Diseases of lettuce crops

HORTICULTURE

Contents

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Introduction

This manual covers fungal and Oomycete disease of lettuce. The extent of losses caused by these diseases to lettuce crops varies considerably according to the disease type, method of crop production, lettuce variety, season and other factors. Many lettuce diseases can cause considerable damage and occasionally complete crop loss.

Some disease types such as downy and powdery mildews can spread very quickly to affect most plants in a crop. Others such as sclerotinia and ring spot tend to remain localised. A few pathogens, notably *Fusarium oxysporum* and *Sclerotinia* spp., can persist in soil for many years.

Management of lettuce fungal diseases differs greatly between outdoor crops, usually grown on a long rotation, and protected crops (permanent glasshouse or polytunnel structures), often grown intensively with 6–8 crops/year on the same land. The cropping and disease history of a site are key considerations for outdoor production. Strict attention to hygiene is critically important in protected crop production. If a serious soil-borne pathogen becomes established in a soil under permanent protection, it may become necessary to disinfest the soil, or to grow crops in a hydroponic system isolated from the soil.

Although protected cropping gives shelter from rain and wind, elements that commonly influence disease development, warmer temperatures and high humidities often promote the growth of pathogens (e.g. fusarium wilt, downy mildew). Once a disease is established in a protected crop, it can cause more damage more rapidly than in an outdoor crop. Watering, ventilation and heating all need to be carefully managed in protected crops to ensure that moisture does not remain on leaves for prolonged periods.

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A well-controlled protected environment can be very effective in management of some diseases by reducing occurrence of spore germination and/or infection.

Production in hydroponic systems is attracting increased interest. It offers greater output (more crop cycles per year), and enables better hygiene between crops; the difficulty of managing soils contaminated by species of *Fusarium, Rhizoctonia* or *Sclerotinia* is no longer a problem. However, crops grown in hydroponic systems are not immune to root-infecting pathogens, and the risk of widespread outbreaks of some diseases (e.g. pythium and phytophthora root rots) is increased.

Although disease resistance is rarely the primary consideration when choosing a variety, it should be given a high priority with regards to downy mildew. A variety with Bl resistance genes effective against the most recent prevalent strains of *Bremia lactucae* is an essential component of downy mildew management. When combined with a suitable fungicide programme, this integrated approach has proven to be very effective in minimising the risk of new metalaxyl-resistant strains

arising. Varietal resistance or tolerance also appears to be a promising tool for future management of fusarium wilt, with new varieties currently being developed. However, for many of the fungal diseases affecting lettuce, there are no commercially-acceptable resistant varieties in the breeding pipe-line. The structure of a lettuce plant can influence disease risk; for example, dense, 'frilly leaf' types are particularly susceptible to botrytis (grey mould).

Season and weather greatly influence risk of fungal and Oomycete diseases. Downy mildew is most prevalent in the autumn when large day/night temperature differences result in condensation of water on leaves. Grey mould is a problem in persistent wet weather. Ring spot is favoured by rain (or overhead irrigation), with water-splash of the causal fungus from soil to plant and subsequent spread by wind-driven rain. Fusarium wilt requires high soil temperatures for infection, and the greatest risk of this disease in the UK is in protected crops from early summer to late autumn.

The life-cycles and critical control points for the various fungal and Oomycete diseases of lettuce are very different. Furthermore, the most appropriate actions may vary according to the cropping situation. This booklet summarises the main control strategies for each of the most common diseases of outdoor and protected lettuce.

Key messages

Lettuce crops can be attacked by several fungal and Oomycete diseases, the principal ones being downy mildew, grey mould and sclerotinia. Other diseases can be very damaging in certain cropping situations, either regularly or occasionally, such as ring spot, powdery mildew and pythium root rot. Fusarium wilt was confirmed at two UK nurseries for the first time in 2017 with further cases identified in 2018; this disease particularly threatens protected lettuce grown in the soil. This manual does not cover bacterial diseases, viral diseases or disorders.

- Many fungal diseases can develop and spread very quickly. Construct a preventative fungicide programme for diseases that occur on your site. Monitor crops regularly and adjust the fungicide programme, if necessary, according to the results of crop inspections
- Strict attention to hygiene is most important in reducing the incidence of diseases, especially in protected crops. Crop debris should be removed as thoroughly as practical and the internal structure of glasshouses and polytunnels and concrete pathways should be treated with a suitable disinfectant. The whole irrigation system, including tanks, of hydroponic crops should be flushed through with a disinfectant and/or consider alternative disinfection methods such as UV light
- Plants need protection against disease from the start. Liaise with your seed supplier to check the health status of seed batches and with the propagator(s) producing your plants; specify treatments to be applied during propagation. Carefully inspect plants for disease when they arrive, before planting. If you are suspicious there may be a problem, have the plants tested, do not plant them
- Soil disinfestation treatment may be necessary to reduce inoculum of soil-borne pathogens, particularly for protected crops
- Be aware of the potential for resistance to fungicides, particularly in downy mildew and grey mould. Try wherever practical to use fungicides from different mode of action groups to reduce the potential for fungicide resistance developing
- Where fungicides are used, take great care in their selection and use to ensure maximum efficacy, cost-effectiveness, and minimal side effects on natural enemies and to avoid unsightly deposits, crop damage, or detectable residues above maximum residue levels (MRL) at harvest
- Management of fungal diseases in organic crops is a particular challenge because of the lack of effective biological options. Cultural control is central, including use of more tolerant varieties, crop rotation and less-intensive cropping

Downy mildew

This is probably the most important foliar disease of lettuce. It occurs in both outdoor and protected crops and can attack all lettuce types. In protected crops it has been known to cause complete crop failure. The causal Oomycete is a complex pathogen with many strains (pathotypes).

Symptoms

The disease appears first as pale-green or yellow angular patches, often delimited by major veins, on the older leaves.

Under cool, moist conditions, copious white sporulation may occur on the lower leaf surface. With time, the lesions turn brown and dry up. Secondary infection by grey mould can occur on damaged leaves, especially those in contact with the soil.

The disease causes reduced yield and quality, and extra work when affected leaves need to be trimmed from the harvested heads.

Biology

Downy mildew is caused by *Bremia lactucae*, an obligate Oomycete parasite (i.e. an organism that only grows on living plant tissues). Asexual spores, seen as white growth on the lower leaf surface, are the dispersal spores. Sexual oospores have been reported occasionally in lettuce but their role in disease epidemiology is uncertain.

Different pathotypes attack different lettuce varieties according to the downy mildew

Figure 1. Downy mildew (*Bremia lactucae*) on outdoor crisphead lettuce

Figure 2. Sporulation of downy mildew on leaf underside

resistance gene complement in a variety. The different pathotypes are identified by testing their virulence on differential sets of various varieties having different resistance genes. The strains identified are numbered, denoted in Europe as Bl: 1EU, Bl: 2EU, etc. (Bl for *B. lactucae*). In 2018 the strain numbering had reached Bl: 35EU; the latest two races reported (Bl: 34EU and Bl: 35EU) were both detected in the UK (**www.rijkzwaan.com.au/news**).

Humid, cool conditions (15–20°C) are optimal for downy mildew development.

In outdoor lettuce the disease is most important in early autumn but it also attacks overwintering lettuce. In protected lettuce the disease can occur at any time of the year, but especially in early autumn. The dispersal spores, which are spread by wind, are relatively short-lived. Infection takes place in only 3–4 hours if there is moisture on leaves or near 100% relative humidity and temperatures are conducive (10–22°C).

Non-chemical methods of control

Use resistant varieties. Keep up-to-date with information on new Bl strains and seek to use varieties which include resistance to these strains. Carefully check transplants on arrival, so that downy mildew is not brought onto the site being planted. In protected lettuce especially, good management of watering and control of the aerial environment to avoid prolonged periods of leaf wetness and high humidity will greatly aid control. Rapid destruction of infected plant tissue after harvest and bagged removal from the site will help prevent disease spread.

Figure 3. Chlorotic and necrotic angular lesions of downy mildew

Fusarium wilt

Reported in Europe (Italy) in 2002, this seed and soil-borne disease was first confirmed in the UK (Lancashire) and Ireland in summer 2017, where it caused serious losses in several glasshouse crops.

Symptoms

Infection in seedlings causes wilt, and in older plants it causes leaves to yellow, wilt and turn brown. The vascular system in the stem turns reddish-brown. Plants are usually stunted and may fail to heart.

Biology

Lettuce fusarium wilt is caused by *F. oxysporum* f. sp. *lactucae* (FOL). UK outbreaks in 2017 were all identified as race 4, a race which has previously been found in the Netherlands and Belgium, where it has caused major losses in protected crops. Further UK outbreaks occurred in 2018 at new sites in Lancashire, Cambridgeshire and in Ireland. FOL race 1 is common in southern Europe, for example in Italy, affecting both outdoor and protected crops. Like other fusarium wilt pathogens, FOL can survive in the soil for long periods of time. The soil-borne population will slowly decline, over years, if the ground is cropped with non-hosts or left fallow. Seed-borne infection has been confirmed and is likely to account for long-distance spread, although soil-borne inoculum is likely the most common source of the disease. The disease tends to be more severe in lettuce planted in the warmer summer months, but significant infection can occur at soil temperatures as low as 15°C at 10 cm depth. The minimum and maximum temperatures for FOL race 4 have not yet been determined. Further details on lettuce FOL can be found on the AHDB website.

Figure 4. Leaf yellowing and wilting caused by lettuce fusarium wilt (*F. oxysporum* f. sp. *lactucae*)

Figure 5. Vascular discolouration of fusarium wilt

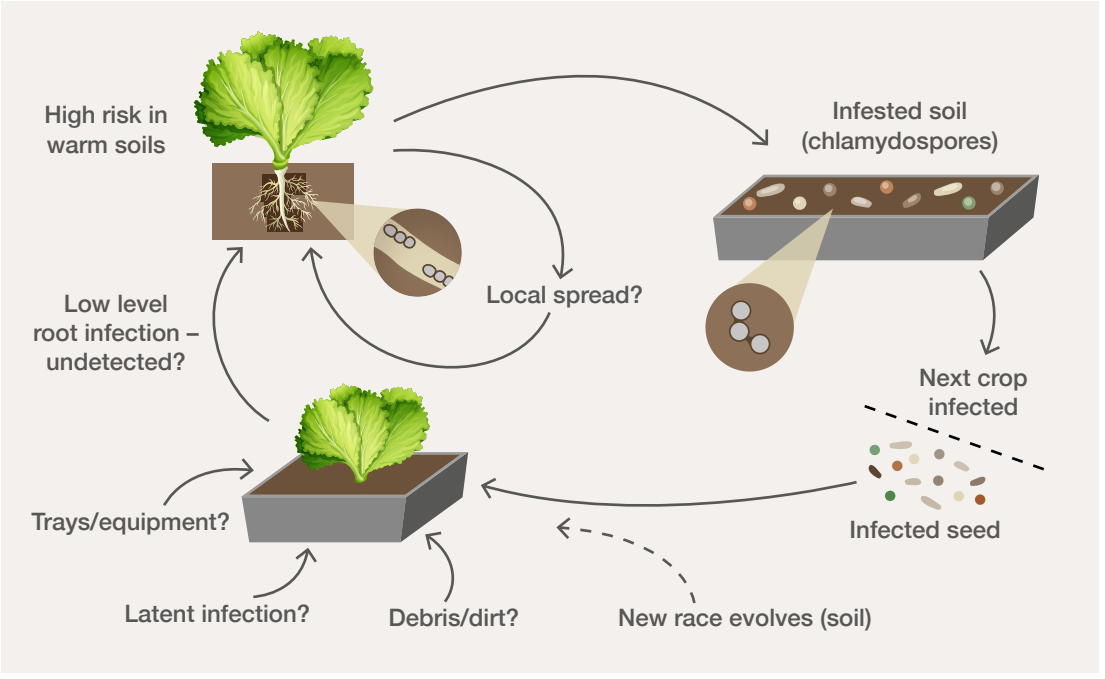

Figure 6. A proposed life cycle of lettuce fusarium wilt

Non-chemical methods of control

Avoid planting lettuce in soils known to be infested with FOL, or plant lettuce in these locations only in the winter when symptoms are likely to be less severe. If available, plant tolerant or resistant varieties. Partial resistance to race 4 is available in some outdoor butterhead, Lolla Bionda, Lolla Rossa, Multileaf, Oakleaf, Romaine, Batavian and Crunchy types. Resistant butterhead types for protected cropping are not yet commercially available although on-farm testing of promising new varieties is underway.

Take precautions to minimise the movement of contaminated soil (e.g. on farm equipment) between sites, fields, cropping glasshouses and propagation areas. For protected crops, consider soil disinfestation (e.g. steaming) or conversion to a hydroponic system.

Note that infection can still occur in hydroponic crops, but disinfestation between crops is generally easier than for soil-grown crops. Crop rotation with non-hosts (e.g. Pak Choi) or leaving the soil fallow will help reduce build-up of FOL race 4 in soil.

Grey mould

Grey mould is a relatively common but usually minor disease of outdoor lettuce; it is most prevalent in spring on overwintered lettuce. In protected crops the fungus can cause serious losses in crops planted in autumn and winter.

Symptoms

Grey mould is identified by the furry grey or brown mould usually affecting the lower leaves. Damaged or ageing leaves in contact with the soil are most susceptible. The fungus uses such tissues as a food base from where it may progress into upper leaves and the stem base, causing wilt and eventually collapse of individual plants. With time, the fungus produces small dark-brown to black resting bodies (sclerotia).

Basal rot caused by grey mould can be confused with that caused by both *Sclerotinia* and *Rhizoctonia* species, and if there is any doubt it is advisable to seek a confirmatory diagnosis.

Biology

The causal agent of grey mould is *Botrytis cinerea*. The fungus survives in crop debris and as sclerotia in the soil. Dispersal spores (conidia) develop on these sources and become wind-borne. It is generally regarded as an opportunist pathogen that gains entry following physical damage (e.g. frost or tip burn), damage from other diseases (especially downy mildew) and on ageing leaves. The fungus can develop over a wide range of temperatures but is most active under cool (12–15°C) humid conditions. There is generally increased grey mould risk in spring outdoor crops under fleece where increased humidity and frost damage provide ideal conditions for infection.

Non-chemical methods of control

Seek to minimise physical damage caused at planting, by cultural practices, environmental extremes, or other pathogens and pests. Reduce leaf wetness duration by careful timing and method of irrigation. Remove or incorporate previous crop residues before planting. Avoid using large transplants as these are prone to more leaf damage during planting, and hence are more susceptible to infection. Planting over polythene or other soil cover can reduce infection from the soil in protected crops. Increased plant spacing to improve air movement around plants may also reduce risk.

Figure 7. Grey mould (*Botrytis cinerea*) basal rot showing typical furry growth of this fungus

Figure 8. Plant collapsed due to grey mould in a protected crop

Phoma leaf spot and basal rot

An occasional and usually minor problem of protected crops in the UK. It has been reported affecting outdoor crops, especially Romaine lettuce, in California.

Symptoms

Circular dark-grey to black spots, up to 3 cm diameter, occur on lower leaves. With time, the inner tissue dries, cracks and falls out, leaving a shot-hole symptom. Stem base infection results in wilting and yellowing on lower leaves, one-sided plant growth, stunting and eventually plant collapse from a mealy dry basal rot. Fruiting bodies (pycnidia) may be seen in the leaf spots. In contrast to grey mould and sclerotinia, there is no visible fungal growth at the base of plants. The leaf spot symptoms are not always present with this disease.

Biology

The causal agent of phoma leaf spot and basal rot is *Phoma exigua*, a soil-borne fungus. The disease is more common during the winter months. Although information on disease epidemiology is lacking, observations indicate infection is favoured by wet conditions.

Figure 9. Leaf spot symptom caused by *Phoma exigua*

Non-chemical methods of control

Avoid over-irrigation and minimise water splash.

Figure 10. Vertical section of lettuce crown showing stem base rot caused by *Phoma exigua*

Powdery mildew

Powdery mildew is an occasional problem on outdoor and protected lettuce which has been seen more frequently in recent seasons.

In dry weather in summer and in hydroponic crops powdery mildew can rapidly become widespread and cause significant reductions in crop quality.

Symptoms

This disease appears as a white powdery growth affecting both upper and lower leaf surfaces. Small brown sexual fruiting bodies (chasmothecia) are occasionally seen in leaves in the autumn. Older leaves are infected first and show the most severe symptoms. Initially the disease results in a lack of leaf lustre; severe infection results in leaf yellowing, deformity, and ultimately necrosis.

Biology

Lettuce powdery mildew is caused by *Golvinomyces cichoracearum* (previously named *Erysiphe cichoracearum*). Although this fungus is reported to infect over 150 plant species, and cross-infection between host species is known to occur, there is evidence that distinct strains are better adapted to certain host species. Initial inoculum arises from airborne asexual spores (conidia) or sexual spores (ascospores). The optimum temperature for growth of the fungus is 18–20°C. Spore infection requires a high humidity (c. 95% RH); free water on leaves may inhibit germination.

Non-chemical methods of control

Varieties differ in susceptibility so where this disease is a problem select more resistant varieties.

Figure 11. Powdery mildew (*Golvinomyces cichoracearum*) sporulation on leaf upperside

Pythium diseases

Pythium root rot is primarily a problem in hydroponic crops and is sometimes very destructive. Pythium basal rot is an occasional problem in winter crops of soil-grown protected lettuce.

Symptoms

In hydroponic systems pythium root rot starts on the youngest roots, where the causal organism generally infects root hairs and tips. Initially roots are colonised extensively without development of overt symptoms. Later, this symptomless biotrophic phase (nutrients absorbed from living tissue) may switch to a necrotophic phase where roots become grey-brown or reddish-brown and ultimately necrotic. Symptoms in the lettuce head include temporary wilting, associated with high daytime temperatures, and stunted growth. Usually, all or most plants in the batch are affected.

In soil-grown protected crops, pythium basal rot becomes evident as a slimy, black wet rot affecting the lower leaves and stem base.

Figure 12. Pythium root rot (*Pythium* sp.) causing root browning, leaf yellowing and stunted growth

Biology

A number of different *Pythium* species are causal agents of root rot in lettuce and other hydroponic vegetable crops. Principal species in hydroponic systems include *P. aphanidermatum*, *P. dissotocum*, *Pythium* group F and *P. ultimum* var. *ultimum*. Primary infection may arise from survival spores (oospores) or fungal strands (mycelium) in plant residues, soil, hydroponic pipes and tubing, or other sources. Swimming spores (zoospores) produced from sporangia formed by the oospores are the principal means of pathogen spread in the circulating nutrient solution. Mycelial fragments are the principal inoculum for some species (e.g. *P. ultimum* var. *ultimum*) which produce no or few zoospores. Fungus gnats and shore flies may introduce *Pythium* spp. to a system. *Pythium* spp. may also be introduced on the young plants at planting.

Factors influencing initial pythium infection and its progression from symptomless infection to obvious disease appear to be numerous and are not well understood.

In pythium basal rot of soil-grown lettuce, it is likely that infection arises from the soil. There is often abundant production of resting spores (oospores) in affected tissues which will be returned to the soil as these leaves rot.

Non-chemical methods of control

Potential control measures include reducing levels of initial inoculum, such as sanitation between crops, hygiene during plant propagation and exclusion of insect vectors. Practices to reduce rates of pythium dispersal and root rot increase include disinfestation of the circulating nutrient solution, addition of biocontrol microorganisms, enhancement of endemic biocontrol microorganisms, addition of surfactants (i.e. detergent) to break down zoospores and control of the microclimate to minimise environmental stresses that enhance pythium (e.g. high temperatures). Research work is required to determine the efficacy of these potential disease management practices in hydroponic lettuce crops. For more information, see AHDB Factsheet 22/15 ***Methods of water treatment for the elimination of plant pathogens***.

Rhizoctonia bottom rot

This disease is generally a minor problem in outdoor crops but it can cause serious disease in soil-grown protected crops.

Symptoms

Infection typically occurs as the heads begin to form. Red-brown sunken lesions form on leaf midribs in contact with the soil. Fine mycelial strands may be seen between successive leaf layers as the causal fungus penetrates into the head and may also be visible on the soil surface. Occasionally small brown sclerotia are present. If conditions are favourable, lesions enlarge and the lower leaves rot. Symptoms are most evident near plant maturity when, if combined with secondary decay organisms, a very soft slimy decay of the base occurs.

Biology

This bottom rot is caused by the soil-borne fungus *Rhizoctonia solani*. The fungus survives as sclerotia and mycelium in crop debris and the soil; there are no spores involved in the disease cycle. Rhizoctonia bottom rot is favoured by warm, moist soil conditions, although it can also occur under cool moist conditions in overwintered protected crops.

Non-chemical methods of control

Rotate lettuce with non-host crops to reduce soil inoculum. Avoid over-irrigation late in crop development so that the bed tops are relatively dry. Consider planting through polythene to isolate lower leaves from the soil during high-risk periods (e.g. autumn). Varieties with a more upright growth habit are less susceptible.

Figure 13. Bottom rot (*Rhizoctonia solani*); note the fungal webbing typical of this disease between successive leaf layers

Ring spot

Ring spot, also known as anthracnose, affects both outdoor and protected crops. If weather conditions favour disease development it can cause widespread losses in outdoor crops, particularly on Romaine varieties.

Symptoms

Broadly circular spots (3–7 mm diameter) occur on the outer leaves and elongated spots, resembling slug damage, on the leaf midribs. These spots are initially small and water-soaked, turning yellow as they enlarge and finally tan-coloured. As spots on the leaf lamina age, the lesions become papery and eventually the centres fall out resulting in shot-hole symptoms. If the disease is severe, lesions may coalesce causing leaf dieback and sometimes stunting of plant growth. The disfiguring symptoms mean that even slight infection downgrades the value of the crop.

Biology

The causal fungus is *Microdochium panattonianum*. The fungus may be carried on seed but the usual source is microsclerotia in plant debris and soil. Endive and chicory may also be affected and serve as sources of inoculum.

The fungus can survive in soil for up to four years as microsclerotia.

The pathogen requires wet conditions for infection and symptom development. Splashing water moves microsclerotia and conidia from soil onto leaves resulting in infection. Optimum temperature for disease development is 18–20°C. With wind-driven rain the disease can quickly become very serious.

In protected crops the disease is most often found under vents or slipped glass where rain may enter or under dripping gutters.

Non-chemical methods of control

Avoid planting lettuce for at least 4 years on fields with a history of the disease. Rotate with non-hosts to reduce soil inoculum. Use irrigation systems that reduce or eliminate leaf wetting.

Figure 14. Ring spot (*Microdochium panattonianum*) causes sunken brown lesions on both lamina and petiole

Sclerotinia

Sclerotinia can be a serious problem in both outdoor and protected lettuce crops.

It is often a patchy disease but if severe most of a planting may be lost. The disease is caused by two species of *Sclerotinia* which are distinguished by the size of their sclerotia: *S. minor* with small sclerotia (3–5 mm) and *S. sclerotiorum* with larger sclerotia (5–10 mm).

Symptoms

S. minor only infects lettuce stems and leaves in contact with the soil. Infection causes a soft, watery decay of the lower leaves and crown. Outer leaves wilt and the whole plant may collapse, usually when the lettuce is near maturity. White fungal mycelium and small, black, irregularly shaped sclerotia form in the affected tissues.

S. sclerotiorum causes symptoms similar to those of *S. minor*. In addition, aerial-dispersed spores can infect upper parts of plants. Profuse white fungal mycelium and black, generally oblong, sclerotia develop in affected tissues.

Biology

S. minor completes its life-cycle in the soil with no aerial spore stage. Germinating sclerotia need to be within 2 cm of a senescing leaf or a taproot for infection to occur. By contrast, *S. sclerotiorum* has an aerial spore stage. Aerial spores are usually produced in the spring and early summer from fruiting bodies (apothecia) that develop from sclerotia left in the soil after previous crops, either lettuce or other hosts (e.g. oilseed rape, potato). *S. sclerotiorum* has a very broad host range, whereas *S. minor* has a relatively narrow host range. Sclerotia of *S. sclerotiorum* and *S. minor* can remain

Figure 15. Collapsed lettuce plant infected by *Sclerotinia minor*; note the small black sclerotia on rotted leaves and soil surface

Figure 16. Rotted lettuce crown following infection by *Sclerotinia sclerotiorum*; note the large sclerotia at the stem base

viable in soil for several years, dependent on soil condition, moisture and depth of burial. Secondary spread by mycelium can also occur, when there is direct contact between diseased tissue on one plant and healthy tissue on an adjacent plant. There is a wide literature on sclerotinia diseases, for example AHDB factsheets for brassicas, carrots, peas and beans.

Non-chemical methods of control

Avoid planting lettuce crops after a severely affected crop or in fields with a history of sclerotinia on any host in recent years. Practice crop rotation with non-host crops, though bear in mind this will not necessarily prevent disease due to risk of airborne *S. sclerotiorum* spores blown-in from other fields. Ascospores require very high humidity to germinate, so good humidity control will reduce risk in protected crops. Research has shown that incorporating biomass from brassica cover crops or waste from broccoli crops can reduce soil inoculum and subsequent disease caused by *S. minor*. Forecasting systems for *S. sclerotiorum* risk in oilseed rape are well developed, as well as monitoring of spore release from apothecia, and may help define high risk periods for lettuce crops and inform spray-timing of fungicides (see for example AHDB Cereals website and BASF website). The mycoparasite *Coniothyrium minitans*, which destroys sclerotia in soil, has shown some promise when incorporated pre-planting, especially against *S. sclerotiorum*, and is marketed as the biofungicide Contans WG (*Coniothyrium minitans* strain CON/M/91-08). Deep ploughing to bury sclerotia below the root zone is helpful in reducing risk where there is a long rotation between lettuce crops.

Minor diseases

A number of other fungal or Oomycete diseases have been recorded very occasionally on lettuce crops in the UK including:

Alternaria leaf spot (*Alternaria* sp.) on field lettuce (eastern England)

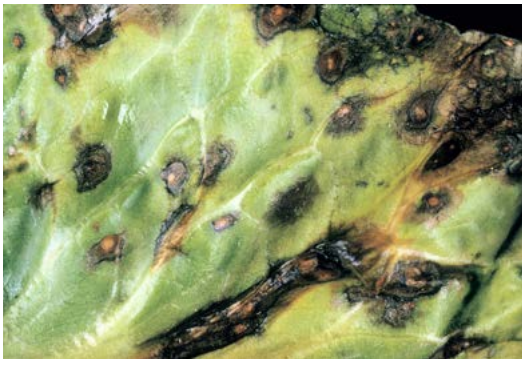

Figure 17. Alternaria leaf spot (*Alternaria* sp.)

Mycocentrospora leaf spot (*Mycocentrospora acerina*) on field lettuce (southern England)

Figure 18. Mycocentrospora leaf spot (*Mycocentrospora acerina*)

Phytophthora root rot (*Phytophthora* sp.) on hydroponic lettuce

Figure 19. Phytophthora root rot (*Phytophthora* sp.) in a hydroponic crop

Pleospora leaf spot (*Pleospora herbarum*) on field lettuce (West Cornwall)

Figure 20. Pleospora leaf spot (*Pleospora herbarum*)

Septoria leaf spot (eastern and north western England)

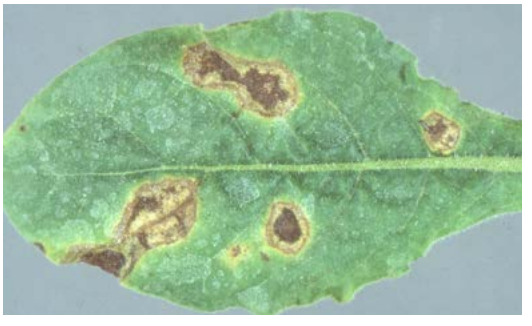

Figure 21. Septoria leaf spot (*Septoria lactucae*)

Whole crop IDM

Integrated disease management (IDM) combines biological, cultural and genetic control with minimal use of chemical fungicides necessary for effective disease management. Cultural control and resistant varieties play a major role in lettuce IDM. Biological control of lettuce diseases is still in the early stages of development. Pre-planting soil disinfestation can be useful in soil-grown protected crops on new sites or on established sites after a severe outbreak of a serious soil-borne disease. Use of hydroponic systems avoids the need for soil disinfestation.

Resistant/tolerant varieties

Make full use of varietal resistance where available, especially for downy mildew, as such resistance genes can be highly effective.

The use of tolerant/resistant varieties is likely to be a key tool in management of lettuce fusarium wilt as experience with other fusarium wilt diseases in the UK, and with lettuce fusarium wilt overseas, indicate that current fungicides and biofungicides offer little or no practical control through to harvest.

Remember that the structure of lettuce plants can influence susceptibility, e.g. basal rots in flat-based lettuce. Check with your seed supplier for the most up to date information on disease resistance/tolerance.

Soil disinfestation

Basamid (dazomet) and closely related soil fumigants are restricted to one application in three years and can be effective for soil disinfestation following an outbreak of fusarium wilt. Soil steaming is generally effective against soil-borne pathogens including fusarium and is not restricted in application frequency. However, it is relatively expensive and involves considerable labour. Correct soil preparation is critical for effective treatment with both chemical soil fumigants and soil steaming. Biological soil disinfestation is under investigation as a potential treatment (e.g. see SF 157, against strawberry verticillium wilt, and for lettuce fusarium wilt in SCEPTREplus).

Seed treatment

Most lettuce seed is currently treated for control of fungal pathogens carried on seed. Treatment is primarily aimed at reduction of seedling diseases. It will not control fungal pathogens carried within seed. There are no systemic fungicide seed treatments.

Cultural control

Detailed attention to cultural measures can help reduce disease problems and the need for fungicide use. Key points to consider are:

- Ask your seed supplier to confirm testing and results for seed-borne diseases
- Carefully check bought-in plants to ensure they are visibly disease free. Do not plant out infected plants
- Avoid plant damage, particularly at planting
- In protected crops, water early in the life of the crop to build up good moisture reserves in the soil. Avoid watering late in crop development
- Keep the plants turgid, avoid stress. Water protected crops early in the day so that the foliage is dry by nightfall
- Ensure good nutrient status in the soil; avoid high nitrogen and low potash levels
- In protected crops, only close vents if it is raining heavily, winds are high, or if heating/CO_2 will be operated; otherwise leave some ventilation on all the time. When vents are closed, create air movement by operating circulation fans
- Harvest crops as soon as possible; seek to avoid holding crops at maturity
- In protected crops, if soil temperatures are high in the autumn, extend the use of summer varieties (e.g. continue cropping summer varieties until late October)

Crop hygiene

- Clear all crop debris immediately after harvest. In outdoor crops with a long rotation it is usual to incorporate debris into the soil. In protected crops it is preferable to remove it out of the house. Keep skips or heaps of crop debris covered while awaiting disposal
- In protected crops, isolated plants affected by sclerotinia should be removed as soon as symptoms are seen, together with a scrape of soil from beneath the plant, and placed in a bag and destroyed. Do not rotovate affected plants back into the soil
- Clean and wash down equipment before moving it between sites. Consider use of a suitable disinfectant where there is a risk of transferring a novel or serious disease problem (e.g. fusarium wilt)
- For protected cropping, a propane burner can be used to kill crop debris and associated fungal inoculum at and immediately below the soil surface, between crops or at the end of the season

Biopesticides

Contans WG has a label for use pre-planting against *S. sclerotiorum* and *S. minor*. Treatment is by incorporation into the soil. Consider use on sites with a history of soil-borne sclerotinia. For optimum effect the soil should be moist and at a temperature of 12-20°C. There is a maximum of one application prior to planting. T34 Biocontrol (*Trichoderma asperellum* strain T34) has an EAMU for use in protected crops against soil-borne *Pythium* and *Fusarium* species. Other biological fungicides are shown in Table 1.

Root diseases of hydroponic crops

Hygiene is very important. See pythium root rot (page 13). Currently there are no fungicides registered for use in the irrigation solution of hydroponic crops.

Chemical methods of control

Control with fungicide and biofungicides

Label recommendations should always be followed and growers should check current approval status prior to application of any products. A list of products permitted on outdoor and/or protected lettuce together with their known activity against lettuce diseases is given in Table 1. For some fungal and Oomycete diseases of lettuce (e.g. fusarium wilt, phoma basal rot, pythium root rot) there are no conventional fungicide products currently available with a label recommendation. The content below provides information on the activity of fungicides against downy mildew, powdery mildew, grey mould, sclerotinia, rhizoctonia and ring spot from recent AHDB-funded research projects: FV/PE 410, 2013-2015 and FV 289, 2006–2008.

Outdoor crops

Downy mildew

In AHDB Horticulture project FV/PE 410, Fubol Gold (metalaxyl-M + mancozeb) and Revus (mandipropamid) were both consistently effective against downy mildew when used at the final spray timings in different spray programmes. Note that populations of *B. lactucae* can be resistant to metalaxyl-M (in Fubol Gold) and related fungicides.

Powdery mildew

In FV/PE 410, in a low disease situation, products with activity against powdery mildew were as effective at half rate as at full label rate. These included Amistar (azoxystrobin) and Fenomenal (fenamidone + fosetyl aluminium). In high disease pressure situations it is inappropriate to use reduced rates or biological products, unless there is good evidence of efficacy with such treatments.

Whilst there is still much to learn about the use and effectiveness of biopesticides, it may be possible to integrate some biological products into programmes to reduce residue risk. These should be considered as they become available, especially for use when disease pressure is low.

Ring spot

In FV 289, Switch (cyprodinil + fludioxonil) was consistently the most effective treatment. Control was also demonstrated with Signum (boscalid + pyraclostrobin) and Amistar. There was significantly poorer control of ring spot when dose was reduced from full to half rate. Robust rates of fungicides are likely to be required at each treatment application to maintain control of ring spot.

Protected crops

Downy mildew

FV/PE 410 demonstrated that reduced fungicide rates can be used effectively in low disease situations and at early spray timings. This can help to minimise residues at harvest and reduce resistance development to the active substances. A standard commercial programme of Fubol Gold/Signum/Teldor (fenhexamid)/ Revus gave good control of downy mildew.

Sclerotinia

In FV/PE 410, products reported effective against *S. sclerotiorum* were tested against *S. minor*. Amistar and Signum were most effective.

Rhizoctonia bottom rot

The most effective control was achieved with spray programmes that included Amistar or a mode of action group 7 fungicide (e.g. boscalid in Signum).

Practical points

Spray timing

For downy mildew especially, it is important to apply products preventatively in advance of symptom development for effective disease control. This includes treatment in propagation.

Monitor crops carefully and consider disease risk for each cropping situation, including prevailing climate and forecasted weather. If weather conditions are conducive to disease in the area, consider reducing the spray interval to maintain effective protection against key pathogens like downy mildew. Conversely, in low disease risk situations, consider extending the spray interval between applications to reduce the overall number of sprays that need to be applied to the crop.

Spray coverage

Good spray coverage from an early stage in crop growth is likely to result in more effective disease control. Some fungicides have translaminar activity, which helps with downy mildew control; others are systemic but only towards the leaf tips. Early treatment to cover basal leaves and the soil surface is particularly important for control of basal rots in soil-grown protected crops.

Product rate

If weather is not conducive to disease, consider reducing rates of application and using tank mixes to broaden the spray programme. It would be inappropriate to use reduced rates in high disease pressure situations or for ring spot.

Residues

There are significant restrictions on the timing of applications of some products so it is imperative that these are used correctly according to label, to minimise any risk of residues above the MRL at harvest. Some common pitfalls which can lead to residue problems are: cutting the crop too soon, before the pre-harvest interval has lapsed; soil containing pesticide residues contaminating the lower leaves and not trimming off oldest, yellowing leaves; failure to check whether a product contains a dithiocarbamate; applying fungicides late in the crop life; failure to clean a sprayer between application of different products; spray drift; the increased risk in lower weight lettuce (residues are measured as a factor of dry weight).

Fungicide resistance

Be aware of the different mode of action groups (see Table 1) for fungicides and avoid overuse of those regarded as moderate-high risk of resistance development. To reduce risk either alternate or tank mix products with active substances from different mode of action groups; or choose products with two active substances from different groups both effective against the target disease.

Spray programmes

The three key reasons for devising and managing spray programmes are: 1) timing the treatment to achieve effective control; 2) avoiding residues in harvested produce; 3) reducing the risk of fungicide resistance. Key points to consider when devising or reviewing a programme for a crop are:

- Start the programme early, in the propagation stage, when the plants are small and it is easier to get good cover. Liaise with the propagator over the fungicides to be used in the propagation stage
- Early treatment in the life of the crop gives you the widest range of fungicide options and minimises the risk of fungicide residues remaining at harvest
- Preventative sprays are generally more effective
- Always use two or more active ingredients from different fungicide groups (where available) against each pathogen
- Comply with the limitations of different products in terms of number of sprays per crop, last spray application time after planting and the harvest interval (which can vary with time of year)
- Where there is a risk of several diseases, consider using products with broad-spectrum activity. Remember that some downy mildew products are specific to this group of organisms
- Application of a fungicide close to harvest will have very little effect on disease control but significantly increase the risk of a residue problem
- Be aware of the potential for phytotoxicity, particularly when plants are young and in weather extremes

Some example post-planting fungicide spray programmes for outdoor and protected lettuce are shown in Table 2.

Table 1. Activity of some fungicides permitted for use on outdoor (O) and/or protected lettuce (P) after planting out against fungal and Oomycete diseases of lettuce[1]

Product[2]	Active substances (and mode of action groups)	Active against[3]						Field of use	
		DM	GM	Scl	PM	RS	Rhi	O	P
Conventional fungicides[4]									
Amistar	Azoxystrobin (11)	✓	(✓)	✓	(✓)	✓	✓	✓	✓
Fenomenal[5]	Fenamidone (11) + fosetyl-aluminium (33)	✓	-	-	-	-	-	✓	✓
Fubol Gold WG	Mancozeb (M3) + metalaxyl M (4)	✓	(✓)	-	-	-	-	✓	✓
Infinito	Fluopicolide (43) + propamocarb hydrochloride (28)	✓	-	-	-	-	-	✓	
Invader	Dimethomorph (40) + mancozeb (M3)	✓	(✓)	-	-	-	-	✓	
Karamate Dry Flo Neotec	Mancozeb (M3)	✓	(✓)	-	-	(✓)	-	✓	
Karma	Potassium hydrogen carbonate (NC)	-	-	-	✓	-	-	✓	✓
Luna Sensation	Fluopyram (7) + trifloxystrobin (11)	-	✓	✓	✓	✓		✓	✓
Omex K50	Potassium hydrogen carbonate (NC)	-	-	-	✓	-	-	✓	✓
Paraat	Dimethomorph (40)	✓	-	-	-	-	-		✓
Perseus	Difenoconazole (3) + fluxapyroxad (7)	-	✓	✓	✓	✓		✓	✓
Previcur Energy	Fosetyl-aluminium (33) + propamocarb hydrochloride (28)	✓	-	-	-	-	-	✓	✓
Revus	Mandipropamid (40)	-	✓	-	-	-	-	✓	✓
Scala	Pyrimethanil (9)	-	✓	(✓)					✓
Signum	Boscalid (7) + pyraclostrobin (11)	✓	✓	✓	✓	✓	✓	✓	✓
Switch	Cyprodinil (9) + fludioxonil (12)	-	✓	✓	-	✓	-	✓	✓
Teldor	Fenhexamid (17)	-	✓	-	-	-	-	✓	✓
Biological fungicides[4]									
Amylox WG	*Bacillus amyloliquefaciens* subsp. *plantarum* strain D747		(✓)		(✓)			✓	✓
AQ10	*Ampelomyces quisqualis* strain AQ10	-	-	-	(✓)	-	-		✓
Prestop	*Gliocladium catenulatum* strain J144632		(✓)	(✓)	(✓)		(✓)	✓	✓
Romeo	*Cerevisane* (*Saccharomyces*) *cervisiae* strain LAS117	(✓)	(✓)		(✓)				✓
Serenade ASO	*Bacillus subtilis* strain QST713		(✓)	(✓)[6]	(✓)		(✓)	✓	✓
T34 Biocontrol[7]	*Trichoderma asperellum* strain T34								✓

Activity key: ✓ = control; (✓) = some control; - = no control; blank box = no information

Key to Table 1:

[1] Information on products permitted on lettuce and their field of use obtained from LIAISON database, June 2018.

[2] Equivalent products with the same active substance(s) are available for many of the products listed.

[3] Information on efficacy taken from product labels and associated literature and results of recent AHDB-funded crop trials. DM = downy mildew; GM = grey mould; Scl = sclerotinia; PM = powdery mildew; RS = ring spot; Rhi =rhizoctonia basal rot.

[4] Check label details carefully. Some products permitted on protected crops can only be used on permanent protected structures with full enclosure.

[5] Due for withdrawal 14 November 2019.

[6] With soil application.

[7] Activity against soil-borne pythium and fusarium.

Table 2. Example post-planting fungicide spray programmes used in FV/PE 410 that gave effective control; see project reports for full details and more options

	Treatment number				
	T1	T2	T3	T4	T5
Application timing	2–7 days post planting	7–10 days after T1	7–10 days after T2	7–10 days after T3	7–10 days after T4
Outdoor lettuce					
Autumn crop (2014)	Amistar + Karamate	Signum + Invader	Infinito	Fubol Gold	Revus
Spring crop (2013)	Amistar + Karamate	Signum	Fubol Gold	Invader	-
Protected lettuce					
Autumn crop (2015)	Amistar	Fubol Gold	Paraat	Serenade ASO	-
Autumn crop (2014)	Amistar	Fubol Gold	Switch	Revus	-
Autumn crop (2013)	Amistar	Fubol Gold	Teldor	Revus	-

Further information

Contacts

Bremia race information
www.worldseed.org/out-work/plant-health/other-initiatives/ibeb/

British Leafy Salads Association
www.britishleafysalads.co.uk

Fungicide Resistance Action Committee
www.frac.info

Health and Safety Executive
www.hse.gov.uk

Red Tractor Assurance
www.checkers.redtractor.org.uk

Factsheets and Crop Walkers' Guides

23/15 *Hygiene and disease avoidance underpin the management of Oomycete stem and root rots*

22/15 *Methods of water treatment for the elimination of plant pathogens*

21/15 *Testing water for plant pathogens*

19/14 *Disinfection for the control of clubroot during propagation*

03/14 *Use of chemical disinfectants in protected ornamental plant production*

01/13 *Practical measures to prevent and manage insecticide, fungicide and herbicide resistance for horticultural crops*

23/05 *Disease control in protected lettuce*

Outdoor salads – Lettuce and Celery Crop Walkers' Guide

Reviews and reports

CP17/18-1006 *Technical review of lettuce fusarium wilt, caused by* Fusarium oxysporum *f. sp.* lactucae

FV/PE 410 *Lettuce: further development of best practice for disease control in protected and outdoor crops*

PC 298 *Protected lettuce – developing best practice for disease control*

FV 289 *Outdoor lettuce – evaluation of new fungicides for ringspot control*

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