Apple Bitter Rot and Glomerella Leaf Spot Caused by *Colletotrichum* Species

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Introduction

Fungal species in the *Colletotrichum* genus can cause bitter rot on apples. The primary culprits belong to the *C. gloeosporioides* species complex (CGSC) and the *C. acutatum* species complex (CASC). These complexes are groups of closely related species in the *Colletotrichum* genus. In Virginia, six *Colletotrichum* species cause apple bitter rot: *C. fructicola, C. chrysophilum, C. siamense* and *C. theobromicola* from CGSC and *C. fioriniae* and *C. nymphaeae* from CASC.

Over the past two decades, bitter rot infections have been increasing in the Mid-Atlantic region, where these pathogens are becoming more prevalent due to increasingly warm and wet weather conditions that favor *Colletotrichum* growth. The region produces approximately $500 million worth of apples every year. Losses to bitter rot can be significant, ranging from 14% to 100% in both conventional and some organic orchards.

Host Range

The CGSC contains about 50 species of *Colletotrichum* and the CASC contains about 40 species, with a majority causing diseases in a wide range of plant hosts. Besides apples, they can cause diseases in other tree fruits such as pear, banana, citrus, avocado, papaya, mango, olive and peach.

Symptoms

In cases of infection on apples, symptoms often manifest as flat to sunken necrotic lesions on fruit, differentiating this rot from other rots which keep the spherical fruit shape (fig. 1). On fruit, the lesions typically range from 0.5 to 6 cm. They are light to dark brown and progress to the core of the fruit in a V-shaped pattern, again differentiating this rot from other typesof rot. Symptoms on leaves, known as Glomerella Leaf Spot (GLS), express as brown angular spots sometimes merging and forming irregular blotches. Early GLS appears as small purple to brown angular spots on the leaf's surface. As symptoms progress, concentric rings become visible on the surface of the spots and purple or chlorotic halos develop around the lesions. Inside the brown spots, irregular-shaped concentric rings differentiate this spot from other leaf spots.

A sign of fungal infection by *Colletotrichum* species on apple fruit is visible as concentric rings on the surface of the fruit lesion consisting of saucer-like fruiting bodies called acervuli, which when dry are black to brown but in humid conditions develop into orange to brown droplets and release numerous pathogen spores called conidia. The CGSC conidia germinate best at temperatures between 25-31 degrees C (77-87.8 degrees F) while the CASC conidia prefer between 21-26 degrees C (69.8-78.8 degrees F). Sporulation in CGSC occurs around 25 degrees C (77 degrees F) and in CASC at 19 degrees C (66.2 degrees F). In both complexes, symptoms are more likely to develop when plant surfaces are unusually wet.

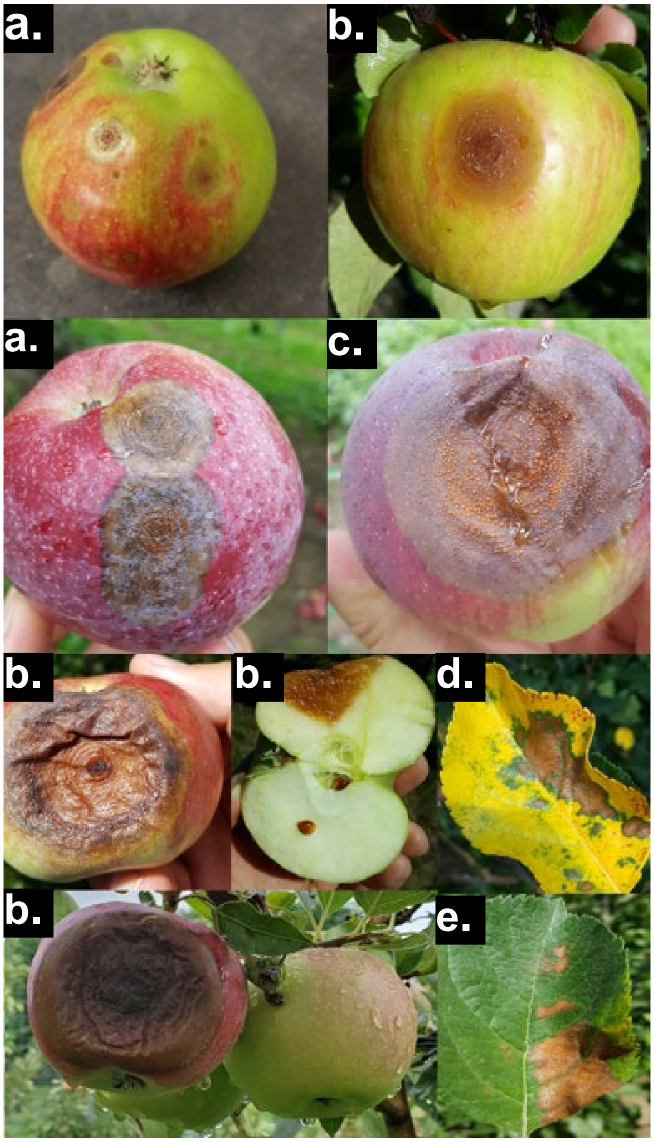

Figure 1. *Colletotrichum* infections on fruit and leaves of various cultivars of apple. a) 'Empire' apple bitter rot. b) 'Honeycrisp' apple bitter rot. c) 'McIntosh' apple bitter rot. d) 'Jonagold' apple leaf with Glomerella Leaf Spot (GLS). e) 'Fuji' apple leaf with GLS. (Photos by S. G. Aćimović, Virginia Tech)

Distribution

The Mid-Atlantic region hosts a diverse range of *Colletotrichum* species with eight species being especially prominent, including *C. fructicola, C. chrysophilum, C. siamense, C. theobromicola, C. gloeosporioides s. s., C. henanense,* and *C. noveboracense* (all from the CGSC), and *C. fioriniae* and *C. nymphaeae* (from the CASC).

C. fructicola is the most prevalent species in Virginia as of 2023 and can be found largely in south and central Virginia. *C. chrysophilum* is the second most common species in the region and has historically been located in the Great Appalachian Valley and Piedmont regions of Virginia (fig. 2). The geographical distribution of *Colletotrichum* species differs likely due to the differences in temperatures for optimal development, growth and sporulation.

The CGSC tends to prefer higher temperatures while the CASC tends to favor cooler temperatures that often come with higher altitudes.

Life Cycle

During early infection periods, *Colletotrichum* species cause no visible damage to fruit tissue while obtaining nutrients from living tissues. This stage is called biotrophic.

As the fruit ripens and increases in sugar content, the fungus switches to a more destructive stage when more prominent symptoms begin to develop, known as the necrotrophic stage. In this stage, fungi break down plant tissue cell walls and feed on the released nutrients. From there, typical bitter rot symptoms develop on the surface of the fruit (fig. 1). Often, orange, brown, or black spots appear on the surface of the rot lesion, which are known as acervuli. These acervuli develop conidiophores which, in turn, grow conidia (also known as conidiospores). Conidia are then spread by rain splash or insects and the next infection cycle begins. There can be multiple generations of conidia developed in one growing season. Conidia are asexual spores and are the most common source of *Colletotrichum* infections. The necrotrophic stage causes a decline in fruit quality and yield, eventually rotting the fruit and rendering it inedible. *Colletotrichum* species are classified as hemibiotrophic plant pathogens because of their dual life cycle.

In rare instances, some *Colletotrichum* infections lead to the development of a sexual stage known as perithecium, a pear-like fungal fruiting body with an opening on top, after a period of overwintering. The perithecium develops sexual spores called ascospores that are then spread by wind or rain splash to susceptible hosts.

After seasonal infection periods have passed, *Colletotrichum* species may overwinter in infected fruit mummies, which are previously infected fruits that have dried up while still hanging on the tree or falling to the ground. The fungi may also overwinter in twigs, buds, and fruit scars, and can do so in the form of a mycelium, conidia, or perithecia. From their overwintering sources, they can continue their growth and disseminate once conditions are favorable.

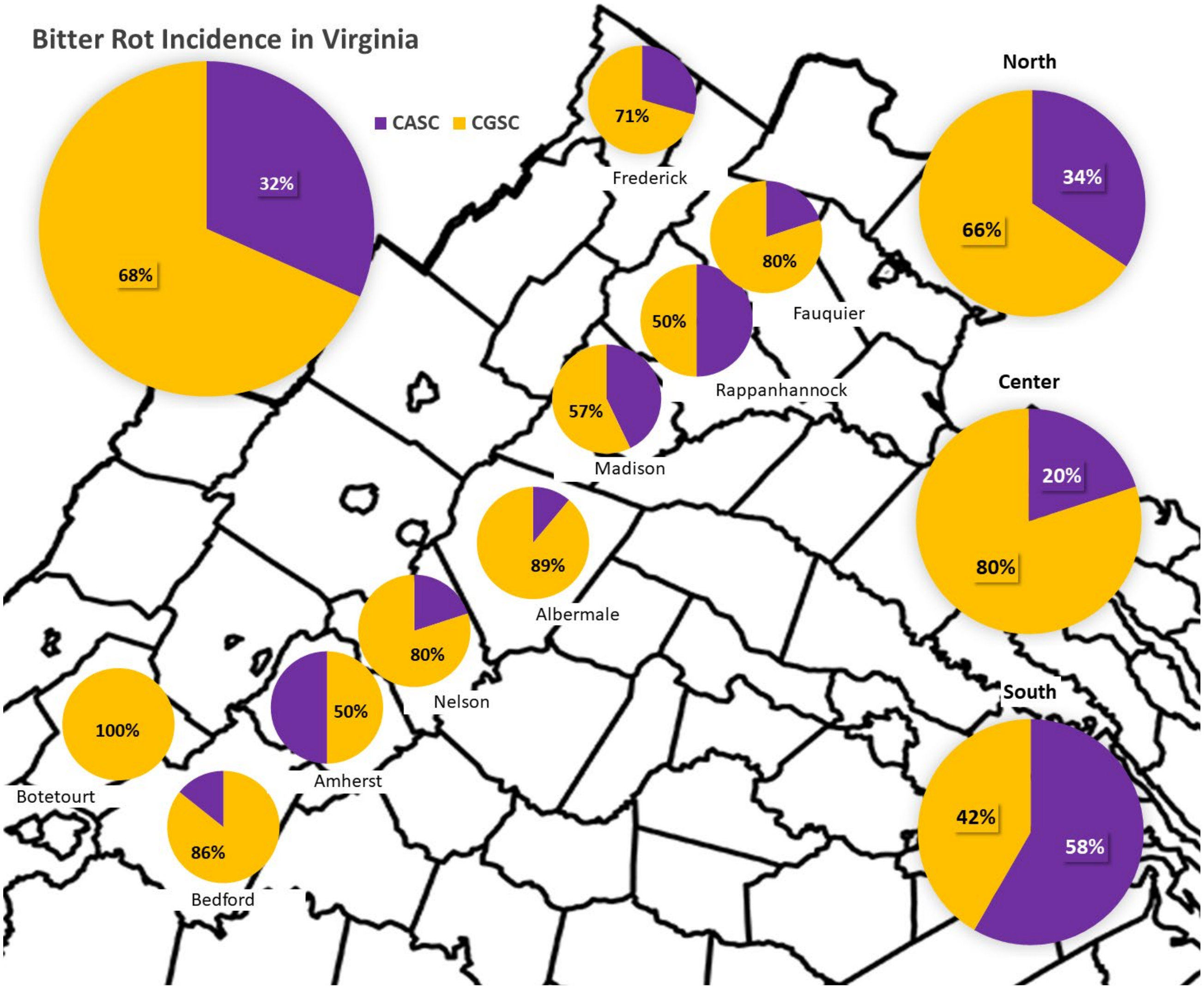

Figure 2. Distribution of *Colletotrichum* species across Virginia. The CGSC makes up around 68% of bitter rot incidence in Virginia. It is mostly found in northern and central Virginia. The CASC is more prominent in regions of higher altitudes where temperatures are cooler. (Diagram by M. Borba, Virginia Tech.)

Cultivar Susceptibility

Visually, some commercial cultivars of apple may seem to be more or less susceptible to bitter rot infections than others. In recent years, there is growing evidence that there is no true resistance in *Malus domestica* against this disease, while resistance has been found in *M. sylvestris* and *M. sieversii*. Past observations indicate that 'Honeycrisp' is a highly susceptible cultivar to infection compared with other cultivars like 'Rome', 'Royal Court', or 'Cameo', which seem less susceptible. Among other highly susceptible cultivars are 'Gala', 'Granny Smith', and 'Fuji', while 'Stayman' and 'Jonagold' tend to be less susceptible. Susceptibility in each cultivar may vary depending on the *Colletotrichum* species responsible for the infection. Cultivar susceptibility remains an important determinant for *Colletotrichum* infection, however, many factors are simultaneously at play leading to visible differences in cultivar responses to bitter rot incidence and onset: apple cultivar skin composition and immunity responses, apple flesh maturation onset and immunity responses, as well as frequency and severity of wet and warm conditions that have developed in the Mid-Atlantic over the past 45 years.

Virulence and Pathogenicity

The major species of *Colletotrichum* that cause apple bitter rot in the Mid-Atlantic vary in their pathogenicity. Pathogenicity describes the ability of the pathogen to cause a disease in its host. Virulence describes the severity or degree of pathogenicity exhibited by a pathogen after its initial establishment.

Two minor species, *C. siamense* and *C. theobromicola*, are among the most virulent species of *Colletotrichum*, while major species such as *C. fructicola* and *C.*

fioriniae are less virulent. Sensitive detection methods for laboratory testing can help growers determine what species of *Colletotrichum* may be present in their orchards. Detection is useful for strain-specific management of bitter rot infections and reducing risks for fungicide resistance in *Colletotrichum* species.

Control of Apple Bitter Rot

Chemical and cultural control are viable avenues for management of apple bitter rot. Some commercial biocontrol agents are currently available. More biocontrol agents have been researched, but few have made it to the shelves of consumers.

Recent studies have focused on the sensitivity of *Colletotrichum* species to commonly used synthetic and biorational fungicides. The EPA and USDA are currently in the process of reevaluating the uses and registration of multi-site fungicides (e.g., ziram, ferbam) and considering the worker exposure and toxicity to mammals. Therefore, a more holistic approach is necessary to control apple bitter rot. Below is a selection of control measures including chemical, biological and cultural that growers should consider when developing management plans for apple bitter rot.

Chemical Control

Chemical control of plant pathogens has long been the most effective, practical approach to bitter rot management since its first appearance in the late 1800s. The Bordeaux mixture and copper carbonates were some of the original materials used for control of apple bitter rot. Since then, the development of carbon-based fungicides with multi-site modes of action like captan, mancozeb, ziram, and ferbam have become dominant. These first became available around the 1960s. In the late 1950s and 1960s, the first single-site synthetic fungicides were introduced. Fungicides are typically classified by mode of action and categorized by the Fungicide Resistance Action Committee (FRAC) for ease of reference and fungicide resistance risk prevention or reduction. Growers are encouraged to rotate FRAC groups to alleviate the risk of fungicide resistance development. Typical FRAC groups for control of apple bitter rot are

- FRAC M – Multisite (captan, ziram).
- FRAC 3 – Demethylation inhibitors in sterol biosynthesis (Triazoles).*
- FRAC 7 – Succinate dehydrogenase inhibitors (Benzovindiflupyr).
- FRAC 11 – Inhibitors of the QoI site of cytochrome b (Strobilurins).
- FRAC 29 – Uncouplers of oxidative phosphorylation (Fluazinam).

* FRAC 3 fungicides are only fair and not excellent in apple bitter rot control. They can reduce the incidence and severity of the disease but may not be as effective as other fungicide classes or under high disease pressure.

These groups act against critical mechanisms in the biosynthetic pathways of the fungi, but pathogens can mutate, leading to single-site fungicide resistance. Resistance to certain FRAC groups may vary based on species and geographic location. For example, *C. fioriniae* isolates from Kentucky were less sensitive to FRAC groups 1, 3, 11, and M than *C. fructicola*. Fungicides can be additionally classified as “systemic” or “contact” based on their mobility in the plant. Systemic (mobile/curative) fungicides are absorbed by the plant to provide a level of internal protection. Fungicides like pyraclostrobin (FRAC 11, Merivon, Pristine) are considered systemic. Contact (protective) fungicides, on the other hand, are only effective at controlling pathogens on the surface of the plant. These fungicides require higher rates for applications on apple and include products like captan, ziram and mancozeb (FRAC M).

In a 2020 screen of fungicide sensitivity, the primary FRAC groups for bitter rot control were evaluated and compiled. Table 1 summarizes those findings and gives recommendations for use in bitter rot management. More recent, unpublished studies conducted in 2022 and 2023 showed FRAC 11 fungicides like Flint Extra (2.9 fluid ounces per acre) and pyraclostrobin (11.84 ounces per acre) were very effective at reducing the incidence of apple bitter rot. Of the FRAC 11 fungicides tested, Sovran (6.4 fluid ounces per acre) was the least effective, allowing a 10% to 30% incidence of bitter rot across two years. Out of all FRAC 7 fungicides tested so far, only Aprovia (5.5 and 7 fluid ounces per acre) was as effective as ferbam (4.6 pounds per acre) at reducing bitter rot incidence in both 2022 and 2023. FRAC 29 fungicide Omega 500 was effective at reducing bitter rot incidence at a high rate of application (13.8 fluid ounces per acre) and as effective as ziram (6 pounds per acre) and captan (3 pounds per acre) when applied at a lower rate of application (6.9 fluid ounces per acre).

Table 1. Recommendations for FRAC code fungicides.

FRAC Group	Recommended?
M	Yes – captan, ziram, ferbam
1	No, CGSC has high risk of resistance, ineffective in field trials
3	No – Fair to poor suppression in field trials
7	Yes – benzovindiflupyr (Aprovia) only. Both low and high rates are effective. Most bitter rot species are insensitive to all other FRAC 7 fungicides.
9	No – poor suppression in field trials
11	Yes – pyraclostrobin and trifloxystrobin. Both work well when premixed with FRAC 7 (Pristine, Merivon and Luna Sensation, respectively). Kresoxim-methyl (Sovran) has weaker efficacy in comparison to the two above. Picoxystrobin (Academy) also has high efficacy in storage conditions.
12	Varies – High efficacy of fludioxonil in postharvest fruit storage conditions (Scholar); little to no efficacy in field conditions (Switch).
29	Yes – fluazinam (Omega) is applied at a high rate under high disease pressure. Lower rate has good efficacy under low disease pressure.

Cultural Control

Cultural control is useful when it targets key transitional periods in the fungal life cycle. Figure 3 highlights the key control points for cultural management of apple bitter rot.

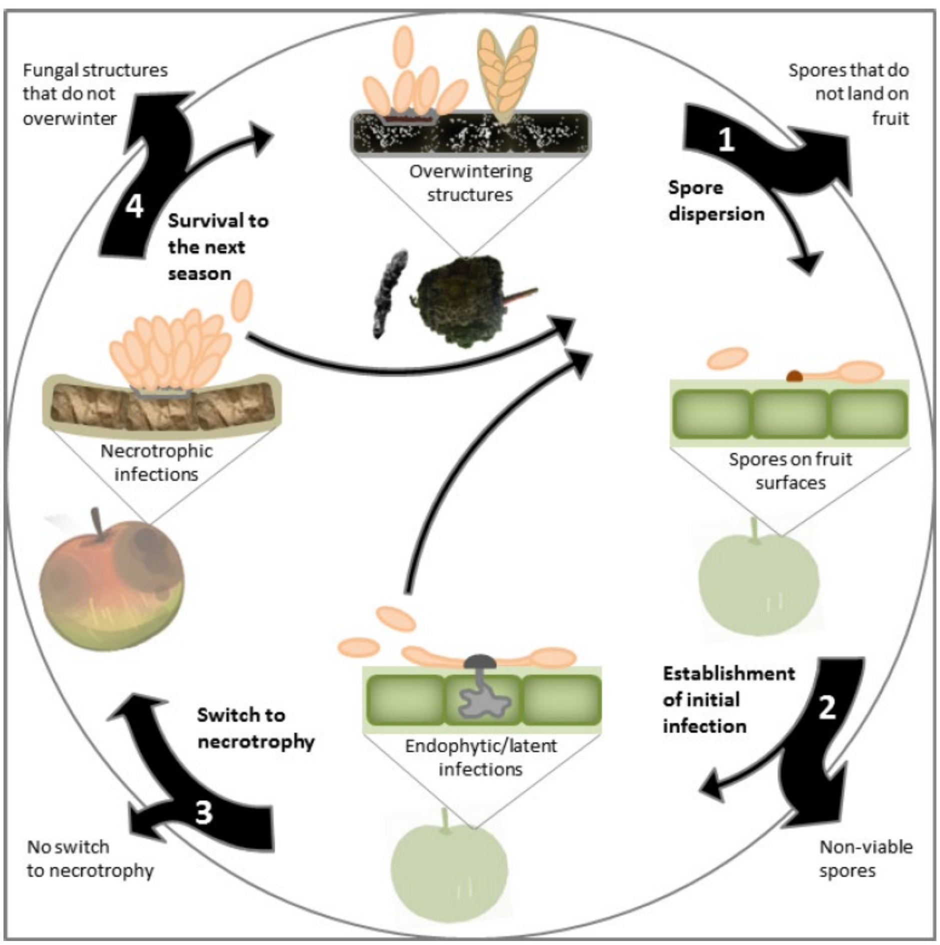

Figure 3. Key control points in the life cycle for cultural management of *Colletotrichum*. (Diagram courtesy of P. Martin, Fruit Research and Extension Center, Penn State.

During the spore dispersal period of the life cycle, fungal spores may land on the fruit surface, which could lead to future infections. Effective control measures involve reducing the number of spores that are produced or that hit the apple's surface. For example, irrigating under the canopy with drip irrigation prevents spore dispersal by water splash.

Initial infections can be reduced through resistant cultivar selection and canopy pruning. It's best to select cultivars that naturally have a lower susceptibility to infection (usually those with hardy fruit skin) and to keep the tree canopies open and well-ventilated by good pruning to reduce surface wetness. Keeping low plant surface wetness reduces the chance of optimal conditions for *Colletotrichum* spore germination. Canopy pruning allows for applied fungicides to penetrate deeper into the canopy, providing better fruit and leaf coverage.

Finally, selecting a good planting site may reduce the chance of infection. By planting on hilltops instead of valleys, trees receive more favorable wind conditions that keep droplets from settling and moisture from accumulating.

After initial infections have been established in the fruit, it is no longer possible to control the infection with nonsystemic fungicides. Surface wetness conditions matter less because the pathogen can gain the moisture it needs from the fruit. Aside from the use of systemic fungicides close to the infection event, very little can be done to control the pathogen's development. Often, fruit ripening facilitates the pathogen's switch from its latent, biotrophic life cycle to the damaging, necrotrophic life cycle. The increase in soluble sugars that accompany the ripening processes provides the fungus with a rich nutrient source, which it uses to fuel its sporulation and further fruit destruction.

Once the infection has passed, both CGSC and CASC may overwinter in infected fruit mummies, twigs, buds and fruit scars. Removal of mummified fruit and diseased twigs from the tree canopies and their destruction is an important step in reducing the presence of bitter rot in orchards. Buds and fruit scars cannot be removed without impacting future yields, so overwintering sources for bitter rot can only be reduced, not completely eliminated.

Biological Control

Biological control agents are microorganisms that are applied to outcompete pathogenic organisms while maintaining plant health. This approach offers an alternative to managing bitter rot infections when compared with traditional chemical controls. Biological control organisms can be broken up into two categories: bacteria and fungi. The organisms noted below are effective at controlling *Colletotrichum,* but many of the biocontrol agents have not been tested for efficacy in the field, or their efficacy can vary widely depending on location, presumably due to environmental conditions.

Bacteria

Some species of *Bacillus* are capable of reducing either disease incidence or pathogen colony growth, or both. For example, *B. subtilis* (Serenade ASO) can reduce the incidence of bitter rot (caused by CASC) by 78-83%. Laboratory-based studies show that there are other plausible options for biocontrol, although none have been formulated yet as commercial products. These include

- For CASC: *Paenibacillus polymyxa* (79% incidence reduction), *Serratia marcescens* (78% growth reduction), and *Bacillus megaterium* (95% growth reduction).
- For CGSC: *Bacillus subtillis* (80% incidence and 60% growth reduction), *Amycolatopsis* sp. (94% growth reduction), and *Paenibacillus polymyxa* (84% incidence and 60% growth reduction).

These strains may act as biocontrol agents, but have not been tested in field conditions and have not been formulated for commercial use. Biocontrol options that reduce *Colletotrichum* growth may be useful as a preventative measure because they compete with the pathogen for nutrients and thus inhibit symptom development.

Fungi

Yeasts and filamentous fungi also offer promising avenues for controlling bitter rot infections. Species within CASC can be managed by *Candida pyralidae, Cryptococcus laurentii, Metschnikowia pulcherrima,* and *Pichia kluyveri* (all of which provide 100% incidence reduction). Species withing CGSC can be managed by *Epicoccum dendrobii*, which also provides 100% incidence reduction.

Commercial Biocontrol Agents

These biocontrol agents work well in laboratory settings but there are only a few available products for commercial use and their efficacy so far is inconsistent from year to year, or insufficient when spray is applied at 14- to 21-day intervals.

- Serenade ASO – *Bacillus subtilis* QST713
- DoubleNickel55 – *B. amyloliquefaciens* D747
- Theia – *B. subtilis* AFS032321
- Howler – *Pseudomonas chlororaphis* AFS009

Disclaimer

Commercial products are named in this publication for informational purposes only. Virginia Cooperative Extension does not endorse these products and does not intend to discriminate against other products, which also may be suitable.

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