When such a change occurs, the level of varietal susceptibility depends on its underlying race-non-specific resistance.

Figure 3. UKCPVS wheat seedling test for yellow rust

Note: For yellow rust on winter wheat, the crop may be susceptible at the seedling stage but resistant at the adult stage (e.g. after stem extension)

Cultivation and drilling

For most diseases (Table 1), cultivation helps break up and bury infected crop residues. However, other factors, such as varietal resistance and rotation, can reduce disease risk at least as much as – and often more than – ploughing.

In general, early drilled autumn-sown crops are at higher risk of disease because they are exposed to infection for longer. For example, delayed sowing of winter wheat (from mid-September to mid-October) reduces septoria tritici pressure, irrespective of varietal resistance rating. In effect, a moderately susceptible variety (rating of 5) sown in mid-September can be comparable to a susceptible variety (rating of 4) sown in mid-October.

Table 1. Crop management decisions and their impact on disease risk

	Early sown (autumn-sown)	High nitrogen or dense crop	Min-till (after host crop)	High seed rate
Septoria tritici	↑	↑	↑	↔ (no effect)
Yellow rust***	↓	↑	↑**	
Brown rust	↑	↑	↑**	
Powdery mildew	↓*	↑	↑**	↑
Fusarium			↑	
Eyespot	↑	↑	↓	
Rhynchosporium	↑	↑	↑	
Ramularia		↓		
Net blotch	↑	↑	↑	

Note: The presence of volunteers increases the risk for all diseases cited in this table. Blanks indicate the effect is not clear

*Mildew tends to cause most damage on late-sown crops. However, it may be most common on early sown, well-tillered crops

**The increased risk is associated with higher volunteer numbers

***Early sowing increases the risk of an autumn epidemic but is less prone to the more damaging spring epidemics

Assuming all other factors are equal, sow resistant varieties before the more susceptible ones. However, be aware that very late-sown crops may be less able to tolerate seedborne and soilborne diseases.

Fertilisation

High nitrogen levels in crops favour the development of biotrophic pathogens (pathogens that rely on living plant cells to survive), such as rusts and mildews. Well-fertilised crops often have a lush growth habit and an altered canopy structure. This can affect the infection conditions and spore dispersal for a pathogen. In such situations, even moderately resistant varieties can suffer high levels of disease. The greatest effect is associated with early nitrogen applications.

To plan crop nutrition, use the ***AHDB Nutrient management guide (RB209)***.

Alternative control

As the options for chemical control dwindle, alternative control options become more important. Although such options can replace or complement conventional chemical fungicides, currently some of these options are relatively limited in cereal production systems.

Biopesticides

A biopesticide is a crop protection agent based on microorganisms or natural products that can be used to reduce or eliminate pests, diseases or weeds. In cereals, very few biofungicides are available, but there are several in development.

Biostimulants

The use of biostimulants may increase plant growth and yield. Some biostimulants are associated with increased crop nutrient uptake and tolerance to environmental and pathogen stresses. There is, however, limited evidence on how to use biostimulants to achieve consistent benefits in the UK.

Intercropping

Intercropping involves growing two or more crops together. This can reduce disease pressure through:

- A dilution effect (pathogen levels are reduced because there are fewer hosts in the field)
- A physical barrier effect (pathogens are unable to spread as easily)
- A chemical effect (some crops produce chemicals that inhibit certain pathogens)

The best crop combination depends on environmental conditions and the biology of the target pathogen, such as its transmission method. Cereal–legume intercrops are the most common, with beans, peas or clovers as the legume component.

For example, the use of a clover living mulch provides a barrier against splash dispersal of septoria tritici in wheat. However, intercropping can create conditions that favour some pathogens. It can also be a challenge to plan rotations.

Variety mixes

Varietal mixtures increase genetic diversity within a field. This can slow or reduce the spread of some diseases, especially when varieties with different disease resistance profiles are grown.

For race-specific pathogens (such as yellow rust), the ways in which varietal mixtures reduce disease are the same as for intercropping (see above). For pathogens that are less specific or unspecific, like rhynchosporium, the mechanisms by which disease is reduced are unclear.

Levels of disease reduction and yield increases depend on many factors, including disease and nutrient levels and crop and varieties chosen. Although disease reductions of 60% and yield increases of 15% are possible, effects are not usually this large.

Crude mixtures, produced on the farm, work better than homogeneous mixing. More complex mixtures show greater disease reduction; a mixture of three or more varieties is best. Such mixtures may also reduce the risk of varietal resistance breakdown.

Differing maturity dates between the varieties in the mix does not tend to be an issue. Both wheat and barley mixtures for feed and wheat for distilling are generally acceptable to markets. However, maltsters do not currently accept mixtures.

Fungicides

Most conventional disease control programmes use fungicides. Detailed information is provided in the seed health, foliar and ear disease sections.

Figure 4. Growing two or more crops together (intercropping) can alter disease pressure

Seedborne diseases

The consequence of planting infected seed depends on the pathogen in question. Seed can be an important source of some pathogens. However, for some seedborne diseases, other sources of the pathogen (e.g. soil or crop debris) are more important.

Symptom expression also occurs at various growth stages. Some diseases may cause the seedling to die before it emerges. In an emerged crop, some diseases may show symptoms in the seedling. For some other diseases, however, visible symptoms may not show until a much later growth stage (e.g. after flowering).

Loose smut (wheat, barley and oats)

Pathogen

Ustilago tritici (wheat),
U. nuda (barley) and *U. avenae* (oats)

High-risk factors

- Sowing untreated infected seed
- Using untested farm-saved seed

When infected seed germinates, the fungus grows through the plant and develops in the ear. Symptoms develop after ear emergence. Varieties with a longer flowering time are more susceptible to infection and windy conditions can increase spread. Cool, moist conditions can prolong flowering and increase the chance that infected crops will spread the disease.

Management

- Inspect seed crops for signs of infection
- Buy certified seed or test home-saved seed for the presence of the pathogen
- Use a fungicidal seed treatment on infected seed

Figure 5. Loose smut-infected wheat ears show masses of fungal spores

Bunt (wheat)

Pathogen

Tilletia tritici

The disease is seedborne and soilborne. Symptoms develop after ear emergence.

Figure 6. Wheat flag leaf showing typical yellow streak symptoms caused by bunt

High-risk factors

- Seedborne infection:
  - Seed sown without a fungicide treatment, especially over many years
  - Slow emergence, caused by suboptimal seedbed conditions
- Soilborne infection:
  - Very short time between harvesting a first wheat and sowing a second wheat
  - Dry soil conditions between harvesting and sowing

Management

- Good machinery and grain storage hygiene
- Delay drilling of a second wheat after harvest of an infected crop or wait until after a wet spell
- Use a fungicidal seed treatment on infected seed

Figure 7. In infected wheat ears, the grain is replaced by seed-like ‘bunt balls’

Fusarium and microdochium (wheat, barley, oats, rye and triticale)

Pathogen

Fusarium avenaceum, F. culmorum, F. graminearum, F. poae, F. langsethiae, Microdochium nivale and *M. majus*

This complex of diseases can be seedborne, soilborne or trashborne. They cause a variety of symptoms, including seedling blight, foot/crown rot and ear (head) blight. Page 39 covers their management.

Ergot (wheat, barley, oats, triticale and rye)

Pathogen

Claviceps purpurea

This ear disease is not strictly seedborne. However, infected seed lots spread the disease. Page 42 covers its management.

Net blotch (barley)

Pathogen

Pyrenophora teres f. *teres* (*Drechslera teres*) (net form), *P. teres* f. *maculata* (spot form)

Historically, infected seed introduced the disease to new areas. Although it can still contribute to epidemics, the trashborne phase is now the main source of inoculum. Page 35 covers its management.

Ramularia (barley)

Pathogen

Ramularia collo-cygni

This disease is seedborne and airborne. Page 36 covers its management.

Rhynchosporium (barley, triticale and rye)

Pathogen

Rhynchosporium commune

The pathogen survives on infected trash and spreads to seedlings, mainly via rain-splash. It can also be seedborne, but the importance of this phase is not well understood. Page 34 covers its management.

Figure 8. Several fusarium species infect cereal crops

Seed sources and health

Whether certified or farm-saved, it is important to understand the quality of seed. By law, seed must be officially sampled and tested before it can be certified. Sampling and testing are also important for grain intended for farm-saved seed, although it is not compulsory.

Certified seed

All seed bought and sold in the UK must be certified. Cereal quality standards are published in the Seed Marketing Regulations. The regulations state: "Harmful organisms that reduce the usefulness of the seed shall be at the lowest possible level." Standards exist for loose smut and ergot contamination, but not for bunt, seedling blights, leaf stripe, net blotch or covered smut. Although not a requirement, most certified seed is treated. There are also standards for varietal and species purity and germination.

If certified seed is supplied untreated (rare, except for organic seed), a grower or merchant should test it for seedborne diseases not covered under the regulations (e.g. microdochium seedling blight in wheat) to decide on the need for a seed treatment. Table 2 details the regulatory and advisory thresholds for disease in seed.

Countries can prescribe stricter standards than the EU minimum. The UK sets a Higher Voluntary Standard (HVS) for seed. Sold at a premium, HVS seed has higher standards for varietal and species purity, ergot and loose smut.

Farm-saved seed

High-quality farm-saved seed can be grown and processed on or off farm. Best practice is to save seed from a crop grown from certified seed. Monitor seed crops regularly and keep grain separate from other grain bulks.

Before cleaning or drying, send a representative sample to a laboratory to test for germination and the presence of seedborne diseases. This will determine if the seed is suitable for use and whether a seed treatment is needed. Do not use seed if the germination rate is below 78%. Adjust seed rates in response to the germination rate and thousand-grain weight.

Table 2 shows the regulatory standards and advisory thresholds for the main seedborne diseases. Where disease levels exceed these standards or thresholds, apply an appropriate seed treatment or do not use the seed. Although these thresholds and standards are not a legal requirement, the use of farm-saved seed with high infection levels will cause inoculum to build up and spread.

Table 2. Regulatory standards and advisory thresholds have been set for key seedborne diseases

Crop	Disease	Method	Duration	Results	Regulatory standard (S) or advisory threshold (A)
Wheat	Bunt *Tilletia tritici*	Wash	48 hours	Spores per seed	(A) Treat if one spore/seed or more
Wheat and barley	Ergot *Claviceps purpurea*	Visual	24 hours	Number of pieces in 500 g or 1,000 g	Maximum pieces: (A) (S) Three pieces/500 g (minimum standard) (S) One piece/1,000 g (Higher Voluntary Standard)
Wheat and barley	Loose smut *Ustilago tritici* (wheat) *Ustilago nuda* (barley)	Embryo extraction	48 hours	% infection in 1,000 embryos (advisory) or 2,000 embryos (certification)	Maximum infection: (A) (S) 0.5% (minimum standard) (S) 0.2% (Higher Voluntary Standard)
Wheat* and barley	*Microdochium* spp.	Agar plate Molecular	7–10 days 48–72 hours	% infection Either over or under 10% infection	(A) Treat if over 10% (wheat) (A) Treat if over 30% (barley)
	Fusarium graminearum	Agar plate	7–10 days	% infection	(A) Treat if over 10%
	Cochliobolus sativus	Agar plate	7–10 days	% infection	Risk is low (wheat) (A) Treat if over 30% (barley)

Table 2. Regulatory standards and advisory thresholds have been set for key seedborne diseases (continued)

Crop	Disease	Method	Duration	Results	Regulatory standard (S) or advisory threshold (A)
Wheat* and barley	Septoria nodorum *Parastagonospora nodorum*	Agar plate	7–10 days	% infection	(A) Treat if over 10% (wheat) Risk is low (barley)
Barley	Covered smut *Ustilago hordei*	Wash	24–48 hours	Spores/ seed	(A) Treat if present
Barley	Leaf stripe *Pyrenophora graminea*	Agar plate Molecular	7–10 days 48 hours	% infection Presence/ absence	(A) Treat if over 2% (A) Treat if present
Barley	Net blotch *Pyrenophora teres* f. sp. *teres*	Agar plate Molecular	7–10 days 48 hours	% infection	(A) Treat if over 15%

*Treat for seedling blights when sum of infection levels exceeds 10%.

Test wheat for bunt and microdochium seedling blight. Also conduct tests for ergot, loose smut, septoria nodorum and fusarium seedling blights, if a problem is suspected (e.g. if it is present in the growing crop).

Test barley for the presence of loose smut, leaf stripe and net blotch (where not previously present). Tests for ergot, covered smut and *Fusarium graminearum* should also be conducted, if a problem is suspected (e.g. if it is present in the growing crop). Microdochium is less of a concern in barley.

It is illegal to sell, share or barter farm-saved seed.

It is a legal requirement for farmers to declare any use of farm-saved seed to the British Society of Plant Breeders (BSPB) and to pay for the use of eligible varieties. The current list of eligible varieties and payment rates and methods are available at **bspb.co.uk**

Farm-saved seed payments support continued investment in improved varieties for UK conditions.

Seed treatment

If disease levels are below those shown in Table 2 and germination is greater than 78%, a fungicide seed treatment is not usually required. However, consider all disease threats, especially if drilling late into cold soils.

> **Do not sow untreated seed without testing for germination and seedborne diseases.**
>
> For a list of seed treatment options, visit **ahdb.org.uk/fungicide-performance**

Organic seed production

Test all seed for organic production for germination and seedborne diseases. Organic-certified seed must meet the same quality standards as conventionally produced seed. Seed merchants are usually able to provide the seed test certificates for each lot.

Seed sampling

It is vital to collect a representative sample of grain for testing.

1. Use seed from one field only to reduce variability within a seed lot
2. Keep grain intended for sowing separate from larger grain bulks
3. Diseased seed lots can contaminate healthy lots. Brush sampling equipment with water and detergent, before and between lots, and allow it to dry

   Note: Bunt spores can also contaminate equipment and storage areas.
4. Subdivide seed lots over 30 tonnes into smaller lots
5. Sample grain before cleaning or drying, ideally with a single or multi-chamber stick sampler
6. Sample across the bulk or trailer at different depths. Each sample taken is a primary sample (a small portion taken from one point in the lot)
7. Take the appropriate number of primary samples for the lot size (Table 3)
8. Thoroughly mix all primary samples in a clean bucket to create a representative 'composite sample' and divide for testing (Figure 9)

> **Do not take only one sample from one point in the bulk.**

Table 3. Primary samples required for given lot sizes, based on International Seed Testing Association Rules

Lot size (tonnes)	Primary samples required
5*	10
10	20
30	40

*Note: For smaller seed lots, it may be cheaper to treat than to test

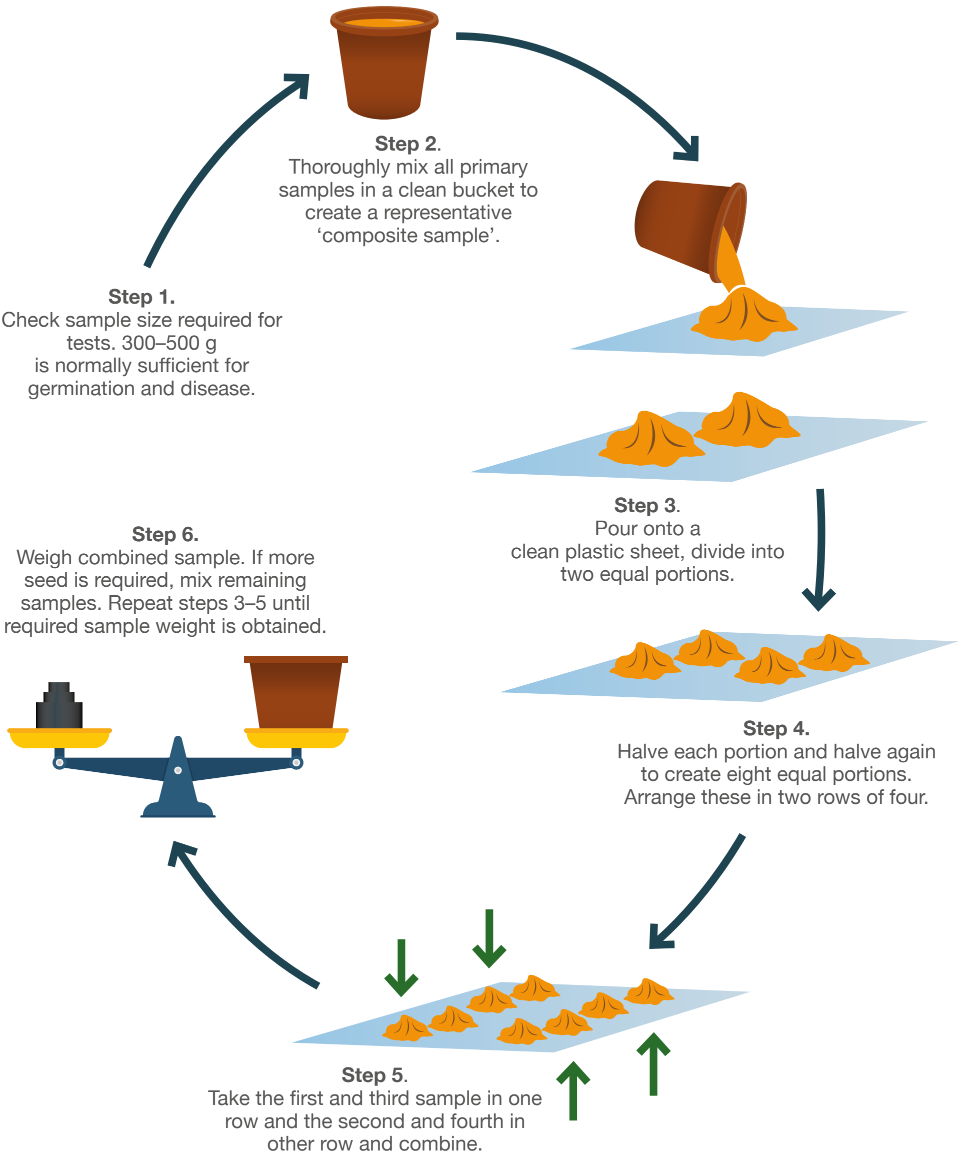


Figure 9. Preparing seed samples for testing

Equipment

A single chamber sampler (or 'deep bin probe' or 'Neate sampler') collects one primary sample at a time. If the depth of grain in the bulk is greater than the length of the sampler, use screw-on extensions.

A multi-chamber sampler usually has three or more chambers. Seed collected in a single sampling action constitutes one primary sample. Suitable for most trailers, use it to sample grain up to 2 m deep. A piece of plastic guttering is useful for collecting samples from this type of sampler.

Trained agronomists can also sample grain.

Germination testing

Low germination is a major cause of poor seed quality. It can be caused by disease, sprouting, drying, mechanical or chemical damage, physiological age, dormancy or heat damage (caused by drying grain at too high a temperature). Send samples to a laboratory for germination testing. When time is limited, the tetrazolium (TZ) test is recommended. Although the TZ test does not detect low germination caused by disease or chemical damage, it does indicate the germination potential of treated seed. Although a basic germination test (e.g. 100 seeds on a wet paper towel) can be used, it does not provide an accurate assessment.

Figure 10. Sampling grain from a heap using a spear

Soilborne diseases

Take-all and rhizoctonia stunt are the main soilborne diseases of cereals. Bunt and fusarium can also survive in the soil and ergots may remain viable on the soil surface for one year.

Seed treatments do not provide complete control. Therefore, cultural control is essential. Good machinery hygiene reduces the spread of infected soil. Rotation with non-host crops can also help reduce inoculum levels. For some diseases, cultivation can help bury or disrupt inoculum.

Take-all (wheat, barley, rye and oats)

Pathogen

Gaeumannomyces tritici (wheat, barley and rye) and the rare *G. avenae* (oats, wheat, barley and rye).

High-risk factors

- Second, third or fourth cereal crop
- Light or alkaline soils
- Warm winter and wet spring/early summer, which encourages take-all development
- Dry summer, which exacerbates take-all symptoms and increases yield loss
- Poor drainage, low nutrient status, early sowing and light, puffy seedbeds
- Cereal volunteers and grass weeds, especially couch and bromes, in break crops that carry the disease through to following cereals

Figure 11. Plants infected with take-all have blackened and rotten roots, which can have a 'rat-tail' appearance

Management

- Extending the rotation is the most effective way to manage take-all
- Seed treatments only give partial control
- Provide good drainage, consolidated seedbeds and adequate nutrition, especially where second, third, or fourth wheats are grown
- Continuous wheats are not affected so much because of take-all decline. However, yields never return to those of first wheats
- Control cereal volunteers and grass weeds in break crops and avoid a green bridge between successive cereal crops
- Avoid very early drilling of first and second wheats. Aim to drill second and subsequent wheats after mid-October
- Varietal resistance and foliar fungicides offer little control

Rhizoctonia stunt (wheat, barley, oats, rye and triticale)

Pathogen

Thanatephorus cucumeris (*Rhizoctonia solani*)

This disease is distinct from sharp eyespot, which is caused by *Rhizoctonia cerealis.*

High-risk factors

- Sandy loam or loamy sand soil texture
- Direct drilling or minimum cultivation
- Barley is much more susceptible to the disease than other cereals

Management

- Inversion tillage

Figure 12. Cereal root systems infected by rhizoctonia stunt become poor, branched and feature brown, rotten tissue

Stem-base diseases

Stem-base diseases can be difficult to distinguish, particularly early in the season during treatment decisions. However, correct identification is essential because eyespot is a much more important disease than either sharp eyespot (*Rhizoctonia cerealis*) or fusarium foot rot.

Eyespot (wheat, barley, oats, rye and triticale)

Pathogen

Oculimacula yallundae (*Helgardia herpotrichoides*), W-type, and *O. acuformis* (*Helgardia acuformis*), R-type.

Figure 13. Eye-shaped lesions with a dark margin often appear at the stem base

The disease is trashborne and airborne.

High-risk factors

- Cereal as a previous crop
- Ploughing
- Westerly region
- Susceptible variety
- High spring rainfall
- Moisture retentive, heavy soil
- Early sowing (especially before early October)
- Volunteers and grass weeds
- Mild, wet winter
- Overfertilised crops

Management

- Use the AHDB eyespot risk assessment to inform field-based risk (**ahdb.org.uk/eyespot**)
- Avoid cereals as a previous crop
- Use minimum tillage and delay drilling
- Grow a resistant variety (wheat only)
- In fields identified as high risk pre-sowing, consider growing a different crop
- In crops identified as high risk after a spring assessment of infected tillers, treat with an azole or azole/SDHI mixture at T1 (for wheat and barley)

Foliar disease management

Importance

Foliar diseases can accelerate senescence of the top leaves and reduce yield and specific weights. Foliar diseases can also spread to the ears and grains, affecting quality. Rotation, variety, weather, cultivation and fungicide programme influence disease severity.

In wheat, infections on leaf one (flag leaf) and two have the greatest impact on yield, as these components contribute 65% to total yield (Figure 14).

In barley, earlier infections (pre-GS31) are more important. These can reduce photosynthetic area, restrict tillering and result in lower yields and higher grain nitrogen content. Disease levels in the crop will partly determine subsequent tiller and spikelet loss.

Smaller grains and increased screenings, which may lead to price penalty or rejection in both feed and malting markets, can result from foliar disease infections after GS39.

Keep wheat and barley crops healthy during grain fill (GS71–81) to help maximise fill and grain size.

Despite increases in varietal resistance, in most situations, fungicides are required to keep the crop healthy during the growth stages that are most important for yield (Figure 15).

Fungicide effects not entirely linked to control of visible disease (e.g. canopy 'greening' or growth regulatory effects) may also increase yield. Yield responses can also occur, even when visible disease is at very low levels.

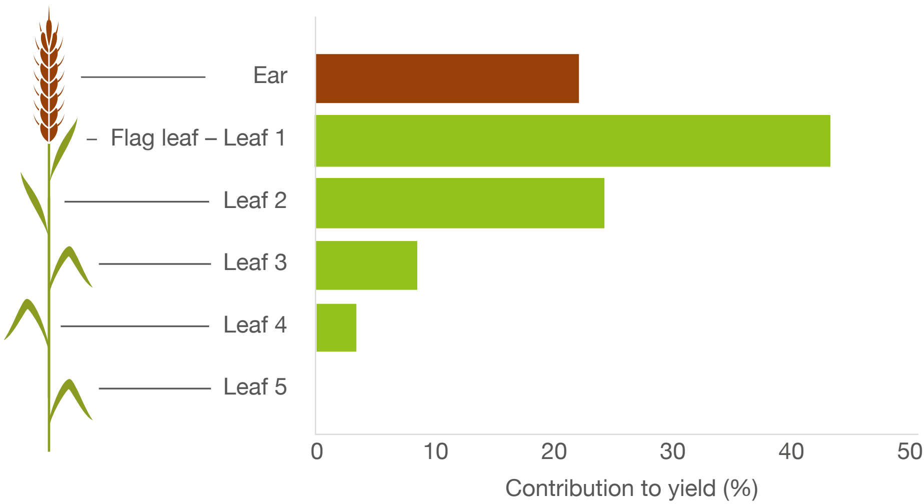


Figure 14. In wheat, the flag leaf and ear contribute 65% of total yield. In barley, the flag leaf is small and the lower leaves, stem and ear are more important

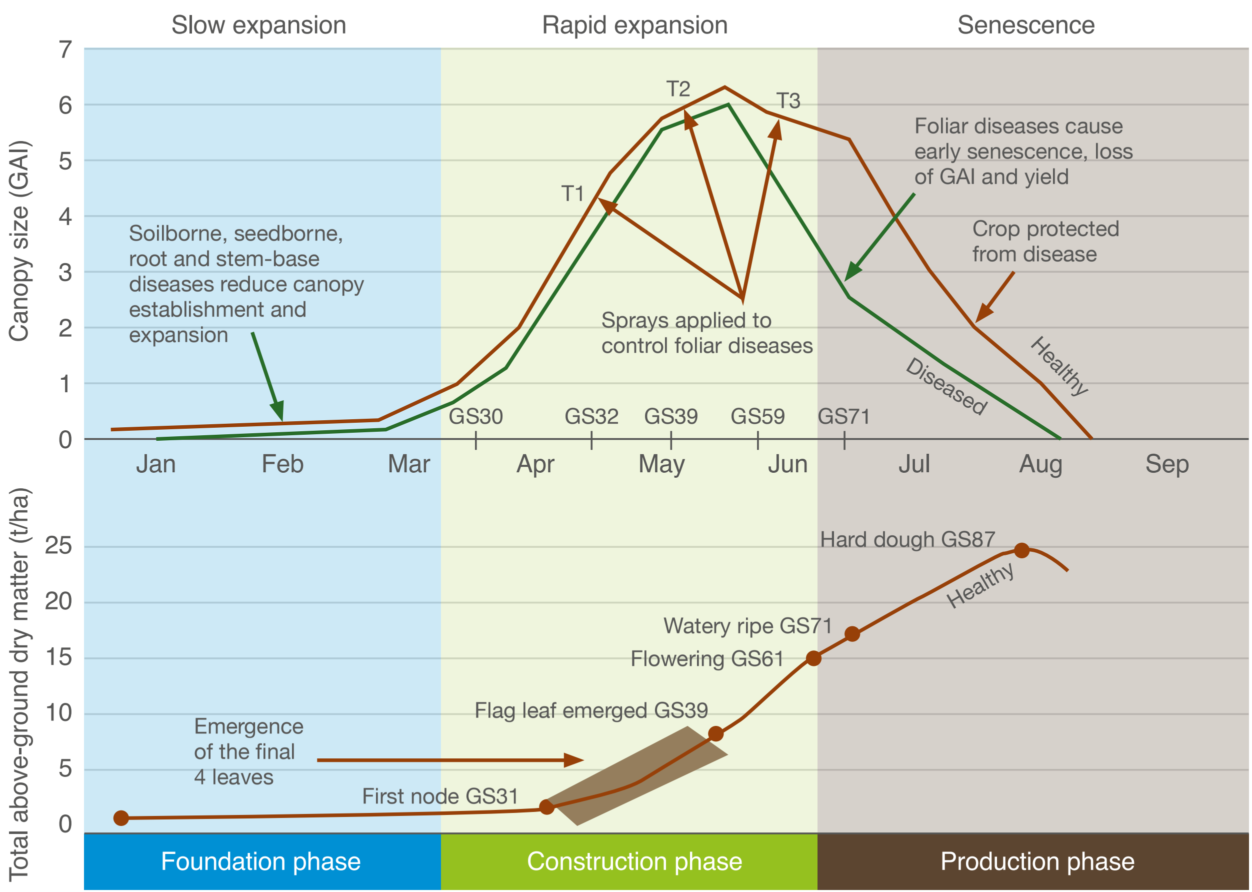


Figure 15. The effect of foliar diseases on yield formation in winter wheat

Initial infection

A 'latent period' follows infection. This is when the fungus grows within the leaf with no visible symptoms (Figure 16). A cycle of leaf emergence, infection, latent period and symptom expression applies to most foliar diseases.

Yield may already be affected by the time infection is established and becomes visible. At this stage, disease control becomes much more difficult. Fungicide control is much more effective in the early phases of the latent period.

The latent period varies considerably between pathogens and periods are shorter at higher temperatures. Generally, latent periods can be as short as 4–5 days (e.g. mildew and brown rust) and symptoms can show before leaves fully expand. Septoria tritici has a long latent period (14–28 days).

In summer, when the latent period may be 14 days, fungicides may provide eradicant control at the beginning of the latent period. Later on, infection may be so far into the latent period that no fungicide, at any dose, will control the fungus, even though there may still be no visible symptoms on the leaf.

Infection from within crops

As stems extend and upper leaves emerge, crops tend to grow away from disease. In wheat, newly emerged leaves appear to be free from septoria tritici between GS32 and GS39 (Figure 17). However, the crucial final three leaves are at risk as soon as they emerge. By this stage, disease lesions on lower leaves are the most common source of infection of emerging upper leaves. Whether disease develops on upper leaves depends on varietal resistance, crop management and weather.

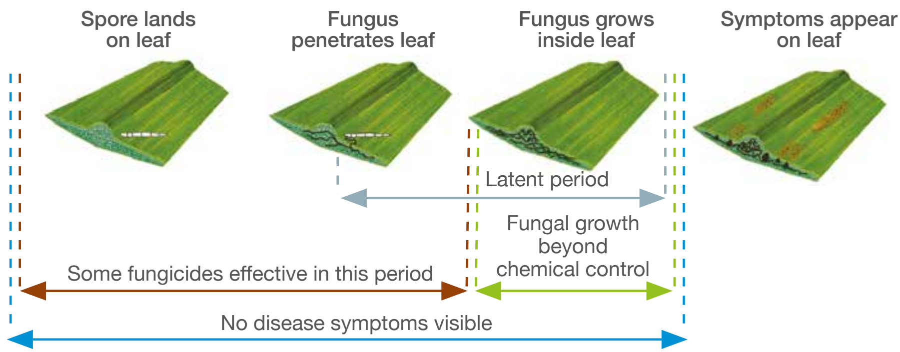


Figure 16. Importance of spray timing and latent period

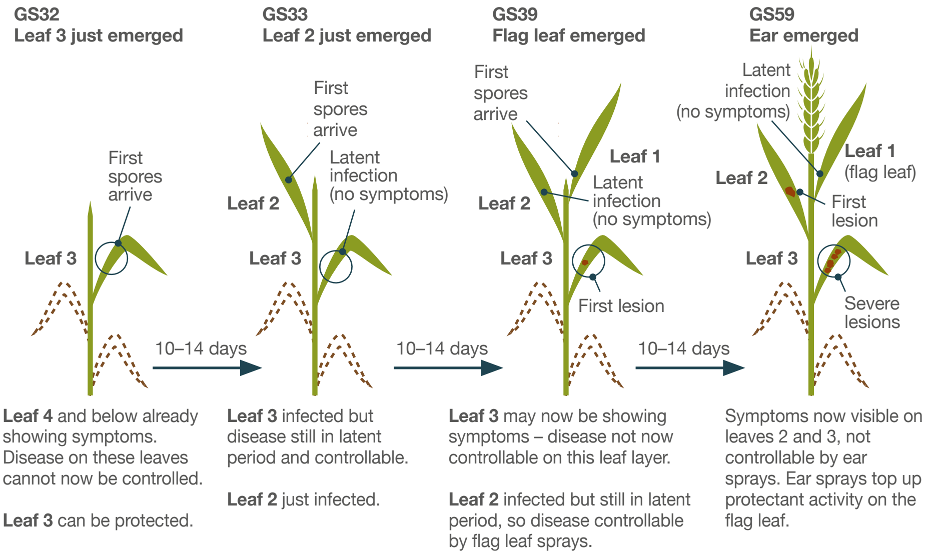


Figure 17. Latent periods, fungicide activity and spray timing in wheat (example based on septoria tritici)

Fungicide timing

The period or 'spray window' for effective disease control is relatively narrow. A decimal growth stage (GS) key is often used to target sprays. However, to ensure adequate protection of the key yield-forming leaves, target fungicide treatments to leaf emergence, rather than the growth stage. The optimum spray timing is when a leaf has just fully emerged. A well-timed spray can avoid the need for higher doses or extra sprays (Figure 18).

See the AHDB growth guides for wheat (**ahdb.org.uk/wheatgg**) and barley (**ahdb.org.uk/barleygg**) for further details on growth stages and the factors that influence the timing of leaf emergence.

Fungicide efficacy

The AHDB fungicide performance programme produces independent information on the efficacy of new and established fungicides against key diseases in wheat, barley and oilseed rape. Trials are located in areas that are most likely to experience high disease pressure for the target disease. Varieties that are highly susceptible to the target disease(s) are grown.

Generally, when a higher dose of fungicide is applied, less disease will be present in a crop. This can be visualised in a dose-response graph (Figure 19). Such graphs show average performance, measured across a variety of sites, seasons and leaf layers and the relative performance of active ingredients.

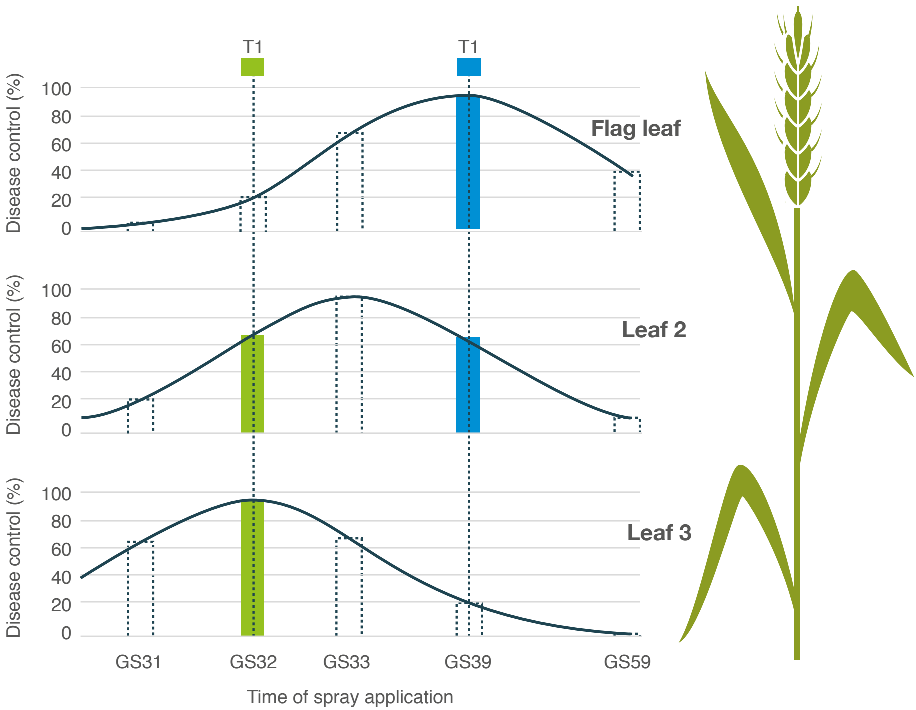


Figure 18. These curves indicate the potential control level that can be achieved on each of the top three wheat leaves for spray timings from GS31 to GS59. The interval between T1 and T2 is particularly important

For the latest dose-response curves, visit **ahdb.org.uk/fungicide-performance**

Fungicide dose

The cost of a fungicide application rises as dose increases, while yield loss caused by disease is proportional to the amount of disease present. The appropriate fungicide dose is the point at which margin is maximised. Doses lower than the appropriate dose reduce profit through inadequate disease control. Doses higher than the appropriate dose reduce profit because the cost of additional fungicide outweighs the value of the extra yield. Selection for fungicide resistance is also more likely with increasing dose.

Appropriate dose can be estimated (Figure 20), although numerous factors must be considered. These include disease risk factors (e.g. weather, varietal resistance, drilling date and previous cropping), grain price, fungicide cost and efficacy. The appropriate dose varies more with disease pressure and varietal resistance than with grain price.

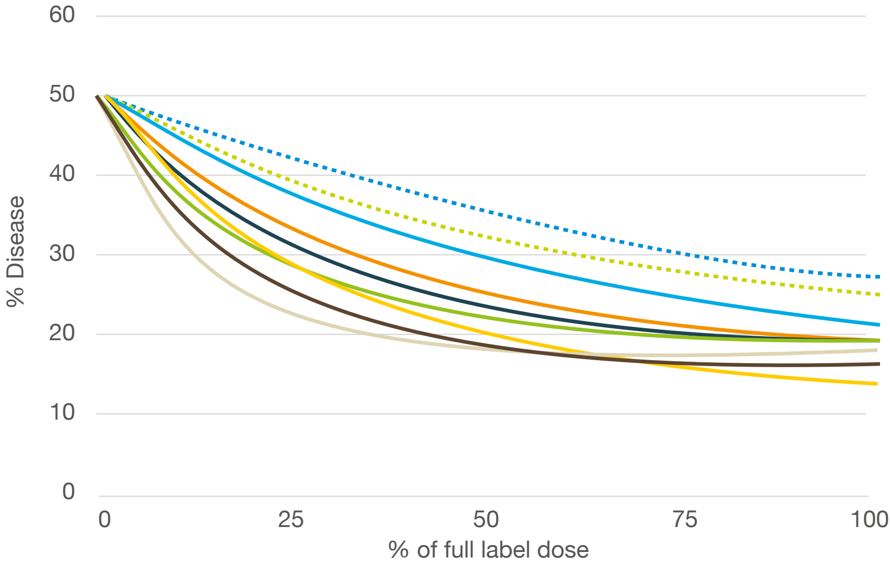


Figure 19. Example of a dose-response graph for nine different fungicide products

Varietal resistance

Growing disease-resistant varieties is an effective way to reduce fungicide inputs and risks associated with disease, especially when combined with cultural practices that reduce disease inoculum.

Fungicide resistance

Fungicide resistance occurs as a pathogen population adapts to a fungicide, either through mutation or natural variation and selection. Some pathogens are more likely to develop resistance. Resistance can arise rapidly, in a single step. However, it can also develop via a series of smaller steps, with the pathogen population becoming progressively less sensitive.

The intensity of fungicide use drives the selection of resistance. Higher numbers of treatments and doses result in faster selection for insensitive strains. Good resistance management limits the exposure of the target pathogen to the fungicide and still provides excellent disease control.

For some pathogens, fungicide resistance has developed for all the major single-site mode of action fungicides available to UK agriculture.

Fungicides with a multisite mode of action are much less prone to resistance. However, the choice of multisite fungicides approved for cereals is becoming limited. The key multisite chlorothalonil is available until spring 2020. Although other multisite fungicides are available, it is not clear whether they have sufficient activity against the target diseases.

Fungicides with multisite modes of action are much less prone to resistance. The process of mutation and selection, leading to resistance, is rarely seen with multisites outside the laboratory.

Fungicide resistance management strategies should:

- Exploit all practical, non-chemical control options
- Use varieties with resistance to the main diseases of concern
- Avoid large areas of any one variety, particularly in areas of high disease risk where the variety is known to be susceptible
- Minimise the number of applications. Only use fungicides when the risk or presence of disease warrants treatment, but treat before the infection becomes well established
- Include a multisite fungicide, where available, in both the early and late-season sprays

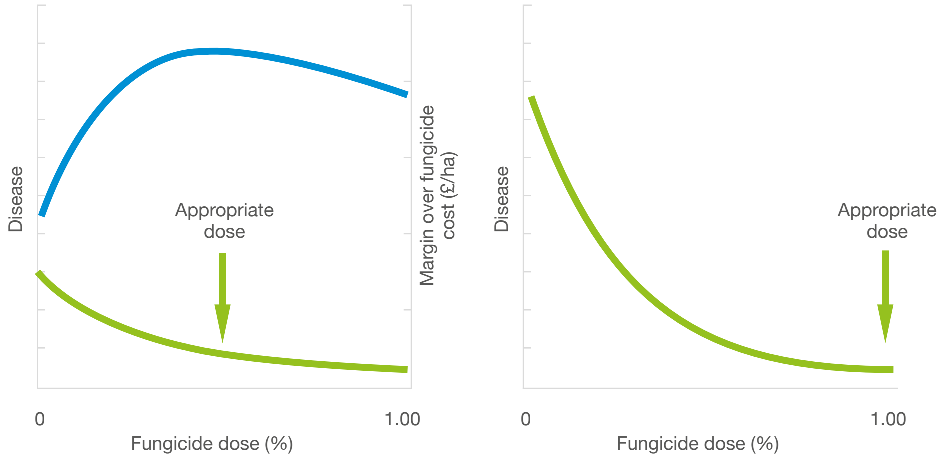


Figure 20. The appropriate dose is the point at which the margin over fungicide cost is maximised. The graph on the left shows the appropriate dose for a moderately resistant variety under a moderate disease pressure (in a hypothetical situation). The graph on the right shows the appropriate dose for a susceptible variety under a high disease pressure

- Make full use of effective fungicides with different modes of action in alternate sprays or mixtures. Where possible, make sure the mixture is balanced (i.e. use mixing partners at doses that give similar efficacy and persistence)
- Avoid repeat applications of the same mode of action
- Take into account any earlier use of fungicide groups as seed treatments
- Use the minimum dose required to effectively control the target
- Aim for optimum control to reduce the need for further applications

Points to remember:

- Any non-target pathogens present will be under selection pressure
- Although azole, strobilurin, and SDHI fungicides are available as single active substance products, they should not be used alone
- Never exceed the maximum number of applications or the total dose stipulated on the label
- Fungicide resistance is not the only thing that causes poor field performance. Poor control could be caused by too low a dose or poor/mistimed applications

For the latest resistance management information, visit the Fungicide Resistance Action Group – UK web page: **ahdb.org.uk/frag**

Fungicide programmes

It is important to tailor fungicide programmes to the risk of disease in the crop, taking account of historic disease pressure, varietal resistance and the sowing date. At some timings, the most appropriate action may be to avoid making an application.

The fungicides available for use in cereals changes frequently. This may be because chemistry loses authorisation or efficacy or because new chemistry comes to the market. Specific information on programmes for winter wheat, winter barley and spring barley, as well as implications for fungicide resistance management, is published in the AHDB Fungicide programmes for wheat and barley factsheet. Access the latest version via **ahdb.org.uk/fungicide-performance**

Septoria tritici (wheat, triticale and rye)

Pathogen

Zymoseptoria tritici

Septoria tritici spreads mainly by airborne spores and by rain-splash within an infected crop.

High-risk factors

- Susceptible varieties
- Early drilling
- Wet weather, especially during May and June
- Windy weather, which can increase the physical spread of spores
- Region (dry easterly regions are at less risk)
- Mild winter

Management

- Grow a variety with a high septoria tritici resistance rating
- Avoid early drilling, especially of susceptible varieties
- The T2 fungicide timing is the most crucial, with T1 also targeted at septoria tritici control. However, the T0 spray rarely gives a yield benefit
- Use a balanced mixture of an azole with a multisite (where possible). Only add an SDHI when disease risk merits it
- Use the lowest dose possible to get the required control, but ensure that each component of the mix gives comparable levels of control

Figure 21. Septoria tritici symptoms include brown, necrotic lesions peppered with black pycnidia

Yellow rust (wheat, barley and triticale)

Pathogen

Puccinia striiformis f. sp. *tritici* (wheat, mainly, but also barley) and *P. striiformis* f. sp. *hordei* (barley)

Within the forms of *P. striiformis*, there are races that only attack particular varieties. The fungus survives on living green plant material and spreads via airborne spores.

Figure 22. Yellow rust symptoms appear as parallel rows of yellowish orange-coloured pustules on cereal leaves

High-risk factors

- Susceptible variety
- Eastern regions of the UK
- Later-sown wheat
- Green bridge from previous crop
- Cool, damp weather conditions
- Mild winter
- Humid microclimate

Management

- Grow a variety with a high resistance rating, but monitor disease levels throughout the season
- Be aware of a variety's seedling-stage and adult-stage resistance rating (**ahdb.org.uk/ukcpvs**)
- In general, resistance to yellow rust increases during the growing season
- Early sowing increases the risk of an autumn epidemic but is less prone to the more damaging spring epidemics
- Eradicate volunteers to remove green bridge
- Manage nitrogen applications to avoid excessive concentrations in plants
- In wheat, apply an azole or strobilurin when yellow rust is seen. SDHIs used for septoria tritici control will also control yellow rust
- Fungicides are rarely required to control yellow rust in barley

Brown rust (wheat, barley, triticale and rye)

Pathogen

Puccinia triticina – formerly known as *Puccinia recondita* f. sp. *tritici* (wheat), *P. hordei* (barley) and *P. recondita* (triticale and rye)

The fungus survives on living green plant material and spreads via airborne spores. The pathotypes do not cross-infect.

High-risk factors

- Susceptible varieties
- Early drilling
- Mild winter
- Hot, humid weather, especially in April to July
- Southern regions of the UK
- Volunteers that provide a green bridge. Note: wheat volunteers are not a risk to barley and vice versa

Management

- Grow a variety with a high resistance rating, but monitor disease levels throughout the season
- Eradicate volunteers to remove green bridge
- Delay drilling of susceptible varieties
- Manage nitrogen applications to avoid excessive concentrations in plants
- In wheat, apply a fungicide with activity against brown rust when the disease is seen and conditions are conducive or at T2 and T3 in high-risk situations
- In barley, use fungicides early to control the disease. However, the azole/SDHI mixes used on other barley diseases will usually provide sufficient control

Figure 23. Brown rust symptoms appear as randomly scattered orange to brown pustules on cereal leaves

Photo copyright of Rothamsted Research

Powdery mildew (wheat, barley, oats, triticale and rye)

Pathogen

Blumeria graminis f.sp *tritici* (wheat and triticale), *B. graminis* f. sp. *hordei* (barley), *B. graminis* f. sp. *avenae* (oats) and *B. graminis* f. sp. *secalis* (rye)

The fungus survives on living green plant material and spreads via airborne spores. Despite the common name 'powdery mildew', it is often referred to as 'mildew' in cereal crops.

High-risk factors

- Susceptible variety
- Warm, humid but rain-free weather
- Mild winter
- Volunteers that provide a green bridge. Note: wheat volunteers are not a risk to barley and vice versa
- Sheltered, fertile locations
- Late drilling (affects tiller number)
- Early attacks (can reduce tiller numbers)
- Excessive nitrogen
- Dense crops

Although infection can look relatively severe, the associated yield loss is not always major. In fact, late attacks (after flowering) on the flag-leaf and ear rarely cause significant losses in wheat.

Management

- Grow a variety with a high powdery mildew disease resistance rating
- Eradicate volunteers and dispose of stubble and debris
- Manage nitrogen applications to avoid excessive concentrations in plants
- Use a mixture of eradicant and protectant chemistry
- Where mildew is the only target, use a specific mildewicide
- In barley, spray in the autumn if extensive disease affects overwintering capability in poorly tillered crops. Otherwise, treat infections on susceptible varieties in early spring
- In wheat, a T0 spray may be economic on susceptible varieties where the disease is active. Otherwise, treatment can wait until T1

Figure 24. Symptoms of early powdery mildew on wheat. Typically, white pustules with a powdery appearance appear

Rhynchosporium (barley, rye and triticale)

Pathogen

Rhynchosporium commune

The pathogen survives on trash and spreads to seedlings, mainly via rain-splash. It can also be seedborne, although the importance of this phase is not well understood.

High-risk factors

- Very early sowing
- Wet weather
- Tight rotations
- Infected trash, stubble, volunteers and seed
- Nearby infected crops
- Western and northern regions
- Reduced tillage, where trash remains on the soil surface

Management

- Grow a variety with a high rhynchosporium resistance rating, but continue to monitor disease on resistant varieties
- Avoid using seed from infected crops
- Minimise barley trash, stubble and volunteers
- Avoid early sowing of spring crops (December–February) and very early sowing of winter crops
- Manage nitrogen applications to avoid excessive concentrations in plants
- Early control with fungicides is important. Later applications may also be necessary, if the weather is wet

Figure 25. Rhynchosporium symptoms on barley appear as grey, water-soaked irregular patches with dark brown margins

Net blotch (barley)

Pathogen

Pyrenophora teres
f. *teres* (*Drechslera teres*) – net form,
P. teres f. *maculata* – spot form

The disease mainly spreads from trash, via airborne spores and rain-splash

High-risk factors

- Infected barley trash and volunteers (e.g. second barley crops after minimum tillage)
- Susceptible variety
- High humidity and mild temperatures in the spring and summer
- Early drilling
- High level of seed infection
- Thick crop

Management

- Grow a resistant variety
- Avoid second barley crops, minimise infected crop debris and control volunteers
- Manage nitrogen applications to avoid excessive concentrations in plants
- Avoid early sowing
- Avoid using highly infected seed
- Treat infected seed with an effective seed treatment
- Use fungicides to control net blotch at the T1/T2 timings. Use mixtures to combat fungicide resistance

Figure 26. Net blotch symptoms can vary depending on the source of infection. Leaves frequently have yellowing associated with all types of lesion

Ramularia (barley)

Pathogen

Ramularia collo-cygni

This disease is seedborne and airborne, although the relative importance of these sources is not well understood.

High-risk factors

- Infected seed
- Northern regions of the UK
- Crop stress

Management

- In high-risk situations, apply a preventative spray of an effective fungicide, where available, at booting (GS45–49)
- Avoid putting the crop under stress, where possible
- Ensure accurate disease identification
- Assess symptom levels late in the season
- Avoid saving seed from heavily infected crops

Figure 27. Ramularia symptoms appear on the upper leaves after flowering. Initial damage is a fine pepper spot that darkens to a square spot, bounded by leaf veins and surrounded by a chlorotic halo

Tan spot (wheat, barley and rye)

Pathogen

Pyrenophora tritici-repentis (*Drechslera tritici-repentis*)

This trashborne disease is of low importance in the UK, but it is becoming more common.

High-risk factors

- Minimum and non-inversion tillage
- Long periods of wet weather from GS32 onwards
- Seed infection

Management

- Use non-host crops to extend the rotation
- Plough and use clean seed
- Specific fungicidal treatment is not usually required

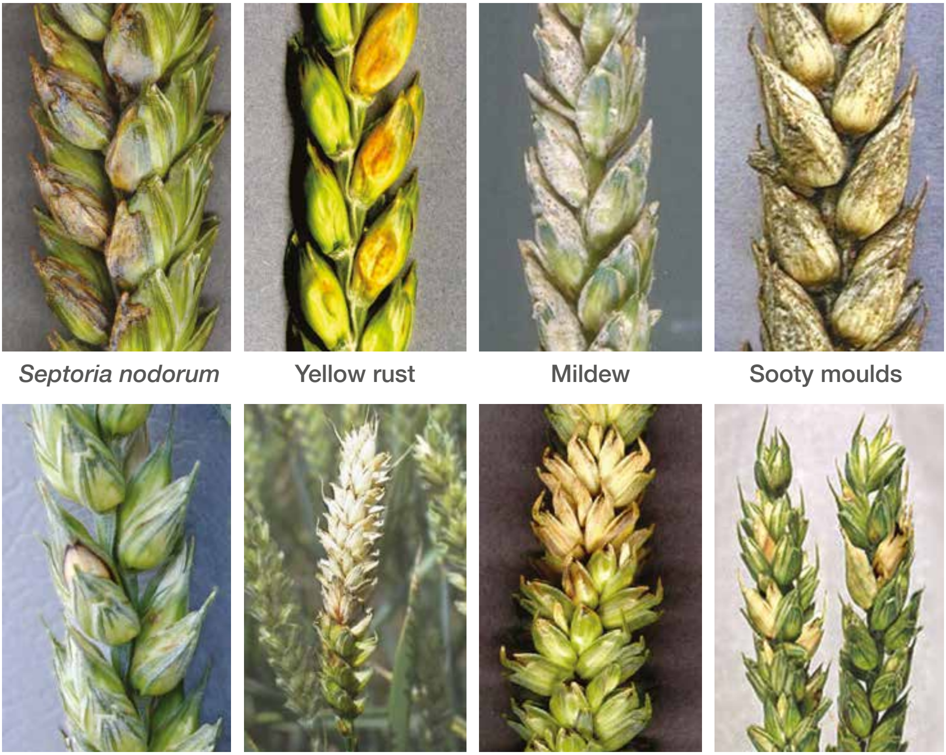
Figure 28. Tan spot lesions often have a dark spot at the centre surrounded by a chlorotic halo

Ear diseases

Wet weather during flowering and grain filling encourages ear and grain diseases. Although they can reduce yield, their main effect is on grain quality.

Infection can reduce grain filling and result in low specific weights and shrivelled grain. In barley, screenings are increased. Crop infection by pathogens that cause fusarium ear blight and ergot may result in mycotoxins. Some also affect grain appearance (e.g. sooty moulds), causing rejection for milling.

Some root and stem diseases can stress the crop and cause premature ripening. Foliar diseases, such as rusts, mildew, rhynchosporium, net blotch and ramularia, can also spread to the ears and awns.



Septoria nodorum | Yellow rust | Mildew | Sooty moulds

Fusarium poae | *Fusarium culmorum* | *Fusarium graminearum* | *Fusarium avenaceum*

Figure 29. Some diseases that affect wheat ears

Fusarium and microdochium – ear/head blight, seedling blight and foot/crown rot (wheat, barley, oats, rye and triticale)

Pathogen

Fusarium avenaceum, *F. culmorum*, *F. graminearum*, *F. poae*, *F. langsethiae*, *Microdochium nivale* and *M. majus*

This complex of diseases, which can be seedborne, soilborne or trashborne, causes various symptoms, with the most economically important being fusarium ear blight. Fusarium inoculum is present in most UK fields. Seedling blight and foot rot are not major problems in UK cereals because effective seed treatments are available.

Fusarium species also produce mycotoxins; chemicals that are toxic to humans and livestock. These include deoxynivalenol (DON) and zearalenone (ZON). Legislation imposes limits on levels in wheat, barley and oats. In most years, few UK grain samples exceed the limits.

The presence of ear blight is not a reliable indicator of mycotoxin risk. Crop assurance schemes require the entry of a mycotoxin risk assessment score on the combinable crops passport. Use the AHDB fusarium mycotoxin risk assessment to generate this score: ahdb.org.uk/mycotoxins

Figure 30. Ear blight infection can cause bleached ears

High-risk factors

Before sowing:

- Untreated infected seed
- Poor seedbeds
- Soil-surface residue from a previous crop – this is the major inoculum source, especially after (in descending order) grain maize, forage maize, sugar beet or grass
- Region: DON and ZON levels in wheat tend to be highest in southern and eastern England, moderate in western England and lowest in northern England and Scotland. Higher humidity in coastal areas may increase risk
- Cultivation: risk is increased with direct drilling and reduced by complete burial of debris
- Growing a susceptible variety

Between sowing and flowering:

- Warm, dry weather from sowing to about GS31 encourages the build-up of fusarium inoculum. Microdochium is more prevalent in cooler conditions
- Various broad-leaved and grass weeds, crop debris, as well as some insects, can provide a source of fusarium

During flowering:

- Wet weather at flowering (GS59–69)

Post-flowering:

Figure 31. Pink grains indicate possible fusarium infection

- Lodging, resulting in humid conditions conducive to mycotoxin production
- Higher rainfall in the weeks before harvest (from GS87) that allows secondary infection
- Delays in harvesting by more than two weeks
- Damaged grain

Note: When ear blight levels are high nationally, the risk of DON and ZON occurrence in crops will increase. Although mycotoxin risk in barley is lower than in wheat, it should be considered, especially when it is commonly grown in the rotation with maize with minimum tillage.

Management

- Remove straw from susceptible crops and avoid following maize with wheat in rotations
- Use inversion tillage
- Grow a resistant variety
- Control grass weeds
- Use the AHDB Fusarium mycotoxin risk assessment tools
- In high-risk situations, apply a fungicide at T3 (GS63–65)
- Harvest high-risk crops as soon as possible

GS59:
Not flowering – 'top up' foliar disease control ✓

GS63–65:
Early flowering – optimal time to control ear diseases ✓

GS69:
Late flowering – too late to spray ✗

Figure 32. A T3 fungicide spray can help 'top-up' foliar disease control or control fusarium and microdochium species that cause the ear disease head blight. The disease target alters the optimum time for the T3 spray

Photo copyright of Bayer Crop Science

Ergot (wheat, barley, oats, rye and triticale)

Pathogen

Claviceps purpurea

Figure 33. The ergot fungus infects cereals during flowering and produces dark sclerotia in place of grain

Ergot has very little direct effect on yield. However, contaminated grain can be rejected, require cleaning or demand a reduced price. Standards for the number of ergot pieces exist for certified seed.

High-risk factors

- Open-pollinated wheat varieties and varieties with a long flowering period
- Cool and wet conditions during flowering, which facilitates spore production and prolongs the flowering period
- Grass weeds, particularly black-grass
- Grass margins containing early flowering grass species
- Late and secondary tillering

Note: Although infected seed lots spread the disease, this ear disease is not strictly seedborne.

Management

- Use non-host crops to extend the rotation
- Plough to bury ergots to at least 5 cm depth
- Control grass weeds, especially black-grass
- Sow later-flowering grass species in grass margins
- Avoid open flowering varieties and varieties with a long flowering period
- Avoid sowing contaminated seed
- No fungicides are approved for use on cereals to control ergot infection. However, some seed treatments may have a small effect
- In heavily infected areas, harvest field headlands and tramlines separately from the bulk of the crop

Virus diseases

Transmitted by the bird cherry-oat aphid and the grain aphid, *Barley yellow dwarf virus* (BYDV) is the main virus threat to UK cereal production. Some soilborne vectors can also transmit viruses to winter-sown crops.

BYDV (wheat, barley, oats, rye and triticale)

In winter crops, infection usually occurs in the autumn and symptoms appear in the spring.

High-risk factors

- Early sowing of winter crops
- Late sowing of spring crops
- Mild conditions in autumn and winter
- Green bridge between harvest and sowing of the next cereal
- Crops drilled after grass
- Proximity to grass margins and hedges

Management

- Delay drilling
- Grow a tolerant variety
- Monitor aphid activity
- Use tools that predict the second generation of aphids, which should be the target of any spray
- Although pyrethroid sprays can be used, some of the UK grain aphid population has moderate levels of resistance to them. Apply pyrethoids at full label rate

Figure 34. Distinct circular yellow patches are often seen in BYDV infected crops

- Maximise natural enemies of crop pests
- Grass strips can provide refuges for cereal aphids. Wildflower strips with a diverse grass mixture are less likely to harbour pests

Cereal mosaic viruses

Viruses

Barley yellow mosaic virus (BaYMV), *Barley mild mosaic virus* (BaMMV), *Oat mosaic virus* (OMV), *Oat golden stripe virus* (OGSV), *Soilborne cereal mosaic virus* (SBCMV) and *Soilborne wheat mosaic virus* (SBWMV).

The soilborne parasitic vector *Polymyxa graminis* infects crop roots and transmits these viruses.

High-risk factors

- Previous infection (virus can persist for up to 25 years)
- Movement of infected soil, especially by cultivations and machinery movement
- Susceptible variety

Management

- Limit spread through reduced cultivation and good machinery hygiene
- Grow resistant barley varieties

Figure 35. Typical yellow streaks and brown flecking of Barley yellow mosaic virus (BaYMV)

Further information

Disease management resources

Encyclopaedia of cereal diseases

The encyclopaedia of cereal diseases (wheat, barley, oats, rye and triticale) describes the pathogens responsible, covering hosts, symptoms, life cycle and importance. Featuring both major and minor diseases, it complements this management guide.

ahdb.org.uk/encyclopaedia-of-cereal-diseases

Recommended Lists

The AHDB Recommended Lists (RL) provide information on yield and quality, agronomic features and market options to assist with variety selection. Varietal resistance should be the foundation of any disease management strategy. The RL presents resistance ratings for several key diseases on a simple scale: 1 (least resistant) to 9 (most resistant).

ahdb.org.uk/rl

Wheat and barley growth guides

The AHDB growth guides for wheat and barley provide comprehensive information on how these crops develop. The guides allow crop progress, structure and final performance to be measured and compared to a series of UK benchmarks. Each guide also includes an illustrated cereal growth stages (GS) key to guide management (e.g. fungicide spray timings).

ahdb.org.uk/wheatgg

ahdb.org.uk/barleygg

Fungicide performance

AHDB's fungicide performance work provides high-quality, independent information on the efficacy of new and established fungicides against key diseases in wheat, barley and oilseed rape. Published annually, use the results to build fungicide programmes – based on mixtures of active ingredients and products – appropriate to the local disease threat profile and in keeping with best practice anti-resistance guidelines.

ahdb.org.uk/fungicide-performance

Fungicide programmes

The availability of cereal fungicides changes frequently because authorisation or efficacy can be lost and new chemistry can come to the market. The AHDB Fungicide programmes for wheat and barley factsheet sheet provides the latest information, including implications for fungicide resistance management.

ahdb.org.uk/cereal-dmg

Access all resources referred to within this guide via ahdb.org.uk/cereal-dmg

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