AHDB

Control of strawberry powdery mildew under protection

Figure 1. Powdery mildew mycelium visible on leaves

This factsheet describes the symptoms (Figure 1) and life cycle of strawberry powdery mildew and how it becomes established and spreads through crops grown under protection. It also provides guidance on management strategies to minimise the risk of damaging epidemics developing.

Action points

- **Applications of fungicides in the autumn and before fleecing in the spring will reduce initial inoculum**
- **New plantings may have low incidence of infection without any visible symptoms. Early application of potassium bicarbonate should be used to control existing infection on new plants, although it provides no protection against further infection. Complementary use of the nutrient silicon helps to modify the cuticle and wax structure of the leaf, which inhibits further infection**
- **Appropriate venting is important for optimising crop development and growth and, as a component of integrated disease management, for suppression of powdery mildew. Venting will help to reduce crop humidity and help to reduce reliance on fungicides. Venting decisions should be based upon on-farm weather condition forecasts and adjusted in response to observations in the tunnels**
- **Leaf cupping is associated with early infection and should be treated as a possible first symptom of powdery mildew infection. It should prompt further leaf assessment for the presence of mycelium**
- **Growers should avoid repeated applications of the same fungicide or fungicides with the same Mode of Action (MOA). Consecutive and frequent applications of products from the same MOA group will increase the likelihood of the pathogen developing fungicide resistance**
- **The use of silicon nutrient through fertigation lines will help to reduce susceptibility to infection by *Podosphaera aphanis* (the cause of strawberry powdery mildew)**

Background

The problem

Strawberry powdery mildew, caused by the fungus *Podosphaera aphanis* attacks the leaves, flowers and fruit of strawberry. Symptoms attributed to infection include patches of fungal mycelium, leaf-cupping (roll) and the formation of dark red leaf blotches. Powdery mildew on strawberries in the UK was first reported in the 1850s. However, it was not a major pathogen at that time. It has become more of a problem in recent years and can be particularly troublesome in tunnel-grown crops if the tunnel environment is not adequately managed. A combination of correct tunnel management, disease monitoring and use of crop protection products is required to maintain control. This adds to the cost of production, but is necessary to avoid the substantial crop losses that can be incurred should powdery mildew infection occur and spread through a crop.

Crop production and finance

The use of polythene tunnels combined with the use of different varieties has lengthened the harvest season from a traditional six-week period, to up to six months and more. During the past 20 years, the area used for strawberry production has remained largely unchanged at around 4,500 hectares. Despite this, over the same period the amount of fruit produced has risen from approximately 41,600 tonnes in 1995 to 115,500 tonnes in 2015 (Source: Defra UK Basic Horticultural Statistics). This represents a rise in the market value of the crop from £65.6 million to over £284 million. The improved production per unit area is attributed to growers becoming more specialised in strawberry production and improving their agronomic techniques.

Although the use of tunnels confers many benefits in terms of season extension, yields, rain protection and fruit quality, if managed incorrectly, they can enhance development of powdery mildew at certain times of the year. Hot and humid conditions prevail under the tunnels when they are closed and such conditions are conducive to the infection and spread of strawberry powdery mildew (see section on disease spread).

The disease can result in yield losses of between 20–70% of the crop potential. At 20% losses, using the above figures, this could contribute to an industry volume of 23,100 tonnes or market value of £56.8 million.

Symptoms

Strawberry powdery mildew exhibits a range of symptoms. Healthy strawberry plants have flat leaves, but they begin to cup soon after infection (Figure 2) and then red blotches (Figure 3) begin to form (depending on variety). Mycelium starts to spread and the production of asexual conidiospores creates the characteristic powdery effect, which may then become visible on the leaves (first on the lower then the upper surfaces – Figure 4) and petioles (Figure 5). In some varieties visible mycelium appears first on the leaves, petioles and peduncles and spreads early to the fruit (Figure 6). If effective treatments are not applied, mycelium can form on the flower buds (Figure 7), open flowers (Figure 8) and fruits (Figures 9 and 10). Leaf-cupping can occur for several reasons but in well managed tunnels where temperature and relative humidity are well controlled, leaf-cupping is highly likely to be the first visible symptom of strawberry powdery mildew. If cupping persists for 24 hours or more and is present early in the morning, it should be noted as the first warning sign of powdery mildew infection and mycelial growth.

Figure 2. Symptoms of leaf cupping soon after infection

Figure 3. Characteristic red blotches that appear after infection in some varieties

Figure 4. Typical fungal mycelium seen on leaf caused by powdery mildew

Figure 5. Infected petioles displaying visible mycelium

Figure 6. Mycelium can spread early to ripe fruits

Figure 7. Infected flower bud with mycelium

Figure 8. Infected flower with mycelium

Figure 9. Under-ripe fruit infected with mycelium

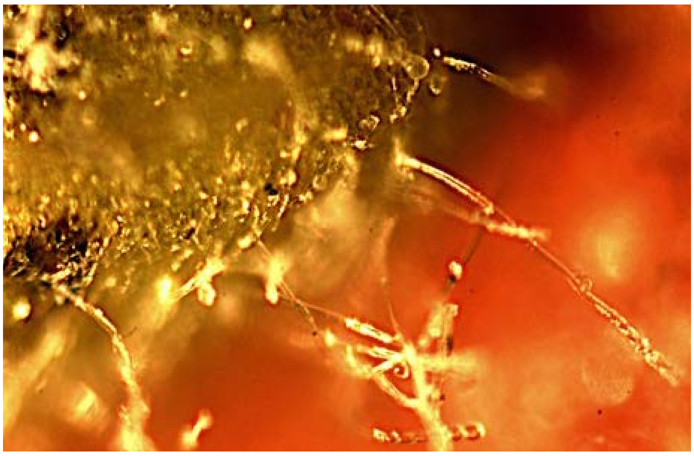

Figure 10. Enlarged strawberry seed with conidial chain and hyphae around it

Research in Project SF 62 compared cupped with flat leaves. Microscopic examination showed that both cupped and red-blotched leaves had more mycelium present than flat (apparently healthy) leaves. However, even on flat leaves, very small amounts of mycelium were sometimes present (upper or lower surface). For each associated symptom, the amount of mycelium measured increased with sample date.

Life cycle

The full life cycle is shown schematically in Figure 11. Strawberry powdery mildew has many asexual generations of the fungus in a season. The asexually produced conidiospores give rise to the seasonal epidemics of the disease. The speed with which it completes its life cycle is dependent on the influence of temperature and humidity on growth from conidiospore germination through to mycelium development and finally to spore production. In favourable conditions the germination for spore production is 7–14 days.

Epidemics can be initiated from overwintering chasmothecia containing ascospores in second or third year crops and from small colonies on young plants (where up to 70% of plants can have small colonies). Sexual reproduction of the fungus results in the formation of ascospores, which are contained in a chasmothecium. These are the long term survival structures of the fungus and are genetically dissimilar. They have a role in the overwintering of the fungus on crop trash, debris and green or old leaves.

Chasmothecia start to form in August and September and are the result of sexual reproduction. They survive low temperatures in the winter and mature and start to release ascospores as the temperature rises in the spring. The use of fleece and mulch in the spring to advance strawberry development, raises the temperature and humidity under the fleece, which hastens the release of the ascospores. Hence the need to consider fungicide sprays before fleecing the crop.

Infection and spread

There are two different situations that need to be considered at the start of each season:

- Newly planted crops
- Established overwintered crops

In the case of newly planted crops, the inoculum often originates during the propagation process, with conidiospores (also known as conidia) and mycelium being present on plants at the time of planting. This means that infected plants can be distributed randomly throughout outdoor and covered crops. In the case of established crops entering second or third seasons, the fungus survives within the crop via infected plants, or as chasmothecia on both dead and green leaves.

In Project SF 62 it was demonstrated that in newly planted crops two generations of the fungus occur before the presence of disease is likely to be detected by normal inspections. These generations occur initially from overwintered lesions on the plants in the cold store followed by new infection from these lesions. The speed of disease cycling depends upon the availability of inoculum (spores) and the prevailing conditions, particularly temperature and humidity under fleece. A summary of the conditions that affect the life cycle can be found in Table 1. Spores are airborne but the majority are deposited relatively short distances from their origin, due to the relative stillness of air within tunnels. Crop disturbance caused by human activity in the tunnels probably distributes spores more widely.

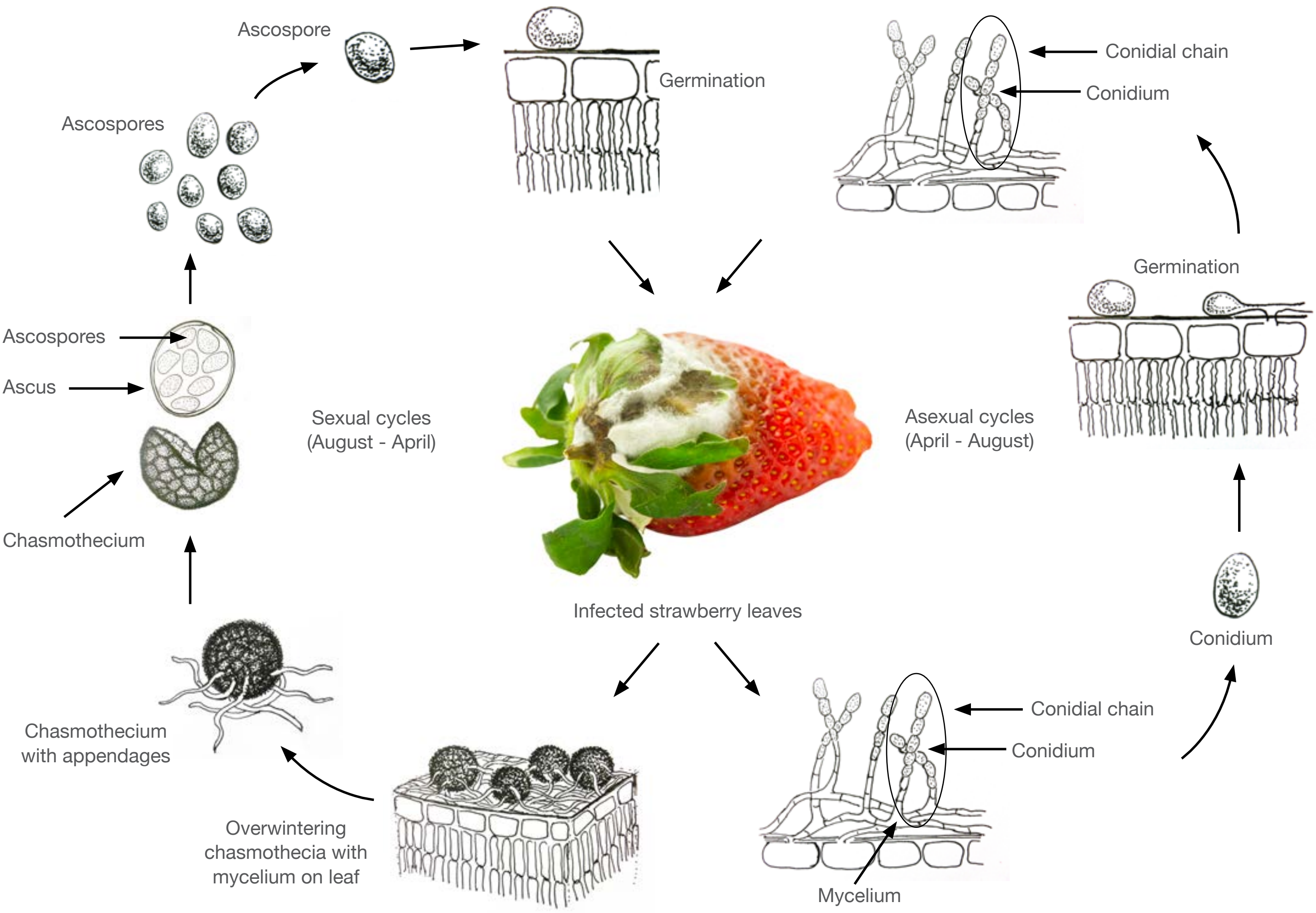

Figure 11. Life cycle of the fungus Podosphaera aphanis (from Xiaolei Jin)

The role of airborne inoculum between tunnels is minimal, so it is not necessary to close tunnels to keep spores out. Venting is the most efficient way to manage tunnels to reduce the temperature and humidity to prevent epidemic build up (see tunnel management). Whilst there are clear benefits from managing levels of primary inoculum, these benefits are likely to delay rather than prevent the build up of disease. Vigilance is required throughout the year to reduce initial inoculum and to monitor disease symptoms throughout the main growing season.

Table 1. Optimum conditions for strawberry powdery mildew conidia

Variable	Germination	Growth
Temperature (°C)	15.5–30	18–30
Relative humidity (%)	> 60	> 90–100

Predicting infection risk periods

During AHDB Projects SF 62 and 62a, a model was developed to predict periods when the crop is at risk of infection. It relies upon the measurement of the numbers of hours of optimum temperature and humidity for disease development and helps growers to identify the best time to apply protective sprays to prevent infection from occurring.

The system has been tested in commercial strawberry production where it helped to reduce the number of spray applications required to gain effective control of powdery mildew. A web based platform to allow growers to use this on a practical basis is currently being developed by NIAB and growers should keep abreast of this development and seek to use it when it becomes commercially available.

Figure 12. Dense crop canopies favour high humidity and the development of strawberry powdery mildew

Control

The aim of any control programme should be to reduce the initial inoculum and then to maintain low levels of disease. Research at the University of Hertfordshire has suggested that plants are highly likely to be diseased at the beginning of every season. Growers therefore need to implement disease control measures as soon as possible after planting and at the resumption of growth in the spring.

Cultural control

Varietal choice

An obvious way to control disease in crops is to grow resistant varieties. Under identical disease pressures the levels of symptoms on different varieties will vary. Although fruit quality characteristics will often assume the greatest priority, the development of resistant varieties is becoming increasingly important in the common aims of breeding programmes.

Nutrition

Growers should avoid excessive feeding and irrigation, which leads to dense crop canopies (Figure 12) and, particularly under tunnels, can give rise to high humidity and favour the development of strawberry powdery mildew. Dense canopies can also reduce spray penetration, thereby reducing leaf coverage, compromising product dose efficiency and slowing the establishment and success of any biopesticides. Thought should be given to plant density when establishing a crop and when crown thinning either after harvest or at the start of the season.

Recent research work by the University of Hertfordshire (see references to scientific papers in the ‘Further information’ section) has shown that the addition of a silicon nutrient via either spray application or through the drip irrigation system shows promise in reducing susceptibility to infection and delaying the onset and development of an epidemic. In the research, the silicon nutrient was used once or twice per week from March throughout the growing season. In this work, when applied as a spray together with fungicides or potassium bicarbonate or in the irrigation lines, no signs of toxicity were observed.

The research work showed that the silicon nutrient is taken up efficiently through the roots and laid down in the vascular tissues of the plant. Silicon modifies the epidermal cell walls, cuticle and wax on the leaf surface.

Tunnel management

Project SF 62 and research at the University of Hertfordshire has demonstrated the importance of good tunnel management in reducing disease development and epidemic build up. Ideally, tunnels should be managed so that the crop environment remains optimal for fruit production for as much of the day as possible, whilst avoiding conditions that are conducive to powdery mildew development. Temperature and humidity can vary from field to field even on the same farm, but should be monitored continuously and tunnels vented accordingly to avoid conditions that are conducive to disease development.

By referring to the temperature and humidity forecast, a venting (Figure 13) plan should be produced each night (or early next morning) for the next day. Such a plan should aim to keep internal temperatures in the range 18–25°C during the day and to reduce the internal relative humidity to less than 75%. Weather forecasts that predict air temperatures of around 15°C or greater, should act as a trigger to plan tunnel venting.

Crop hygiene

Good crop hygiene is also important in reducing disease risk. The removal of old trash or leaf debris from second or third year crops in the spring will help to reduce the levels of inoculum that overwinters in the crop (particularly in the form of chasmothecia). However, in the current commercial climate, it is accepted that most growers have neither the labour resource nor sufficient finance to do so. Project SF 62 has illustrated that good control can still be achieved by following the other measures included in this factsheet.

Chemical control strategies

Disease is most easily controlled when the amount of inoculum present in the crop is small. By implication, more effective control is achieved if treatments are applied before severe disease symptoms are evident. The primary aim should be to reduce the initial inoculum. Hence, inoculum levels need to be managed throughout the year and this will entail treatments early in the season.

Figure 15 (see insert in back cover) provides a calendar of powdery mildew development on strawberry and offers guidance on chemical control strategies. The best time to gain control of the disease is before either conidia (asexual phase) or ascospores (sexual phase) are released, as these lead to rapid spread of the pathogen. An autumn fungicide spray has been shown to reduce the amount of overwintering chasmothecia and thus reduce the number of ascospores available as initial inoculum in the spring. A pre-season fungicide spray before fleecing (Figure 14) and again after fleece removal and tunnel covering will reduce the risk and delay the start of an epidemic.

Choosing the appropriate fungicide

Strawberry growers have a limited range of active ingredients with which to control powdery mildew. All of those fungicides currently approved (March 2017) for use in strawberries, which provide some effective control of powdery mildew are listed in Table 2 (see insert in back cover). It is crucial that these are used within strategies that slow the development of fungicide insensitivity and resistance in the target pathogens. When choosing fungicide products, growers should consider both their activity (ie, protectant, eradicant, systemic etc) and their mode of action. The same fungicide or fungicides with the same modes of action should not be used consecutively or too frequently. Follow the guidance provided in the footnote under Table 2.

Fungicide spray programmes

Fungicidal products with different activities were tested in Project SF 62. Fortress (quinoxyfen) was the most effective protectant fungicide product tested, and provided a long-lasting effect. Fortress therefore is likely to be effective at the start of the season when infection levels are low, when it can give long term protection.

On outside crops Corbel (fenpropimorph), which acts as a systemic eradicant, can be used to reduce or remove any overwintering inoculum, enabling the application of Fortress to have the greatest effect. Corbel and potassium bicarbonate can both be used to reduce inoculum before the pre-season use of Fortress.

Potassium bicarbonate was found to be very effective at controlling established infection. Bicarbonate works by contact, so good leaf coverage is necessary to achieve the optimum control. Bicarbonate has a very short harvest interval so it is an ideal product to use at the time fruit is being picked. Bicarbonate does not provide long lasting protection; it will only kill the mycelium that it contacts. Recent research at the University of Hertfordshire showed evidence that a silicon based wetter improved the performance of the bicarbonate.

Spray application

The risk warning system has been designed to help growers achieve good control of powdery mildew with reduced fungicide applications. Growers should pay particular attention to spray coverage as results show that there is more, early mycelium on the underside of the leaves.

Figure 13. Special attention to venting will help to reduce humidity and reduce the risk of infection

Figure 14. A pre-season fungicide spray before fleecing and again after fleece removal will reduce the risk and delay the start of an epidemic

Table 2. Summary of fungicides currently approved for use in strawberry with recommendations for powdery mildew control

Active ingredient	Product	Approval type	Activity	Mode of action*	Harvest interval	Maximum number of applications/year and other information
Ampelomyces quisqualis strain AQ 10	AQ 10	Full	Protectant	Not classified	Nil	12 applications. Protected crops only. Biofungicide containing a hyperparasitic fungus
Boscalid + pyraclostrobin	Signum	Full	Protectant Systemic	7, 11	3 days	Max total dose: 3.6 kg/ha/year Outdoor and protected crops
Bupirimate	Various	Full	Protectant & Eradicant Systemic	8	1 day	3 applications. Outdoor and protected crops
Cyflufenamid	Takumi SC	EAMU	Protectant & Eradicant	U6	3 days	2 applications. Outdoor and protected crops
Fenpropimorph	Various	EAMU	Protectant & Eradicant Systemic	5	14 days	Max total dose: 3 l/ha/year. Outdoor crops only
Fluopyram + trifloxystrobin	Luna Sensation	Full	Protectant Systemic	7, 11	1 day	2 applications. Protected crops only
Kresoxim-methyl	Stroby WG	Full	Protectant	11	7 days (outdoor) 3 days (protected)	2 applications. Outdoor and protected crops
Meptyldinocap	Kindred	Full	Protectant	29	3 days	3 applications. Protected crops only
Myclobutanil	Systhane 20 EW	Full	Protectant & Eradicant Systemic	3	3 days	Max total dose: 2.7 l/ha/year. Outdoor and protected crops. Approval ends September 2017
Penconazole	Various	Full	Protectant	3	3 days	2 applications on outdoor crops. 4 applications on protected crops
Potassium bicarbonate	Commodity products	Commodity substance	Eradicant	Not classified	Not stated	Max total dose: 60 kg/ha/year. Outdoor and protected crops
Proquinazid	Talius	EAMU	Protectant	13	3 days	1 application. Protected crops only
Quinoxyfen	Fortress	EAMU	Protectant Systemic	13	14 days	Max total dose: 0.5 l/ha/year. Outdoor and protected crops
Sulphur	Various	Full	Protectant	M2	Nil	Unlimited. Outdoor and protected crops

*FRAC code. Further details about FRAC (Fungicide resistance action committee) and the full FRAC code list, can be found at frac.info/publications. Products with the same Mode of Action should not be applied consecutively. For example, if ‘Signum’ (7, 11) was applied, it should not be followed by another ‘Signum’ application or ‘Stroby WG’ (11).

Figure 15. The production cycle of strawberry

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Further information

Useful AHDB project reports

SF 62 – ***The epidemiology and control of strawberry powdery mildew under protection*** (Project leader: Avice Hall, University of Hertfordshire).

SF 62a – ***Extending and exploiting new knowledge of strawberry powdery mildew*** (Project leader: Avice Hall, University of Hertfordshire).

SF 113 – ***Comparison of five non-pesticide mildew control projects on strawberry*** (Project leader: James Carew, FAST Ltd).

SF 157 – ***Improving integrated disease management in strawberry*** (Project leader: Xiangming Xu, NIAB EMR).

Image credits

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Other useful scientific references

Fatema, K, Hall, A. & Naseby, D. C. (2012). A study in the role of silicon in the control of strawberry powdery mildew (Podospheara aphanis) in a field trial. Aspects of Applied Biology 117, 229–234.

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Liu, B. & Hall, A.M. (2013). Practical experience of using a prediction system to control strawberry powdery mildew in Fruits and Roots: A celebration and look forward (edited Bishop, G.) Aspects of Applied Biology, 119, 227–232.

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