One Disease Many Causes: The Key *Colletotrichum* Species Causing Apple Bitter Rot in New York, Pennsylvania and Virginia, Their Distribution, Habitats and Management Options

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Bitter rot will continue to be an issue for growers for the foreseeable future considering the observed climate trends and consumer demand for susceptible cultivars like Honeycrisp. Our research has shown the most common species causing this disease in the mid-Atlantic is *Colletotrichum fioriniae* but other species are also present. We have also identified the most effective fungicides to keep this troublesome disease in check.

Apple bitter rot is a widespread disease in the East coast and Midwest states of the USA, occurring as far north as Ontario, Canada (Sutton et al. 2014; Celetti 2016). It has been known from the late 1800s to plant pathologists in the U.S., who reported that bitter rot is a destructive disease that can infect apples during any period of the season when hot, humid weather prevails (Alwood 1894; Burrill 1907). Burrill (1907) estimated losses to apple bitter rot in the U.S. to $276 million a year, expressed in today's dollar value (CPI Inflation Calculator). In New York (NY), apple fruit losses to bitter rot usually range between 14 to 25%, but in very wet years can reach 60% in poorly protected conventional orchards and up to 100% in organic orchards (Aćimović 2018; Iungerman 2013). The most affected cultivars in NY from 2017 to 2019 were Honeycrisp, Gala, Fuji, Empire, McIntosh, Enterprise, Idared and Crimson Crisp. Losses in NY in 2017 were up to 80% on Asian pear and between 2 to 10% on European pear (Pavlović et al. 2019). In 2018, losses to bitter rot in Pennsylvania (PA) ranged from 5 to 100%, with cv. Honeycrisp and Empire most affected (Peter, *personal observations*). In Kentucky, apple losses on average are 30%, with some orchards a complete loss (Gauthier et al. 2017; McCulloch et al. 2019). In North Carolina losses can reach 100% (Villani, *personal communication,* Mertz 2019).

Bitter rot is favored by warm, wet and humid weather conditions during late spring and summer and can occur both in the orchard and after storage as a postharvest decay (Biggs & Miller 2001; Sutton et al. 2014; Rosenberger 2016). On apples and pears this disease can be caused by at least 19 different fungal species of the genus *Colletotrichum*. Many of these species used to be called *Glomerella cingulata*, a name that is still found on some fungicide labels. These species largely belong to three different species complexes (groups): (1) *Colletotrichum acutatum* species complex, (2) *Colletotrichum gloeosporioides* species complex and (3) *Colletotrichum boninense* species complex, with majority of apple pathogens being in the first two complexes. In general, species in the *C. acutatum* species complex (CASC) have lower optimal temperatures (around 77°F) than the species in the *C. gloeosporioides* species complex (CGSC) (around 86°F), which makes them more prevalent in cooler and warmer growing regions of the world, respectively, although their distribution ranges are highly overlapping (Damm et al. 2012; Weir et al. 2012; Dowling et al. 2020). Overall, the symptoms of bitter rot on apple fruit caused by these various *Colletotrichum* species are almost identical (Fig. 1), however, the pathogen biology and the effective management strategies can differ significantly among these species and species complexes (Rosenberger 2016).

Colletotrichum species in southeastern US and Brazil can also cause a leaf disease called Glomerella leaf spot (GLS) which can rapidly defoliate Golden Delicious and Gala trees, although Pink Lady, Jonagold, Goldrush, Pristine and Granny Smith can also be severely infected (González et al. 2006; Rosenberger 2012; Velho et al. 2015; Aćimović 2016, *personal observations*); Villani 2018. *Colletotrichum* species in NY have occasionally been found in leaf spots that resemble GLS, but it was not confirmed if these species were actually causing those spots (Beaudoin et al. 2015; Rosenberger 2012).

The same species that cause bitter rot can also cause diseases on over 100 different vegetables and fruits, including ripe rot on grapes and anthracnose in strawberry and blueberry (Damm et al. 2012; Weir et al. 2012). Because of variations between species

Figure 1. Variability in manifestation of bitter rot lesions on apple fruit caused by *Colletotrichum* species depicting unique flat to sunken saucer lesion profile and a tell-tale V-shaped rot appearance in flesh on fruit cross section.

and the possibility that this could allow us to fine-tune our bitter rot management we wanted to determine which *Colletotrichum* fungal species infect apple fruit in the Mid-Atlantic region of NY, PA and surrounding states.

Which Species are Causing Bitter Rot in the Mid-Atlantic Region?

Although bitter rot was present and known to growers in the past, it was unknown which *Colletotrichum* species are the major causes of apple fruit bitter rot in the Mid-Atlantic region. After an extensive, multi-year regional collection of infected fruit from 32 locations in PA, 12 in NY, and 4 in Virginia (VA), and one location each in Ohio, Maryland and Delaware, we isolated the causal fungi and using gene sequencing and phylogenetics, we determined the following species.

Colletotrichum fioriniae from CASC was the most prevalent and widely distributed species to cause apple bitter rot in NY and PA (Fig. 2). About 50 to 65% of isolates in NY exhibited the distinct salmon to red colony color, fusiform spores, and slower growth rate on potato dextrose agar (PDA) medium that is characteristic of *C. fioriniae* (Fig. 2). Within the CASC we found a single isolate of another species, *C. nymphaeae*, on a farm that was organically managed. *C. nymphaeae* is known as a common cause of strawberry anthracnose (Wang et al. 2019) and causes bitter rot of apple in Kentucky (Leonberger et al. 2019). The dominance of *C. fioriniae* as a bitter rot cause aligns with the previous reports of this species being very common on apple, both in the US (Pennsylvania, Kentucky), and in Croatia and Korea (Ivić et al. 2013; Munir et al. 2016; Park et al. 2018; Kou et al. 2014).

In the CGSC we were surprised to find *C. chrysophilum* and *C. noveboracense* (the latter is a new species we described in Khodadadi et al. 2020) (Fig. 3), with their distribution spanning throughout the Hudson River Valley of NY, south-central and southeastern PA, to the Great Appalachian Valley and Piedmont regions of VA (Fig. 4).

The new species name *noveboracense* is derived from Noveboracum which is New York translated in Latin. The distributions of most prevalent species of *C. fioriniae, C. chrysophilum* and *C. noveboracense* in NY, PA, OH, DE and VA are presented in Fig. 4. The surprise lies in the fact that *C. chrysophilum* has only been recently identified and described as a species in the *Colletotrichum* genus, having been reported as a pathogen of banana and cashew (Vieira et al. 2017; Veloso et al. 2018). An isolate of the new species *C. noveboracense* was previously found in Oklahoma as a leaf endophyte of black walnut, *Juglans nigra* (Doyle et al. 2013). Some isolates of both of these species have sometimes been misidentified as *C. fructicola* (Hu et al. 2015; Munir et al. 2016; Chen et al. 2016; Khodadadi et al. 2020).

Also in the CGSC and in addition to the two species mentioned above, *C. siamense*, was detected in our apple samples from southern PA and farther south; *C. fructicola* was found only in the two locations in central and southern VA; a single isolate of *C. gloeosporioides* sensu stricto was found on a MD farm that had no summer fungicide applications; and four *C. henanense* isolates were found in a conventionally managed farm in PA with diverse tree and berry fruit (Fig. 4).

Because these species are more prevalent in the south, it is possible that climate change (Kunkel et al. 2013; NRCC 2019) has favored the expansion of these warm climate pathogens into the northeastern U.S. (Bebber et al. 2013). In 2018, precipitation

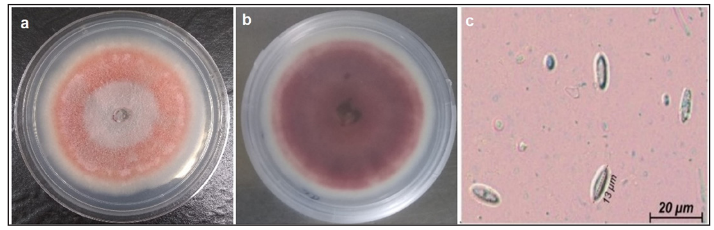

Figure 2. Morphological characteristics (colony color, conidial shape) of *Colletotrichum fioriniae Colletotrichum* isolated from bitter rot-infected apple fruit: (a) Front, (b) Reverse, (c) Conidial shape. (From: Khodadadi et al. 2020).

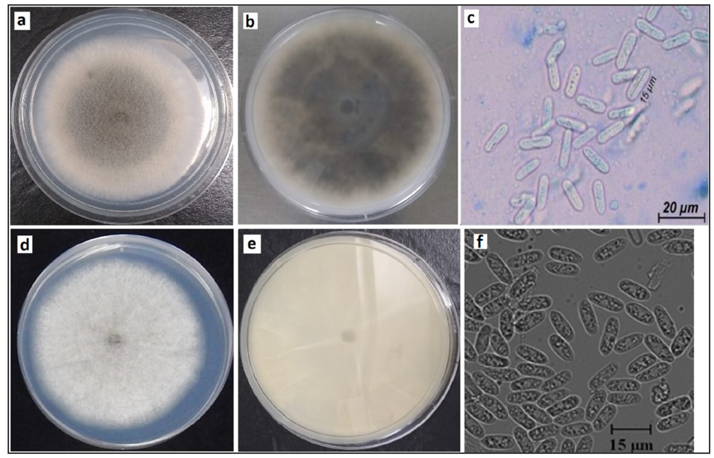

Figure 3. Morphological characteristics (colony color, conidial shape) of *Colletotrichum chrysophilum* (a, b, c) and *C. noveboracense* isolated from bitter rot infected apple fruit (d, e, f) (From: Khodadadi et al. 2020).

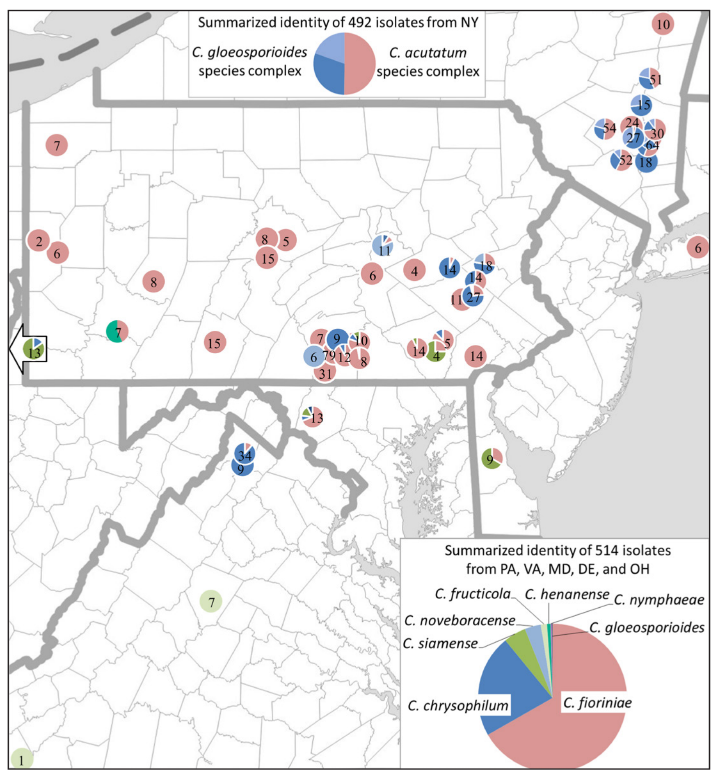

Figure 4. Map of sampling area with pie-charts at bitter rot collection locations showing the identity of species from that location. The number in the pie-chart is the number of *Colletotrichum* fungal isolates obtained from that location. Isolates from NY were identified based on morphology and species complex specific PCR. Isolates from other locations were identified based on gene sequencing (From Martin et al. 2021).

in 90% of NY state was more than 10 inches above average, with some regions more than 20 inches above average (NRCC 2019; Aćimović & Meredith 2019). PA recorded its wettest year on record in 2018, with 63.6 inches of precipitation statewide (with some regions receiving significantly more precipitation), which was 20+ inches more precipitation for an average year (NOAA). Between 1895 and 2011, temperatures in the Northeastern U.S. increased by 2°F (0.16°F/decade), while annual precipitation increased by about 5.0 inches, or 0.4 inches per decade (Kunkel et al. 2013). Between 1958 and 2010, the Northeast had a more than 70% increase in precipitation (Groisman et al. 2013). In South Carolina, average temperature has increased 0.5°F since the early 20th century and extreme rain deposits are projected to enlarge (Runkle et al. 2017). From 1895, annual total rainfall in the AL, FL, and GA has increased about 10% during the past century (Florida Climate Center, 2019). Therefore, environmental conditions on the East Coast are highly favorable for bitter rot outbreaks because warmer and wetter weather patterns predominate (Coakley et al. 1999; Hayhoe et al. 2007; Frumhoff et al. 2007; Groisman et al. 2013).

It is important to appreciate the diversity of *Colletotrichum* species causing apple bitter rot in the Mid-Atlantic, however, the core tenants for management recommendations most likely will be consistent. Knowing all the causal species of bitter rot in a certain region or an apple farm is significant for research purposes because different *Colletotrichum* species differ in their infective aggressiveness i.e. virulence, sensitivity to fungicides, temperature requirements, and very likely the mechanisms through which they develop resistance to fungicides. All these traits are critical for successful management of these and other fungal species.

What Are the Lifestyles and Habitats of *Colletotrichum fioriniae*?

The *Colletotrichum* species that cause bitter rot are known as hemibiotrophs, which means that the initial penetration of plant tissue is followed by a period of time known as the biotrophic, latent, or quiescent phase, after which rot symptoms become visible, which is known as the necrotrophic phase. This means that even though bitter rot might not be observed until close to or after harvest, the initial infection could have happened much earlier in the growing season. To complicate things further, *Colletotrichum* species can grow on and inside of many different plants without ever causing disease, in which case they are considered epiphytes or endophytes (epi means on, endo means inside, phyte means plant). These plants could then serve as hosts for these *Colletotrichum* species, which could spread to nearby orchards and fields. In our effort to better understand the lifestyles of the *Colletotrichum* species that cause bitter rot, we chose to focus on *C. fioriniae*, the most common species causing bitter rot in the Mid-Atlantic region.

Since *C. fioriniae* was previously isolated from the leaves of forest plants (Marcelino et al. 2009), we decided to see if we could trap any conidia (asexual spores) of this fungus in the forest and compare it with how many conidia we could trap in the orchard. We used the molecular-based pathogen diagnostic method called q-PCR to test over 500 samples from heavily bitter-rot-infected apple orchards and nearby forest woodlots over two summers. While we were expecting to find some *C. fioriniae* conidia in the forest, we were surprised to find that our forest spore traps captured more conidia than the traps in the orchards (Martin & Peter 2020).

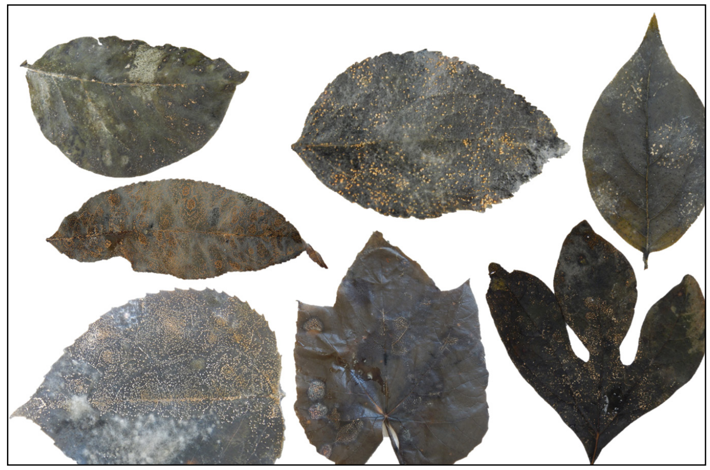

Figure 5. Examples of leaves of various orchard and forest plants showing masses of *C. fioriniae* conidia that are visible as tiny orange dots. Clockwise from lower left the leaves are from quaking aspen, black cherry, poison ivy, apple, Amur honeysuckle, sassafras, and wild grape.

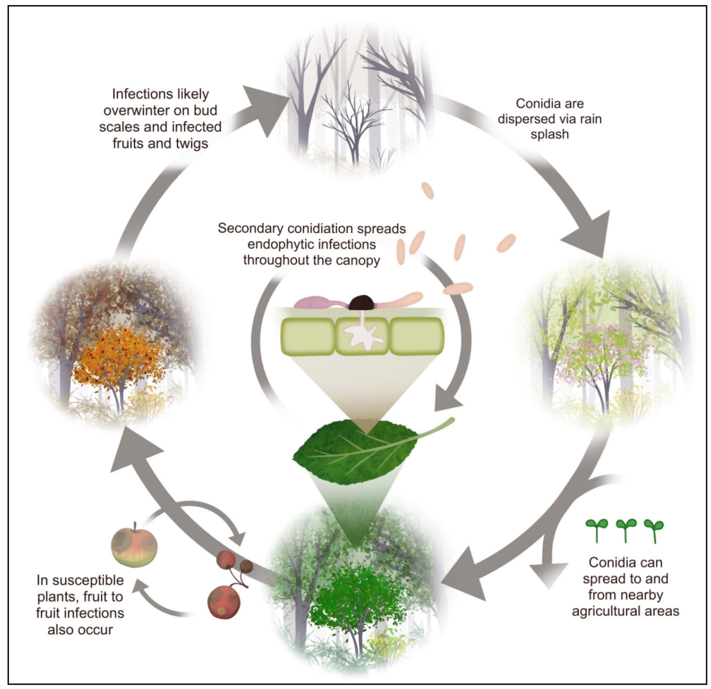

Figure 6. Hypothesized generalized infection cycle for *C. fioriniae*. This infection cycle is based mostly on endophytic leaf infections, but includes necrotrophic fruit infections where susceptible fruits are present (From Martin et al. 2020).

To confirm our conidia trap counts were correct, we isolated directly from leaves using a freezing method, in which the leaves were surface disinfected to kill microbes on the surface, frozen to kill the leaves but not the fungus, and incubated for two weeks at 70 to 72 F° to allow any fungi inside the leaf to emerge and sporulate. We tested over 1,000 leaves of apple and 24 different forest plant species and found *C. fioriniae* was present in many of them (Martin & Peter 2020; example photos in Fig. 5). *C. fioriniae* isolates from leaves were pathogenic on apple fruit and multi-locus DNA sequence analysis showed 100% identity to *C. fioriniae* between most isolates from leaves and those from diseased fruit. We therefore concluded that *C. fioriniae* is primarily a leaf endophyte and present the conclusion as a generalized *C. fioriniae* infection cycle that provides an updated framework for its integrated management in agricultural systems (Fig. 6).

The implications of this discovery are that most of the *C. fioriniae* populations in orchards likely originally came from nearby fence rows and forests. However, since *C. fioriniae* conidia are dispersed by rain splashing and most conidia land within a few yards of their source, conidia would only come from fence rows and forests during extreme rain and wind events. The vast majority of conidia would cycle within the orchard due to their limited mobility. It also showed that *C. fioriniae* can live as an endophyte in apple leaves without causing any disease symptoms, and it is likely that these endophytic apple leaf infections produce some of the conidia that infect the fruit. C. *fioriniae* did not seem to be causing disease in the forest plants from which it was isolated, suggesting these plants must be genetically resistant to disease by *C. fioriniae*. Combined with the variation observed in susceptibility of apple cultivars, this indicates that selecting apple cultivars that are less susceptible to bitter rot may be the best long-term bitter rot management strategy since eliminating the pathogen infection sources is not feasible.

Do We Have Fungicide Resistance in *Colletotrichum* Species Found in the Mid-Atlantic?

Due to the ability of *C. fioriniae* to inhabit apple leaves without causing any disease symptoms on these leaves, the fungus likely gets exposed to all fungicides used to manage apple scab and powdery mildew. If fungicide resistance management for apple scab and powdery mildew is being followed, this will also reduce the risk of fungicide resistance in *Colletotrichum* species.

An important fungicide group of particular concern for resistance in many different pathogen species is the Quinine Outside Inhibitors (QoI-s), often referred to as strobilurins or FRAC group 11 fungicides. Plant pathogens are prone to QoI fungicide resistance, which is due to mutations (G143A, F129L) in the cytochrome *b* gene. These mutations seem stable in plant pathogen populations and do not induce a fitness penalty. Therefore, fungicide resistance will persist in a population once present. Because of the threat of QoI resistance, fungicide label requirements limit commercial farms to only four applications per season of any QoI fungicide (Flint Extra, Sovran, Luna Sensation, Pristine, Merivon). Over the last five years, numerous reports warn that *Colletotrichum* species from apples and other fruit crops around the world are developing resistance to QoI fungicides (Koenig et al. 2012; Forcelini et al. 2016; Kim et al. 2016; Nita & Bly 2016; Munir et al. 2016). However, the prevalence in the Mid-Atlantic of QoI resistance is low to-date and has been confirmed only in a few *C. siamense* isolates from orchards in Maryland (Martin et al. 2020) and Illinois (Chechi et al. 2019); resistance has yet to be detected in *C. fiorinae* in the Eastern U.S. Consequently, Mid-Atlantic fruit growers are in an excellent position to be proactive in limiting the progression of fungicide resistance among the *Colletotrichum* species populations that exist in our region.

What Fungicides Are Most Effective for Bitter Rot Control?

Taking into consideration the issue of fungicide resistance management, we wanted to better understand the scope of the efficacy of available fungicides to control bitter rot. In 2020, we evaluated 13 different fungicide spray treatments with 12 of them consisting of a single active ingredient, or its different rate (Table 1). We selected these fungicides based on their novelty or a promising potential for bitter rot control in previous trials (Villani 2017). The treatments listed in Table 1 were initiated on 4 Jun and applied subsequently at 9 to 23-day intervals depending on the weather conditions. Rain amounts were recorded for Highland NY via an on-site NEWA weather station: http://newa.cornell.edu/index.php?page=all-weather-data. We used 19-year-old apple trees, which included cultivars Honeycrisp/M.9(337)/EMLA111, Cameo/B.9, and Royal Court on M.9(337)/EMLA111 in the experimental orchard at Cornell University's Hudson Valley Research Laboratory in Highland, NY (41°44'59.6"N, 73°58'03.4"W), with 8 ft between trees, 14 ft between three-cultivar plots, and 25 ft between rows. Treatments were replicated on three trees of each cultivar using a complete randomized design (CRD). Each replicate plot consisted of all three cultivars stated above. To secure good canopy coverage, all spray treatments were spray applied dilute to drip (300 gal/A) using a tractor-carried brass handgun sprayer (Rear's Pak-Tank 100-gal sprayer, 250 PSI). Various insecticides for protection against insect pest were applied according to entomologist recommendations for 2020 season: https://blogs.cornell.edu/jentsch/.

We prepared *C. fioriniae* inoculum for this trial by inoculating mature apple fruit of Honeycrisp in the laboratory with *C. fioriniae* mycelial plugs and incubating the fruit at 25°C (77°F) in the dark for 15 days or until bitter rot lesions yielded fungal spores on the fruit surface. Once sporulation was detected on all fruit, the inoculated fruit were placed in onion bags, which were then hung as inoculum in the middle top of the canopy of each Honeycrisp and Royal Court tree on 5 Jun 2020, being fungicide-treated or untreated (growth stage: fruit size up to 15mm), and of each Cameo tree on 7 Aug 2020 (growth stage: fruit about 60%

Table 1. Treatments for control of apple bitter rot (*Colletotrichum fioriniae*) evaluated in Highland NY in 2020 including new and classic SDHI fungicides (FRAC): indiflin (Excalia), pydiflumetofen (Miravis), benzovindiflupyr (Aprovia), fluxapyroxad (Sercadis), pyraziflumid, and penthiopyrad (Fontelis; a DMI): mefentrifluconazole (Cevya; a QoI): trifloxystrobin (Flint Extra); captan (Captan 80 WDG); fluazinam (Omega 500); and polyoxin D zinc salt (OSO 5% SC).

#	Treatment/ Rate per Acre	Dates of Application/ Products and Rates per Acre
1	Untreated Control	4, 13 Jun; 6, 21 Jul; 3, 20 Aug; 3 Sep; 1 Oct
2	Captan 80 WDG 3 lb	
3	Omega 500 13.8 fl oz	
4	Omega 500 (Low) 6.9 fl oz	
5	Excalia 3 fl oz	
6	Miravis 3.42 fl oz	
7	Aprovia 5.5. fl oz	
8	Fontelis 16 fl oz	
9	Sercadis 4.5 fl oz	
10	Pyraziflumid 4.65 fl oz	
11	Cevya 5 fl oz	
12	Oso 5% SC 10 fl oz	
13	Flint Extra 2.9 fl oz	
14	Grower's Standard	4 Jun: Topsin M 1 lb + Captan 80 WDG 2.5 lb 13 Jun: Prophyt 64 fl oz + Captan 80 WDG 2.5 lb 6 Jul: Flint Extra 2.9 oz + Captan 80 WDG 2.5 lb 21 Jul: Pristine 14.5 oz + Captan 80 WDG 2.5 lb 3 Aug: Captan 80 WDG 3 lb 20 Aug: Merivon 5.5. fl oz + Captan 80 WDG 2.5 lb 3 Sep: Merivon 5.5. fl oz + Captan 80 WDG 2.5 lb 1 Oct: Captan 80 WDG 3 lb

final size). The inoculation dates were offset intentionally due to different average maturation times of these cultivars in the lower Hudson River Valley, which is early to mid-September for Honeycrisp, mid- to late September for Royal Court, and mid- to late October for Cameo.

The fruit bitter rot incidence was visually rated on 9 Sep 2020 (Fig. 7), which is the usual time when harvest of Honeycrisp starts, and second time on 14 Oct 2020 (Fig. 8), which is the usual time when harvest of Cameo starts. The mean percent bitter rot incidence on apple fruit was calculated from the number of fruit with bitter rot lesions versus the number of fruit without lesions on 150 fruit for each cultivar (50 fruit per each tree). Disease incidences on fruit for each treatment were subjected to LSD tests (α=0.05) for a CRD (Fig 7, 8).

Consistently across both rating dates of 9 Sep and 14 Oct, fungicides Captan 80 WDG, Aprovia, Omega 500, Flint Extra and Grower's Standard performed the best on Honeycrisp (Figs 7, 8), which is the most susceptible cultivar to bitter rot (Biggs & Miller 2001). On Honeycrisp (Fig. 8), captan provided significant bitter rot reduction, i.e. 97.8% control, while Aprovia (benzovindiflupyr) gave 90.1% control, compared to the untreated control, which agrees with previous report of benzovindiflupyr being effective on CASC (Ishii et al. 2016). Omega 500 high and low rates gave 90.3% and 78.2% control, respectively, compared to the untreated control, which agrees with previous trials and recommendations (Villani 2017). Grower's standard showed 100% control and Flint Extra showed 95% control, compared to the untreated control (Fig. 8). Keep in mind that Aprovia cannot be applied within 30 days of harvest and has been primarily intended for controlling apple scab early in the spring. However, including one or two applications of Aprovia, mixed with captan or ziram, during July or early August (30 days before harvest), might help to slow or prevent buildup of potential QoI-resistant individuals in *C. fioriniae* populations in apple orchards (Rosenberger 2017). We are happy to see that the QoI fungicide Flint Extra showed high efficacy in bitter rot control and allowed only 3.7% disease incidence on Honeycrisp, indicating that the *C. fioriniae* is susceptible to QoI-s (Fig. 8). Nevertheless, we intend to repeat the trial in 2021 to confirm the consistency of these results.

On cv. Royal Court, Captan 80 WDG, Aprovia and Flint Extra each provided 100% control (Fig. 8). On cv. Royal Court, Omega 500 high and low rates gave 87.4 and 96% control, respectively, while Grower's Standard provided control of 94% (Fig. 8). On cv. Cameo, Captan 80 WDG and Omega 500 high rate provided control of 100% each, while Aprovia and Grower's Standard each provided 96% control. On cv. Cameo, Omega 500 low rate gave 88.6% control (Fig. 8). Based on the low bitter rot incidence developing on cvs Cameo and Royal Court (Figs 7, 8), especially in the untreated control (15-20%), it seems that these cvs are less susceptible to bitter rot, agreeing with previous reports based on natural infection pressures (Rosenberger 2012, 2015a).

The large increase in disease incidence on Honeycrisp fruit detected from 9 Sep to 14 Oct (35 days) in the ineffective treatments and untreated control (Figs 7, 8), indicated that prolonged wetting from 11 Sep to 1 Oct in the form of dew and rain events, coupled with lower temperatures (Fig. 9), favored spreading of bitter rot infections and worked in concert with high susceptibility of this fully mature cultivar. Good control of bitter rot was observed on 9 Sep (Fig. 7) for Honeycrisp when Sercadis (79.2%) and Fon-

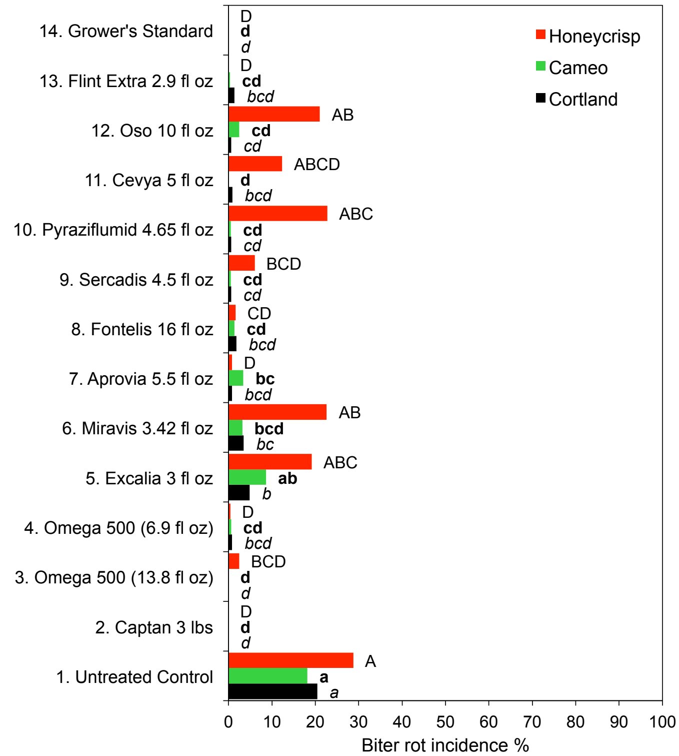

Figure 7. Apple fruit bitter rot control on 9 Sep 2020 on Honeycrisp, Cameo and Royal Court, after 7 consecutive summer applications of individual fungicides or their rates listed in each numbered treatment, except in treatment 14 which consisted of many different fungicides (LSD test, *P* < 0.05). Means within each cultivar i.e. bar color followed by different letters are significantly different.

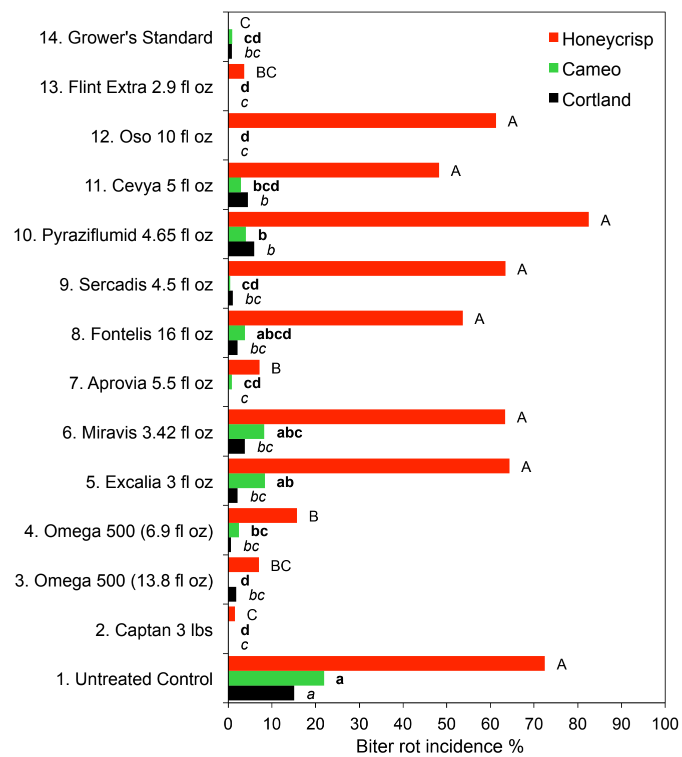

Figure 8. Apple fruit bitter rot control on 14 Oct 2020 on Honeycrisp, Cameo and Royal Court, after 8 consecutive summer applications of individual fungicides or their rates listed in each numbered treatment, except in treatment 14 which consisted of many different fungicides (LSD test, *P* < 0.05). Means within each cultivar i.e. bar color followed by different letters are significantly different.

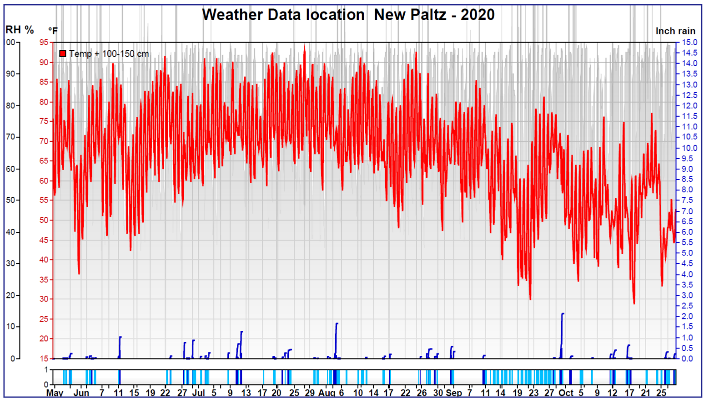

Figure 9. Weather conditions during the bitter rot fungicide trial in 2020 in Highland, NY, recorded by a nearby NEWA weather station in New Paltz, NY. Top graph: red line shows temperatures (left y-axis in red), blue curved lines show rain lengths and amounts in inches (right y-axis in blue), grey background represent relative air humidity (RH) in % (far left y-axis in black). Bottom graph with dates shows the length of rain (dark blue) and of wetting periods after the rain stopped or from dew (light blue).

telis (94.1%) were used, however, this control was transient (Fig. 8). It is possible that if the Honeycrisp fruit were harvested on 9 Sep and immediately cooled below 41°F (5°C), bitter rot might not develop and become a problem during storage or after sale (Brooks & Cooley 1917). The failure of Fontelis to maintain the level of control on 14 Oct achieved on 9 Sep disagrees with previous work reporting that penthiopyrad has good activity against pathogens in the CASC, and this may be related to the 16 fl oz rate, which is lower than the 20 fl oz rate recommended in the Fontelis special use label for bitter rot (Ishii et al. 2016, Yoder et al. 2016a, 2016b). Failure of Sercadis to maintain the level of control on 14 Oct achieved on 9 Sep agrees with previous work showing that the SDHIs fluxapyroxad (Sercadis; one of the two components in Merivon), fluopyram (one of the two components in Luna Sensation) and boscalid (one of the two components in Pristine), are not effective against *C. acutatum* (Ishii et al. 2016). Finally, Sercadis also cannot be applied within 30 days before harvest. Therefore, this narrows the SDHI choice for bitter rot control only to all Aprovia applications with the optimal time for using it in mid-summer when bitter rot begins to build up its symptomless presence in leaves and forms quiescent infections on fruit. Keep in mind that only limited amount of Aprovia (27.6 fl oz/A/year) can be used each year (5 to 4 applications with either 5.5 or 7 fl oz/A). Growers who use Aprovia for apple scab control early in the season may "run out of bullets" and not be able to apply it during summer. Bear in mind that no more than two consecutive applications of Aprovia can be applied on a 7-day interval and that all other applications must be applied no closer than at a 14-day interval. Failure of Cevya to control bitter rot on Honeycrisp aligns with previous observations that DMI fungicides are not as effective for bitter rot control, especially in years with heavy infection pressures (Brannen 2018). In peach orchards, *Colletotrichum* species that were collected in South Carolina and Georgia varied significantly in their susceptibility to DMI fungicides (Chen et al. 2016). However, even though DMI-s like Inspire Super and Indar can provide good control of sooty blotch and flyspeck and fair control of fruit rots during summer, they can contribute selection pressure to DMI-resistant individuals in apple scab fungus populations.

QoI fungicides can be used for control of bitter rot during the summer cover sprays as long as they are applied in a tank mix with a contact fungicide (e.g. captan, ziram or ferbam) just before the warm wetting events that favor this disease, with the last application just before harvest if that specific QoI has zero days pre-harvest interval (Pristine, Merivon). Based on our data, the concept of alternating modes of fungicide action by using Aprovia (FRAC 7), Omega 500 (FRAC 29) at a high rate, and/or QoI fungicides (FRAC 11) in tank mixes with captan, ferbam or ziram, during June, July or early August, to help slow selection pressure for resistance in *Colletotrichum* species in apple orchards, seems a logical choice well supported in published literature.

Below we list summer cover spray combinations you could rotate, with no more than two consecutive applications of any of these combinations (Do not apply Ziram within 14 days of harvest and Ferbam is not recommended for late-season cover sprays on fresh market fruit due to the potential for dark residual spots of Ferbam at harvest. Do not apply Ferbam within 7 days of harvest):

- Captan 80 WDG 2.5 LB/A + Inspire Super* 12 fl oz/A
- Captan 80 WDG @ 2.5 LB/A + Prophyt** 64 FL/A
- Captan 80 WDG @ 3 LB/A + Topsin M** 1 LB/A
- Captan 80 WDG 2.5 LB/A + Flint Extra 2.9 fl oz/A
- Captan 80 WDG 2.5 LB/A + Omega 13.8 fl oz/A
- Captan 80 WDG 2.5 LB/A + Aprovia 5.5 fl oz/A to 7 fl oz/A
- Captan 80 WDG @ 2.5 LB/A + Ferbam 76 WDG or Ferbam Granuflo 4.6 lbs/A
- Captan 80 WDG @ 2.5 LB/A + Ziram 6 lbs/A
- Captan 80 WDG @ 3 LB/A

*Under high disease pressure, DMI fungicides and are not effective for bitter rot control (Brannen 2018).

**Phosphites and thiophanate-methyl are not effective for bitter rot control (Rosenberger 2015b).

Ziram and/or ferbam can be substituted for captan when used with Flint Extra, Aprovia, Omega, Inspire Super, or Topsin M. Remember your cover spray is worth 14 days or 2 inches of rain, whichever comes first. If you do not get rain for 14 days, you can extend the spray interval to 21 days, under the condition that you do not get rain during the 7 additional days.

Bitter rot will continue to be an issue for growers for the foreseeable future considering the observed climate trends and consumer demand for susceptible cultivars. However, growers have tools to be able to keep this troublesome disease in check. In addition to practicing fungicide resistance management and keeping coverage consistent during warm, wet seasons, sanitation practices, such as proper pruning, removal of dead wood and fruit mummies, should not be overlooked. Fungicides are a major line of defense and we have current ongoing studies comparing fungicide sensitivity of *Colletotrichum* species isolates from commercial and unsprayed orchards. By monitoring the prevalence of resistance to the key fungicides we will be able to prevent major fungicide failures and ultimate crop loss.

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