THE RESISTANCE
ROADSHOW

Let's tackle insect pest, weed and disease resistance ... together

WORKBOOK

With thanks to Defra for funding this initiative, and our collaborators:

Collaborators

The Resistance Roadshow is a collaborative event series, funded by Defra and facilitated by AHDB. The event series combines resistance management information and practical expertise from across the industry, working with ADAS, Niab, Harper Adams University, Rothamsted Research and the Voluntary Initiative. With a focus on practical on-farm action, the Resistance Roadshow promotes powerful and consistent messages on effective resistance management to reduce the development of pesticide resistance.

Purpose of this workbook

This workbook sits alongside the Roadshow to give you a clear, accessible guide to the key terms and principles behind insect pest, weed and disease resistance management. It keeps things simple and practical, focusing on what matters most on farm. To dig deeper into the technical detail, you'll find extra resources and guidance throughout the workbook

Key resistance management resources

The Resistance Action Groups (RAGs) are voluntary, UK-based groups consisting of experts from the Crop Life UK member companies, other representatives from the agrochemical industry, a range of independent organisations, including public-sector research institutes, agronomy groups and the Chemicals Regulation Directorate (CRD).

For more information on resistance management, Insect pest, Weed and Fungal disease Resistance Action Groups please visit:

ahdb.org.uk/ipm **ahdb.org.uk/wrag** **ahdb.org.uk/frag** **ahdb.org.uk/irag**

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What is resistance?

Pesticide resistance occurs when a pest (such as a weed, fungal disease or insect pest) survives pesticide application, allowing the resistance trait to increase and spread.

Resistance develops through naturally occurring genetic mutations that arise by chance within a population. These genetic changes can be as simple as a single mutation at one location on the genome, or they can be complex, involving multiple genes across the whole genome. When a pesticide with a specific mode of action (MoA) is used repeatedly either within or across seasons, individuals with resistance mutations are more likely to survive, passing these traits on to their offspring. One way to combat this is to limit the dose or number of applications for a particular MoA.

Mode of action (MoA)

Mode of action (MoA) describes the biochemical or physiological process through which a pesticide will affect a living organism. It refers to the action at the cellular or molecular level that begins when a pesticide interacts with the biological target. This disrupts normal cellular function, which can lead to impaired growth, injury, or death of the insect pest, plant pathogen or weed.

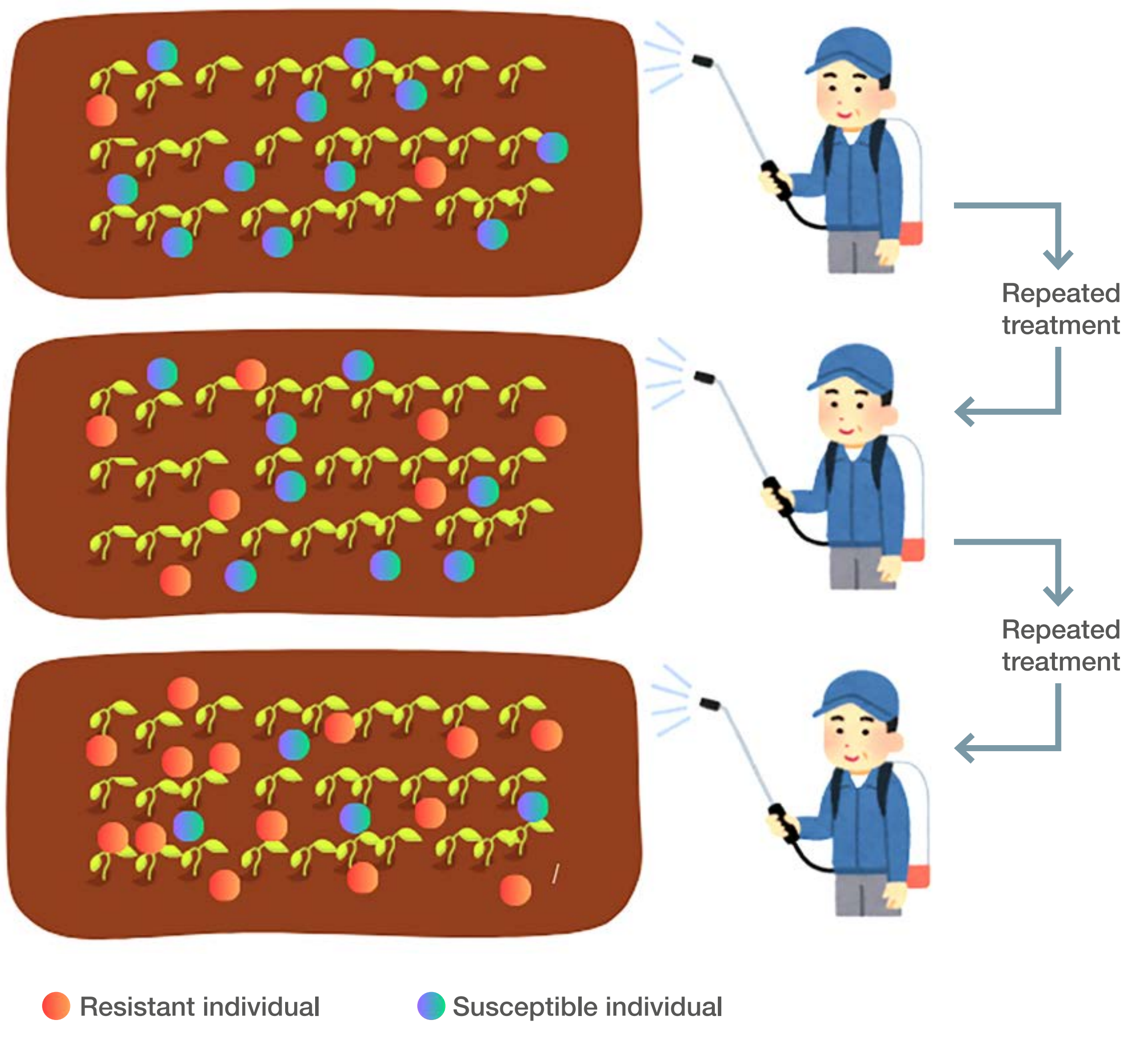

Figure 1. Increasing proportion of resistant insect pests, weeds or fungal pathogens within a population following repeated application of the same mode of action treatment

The way in which resistance develops in insect pests, weeds or fungal pathogens may be driven by different mechanisms. Sometimes, a single genetic mutation is enough to make the pest less sensitive, but sometimes multiple mechanisms are present, and the way in which pesticide performance is affected is much more complex. This is reflected in the different ways in which resistance impacts field performance of pesticides:

- Pesticides are grouped based on their MoA. If resistance occurs to one pesticide in a MoA group, it may affect some or all members of that group
- Cross-resistance can occur when a single mechanism confers resistance to more than one MoA. Pesticides in the same and different MoA groups can be affected to different degrees and become less effective in the field
- Multiple mechanisms can be present in the same populations. Selection for resistance to pesticides over time – either one after the other or in parallel – can lead to multiple resistance mechanisms occurring in the same pest population

Field scale development and spread

Resistance can build up and eventually dominate a pest population, resulting in the affected pesticides having reduced efficacy. Once resistant weeds, insect pests or fungal pathogens have established within a field, it is possible for resistance to spread across and between fields and more widely. This spread is more likely for insect pests and fungal pathogens which are dispersed more freely, but less so with weeds. Insect pests, fungal pathogens and weeds can be dispersed in a range of ways, including by wind, water and soil. It is possible for resistant organisms to be picked up and transported longer distances by machinery, straw and manure, slurries or digestate, moving between fields or farms, resulting in a wider geographic spread (see Figure 2).

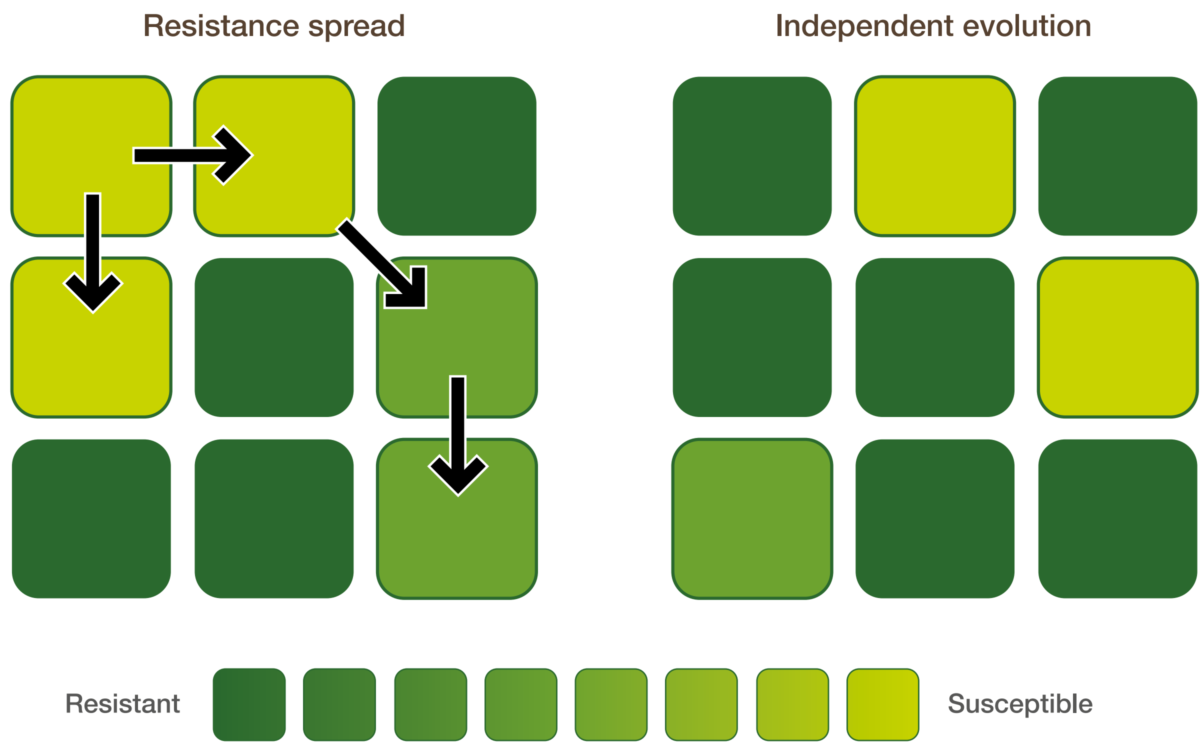

Figure 2. Theoretical spread of resistance between neighbouring fields via independent evolution or movement of resistant pests, weeds or disease pathogens

Mechanisms of resistance

Resistance mechanisms are diverse but can be broadly divided into two classes: target-site and non-target-site resistance. The latter includes several sub-types of resistance mechanisms.

1. Target-site resistance (TSR)

Target site resistance occurs when mutations change the structure of the proteins that pesticides normally bind to, making them less sensitive or completely insensitive to the chemical. Several target-site mechanisms can exist within one species.

Examples in herbicides include Acetyl-CoA carboxylase (ACCase) and acetolactate synthase (ALS) resistance. Resistance to the former affects the ACCase binding site targeted by 'fop', 'dim', and 'den' herbicides used against grass weeds. It can spread quickly and cause significant loss of control. Resistance to the latter affects the binding site for the ALS enzyme, which would be inhibited by sulfonylurea and related herbicides, reducing control of both grass and broad-leaved weeds.

Examples in insecticides include knockdown resistance (kdr and super-kdr), which alters sodium channels targeted by pyrethroids, MACE (modified AcetylCholinEsterase), which affects the enzyme targeted by organophosphates and carbamates, and neonicotinoid resistance, which affects the receptor targeted by neonicotinoids. The peach–potato aphid (*Myzus persicae)* in the UK commonly has both super-kdr and MACE, but populations with neonicotinoid resistance were detected in England in 2023.

Examples in fungicides include resistance to quinone outside inhibitors (QoIs, e.g. strobilurins) and succinate-dehydrogenase inhibitors (SDHIs) in septoria leaf blotch (*Zymoseptoria tritici*), and resistance to sterol demethylation inhibitors (DMIs, e.g. azoles) in ramularia leaf spot (*Ramularia collo-cygni*). Resistance to quinone outside inhibitors (QoIs e.g. strobilurins), such as the G143A mutation affecting strobilurin fungicides, can result in loss of efficacy very quickly (within one to two years), with total control failure in the field. Resistance to azole fungicides for septoria leaf blotch (*Zymoseptoria tritici*), developed progressively over time. When resistance develops slowly, individual isolates may show reduced sensitivity in laboratory tests, but there may be no loss of field performance detected immediately.

2. Non-target site resistance (NTSR)

There are many known forms of NTSR:

Metabolic resistance

Metabolic resistance (or 'enhanced metabolism') involves increased production of the enzymes that break down pesticides before they reach their target sites. This is relatively common in insecticide and herbicide resistance but rare in fungicide resistance. Common enzyme systems include esterases, oxidases (such as P450s) and glutathione S-transferases. For instance, in beetles and aphids, overproduction of P450 or esterase enzymes provides resistance to pyrethroids, organophosphates and neonicotinoids. Cabbage stem flea beetle in the UK is thought to have a combination of target-site resistance (kdr/super-kdr) and metabolic resistance.

Target overexpression

Excess production of the target enzyme occurs, diluting the fungicide's effect. Most common in fungicide resistance.

Modified translocation and compartmentalisation:

This occurs in herbicide resistance whereby the herbicide is prevented from translocating to the growing points, either by compartmentalising the herbicide in vacuoles or hindering movement across membrane barriers.

Enhanced efflux or reduced uptake or penetration resistance

Pesticide molecules are expelled or prevented from entry. This mechanism is relatively rare. For example, changes to an insect's outer cuticle may slow the absorption of pesticides. This may be through developing thicker, waxier or less permeable cuticles, which slow down or reduce the amount of pesticide that can enter their bodies. The result is that less of the active ingredient reaches the target sites inside the insect, so the pesticide doesn't work as well.

Bypass mechanisms

Alternative biochemical pathways restore essential functions. There is very limited evidence of this occurring in controlled or field environments.

Behavioural resistance

Behavioural resistance occurs when pests modify their behaviour to avoid exposure to an insecticide – such as moving away from treated areas, repellence from the odour of the pesticide or reducing feeding after exposure. Although relatively uncommon in crop pests, it has been observed in some species exposed to organophosphates, carbamates and pyrethroids.

The various NTSR mechanisms can occur together and allow pests, weeds and diseases to tolerate a wide range of pesticides, regardless of their MoA. This usually happens because the organism becomes more efficient at breaking down or detoxifying pesticide compounds. It typically develops gradually and is the most widespread resistance mechanism in UK grass weeds.

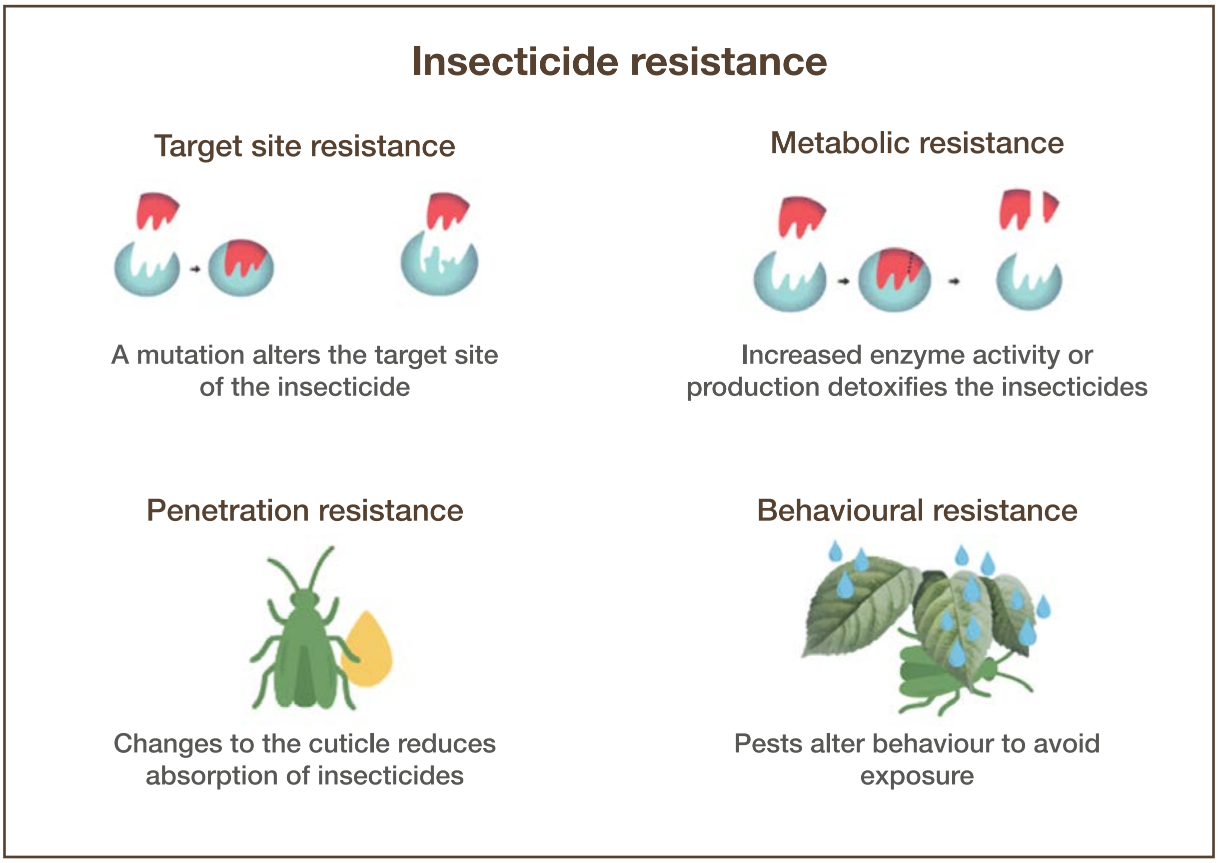

Figure 3. The main resistance mechanisms affecting insecticides

How to identify resistance

How to identify insecticide resistance in arable pests

To identify insecticide resistance in arable pests, laboratory-based bioassays or molecular assays can be used to test field-collected insects against specific insecticides.

Bioassays

These tests expose live insects to specific concentrations of an insecticide and measure the mortality rate (pesticide efficacy).

- Diagnostic/discriminatory concentrations: Use concentrations that cause a high mortality rate (e.g. 95–99%) in a susceptible population to quickly screen for resistance
- Dose-mortality assays: Determine the median lethal dose (LD50), which is the concentration that kills 50% of the population. A higher value in a field population compared to a susceptible reference strain indicates reduced sensitivity and potential resistance

Molecular analysis

Detect genetic changes associated with resistance. Genetic changes can present in various ways:

- The presence of known resistance mutations
- The detection of genetic markers that infer resistance
- Changes in gene expressions levels that infer resistance, such as those for enzymes that detoxify insecticides
- Measuring specific enzyme levels in insects, such as esterases, which can be elevated in resistant individuals

As resistance can occur through from different mechanisms, molecular methods (e.g. DNA & RNA As resistance can occur through different mechanisms, molecular methods (e.g. DNA and RNA analyses) can help identify the specific mechanism in a way that bioassays may not. However, bioassays allow resistance to be identified where the resistance is novel (i.e. before genetic markers, etc., are known).

Routine resistance monitoring and checking insecticide effectiveness after application is important. Collecting pest samples from a field over time and analysing them can identify resistance trends. In 2025/26, ADAS is leading a Defra-funded project to monitor insecticide resistance in the UK. If you are interested in providing pest populations for this work and receiving feedback on the resistance status of your population, then please see ‘Further resources’ sections in the workbook.

How to identify herbicide resistance in arable weeds

Selection for reduced sensitivity and resistance to herbicides often occurs independently in individual fields, and because of this, weed populations in different fields can have a unique resistance profile.

- Identification of herbicide resistance starts with monitoring and recording, keeping on a field-by-field basis and being aware of any developing patterns of failure or reduced control
- In the field where weeds survive appropriate applications of herbicide, carefully observe if individual weeds are healthy right next to other plants which have been effectively controlled
- At least initially, resistance will occur in small patches or clusters at the very earliest stage; this is quite distinctive. To support monitoring and surveillance, test seed or plant samples regularly (at least once every two to three years) on a field-by-field basis
- Keep accurate field records of cropping, cultivation, herbicide use, weed infestation and control achieved
- Ensure samples are representative of the field
- Resistance variation within a patch of the same weed is likely to be negligible, but variation can occur between patches and across fields

- Discuss sample collection and testing options with your adviser or crop protection supplier
- Most tests use seeds from weeds that survive herbicide treatment, although some tests use plants
- Seed or plant samples collected for testing are subject to glasshouse or laboratory tests to determine their response to herbicide applications

Interpreting results

Usually, resistance tests are based on herbicide treatment survivors. This bias means results are likely to exaggerate the level of resistance in the weed seed bank. How representative the results are of the entire field depends on the accuracy of sampling, weed density and distribution, and the proportion of plants that survived treatment across the field. Inherent bias does mean resistance can be detected at an early stage, so it should be seen as a positive attribute rather than a reason for not testing.

What do results mean?

Most glasshouse or laboratory resistance tests in the UK use the standard ‘R’ rating system to show resistance severity and likely impact on herbicide performance.

Weed resistance is rated using an ‘R’ system:

- RRR – resistance highly likely to reduce herbicide performance
- RR – resistance likely to reduce herbicide performance
- R? – early indications of resistance development, possibly reducing herbicide performance
- S – susceptible, no effect on herbicide performance

Contents summarised based on WRAG publication entitled: Maximising the benefits of herbicide resistance testing.

How to identify fungicide resistance in arable diseases

- Most modern fungicides have single-site modes of action, acting on specific biochemical pathways in the target fungal pathogen
- Repeated use of fungicides with the same MoA can select for isolates of the fungal population that have a reduced sensitivity to the fungicide – leading to a loss of efficacy
- Tests, conducted on fungal isolates, can determine a population’s EC50 value for specific fungicides
- An EC (effective concentration) of 50 is the fungicide dose that results in a 50% inhibition of the isolate, compared to a control (no fungicide applied). A higher value in a field population compared to a susceptible reference strain indicates increased tolerance and potential resistance. An EC50 value based on laboratory tests is not directly transferable to field application rates
- If isolates with increased EC50 values remain at low levels within the population, they may have no impact on the field performance of the fungicide when used at commercial doses
- Resistance can arise rapidly and completely, so that disease control is lost in a single step. More commonly, resistance develops gradually so that the pathogen population becomes progressively less sensitive

Keep an eye on the AHDB fungicide performance data produced annually. This data provides high-quality, independent information on the relative efficacy of fungicides against key diseases in wheat, barley and oilseed rape. These efficacy results can be used to help build fungicide programmes – based on mixtures of active ingredients and products, and appropriate doses – appropriate to the local disease threat and in keeping with resistance management guidelines.

How to manage resistance

Pesticides remain an essential tool for maintaining healthy crops and achieving reliable, high-quality yields. Ensuring long-term effectiveness of pesticides requires using them alongside other pest management approaches as part of an integrated pest management (IPM) strategy.

Integrated Pest Management

IPM is a coordinated and planned on-farm strategy for the prevention, detection and management of pests, weeds and diseases. The inclusion of preventative approaches, as well as monitoring pest activity and risks, supports better management decisions. In the context of resistance management, an effective integrated approach reduces the population size, or rate of population growth, of a pest, weed or disease, and so reduces the frequency and/or amount of pesticide applications needed to avoid economic damage. When pesticide applications are needed, the IPM strategy should include a plan to minimise the risk of resistance, optimising the timing and application to target the pest and use a range of modes of action.

The aims of an IPM approach are to (Source: Defra 2024):

1. Support healthy crops using a range of plant protection methods.
2. Support resilient and sustainable agricultural production.
3. Help manage pesticide resistance.
4. Encourage natural control mechanisms.
5. Enhance wildlife and biodiversity.
6. Reduce reliance on the use of chemical pesticides, also known as plant protection products (PPPs).

Whole-farm IPM is good agricultural practice and has been implemented in UK agriculture for decades. There are eight IPM principles (Barzman 2015), but these are often condensed and visualised as a pyramid of five key principles (Figure 4). The five pillars of holistic IPM (Figure 5) suggest an alternative model, highlighting the importance of selecting approaches from across all pillars, rather than in the hierarchical order of the pyramid.

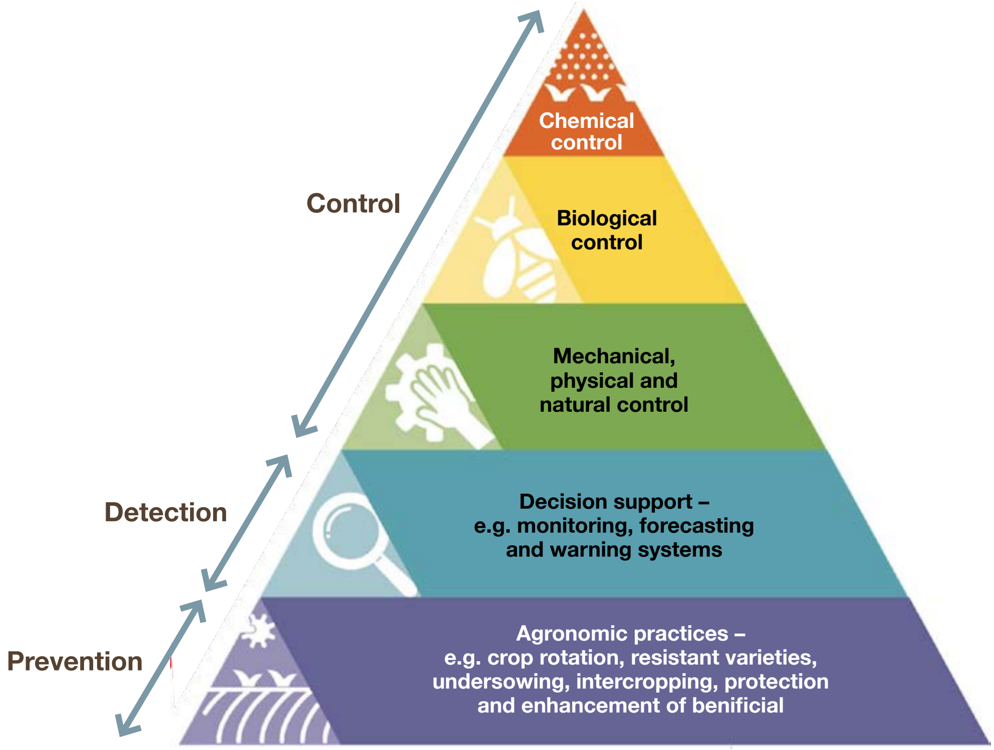

Figure 4. An IPM pyramid (Courtesy of the SmartProtect Thematic Network)

Table 1. Summary of resistance management

Managing resistance

Do

- Select crop varieties with a high degree of resistance to diseases or pests known to be prevalent in your area
- Monitor crops regularly and treat before the pest, weed or disease becomes well established
- Use treatment thresholds to determine whether pests, weeds or diseases (or their damage) are present at levels that warrant treatment with pesticides
- Use a dost that will give effective control and which is appropriate for the variety and pressure
- Make use of different modes of action in mixtures or as alternate sprays

Avoid

- Growing large areas of any one variety
- Repeated applications of the same product or mode of action. From 2023, all UK plant protection products include mode of action information on their labels

Don't

- Use a pesticide unless absolutely necessary
- Exceed the maximum recommended dose or number of applications
- Apply less than the label stated dose for insecticides or herbicides
- Apply less than the dose required for effective disease control

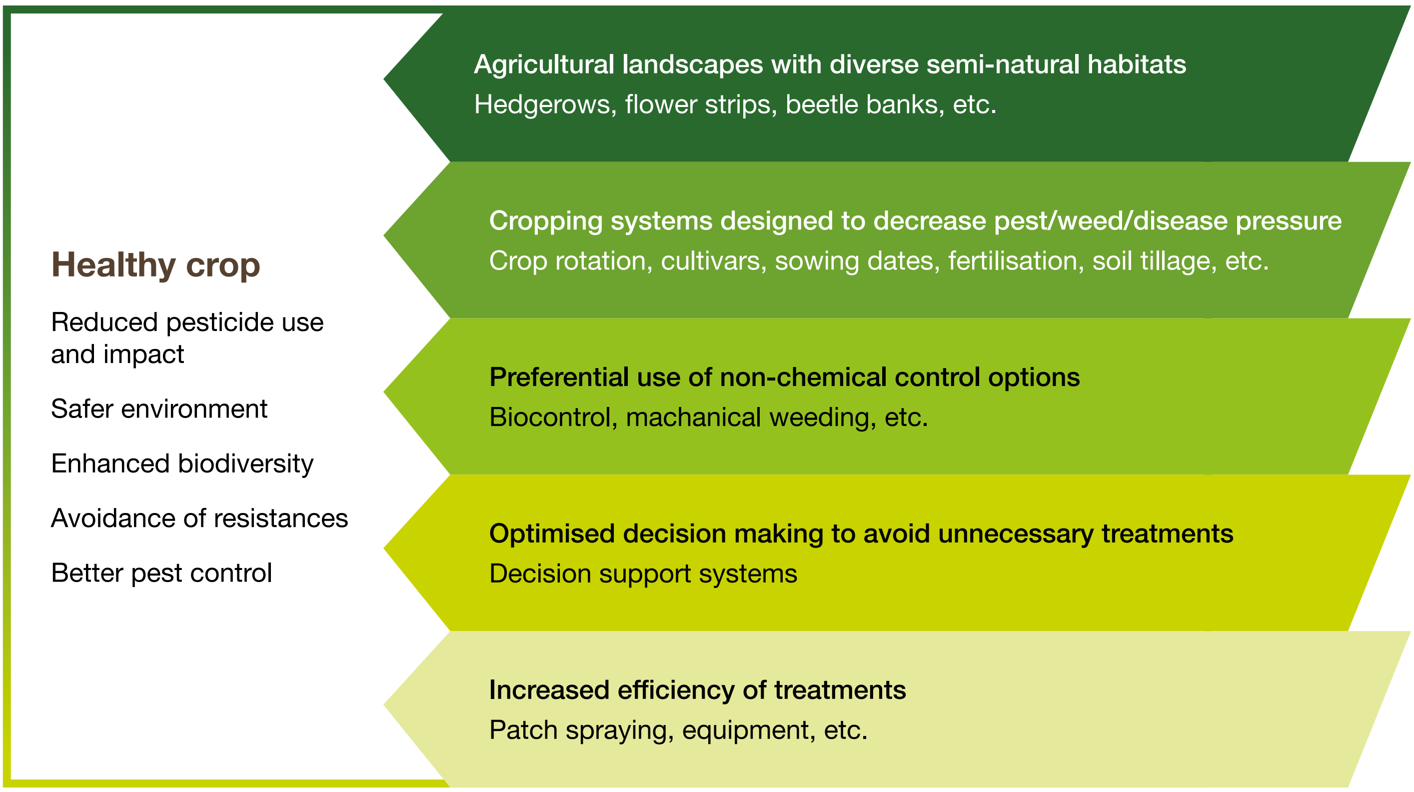

Figure 5. The five pillars of holistic IPM. (Source: IPM Works 2025)

Resistance management and IPM: Insect pests

For many insect pests, pyrethroids are the only synthetic chemical option registered, making maintaining the efficacy of pyrethroids key for UK arable agriculture. Alternative chemistry is either absent, has restricted uses or will need complete registration for the UK (and is likely to be more expensive), and resistance management options are limited in terms of alternation of MoAs or mixtures. At least 10 UK invertebrate species have already developed resistance to pyrethroids.

Effective resistance management relies on reducing pesticide use by adopting multiple **IPM practices** and selecting the insecticide dose carefully.

Practices to manage resistance

- Using approaches to minimise the risk of pest pressures reaching levels that warrant an insecticide is key to reducing insecticide use. These include selecting varieties with resistance/ tolerance (e.g. orange wheat blossom midge, *Barley yellow dwarf virus*), using an appropriate cultivation method, including companion or trap crops, adjusting sow dates and encouraging the activity of natural enemies
- Correct pest identification is essential to choose appropriate strategies, with identification resources available through AHDB
- Monitoring pests during vulnerable crop stages and under favourable conditions (e.g. mild temperatures for aphids) allows for timely and targeted control and ensures treatments are needed, i.e. using treatment thresholds. Natural population fluctuations and weather effects, such as frost, should also inform treatment decisions. Use decision support systems to assist with need for and timing of insecticides (e.g. the *Barley yellow dwarf virus* tool).
- The beneficial presence of natural enemies (e.g. ladybirds, parasitoid wasps, hoverflies) should be considered, as broad-spectrum products like pyrethroids can also target beneficial invertebrates and disrupt biological control. Seek to encourage and provide resources for natural enemies to support natural pest control on farm
- If an insecticide is needed, then use the full label rate. Under-dosing encourages resistance. Time the insecticide for optimal performance to minimise resistance risk
- Labels provide key resistance management information, including limits on product or MoA use per crop. Growers should follow these instructions carefully and seek advice from BASIS-qualified advisers or manufacturers when unsure
- Post-application monitoring is necessary to confirm efficacy; poor control may result from factors such as inadequate coverage rather than true resistance. If control failure occurs despite correct application, avoid reusing insecticides from the same MoA and report potential resistance cases for testing

IPM: insect pests – further resources

Wanted dead or alive! Reward: information on YOUR resistance status!

- ADAS is seeking populations of 1) Peach potato aphid 2) Bird-cherry oat aphid 3) Grain aphid and 4) Cabbage stem flea beetle for molecular and bioassay testing for a Defra-funded resistance monitoring project
- Collection kits and pre-paid return postage, as well as results feedback will be provided

For more information on how to send your sample, **email enquiries@adas.co.uk or** visit: **adas.co.uk/news/wanted-dead-or-alive-pests-to-test-for-resistance**

Cabbage Stem Flea Beetle (CSFB) research

New collaborative research project between AHDB, ADAS, NIAB and Rothamsted Research will:

- Explore novel CSFB control products, such as novel insecticides, seed treatments, biopesticides, nematodes and synergists
- Improve understanding of CSFB traits to better target control measures
- Extend cultural control methods available
- Study the two main natural enemy parasitoids of CSFB

Latest project information at: **ahdb.org.uk/csfb-research**

Cabbage Stem Flea Beetle (© Rothamsted Research)

Resistance management and IPM: Weeds

Target site and non-target site resistance mechanisms are present in UK grass weeds, to various degrees. For example, multiple herbicide resistance now occurs on the majority of farms where herbicides are used against black-grass. Control has relied increasingly on pre-emergence herbicides, which can be more variable.

Most cases of broad-leaved weed resistance are to the ALS inhibitor group of herbicides. Resistance is most common in poppy, followed by chickweed and then mayweed. Resistant plants are almost completely unaffected by ALS herbicides applied at normal field rates.

ALS (e.g. sulphonylurea) and ACCase (fops, dims and dens) herbicides pose a very high risk of resistance development. No new herbicide modes of action are expected in the near future, and once resistance develops, it is permanent. Because resistance is already widespread, immediate action is essential.

Practices to manage resistance

- Use of diverse chemistry (mixtures or sequences with more than two MoAs) and avoiding repeat use of the same MoA in one season
- Minimising use of herbicides with high risk of resistance (e.g. ALS (sulphonylurea) and ACCase (fops, dims and dens))
- Maximise efficacy by correct herbicide use following label rates and timing
- Minimum dose should ensure 100% kill of target weeds (accounting for the growth stage of the weeds and application conditions)
- Monitor herbicide performance to confirm efficacy; poor control may result from factors such as inadequate coverage rather than true resistance
- Integrated weed management – combining chemical, cultural and mechanical controls
- Varied crop rotations (winter and spring crops) and leys
- Maintain low weed densities
- Monitor changes in weed population
- Resistance testing is a valuable diagnostic tool

Control of seed spread is crucial. For example, black-grass can spread widely and produce up to 50,000 seeds/m^2. This makes managing the weed seedbank one of the biggest challenges for growers and agronomists.

IPM: Weeds – further resources

Top tips to manage herbicide resistance in arable weeds

Scan the QR code or visit **ahdb.org.uk/knowledge-library/top-tips-to-manage-herbicide-resistance-risks-in-arable-weeds**

Resistance management and IPM: Diseases

Most modern fungicides act on single sites within specific biochemical pathways of fungal pathogens. They are highly effective but also vulnerable to resistance. Repeated use of fungicides with the same MoA selects for fungal isolates with reduced sensitivity, leading to a gradual or sometimes sudden loss of efficacy.

Effective fungicide resistance management depends on early implementation of anti-resistance strategies, ideally before sensitivity shifts occur. This helps to preserve efficacy and protect future crop protection options.

Using integrated pest management strategies can slow the disease epidemic through biological, cultural and physical means, and it can reduce the requirement for fungicide treatment. Fungicides should only be used in situations where the risk of disease warrants treatment. Make use of varieties that exhibit a high degree of resistance to diseases known to be prevalent in your area. Avoid growing large areas of any one variety. Consider the effect of sowing date and rotation, establish disease-free seed lots, good hygiene and control of volunteers. Make use of decision support tools and consider variety mixtures, which can reduce disease pressure.

Practices to manage resistance

- Monitor fungicide performance to confirm efficacy; poor control may result from factors such as inadequate coverage rather than true resistance
- Consider varieties with higher resistance to diseases of concern
- Adjust sow dates accordingly. For example, early sowing can increase septoria leaf blotch (*Zymoseptoria tritici*) pressure early in the season
- Control volunteers and reduce crop debris. This can help to reduce initial sources of yellow (*Puccinia striiformis*) and brown (*Puccinia* spp.) rust, rhynchosporium (*Rhynchosporium commune*) and mildew
- Avoid repeated applications of the same product or MoA, and never exceed the maximum recommended label dose or number of applications
- Make full use of effective fungicides with different modes of action – in mixtures or as alternate sprays (use Fungicide Resistance Action Committee (FRAC) codes to determine MoA and resistance risk). FRAG provides UK-specific guidance based on FRAC codes and resistance monitoring
- Use multisites* as a cost-effective mixture partner to protect higher-risk single site-acting fungicides (e.g. azoles and SDHIs) at each application timing
- The minimum dose and number of sprays required for effective disease control should be used, appropriate for the variety and disease pressure. The AHDB fungicide performance project can be used to identify effective fungicides and inform where dose can be reduced while retaining effective control (for information on how to use fungicide performance data, see below)
- Many fungicide MoAs have restrictions on the number of applications that can be made to a crop. For example, two applications each of strobilurins and SDHIs can be made to cereal crops, while a single quinone inside inhibitor (QiI) can be applied
- Make full use of effective fungicides with different modes of action and stay up to date with the most recent efficacy data, and always use different MoAs in mixtures
- Ensure that mixing partners are used at doses that give similar efficacy and persistence

*The multisites chlorothalonil (CTL) and mancozeb were withdrawn from use in May 2020 and November 2025, respectively. As folpet has lower efficacy than CTL, higher doses are required.

How to use AHDB fungicide performance data to control crop diseases

The AHDB fungicide performance project in wheat, barley and oilseed rape conducts independent UK trials to assess the effectiveness of fungicide-active ingredients under field conditions. The programme measures the relative efficacy of products against key diseases, such as septoria leaf blotch (*Zymoseptoria tritici*), yellow (*Puccinia striiformis*) and brown (*Puccinia* spp.) rust, rhynchosporium (*Rhynchosporium commune*) and light leaf spot *Pyrenopeziza brassicae* (asexual stage, *Cylindrosporium concentricum*).

Trials are conducted at multiple sites under high disease pressure, using replicated small plots and protocols tailored to the target disease. A range of product dose levels (quarter, half, full and double label rates. Note – double label rates apply to cereal trials, but not oilseed rape trials) are tested to generate dose-response curves. The curves illustrate the effectiveness of fungicide products and doses for disease control and yield impact, and can help identify the best products and doses to use in different situations. The minimum effective dose is the smallest amount of product required for sufficient pathogen control.

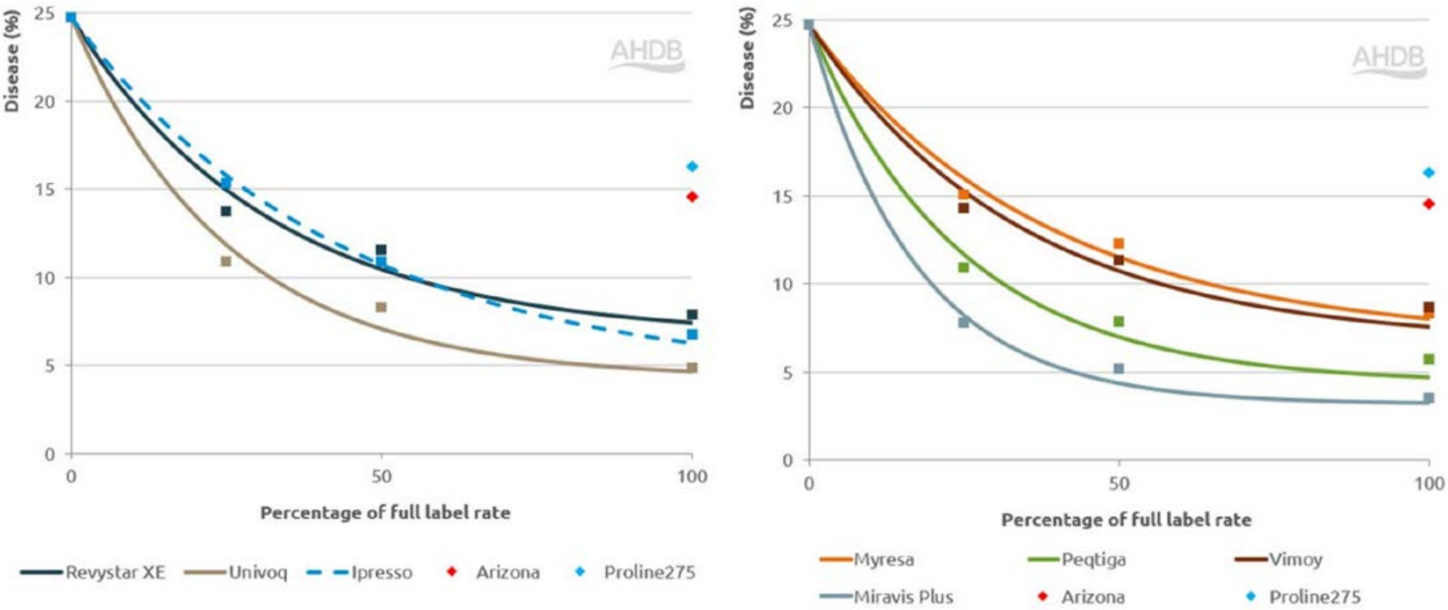

Figure 6. Septoria protectant over year 2022–24 (16 trials)

Given the diversity of pathogens and regionally variable disease pressure, the **minimum effective dose** is typically a range rather than a single value. It is important to note that there is no single standard acceptable level for disease control. Different crops, varieties and diseases have different disease tolerance levels before yield is impacted, and economic loss occurs.

Fungicide choices can be made using this data, alongside crop information such as variety, sowing date, weather, crop growth stage and cost of product, to establish the most appropriate dose.

Monitoring changes in pathogen virulence

Virulence refers to the ability of a pathogen isolate – such as a strain of the yellow rust fungus (*Puccinia striiformis* f. sp. *tritici*) – to infect and cause disease on a host plant that carries a specific resistance gene. If a disease is virulent on a variety carrying a known resistance gene, it means that the pathogen can infect and produce disease symptoms on that variety despite the presence of that resistance. Conversely, an isolate is avirulent if it cannot infect a variety carrying that resistance gene. How do we measure this?

IPM: Diseases – further resources

UK Cereal Pathogen Virulence Survey (UKCPVS) needs you!

UKCPVS uses pathogen samples, taken from diseased cereal leaf samples, to check which varieties they can infect. The tests can help detect new races of wheat and barley pathogens capable of causing disease on previously resistant cereal varieties.

To assess the distribution of pathogens and the impact on varietal resistance, the UKCPVS needs samples of diseased leaves from diverse wheat varieties and regions.

To get involved, full sampling instructions are available by scanning the QR code or visit **niab.com/uk-cereal-pathogen-virulence-survey**

Case studies: IPM in practice

David Jones: Morley Farms Ltd, Norfolk

Morley Farms Ltd. is a 750 ha farming enterprise, 700 ha of which is cropped. The rotation includes wheat, malting barley, oilseed rape, sugar beet and dried peas. Morley Farms Ltd. is a commercial farming enterprise which farms the land owned by The Morley Agricultural Foundation (TMAF). The charity invests in agricultural research and education as well as hosting plot and field-scale trials for multiple research organisations. As a result, farm manager David Jones has become familiar with on-farm innovation. David joined the AHDB Strategic Cereal Farm Network in 2023 and has been exploring several research topics, including IPM.

BYDV risk management to facilitate an insecticide reduction

As part of his AHDB Strategic Farm tenure, David expressed an interest in reducing his insecticide usage, long before the Sustainable Farming Incentive (SFI) £45/ha incentive. However, in order to facilitate a reduction in insecticide use, David knew he would need to employ management practices to reduce his *barley yellow dwarf virus* (BYDV) risk. David has taken a multi-faceted approach, utilising variety selection and decision support systems (DSS). To date, a two-field approach has been used. One field with a variety marketed as exhibiting resistance to BYDV (RGT Grouse) and one with a susceptible variety (KWS Dawsum). Two DSS were used to determine the risk of BYDV spread and the need for insecticide applications: the T-sum tool, which uses a thermal sum (time taken to reach 170-day degrees above a 3oC baseline), and a new pilot model, which considers many more factors that influence BYDV risk. In-field aphid and beneficials monitoring also occurred.

With several low aphid pressure years, no insecticides have been applied on the trial so far. The use of a BYDV-resistant variety has shown a slight reduction in yields, but in-field variation and very low levels of BYDV may have contributed to this. Trials so far have shown that DSS can indicate risk and focus on in-crop monitoring, helping to target insecticide use. Insecticide treatment is still only justified when the risk of BYDV spread is high, and, where compatible with your IPM Plan, resistant varieties may offer additional protection against high levels of BYDV, particularly for early drilled crops.

Alistair Craig: Carse Hall Farm, Limavady

Carse Hall Farm spans 240 ha, with a 100 to 140 ha split of arable and grassland. The farm also has 300 milking cows and stock bulls. Alistair, who co-runs the farm with his father and uncle, decided to become an AHDB monitor farmer in 2022. Alistair's main crop is winter barley with the occasional winter wheat or spring barley with a rotation of grass or lucerne every six years roughly. Alistair is moving towards a min-till farming system.

A 'less is more' approach to IPM

Carse Hall Farm has taken multiple steps to reduce insecticide, fungicide and herbicide usage. At present, no insecticide has been used on the farm for over five years. Instead, they are looking to increase beneficial insect populations by reducing hedge cutting and implementing wildflower margins. To decrease fungicide requirements, multi-variety winter barley mixtures are used, and high resistance varieties are selected. In addition, they are looking at approaches to decreased fertiliser requirements, as excessive nitrogen fertiliser use can increase crop susceptibility to disease. Instead, trace elements and biologicals are used. Alistair is also no stranger to novel IPM approaches – milk has been trialled as an aphicide, as a cheap and readily available alternative to insecticides. Cow's milk is authorised as a basic substance in the UK.

Chris Greenaway: Garnstone Farms, Herefordshire

Garnstone is a mixed in-hand farming estate comprising of 1400 ha (880 ha arable) and a beef enterprise. The primary crop has been winter wheat with several break crops, including tenderstem broccoli. Chris Greenaway, the farm manager, has only been in post for a few years and joined the AHDB Monitor Farm network in 2024 as an opportunity to scrutinise changes implemented and find ways to improve the business.

'A holistic approach'

When asked about his approach to IPM, Chris said ...

We attempt a holistic approach across the farm, whereby a lot of what we produce is used within the wider business. Maize goes to the anaerobic digester, wheat straw goes for cattle bedding and broccoli residue goes for grazing, just to name a few. We maintain this holistic approach when it comes to IPM.

IPM is based around variation and the ability to be dynamic and adaptable. Rotation variation is key. We aim for a mixture of plant families, switch between autumn and winter planting and try to vary the active ingredients we use.

When it comes to weed control, we aim to prevent reproduction of volunteers rather than persistently destroying them. Glyphosate is still used on occasion on the farm, but cultural control methods are implemented first. These come in the form of grazing either by our own cattle or sheep on tack. Silage cuts and cultivations are used to prevent less desirable plants from going to seed.

Companion crops are used to maintain habitat for beneficial insects and to maintain a living plant in the soil after a harvest of maize, cereals or beans. No insecticides are used in our rotation and as many nutrients as we can are sourced from our own farmyard manure. Soil health and successfully established crops are one of our best tools to out compete or compensate for pest threat.

Further Information

Latest resistance management information

Visit the Resistance Action Groups – UK web pages:

ahdb.org.uk/irag
ahdb.org.uk/frag
ahdb.org.uk/wrag

Insect pest, weed and disease guides

Visit AHDB's main hub pages at:

ahdb.org.uk/pests
ahdb.org.uk/arable-weeds
ahdb.org.uk/cereal-diseases
ahdb.org.uk/osr-diseases

Resistance management guides

Head to the AHDB knowledge library and search "resistance"

ahdb.org.uk/knowledge-library

General and crop-specific guidance on Integrated Pest Management

Freely available resources on pest, weed and disease ID in arable crops plus management guidance can be found on the AHDB website.

ahdb.org.uk/integrated-pest-management-ipm-hub

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 provides the latest information, including implications for fungicide resistance management.

ahdb.org.uk/fungicide-performance

United Kingdom Cereal Pathogen Virulence Survey (UKCPVS)

The UKCPVS monitors changes in the pathogen population of cereal rusts and mildews in the UK. Monitor crops and, if resistance breakdown is suspected, send a leaf sample to the UKCPVS.

ahdb.org.uk/ukcpvs
niab.com/uk-cereal-pathogen-virulence-survey

Variety selection

The AHDB variety selection tool can help you make better variety choices. Use it to calculate an 'agronomic merit' score for each variety.

ahdb.org.uk/vst

Resistance action committees and modes of action

Insecticides: **irac-online.org**
Fungicides: **frac.info**
Herbicides: **hracglobal.com**

Resistance key messages

Implementation of anti-resistance management strategies is key for effective integrated pest management

IPM practices – combining chemical, biological, cultural and mechanical interventions – can reduce pest and disease pressure and pesticide reliance. Embed IPM into crop protection planning – do not treat it as an optional extra.

Using effective non-chemical options is key to minimising pesticide applications to 'must use' situations. This includes cultural controls to minimise risk of reaching treatment thresholds, crop monitoring to ensure treatments are needed and use of decision support systems (DSS), where available, to support decisions around the need for and timing of pesticide application.

Monitoring is key

Monitor pesticide performance after a treatment to confirm it was effective. Record suspected treatment failures (possible resistance) and follow up with testing. Poor control may result from other factors, such as inadequate product coverage, rather than true resistance.

Fungicides

Less is more: Reduce use to reduce resistance

Evidence shows that reducing total fungicide use – either by dose or number of applications – slows resistance development. Using reduced doses and fewer applications, where agronomically justified, helps prolong the effective life of a fungicide.

Mix and alternate – but do both

Mixing fungicides with different modes of action and alternating them across applications are both effective resistance management strategies. Doing both together offers the best protection.

When selecting a mixture, try to minimise the use of high-risk partners and maximise the use of low-risk options like multi-sites, where possible. This helps to dilute selection pressure on high-risk activies.

Curative vs protectant use: Timing and strategy matters

The disease pressure, or size of a pathogen population when you treat (nil / trace = protectant / larger = curative), has little influence on resistance risk; however, it may affect how well a fungicide controls the target pathogen.

Protectant applications, where disease is mostly absent, may reduce the need for repeated or higher dose applications later in the season.

Insecticides

Insecticide resistance is a present danger to arable crop production

At least 10 species have developed resistance to pyrethroids.

Maintaining the efficacy of pyrethroids is key

Maintaining the efficacy of pyrethroids is key, as alternatives are either absent, have restrictions on use or will need to complete registration for the UK (and are likely to be more expensive).

As pyrethroids are, in many cases, the only synthetic chemical option registered, then resistance management options are limited (e.g. in terms of alternation or mixtures). This means rationalising insecticide use and dose selection are the key resistance management tools.

Maintain rates where usage is necessary

If an insecticide is needed, then use the full label rate and time for the insecticide for optimal performance to minimise resistance risk.

Herbicides

Mix it up

Use a wide range of herbicides (mixtures or sequences with more than two MoAs) and avoid repeat use of the same MoA in one season.

Minimise usage of high-risk groups

Minimise the use of herbicides with high risk of resistance (e.g. ALS (sulphonylurea) and ACCase (fops, dims and dens)).

Maximise effectiveness

Maximise weed kill by using the right herbicide and following correct label rates and timing.

Monitor populations

Monitor changes in your weed population and keep weed densities low on farm. Test for resistance every 2–3 years.

Key references

Barzman, M., Bàrberi, P., Birch, A.N.E., et al. Eight principles of integrated pest management. Agron. Sustain. Dev. 35, 1199–1215 (2015). doi.org/10.1007/s13593-015-0327-9

Cook, S.K., Tatnell, L.V., Moss, S., Hull, R., Garthwaite, D. and Dyer, C., 2023. Herbicide resistance in Alopecurus myosuroides: The value of routine testing of seed samples submitted by farmers since 1985. Weed Research, 63(6), pp.339-347.

Defra 2024. Integrated Pest Management (IPM) in farming.
gov.uk/guidance/integrated-pest-management-ipm-in-farming

FRAG 2025. Fungicide Resistance Action Group.
ahdb.org.uk/frag

Hull, R., Tatnell, L.V., Cook, S.K., Beffa, R., Moss, S.R. 2014. Current status of herbicide-resistant weeds in the UK. Aspects of Applied Biology 127:261-272.

IPM Works 2025. Recommendations for Scaling Up IPM Adoption.
ipmworks.net/2025/03/27/policy-brief-recommendations-for-scaling-up-integrated-pest-management-ipm-adoption

IRAG 2025 Insecticide Resistance Action Group.
ahdb.org.uk/irag

LEAF 2020. Simply Sustainable Integrated Pest Management.
leafuk.org

Nature Friendly Farming Network 2024. A Practical Guide to Integrated Pest Management.
nffn.org.uk

Oliver, R.P. and Beckerman, J.L. 2022. Fungicides in Practice. CABI 2022. DOI: 10.1079.9781789246926.0010

SmartProtect Thematic Network. European Union's Horizon 2020 research and innovation programme under grant agreement No. 862563.

WRAG 2025. Weed Resistance Action Group.
ahdb.org.uk/wrag

WRAG 2020. Maximising the benefits of herbicide resistance testing.
ahdb.org.uk/knowledge-library/the-weed-resistance-action-group-wrag

Glossary

Multiple resistance: Where a pest, weed or disease vector becomes resistant to several different pesticides.

Basic substance: Basic substances can be described as “active substances, not predominantly used as plant protection products but which may be of value for plant protection and for which the economic interest of applying for approval may be limited”.

Cross resistance: When a pest population develops resistance to a new pesticide due to exposure to a different one with a similar resistance mechanism.

Integrated Pest Management (IPM): An environmentally sensitive and sustainable approach to pest control that uses a combination of biological, cultural, physical and chemical methods to manage pests and minimise economic, health and environmental risks.

Non-target site resistance (NTSR): A complex mechanism where pests and diseases evolve to resist pesticides without changing the pesticide’s target site. Instead, resistance is achieved through other physiological processes, like increased metabolism or sequestration of the pesticide, making it less toxic or unable to reach its target.

Target site resistance (TSR): Mutations alter the specific target site within the plant where a pesticide normally acts, preventing the herbicide from binding properly, so it no longer controls the weed effectively.

Enhanced metabolism resistance (EMR): Mechanism of non-target site resistance (NTSR) in plants, primarily weeds where the plant has an enhanced ability to detoxify or break down herbicides.

Acetyl-CoA carboxylase (ACCase): A key enzyme that catalyses the conversion of acetyl-CoA to malonyl-CoA, an essential first step in fatty acid synthesis.

Acetolactate synthase (ALS): The acetolactate synthase enzyme is a protein found in plants and microorganisms. ALS catalyses the first step in the synthesis of the branched-chain amino acids.

Mechanism of resistance: The biological or behavioural adaptation that allows a pest population to survive and reproduce despite exposure to a pesticide that was previously effective.

Mode of action (MoA): The specific molecular and physiological process a pesticide disrupts to kill the pest, such as nerve and muscle function, or growth regulation.

Minimum effective dose: Pesticide dose which is necessary to achieve sufficient efficacy against a target pest across the broad range of situations in which the product will be applied.

Pesticide active substance: The component in a pesticide product, such as a chemical, plant extract or microorganism, that provides the primary action against harmful organisms or pests.

Pesticide efficacy: Effectiveness of a pesticide to produce the desired effect, such as killing or repelling a target pest, under controlled condition.

Modified AcetylCholinEsterase (MACE): Refers to the enzyme after it has been altered through genetic mutations, chemical attachment of molecules or post-translational modifications, which can change its properties. These modifications are used to improve its stability, alter its catalytic activity or make it resistant to certain chemicals like insecticides.

Knockdown resistance (kdr): A genetic trait in insects that causes resistance to certain pesticides. This resistance occurs when point mutations in the insect’s nervous system reduce the pesticide’s ability to bind to its target, resulting in a reduced “knockdown” or incapacitating effect on the pest.

Barley yellow dwarf virus (BYDV): A destructive aphid-transmitted viral disease that affects cereal crops, including barley, wheat and oats, and a wide range of grasses.

Sustainable farming incentive (SFI): A government payment scheme that rewards farmers for adopting environmentally sustainable practices. New applications are on pause until 2026.

Decision support systems (DSS): An interactive, computer-based system that helps people make decisions based on available data and models.

Cabbage stem flea beetle (CSFB): A small, iridescent black beetle that is a significant pest of cruciferous crops, especially oilseed rape. It damages plants by chewing “shot-holes” in the leaves as adults and by boring into the stems as larvae, which can lead to significant yield losses and even plant death.

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