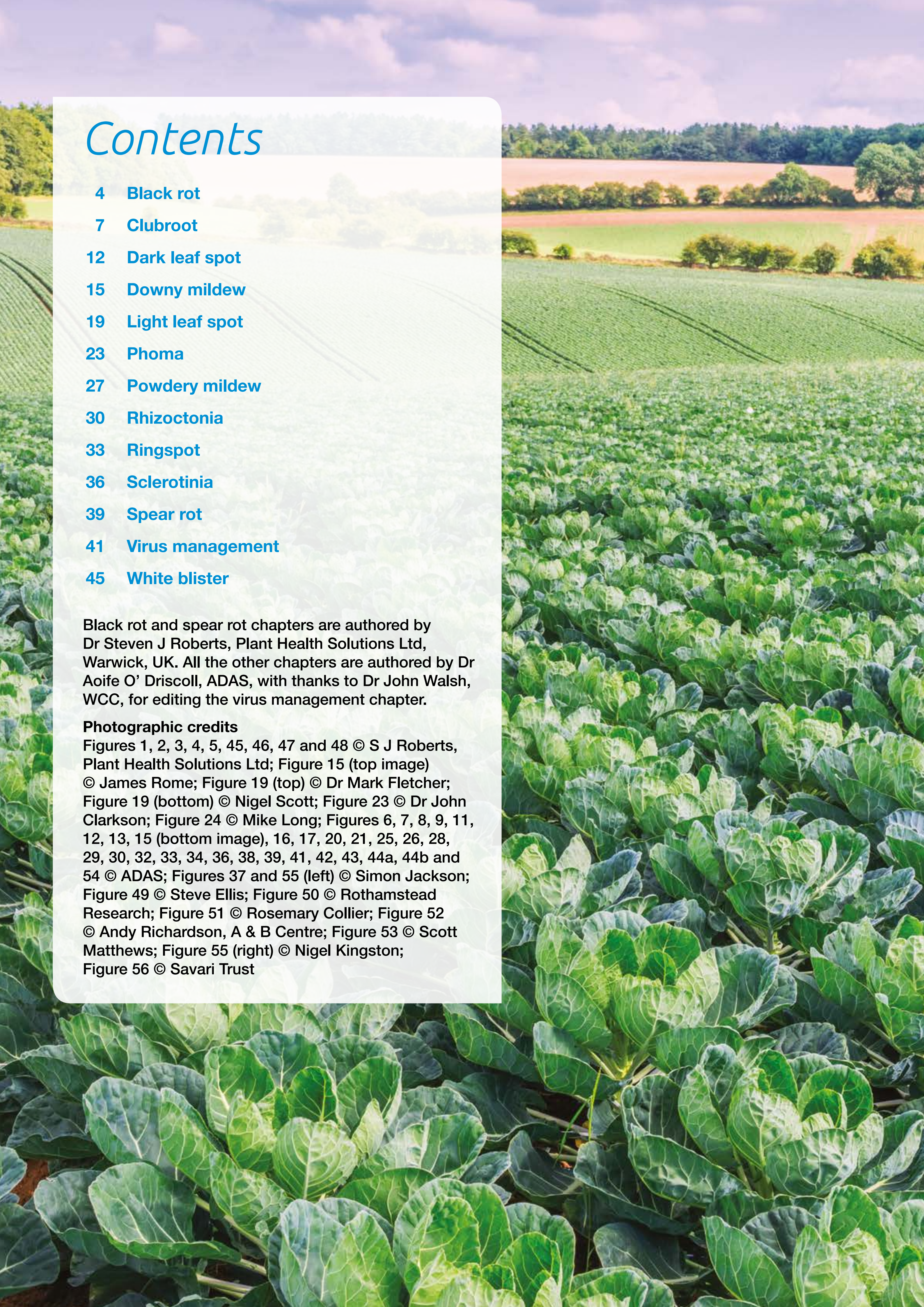
Brassica diseases



Contents

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Introduction

This best-practice guide covers the 13 main diseases of horticultural brassicas that cause economic losses to growers in the UK. These diseases are caused by a range of organisms: fungi, oomycetes, bacteria and viruses. This guide supersedes the series of factsheets on brassica diseases previously produced by AHDB and complements the Brassica Crop Walkers' Guide.

The guide is divided into chapters, which deal with each disease in turn. A background to each disease gives an idea of its relative importance and the likelihood of it occurring. Action points provide practical suggestions for disease control for growers and, where relevant, specifically for propagators.

Photos taken in the field show the key disease symptoms to look out for when crop walking and the important differences between the symptoms of different diseases. More detail is provided indicating when symptoms are likely to occur in the growing season and thus the life cycle of the causal pathogen.

The use of integrated pest management is advocated, starting with an understanding of the biology and life cycle of the causal pathogen, so that steps can be taken to break the life cycle and establish control.

The guide gives suggestions for where in the life cycle crop management should be prioritised for each disease, from seed testing before the crop is sown to destruction of crop residues after the crop has been harvested. The relative merits of cultural control and the use of resistant varieties are also considered for each disease.

This guide does not contain advice on chemical active ingredients as their approvals change so rapidly that it would soon be out of date. Where biologicals are available, these are given, but, again, please check approvals or consult a BASIS-trained adviser before using them.

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Black rot

Background

Black rot (*Xanthomonas campestris* pv. *campestris*) is considered one of the most important diseases of brassicas worldwide. At its most severe, it can cause complete crop loss, but this is less likely under UK conditions than in warmer climates. However, it regularly caused significant losses in marketable yield in the UK in the late 1990s, particularly in autumn and winter crops. It is now less common, most likely due to improved understanding of the epidemiology and the application of more stringent seed health standards appropriate to the production systems.

Action points

For plant propagators

- Confirm that all brassica seed coming onto the unit has been tested for *X. campestris* pv. *campestris* to an appropriate standard
- Request information from seed suppliers on the effective tolerance standards applied (e.g. number of seeds tested)
- Module trays should be cleaned and disinfected before each use
- Clean and disinfect sowing equipment before each new batch of seed
- Clean and disinfect glasshouses/bays before each batch of transplants
- Separate batches of plants grown from different seed lots as much as possible
- Minimise the use of overhead irrigation
- Consider the use of sub-irrigation systems (e.g. capillary matting, ebb and flood)
- Clean and disinfect equipment between batches
- Don't water transplants when stacked in stillages

For growers

- Confirm that brassica seed has been tested for *X. campestris* pv. *campestris* to an appropriate standard
- Request information from seed suppliers on the effective tolerance standards applied (e.g. number of seeds tested)
- Check that transplant suppliers only use tested seed and have appropriate hygiene policies
- Don't dip transplants before planting
- Clean and disinfect machinery and equipment, clothing and footwear when moving between crops
- Post-harvest cultivations should aim to encourage rapid breakdown of crop residues
- Use a non-brassica break crop in the rotation for two years after field outbreaks of black rot

Symptoms

The most obvious and characteristic symptoms in the field are yellow 'V-shaped' lesions with blackened veins that develop from the edges of the leaves (Figures 1 and 2). As the lesions enlarge, they become necrotic, pale brown and dry, due to blocking of the vascular system. Systemic infection can also be seen as blackened vascular bundles (Figure 3) in the leaf petiole or main stem and result in (often one-sided) wilting. Severe infections can result in stunted or dead plants.

Leaf loss can also occur at relatively low levels of infection and this can be a particular problem in winter cauliflowers, when wrapper leaves are lost, exposing the curd so that it becomes unmarketable. Secondary soft rots may also occur, exacerbating the symptoms in cabbage and cauliflower.

Less commonly, the disease may be seen as dark, water-soaked spots or larger areas on leaves, which may progress to become systemic, with the typical symptoms described above or papery 'blight' symptoms (Figure 4). However, water-soaked leaf spots can also be caused by other bacterial pathogens such as *X. campestris* pv. *raphani* or *Pseudomonas syringae* pv. *maculicola*.

Figure 1. Typical field symptoms of black rot in a winter cabbage crop: yellow V-shaped lesions developing from the leaf edges

Figure 2. Close-up of a V-shaped lesion

Figure 3. Blackened major veins on a cabbage leaf

Figure 4. Papery blight symptoms on cauliflower

Figure 5. First symptoms on cotyledons in transplants are difficult to spot

Initial symptoms can be difficult to spot in seedlings and transplants. Infected cotyledons may have slight yellowing and necrosis (Figure 5) but often shrivel up completely and drop off before they are noticed. Typical lesions may develop on young leaves, but transplants are often planted out before they are obvious or have had time to develop.

The pathogen and biology

The disease is caused by the rod-shaped, motile, gram-negative bacterium *Xanthomonas campestris* pv. *campestris*. All cultivated brassicas, radish, cruciferous weeds and a number of ornamental species can be infected. However, the pathovar is divided into a number of distinct races, which have different host ranges. There are currently at least nine races; these are differentiated by their pathogenicity on a number of differential brassica species and cultivars. Worldwide, races 1 and 4 are the predominant races in vegetable brassicas. The apparent dominance of these races may reflect the lack of resistance to these races in the hosts.

Most infection occurs via hydathodes (pores at the edges of leaves) and is the reason for the most typical symptoms, but infection can also occur via stomata or wounds caused by hail or mechanical damage.

The disease is generally considered to be favoured by warm, wet weather. At optimum temperatures (c. 25°C), symptoms generally take 10 to 14 days to appear following infection, but may take much longer at lower temperatures.

Epidemiology

Seeds are the primary source of inoculum and means of long-distance spread. Although crop debris and cruciferous weeds can potentially act as sources of inoculum, almost all significant field outbreaks of black rot have been associated with seed infection. In the past, certain varieties have been noted as being more susceptible than others, when, in fact, differences may have been due to the presence/absence of infection in the seed stocks.

Most local (within-crop) spread occurs by water splash, irrigation or wind-driven rain, but anything that moves within and between crops, such as people, animals, insects, equipment and machinery, can potentially spread the bacterium. It is important to be aware that considerable numbers of bacteria may be present and significant spread may have already occurred before any symptoms are seen.

Of critical importance is the potential for very rapid spread in transplants with the overhead gantry irrigation systems typically used by plant propagators. Thus, even relatively low levels of seed infection can result in almost all transplants being contaminated at the time of planting. Experimental data has demonstrated spread from one infested seed to 4,500 transplants in six weeks. Most of these transplants are likely to be symptomless and symptoms then ‘suddenly’ appear simultaneously in the field throughout the whole crop when suitable conditions occur.

In the UK, the disease has been more commonly associated with late-autumn and winter crops. Module transplants for these crops are raised during the hottest months of the year, resulting in much more frequent irrigation and potential for spread than in transplants raised for early crops.

Carry-over in the field has been shown to occur when crop debris from the previous crop was still visible in the soil, but as the rate of spread is much lower than in transplants, the pattern of disease is likely to be much more patchy and overall disease levels lower than when infection has originated from seed and transplants.

The pathogen may survive for long periods in dry crop debris or in infested seeds. It does not appear to survive or compete well when free in the soil and so is likely to survive only as long as the crop debris.

Control

Seed testing and treatment

The primary means of control is to use healthy seed, which has been tested to confirm that it meets the required standards.

Modelling of different risk scenarios has indicated that effective control (overall risk of disease less than 10%) in transplanted brassicas can be achieved by testing 6 x 10,000 seeds by a method that incorporates a centrifugation step.

Hot water and similar physical treatments may be considered if valuable seed stocks are known to be infected, but it is vital that post-treatment testing is performed to demonstrate that the treatment has been effective.

Chemical

Attempts at chemical control in the field are unlikely to be cost-effective, as significant spread has most likely occurred by the time symptoms are seen.

There are currently no chemical controls approved for use.

Biological

The biopesticide Serenade (*Bacillus subtilis* QST 713) has some activity against *Xanthomonas*. As a weekly spray, it gave some (but not significant) reduction in spread in transplants. It has current (March 2020) authorisations:

- EAMU 20150306 (Feb 2015) as a root drench for the control of *Pythium* spp. and damping off.
- EAMU 20182357 (Sep 2018) for the control of *Botrytis*
- EAMU 20182825 (Oct 2018) as a post-harvest drench for outdoor cabbage before storage, for the control of *Botrytis cinerea*

Note: EAMU 20130706 expired on 29th February 2020.

Hygiene

Good hygiene is essential, to prevent cross-contamination between different batches of transplants on the nursery and to prevent spread from affected to nearby healthy crops in the field:

- Module trays should be cleaned and disinfected before use
- Glasshouse bays should be cleaned and disinfected between batches of transplants
- Machinery, clothing and footwear should be washed down and disinfected after visiting infected crops
- Most general-purpose disinfectants are likely to be effective against *Xanthomonas*

Crop rotation

Infected crop debris should be chopped as much as possible to encourage rapid breakdown and there should be a two- to three-year break from brassicas to ensure residues have completely disappeared.

Plant resistance

Breeding resistant varieties has long been recognised as an important target for disease control and was the focus for a lot of work in the late 1990s and early 2000s. It should also be noted that some varieties are already resistant to some races of the pathogen. Useful sources of resistance have been identified and their inheritance studied, particularly in non-vegetable brassica (i.e. not *B. oleracea*) species, but seems not to have been a priority for commercial breeders in recent years.

Clubroot

Background

Clubroot caused by the pathogen *Plasmodiophora brassicae* affects all cultivated and wild cruciferous plants. In addition to oilseed rape, all vegetable brassica species are affected, including turnip, swede, Brussels sprouts, cauliflower, calabrese and mustard. Numerous weed species, such as charlock and shepherd's purse, are also common hosts.

Clubroot is a global problem and has increased in recent years. For example, many new UK cases were reported in 2016, often on farms with no history of the disease. The trend for shorter rotations, along with milder and wetter winters, have probably contributed to the rise.

Although yield losses may not be significant at a national level, losses of 10% are common in infected fields of oilseed rape. Infection leads to wilting, death and total crop loss, especially when young plants are invaded. Older plants will generally be less affected and so may only experience a reduction in yield, but the main problem is that plant maturity will be erratic and harvesting schedules will be disrupted. In species grown for their storage roots, quality losses due to visual appearance also occur.

Symptoms

The first symptoms usually occur within six weeks of planting, provided soil temperatures are greater than 15°C. In oilseed rape, symptoms commonly start in late autumn. Roots become swollen and distorted and develop small, irregular, white-coloured, solid galls. These are present on taproots and/or lateral roots. As the season progresses, galls may enlarge and discolour, before starting to rot.

Above-ground symptoms do not usually develop until later in the season. Typical symptoms include stunting and yellowing. Under dry conditions, plants may wilt, especially when galling is severe. Distinct patches of poor growth are often visible. Plant loss occurs in the most severely affected areas and, occasionally, the whole field may fail.

Action points

For propagators

- When working with vegetable transplants, use compost with good provenance that is guaranteed clubroot-free
- Strict hygiene is required during propagation and trays that are reused should be thoroughly cleaned and disinfected

For growers

- Use one of the commercially available soil tests for clubroot
- Monitor crops carefully and assess the levels of clubroot present, especially for higher-risk fields
- Keep accurate crop records of clubroot occurrence, location and intensity and where varietal resistance has been deployed in field
- Use field maps to identify hotspots to aid management strategies
- At sites with higher frequencies of susceptible crops in a rotation, increase the frequency and detail of tests
- If levels of infection start to increase, change strategy – especially where 'resistant' varieties have been deployed
- Manage volunteers and susceptible weeds, within and between susceptible crops, as early as possible
- Be mindful of other susceptible crop choices when planning rotations – spring rape is vulnerable and cover-crop mixes often contain susceptible species
- Make decisions based on long-term profitability and sustainability of a field, not on a single season's predicted margin

Figure 6. Clubroot symptoms in oilseed rape

Figure 7. Clubroot symptoms in swede and turnip

Figure 8. Symptoms of clubroot in shepherd's purse

Epidemiology

Risk factors

The following factors are associated with an increased clubroot risk:

Field/soil factors

- Fields with a history of clubroot infection
- Warm (above 15°C) and wet soils – particularly, compacted, poorly drained soils and flood-prone fields
- High numbers of susceptible cruciferous weeds and volunteers
- Acidic soils (pH less than 7)
- Boron-deficient soils

Contaminating factors

- Poor machinery hygiene, resulting in transfer of infected soil
- Use of manure from animals fed on infected produce
- Use of infected green mulches, composts and straw
- Movement of infected vegetables, such as feed swedes and turnips, onto clean land

Cropping factors

- Short rotations (less than one in four years)
- Use of susceptible crops and varieties
- Repeated use of clubroot-resistant varieties, especially in short rotations
- Early-drilled oilseed rape

Figure 9. Clubroot has spread across the field in the direction of cultivation

Life cycle

A simplified version of the clubroot life cycle is presented in Figure 10. Clubroot is a soilborne pathogen that produces resting spores. These spores have thick walls and help the pathogen survive for at least 15 years in the soil. Chemicals, released by the roots of host plants, cause nearby resting spores to germinate and release motile spores (zoospores). These move through soil water and infect the host's root hairs, where a secondary spore stage occurs. These spores invade the outer layer of the root (the cortex) and form structures called secondary plasmodia. These structures cause the root cortical cells to enlarge and increase the rate of cell division. Ultimately, this results in the formation of the characteristic clubroot galls. These galls decay during the season and release large numbers of resting spores back into the soil.

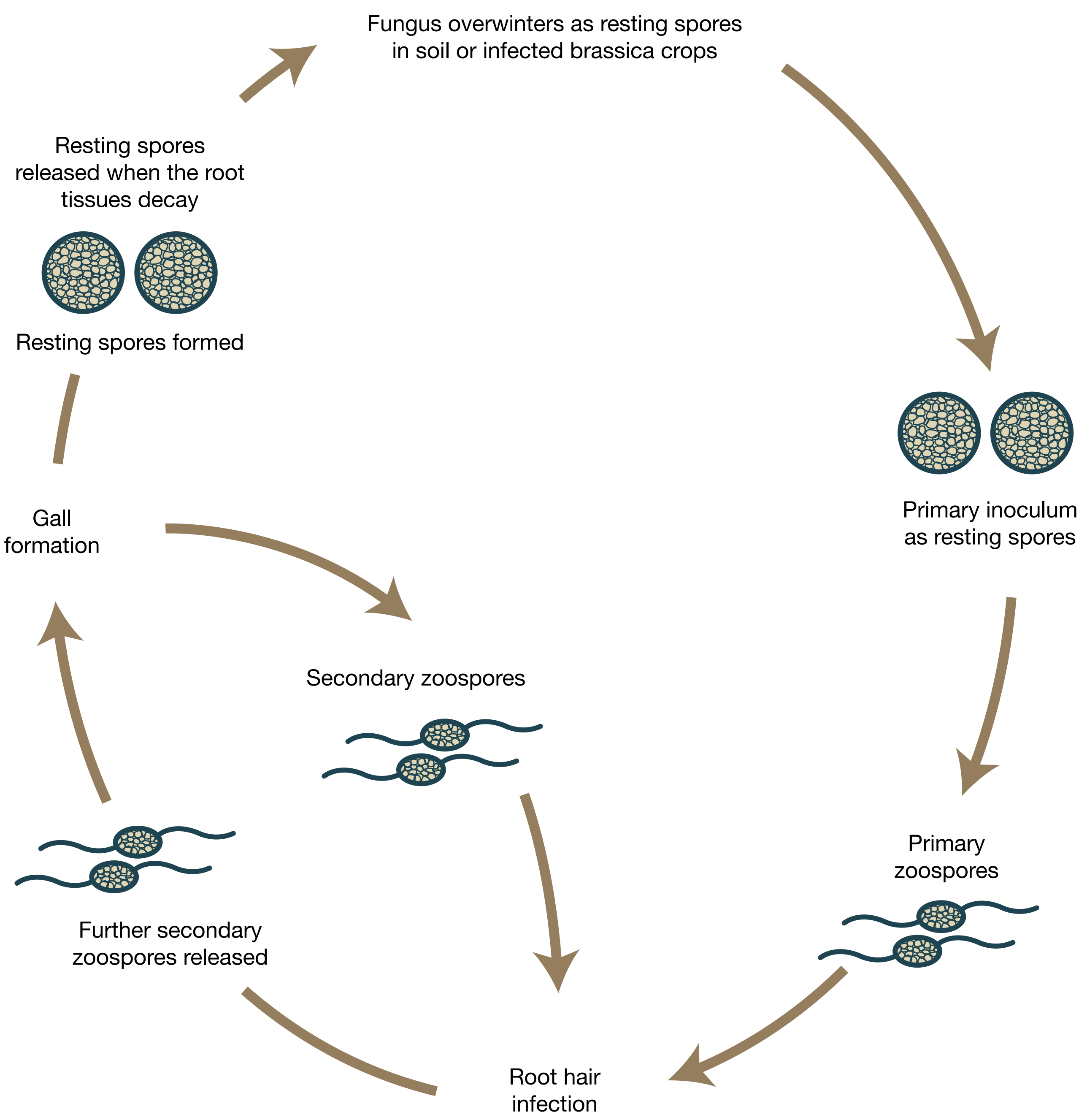


Figure 10. The clubroot life cycle

Control

Use an integrated management strategy to ensure the long-term profitability and sustainability of clubroot-susceptible crops in the rotation. In practical terms, this means adopting sustainable rotations, judicious use of varietal resistance, diligent monitoring, surveillance and testing, combined with good biosecurity measures, and the use of wider agronomic practices, such as drainage and liming.

Monitoring

Identify high-risk areas

Early detection of clubroot infection is extremely important. As patches of poor growth or establishment can have multiple causes, it is important to investigate them. Where clubroot is suspected or confirmed, establish hygiene measures around the infected area immediately and adapt rotational and agronomic plans, accordingly.

Soil tests

Conduct soil tests prior to planting any susceptible crop. Prioritise high-risk areas for tests, such as wet hollows, gateways/field entrances, recently flooded fields (especially those near infected fields) and where civil infrastructure projects have occurred.

Tests are based on traditional assay techniques, such as growing susceptible bait plants in suspected infected soil, or molecular diagnostics. SRUC, Fera, PGRO and Eurofins all offer testing services. Molecular test results can show the quantity of spores per gram of soil. Although suggested spore risk thresholds have been set for vegetable brassicas, no validated thresholds exist for oilseed rape.

Visual tests

Visual symptoms are not always present above ground, so root systems should be monitored for galls. Use the field's tramlines to establish a sampling grid. Ideally, sampling points should be no more than 50 m apart. At each sampling point, pull up and inspect 10 plants.

Clubroot maps

Use test results to create field maps of clubroot patches. Since clubroot persists for at least15 years, knowledge of patches remains useful for several seasons.

As patches remain relatively stable within a season, targeted treatment of affected areas can be cost-effective. Targeted treatments include the use of liming, resistant varieties or fallow/grass.

Cultural controls

Minimise contamination

Movement of infected soil or water is the main cause of clubroot introduction and spread.

On average, farm equipment transfers 250 kg of soil, most of which is deposited close to gateways and field entrances. Ensure farm staff and contractors follow good hygiene protocols and strict biosecurity procedures. Plan machinery movements to avoid travel from infested to clean fields. Restrict access to severely infested fields. Where land is rented, ensure tenants understand and manage risks in the same manner as farmer-owned land.

Where non-agricultural personnel need to access land, ensure they have sufficient biosecurity awareness, as contamination risks can be relatively high. For example, civil infrastructure projects can involve a high level of machinery movement. In such situations, additional hygiene measures may be necessary, such as hardstanding and wash-down facilities for vehicles and machinery.

Infected animal manures, composts, green mulches and straw can also introduce spores. It is important to understand the infection risk associated with these materials. Avoid the movement of feed swedes and turnips onto clean land. Risk associated with digestate use is low, particularly if it is compliant with PAS100 or PAS110 standards, but a risk remains, especially where high volumes are spread. When working with vegetable transplants, use compost with good provenance that is guaranteed clubroot-free.

As clubroot zoospores move through soil water, ensure soils are not compacted or waterlogged.

Maintain soil pH above 7

Crops grown in acidic soils are at greater risk of developing severe symptoms. Check soil pH routinely, particularly before establishing a susceptible crop. Aim to maintain the pH to above 7: even small increases (0.5–1 pH units) in pH can decrease clubroot severity. Calcium also has a direct effect on the pathogen.

Agricultural lime products, which are associated with a spike in pH and available calcium at drilling, can significantly reduce clubroot infection. High doses of lime (applied at 8 t/ha) can reduce clubroot severity by 25%. AHDB research shows that targeted treatment of the worst clubroot-affected patches can improve economic returns, compared with whole-field approaches.

As boron also has some activity against clubroot, any deficiencies in the soil should be corrected.

Extend the rotation

In clubroot-affected land, extend the rotation to a break of at least four years between susceptible brassica crops. Clubroot resting spores can remain viable in the soil for over 15 years but have a half-life of approximately 3.5 years. Consequently, the longer the break, the greater the reduction in the number of viable spores. Thus, extending the rotation is often the most sustainable long-term management strategy.

Cover-crop mixes that contain susceptible brassica hosts should be avoided on infested land. Agricultural radish is resistant to clubroot, but the mechanism is the same as in oilseed rape. There is limited evidence for reduced soil inoculum after growing radish and the advice is not to grow it in severely infested fields. Spring oilseed rape is also susceptible.

Avoid early sowing on infested sites

Infection is most likely in warm, wet soils (optimum temperature 16–25°C) when conditions enable zoospores to disperse through soil water. Disease activity reduces as soil temperatures drop below the optimum. Typically, winter-grown crops are most susceptible to infection from August to mid-September. Crops are most vulnerable at the seedling growth stage (one to two leaves unfolded). Delayed drilling minimises the potential window of infection and helps the crop to avoid clubroot.

Control weeds and volunteers early

Cruciferous weeds, such as charlock and shepherd's purse, are common hosts to clubroot, along with volunteer oilseed rape. Consequently, they should be managed within and between susceptible crops. Early weed control (7–14 days post-emergence), by either herbicide application or shallow disking, reduces the number of resting spores in the soil.

Varietal resistance

Where a susceptible crop is grown in an infected field, a resistant swede, vegetable brassica or oilseed rape variety should be selected. However, resistant varieties are not immune to attack and small galls are likely to develop. Based on a single dominant gene, the same mechanism (Mendel) is present in all resistant crop varieties. However, recent research shows there is a high pathotype diversity in the UK and resistance is not effective against all pathotypes of clubroot. Where resistance is deployed frequently in rotations or in very heavily infested soil, resistance-breaking strains are more likely to evolve and establish. This has already started to occur in some parts of the UK. As a rule of thumb, a resistant variety should have less than 30% infection compared with a susceptible variety (volunteers and off-types should not be included in the observation). Resistance breakdown is most likely to appear in patches. These patches can act as an early warning of changes in the pathogen population. Extend the rotation, where resistance breakdown is suspected.

Products

Fungicide and biocontrol options are not available for clubroot control.

Dark leaf spot

Background

Dark leaf spot on vegetable brassicas is caused by two fungi: *Alternaria brassicae* and *Alternaria brassicicola*. Both species can infect all types of commercial brassica crops. The disease has become less problematic in vegetable brassica crops over recent years. It is unclear why this has occurred, but one explanation may be related to the increased use of fungicides in winter oilseed rape and low disease levels in that crop. An alternative explanation is that fungicidal sprays have been targeted more effectively in vegetable brassicas in comparison with the protective routine spray programmes used in the past. Dark leaf spot can also be seedborne. In the past, yield losses of 70% resulting from infection by *A. brassicicola* have been reported in vegetable brassicas, while yield losses greater than 50% have been reported in oilseed rape crops infected with *A. brassicae*. Yield losses in vegetable brassicas result from cosmetic damage to the crop in the form of dark brown spots and flecks. In arable brassicas, the yield loss is related to the severity of pod symptoms.

Action points

- Use healthy seed
- Plough in crop residues as soon as possible after harvesting the crop
- Symptoms of dark leaf spot appear within 2–5 days after infection, regardless of temperature
- Applying sprays early in the life of the crop is important, particularly during periods of oilseed rape harvest in proximity to the vegetable brassica crop
- Dark leaf spot shows considerable variation from year to year, as well as between crops. Monitor crops at least weekly and use fungicides when the first leaf symptoms start to appear

Symptoms

Both species of *Alternaria* can produce pale brown to dark brown circular and zonate leaf spots on all types of brassicas and related weeds, with most severe symptoms usually occurring on Chinese cabbage, turnip and cabbage. Upon successful pathogen attack, dark brown spots of different sizes (1–2 mm to 20 mm in diameter) appear on the leaves; the spots of characteristic concentric circumferences sometimes have a yellow chlorotic halo with a well-defined margin (Figure 11). When mature, the centre of the lesion is often raised and can cross major leaf veins. Immature lesions do not sporulate easily. *A. brassicicola*-derived spots are darker and less regular in shape compared with those of *A. brassicae* origin. As the disease progresses, the spots enlarge and become dark brown with a sooty appearance when mature (Figure 12). Symptoms appear within 2–5 days after infection, regardless of temperature.
The infected plant tissue perishes and crumbles, giving rise to dents and hollows. On head brassicas, the lower leaves are mainly affected. The disease may occasionally affect the spear (Figure 13), but the economics of treating maturing crops may be questionable.

Figure 11. Dark leaf spot causes necrotic lesions on the leaves of brassicas

Figure 12. Spotting symptoms on Brussels sprout buttons

Figure 13. Dark leaf spot symptoms on broccoli head

Epidemiology

Both pathogens can infect oilseed rape and vegetable brassica seeds; however, modern seed treatments used in vegetable brassica production have reduced the importance of this source of infection. Both pathogens are much more prevalent on arable brassicas and there is a high likelihood of interaction between vegetable and arable brassicas overwinter, causing epidemic development in the spring.

A. brassicae is the more prevalent of the two fungal species. While *A. brassicicola* may predominate in some crops, it usually occurs along with *A. brassicae*. Both pathogens can result in considerable yield losses in arable brassicas because they occur on the pods of oilseed rape plants. Much of the transmission between crop types may relate to the timing of arable brassica harvesting activities. During harvesting, a great deal of material is ejected into the atmosphere, where it is readily dispersed over considerable distances. Material, including spores, can be deposited within raindrops, leading to germination and infection of vegetable brassicas.

There is a great deal of evidence to show that a peak of *Alternaria* spores occurs in the air during June or July in most years in the UK. In Mediterranean areas, more than two peaks are often observed, but this may be related to variations in cropping/harvesting between temperate and Mediterranean areas. There are other *Alternaria* species present in vegetable brassica crops which may also cause dark-leaf-spot-like lesions. However, the importance of these is not clear. It is possible that their presence results in spotting on the crop but they do not give rise to dark leaf spot epidemics. To date, isolations taken from sporulating lesions in vegetable crops show only the presence of *A. brassicae* and *A. brassicicola*.

Life cycle

A simplified version of the life cycle of dark leaf spot is shown in Figure 14. Dark leaf spot requires free water for spore germination and infection. At optimal temperatures of 20°C, infection by *A. brassicae* may occur within six hours, but for substantial disease development at least 10 hours of wetness is required. Both dark leaf spot species require at least 12–14 hours with a relative humidity of greater than 90% for sporulation to occur. The sporulation rate by *A. brassicae* is optimal between 18°C and 24°C. Sporulation is inconsistent at 26°C and spores formed at this temperature are often not viable. Sporulation by *A. brassicicola* is observed over a greater temperature range, from 18°C up to 30°C. However, time to 50% spore production is greater over the lower temperature ranges, indicating a higher temperature optima for this species. No sporulation by either pathogen is observed below 5°C.

Both pathogens are disseminated from infected host tissue by means of spores produced on mature fungal lesions. Spore dispersal can occur by a number of mechanisms, including air currents, rain splash or dew droplets. Dispersal in the air is potentially over much greater distances than by rain splash. Spores of dark leaf spot have been shown to travel at least 1.8 km from their source. Viable spores landing on healthy plant tissue germinate on and penetrate the host surface. *A. brassicae* and *A. brassicicola* exhibit distinct differences in host plant tissue penetration. *A. brassicae* invades host plants solely through their stomata, while for *A. brassicicola*, direct plant tissue penetration prevails over stomatal infections. Hyphae of both pathogens develop well on the epidermis, directly beneath the leaf waxes.

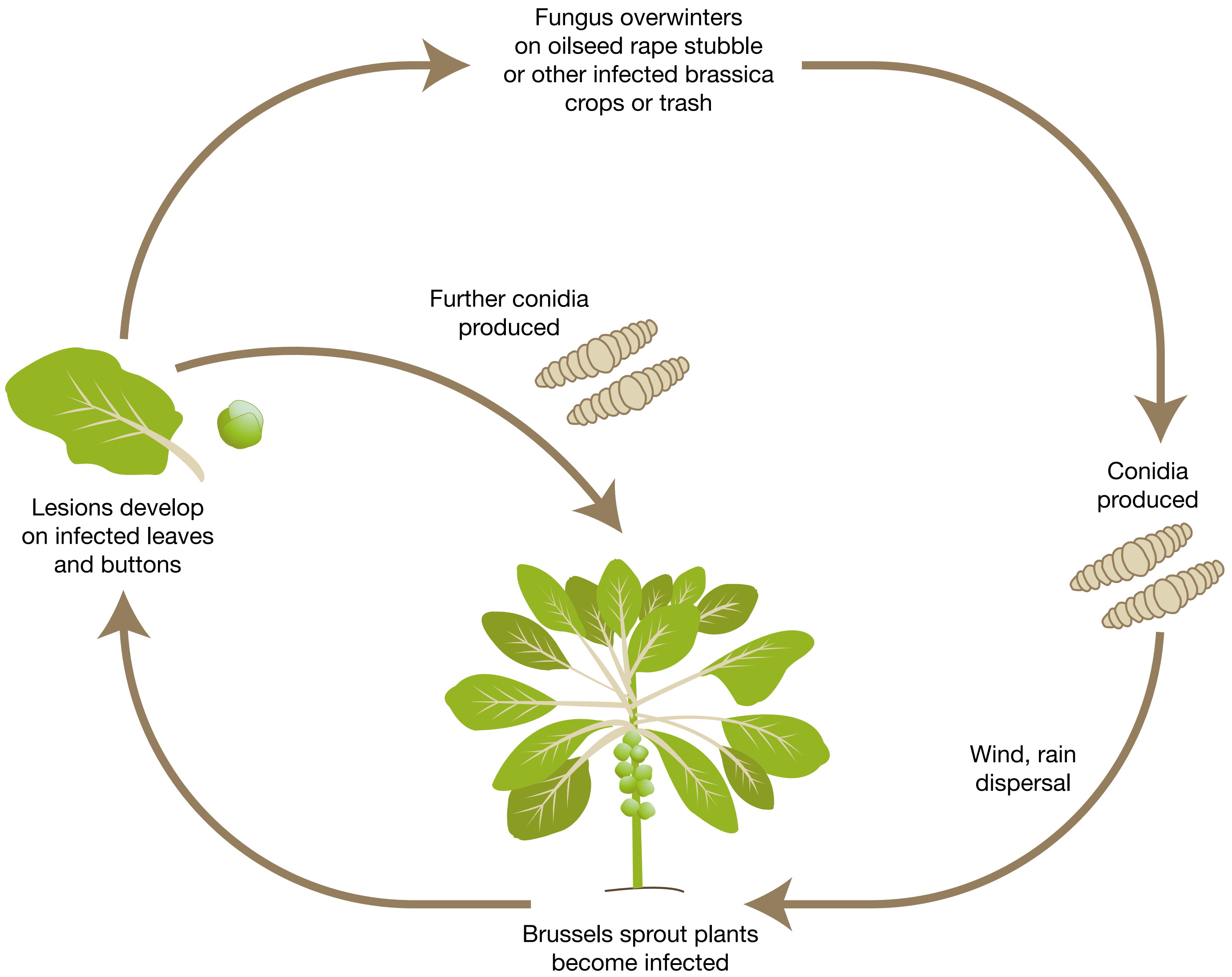


Figure 14. Life cycle of dark leaf spot on vegetable brassicas

Control

Monitoring

Dark leaf spot shows considerable variation from year to year, as well as between crops, so regular crop monitoring is required. Take note of the disease situation in oilseed rape and be prepared for movement of spores into vegetable brassicas when oilseed rape is harvested. Where infection and sporulation occur frequently under the right conditions and the pathogen completes its life cycle relatively rapidly, prediction of complete cycles of sporulation and infection can be made from microclimate measurements, which can be used as an aid in determining the necessity of control measures. In-field air-sampling systems and tests are available for dark leaf spot. By identifying spores in field air samples, growers can time sprays more effectively and make informed decisions on when to apply appropriate fungicides.

Cultural controls

Consider the effect of, and alternate, break crops in your rotation, where possible. Mustard and radish grown as green manure on farmland have the potential to act as ‘a green bridge’ between cropping systems. No plant protection products are applied to green manure, which makes these crops a perfect reservoir for many pathogens of vegetable brassicas.

Varietal resistance

Dark leaf spot is problematical on Chinese cabbage, where there appears to be little known resistance. Turnips are more susceptible than swedes. Other vegetable brassica types appear uniformly susceptible.

Products

Applying sprays early in the life of the crop is important, particularly during periods of oilseed rape harvest in proximity to the vegetable brassica crop.

Downy mildew

Background

Downy mildew, caused by *Hyaloperonospora brassicae*, is a widespread disease that affects many vegetable brassica and ornamental crops in the UK. It is particularly a problem in vegetable brassica crops where seedlings are raised in glasshouses as transplants. Downy mildew can inhibit seedling growth and cause stunting of seedlings, which renders these plants unsuitable for transplanting into the field. Latent downy mildew infections (no observable disease) at a low incidence in glasshouse-raised transplants are often not noticed by transplant producers and may provide inoculum, leading to epidemics in the field. Although primarily a seedling disease, systemic downy mildew in head brassicas causes dark discolouration of vascular tissues, which extends up into the stalks and heads. Systemic downy mildew, often considered as the most serious disease affecting growers of head brassicas in the south of the UK, is also now becoming an issue in Scotland. This could be due to climatic conditions and changing weather patterns or changes in production systems, e.g. different varieties or cool-chain systems.

Action points

For propagators

- Downy mildew has a very short latent period, making disease development fast and unforeseen. Staff education in recognising early symptoms of downy mildew is an important component of monitoring and disease management
- Spore dispersal can occur within the crop after only 30 minutes of leaf wetness. Irrigation should be done in the morning so that plant surfaces can dry as quickly as possible
- Ventilate glasshouses to avoid a warm, humid atmosphere
- Sterilise greenhouses between crops and sterilise trays between batches of plants

For growers

- Fungicide treatments should be applied as preventative applications, as cotyledons and the first true leaves are the most susceptible to downy mildew
- Do not grow new crops with old in the same area
- Monitor heads in store for symptoms

Symptoms

Lesions are first seen on cotyledons and leaves of brassica seedlings as pale green-yellowish spots, which are angular in shape and usually bound by leaf veins (Figure 15). The pathogen readily sporulates on the underside of the infected leaves and the downy appearance of these structures gives rise to the common name for the pathogen (Figure 16).
In transplants, the pathogen sporulates profusely on infected cotyledons seven days after infection when temperatures are optimal, and infected cotyledons usually drop off after sporulation.

Infected seedlings are not usually killed by downy mildew infection and fresh growth is produced as normal, provided the apical meristem is unaffected by the disease. Most brassicas show some leaf infection during the growing season, but its severity is usually low. Broccoli and cauliflower show symptoms of systemic downy mildew infection in the form of discolouration of the interior of the head or black spots on the curds (Figure 17). Running down the floret stems, it produces a browning which can look like insect damage. Yellow or black speckling symptoms occur on the buttons of Brussels sprouts and these can extend through several leaf layers into the button. Similar penetrating lesions may also develop on stored cabbage. In field conditions, crops of turnip and swede will often outgrow the disease. Rocket, a related crop, can also suffer crop loss from downy mildew when weather is conducive for spread.

Figure 15. Downy mildew spotting symptoms on early cauliflower and cabbage. The lesions are characteristically bound by leaf veins

Figure 16. In optimal conditions, downy mildew rapidly sporulates on the cotyledons

Figure 17. Downy mildew infection on curds of cauliflower

Epidemiology

Sequential sowing of cultivars and the production of spring transplants enables downy mildew to occur throughout the year within glasshouses. Epidemics can become severe in the spring, when average temperatures within the glasshouse increase. Transplants are irrigated, creating very conducive environments for downy mildew infection. Crops grown under netting are also more prone to downy mildew attack.

The field environment is less optimal for downy mildew and, generally, adult plant resistance is observed with this disease. Lesions of brassica downy mildew can often be observed under field conditions, but they are usually of little economic importance. However, field infections may play a role in the reinfection of glasshouse crops grown in proximity to field crops. Infection at the seedling stage has never been shown to have a direct link to head symptoms.

Thick-walled oospores (or resting spores) are formed in infested plant tissues, which allow the fungus to survive in plant debris and in the soil until the next season and, in most cases, for many years. Soilborne spores can initiate infection of direct sown seedlings and there are many periods where established seedlings with symptoms can give rise to new infections on freshly sown crops. Seedlings are sown in sequence in the autumn for spring planting and in the spring for autumn planting. Mature crops may also have sporulating lesions, which give rise to glasshouse seedling infection. The pathogen can also overwinter on other cruciferous crops and weed species, allowing for potential carry-over of infections in the following season.

Systemic infections are thought to result from oospores that are present in the soil and infect through the root systems of young plants or from foliar infections at the seedling stage. When systemic infection occurs, the pathogen grows and spreads through the vascular tissues of the plant, which results in dark discolouration of these tissues that can extend up into the stalks and heads.

There is evidence of host specificity, with some evidence that certain isolates are able to infect some hosts better than others, but, to date, little work has been done to characterise these differences. The pathogen is also known to be geographically specialised. Several genes have been identified from certain lines of *Brassica oleracea*, which confer resistance, or at last partial resistance, to a range of UK isolates of *Hyaloperonospora brassicae*.

Life cycle

A simplified version of the brassica downy mildew life cycle is shown in Figure 18. The disease cycle begins when resting oospores (asexual) germinate via development of a germ tube that then forms into a haustoria, which is the key infection organ for the pathogen to penetrate the host. Within a few hours, the haustoria penetrates epidermal cells and the hyphae continue to progress, leading to the development of fungal colonies on host plants. Sexual zoosporangia are formed in the pustules on leaves, which are spread by wind or rain splash. New infections appear on other plants in as little as three to four days.

Hyaloperonospora brassicae germinates and penetrates at temperatures ranging from 6°C to 24°C, colonises at 8°C to 16°C and sporulates at around 24°C. Spore dispersal within the crop can occur after only 30 minutes of leaf wetness. Spores dispersed through the air require four hours of leaf wetness, such as periods of heavy fog or light rain, to infect brassica seedlings at the same temperatures.

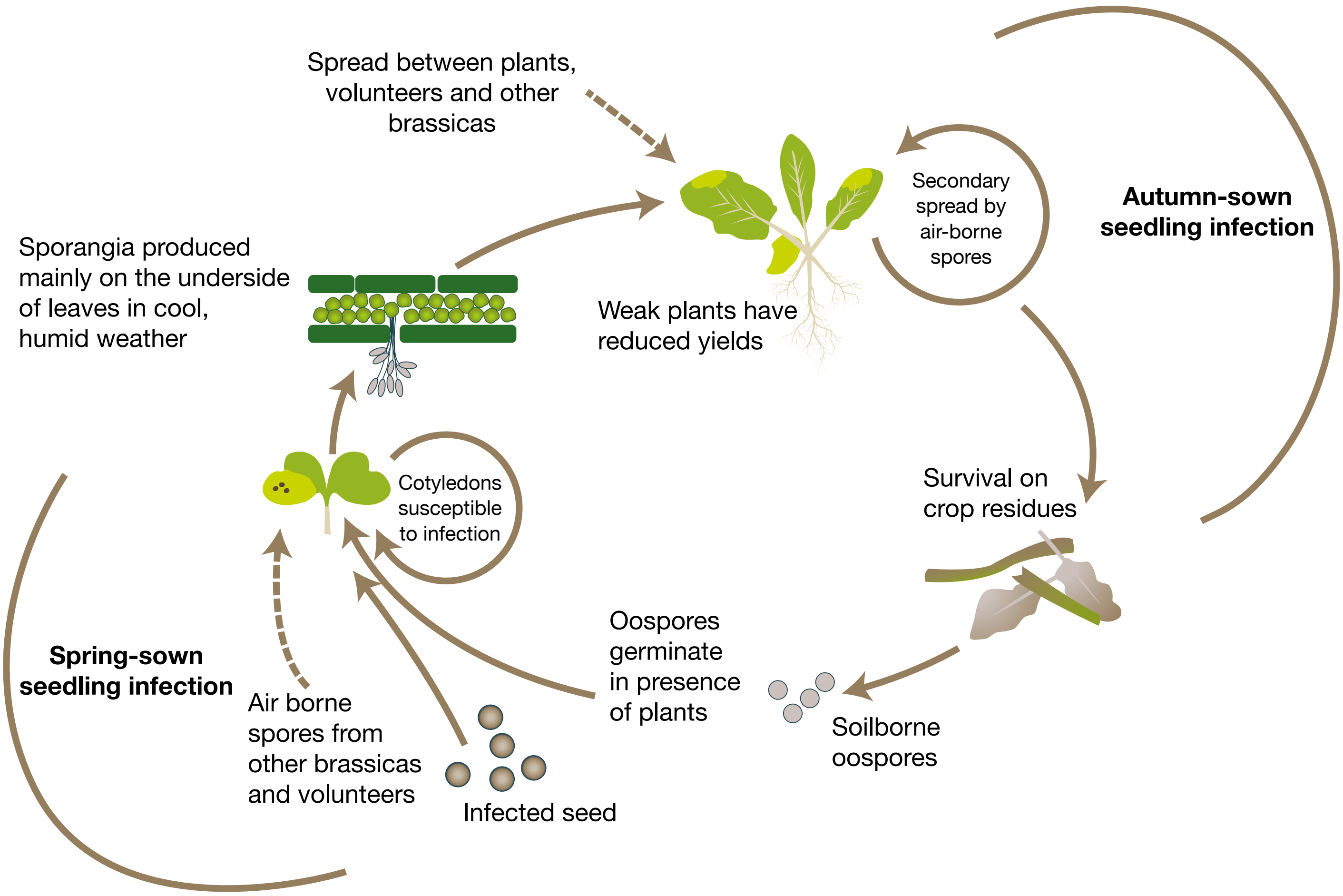


Figure 18. Life cycle of downy mildew on vegetable brassicas

Control

Monitoring

One of the challenges in managing downy mildew is that it has a very short latent period, making disease development fast and unforeseen. In glasshouse production, staff education in recognising early symptoms of downy mildew is an important component of monitoring and disease management. Monitor heads in store frequently – heads of cauliflower only need to be stored at ambient temperature for a few days before head symptoms appear.

Cultural controls

Good hygiene in propagated crops, including growing on plastic or concrete to avoid soil contact, should remove the risk of infection via oospores found in soil and crop debris. Propagators should take care to ensure glasshouses and trays are sterilised between crops and to avoid cross-contamination of plants by not growing old crops in the same area as new crops.

Irrigate plants in the morning or soon enough to allow leaves to dry off before the night and reduce leaf wetness. Avoid the use of overhead irrigation by using drip or furrow irrigation systems. The amount of time seedlings are allowed to sit wet in the glasshouse should be kept to a minimum. Maintain adequate ventilation, with good air circulation and adequate plant spacing, to avoid a warm, humid and still environment. Control feeding to prevent overly soft growth.

Research into light treatments under protection to protect against downy mildew epidemics during propagation has shown promising results, with blue light frequencies being inhibitory to *Hyaloperonospora brassicae* sporulation.

Dispose of unused transplants properly and do not put in discard piles. The disease can continue to develop on infected plants, which can then serve as a source of inoculum for nearby crops.

Because the pathogen can overwinter in crop debris, a rotation of two to three years of non-cruciferous crops is recommended, if possible. Incorporate crop debris and eliminate volunteer plants and weed hosts to reduce the amount of inoculum present.

Varietal resistance

Head brassicas, particularly broccoli and cauliflower, appear to be more susceptible than other types of brassicas. Current commercial varieties are susceptible at the seedling stage, while symptoms of systemic infection of the heads are now being more commonly observed. There are some varieties of Brussels sprouts and cauliflower available offering partial or intermediate resistance to downy mildew.

Products

Growers should consult with their agronomist or adviser on how to incorporate products into their disease management programme. Resistance to metalaxyl in brassica downy mildew was confirmed soon after the fungicide was introduced about 40 years ago. Diversify fungicide regimes to reduce the risk of selecting fungicide-resistant strains. It may not be practical or economical to treat maturing crops; however, wet weather may justify control.

Light leaf spot

Background

In Scotland and parts of Northern England, light leaf spot (*Pyrenopeziza brassicae*, anamorph, *Cylindrosporium concentricum*) is the predominant airborne pathogen affecting vegetable brassica crops, with other regions also affected. Light leaf spot is a polycyclic disease, which infects oilseed rape leaves, stems, flowers and pods during the course of the season, between sowing in autumn and harvest in summer. Light leaf spot has now replaced phoma stem canker as the main disease on winter oilseed rape in the UK. The disease remains active at far lower temperatures than other pathogens of vegetable brassicas, down to 4°C, so continues to cause outbreaks right through the winter. Light leaf spot is of particular concern to Brussels sprouts growers, with the pathogen continuing to spread further south and across Lincolnshire in recent seasons. Other brassicas may require extra trimming and rejection of heavily infected plants may occur.

Action points

- Light leaf spot has a relatively long latent period of 3–4 weeks. Monitor crops from August onwards for disease development
- Do not grow vegetable brassicas close to oilseed rape
- Brassica Alert is now spore trapping for light leaf spot, providing notification of risks to better manage spray timing. It is available to all growers as text alerts, through the Syngenta UK website
- Fungicide applications are becoming less effective in controlling light leaf spot in the UK. Avoid blanket crop spray programmes and prioritise applications at times when the inoculum is in the air or when the pathogen is growing without visible symptoms

Symptoms

A light leaf spot lesion can be recognised as groups of small black spots on the underside of leaves, clustered in to a ‘thumbprint’ (Figure 19). These occur on Brussels sprouts, cabbage (particularly spring greens), cauliflower and various other brassicas. Small white spore droplets are produced on and around these lesions (Figure 19). On very susceptible varieties, large areas of individual leaves may be affected and large pale blotches develop (Figure 20). Cauliflowers may show pinkish black lesions at the base of the leaves and petioles, which spoil the appearance of trimmed heads. Lesions on the older yellowing leaves often have a ‘watermark’ appearance, confined to one side of the leaf and developing a pinkish or red colour.

Leaf lesions are not very numerous in summer but become easier to find on the upper leaves in autumn and winter. The symptoms on sprout buttons are also ‘thumbprint’ lesions and these develop on the outer leaves and underneath the wing leaves (Figure 21). The white spore droplets are usually found around the edges of the lesions but are less likely to be found when buttons have been wetted by rain. Lesions on buttons induce considerable yellowing of the outer leaves and advanced symptoms may be confused with overmaturity and soft rots.

Symptoms of light leaf spot can appear as early as July, but disease symptoms become most prevalent during autumn and winter. A feature of the disease is its rapid development on buttons in autumn, despite little evidence of earlier leaf infection. This is probably due to the spread of airborne spores from debris in nearby fields, rather than secondary spread within the crop itself. Because light leaf spot is one of several diseases which cause black spots in brassicas, reliable identification may require laboratory diagnosis.

Figure 19. Light leaf spot lesions look like thumbprints on the underside and upper surface of leaves. Small white spore droplets are produced around the edges of the lesions

Figure 20. Cabbage head heavily infected by light leaf spot

Figure 21. Early and more developed symptoms on Brussels sprout buttons

Epidemiology

Light leaf spot is more common in Brussels sprouts crops adjacent to oilseed rape crops than in more distant crops. The long growth cycle of some vegetable brassica crops means that the crop is at risk over considerable periods of time, which is an additional problem if light leaf spot is to be controlled. The wind-dispersed ascospores of light leaf spot are likely to be responsible for transmitting the disease to crops. These ascospores are produced on leaf debris underneath oilseed rape crops in spring/early summer when horticultural brassica crops are transplanted to the field, and on stem and pod debris after oilseed rape harvest during late summer/autumn when horticultural brassica crops have been fully established. Once infected, leaves and buttons can remain symptomless for long periods of time (3–4 weeks), especially during cold weather. Volunteer oilseed rape plants may also act as a 'green bridge' between crops and thus provide another inoculum source.

Infection is influenced by environmental factors, including temperature and leaf wetness duration. In experiments on oilseed rape, infection occurred most quickly at 16°C when the leaves were wet. Infection was delayed when temperatures reached as high as 20°C or as low as 4°C. Little is known about the relative effectiveness of the two types of light leaf spot spores (ascospores and conidia) in causing a successful infection. However, controlled environment work on the infectivity of ascospores and conidia on oilseed rape and Brussels sprouts leaves suggests that ascospores may be more infective than conidia.

During the past decade, there has been a considerable increase in the severity of light leaf spot epidemics in northern Europe, perhaps due to changes in *P. brassicae* populations, to render ineffective some sources of resistance and some previously effective fungicides. Isolates from oilseed rape can cause light leaf spot on cabbage or Brussels sprouts, and vice versa. Areas with both vegetable brassica and oilseed rape production may have greater *P. brassicae* population diversity and thus a greater risk of severe epidemics than other areas. Seedborne infection of light leaf spot is not yet well understood and there are no control measures at present.

Life cycle

A simplified version of the light leaf spot life cycle is shown in Figure 22. Light leaf spot is a polycyclic disease in that it switches spore type throughout its life cycle within the crop. This ability to switch allows further spread by rain splash, with symptoms often appearing patchy in the crop. Light leaf spot produces ascospores on dead tissue and conidia are formed in acervuli on living tissue. Ascospores and conidia are morphologically similar when observed under a light microscope. Ascospores are hyaline, cylindrical, septate and roughly 15.0 µm x 2.5 µm in size, while conidia are hyaline, cylindrical, aseptate and roughly 10-16 µm x 3–4 µm. Ascospores play an important role in initiating epidemics in the autumn, when they are released from infected oilseed rape debris as it dries after overnight dew or rainfall, and are dispersed by wind. The sexual stage has been found to occur on dead leaves within crops of Brussels sprouts and other brassicas. Thus, there may be further spread of light leaf spot within later-maturing crops by ascospores. Conidia only travel short distances by splash dispersal and are responsible for secondary spread of the disease during autumn and winter. These later infections by secondary spores will not be picked up by spore trapping. Dry conditions delay spore maturation and release but do not prevent it.

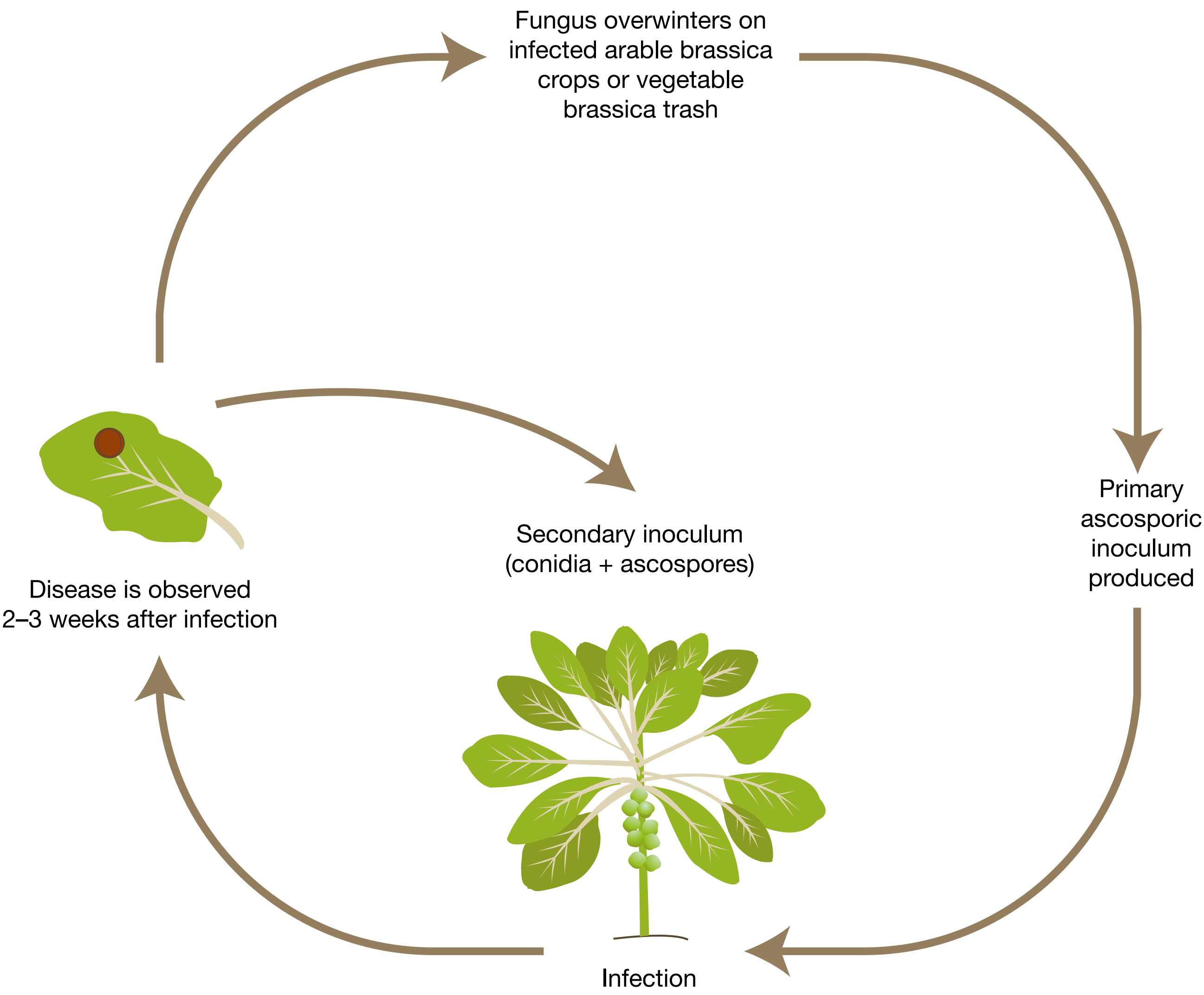


Figure 22. Life cycle of light leaf spot on vegetable brassicas

Control

Monitoring

Crops should be monitored weekly from August onwards for disease development. However, crop walking to find early symptoms of light leaf spot may not always be a reliable guide to disease risk. Symptoms of light leaf spot can appear suddenly in large numbers where there is infection from airborne spores.

Light leaf spot ascospores appear in the air in high enough concentrations to be a problem only during discrete periods. Air-sampling systems and in-field lateral flow tests are available for light leaf spot and a disease risk threshold has been identified. This information has been incorporated into the Syngenta Brassica Alert disease warning system. Brassica Alert is now spore trapping for light leaf spot, providing valuable notification of risks to better manage spray timing. Brassica Alert is managed in field by the Allium and Brassica Centre and is available to all growers as text alerts, through the Syngenta UK website.

Cultural controls

After harvest of any brassica crop, especially if it is infected with light leaf spot, quickly destroy all remaining plant debris by ploughing down. This will prevent the sexual stage of the fungus developing and subsequent transmission to other crops. Avoid growing brassica crops in a following season on a field that had an infected brassica crop.

Varietal resistance

Varieties differ in their susceptibility to light leaf spot, but no recent independent data is available.

Products

Protect Brussels sprout buttons with fungicide as they develop. On other brassicas, fungicides may be required 4–12 weeks before harvest. For greens and cabbage crops, protection with fungicides is usually targeted during the 8-week period up to harvest. Poor disease control is often due to poor spray timing. Fungicide applications can provide good control of light leaf spot if applied at times when the inoculum is in the air or when the pathogen is growing asymptomatically (without visible symptoms). Where routine ‘blanket’ crop spray programmes have been used, control can be ineffective. Fungicide applications are becoming less effective in controlling light leaf spot in the UK, and reduced sensitivity to azole fungicides has been reported in *P. brassicae* populations.

Phoma

Background

Phoma diseases (*Leptosphaeria maculans* and *Leptosphaeria biglobosa*; asexual stage *Phoma lingam*), also known as blackleg, are important worldwide in brassica crops, including the leafy and flower head types, turnip, Chinese cabbage and pak choi, oilseed rape, swede and mustard. In the UK, phoma stem canker of oilseed rape is the most economically important disease in southern, eastern and central England. Severe losses can occur in cauliflower and swede, but it is mainly a leaf blemish on other vegetable brassicas. Once leaf spots appear, the fungus can grow in the plant without causing any symptoms before causing severe stem symptoms.

Action points

For propagators

- Use healthy seed
- Monitor crops regularly and use fungicides at the propagation stage when phoma leaf spots are first detected
- Seedborne phoma can result in problems in individual varieties if there is a high level of seedborne infection and/or spread during plant propagation

For growers

- Bury crop residues and use non-brassica crops in the rotation where phoma problems are identified
- Do not grow leafy brassicas close to oilseed rape

Symptoms

Leaf symptoms can occur from the cotyledon stage onwards. Very young seedlings can be killed very rapidly. Phoma leaf spots are variable in shape; they are pale brown or white with numerous dark brown dots within the lesion, these are the fruiting bodies called pycnidia which produce the spores (Figure 23). This contrasts with ringspot symptoms; lesions of ringspot have more numerous tiny black fruiting bodies, called pseudothecia within the lesions. Another characteristic difference is that the fruiting bodies within lesions of ringspot tend to form in concentric circles.

Pycnidia produce a deep pink spore exudate that is diagnostic for *Phoma lingam*. Lesions are usually greenish on the underside of the leaf (Figure 24) and this enables them to be distinguished from downy mildew lesions that are often yellow or pale brown on the underside. As leaf spots enlarge (1–2 cm in diameter), they may develop a darker margin and show yellowing around the lesion. There is darkening of the leaf veins within the leaf spots and around the lesions, indicative of phoma spreading through the leaf towards the stem.

The leaf symptoms caused by *L. biglobosa* are smaller and darker than those caused by *L. maculans* and also contain fewer pycnidia. Vegetable brassicas with more delicate leaves, such as pak choi and Chinese cabbage, are very susceptible to leaf spotting. On mature, leafy brassicas, there may be few signs of leaf spotting and only low levels are usually found on buttons of Brussels sprouts. The spread of phoma through the leaf and petiole is largely symptomless. It invades the stem via the vascular system of the infected leaf and after a period of several weeks stem cankers form (Figure 25). These cankers are sunken areas on the lower stem and roots and have a distinct black margin. Sectioning the root shows internal blackening of the woody tissues and a dry rot that can weaken the stem or kill the plant. Problems in cauliflower may only become apparent when plants start to wilt and die close to maturity. In swede roots, the disease causes a dry rot in the neck and shoulders of the root, which progresses through the root even when temperatures are low (Figure 26). Root infection in swedes can occur in the presence and absence of leaf symptoms. Root wounding increases the proportion of the crop affected and the severity of the infections. In seed crops and oilseed rape, phoma affects the leaves, stem base (canker lesions), the upper stem and branches, flower buds and pods.

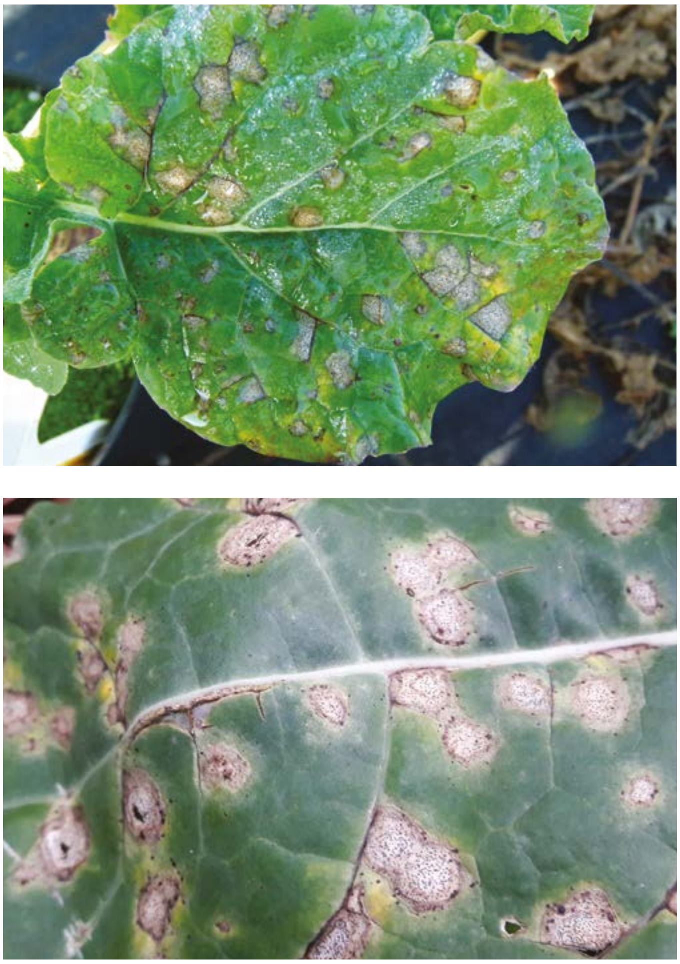


Figure 23: Typical symptoms of phoma are light lesions, varying from white to pale brown with numerous dark brown spots on them. These dark spots are the fruiting bodies, called pycnidia, which produce the spores.

Figure 24. Phoma lesions on the underside of oilseed rape, with a characteristic green tinge

Figure 25. Phoma travels from the lesions in the leaf down to the lower stem and roots, causing a canker, which can weaken the stem or kill the plants

Figure 26. In swede roots, the disease causes a dry rot in the neck and shoulders, which progresses through the root even when temperatures are low

Epidemiology

There are different types of epidemics because the initial source of disease may be infected seeds or airborne spores. Airborne ascospores are dispersed after periods of rainfall or high humidity and can germinate after as little as four hours of leaf surface wetness. The proportion of spores producing lesions increases as the duration of surface wetness increases to 24–48 hours. Symptoms appear in 5–6 days, when temperatures are near the optimum of 20°C. Secondary spread by pycnidiospores is also favoured by long periods of leaf wetness and warm temperatures. Phoma is also able to invade the plant where there is physical damage or pest injury.

Growth through the leaf to the stem is thought to occur at a rate of several millimetres/day under optimum temperature conditions. Thus, stem infection and, hence, survival on woody crop residues does not occur in short-term brassica crops because the fungus does not reach the stem. In oilseed rape, for example, stem canker lesions develop in spring, about six months after leaf infection in the autumn. Stem symptoms appear more rapidly in spring-sown crops because temperatures are more favourable for fungal growth. Where there is seedborne infection, phoma can spread in seedbeds and in module production under glass. When bare root transplants are used, spread is facilitated by washing plants, particularly where plants also have damaged roots.

Both phoma species present on oilseed rape in the UK (*L. biglobosa* and *L. maculans*) can infect swede roots and leaves. This has significance for disease control as *L. biglobosa* is often associated with phoma development later in the season than *L. maculans* and it is critical that strategies to monitor and control the disease are effective on both species.

Life cycle

A simplified version of the phoma life cycle is shown in Figure 27. Epidemics can be initiated by airborne spores (ascospores) produced on crop residues and dispersed by wind. Ascospores are produced mainly on stubble in minute structures called pseudothecia. Ascospores form on infected woody stems and roots after cropping. Survival of the pathogen and spore production can continue for several years until the woody remains decay.

Winter oilseed rape stubbles are an important source of inoculum when located near to areas of brassica production. The main period of ascospore production is during the autumn and winter, so crops planted in the spring and summer are only lightly infected or escape infection altogether. Leaf spots produce pycnidiospores that are splash-dispersed within the crop. Above-average rainfall in August and September encourages early ascospore production. The spores are produced over several months. If weather in the autumn is dry, spore production is delayed but continues longer into the spring.

Phoma can be seedborne and this can result in problems in individual varieties if there is a high level of seedborne infection and/or spread during plant propagation. Ascospores can enter propagation glasshouses through the open vents and introduce the disease onto seedlings. There are different races of *L. maculans* that are characterised by their ability to overcome different resistance genes in brassicas. This has been investigated in oilseed rape, where several resistance genes have been overcome by the pathogen. The situation in vegetable brassicas is not well understood. As leaf symptoms are much less prevalent on cabbage, cauliflower and Brussels sprouts than nearby oilseed rape, there appears to be useful ‘resistance’ in some vegetable brassicas. *L. biglobosa* often occurs along with *L. maculans* on leaves but is considered less damaging and causes more superficial stem lesions and some blackening of the pith within the stem.

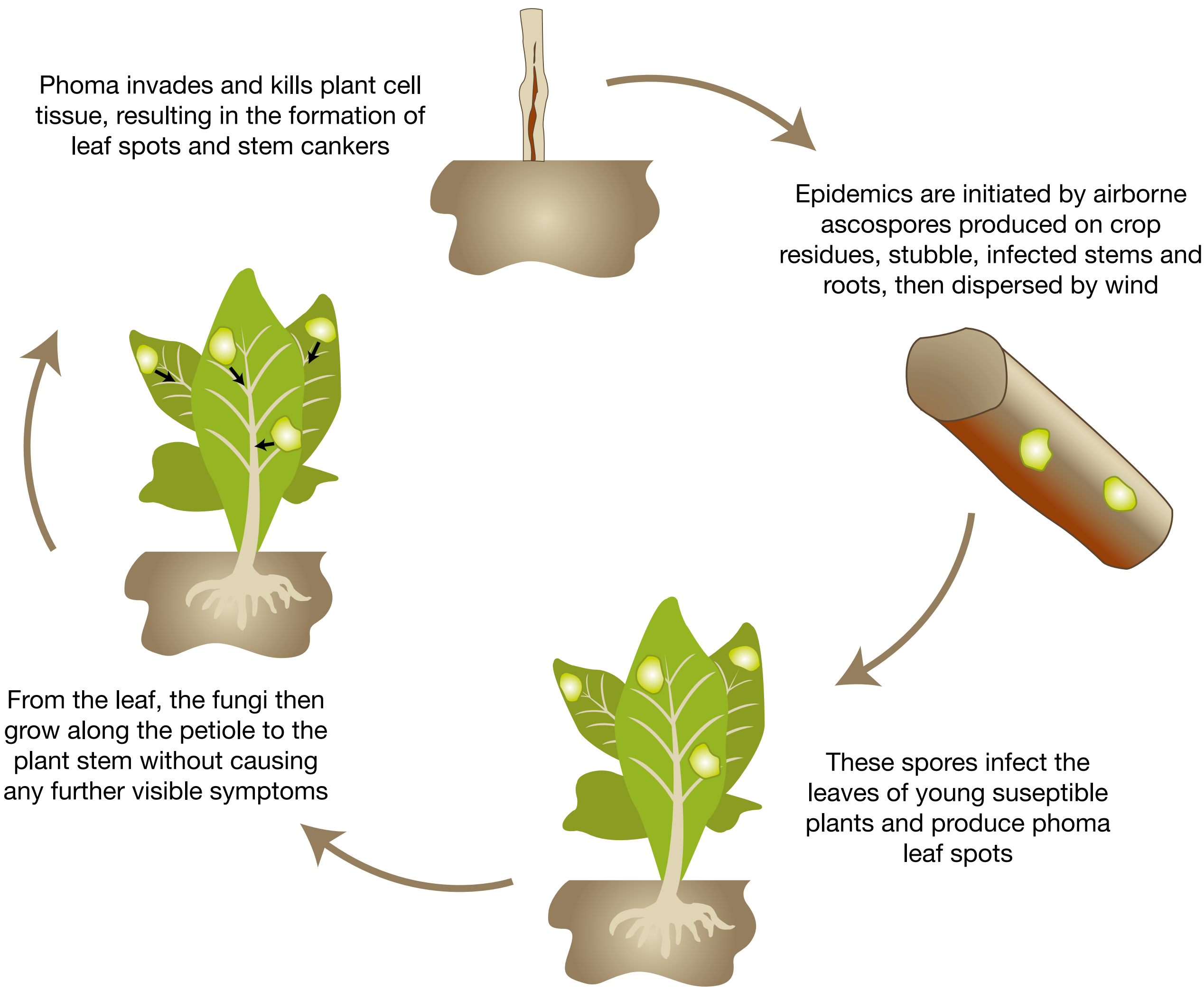


Figure 27. The phoma life cycle
Source: The University of Hertfordshire

Control

Monitoring

Monitor seedlings regularly during propagation and be prepared to apply fungicide treatment if phoma leaf spots are found.

Cultural controls

Avoid planting vegetable brassicas close to oilseed rape. Use healthy seed. Where seed is known to have a low level of phoma infection, use a fungicide seed treatment or hot water treatment. Dispose of crop residues, unharvested crops and volunteers to reduce the carry-over of inoculum, particularly where crops are planted in quick succession. Chopping and burial of stems and roots will encourage more rapid breakdown of crop residues that might otherwise persist for several years. Use a rotation with non-brassica crops for at least two years where severe phoma problems have occurred, to allow crop residues to decay.

Varietal resistance

Little is currently known about varietal differences in the susceptibility of many vegetable brassicas to phoma diseases.

Products

Local knowledge of recent problems is important to guide decisions about using fungicides on swedes, as treatment timings have not been investigated. Foliar fungicides may be beneficial during the growing season when used as phoma leaf spots start to appear. Note that fungicides used against other foliar diseases may have some effect on phoma development.

Powdery mildew

Background

Powdery mildew, caused by *Erysiphe cruciferarum*, is one of the most common foliar diseases of vegetable brassicas in the UK. It is an important cause of blemish on Brussels sprout buttons and on cabbage. When swedes and turnips are severely affected, it causes loss of yield and quality. However, many brassicas show only slight infection that does not impair quality. It can also occur on brassicas grown under protection. There is some variation in the severity of epidemics from year to year, but the main risk period is usually from late July to October.

Action points

For propagators

- Maintain adequate ventilation, with good air circulation and adequate plant spacing, to avoid a warm, humid and still environment
- Avoid fluctuations of temperature in the greenhouse
- Biofungicides are available as a preventative measure on both outdoor and protected crops; always check the label and/or consult with your agronomist before use

For growers

- Monitor crops regularly and be prepared to use fungicides from disease onset. Severe disease outbreaks are associated with warm, dry summers with limited rainfall
- Managing crop nutrition is beneficial, as powdery mildew occurs where plants are under stress from nutrient deficiencies and is aggravated by excessive nitrogen applications
- Dispose of crop residues, unharvested crops and volunteers to reduce the carry-over of inoculum, particularly for overwintered crops
- Use resistant varieties, particularly for swedes and Brussels sprouts

Symptoms

The first signs of powdery mildew are small scattered colonies of white fungal growth (Figure 28). Colonies develop on upper and lower leaf surfaces and petioles. These are almost translucent and difficult to detect in the early stages. The powdery mildew pustules become larger and develop the characteristic white powdery appearance that can cover most of the aerial plant surfaces in susceptible varieties (Figure 29). This leads to yellowing and premature loss of leaves. On more resistant varieties, the colonies are more restricted in size and greyish in colour, though some may show only fine black speckling with little fungal growth. There may be purpling of the underlying plant tissues associated with lesions.

On Brussels sprouts, powdery mildew produces colonies in the stem between the buttons and often black speckling on the outer leaves of the buttons (Figure 30). This is easily confused with various other conditions, such as oedema and overmaturity, that cause fine black spotting on buttons. Accurate diagnosis is essential. There may be more pronounced button symptoms if infected buttons are subject to frost. In seed crops, the stems and pods may become heavily infected.

Figure 28. The first signs of powdery mildew are scattered colonies of white fungal growth

Figure 29. In susceptible varieties, powdery mildew develops a characteristic white powdery appearance

Figure 30. Powdery mildew causes black speckling on Brussels sprout buttons

Epidemiology

To date, there is little information on the environmental requirements of brassica powdery mildew development, although it appears to be favoured by dry conditions. The spores can germinate at low relative humidity, and free water, or rain, can be inhibitory. Powdery mildew is highly airborne and small numbers of conidia (spores) can be wind-dispersed over long distances. New colonies are produced within 7–10 days in summer. Severe disease outbreaks are associated with warm, dry summers with limited rainfall. Disease development is often evident towards the end of July and continues into the autumn until curtailed by frost.

On Brussels sprouts, the disease develops from late August onwards, initially infecting all types of foliage but becoming more prevalent on sprout buttons. The presence of the disease on the sprout buttons can downgrade their value, especially if cold weather occurs, which gives rise to melanisation of the mycelium, producing a speckled appearance to the button. Infection with *Erysiphe cruciferarum* can encourage the entry of secondary organisms on infected tissues, such as grey mould (*Botrytis cinerea*). Periods of moisture stress may also render plants more susceptible to powdery mildew infection.

Life cycle

A simplified version of the powdery mildew life cycle is presented in Figure 31. Epidemics are initiated by airborne spores (conidia) produced in overwintered crops and volunteers and dispersed by wind. Mild winters are conducive to the survival of inoculum. The conidia can spread over considerable distances and once new crops are affected there can be rapid development and spread within and between crops in close vicinity. The pathogen sometimes forms a sexual stage, producing pinkish brown to dark brown fruiting bodies (cleistothecia) on diseased foliage, though its importance is not known.

There are different strains of powdery mildew that show varying degrees of specialisation to different brassica species. Turnip isolates are reported not to affect Brussels sprouts, for example. There may be some cross-infection between oilseed rape and other brassicas.

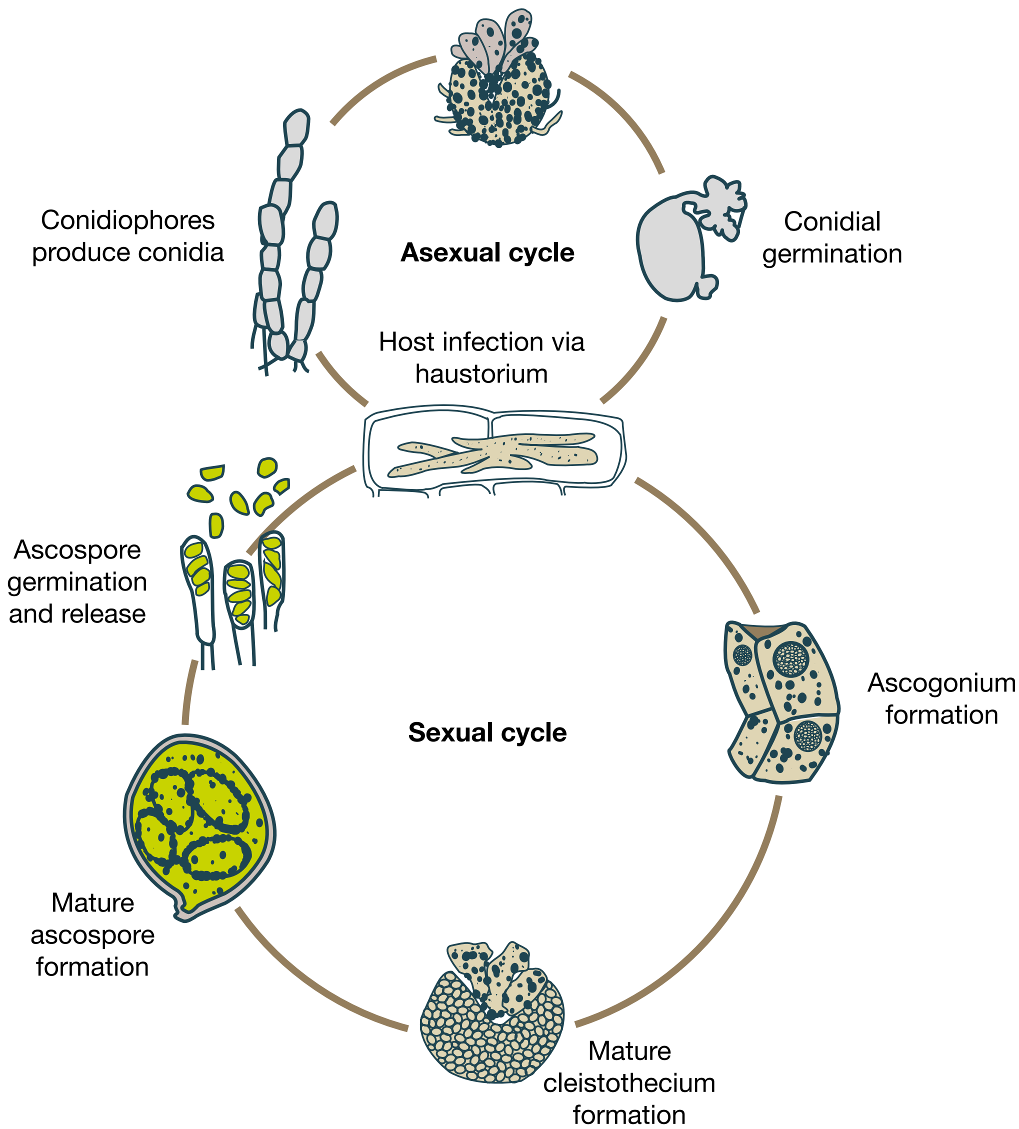


Figure 31. The life cycle of powdery mildew in vegetable brassicas

Control

Monitoring

Regular crop inspection is important, to identify the onset of an epidemic and to help identify situations where the seasonal risk is higher than usual. In-field lateral flow tests are available for monitoring and testing for powdery mildew. A biological disease threshold has not yet been established for powdery mildew in brassicas.

Cultural controls

Careful management of nutrition is beneficial as powdery mildew is aggravated by excessive nitrogen applications and where plants are under stress from nutrient deficiencies. In glasshouse production, maintain adequate ventilation, with good air circulation and adequate plant spacing, to avoid a warm, humid and still environment. In the field, appropriate disposal of crop residues, unharvested crops and volunteers are important to reduce the carry-over of inoculum, particularly for overwintered crops.

Avoid fluctuations in temperature in the greenhouse.

Varietal resistance

There are significant varietal differences in the susceptibility of many brassicas to powdery mildew. Guidance should be sought from plant breeders and/or your agronomist, particularly for Brussels sprouts and swedes, as there is no recent independent data available. Local data on the resistance of varieties should be collected to guide future decisions.

Products

A programme of fungicides may be required to protect crops during the August to October period. Some infection of cauliflowers or broccoli can be tolerated, but early powdery mildew activity may require an intervention in epidemic years. The biofungicide Amylo-X (*Bacillus amyloliquefaciens* D747) may be used preventatively on both outdoor and protected crops; however, as with all products, always check the label and/or consult with your agronomist for restrictions around the maximum number of applications, spray intervals and, in particular, the time of year for use in outdoor cropping systems.

Rhizoctonia

Background

Rhizoctonia, caused by the fungal pathogen *Rhizoctonia solani*, can occur from sowing onwards; however, it does not usually cause severe problems in vegetable brassicas. It is one of the pathogens (along with *Pythium* spp.) that cause damping-off of seedlings. On young plants, the disease is known as 'wirestem'. In swedes and turnips, the quality of roots can be affected when the infection causes black spots which disfigure the roots. Root symptoms are also an important problem on radish. There are occasional reports of foliar symptoms, including leaf spots and bottom rots, on cauliflower, cabbage and other brassicas. Growers also report that calabrese can be more severely affected than cabbage.

Action points

For propagators

- Strict hygiene is required during propagation and trays that are reused should be thoroughly cleaned and disinfected
- Monitor for poor emergence and collapse of seedlings soon after emergence; these are the first signs of rhizoctonia infection
- Composts should be kept covered prior to use so that they do not become contaminated
- A number of biofungicides are available for preventative disease management of rhizoctonia

For growers

- Plants should be hardened off before transplanting as this reduces their susceptibility to attack
- Avoid using soft plants and treatments that might stress the plant or affect its ability to grow away quickly
- Crop rotations with non-brassica crops should be beneficial, particularly where AG 2-1 strains are involved or severe attacks have occurred
- Fungicides may be required to control black spot in swedes and turnips

Symptoms

Poor emergence and collapse of seedlings soon after emergence are the first signs of rhizoctonia infection. Other pathogens, notably *Pythium* spp., can cause similar symptoms and laboratory diagnosis may be required to identify the cause. Rhizoctonia attacks the roots and lower stem of young seedlings (Figure 32). Plants become less susceptible as they get older. Affected plants show browning and cracking of the outer tissues of the stem around soil level and develop 'wirestem' symptoms, where only the core of vascular tissue remains. Where direct-sown or transplanted crops are affected, plant growth is uneven and there are numerous gaps where plants have died (Figure 33). Badly affected plants die subsequently or may snap off in windy weather. Cauliflowers are usually the most susceptible of the brassicas. On root brassicas, small black or brown spots, up to 1 cm in diameter, develop on roots of swedes and turnips (Figure 34). These lesions become sunken as the rot progresses. Rather larger lesions with concentric light and dark zones also develop on the roots. Dark, slightly sunken lesions develop on radish roots. Webs of fungal mycelium of rhizoctonia can spread over the underside of leaves and cause grey leaf lesions or bottom rots on cabbage, particularly where these are in contact with soil.

Figure 32. Rhizoctonia attacks the roots and lower stems of young seedlings

Figure 33. In affected crops plant growth is uneven, with numerous gaps where plants have died

Figure 34. In swedes and turnips, rhizoctonia causes small black or brown spots, up to 1 cm in diameter

Life cycle

A simplified version of the rhizoctonia life cycle is presented in Figure 35. Rhizoctonia occurs commonly in soil and composts, where it survives saprophytically. It has brown pigmented fungal filaments called hyphae and many strains produce sclerotia that aid their survival. Hyphae grow through soil, but *R. solani* is able to grow more rapidly over the soil surface under humid conditions. There is a sexual stage (*Thanatephorus cucumeris*) that produces airborne spores, typically forming a white collar of fungal growth just above soil level on a range of plants.

Strains of *R. solani* are separated into groups and the strain AG 2-1 is specific to brassicas and closely related species, such as radish. AG-4 strains also affect brassicas but have a wider host range and tend to be less virulent than AG 2-1 isolates. Other strains of rhizoctonia may sometimes occur on brassicas in the UK.

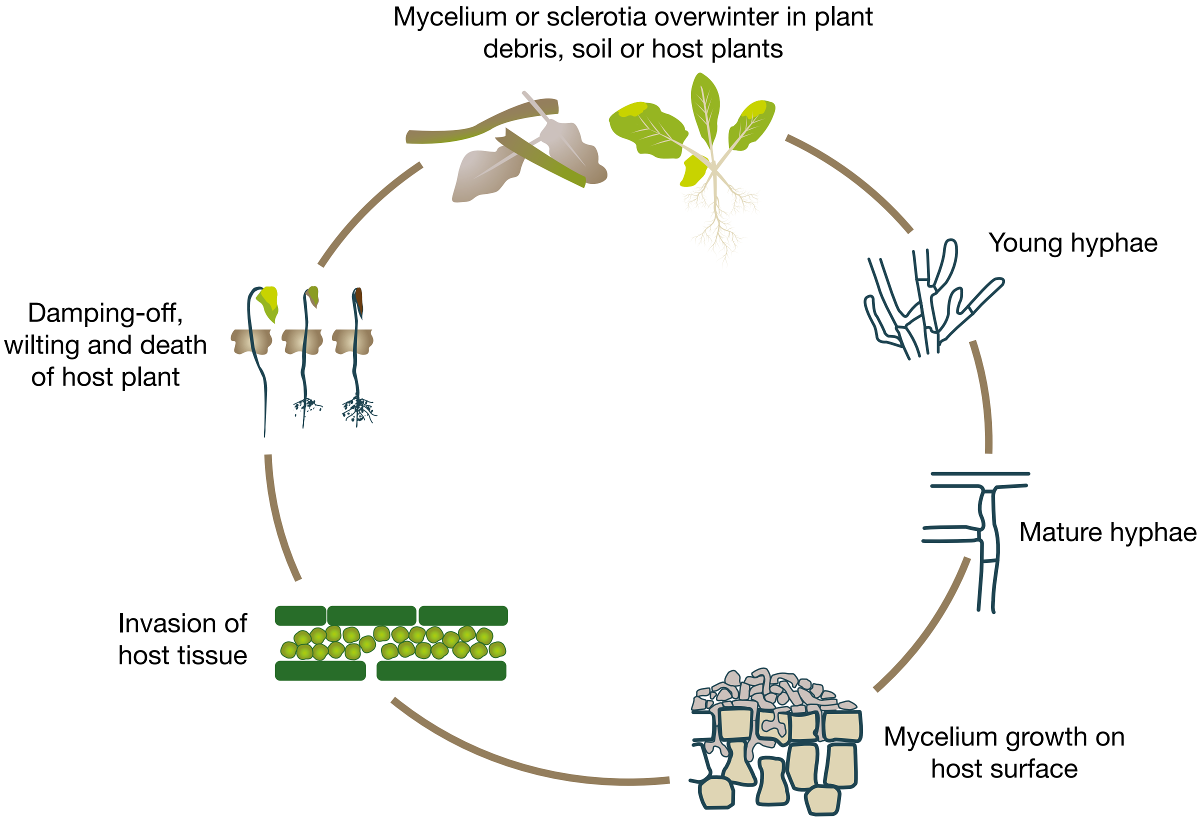


Figure 35. Life cycle of *Rhizoctonia solani*

Epidemiology

The occurrence of rhizoctonia disease is influenced by the weather or glasshouse environment and the level of fungal inoculum present. Cool (7–8°C), wet conditions at sowing favour damping-off by AG 2-1 strains, whereas AG-4 strains cause little damage at these low temperatures. Conversely, AG-4 causes most damage when temperatures are above 25°C and can attack more mature plants. The disease often occurs in patches and spread from plant to plant may occur while seedlings are still at a susceptible stage. Recent studies have shown that *R. solani* cannot always be detected within glasshouse production systems; however, it is more consistently present in the stem bases of field crops. Seedborne infection has been reported but is uncommon and may be associated with poor-quality seed lots contaminated with soil and plant residues.

Control

Monitoring

This disease is often a minor problem and careful crop management can minimise its occurrence. Monitoring at both the propagation stage and in the field is a key component of disease management. Pick out and remove any symptomatic plants as soon as they are noticed. Careful monitoring for symptoms ensures that management practices can be put in place to avoid further loss of plants.

Cultural controls

Propagation conditions for sowing depth, temperature, nutrition, compost quality and moisture should be adjusted to ensure that seedlings emerge quickly. Plants should be hardened off before transplanting as this reduces their susceptibility to attack. Avoid planting modules too deep.

Good hygiene measures are required on propagation nurseries as rhizoctonia problems are often associated with reused trays that have not been thoroughly cleaned and disinfected. The general nursery area should be kept clean as windblown soil and dust can introduce the pathogen. Composts should be kept covered prior to use so that they do not get contaminated. *R. solani* often occurs in association with plant material, although the basis of this association is not clear. If part of a tray has rhizoctonia symptoms, the whole tray should be discarded. Soil steaming and disinfection can be used on nurseries to eliminate infection; however, this is costly.

In the field, crop rotation with non-brassica crops should be beneficial particularly where AG 2-1 strains are involved or severe attacks have occurred. Where brassicas are grown intensively, avoid using soft plants and treatments that might stress the plant and affect its ability to grow away quickly.

Varietal resistance

There are no resistant varieties, though cabbage and Brussels sprouts are generally less susceptible than cauliflowers. Growers also report that calabrese (broccoli) is susceptible.

Products

A number of biofungicides are available for preventative disease management of rhizoctonia. Serenade ASO (*Bacillus subtilis*, strain QST 713) is to be applied as a root drench during drilling, planting or transplanting. Prestop (*Gliocladium catenulatum* strain M17223) should be applied as a drench or via direct incorporation into the growing medium. Growers are advised to test Prestop on a small area of crop prior to wider commercial use. Amylo-X (*Bacillus amyloliquefaciens* D747) may also be used preventatively on both outdoor and protected crops. Always check the label and/or consult with your agronomist for restrictions around the maximum number of applications, spray intervals and, if relevant, restrictions in the time of year for use in outdoor cropping systems.

Ringspot

Background

Ringspot, caused by *Mycosphaerella brassicicola*, is an important foliar disease of vegetable brassicas in the UK. In areas of intensive vegetable brassica cultivation, ringspot control is problematic because of the airborne nature of the inoculum and the prevalence of the favourable environmental conditions required for infection to occur. The ability of the pathogen to spread from heavily infected overwintered crops onto sequentially transplanted crops in the same area has a major impact on control of the disease during the season. Long-season Brussels sprouts are particularly badly affected by ringspot. Extra trimming may be required to remove affected leaves in cabbage and kale. To maintain the high quality of produce demanded by the market, there is heavy reliance on regular fungicide applications.

Action points

- Use rotations with non-brassica crops
- Plough in or incorporate residues immediately after harvest. Break the year-round cycle of brassica cropping for several months to allow crop residues to decay
- Do not plant new crops next to mature crops with ringspot
- Ringspot has a long latent period – the time between infection and symptom development can be between 10 and 28 days
- Ringspot can be limited by low temperatures and dry conditions
- The Brassica Alert prediction system to identify risk periods for ringspot is managed in field by the Allium and Brassica Centre and available to all growers as text alerts, through the Syngenta UK website

Symptoms

Ringspot lesions are usually grey or light brown when mature, but can be black in appearance when developing. Mature lesions develop black pinhead-size fruiting bodies (pseudothecia) within the brown areas of the lesion (Figure 36). These are formed when free water (as droplets) is present on the lesions, giving rise to rings of black fruiting structures, from which the name of the disease arises. These fruiting bodies are smaller and more numerous than those found in phoma leaf spots. Ringspot lesions characteristically have a distinct margin when they are developing on leaves (Figure 37). This is often best seen on the underside of the leaf. This characteristic is not normally associated with other leaf spots on vegetable brassicas. Severe infection causes premature loss of leaves and can reduce both yield and quality (Figure 38).

Ringspot affects all types of vegetable brassica. However, it is a major problem on the buttons of Brussels sprouts, where even mild levels of disease can reduce yield in the crop disproportionately (Figure 39). The occurrence of one lesion on the Brussels sprout button can render it unmarketable. Ringspot is a minor disease of oilseed rape in the UK and it also affects forage brassicas, such as kale. The disease is less economically important on other vegetable brassicas, where only infection of the packing leaves of cauliflowers or broccoli could render the heads unsaleable, which can result when high levels of disease occur in the crop. Extra trimming does, however, increase labour costs.

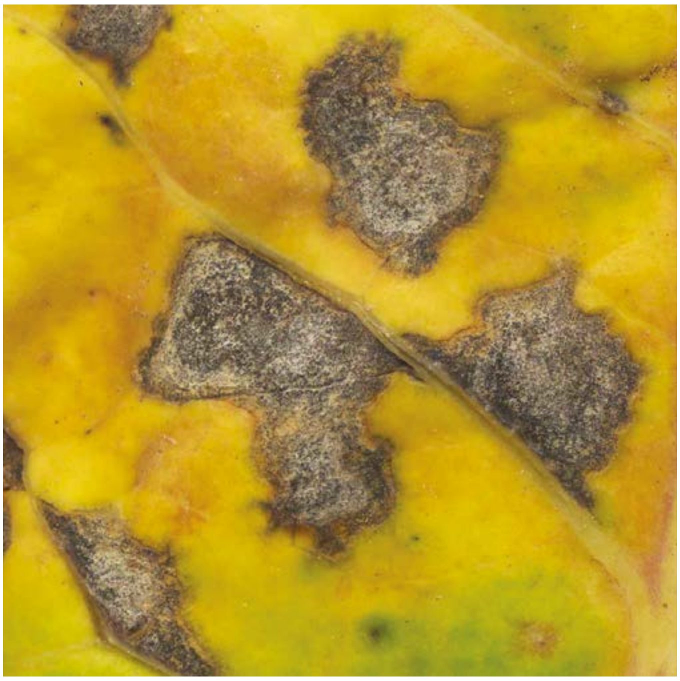


Figure 36. Symptoms of ringspot on cabbage, showing concentric rings that can be brown or grey in colour

Figure 37. Ringspot on broccoli leaves

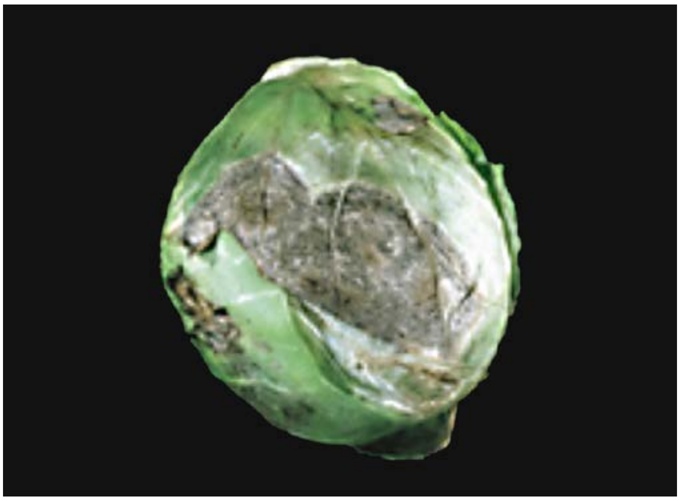


Figure 38. Severe symptoms of ringspot on cabbage in storage, affecting the whole of the head

Figure 39. Ringspot symptoms on Brussels sprout buttons

Epidemiology

Fruiting structures (pseudothecia) release ascospores (the main infective spore type) from mature leaf lesions. A second stage forms on young lesions, but these spores are unable to infect the brassica plant. Ascospores are windborne over considerable distances. After leaf infection, the pathogen requires relatively long periods of leaf surface wetness for the development of pseudothecia and production of ascospores. At low temperatures (7°C), spores have been shown to require over four days of leaf surface wetness to germinate. Optimum temperatures for infection are 16–20°C and new lesions appear in 10 to 28 days.

Spore discharge takes place over a wide range of temperatures – from 0°C up to 22°C – is stimulated by rainfall and mainly occurs in daylight. After discharge, the ascospores are dispersed by wind. Studies measuring ringspot in airborne spore samplers have shown that, under ideal environmental conditions, high concentrations of spores are required in the air for infection to occur (2,000 spores per cubic metre).

The temperature and wetness optima for development of this disease means it can be limited by low temperatures and dry conditions. For this reason, ringspot is not often present in colder production areas of the country, such as Scotland. When there is a short cropping interval between planting and harvest, the disease impact is limited if disease development comes from spores produced within the crop. Under optimal conditions, it can take 4–6 weeks between infection and inoculum production.

Life cycle

A simplified version of the ringspot life cycle is presented in Figure 40. Under optimal environmental conditions, hyphae of *M. brassicicola* ascospores penetrate host leaves 10 days after infection. Following a period of intercellular growth, which lasts up to 15 days, host cell walls are destroyed and the fruiting structures (pseudothecia) develop. Pseudothecia can overwinter in the soil.

Ringspot thrives where there is year-round production of brassicas. Once ringspot is established within the crop, secondary spread occurs by means of ascospores produced on mature leaf lesions. There are different strains of ringspot and some appear to be only able to infect cabbage.

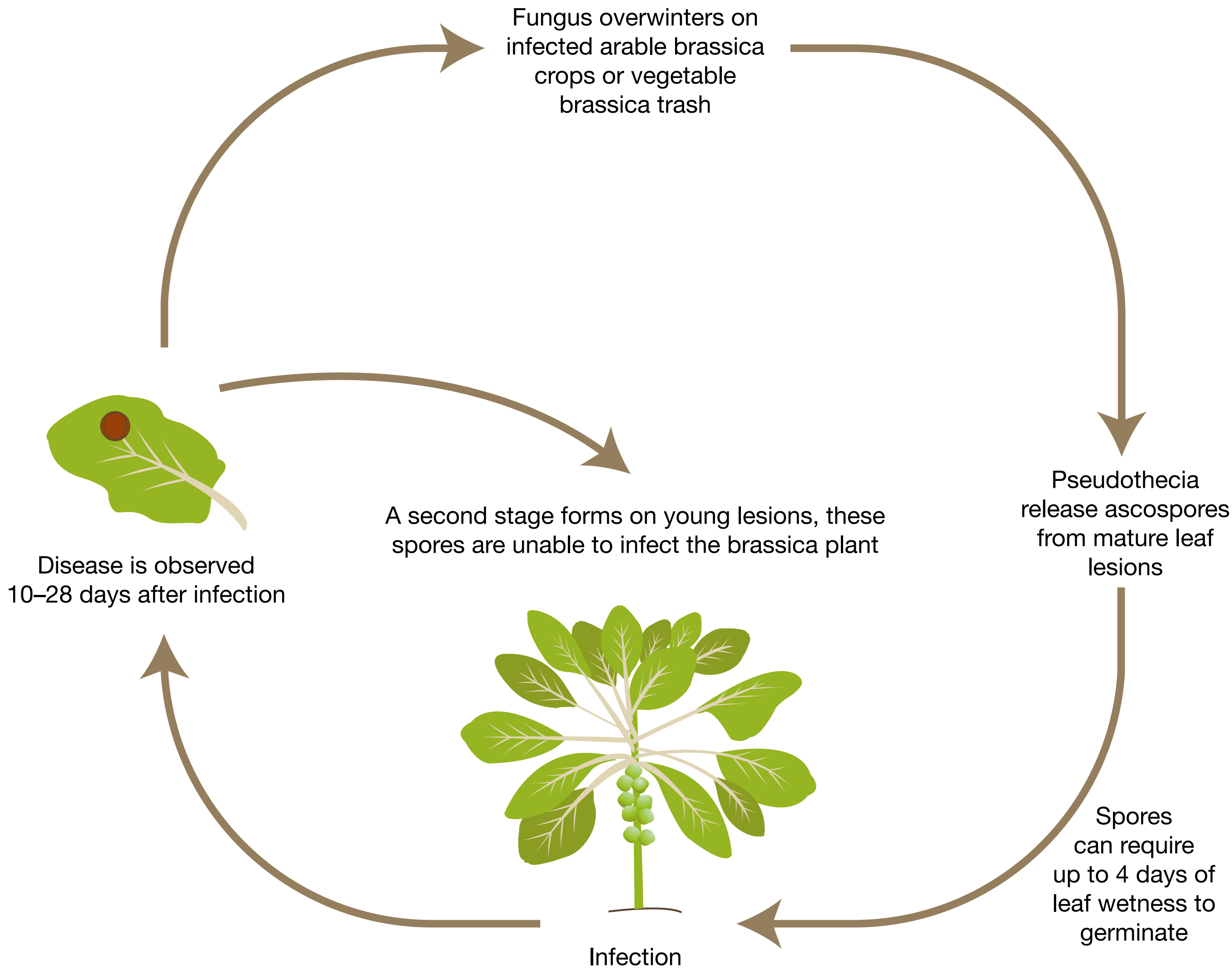


Figure 40. The ringspot life cycle on vegetable brassicas

Control

Monitoring

Information on temperature, rainfall and relative humidity allows for predictions of the likely ascospore inoculum availability from lesions within the crop. This information has been incorporated into a disease warning model called Brassica Alert. Risk is determined by spore captures and weather data. Brassica Alert is managed in field by the Allium and Brassica Centre and available to all growers as text alerts, through the Syngenta UK website. Detecting the ascosporic source of inoculum is potentially important if more accurate timing of fungicide application to the crop is to be achieved, to improve efficient use of fungicides. However, infection resulting from long-distance dispersal of ascospores cannot be predicted.

Cultural controls

Crop rotation with non-brassica crops and hygiene measures to dispose of crop residues are important for control of ringspot. Plough in or incorporate crop residues immediately after harvest. Avoid planting new crops adjacent to mature crops with ringspot and break the year-round cycle of brassica cropping for several months to allow crop residues to decay.

Varietal resistance

There are some varieties of cauliflower and Brussels sprouts available offering partial or intermediate resistance to ringspot.

Products

A preventative approach with fungicides is required in high-risk areas so that ringspot does not become established within the crop.

Sclerotinia

Background

Sclerotinia can affect vegetable brassicas at all stages of growth, from seedlings to flowering, seed crops and stored crops. The various names of sclerotinia disease reflect the symptoms it causes at the different plant growth stages. These include: watery soft rot, white mould, stem rot and cabbage drop. Brassicas most at risk are seed crops, or crops predisposed to infection by damage or poor management. Epidemics may occur in oilseed rape when weather conditions favour infection during flowering.

Action points

For propagators

- Practice good hygiene on propagation nurseries
- Appropriate plant spacing can help stop spread by direct contact from plant to plant
- Biofungicides are available for use under propagation and should be used as a preventative measure against infection

For growers

- Be aware of individual site history and local knowledge of sclerotinia problems
- Spores of sclerotinia have limited ability to infect healthy plants. Most attacks happen when there are additional nutrients available from fallen petals or physical damage to the crop
- Review rotations to ensure that different susceptible crops (including oilseed rape, potatoes, legumes (apart from winter field beans), carrots, lettuce and many other vegetables) are not grown too close in the rotation. An interval of 3–4 years between susceptible crops should allow some decline in sclerotial numbers
- Ensure harvested seed is not contaminated by sclerotia
- Careful handling is essential for crops going into storage, to avoid physical damage
- Protect seed crops with fungicides at flowering. Biofungicides are available as both preventative and curative measures against infection. Always check the label and/or consult with your agronomist on how best to use these

Symptoms

Sclerotinia is an aggressive pathogen that grows rapidly under cool, moist conditions. When its fungal resting bodies (sclerotia) are seedborne, it can cause damping-off, which results in patches of collapsed seedlings. Leaf infection can occur on module-raised transplants, where there are senescent leaves or scorch. Fluffy white fungal growth develops on the foliage, under humid conditions, followed by the production of small black sclerotia. If conditions remain favourable for its development, there is progression to stem rotting and collapse of the young plant. The fungus can continue spreading by direct contact from plant to plant.

On cabbage, a watery soft rot symptom can develop on the leaves and head, resulting from infection taking place at, or near, soil level (Figure 41). Similar symptoms can occur on the developing heads of flowerhead brassicas and on other types of brassica, where there is scorch or physical damage (Figure 42). On winter white cabbage, heads may show white mould in the field and these have numerous black sclerotia on the surface of the head (Figure 43). Often, the affected plants are just a few scattered heads near the edge of the crop, where machinery has damaged the plant during field operations. Similar symptoms occur on stored heads under both ambient and cold storage conditions.

Flowering brassicas are particularly prone to sclerotinia attack as the petals provide a nutrient source that enables sclerotinia spores to infect the plant. Pale brown or white lesions develop on leaves or directly on the stems and gradually enlarge to produce large girdling stem lesions. They kill the upper part of the plant and can weaken the stems so that the plant falls over. Black sclerotia are produced within the stem cavity and occasionally on the outside of the stem. Stem lesions continue to enlarge, given humid conditions, and can spread into the root system.

Figure 41. Sclerotinia infection in cabbage

Figure 42. Sclerotinia infection in Brussels sprouts

Figure 43. Sclerotinia on cabbage with sclerotia present

Figure 44a. Sclerotinia infection on swede - early stage

Figure 44b. Sclerotinia infection on swede - late stage

Epidemiology

While *S. sclerotiorum* occurs very widely in broad-leaved crops and weeds, the localities where severe attacks occur usually have a history of problems in one or more susceptible crops. Sclerotia require a period of dormancy and cold conditioning before they produce saucer-shaped fruiting bodies (apothecia) at the soil surface. This conditioning usually occurs during the autumn and winter so that sclerotia germinate and produce apothecia in spring when soils are moist and soil temperatures are above 10°C. Sclerotia stored at sub-freezing temperatures have been shown to germinate successfully. Moisture is a key factor influencing the survival of sclerotia. Sclerotia have a lower survival rate in flooded soils compared with dry soil, but this is offset by the production of secondary sclerotia in flooded conditions, where a balance of destruction and formation is achieved in completely saturated soil.

Ascospores are produced a few days after apothecia first appear and are dispersed mainly within the field and adjacent areas. The ascospores may be able to survive for several weeks on leaves and require long periods of high humidity (minimum 23 hours) with temperatures of at least 7°C for plant infection to occur. Once plant infection has occurred, further fungal growth can occur over a temperature range of 0–25°C but can be inhibited by hot, dry conditions. At the end of cropping, the sclerotia produced in the crop fall to the soil, where they are usually buried by cultivations. Some sclerotia may be harvested with the seed crop and small ones may contaminate seed if they cannot be removed during seed cleaning.

Life cycle

The disease cycle has two main components: soilborne sclerotia capable of long-term survival when buried deeply and airborne ascospores produced when sclerotia near the soil surface germinate and form fruiting bodies (apothecia). When the sclerotia are brought close to the soil surface, they germinate to produce mushroom-like apothecia that release airborne ascospores, which infect aerial plant parts. Spores can be produced from late winter until the autumn and can initiate infection in a very wide range of broad-leaved crops and weeds. They have limited ability to infect healthy plants and most attacks occur when there are additional nutrients available from fallen petals or damaged or senescent foliage. Once initial infection has occurred, there is spread through the plant, and from plant to plant, by direct contact. Sometimes, sclerotinia infects weeds in the crop and then spreads from weeds to crop plants.

If plant stems or leaves are in almost direct contact with sclerotia, there may be direct infection. Similarly, if there are infected plant residues in the field when the new crop is planted, sclerotinia can infect by direct mycelial growth. Sclerotinia may also be seedborne and this is difficult to detect even in untreated seed as some sclerotia are the same size and colour as brassica seeds.

Control

Cultural controls

Good hygiene measures are vital on propagation nurseries. The general nursery area should be kept clean, as windblown soil and dust can introduce the pathogen. Soil steaming and disinfection can be performed on propagation nurseries to eliminate infection sources; however, this is costly. Appropriate plant spacing can help stop spread by direct contact from plant to plant.

Crop rotation is an important part of controlling this disease. As sclerotinia problems occur infrequently, rotational planning and local knowledge of sclerotinia issues are important. The whole rotation should be considered when assessing the risks of sclerotinia diseases. Oilseed rape, potatoes, legumes (apart from winter field beans), carrots, lettuce and many other vegetables are susceptible and contribute to maintaining soilborne populations. An interval of 3–4 years between susceptible crops should allow some decline in sclerotial numbers. Risks will be increased by growing susceptible crops close together in the rotation. Deep ploughing to bury sclerotinia may be worthwhile. However, sclerotia should not be brought back to the surface by subsequent cultivations when susceptible crops are grown.

Varietal resistance

There are no resistant varieties currently available; however, previous research at the University of Warwick identified lines of oilseed rape, kale and swede which showed useful levels of resistance to sclerotinia, compared with standard commercial cultivars. This resistance could be of benefit to future brassica breeding in the UK. These resistant lines were also shown to reduce the number of sclerotia formed in stems, which would help prevent the build-up of inoculum in the field.

Products

Fungicide treatment may be required on seed crops at flowering or where a crop is prone to infection because site history or has suffered some form of damage. Incorporation of the biofungicide Contans (*Coniothyrium minitans* strain CON/M/91-08 (DSM 9660)) into the soil may decrease sclerotial populations where soil is known to be infested or after a crop has been heavily infected. This naturally occurring fungus colonises and deactivates soilborne sclerotia, which limits potential for infection. Amylo-X (*Bacillus amyloliquefaciens* D747) may also be used preventatively on both outdoor and protected crops. However, always check the label and/or consult with your agronomist for restrictions around the maximum number of applications, spray intervals and, in particular, the time of year for use in outdoor cropping systems.

Spear rot

Background

Spear rot (or head rot) of calabrese and broccoli can be a major cause of losses in the UK. Estimates of losses vary, but the most recent suggest average losses of around £3.7 million per annum.

Action points

- Select varieties with reduced susceptibility, particularly for late-season/autumn production
- Do not apply excessive nitrogen
- Consider minimising overhead irrigation, particularly reducing the frequency
- Avoid growing late crops in high-risk fields

Symptoms

Spear rot first becomes apparent as water-soaked blackening of individual florets (buds) (Figure 45). The lesions expand to produce larger blackened areas and a progressive soft rot of the whole head (Figures 46 and 47). Affected heads are completely unmarketable. Disease symptoms usually become apparent in the field as the crop approaches maturity or may develop after cutting.

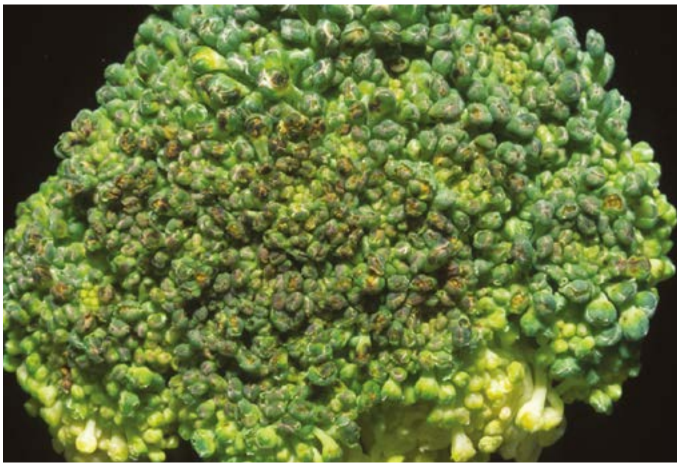


Figure 45. Initial dark water-soaked lesions on individual florets

Figure 46. Progressive rot of whole head

Figure 47. Cross-section of an affected calabrese head

The pathogen and biology

There has previously been some confusion about the cause of the disease: it is primarily caused by particular pectinase- and biosurfactant-producing strains of the bacterium *Pseudomonas fluorescens* (synonymous with *Pseudomonas marginalis*), belonging to LOPAT group IV. Pectinases are enzymes responsible for the soft rot of the tissues, and biosurfactants are wetting agents that enable the bacteria to get into the floret tissues. This was conclusively demonstrated during work at Wellesbourne in the late 1990s and also confirmed by scientists in Canada.

Another pectinase-producing bacterium, *Pectobacterium carotovorum* subsp. *carotovorum* (formerly *Erwinia carotovora*), is often isolated and has sometimes been described as the primary cause, but it is more likely that *Pectobacterium* is a secondary invader of rots already initiated by *Ps. fluorescens* or other pathogens, such as downy mildew or botrytis, or following physical damage from hail or frost, etc. Two key factors have contributed to the confusion: the addition of wetters in inoculation experiments and the inoculation, or production, of plant material for inoculation in protected environments.

Further difficulties in understanding of the disease arise due to the uncertainties with the taxonomy/nomenclature of pathogenic *Pseudomonas* strains. The ‘species’ *Ps. fluorescens* is actually a ‘species complex’ containing a number of quite different subtypes, many of which are non-pathogenic and may arguably be considered as distinct species.

Epidemiology

Pathogenic *Ps. fluorescens* strains have been found on commercial seed lots. It has also been shown that they can be seed-transmitted and then survive epiphytically (on leaf surfaces in the absence of symptoms) until heading. Although the bacterium is often reported as soilborne and 'ubiquitous', this has not been proven for pathogenic strains. While fluorescent pseudomonads, including *Pseudomonas fluorescens*, can be frequently isolated from the environment (including the soil), there is no direct evidence linking specific strains originating from soil with spear rot.

Thus, at the current time, the relative importance of seed and transplants as sources, versus other potential sources of the pathogen, is not clear.

Spread in the field most likely occurs via water or rain splash, and the disease is encouraged by overhead irrigation and soft growth. It seems to be particularly associated with periods of prolonged wet weather and so is more prevalent in late-maturing crops.

Control

Cultural control

AHDB Horticulture projects FV 104 and FV 104b showed that mulching reduced the levels of spear rot. This approach was based on the idea that the primary pathogen is ubiquitous in the soil, but this may not be the case, and it has not been taken up commercially.

High levels of nitrogen have been shown to increase levels of spear rot, but this effect may be variety-dependent. Thus it is important that growers do not apply excessive nitrogen.

A study in the US indicated that irrigation frequency, but not the amount of water applied, nor the timing, had an effect on the amount of bacterial head rot. Although these trials used *Pectobacterium carotovorum* as inoculum, it is possible that the same applies to *Pseudomonas*.

As the disease is associated with periods of prolonged wetness, it makes sense to select growing sites for later crops that are less sheltered and away from coastal areas that are prone to fog.

Hygiene

Given the potential for seed transmission and spread in transplants, good hygiene during plant-raising could play a role in disease management.

Varietal resistance

A number of studies have demonstrated differences in susceptibility amongst cultivars. For example, the variety Marathon (and likely its genetic derivatives) has significant levels of resistance, and it is likely that the popularity of varieties for late production is, to some extent, an indication that they are less susceptible. As well as tissue resistance, a number of phenotypic/agronomic traits may also have an effect on susceptibility, e.g. domed heads, tightness of buds. It is important to be aware that tests done on heads from plants raised under protection can give spurious results (more susceptible), due to the effects of the growing conditions on surface wax.

Figure 48. A good wax coating on the head that encourages beading of water droplets reduces susceptibility to spear rot

Virus management in vegetable brassicas

Background

There are five potential viruses of vegetable brassicas in the UK: turnip yellows virus (TuYV), cauliflower mosaic virus (CaMV), turnip mosaic virus (TuMV), turnip yellow mosaic virus (TYMV) and broccoli necrotic yellows virus (BNYV). Management of TuYV is the focus of this chapter. However, general principles centred on monitoring for aphids, cultural and chemical controls and management of insecticide resistance can be applied to all important viruses of vegetable brassicas.

Action points

For propagators

- Use of the Phyto-Drip precision-application system is an effective way of delivering treatment to seeds and growing medium blocks at the time of seed sowing

For growers

- Early infection of plants by TuYV reduces yield much more than later infections, therefore try to stop aphids, particularly the peach-potato aphid (*Myzus persicae*) feeding on plants
- Encourage natural predators through diverse field margins and minimised pesticide inputs
- Timing of insecticide application is critical, so pest forecasts should be used as a guide to spraying. Aphid migration predictions are freely available via the AHDB Pest Bulletin – combine this information with in-crop monitoring using water traps to get local information on aphid numbers and movements, which can help identify when to spray
- Natural plant resistance, integrated with cultural practices and use of chemicals to control vectors, is the best management strategy for virus management in vegetable brassicas

Turnip yellows virus (TuYV)

Turnip yellows virus (TuYV) belongs to the genus *Polerovirus* in the family *Luteoviridae*. There are 13 virus species in this genus, all of which are spread by aphids.

Importance

TuYV, formerly known as beet western yellow virus (BWYV), is the most important viral disease of vegetable brassicas in the UK. Annual sampling has shown that up to 72% of winged forms of the peach-potato aphid can carry TuYV. In oilseed rape, the virus can decrease yields by up to 26%, affecting both the seed production and oil content. Yield reductions of 22–65%, depending on the variety, have been seen in Brussels sprouts in the UK, with weight yield in Dutch white cabbage reduced by 16–22%, again depending on variety. Further losses in the marketability of infected cabbage have been caused by TuYV-induced tipburn. Tipburn in cabbage has contributed to significant losses in some years, including one study by the University of Warwick which reported a yield loss of 1,200 tonnes from one store alone in one year.

Distribution and incidence

TuYV is present throughout the UK, with particularly high levels in southern England and other areas where there is intensive brassica production, including Lincolnshire and Suffolk. Incidences of up to 100% of TuYV infection have been found in oilseed rape crops tested around the UK. A 2010 survey of TuYV infection in cauliflower and Brussels sprout crops in many areas of the UK revealed widespread infection in Lincolnshire, Lancashire, Yorkshire, Kent and Cornwall, in a year when few aphid vectors had been recorded. Lower levels of infection were detected in Scotland. The following year (2011), Lincolnshire experienced 96% TuYV infection in a field of Brussels sprouts five weeks after transplanting and 100% infection after a further two weeks.

The virus is well established in mainland Europe and has been detected in crops in most European countries, including France, Belgium, Germany, Poland, Ukraine, Denmark, Austria, Czech Republic and Serbia. It is also present in North America, China and Australasia. Although the full extent of its worldwide distribution cannot be confirmed, TuYV is clearly very widespread.

Host range

The crop host range of TuYV is very wide, including most brassica types (oilseed rape, cabbage, Brussels sprout, broccoli, cauliflower, kale, swede, turnip, and Chinese cabbage), radish, lettuce, spinach, peas, beans, courgette and rhubarb. It is also reported to infect a wide range of common weeds, including wild brassicas, wild radish, shepherd's purse, chickweed, mayweed, groundsel, dandelion, dead-nettle, speedwell and nettle. In addition to oilseed rape, weed hosts provide a significant overwintering reservoir of TuYV, threatening vegetable crops.

Symptoms

TuYV infection is associated with tipburn in cabbage. Externally, the heads look normal, but when cut open, breakdown of the leaf margin is apparent. This is characterised initially by grey-coloured papery tissue, becoming brown as it develops. Symptoms of tipburn are exacerbated when CaMV is present in combination with TuYV or TuMV. If the cabbage has a mixed infection of CaMV and TuMV, the internal disorders are more severe and losses can be as high as 65%.

In oilseed rape, infection can initially appear as purple or red tinging of leaf edges, with later symptoms (interveinal yellowing and reddening of leaf margins) usually expressed after stem extension (Figure 49). Infection can also cause stunting of growth. The signs of TuYV can be easily confused with frost damage, nutritional deficiencies or other stress symptoms. It is common for infected plants of both vegetable and arable brassicas, to remain symptomless, meaning that infection can go unnoticed throughout the growth period.

Figure 49. TuYV symptoms in oilseed rape

Life cycle and vectors

TuYV is transmitted by aphids in a circulative, non-propagative manner. It is spread by aphids, mostly the peach-potato aphid. These aphids are green, yellow or light red (Figure 50). Aphids acquire the virus from the phloem of infected plants. Infection of plants results from introduction of virus particles in saliva into plant phloem tissues via the salivary duct, during aphid feeding. This intimate relationship between the virus and its aphid vectors means that it takes aphids some time (c. 5 minutes) to acquire the virus from plants and slightly longer (c. 10 minutes) to transmit the virus to plants. However, once an aphid has acquired TuYV, it retains the ability to transmit the virus for the rest of its life, which can be more than 50 days.

Figure 50. Colour variation in the peach-potato aphid (*Myzus persicae*)

Risk factors

The prevalence of TuYV varies from year to year but tends to be relatively high in southern England and in areas of high brassica production, such as Lincolnshire and Suffolk. With more farmers delaying drilling and encouraging green stubbles to control black-grass, there is a higher risk of infection being spread to oilseed rape and vegetable brassicas. The large area of overwintered oilseed rape provides a massive reservoir of vectors, ensuring that the virus persists throughout the year and can go on to infect vegetable brassicas.

The earlier the infection, the greater the impact on yield. Risk of infection is higher when aphids are numerous, typically following mild winters and warm springs. Mild autumns also create favourable conditions for aphid migration and reproduction and, therefore, increase the risk of virus spread. Aphid activity is greatly reduced at temperatures below 3°C.

Management of TuYV

The reservoir of TuYV in oilseed rape crops means that it is very difficult to control the virus in vegetable brassicas. Currently, the only options are insecticide treatments targeted at preventing aphids transmitting the virus to crops, and growing less susceptible brassica varieties. Delaying infection of brassica plants by TuYV has been clearly shown to reduce weight yield losses and tipburn in cabbage.

Monitoring

Growers and agronomists should be alert to the potential for aphid movements into crops, especially where brassica crops or potatoes, that may have been hosting aphid populations, are burnt off or harvested. Monitoring should continue for as long as conditions remain conducive for aphid migration. For example, in the autumn, aphids will fly if temperatures are above 15°C but continue to move within crops at relatively low temperatures. Winter temperature is the primary factor affecting spring aphid migration behaviour of peach-potato aphid, with a 1°C increase in average winter temperature advancing aphid migrations by 4–19 days, depending on the species. Aphid migration predictions in the UK are freely available via the AHDB Pest Bulletin. This gives a good indication of migrating background populations, but in-crop monitoring with water traps is far more indicative of local numbers for better timing of treatments (Figures 51a and b). Field inspections should be made for the symptoms of viruses by cutting open and inspecting cabbage heads. Testing cabbages for TuYV in the field pre-storage by ELISA does not accurately estimate levels of tipburn symptoms in the crop.

Figure 51a. Water trap in field for aphid capture

Figure 51b. Water trap in field for aphid capture

Cultural controls

Most cabbage aphid infestations develop from colonies that overwinter on old brassica crops and autumn-sown oilseed rape. Plough in, or otherwise destroy, old crop residues to help reduce aphid populations. Cabbage crops intended for storage should not be grown in fields close to overwintering brassicas, especially oilseed rape, as these can be important sources of viruses, through aphid transmission.

Natural enemies can help control aphid numbers through predation and parasitism but may not prevent virus transmission. Ground beetles, soldier beetles, rove beetles and spiders may attack aphids in the autumn and winter, and parasitoids can be active in mild weather. In the summer, parasitic wasps, hoverflies, lacewings and ladybirds are attracted to aphid infestations and can provide control of potentially damaging populations. Use of diverse field margins and minimised pesticide inputs can also help increase natural enemies in field populations. Weed management, particularly of cruciferous weeds, is also important to reduce the risk of 'green bridge' infection.

Varietal resistance

The best control option for TuYV in vegetable brassicas is natural plant resistance to the virus. Results from studies at the University of Warwick have shown that in years with high aphid activity and a lot of TuYV infection, growers could double their profits by growing the least affected Brussels sprout variety rather than the most susceptible ones. Guidance on varietal resistance should be sought from the various seed companies. Natural plant resistance to TuYV has been identified at the University of Warwick and they are collaborating with a number of seed companies to develop TuYV- and TuMV-resistant vegetable brassica varieties. Past (NIAB) Descriptive Lists have rated winter white cabbage varieties for resistance to TuMV and CaMV. However, there is no independent trials data available for the full spectrum of current varieties used in the industry.

Chemical control

Peach-potato aphid is resistant to a number of active ingredients, and options for chemical control are limited. Timing of treatment is important. Preventing early infection of TuYV while plants are small is crucial for both maintaining yield and limiting storage losses. Loss of several active ingredients has caused concerns with regard to TuYV in long-growth-cycle brassica crops, such as storage cabbage and Brussels sprouts. Use of a seed treatment is the best way of controlling virus spread early on in the crop's life; it is these early infections that result in significant yield loss, as well as internal issues in cabbage. The introduction of the Phyto-Drip precision-application system, where a single drop of seed treatment solution is dripped onto each seed, has proven to be an effective way of delivering treatment to seeds and growing medium blocks at the time of seed sowing.

Shorter-season crops, including broccoli, are still regularly grown without a seed treatment and frequently require a full foliar programme. However, foliar sprays do not work as well at combatting the spread of TuYV.

Insecticide resistance management

There are three different mechanisms of insecticide resistance in peach-potato aphid in the UK: knockdown resistance (kdr) confers resistance to pyrethroids; modified acetylcholinesterase (MACE) confers resistance to carbamates (such as pirimicarb); and elevated carboxylesterase confers resistance to organophosphates. Neonicotinoid resistance in peach-potato aphid has been discovered in southern mainland Europe, but fortunately, to date (2019), no aphids in the UK have been identified with this form of resistance. Ongoing screening programmes in the UK have also shown no evidence of resistance to pymetrozine or flonicamid in *M. persicae* in the UK.

The Insecticide Resistance Action Group has issued guidelines for controlling aphids in brassica crops and combating insecticide resistance in the peach-potato aphid (**ahdb.org.uk/irag**). While pyrethroid sprays are available, they are highly likely to be ineffective, due to aphid resistance, and are more likely to harm beneficial insects in the crop. If an insecticide treatment is deemed necessary, products should be applied at their full label rate. Applying insecticides below label rates can lead to a subsequent increase in resistance problems.

Figure 52. Turnip Yellows Virus is largely symptomless but infections occurring soon after planting can cause significant yield loss and internal tipburn symptoms in storage cabbage

White blister

Background

White blister, caused by the oomycete pathogen *Albugo candida*, occurs frequently in vegetable brassica crops and has a widespread distribution, covering most vegetable brassica production areas in the UK. The impact of disease in these crops is of a cosmetic nature and can render crops unmarketable. In the UK, strategies to control the disease are largely based on routine spray programmes. White blister has a long incubation period between infection and appearance of disease. This means that success or failure of control is only apparent in some cases weeks after fungicide applications. This can lead to white blister becoming well established in crops before the disease is really visible.

Action points

For propagators

- Regular crop monitoring by glasshouse staff and advisers is required to detect the early stages of the disease
- Scheduling overhead irrigation in the morning, as opposed to in the evening, can reduce disease incidence

For growers

- Use healthy transplants
- Symptoms of white blister infection can occur within three days, but up to 14, after infection, depending on the environmental conditions; no symptoms will occur at temperatures below 8°C
- Monitor crops regularly and be aware of potential for spread of white blister from infected crops to nearby fields
- Cultivars of Romanesco cauliflower, Brussels sprouts and broccoli are available, showing at least partial resistance to white blister infection
- Brassica Alert provides valuable notification of risks to better manage spray timing. It is managed by the Allium and Brassica Centre and available to all growers as text alerts, through the Syngenta UK website
- Several fungicide treatments are likely to be required to maintain protection. Control is difficult to achieve if the disease becomes well established in the crop

Symptoms

White blister symptoms first appear as yellow spots on leaves, which eventually become white in colour (Figure 53). On older leaves, the yellow spots may not develop further and white lesions are not formed. Infected tissues can become distorted, especially when immature. This facilitates spore dispersal as infected tissues are more exposed to air streams within the crop. Hollows in leaves also aid dispersal by creating funnels, which are important because the airborne spores of white blister are relatively large and need help to become airborne over wider areas. White blister infects young, immature tissue and this is the reason that on some older leaves the white lesions are not readily formed. The maturity of the tissue also affects the time between infection and symptom appearance. Once tissues are mature, they do not show symptoms. If symptoms occur on inflorescences, they can result in distortion of tissues – a symptom which is often referred to as 'stag's head' (Figure 55). Stag's head can result in significant yield loss in seeding crops, on head brassicas such as broccoli and on Brussels sprout buttons. Oospore (the sexual spore form) formation may occur on inflorescences or on tissues showing stag's head symptoms. Oospores can germinate directly on the plant by germ tube formation or by zoospore release. It is common for white blister to form systemic, asymptomatic infections that are not visible for long periods of time. Downy mildew (*Hyaloperonospora parasitica*) sometimes grows on white blister lesions and can confuse diagnosis. Small root galls may develop on radish. Infection with white blister has been shown to suppress host defences and increase the likelihood of secondary infections by other diseases such as sclerotinia.

Figure 53. White blister lesions on cabbage

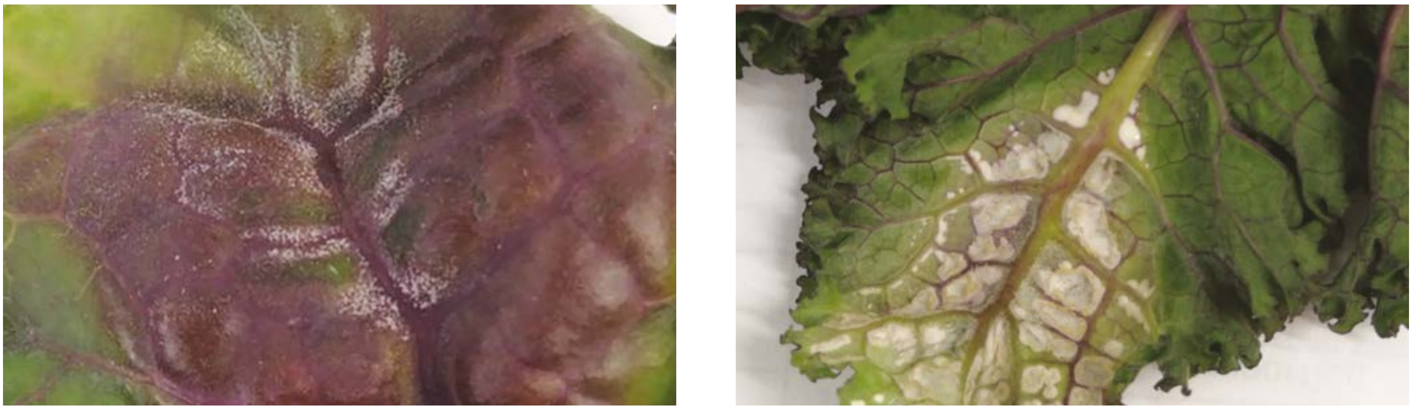


Figure 54. White blister symptoms on the underside and upper leaf surface of kale

Figure 55. White blister infection on broccoli can cause significant yield losses

Figure 56. Symptoms on the upper leaf surface and underside of mustard (*Brassica juncea*)

Epidemiology

To date, more than 24 distinct biological races of *A. candida* have been identified and classified based on host specificity. Race 9 has been identified as the primary cause of infection in vegetable brassicas. Strains affecting radish are unlikely to affect leafy brassicas. White blister is common on various cruciferous ornamental species and weeds, such as shepherd's purse, but this strain does not infect vegetables.

Disease outbreaks are initiated from oospores in soil or plant debris, though during the growing season airborne spores are likely to be more important in the spread between nearby crops. White blister, like other pathogens of vegetable brassicas, requires free water for infection by the zoospore (the main infective propagule). Once the disease is established, relatively short dewfall periods can be very favourable for white blister development. High temperatures result in relatively short periods of time elapsing between infection and symptom appearance on the plant. This is dependent on the temperature at which the plants are grown. The optimal temperature for spore development is around 20–25°C, when symptoms can occur within three days of infection; below 8° C, symptoms do not develop. This explains why white blister is not prevalent in Scotland and many northerly areas of vegetable brassica production. Results indicate that epidemics will not develop in areas with cooler daily average temperatures because there is not sufficient time for white blister symptoms to occur.

Life cycle

The life cycle of white blister is quite complex (Figure 57) with both a sexual and an asexual stage. In the UK, the sexual stage is not often observed but may be present, within lesions associated with specific environmental conditions. In Australia, white blister (Race 9) sexual stages are sometimes observed as galls on the stems of seedlings. The asexual stages are commonly called zoosporangia and are the white spores most commonly associated with white blister lesions. Zoosporangia germinate in the presence of free water to release zoospores. However, zoospore release is not associated with high temperatures and occurs more frequently if the water is at approximately 4˚C. Released zoospores quickly stop moving if the temperature of the water rises above 10˚C. For these reasons, white blister infection is frequently associated with dew on the crop. Infection of immature tissues occurs within four hours at temperatures of 10–24˚C. Infection rarely occurs below 6˚C or above 26˚C. No symptom expression occurs at 8˚C or below. The time between infection and symptom appearance is approximately 2–3 days at a constant temperature of 20˚C, but can be up to 14 days at 10˚C.

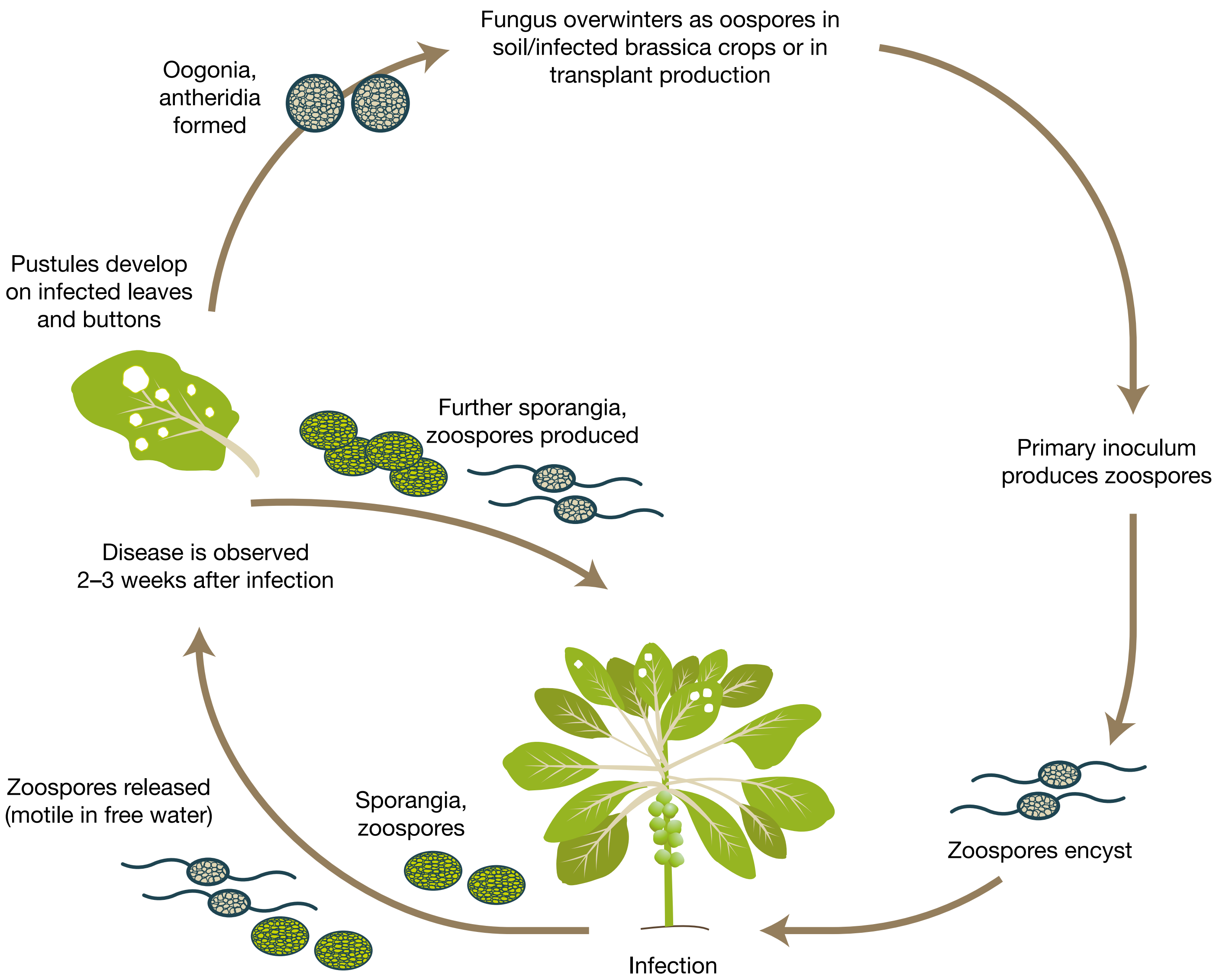


Figure 57. Life cycle of white blister on vegetable brassicas

Control

Monitoring

Regular crop monitoring is required to detect the early stages of the disease. Infection models have been developed, such as BrassicaSpot, which are used to predict the length of the incubation period, determine when infection periods begin and when infection is no longer possible during the growing season. Spore thresholds have been developed for white blister and, when used in conjunction with in-field air samplers to identify white blister spores, can help growers make informed decisions on when to apply the appropriate fungicide sprays. This information has been incorporated into a disease warning model called Brassica Alert, which is managed in field by the Allium and Brassica Centre and is available to all growers as text alerts, through the Syngenta UK website.

Cultural controls

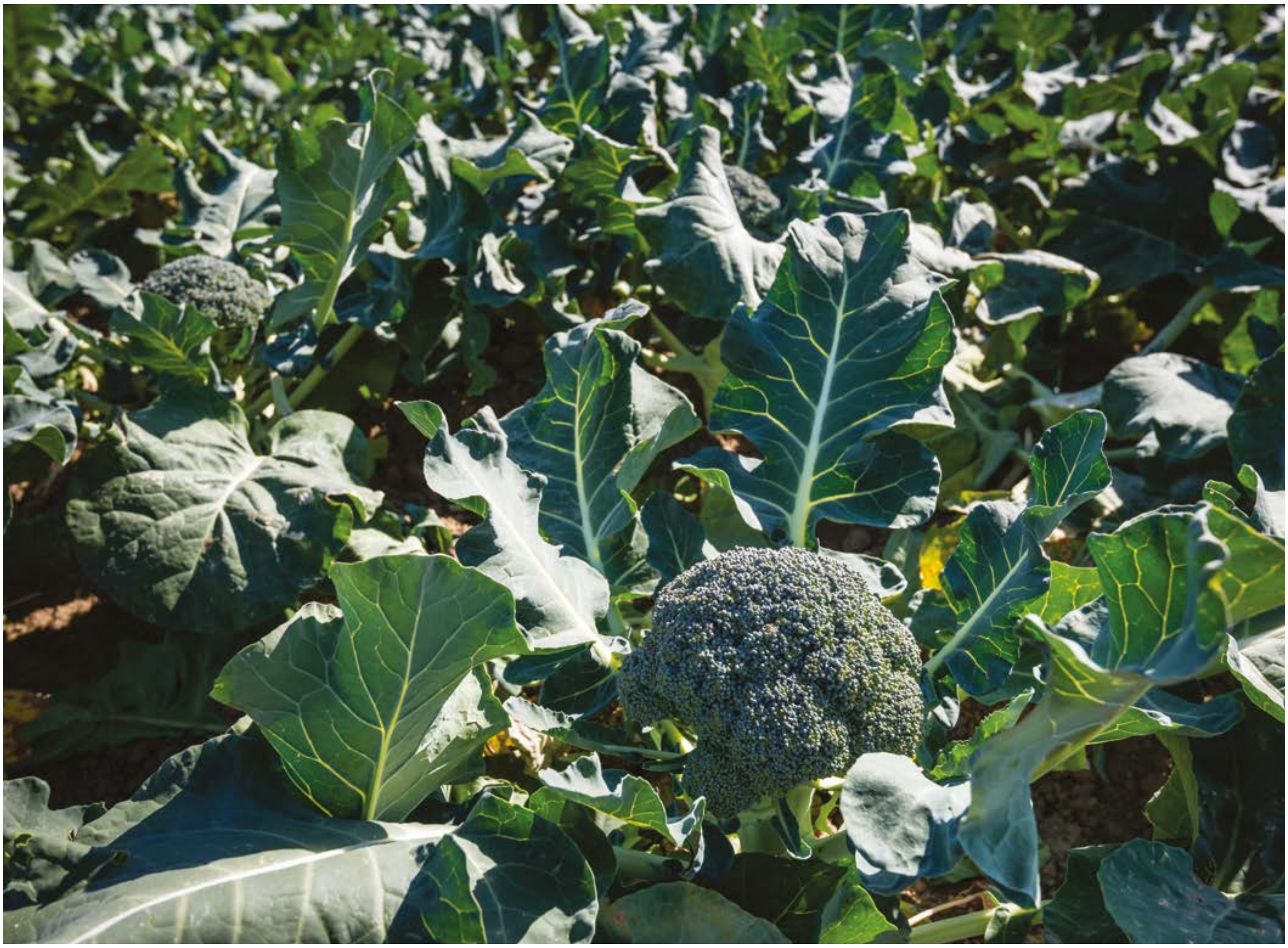
White blister is occasionally found on transplants. In glasshouse production, scheduling overhead irrigation in the morning, as opposed to in the evening, can reduce disease incidence.

Varietal resistance

There are a number of Romanesco cauliflower, Brussels sprouts and broccoli cultivars available offering at least partial resistance to white blister infection. Previous testing in the UK with Brussels sprouts (cv. Adonis), broccoli (cv. Shogun), cauliflower (cv. Belot), red cabbage (cv. Rodon) and savoy cabbage (cv. Tarvoy) showed little variation in infection or in time to symptom development. This indicates that races found on vegetables in the UK may be able to infect all brassica types. Other races of white blister in other areas of the world may have specific host ranges. Given that only immature tissues can become infected, it is likely that varieties differing in growth habit might vary in their susceptibility to white blister infection. For this reason, early-season cultivars of Brussels sprouts may have a higher chance of becoming infected with white blister. Also, early-season cultivars usually grow at times of the year when environmental conditions are more favourable for white blister infection.

Products

Several fungicide treatments are likely to be required to maintain protection against white blister. Brussels sprouts and cabbage are most at risk. Control is difficult to achieve if the disease becomes well established in the crop.



Notes

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