# A review into management practices of botrytis in peony

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## Background

Botrytis is one of the most economically significant pathogens affecting peony, and can result in crop losses in excess of 20% during wet years. Management of the disease is reliant on cultural control, site hygiene measures and fungicide inputs. Withdrawal of key fungicide actives, including Bravo (chlorothalonil), has put pressure on the remaining actives, increasing the risk of resistance development occurring. This report reviews recent research on peony botrytis, the current control measures used by growers, providing best practice guidance recommendations, and proposes future trials to generate information.

## Objectives

1. To review and summarise published information on peony botrytis from the UK and the USA.
2. To collate information on current UK grower practices directed at management of the disease.
3. To propose future field trials work that will test different treatments to determine their effectiveness in disease control.

## Summary of main findings

- Prolonged leaf wetness is essential for disease develpoment. Avoiding this represents the single most effective tactic to manage botrytis in peony, however this is difficult to achieve with field-grown crops.
- Locate peony crops away from infection sources where practical, and plant in well drained soil avoiding excessive shade and areas prone to late frosts.
- Reduce planting density if financially feasible, siting crops in a more open situation.
- Select resistant or tolerant varieties, using propagative material certified free of disease where possible.
- Mulch where necessary to reduce frost damage, but remove this material before stem emergence, allowing sufficient time for the soil to dry.
- Treat or remove weeds which may act as sources of botrytis inoculum and limit airflow, prolonging leaf wetness.
- Remove infected shoots early on, and all other infected material when observed. Avoid flower bloom in fields, or remove heads before petal fall.
- If used, avoid overhead irrigation to reduce periods of leaf wetness.

- Target preventative fungicide applications before rainfall events and following harvest to protect cutting wounds and apply close to harvest to protect against botrytis developing in postharvest stores. Following frosts, do not apply fungicides for 48 hours.
- Treat for pests (e.g. thrips) which may cause damage to buds creating wounds for pathogen entry.
- Weak, damaged or nutrient deficient plants are more susceptible to infection. Maintain plant health and good nutrition at all times.
- Use sharp, clean blades to harvest flower buds and frequently disinfect these with a product known to be effective against botrytis.
- Maintain low relative humidities and avoid fluctuations in stores to further reduce post-harvest losses.
- Many fungicide active ingredients for use against botrytis have been withdrawn, or are at risk of withdrawal. The efficacy and safety of newly authorised products, such as Frupica SC (mepanipyrim), Prolectus (fenpyrazamine) and Sercadis (fluxapyroxad), should be demonstrated in commercial trials to increase their uptake.
- The efficacy of the currently approved biopesticides Amylo X WG (*Bacillus amyloliquefaciens* D747), Prestop (*Gliocladium catenulatum*) and Serenade ASO (*Bacillus subtilis*) requires further assessment.
- A range of elicitors, such as Frutogard (potassium phosphonate) and Fytosave (cos-oga), and plant extracts like orange oil, are known to offer various levels of control, but these need further screening to assess their relative efficacy compared to other plant protection products.

# Introduction

The demand for ornamental plants in the UK is increasing, with an estimated value to the UK economy of £1.3 billion in 2018 (Defra Horticulture Statistics). This includes UK grown cut flowers which are valued at £121 million. A significant proportion of cut flowers that are sold in the UK are imported. Often grown in equitorial regions, these benefit from warm and stable temperatures, constant day lengths and a cheap labour force.

A desire by supermarkets (and consumers) to market wholly British bouquets is gaining popularity, and the proportion of British blooms sold is set to increase. The National Farmers Union ‘Plants and Flowers Pledge’ supports UK cut flower growers by promoting price certainty, enabling them to compete with cheaper imports. Currently, Aldi and the Co-op have signed up to the pledge, but it is hoped other major supermarkets will join, further expanding the UK cut flower market for seasonal product.

Cultivation of larger quantities, and an increased diversity of cut flowers will increase local biodiversity, supporting species including pollinators which have been suffering significant declines.

# Peony overview

Peony, *Paeonia lactiflora,* is a flowering plant of the genus *Paeonia*. Native to Europe, Asia and North America, thirty three species have been described, however it is predicted that at least 40 species exist (Garfinkel and Chastagner 2016). Most varieties grown are *P. lactiflora* hybrids which originated from China. Peony are field-grown and culivated in the same soil year-on-year and are propagated exclusively via vegetative propagation of the root crown/roots. Most varieties are herbaceous perennials, however woody shrub types and tree peony types, *paeonia suffruticosa* exist. These types are not covered in this review.

Peony are grown for their large compound flowers which are very popular within the wedding market, and more recently on on-line platforms including Instagram. Single and double types of multiple colours and varieties are available, many of which are scented. Once harvested, blooms have a relatively short vase life in water, which varies by cultivar (Rabiza-Świder, Skutnik et al. 2020).

In the UK, peony is a minor crop, grown by a small number of growers. The UK season is short, running from mid-May to early July and is dependent on environmental conditions. Peony are also sourced from the Netherlands, the south of France and Italy. Outside of Europe, flowers are imported from further afield including Kenya and South Africa.

Considerable financial inputs are required to cultivate peony and any pest and disease issues which develop, before or during the short harvest period, can place an entire crop at risk. Peony are susceptible to a variety of fungal pathogens, including Botrytis (grey mould or botrytis blight), Phytophthora (*Phytophthora cactorum*), powdery mildew (e.g. *Podosphaera xanthi),* leaf spots (*Alternaria* spp., *Cercospora* spp. and *Septoria* spp. etc.) and root rots (e.g. *Fusarium* sp. and *Verticillium* spp.). An integrated pest and disease management approach is needed to manage all outbreaks. In addition, plants are susceptible to physical damage from heavy rain or hail. Where damage occurs to buds before, or during the critical harvest period, this can render entire crops unmarketable (as occurred on some production areas in France during 2018). Wound sites are also responsible for providing entry points for opportunistic pathogens, including botrytis.

# Peony botrytis

Peony botrytis can be considered the most economically significant disease of peony (Whetzel 1939). Several botrytis species are known to infect peony, including *Botrytis paeoniae, Botrytis cinerea, Botrytis pseudocinerea* and *Botrytis euroamericana* (Garfinkel, Lorenzini et al. 2017). Generally, *B. paeoniae* is responsible for early blight and is considered specific to peony (Daughtrey, Wick et al. 2000) whilst *B. cinerea* and *B. pseudocinerea* are responsible for late blight.

Developing in the spring, botrytis is a recurrent problem for all peony growers, especially during wet periods where the disease can be very prevalent. Infections affect new shoots and foliage leading to bud abortion or unsightly and unmarketable blooms. As a perennial crop, inoculum levels will accumulate over time where not addressed, increasing losses. Severe outbreaks can lead to the loss of a large proportion of young stems, as well as affecting the developing buds/blooms. In the UK, crop losses from botrytis infection in the field are normally less than 0.5%, however losses as high as 20% can occur if the disease is not managed effectively. Post-harvest losses are also a problem where symptoms develop on buds/blooms in stores, or in customers' homes (Garfinkel and Chastagner 2016). Supermarket rejections are a major commercial issue for all peony producers.

# Disease symptoms

Botrytis can develop on almost all plant tissues, at every developmental stage (Garfinkel and Chastagner 2016). Early in the season, the presence of inoculum sources at stem emergence enables early blight infections to develop almost immediately. Infected young shoots, only a few inches tall suddenly wilt and fall over due to lesions which can fully girdle the stem (Figure 1). On well-developed lesions, under conducive climatic conditions, spore-bearing structures emerge, shedding spores for further infections.

Flowers are the most susceptible tissue type to botrytis infection and can be infected from the earliest stages of bud development. Bud blast (early blight) develops on small young buds (pea sized), where infection causes them to blacken and fail to open (Garfinkel and Chastagner 2016).

Mature buds can also become infected failing to open, or only partially open. Individual petals may become infected, starting as brown spots before coalescing to cover the entire petal, eventually taking on a papery, dry appearance (Figure 2). During favourable conditions of leaf wetness, a velvety grey mass of fungal spores will develop which can rapidly cover part of, or all of the bud (Figure 3). Further infection can develop down the flower neck, and after time the infected bloom may fall away.

Infected stems which do not collapse early, develop a tan appearance with concentric rings which can fully girdle the stem (Figure 1). Small 'loaf-shaped' sclerotia form under the epidermis of infected stems ready to infect later growth (Chastanger 2014). In situations where leaves become infected e.g. from wounding, or as a consequence of infected petal drop, large irregular concentric brown leaf spots develop, often from the leaf tip spreading inwards. In periods of leaf wetness grey mould will develop on the surfaces of infected leaves (Figure 4). During very severe infections rotting of the crown and roots may develop, but this is uncommon.

Late blight infections differ from those of early blight. Typically affecting late opening flowers, the fungal growth is more diffuse than the tight mycelial growth in early blight infections. Sclerotia also form at stem bases, however these are much larger and flatter than those associated with *B. paeoniae* (Botrytis Blight, Pacific Northwest Handbook).

Figure 1 (top left) - Infected stems with a tan appearance and lesions which fully girdle the stem base, *Source: Michelle Grabowski, University of Minnesota Extension - Horticulture, Bugwood.org*
Figure 2 (top right) – Brown and papery petals as a consequence botrytis infection, *Source: ADAS Horticulture*
Figure 3 (bottom left) – Velvety grey botrytis sporulation at the flower base, *Source: ADAS Horticulture*
Figure 4 (bottom right) – Early botrytis sporulation and tissue browning on infected peony leaf, *Source: ADAS Horticulture*

## Alternative causes of early bud abortion

Bud blast is a characteristic symptom of early botrytis blight, however other factors are responsible for the abortion of buds, e.g. late frosts, and these should be considered to ensure that best cultivation practices are followed. In situations where botrytis is not responsible for bud abortion, affected buds will initially take on a reddish, rather than brown appearance and grey botrytis colonies will not develop. However, buds will brown as they decay, falling from stems which can make identification of the cause of the bud abortion more difficult over time.

Severe thrips damage to peony buds may also cause bud abortion. Symptomatic heads can be removed and gently shaken onto white paper to check for pest presence. Thrips damage will impact the quality and marketability of buds, as well as provide wound sites for botrytis spore entry.

# Life cycle of peony botrytis

Understanding the life cycle of botrytis, and linking this with the cultivation cycle of peony is essential to plan effective management strategies and optimise fungicide application timings.

Botrytis is considered an anamorphic fungi, reproducing almost exclusively via asexual reproduction. A sexual stage of the fungal life cycle is known to exist, however this is rarely observed. The fungus favours prolonged leaf wetness (Ciliberti, Fermaud et al. 2015), and warm conditions, around 15-20°C, although it will infect at temperatures as low as 5°C (Bulger, Ellis et al. 1987). Hyphae, housed within sclerotia, present on the surface of overwintered decayed peony foliage, germinate under wet conditions in the spring. Within hours germ tubes emerge leading to the development of appressorium, specialised flattened hyphae. These contain penetration pegs which secrete enzymes, including cutinases and lipases (Schäfer 1998), as well as hydrogen peroxide to breach the cuticle and penetrate the host. Once breached, the penetration peg grows into the epidermal cells triggering an oxidative burst and cell death (Boddy 2016). These dead cells provide resources for fungal growth, where it will continue to survive as a saprotroph (or necrotroph in the case of plant death). Conidiophores, containing masses of conidia, asexual non-motile spores (the primary inoculum source for botrytis infections) are produced. Once mature, these are dispersed locally by water splash, or by plant movement, whilst further spread is facilitated by wind, insects or by crop workers and equipment/machinery.

Secondary infections occur when conidia gain entry into plants via natural openings, or wounds. Once attached to the host, conidia germinate developing germ tubes for invasion of the host restarting the cycle which may repeat several times per year. Sclerotia may also form, often as a consequence of low nutrient availability or environmental conditions. These comprise a compact mass of melanised mycelium which enable long-term survival and overwintering of the fungus.

In milder locations, conidia may develop on over-wintered mycelium, skipping the requirement for the sclerotial stage of the life cycle entirely (Garfinkel and Chastagner 2016). This can increase the inoculum level present during stem emergence leading to increase shoot collapse. In the future a warming climate may mean that conidia arising from overwintered mycelium may become the primary source of early inoculum.

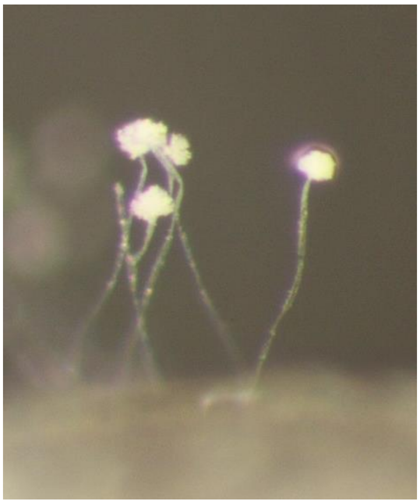

Figure 5. Botrytis conidiophores containing maturing conidia. *Source: ADAS Horticulture*

In addition to spread by conidia, infected petals may also act as a source of infection. Petal fall, and subsequent adhesion onto healthy leaves (often as a consequence of rainfall) enables close contact of mycelium from infected petals to directly infect healthy tissue (Daughtrey, Wick et al. 2000).

# Disease sources

Botrytis is a near ubiquitous fungus producing huge quantities of airborne spores (conidia) which are present in almost all environments. Despite the abundant presence of this organism, infections occur predominantly on dead, weakened and/or stressed plants. The perennial nature of peony cultivation allows for accumulation of botrytis species over time and this must be managed to limit losses. In the

UK two species of botrytis are confirmed to infect peony, however research in the USA suggests that a much greater diversity of botrytis species may also cause disease, many of which could be present in the UK.

*Botrytis paeoniae:* This is responsible for early blight (bud blast) and is believed to be species specific to peony. The initial source of *B. paeoniae* is likely to be from propagative materials, or transmission from equipment and machinery used at other peony production sites. Longer term inoculum sources include debris, sclerotia, or overwintered mycelium, from previous seasons.

*Botrytis cinerea*: Responsible for late blight, *B. cinerea* has been demonstrated to infect over a thousand plant species, across more than 580 genera (Williamson, Tudzynski et al. 2007, Elad, Pertot et al. 2016). Similar to *B. paeoniae, B. cinerea* can overwinter in debris as sclerotia or mycelium. *B. cinerea* inoculum sources may also be introduced to peony from nearby host species e.g. crops and weeds.

*Botrytis pseudocinerea:* This is a cryptic species of botrytis, one which is morphologically identical to *B. cinerea*, but can only be differentiated by genetic sequencing (Walker, Gautier et al. 2011). *B. pseudocinerea* is a pathogen of peony grown in the USA, but has not been confirmed infecting UK peony. However, *B. pseudocinerea* is present in the UK, and it is anticipated to be a pathogen of this species.

## Diversity of peony botrytis species in the USA

As a minor crop in the UK, limited research into the diversity of botrytis species infecting peony has been undertaken, however much work has been carried out in the USA.

The genus *Botrytis*, includes thirty three described species, most of which impact commercial crops, including ornamentals (Garfinkel and Chastagner 2016). Researchers at the Washington State University Puyallup Research and Extension Centre collected and sequenced 178 individual isolates of peony botrytis collected across the Pacific Northwest, including Oregon, Washington and Alaska. Sequencing of these isolates revealed a previously unknown diversity of peony botrytis species (Garfinkel, Coats et al. 2019).

*B. paeoniae, B. cinerea* and *B. pseudocinerea* accounted for the bulk (76%) of isolates sequenced, however, several other botrytis species were identified. *B. euroamericana,* a newly discovered botrytis species of Italian grape and peony in Alaska (Garfinkel, Lorenzini et al. 2017) was found, which were responsible for 5% of the isolates sequenced. In Alaska, isolates related to *B. prunorum,* a botrytis species described on plums in Chile (Ferrada, Latorre et al. 2015), and an isolate related to *B. fragariae* associated with strawberry in Europe (Rupp, Plesken et al. 2017) were also present. The remaining isolates did not correspond with any known botrytis species and represent up to 10 novel species. It is uncertain if all species identified in this genetic study are pathogenic, however this highlights the diversity of botrytis species which are present on peony. Similar studies on other commercial crops have identified novel botrytis species, but not to the diversity found in peony, which hosts double the botrytis species reported in Allium, the species with the second most diverse botrytis species known (Elad 2016).

In addition, several botrytis isolates sequenced from peony have been linked with endophytes of weed species, including *Centaurea stoebe* (spotted knapweed). It is not known if these are pathogenic, or simply endophytes on peony (Duffy 1994, Garfinkel, Coats et al. 2019).

The extent to which the botrytis species identified in this study are present within the UK, or what the true diversity of peony botrytis in the UK is, remains unknown, as is the impact that this diversity has on UK management strategies. Currently cultural, hygiene and chemical control measures are sufficient to control most botrytis outbreaks, however a greater understanding of species specific epidemiology and pathogenicity will only improve this. Botrytis is prone to developing resistance e.g. *B. euroamericana* resistance to fenhexamid, and an understanding of the fungicide sensitivity of different UK botrytis species, as well as their geographical distribution, would contribute to identifying the most appropriate fungicide programme, improving resistance management strategies.

# Management strategies

Similar to all botrytis outbreaks on ornamental plants, management of peony botrytis is most difficult during, or following wet seasons. Once emerged, peonies grow rapidly and are not resilient to sudden environmental changes. Cultural and site hygiene measures in combination with fungicide (chemical/biological) applications, provide the most effective control strategy.

## Cultivar selection

Cultivar choice is a key component of any control strategy and the use of tolerant, or resistant cultivars can significantly reduce the requirement for fungicide inputs. Cut flowers, including peony are marketed based on their aesthetics and cultivar choice is often dependent on customer demand, and not resistance management.

A range of peony cultivars are available, however a review of commercial catalogues provided little to no information on the relative susceptibilities of these varieties to botrytis. Where information is available it is based on consumer experience and is often contradictory. The popular cultivar Sarah Bernhardt claims full resistance by some, but is described as moderately resistant by others. In the 1930s over 220 cultivars were trialled for their relative resistance to botrytis (Winters 1930), and this revealed a wide range in susceptibilities (Table 1). Many of these cultivars are no longer grown commercially and an updated susceptibility study would provide valuable information to the industry.

Several growers claim that vigorously growing varieties, and those with thicker stems are more susceptible to botrytis, however no published work investigating this is available. Intersectional varieties, hybrids between herbaceous and tree peonies are also considered to have greater resistance, but are less suitable for cut flowers, as blooms from these types have a shorter vase life.

Table 1. The relative susceptibility of peony cultivars to botrytis, adapted from Winters 1930

| Susceptibility | Cultivar |
|---|---|
| Resistant | Akalu, Argus, Arthemise, Attraction, Avalanche, Balliol, Baroness Schroeder, Baron James Rothschild, Black Prince, Cavalleria Rusticana, Chalice, Christine Gowdy, Christine Ritcher, Comte de Nanteuil, Dorothy, Dorothy Echling, Dorothy E. Kibby, Ella Wheeler Wilcox, Eucharis, Eureka, Fragrans, Fulgida, General Bertrand, General Cavaignac, Gloire de Chenonceaux, Glorious, Flory of Somerset, Gretchen, Griff Thomas, Hermes, Hogioku, Iten-shikai, King of England, Kumagaye, Lady Bellew, Lady Mayoress, L'étincelante, Lord Salisbury, Luetta Pfeiffer, Madame Lemoinier, Madame Schmidt, Maud L. Richardson, Meissonier, Monsieur Boucharlataine, Mrs. Gwyn-Lewis, Mr. L. van Leeuwen, Old Silvertip, Petite Renée, Plutarch, Princess Ellen, Purpurea Superba, Queen Wilhelmina, Red Bird, Ruigegno, Sarah Bernhardt, Speedwell, Sweet Home, Yeso. |
| Moderate resistance | Admiral Dewey, Agnes Mary Kelway, Albâtre, Albert Crousse, Alfred de Musset, American Beauty, Archie Brand, Asa Gray, Augustin d'Hour, Aunt Ellen, Béranger, Bullock, Carnea Elegans, Carnot, Charles Binder, Charles Verdier, Charlotte Cushman, Clarisse, Comet, Conqueror, Couronne d'Or, Daubenton, Daybreak, Dorchester, Dorothy Kelway, Duchess of Portland, Duke of Devonshire, Edwin Forrest, Emile Lemoine, Enchantment, Eternal Ciety, Etta, Faust, Favorite, Festiva Maxima, Flambeau, Frances Shaylor, Graziella, Grizzel Muir, Gypsy, Henry Avery, Hon. Mrs. Portman, Innocence, John Fraser, June Day, Jupiter (Calot), Kelway's Queen, La Coquette, Lady Alexandra Duff, Lady Somerset, La Fraicheur, Lake of Silver, La Perle, La Sublime, La Tulipe, La Vestale, L'étincelante (Dessert), Lord Lytton, Louis van Houtte, Mabel L. Franklin, Madame Coste, Madame de Guerle, Madame de Vatry, Mademoiselle Gaillant, Mafeking, Mary L. Hollis, Masterpiece, Mathilde de Roseneck, Mazie Terry, Monsieur Paillet, Monsieur Pasteur, Muchelny, Norfolk, Octavie Demay, Pallas, Phoebe Cary, Pierre Duchartre, Pink Enchantress, Princess Maud, Queen of Beauty, Rauenthal, Rhoda, Rubicunda, Ruth Brand, Simonne Chevalier, Sir Robery Gresly, Snowflake, Sosthenes, Sully Prudhomme, Torquemada, Triumphata, Trojan, Venus, Victoria, Ville de Nancy, Waterloo, Welcome Guest. |
| Susceptible | Adam Bede, Agnes Barr, Amalthea, Armand Rousseau, Bertha, Camille Calot, Canariensis, Carlotta Grisi, Carnea Triumphans, Caul, Chrysanthemiflora, Comte de Cussy, Comte de Paris, Countess of Clancarty, Daniel d'Albert, Delachei, Duc de Cazes, Duc de Wellington, Eastern Beauty, Edmond Lebon, Etienne Mechin, Frances Shaylor, General Grant, Grandiflora, Jules Calot, Lady Beresford, Lutetiana, Madame de Verneville, Madame Emile Galle, Madame Hutin, Magnifica, Marie Lemoine, Marquise d'Ivry, Mathilde Méchin, Meadowvale, Monsieur Chevreul, Mrs. Lowe, Myrtle, Pottsi, Princess Beatrice, Pulcherrima, Queen's Perfection, Roem de Boskoop, Sappho, Sea Foam, Snowball (Hollis), Souvenir de Gaspard Calot, Strasbourg, Sunrise, Thomas S. Ware, Torch, Triomphe du Nord, Turana, Vicomtesse de Belleval, Virginie, Virgo Maria, Viscountess Folkestone, Whitleyi. |
| Highly susceptible | Antione Porteau, Armandine Méchin, Assmanshausen, Belle of France, Charles Toche, General Bedeau, Grandiflora Lutescens, Irma, Lutea Plenissima, Nivea Plenissima, Paradise, Territorial, Victoire Modeste. |

## Cultural control and site hygiene measures

A range of cultural control and site hygiene measures are available which can reduce sources of botrytis inoculum and limit in-crop damage. The following lists best practice recommendations for managing botrytis in peony.

*Leaf wetness:* Prolonged leaf wetness is essential for conidial attachment and germination (disease development). Avoiding this represents the single most effective tactic to manage botrytis in peony.

*Start clean*: Ensure all propagative material is disease free to avoid introducing sources of inoculum at planting, (especially sources of *B. paeoniae*), where possible use nursery stock that is certified free of disease.

*Site selection*: Plant new peony crops during cool weather in the autumn, before the first frost. Place away from potential sources of botrytis inoculum (including other peony fields). If feasible reduce plant density, or site crops in an open situation which will increase airflow, reducing periods of leaf wetness. Peony require well drained soils, so avoid heavy clay soil types which retain moisture, or loosen the top soil before shoot emergence. Do not plant in situations of excessive shading, e.g. tall hedgerows/woodland which prolong leaf wetness. Avoid areas which frequently receive late spring frosts, high winds or hail storms to reduce crop damage.

*Mulching:* Where mulching is used to prevent freezing, it should be removed in spring to allow the ground to dry around newly emerging stems. Farmyard manure has been implicated with favouring botrytis establishment and should be avoided.

*Weed and debris removal:* Weeds should be well controlled to improve airflow around the base of plants, and to remove potential inoculum sources of *B. cinerea*. In early autumn (mid-September) all plant material should be cut back to, roughly 10cm above the soil, with the debris removed and destroyed. Composting is not advised, unless processed well away from peony cultivation areas.

*Removal of infected material:* In the spring remove young infected shoots as soon as wilting appears to reduce secondary inoculum sources. Infected buds, and other infected material should be removed when found.

*Plant protection products*: Target preventative fungicide applications before rainfall events and following harvest to protect recently harvested stems and apply a fungicide close to harvest to protect against botrytis rots developing in post-harvest stores. Treat for pests, such as thrips, which wound buds and increase the risk of botrytis infection and treat for slugs which kill or wound young shoots. Following frosts, do not apply fungicides for 48 hours.

*Irrigation*: Avoid using overhead irrigation to further reduce leaf wetness and the impact of water splash in inoculum spread.

*Bloom avoidance*: Petals are highly vulnerable to botrytis infection and once infected can act as secondary sources of inoculum as a consequence of petal stick. Avoid flower bloom in fields, or remove heads before petal fall. This will reduce post-harvest losses through reducing inoculum present on harvested buds.

*Top soil removal*: After severe outbreaks consider removal and replacement of a few centimetres of top soil to reduce soil sclerotia load. If carried out, great care should be taken not to injure peony roots.

*Plant health*: Weak, damaged or nutrient deficient plants are more susceptible to infection. Maximise plant health and nutrition, including calcium and silicone for leaf strength, to reduce this risk.

*Harvest*: Use sharp, clean blades to harvest flower buds and that these are frequently disinfected with a product known to be effective against botrytis. Consider routinely disinfecting footwear to prevent transmission between rows.

*Post-harvest:* Maintain low relative humidities and avoid fluctuations in post-harvest stores to reduce losses.

# Chemical fungicides, biopesticides and elicitors

**Chemical fungicides**

Almost all commercial peony production is reliant on plant protection products. As botrytis is able to infect at stem emergence, timely and preventative application of fungicides is essential for effective management. The degree of chemical control required will be dependent on environmental conditions, the age of the crop and the severity of the disease the previous season. These factors must be considered when developing fungicide programmes.

Botrytis is prone to developing fungicide resistance, with resistance to dicarboximides and benzimidazoles widespread (Leroux 2007). All fungicides must be applied according to label instructions, best practice guidelines and follow Fungicide Resistance Action Committee (FRAC) guidance. In the UK, fungicide use is becoming increasingly restricted, following the withdrawal of several commonly used actives. In addition, the maximum number of applications for many fungicide products have been reduced, or the duration of harvest intervals increased. Peony are hand harvested and operator exposure risks must be considered when developing fungicide programmes.

Many fungicides are available to treat peony botrytis, covering multiple active ingredients and several modes of action (Table 2). Over the course of a season, a peony crop will receive four (or more) fungicide applications for botrytis control, dependent on conditions and varietal susceptibility. The first fungicide application should be a preventative, systemic treatment, applied at stem emergence to protect developing shoots. This targets *B. paeoniae* conidia originating from germinating sclerotia.

Further fungicide applications may be applied as frequently as every 14 days after bud formation (targeting *B. paeoniae* and *B. cinerea*). However, additional applications may be necessary during wet periods, or to protect crops following damage from high winds, frost, heavy rain or hail. Fungicide application prior to harvest will suppress the inoculum present on buds, reducing post-harvest rots and supermarket rejections. Harvested plants need to be treated after cutting is complete, protecting the wound sites which are susceptible to pathogen invasion. Further fungicide use will reduce disease levels as the crop moves into winter, limiting the inoculum (sclerotia) present to infect the next year's growth.

Table 2. Products used by UK peony growers as part of fungicide programmes to manage botrytis in peony (December 2020)

| Product | Active ingredient | FRAC code and resistance risk | Notes |
|---|---|---|---|
| Amistar | Azoxystrobin | 11 - high risk | Systemic, translaminar and protectant fungicide |
| Bravo | Chlorothalonil* | M5 - low risk | Protectant fungicide |
| Manzate | Mancozeb** | M3 - low risk | Protectant fungicide |
| Nativo | Trifloxystrobin + tebuconazole*** | 11 - high risk<br>3 - medium risk | Protectant fungicide<br>Systemic fungicide |
| Signum | Boscalid + pyraclostrobin | 7 - medium risk<br>11 - high risk | Protectant fungicide<br>Systemic fungicide |
| Switch | Cyprodinil + fludioxonil | 9 - medium risk<br>12 - low/medium risk | Broad spectrum fungicide mixture |

*Chlorothalonil was withdrawn from use in 2019, with final use of remaining stock by May 2020.
**At the time of writing the withdrawal of mancozeb has been confirmed by the EU, however a withdrawal notice has not yet been issued by the Chemicals Regulation Division (CRD) confirming grace periods for sale and use in the UK.
***The future of tebuconazole is in doubt as it is a potential endocrine disruptor.

The recent withdrawal of chlorothalonil and mancozeb, as well as other botrytis fungicides including iprodione, will leave gaps in the fungicide programmes used by peony growers. This situation is only likely to worsen with the potential loss of tebuconazole. A greater number of actives are being withdrawn than are being registered and alternative products are needed to maintain disease control.

The AHDB SCEPTREplus programme exists to accelerate the process of testing plant protection products and bringing new products to market, so that the UK industry is better equipped to manage pest, weed and disease control. This includes trialling products not currently authorised for use in certain crop sectors and securing an Extension of Authorisation for Minor Use (EAMU). Efficacy trials on *Botrytis* sp. of ornamentals, including *Botrytis narcissicola* in narcissus have demonstrated the effectiveness of three fungicides, Frupica SC, Prolectus and Sercadis (Table 3), which have since gained EAMU for use in outdoor ornamental production.

Table 3. Fungicide products recently granted EAMUs for use against botrytis in ornamental production (December 2020)

| Product | Active ingredient | FRAC code and resistance risk | Notes |
|---|---|---|---|
| Frupica SC | Mepanipyrim | 9 - medium risk | Protectant fungicide.<br>Applications to be made between 15th May – 30th September, and must only be made after 1st flower (BBCH 49), immediately post trimming. |
| Prolectus | Fenpyrazamine | 17 - low/medium risk | Protectant fungicide.<br>Applications can be made between 1st March and 30th September. Final application: 1 day pre-harvest. |
| Sercadis | Fluxapyroxad | 7 - medium risk | Protectant fungicide.<br>Application must only be made between 1 April and 30 September. |

The restricted application timings of the products in Table 3 are not best suited to all outdoor ornamental production crop cycles and work is underway to adapt these. In addition, Luna Privilege (fluopyram) has been put forward for an EAMU in ornamental production and should be available too.

In the USA, fenhexamid is authorised for use against botrytis, but instances of fenhexamid resistance have been reported in both *B. cinerea* and *B. pseudocinerea* (Garfinkel and Chastagner 2019). This product is not authorised for use in UK ornamentals, and it is unknown if resistant isolates are present in the UK. Alternative products available for use against peony botrytis in the USA, include, Luna Privilege and Collis (boscalid + kresoxim-methyl).

**Biofungicides, elicitors and plant extracts**

Alongside chemical fungicides, biopesticides have been demonstrated to be effective against a range of fungal species and several products are now available for use in outdoor settings in the UK (Table 4). Unlike fungicides, careful consideration on how to apply these products must be made to ensure their use is optimised. Most biofungicides have the benefit of being appropriate for use in an organic setting, leaving no chemical residues. Several have short, or zero day harvest intervals enabling application right up to harvest (protecting harvested buds), as well as avoiding some of the operator exposure risks associated with conventional fungicide use.

Table 4. Biofungicides currently authorised for use in outdoor ornamental production in the UK (December 2020)

| Product | Active ingredient | Type | Maximum no. applications | Notes |
|---|---|---|---|---|
| Amylo X WG | *Bacillus amyloliquefaciens* D747 | Bacterial | 6 | Preventative, apply before, or immediately after the pathogen is first observed. |
| Fytosave | COS-OGA | Plant defence elicitor | 8 | 2-3 preventative applications are required prior to pathogen challenge to elicit a good level of plant defences. |
| Prestop | *Gliocladium catenulatum* | Fungal | 1 | Preventative, antagonistic to other fungi (multiple modes of action). |
| Serenade ASO | *Bacillus subtilis* (strain QST 713) | Bacterial | 6 | Preventative, apply before, or immediately after the pathogen is first observed. |

Several biofungicides are also authorised for use in protected ornamental production, including, Harmonix Ornamental Plant Defence (*Bacillus subtilis*, strain QST 713), Lalstop K61 WP (*Streptomyces griseoviridis,* strain K61), T34 Biocontrol (*Trichoderma asperellum*, strain T34) and Trianum P and Trianum G (both *Trichoderma harzianum*, strain T22), however none of these are authorised for use in an outdoor setting.

Recent AHDB SCEPTREplus work validated the efficacy of several alternative biofungicides against botrytis species, including *B. cinerea* and *B. narcissicola.* These, and others are currently in the process of gaining authorisation, including Romeo (Cerevisane), a plant defence elicitor based on an extract from *Saccharomyces cerevisiae* strain LAS117, and Frutogard (potassium phosphonate and phosphonic acid equivalents) which are anticipated to become available to outdoor ornamental growers in 2021. In addition three other bacterial based (*Bacillus* sp.) biofungicides are in the pipeline for authorisation.

A huge variety of plant extracts exhibiting anti-fungal properties exist, and represent a considerable component of future control strategies. Essential oils including, citrus and thyme oils have been demonstrated to have efficacy against botrytis when applied in crop, as well as during inoculated post-harvest studies (Behdani, Pooyan et al. 2012, Vitoratos, Bilalis et al. 2013). Blad, an oligomer with wide spectrum anti-fungal properties isolated from lupin seed has been shown to significantly reduce botrytis severity in inoculated strawberry when compared with an untreated control (Monteiro, Carreira et al. 2015). In some experiments, when applied at its maximum rate, the Blad-oligomer was as effective, or performed better at reducing the incidence and severity of botrytis than the industry standard. Other plant extracts with anti-botrytis activity include shoot extracts of *Quillaja saponaria* (the soapbark tree) which reduce conidial germination and mycelial growth (Ribera, Cotoras et al. 2008), and seed and leaf extracts of *Moringa oleifera* (the drumstick tree) which caused irreversible surface and ultra-structural changes to botrytis conidia and mycelium morphology (Ahmadu, Ahmad et al. 2020). It is unknown if extracts of *Quillaja saponaria* or *Moringa oleifera* are being investigated by biofungicide companies, but they highlight the diversity of anti-fungal plant extracts that have been identified.

## Proposed efficacy trial work

Table 5 summarises candidate products that have shown efficacy against botrytis on horticultural crops. This list includes conventional and biological products recently authorised for use against botrytis, as well as products which may have been tested on other ornamental plants, but have not yet been tested on peony. It also includes products not yet registered for use in the UK, but have a route to market. Evaluation of newer fungicides and botryticides which lack approval for use on ornamentals, and biological products such as plant extracts, is required in consultation with manufacturers.

Trialling these plants in a commercial setting will validate their efficacy, identify any phytotoxicity concerns and prove to UK peony growers their value in fungicide programmes. This will plug the gaps left by the recent withdrawal of several commonly used fungicides, as well as increasing the number of active/modes of action used in fungicide programmes, enhancing control and resistance management strategies.

Biological products may be applied alone, or in programmes in combination conventional products to demonstrate their place in control programmes.

Table 5. Preliminary list of candidate products to test for efficacy against peony botrytis

| Candidate product | Active ingredient | Manufacturer | Product type |
|---|---|---|---|
| Frutogard | Potassium phosphonate | Certis | Defence elicitor |
| Sercadis | Fluxapyroxad | BASF | Chemical fungicide |
| Fytosave | COS-OGA | Gowan | Defence elicitor |
| Prolectus | Fenpyrazamine | Interfarm | Chemical fungicide |
| Frupica SC | Mepanipyrim | Certis | Chemical fungicide |
| Prev Am | Orange oil | Oro Agri | Plant extract |
| ProBLAD | Blad-oligomer | Certis | Plant extract |
| Romeo | Cerevisane | Fargro | Fungal extract |
| Teldor | Fenhexamid | Bayer | Chemical fungicide |
| Serenade ASO | *Bacillus subtilis* (strain QST 713) | Bayer Crop Science | Bacterial biofungicide |

In addition fungicide manufacturers and the AHDB can be contacted to identify alternative products not yet authorised for use in the UK, but have a clear route to market which could be included in efficacy studies.

# Conclusions

The ability of botrytis to infect such a broad range of species makes it one of the most successful plant pathogens known to exist. As a consequence of this, significant research into the lifecycle and epidemiology of botrytis species has been carried out, and these are now well understood. Recent research in the USA identified an unexpected diversity of botrytis species present on peony, and it is anticipated that a greater diversity of botrytis species infect UK grown peony than is currently known, however the impact of this diversity on disease management is unclear.

In the UK, peony botrytis is well controlled using a mixture of cultivar choice, cultural measures, site hygiene and fungicide inputs. Despite this, the disease remains a problem during wet years where losses can exceed 20%, as well as rejections from customers due to post-harvest rots. This review highlights reducing periods of prolonged leaf wetness, removal of inoculum sources (crop debris) and timely and effective fungicide use as the most effective management strategies to control botrytis in peony.

*Botrytis* species are prone to developing reduced sensitivity, or full resistance to fungicides. Effective control and resistance management strategies, including the use of several different active ingredients and modes of action must be used to mitigate against resistance development. The recent loss of actives used by UK peony growers, including chlorothalonil and mancozeb, leave gaps in the programmes used by most growers. Alternative products with efficacy against botrytis, including Frupica SC, Prolectus and Sercadis are now authorised for use in outdoor ornamental production. Other products, including biofungicides, plant extracts and defence elicitors are also available, or are in the pipeline. The efficacy of these products should be demonstrated to UK cut flower producers in screening trials to increase their rate of uptake, and show the benefit of biological products in spray programmes.

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