A PHOTOGRAPHIC DIAGNOSTIC GUIDE FOR IDENTIFICATION OF COLD-CLIMATE WINE GRAPE PATHOGENS

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Introduction

Many images used in grape disease diagnostic guides or disease compendia are collected from European wine grape (*Vitis vinifera*). We have often found these images to be inconsistent with symptomology in cold-climate grape hybrids on which the wine-grape industry of Wisconsin is based. There is also a difference in symptomology among commonly grown cultivars. Further, even for a single cultivar, symptoms vary throughout a growing season. These inconsistencies may lead to incorrect field diagnosis and contribute to overspray or application of a product that is not appropriate for the pathogen causing damage. The purpose of this chapter is to i.) illustrate distinctions in disease symptoms seen in common grape cultivars in the cold-climate wine-grape industry and ii.) provide northern grape growers with a season-long visual guide for identifying downy mildew, powdery mildew, and black rot symptoms on cold-climate cultivars.

The images in this guide were collected during the 2015 and 2016 growing seasons at the West Madison Agricultural Research Station in Verona, WI (WMARS, USDA zone 5a) and the Peninsular Agricultural Research Station in Sturgeon Bay, WI (PARS, zone 5b). These two locations represent significant regions for cold-climate viticulture in Wisconsin. Each site has a vineyard consisting of 200 vines (eight cultivars x five randomized replicates x five vines/replicate) established in 2012. The cultivars at each site were 'Brianna,' 'Frontenac,' 'Frontenac gris,' 'La Crescent,' 'LaCrosse,' 'Marquette,' 'St. Croix,' and 'Valiant.' Although typically considered a cold-hardy juice grape rather than a wine grape, 'Valiant' was included as part of the planting as a check cultivar due to previous reports of severe susceptibility to downy mildew, powdery mildew, and black rot (Smiley et al. 2015). These vineyards had been maintained by conventional practices (Bordelon et al. 2016) from the time of their establishment in 2012 through 2014. Starting in 2015, fungicides were withheld from the spray program in both vineyards.

A third vineyard block was included in the study in 2016. The third vineyard was located at PARS and consisted of 144 vines (9 cultivars x 4 randomized replicates x 4 vines/replicate) established in 2008. The cultivars were 'Brianna,' 'Frontenac,' 'Frontenac gris,' 'La Crescent, 'LaCrosse,' 'Léon Millot,' 'Maréchal Foch,' 'Marquette,' and 'Petite Pearl.' This vineyard had been maintained by conventional practices prior to 2016, but in 2016 fungicides were withheld from the spray program.

Aside from the absence of fungicide application, the three vineyards were maintained according to conventional practices (Bordelon et al. 2016). Winter spur pruning took the number of buds down to three buds per established spur, and shoots were thinned in the spring down to three per established spur (about six shoots per foot). Vines were hedged as needed, sucker sprouts were removed, and netting was used to prevent damage from birds during berry ripening. Insecticides were applied as needed at both WMARS and PARS to control grape phylloxera, grape berry moth, and Japanese beetle. All vines were trained in the vertical shoot positioning system at the time of establishment. The three diseases of interest had been reported previously at these locations, so no pathogen spores were added artificially.

Beginning when leaves unfolded in the spring, all vineyards were scouted and photographed one or two times per 2-week period by the same researcher for the duration of the growing season in both 2015 and 2016, ending 2 weeks after harvest. The images shown are representative of diseases observed over 2 years at two distinct locations. However, users of this guide should bear in mind that the appearance of symptoms throughout the growing season may differ at other locations and under different environmental conditions.

Brianna

This 2001 release developed by amateur breeder Elmer Swenson is among the most widely planted white wine grapes in the northern U.S (Tuck and Gartner 2014). We found Brianna to be reliably winter hardy and fruitful in USDA zones 5a and 5b. In our trials, Brianna was moderately susceptible to foliar downy mildew. Although production of spores on Brianna can be heavy, it did not suffer from premature defoliation and carried its canopy to the end of the season, even under heavy infection. Fruit were not visibly affected by the pathogen. Brianna can experience severe powdery mildew both on leaves and fruit, particularly late in the season. Our trials indicate that it is moderately susceptible to black rot (caused by *Guignardia bidwellii*), and severely susceptible to phomopsis cane and leaf spot (caused by *Phomopsis viticola*).

Downy Mildew (*Plasmopara viticola*). Brianna did not suffer from severe early season downy mildew, and the fruit were not affected by the disease. However, downy mildew was observed by July or early August in both 2015 and 2016. Disease ranged from moderate to severe, but vines were not prematurely defoliated by the disease in either 2015 or 2016. Terminal growth at the tips of primary axillary shoots tends to be particularly prone to extensive damage from downy mildew lesions as the season progresses.

MAY, JUNE: downy mildew did not damage Brianna in May or June 2015 or 2016 in our trials

JULY:

Figure 1: Downy mildew oil spots on the upper surface of a Brianna leaf. The oil spot phase of downy mildew on Brianna can be brief, lasting just a few days.

Figure 2: Downy mildew spores on the lower surface of a Brianna leaf. Spore production on Brianna can also be very brief, lasting just a few days. It is common to find symptoms like those pictured below (Figures 3 and 4) instead of actively spore-producing downy mildew.

Figure 3: Dead tissue caused by downy mildew on the upper surface of a Brianna leaf. These lesions are found predominately on young foliage. Older leaves do not typically show the same symptoms.

Figure 4: Spore production is not always visible on the underside of downy mildew lesions. Spores are often depleted from the underside of the lesion by the time a lesion is discovered.

Figure 5: Downy mildew lesions at mixed stages of development. These symptoms are mostly limited to young leaves in the canopy.

Figure 6: Figure 6: Spore production on Brianna tends to be particularly concentrated on younger leaves. Notice the brown spots in the middle of many of the white patches of spores. These are regions in which the spores have already been depleted. Eventually the entire underside of these lesions will be brown and devoid of spore production.

AUGUST:

Figure 7: Downy mildew symptoms on older leaves of Brianna are distinctive. Lesions are dark in color and small, turning black or brown rather than having a prolonged yellow/dirty yellow "oil spot" phase that is seen on other cultivars.

Figure 8: Spore production by downy mildew on older leaves of Brianna is distinctive. Patches of spores have a smaller diameter than is seen on other cultivars, and are limited to older, darker lesions.

Figure 9: Dead spots are easier to find than oil spots later in the season, particularly on young leaves. Axillary shoots are particularly prone to these symptoms.

Figure 10: Older leaves that are severely damaged by downy mildew can become yellow. The black/brown spots following the veins on this otherwise yellow leaf are old downy mildew lesions.

Powdery Mildew (*Erysiphe necator*): Brianna was among the most susceptible cultivars to powdery mildew in both 2015 and 2016. Both fruit and foliage were affected. Rachises of this cultivar are particularly prone to infection by the powdery mildew pathogen. There was no premature defoliation, but damage to rachises and leaves may lead to delayed ripening when disease is severe.

MAY, JUNE: powdery mildew did not damage Brianna in May or June 2015 or 2016 in our trials.

JULY:

Figure 11: White powdery mildew colonies (areas of concentrated spore production) on the upper side of a Brianna leaf. Note that early in the season the colonies are only visible when held in direct sunlight. The shaded portion of the leaf looks green and healthy here in spite of disease that can be seen on the non-shaded portion of the leaf. Move suspected leaves into direct sunlight to

AUGUST:

Figure 12: As the season progresses, white powdery mildew colonies become visible on Brianna even in the shaded regions of the plant. Severely infected leaves become almost entirely covered in light gray fungal growth as individual colonies expand and coalesce. The large holes in the leftmost leaf are not related to powdery mildew.

Figure 13: Late season powdery mildew causes a graying of the canopy, with the oldest leaves in the fruiting zone turning yellow and curling. Premature defoliation does not appear to be a concern on Brianna despite severe disease.

Figure 14: Graying of the upper surface of a Brianna leaf.

Figure 15: Powdery mildew on the rachis of a Brianna cluster.

SEPTEMBER:

Figure 16: Powdery mildew on a Brianna cluster. Powdery mildew on fruit is not necessarily white or powdery. Look for a grey net-like pattern on fruit, which is a result of cell death due to poor expansion of surface cells.

Figure 17: Powdery mildew can affect older leaves in September, particularly if management is neglected following harvest.

Black Rot (*Guignardia bidwellii*). We found Brianna to be moderately susceptible to black rot. Foliage suffered from light damage in 2015 and 2016. Clusters can be heavily damaged by the disease. However, Brianna tends to lose isolated berries in a cluster while the rest of the berries in the same cluster ripen. This pattern contrasts with cultivars such as Frontenac, Valiant, and Marquette, which tend to show widespread damage radiating out from a central diseased berry.

MAY: Black rot symptoms were not observed on Brianna in May 2015 or 2016.

JUNE:

Figure 18: Black rot on upper surface of Brianna leaf. As is the case with most other cultivars, black rot is heavily concentrated on the two to three oldest leaves of shoots at this time of year.

JULY:

Figure 19: Black rot on Brianna berries. Shriveling and mummification of infected fruit progresses rapidly during fruit sizing and development.

Figure 20: Cluster damage is commonly found close to older leaves with black rot damage within the fruiting canopy.

AUGUST:

Figure 21: Black rot mummies on a ripening Brianna cluster.

Figure 22: Brianna berries are notably larger than berries of many other cold-climate cultivars, and tend to form a tight cluster. As the cluster expands, the gaps left by fully mummified berries are often partially or fully filled by adjacent healthy berries.

Figure 23: Although black rot develops on Brianna, clusters tend to mature even if several berries are damaged by this disease. Spread within the cluster seems more limited than in other cultivars. This image was collected at harvest time, and the remainder of the berries in these clusters were healthy.

Phomopsis cane and leaf spot/fruit rot: We noted that Brianna was particularly prone to phomopsis fruit rot (caused by *Phomopsis viticola*) at both field sites. Damage was particularly severe in the second year of the study, illustrating the tendency for this pathogen to build up in vineyards when not managed appropriately.

Figure 24: Phomopsis fruit rot on Brianna. Tiny, black spore-producing structures can be seen on infected berries.

Figure 25: Phomopsis fruit rot on Brianna. Note that while these symptoms resemble black rot, Phomopsis only affects ripening fruit, while black rot destroys fruit prior to veraison. The brown, rough areas on the berries in this image are not a result of damage from Phomopsis fruit rot.

Figure 26: Phomopsis lesions on a Brianna shoot.

Figure 27: Phomopsis lesions on a Brianna shoot. These symptoms are often found together with berry damage, indicating a "hot spot" within the vineyard.

Magnesium deficiency: We noted that Brianna is prone to magnesium deficiency in calcareous soils, particularly late in the season. Petiole analysis showed that these leaves (Figures 28 and 29) were deficient in magnesium. High levels of calcium in the soil may inhibit the uptake up magnesium in Brianna and other cultivars that are particularly susceptible to deficiency. These symptoms can resemble old downy mildew lesions, making identification of downy mildew spore-producing structures on the lower leaf surface prior to fungicide application critical. These symptoms are particularly common on the oldest leaves, which are found near clusters at the base of spurs.

Figure 28: Early development of magnesium deficiency in Brianna.

Figure 29: In severe cases, magnesium deficiency can cause light green veins on large portions of affected leaves.

Frontenac

Our trials showed Frontenac to be reliably vigorous and fruitful from year to year, producing well in both 2015 and 2016. We rate Frontenac as slightly susceptible to downy mildew, as it appears to tolerate infection without loss of leaves or fruit. This is consistent with current reports for this cultivar (Bordelon et al. 2016). This apparent tolerance is significant for growers in Wisconsin, as our humid, and often wet summers can lead to economically significant outbreaks of downy mildew. Our trials also showed that Frontenac can experience severe powdery mildew on both fruit and foliage. We also found Frontenac to be moderately susceptible to black rot.

Downy Mildew. Our trials showed that highly susceptible cold climate cultivars (e.g., Valiant) exhibit downy mildew as early as late May. Growth and development of Frontenac, however, continues through most of July without apparent damage from the disease. However, oil spots and spores can develop in August and September, and are concentrated on old leaves within the fruiting canopy. Less commonly, oil spots can be found on young foliage in August and September, particularly on axillary shoots. Spore production on Frontenac is notably different from what is seen in many diagnostic guides, being absent or very sparse with only a small number of spore-producing structures underneath most oil spots. A hand lens is a useful for identifying downy mildew on Frontenac, and spore production is often impossible to find even with this tool.

MAY, JUNE, JULY: Downy mildew did not damage Frontenac fruit or foliage in 2015 or 2016 in our trials.

AUGUST:

Figure 1: "Oil spots" on the upper surface of a Frontenac leaf. Frontenac is prone to downy mildew on old foliage in the fruiting zone late in the season. Look for oil spotting on the oldest leaves, near the fruit.

Figure 2: Underside of the leaf pictured in Figure 1. Spore production on Frontenac can appear sparser than on other cultivars, with undersides of oil spots often having a dark color. A hand lens is often necessary to observe spore production, and lesions often lack spore-producing structures altogether as the few of those structures that were present are quickly dispersed.

Figure 3: Faint oil spots on the upper surface of a leaf at the tip of an axillary shoot in late August. While these symptoms can be common on the upper surfaces of leaves, spore production on undersides of these lesions is difficult to find. Spore production can be found briefly after rain events or particularly humid nights, but it quickly disappears when humidity drops.

Figure 4: Lower surface of the leaf pictured in Figure 3. Note that no spore production is visible in spite of oil spotting on the upper surface.

SEPTEMBER:

Figure 5: Oil spots on the upper surface of a Frontenac leaf in late September. These spots are typical on old leaves in the fruiting canopy, but are rare on young leaves and axillary shoots.

Figure 6: Lower surface of a Frontenac leaf affected by downy mildew. Spore production is often difficult to observe on this cultivar in September.

Powdery Mildew. Both the fruit and the foliage of Frontenac are highly susceptible to powdery mildew, particularly late in the growing season. Although the disease does not cause premature defoliation or problems with overwintering, it can damage rachises and berries within the cluster, leading to delayed ripening and poor fruit expansion and development.

MAY, JUNE: Powdery mildew did not damage Frontenac fruit or foliage in May or June 2015 or 2016 in our trials.

JULY: We found that both the fruit and the foliage of Frontenac can be highly susceptible to powdery mildew later in the growing season.

Figure 7: Characteristic powdery mildew infection of developing berries. The powdery white fungal spores cause a graying of the berry as small patches of surface cells are killed from fungal invasion.

Figure 8: Characteristic foliar symptoms of early powdery mildew. The powdery appearance of this fungus is due to production of spores, which can be seen with a hand lens in chains of eight or fewer spores.

AUGUST:

Figure 9: Powdery mildew on the upper surface of a Frontenac leaf.

Figure 10: Yellow spots on the upper surface of a Frontenac leaf. These lesions are easily confused with downy mildew "oil spots." The diagnostic difference is spore type found by flipping over the leaf to inspect the lower leaf surface (see Figure 11).

Figure 11: Area affected by powdery mildew on the lower leaf surface of a Frontenac leaf. Rather than the patches of white, lemon shaped spore-producing structures characteristic of downy mildew, powdery mildew produces small, round, black spore-producing structures.

SEPTEMBER: A late-season powdery mildew outbreak can cause canopy bronzing, but it does not appear to cause defoliation in Frontenac. Canopy is retained through the fall, allowing the vine to go into dormancy at an acceptable time. However, because both canopy and fruit are susceptible, this disease can pose a major threat to fruit quality if not managed properly.

Figure 12: Powdery mildew on the upper surface of a Frontenac leaf in late September.

Figure 13: Powdery mildew on Frontenac cane.

Black Rot.

MAY: Black rot did not damage Frontenac fruit or foliage in any of our trials in May 2015 or 2016.

JUNE:

Figure 14: Black rot symptoms are concentrated on the two to three oldest leaves on shoots early in the growing season. While individual lesions are typically circular, lesions can coalesce when infection is severe.

Figure 15: "Bull's eye" spot typical of early black rot.

Figure 16: Black rot mummies are typically concentrated in regions that also show leaf lesions. Early season infection of leaves results in additional dispersal of pathogen spores that can cause severe damage to fruit.

JULY:

Figure 17: Black rot mummies dry down to a very small size on Frontenac. Unlike many other cultivars, black rot mummies on this cultivar are often not firmly attached to the rachis and can fall off while healthy berries are ripening.

AUGUST/SEPTEMBER:

Figure 18: Varying stages of black rot on Frontenac clusters. Notice the "bull's eye" pattern on several berries. These early symptoms give way to the shriveled berries also seen in this image, called "mummies."

Figure 19: Young leaves are particularly susceptible to black rot. Suckers, axillary shoots, and terminal (shoot tip) growth are hot spots for black rot infection later in the growing season.

Figure 20: Black rot mummies often fall from Frontenac clusters before harvest. Note the fully dried mummy at the top of the cluster and the tan stub directly below it where another black rot mummy once was attached.

Figure 21: Black rot lesions will continue to develop on young foliage at the growing tips throughout the growing season, but can be easily confused with spots caused by rupestris speckle. Only the tan lesion with the brown edges in this picture is caused by black rot. The rest of the spots are caused by rupestris speckle.

Other. We noted in both 2015 and 2016 that Frontenac and Frontenac gris often display small, black, and slightly sunken lesions on leaves and shoots early in the season, just after bud break in mid-May. The lesions are isolated, do not produce spores when placed in a moist chamber, and vanish as the young shoots develop. These symptoms can be initially alarming, but they were not harmful or persistent in our trials. We were not able to determine the cause of these transient lesions.

Figure 22: Above: isolated lesion on Frontenac leaf shortly after bud break. Right: isolated lesions on two Frontenac gris shoots shortly after bud break.

Rupestris Speckle. This presumed physiological deformity is commonly mistaken for a disease. Rupestris speckle is thought to be associated with grape hybrids containing lineage from *Vitis rupestris*. It is well documented in both Frontenac and Frontenac gris, and our trials also indicated that Marquette can display it as well. Symptoms typically start developing as the hottest summer weather arrives, usually in July. Grapes grown in warmer climates are more likely to show symptoms.

Figure 23: Rupestris speckle on the upper surface of a Frontenac leaf, a common downy mildew lesion lookalike that appears during hot weather in July and August. Flip the leaf over and investigate with a hand lens for spore production. Rupestris speckle lesions are small, circular and brown to black in color, and will not have spores of any kind on either side of the leaf. Downy mildew oil spots are angular and larger in size, ranging from yellow to brown/black with white patches of on the lower side of leaves.

Figure 24: Rupestris speckle on upper surface of a Frontenac leaf. Spots expand and turn brown as symptoms progress. Rupestris speckle is sometimes confined to one half of a leaf.

Figure 25: More advanced rupestris speckle spots can coalesce and form dead regions on Frontenac and Frontenac gris leaves. While these symptoms can be alarming, they do not cause significant damage to vines.

Frontenac gris

We found that Frontenac gris performs similarly to Frontenac in most respects. Like Frontenac, Frontenac gris is a reliably vigorous, hardy vine that performed well in no-spray conditions in both 2015 and 2016. As with Frontenac, we noted that it is particularly tolerant to foliar downy mildew, not suffering from defoliation or fruit damage in either season in spite of severe damage to surrounding cultivars at both sites. It is highly susceptible to powdery mildew, particularly late in the season under dry conditions, and is moderately susceptible to black rot.

Downy Mildew. Like Frontenac, Frontenac gris is not susceptible to downy mildew early in the season, lasting through the end of July without symptoms in 2015 and 2016. Oil spots and spores can develop in August and September. However, this late disease development did not cause premature defoliation. Frontenac gris fruit are not susceptible to damage from the downy mildew pathogen.

MAY, JUNE, JULY: downy mildew did not damage Frontenac gris fruit or foliage May, June, or July 2015 or 2016 in our trials.

AUGUST:

Figure 1: Oil spots on the upper surface of terminal (youngest) leaves in late August, 2016. The holes in leaves were caused by insect feeding.

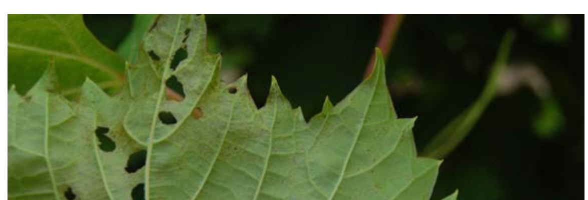

Figure 2: While oil spots can sometimes be found on terminal leaves, spore production is rare. Note that no spore production is visible on the lower surface of this leaf in spite of oil spots on the leaf surface.

Figure 3: Oil spots on the upper surface of a Frontenac gris leaf. Note that lesions often follow veins. Also note that downy mildew, seen as yellow spots in this image, is often accompanied by rupestris speckle (the small black dots) on Frontenac and Frontenac gris.

Figure 4: Downy mildew spore production on lower surface of a Frontenac gris leaf. Even this heavy spore production is less dense than other cultivars, appearing more spread out on the lower leaf surface.

Figure 5: Sparse spore production on the lower surface of a Frontenac gris leaf.

SEPTEMBER:

Figure 6: Spore production is rarely visible on the lower surface of Frontenac gris leaves late in the season.

Figure 7: Oil spots and dead spots caused by late season downy mildew on Frontenac gris.

Powdery mildew: We found that Frontenac gris can experience severe powdery mildew infections. Both fruit and foliage can be infected by this pathogen. Although powdery mildew did not cause defoliation at any of our sites, severe infection can limit photosynthetic output, delay ripening, and cause uneven fruit sizing due to poor expansion of the outer layer of cells. Overall, we found Frontenac gris to be moderately to severely susceptible to powdery mildew, and noted that both fruit and foliage are damaged by the disease.

MAY, JUNE: powdery mildew did not damage Frontenac gris fruit or foliage in May or June 2015 or 2016 in our trials.

JULY:

Figure 8: Powdery mildew on a Frontenac gris cluster. Note the powdery white areas and graying of the fruit rachis. Powdery mildew can cause fruit to split open by impairing the expansion of the outer layer of cells.

AUGUST:

Figure 9: Powdery mildew on rachises and berries. Uneven sizing and greying of the fruit is often evident when disease is severe.

Figure 10: Frontenac gris leaves can be heavily infected by powdery mildew. The upper surface of leaves takes on a grey to whitish hue.

Figure 11: Powdery mildew on stems causes a black, net-like pattern of dead tissue as the pathogen kills cells in the outer layer of cells.

SEPTEMBER:

Figure 12: Powdery mildew on a Frontenac gris cluster. Rachises may appear silver in color or have a blackened appearance.

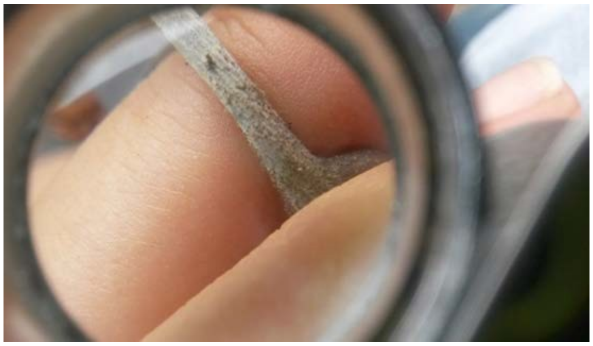

Figure 13: Browning of the rachis from heavy powdery mildew infection. A hand lens will reveal tiny black dots, which are the spore-producing structures of the pathogen.

Figure 14: Blackened tissue on cane and rachis affected by powdery mildew.

Black Rot. Frontenac gris clusters can be severely damaged by black rot. The foliage can also be damaged, but foliar black rot levels were low at all field sites in both 2015 and 2016, and did not cause defoliation. Overall, we found Frontenac gris to be moderately susceptible to black rot.

MAY: Frontenac gris did not display black rot symptoms in May in 2015 or 2016 in our trials.

JUNE: Black rot leaf lesions are concentrated to the first 2-3 fully expanded leaves early in the growing season. Mummies later in the season tend to be concentrated in these regions if left unmanaged, as the early season leaf lesions contribute pathogen spores that infect and later damage fruit during the 4-week window of peak susceptibility following bloom.

Figure 15: Black rot lesion on the upper surface of a Frontenac gris leaf in early June, 2016. These symptoms are frequently found on the first fully expanded leaves early in the season.

Figure 16: Young leaves can develop extensive lesions if black rot is not managed, particularly if mummies from the previous year are left in the canopy. This leaf was collected from a region adjacent to a mummy from the previous year. Note the varying stages of lesion development. The faint, less defined lesions are newer than the lesions with vivid purple-brown edges and tan colored centers.

JULY:

Figure 17: Black rot mummies on a Frontenac gris cluster.

Figure 18: Unmanaged black rot can lead to serious losses, particularly if management is neglected for consecutive years. Clusters such as this were common in several “hot spots” within the vineyards in 2016, the second year of no-spray conditions.

AUGUST, SEPTEMBER:

Figure 19: Black rot on a Frontenac gris cluster.

Figure 20: In early August, berries at various stages of mummification can be observed. By late August, all mummies have become fully dehydrated and shrunken.

Rupestris speckle. As mentioned above under 'Frontenac,' Frontenac gris' display symptoms of rupestris speckle throughout the growing season.

Figure 21: Rupestris speckle on the upper surface of a Frontenac gris leaf.

Figure 22: Rupestris speckle is often found on only one section of a leaf.

Figure 23: In severe cases, rupestris speckle lesions can coalesce, leading to larger patches of dead leaf tissue.

La Crescent

This introduction from the University of Minnesota has become a favorite of the cold-climate industry, and produces some of the highest quality white wines of the North. We found that La Crescent is highly susceptible to downy mildew but minimally susceptible to powdery mildew. In, wet conditions downy mildew can cause severe premature defoliation in La Crescent, marking it as distinctively more susceptible than several of the other cultivars in the research vineyards. While moderate to heavy spore production is common in several cold-climate cultivars, premature defoliation is less typical. However, defoliation in La Crescent can begin as early as mid to late August in no-spray conditions, and can result in delayed fruit ripening and poor overwintering. In spite of severe foliar susceptibility, fruit of La Crescent do not appear to be susceptible to downy mildew. La Crescent is minimally susceptible to black rot, consistently displaying lower levels of both foliar and fruit symptoms than several other cultivars in both 2015 and 2016. Fruit set can be variable from year to year, and shattering (premature dropping) of fruit prior to harvest was observed in both 2015 and 2016. While downy mildew management may be challenging for the cultivar, its apparent resistance to black rot and minimal susceptibility to powdery mildew may make this cultivar a potential candidate for organic production. Downy mildew can be effectively managed with copper-based fungicides, some of which are available to organic growers (Bordelon et al. 2016; Weigle and Carroll 2016). Conversely, black rot is not sensitive to copper fungicides, which makes this disease among the hardest to control organically (Weigle and Carroll 2016).

Downy Mildew. La Crescent is highly susceptible to downy mildew. However, symptoms develop later on this cultivar than other highly susceptible cultivars (Valiant, LaCrosse), and were not detected until July in 2015 and 2016. Other highly susceptible cultivars developed uniform symptoms as early as mid-June. However, like other highly susceptible cultivars, La Crescent can be severely prematurely defoliated by this disease.

MAY: La Crescent fruit and foliage did not display downy mildew symptoms in May 2015 or 2016 in our trials.

JUNE:

Figure 1: Downy mildew lesions quickly turn brown and die, particularly during spells of hot weather. Look for these lesions near the tips of shoots early in the season

Figure 2: If a downy mildew lesion is not discovered until the tissue is dead, spore production will often not be visible. If visible, it will be sparse and concentrated at the edge of the lesions on the lower leaf surface.

JULY:

Figure 3: Oil spots on upper surface of a La Crescent leaf. Note the bright, yellow color with the slightest tint of brown near some centers as cells are killed by the disease.

Figure 4: Thick, downy patches of spore-producing structures on the lower surface of the leaf in Figure 3. Early season spore production is thick, widespread across the leaf blade, and concentrated directly underneath oil spots on La Crescent.

Figure 5: Like other susceptible cultivars, La Crescent (right) quickly separates itself from less susceptible cultivars such as Marquette (left).

Figure 6: Severely damaged leaves can become prematurely yellow. This is particularly common on older leaves in the canopy.

AUGUST:

Figure 7: Spore production is typically still visible on the lower leaf surface even on leaves that have turned completely yellow.

Figure 8: Large numbers of dead spots are particularly common on youngest leaves of both main and axillary shoots.

Figure 9: Lesion size and shape can be highly variable.

Figure 10: Lower surface of leaf pictured in Figure 9. Note that spore production is not visible on this leaf. Old lesions can be devoid of spore production, particularly if weather has been hot and dry.

Figure 12: As infection progresses, oil spots coalesce and become indistinguishable from one another. Large areas of yellow with brown to black spots become common.

Figure 13: Just as oil spots become indistinguishable from one-another, patches of spore-producing structures develop. Large patches of spore production are common, with individual patches becoming smaller in size than what is seen earlier in the season. Light spore production also tends to follow veins on the lower surface of the leaf.

Figure 14: By late August, many oil spots have turned brown or black. Patches of spore production are numerous but highly variable in size, and most are smaller than early in the season.

Figure 15: Centers of old lesions can fall out, leading to a "shot hole" appearance late in the season.

SEPTEMBER:

Figure 16: By the end of the growing season, spore production can cover nearly the entire lower surface of the leaf. The edges of the leaf tend to be the first regions to die, with death of tissues spreading inwards. Leaf drop becomes common at this

Figure 17: The upper leaf surface of severely diseased leaves begins to brown in large patches late in the season, culminating in leaf drop.

Figure 18: Extensive premature defoliation is common in La Crescent if downy mildew is not properly managed. This defoliation response is distinctive of severe foliar susceptibility. Several other cultivars can tolerate moderate to heavy spore production without defoliating prematurely.

Figure 19: Severely defoliated vines often have only axillary and minimal tip growth left by the end of the growing season. Young growth displays dead spots rather than oil spots late in the season.

Figure 20: Death of entire leaves affected by downy mildew is common on highly susceptible cultivars such as La Crescent.

Powdery Mildew. We found La Crescent to be slightly susceptible to powdery mildew. La Crescent was consistently the among the least susceptible cultivars to this disease in our trials in both 2015 and 2016.

MAY, JUNE, JULY: La Crescent was not damaged by powder y mildew in May, June, or July in 2015 or 2016 in our trials.

AUGUST, SEPTEMBER: Both berries and foliage of La Crescent can be damaged by powdery mildew, but severe damage was not typical in our trials.

Figure 21: Left: La Crescent berries with powdery mildew. Note the greying of berries and the uneven berry size. Above: Faint patches of powdery mildew on the upper surface of a La Crescent leaf. Powdery mildew can be difficult to see unless held into direct sunlight, particularly at early stages.

Black Rot. La Crescent fruit and foliage were only slightly susceptible to black rot in 2015 or 2016, and were consistently the lowest in both incidence and severity for this disease.

MAY: La Crescent did not display black rot symptoms in May in 2015 or 2016 in our trials.

JUNE:

Figure 22: Black rot lesions on the upper surface of a La Crescent leaf. Darker lesions with less defined edges are still developing and lack. spore-producing structures

JULY, AUGUST, SEPTEMBER:

Figure 23: Black rot on La Crescent berries in early July. While La Crescent was generally less damaged by black rot than other cultivars in both 2015 and 2016, isolated patches of severe symptoms were still noted.

Micronutrient deficiency: La Crescent suffered from magnesium deficiency in 2015, likely due to the calcareous soil in which it was planted at both sites. The lesions present on this leaf may look like black rot at first glance. However, note the linear distribution of the lesions in between veins, which contrasts with the random or patchy distribution of black rot lesions. The lesions also lacked tiny black dots, or spore-producing structures, when inspected with a hand lens.

Figure 24: Magnesium deficiency on La Crescent. Note the linear distribution of the lesions and absence of spore-producing structures.

LaCrosse

This cultivar, developed by amateur breeder Elmer Swenson, is particularly popular as a blending wine. LaCrosse has proven to be a reliably vigorous, winter hardy cultivar in our trials, although we have noted that it has a strong tendency to form “bull canes” during establishment. Its downward growth habit also makes it a poor choice for the VSP training system used in our vineyard trials. LaCrosse is highly susceptible to foliar downy mildew, although fruit are not affected by the disease. It is slightly susceptible to foliar powdery mildew. However, the fruit are particularly susceptible to powdery mildew damage due to their thin skin, which can be prone to splitting and cracking due to poor expansion of the skin in the presence of this disease. LaCrosse is moderately susceptible to black rot, and is moderately susceptible to Phomopsis fruit rot.

Downy Mildew. LaCrosse is highly susceptible to foliar downy mildew, one of the two most susceptible cultivars that we tested (Valiant was the other). LaCrosse and Valiant were the first two cultivars to experience damage from downy mildew in the spring. Symptoms on LaCrosse advanced rapidly, with heavy spore production evident by June or early July at all field sites in 2015 and 2016. This cultivar was severely defoliated by downy mildew in late August and early September in both 2015 and 2016. LaCrosse berries were not noticeably susceptible downy mildew. Downy mildew symptoms on LaCrosse were unusual. Rather than a yellow “oil spot” phase, LaCrosse leaves commonly displayed dead lesions and spore production at the same time rather than an oil spot leading into a dead lesion.

MAY:

Figure 1: Early symptoms of downy mildew on the upper surface of a LaCrosse leaf. Notice that the lesion is brown rather than the more traditionally recognized yellow “oil spot” type of lesion. Downy mildew is characterized by cottony white spore production on the underside of the lesion.

Figure 2: Downy mildew spore production on the lower surface of a LaCrosse leaf. Spore production is limited to the underside of the dead lesion.

JUNE:

Figure 3: A dead area caused by downy mildew on the upper surface of a LaCrosse leaf.

Figure 4: Underside of lesion pictured in Figure 3. Note the sparse spore production.

Figure 5: Oil spots on the lower surface of a LaCrosse leaf.

Figure 6: Oil spots on LaCrosse quickly acquire a distinctive "dirty" appearance. Oil spots on LaCrosse are dappled with small black dead regions, even very early in the season. Lesions can coalesce early in the season if symptoms are severe.

Figure 7: Downy mildew lesions on a LaCrosse leaf. The tissues in lesions die very quickly on this cultivar.

Figure 8: Underside of lesions pictured in Figure 7. Note that no spore production is visible at this stage of disease.

JULY:

Figure 9: Advanced downy mildew on upper surface of LaCrosse leaf. Lesions become brown and die and begin to accumulate, giving the canopy of the vine a scorched appearance.

Figure 10: In spite of heavy foliar infection and defoliation, the fruit of LaCrosse is not visibly damaged by downy mildew.

Figure 11: Downy mildew lesions with dead tissue on the upper surface of a LaCrosse leaf.

Figure 12: Underside of the downy mildew lesions pictured at left.

AUGUST, SEPTEMBER:

Figure 13: Downy mildew lesions on young tip growth. Dead spots are very common on young leaves, while old leaves often have an oil spot phase.

Figure 14: Downy mildew lesions on the upper surface of an older leaf.

Figure 15: Severe downy mildew can give LaCrosse vines a scorched look late in the season as leaves die and fall from the vine.

Figure 16: Spore production on the lower surface of a LaCrosse leaf.

Powdery Mildew. We noted that LaCrosse fruit are particularly susceptible to this pathogen. Powdery mildew can cause fruit cracking due to poor expansion of the skin, and the thin skin of this cultivar makes this problem more widespread. The foliage of LaCrosse appears to be only lightly susceptible to powdery mildew.

MAY, JUNE, JULY: LaCrosse was not damaged by powdery mildew in May, June, or July 2015 and 2016 in our trials.

AUGUST, SEPTEMBER:

Figure 17: Powdery mildew on LaCrosse berries.

Figure 18: Powdery mildew on a LaCrosse cane. Cane damage is more prominent than leaf damage when powdery mildew is present.

Figure 19: Splitting and cracking of LaCrosse berries due to powdery mildew.

Black Rot. We found LaCrosse to be moderately susceptible to black rot. Foliar damage was light to moderate in both 2015 and 2016 compared to other cultivars in our trials. The same was true for both incidence and severity of damage to clusters.

MAY: Black rot damage was not observed on LaCrosse in May 2015 or 2016 in our trials.

JUNE:

Figure 20: Black rot lesions on an early expanded leaf. Lesions are heavily concentrated on these leaves early in the growing season.

Figure 21: Two black rot lesions on the upper surface of a fully expanded LaCrosse leaf. Note that lesions can be roughly circular, as seen to the right of the midvein, or irregular in shape, as seen near the edge of the leaf.

JULY:

Figure 22: Black rot on a LaCrosse cluster. Mummies tend to be very small on this cultivar.

AUGUST, SEPTEMBER:

Figure 23: Black rot on LaCrosse clusters. Damage to leaves in this image is from both black rot and downy mildew. Leaf lesions tend to be concentrated in regions with mummies.

Figure 24: Black rot mummy on LaCrosse.

Phomopsis fruit rot. We noted that LaCrosse appeared to be susceptible to phomopsis fruit rot in both 2015 and 2016. Death of rachis tissue and loss of rachis side arms was widespread. Symptoms developed shortly before berries were fully ripe. Phomopsis fruit rot may mummify berries within a cluster. These symptoms set in much later than those seen by black rot, beginning between verasion and full ripening. Spore-producing structures of the pathogen are visible on these berries.

Figure 25: LaCrosse cluster affected by phomopsis fruit rot. Note that portions of the rachis have been killed, causing berries to dehydrate and rot.

Figure 26: Dead rachis with unripe berries and infected berries. The black, shriveled berry is covered with spore-producing structures of *Phomopsis viticola.*

Figure 27: Phomopsis commonly infects the side arm of the rachis, causing it to shrivel and fall off. The small, white circular scar at the top of the rachis (arrow) in this image is all that that remains of the side arm of the rachis and cluster.

Figure 28: Brown, shriveled berry covered in spores. The berries on the rachis are dehydrating because the rachis has been killed by the disease.

Micronutrient Deficiency: Like Brianna, LaCrosse appears to be prone to magnesium deficiency in calcareous soils. Symptomatology is similar, with yellowing developing between veins starting at leaf edges, and moving inwards depending on the severity of deficiency.

Figure 29: Symptoms of magnesium deficiency begins at the leaf edge and travels inward. Early symptoms strongly resemble black rot lesions, but lack spore-producing structures and have a linear distribution between veins that is not seen in black rot.

Figure 30: In severe cases of Magnesium deficiency, lesions in between veins coalesce.

Léon Millot

This cultivar originates from the same cross that generated Maréchal Foch, and is among the oldest cultivars used by the cold-climate wine industry (Smiley et al. 2015). It was introduced to the U.S. in the 1950's by Philip Wagner, who obtained the cuttings from France (Smiley et al. 2015). Léon Millot has proven to be reliably vigorous and hardy at both WMARS and PARS, although its downward growth habit make a VSP training system a poor choice for this cultivar. Wines made from this cultivar have been described as being high in quality, and are often compared to those made with Maréchal Foch (Smiley et al. 2015). Although currently accounting for only a small percentage of acreage in the cold-climate wine grape industry (Tuck and Gartner 2013), its popularity may increase as it tends to be higher in vigor and more fruitful than Maréchal Foch (Smiley et al. 2015). This cultivar is highly susceptible to powdery mildew and moderately susceptible downy mildew. It is slightly susceptible to black rot.

Downy Mildew: Léon Millot can be severely damaged by foliar downy mildew, particularly late in the growing season. Spore production on this cultivar is more easily seen than on many other cultivars, appearing in thick, white masses on leaf undersides. Rather than yellow colored "oil spots," lesions can instead appear as faint brown patches on leaves, particularly older leaves found in the fruiting zone of the canopy. Berries of Léon Millot do not appear to be susceptible to the disease.

MAY, JUNE: Léon Millot was not damaged by downy mildew in May or June in our trials.

JULY:

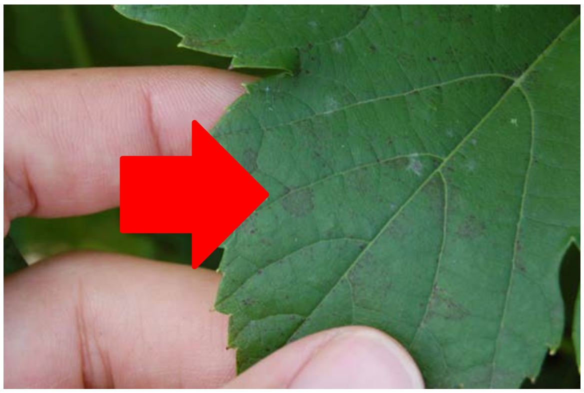

Figure 1: Downy mildew lesions on the upper surface of a Léon Millot leaf.

Figure 2: Downy mildew spore production on the lower surface of a Léon Millot leaf.

AUGUST:

Figure 3: Dead spots caused by downy mildew on the upper surface of a Léon Millot leaf. Lesions that develop later in the season often die completely and can resemble anthracnose lesions.

Figure 4: Spore production is not always evident on the lower surface of leaves with dead downy mildew lesions.

SEPTEMBER:

Figure 5: Leaf death can occur, particularly late in the growing season as dead lesions coalesce and cause more extensive damage.

Figure 6: Spore production remains evident on Léon Millot throughout the growing season.

Figure 7: Damage can be particularly severe at the growing tips of main and axillary shoots, typically displaying a mix of "oil spots" and dead spots. Spore production is evident on the undersides of oil spots in this cultivar.

Powdery Mildew: Léon Millot leaves and berries can be severely damaged by powdery mildew, particularly late in the growing season.

MAY, JUNE: Léon Millot was not damaged by powdery mildew in May or June in our trials.

JUNE:

Figure 8: Powdery mildew on developing Léon Millot berries.

Figure 9: Early powdery mildew disease with fungal structures and symptoms on the upper surface of a Léon Millot leaf.

AUGUST, SEPTEMBER:

Figure 10: Severe powdery mildew on the upper surface of a Léon Millot leaf. As disease spreads, leaves will develop black-brown patches as cells are killed by the pathogen.

Figure 11: Powdery mildew on a Léon Millot cane.

Figure 12: Severe powdery mildew on the upper surface of a Léon Millot leaf. Dead leaf tissue can become extensive when infections progress to this point.

Black Rot: Léon Millot is only slightly susceptible to black rot, and damage was extremely minimal in 2016. Leaf lesions were minimal and fruit rot was low.

MAY, JUNE, JULY, AUGUST, AND SEPTEMBER:

Figure 13: Black rot lesion on the upper surface of a Léon Millot leaf.

Maréchal Foch

This cultivar is among the oldest of the cold-climate wine-grapes used by today's industry. Originally bred in Alsace, France by Eugene Kuhlmann in 1920, this grape was brought to the U.S. in 1951 (Smiley et al. 2015). It has remained a prominent cultivar in cold-climate grape acreage ever since (Tuck and Gartner 2013). This cultivar has a reputation for having produced a wide array of styles of high quality wines, and figures to continue to be a popular selection for grape growers and winemakers alike (Smiley et al. 2015). We have found it to be low in vigor but acceptably hardy at both PARS and WMARS. Maréchal Foch is slightly susceptible to downy mildew, particularly late in the season, but berries are not visibly affected by the disease. It was minimally susceptible to black rot in our trials, and moderately susceptible to powdery mildew. As we have observed in several other cultivars, both powdery and downy mildews appear late in the growing season in no-spray conditions.

Downy Mildew:

MAY, JUNE: Maréchal Foch was not damaged by downy mildew in May or June in our trials.

JULY:

Figure 1: Downy mildew "oil spots" on the upper surface of a Maréchal Foch leaf.

Figure 2: Downy mildew Spore production on the lower surface of a Maréchal Foch leaf.

AUGUST:

Figure 3: Downy mildew "oil spots" on the upper surface of leaves on an axillary Maréchal Foch shoot. Damage to axillary shoots from downy mildew is particularly common as the season progresses.

Figure 4: Downy mildew spore production on the lower surface of a Maréchal Foch leaf from an axillary shoot.

Figure 5: Downy mildew "oil spots" on the upper surface of a Maréchal Foch leaf within the fruiting zone of the canopy. "Oil spots" tend to be less pronounced on fully expanded, older leaves than on young, developing leaves.

Figure 6: Downy mildew spore production on the lower surface of a fully expanded Maréchal Foch leaf within the fruiting zone of the canopy

SEPTEMBER:

Figure 7: Downy mildew oil spots on the upper surface of a primary shoot tip.

Figure 8: Downy mildew Spore production on the lower surface of a shoot tip.

Figure 9: Downy mildew lesions on the upper surface of a Maréchal Foch leaf.

Figure 10: Downy mildew Spore production on the lower surface of a Maréchal Foch leaf with dead downy mildew lesions. Spore production is no longer limited to the lower surface of lesions late in the growing season. Instead, it can be found scattered all across the lower surface of infected leaves, even under tissues that appear healthy on the upper surface.

Figure 11: Severely damaged Maréchal Foch leaf.

Figure 12: Extensive spore production on the lower surface of a heavily damaged Maréchal Foch leaf.

Powdery Mildew:

MAY, JUNE: Maréchal Foch was not damaged by powdery mildew in May or June in our trials.

Figure 13: Severely damaged Maréchal Foch leaf.

Figure 14: Extensive spore production on the lower surface of a heavily damaged Maréchal Foch leaf.

AUGUST:

Figure 15: Advanced powdery mildew on a Maréchal Foch cane.

Figure 16: Severe powdery mildew on the upper surface of a Maréchal Foch leaf.

SEPTEMBER:

Figure 17: Leaves that are severely damaged by powdery mildew can die as cells in the leaf surface are killed by the pathogen.

Figure 18: Severe powdery mildew on the upper surface of a Maréchal Foch leaf.

Black Rot:

MAY: Maréchal Foch was not damaged by black rot in May in our trials.

JUNE, JULY, AUGUST:

Figure 19: Black rot lesion on the upper surface of a Maréchal Foch leaf.

Figure 20: Black rot mummies on a Maréchal Foch cluster.

Marquette

Since its introduction in 2008 from the University of Minnesota, Marquette has quickly taken hold as one of the most popular red wine grape cultivars of the North (Tuck and Gartner 2013). Marquette is relatively resistant to downy mildew. Marquette was not significantly damaged by downy mildew in either 2015 or 2016 at either location, in spite of heavy damage suffered by neighboring cultivars. Marquette is moderately susceptible to powdery mildew on both fruit and foliage, particularly late in the growing season under warm, dry conditions. It is highly susceptible to black rot on both fruit and foliage. Its apparent resistance to downy mildew could make it an ideal choice to test in low spray trials in the future, but black rot will have to be carefully managed to prevent widespread loss of fruit on this cultivar.

Downy Mildew. No downy mildew spores were observed on Marquette at either location in 2015, and only isolated lesions were observed in 2016. Fruit were not susceptible to this disease.

MAY, JUNE, JULY: Marquette was not damaged by downy mildew in May, June, or July in our trials.

AUGUST:

Figure 1: Downy mildew damage can appear on tip growth, particularly on axillary shoots.

Figure 2: Spore production on the undersides of these “oil spots” is both sparse and short in duration. Unless observed immediately after a cool, humid night it is rare to see spore production on this cultivar.

Figure 3: Downy mildew lesions on Marquette tend to be isolated, and die almost immediately with little spread.

Figure 4: Underside of a downy mildew lesion pictured in Figure 3. No spores are visible at this stage of development.

SEPTEMBER:

Figure 5: Tip growth, particularly axillary tip growth can develop "oil spots" late in the season. Spore production is rare on these lesions.

Powdery Mildew. Overall we found Marquette to be moderately susceptible to powdery mildew. Marquette can be severely damaged by powdery mildew, particularly in warm, dry conditions near the end of the season, with damage to both fruit and foliage. However, severe damage from powdery mildew was unusual in our trials.

JULY:

Figure 6: Marquette leaf with powdery mildew infection (left) compared to Valiant leaf with downy mildew infection (right).

AUGUST, SEPTEMBER:

Figure 7: Yellow spots on the upper surface of a Marquette leaf with powdery mildew.

Figure 8: Severely diseased leaves can become grey as individual spots coalesce.

Figure 9: Ripe Marquette clusters with powdery mildew visible on the rachis.

Figure 10: Late in the season as canes become woody, blackened areas damaged by powdery mildew can still be observed.

Black Rot. Severe susceptibility to black rot may be this cultivar's biggest downfall. Both foliage and clusters of Marquette can be heavily damaged by black rot. Black rot showed up earlier on Marquette than on all other cultivars except Valiant at our field sites. Leaf lesions can be observed as early as late May prior to flower opening. Marquette fruit and foliage were consistently among the most severely damaged of all cultivars in 2015 and 2016.

MAY:

Figure 11: Black rot can show up on Marquette by late May. Look for black rot on the first fully expanded leaves at the base of shoots early in the season. The disease tends to be concentrated in this region at this time.

Figure 12: Black rot lesions on young, fully expanded leaves. Note that the flower cluster at the top of the photo still has not opened. Look for tiny black dots within the lesions when scouting black rot. These are reproductive structures of the of the black rot fungus.

JUNE:

Figure 13: After developing on the oldest leaves in the canopy early in the season, black rot begins to appear on newer leaves as shoots develop.

Figure 14: Young foliage is highly susceptible to the disease. Severe damage to early expanded leaves was common in our trials.

Figure 15: Early expanded leaves can become heavily diseased. Note that the flowers have not yet opened. The lesions on these leaves will release spores during bloom. Grape berries are most susceptible to infection between bloom and 4 weeks post-bloom, so having spore-producing lesions present during bloom increases the risk of disease significantly.

Figure 16: Early black rot on a Marquette cluster. Note the characteristic "bull's eye" pattern

JULY:

Figure 17: Where black rot damage is severe, severe damage to clusters will likely follow if black rot is not managed.

Figure 18: Above: black rot continues to cause severe damage on Marquette leaves throughout the growing season, particularly on young foliage at growing tips. Left: fully developed mummies on a Marquette cluster.

AUGUST:

Figure 19: Black rot lesions on Marquette in August 2015. Notice that the center of several of the lesions has fallen out, leaving a “shot-hole” appearance. Remaining lesions still have small black spore-producing structures visible on the lesion surface.

Figure 20: Mummies often become difficult to see by the time fruit ripening begins due to the expansion of adjacent berries.

Figure 21: Mummies on Marquette clusters. In lightly damaged clusters undamaged berries will often ripen normally. Mummies will hang tightly to the rachis however, and could lead to wine quality problems, particularly if present in high numbers.

Figure 22: Marquette tip growth is highly susceptible to black rot throughout the growing season. High levels of damage can be seen late in the season.

Petite Pearl

Bred by Minnesota grape breeder Tom Plochner, this red wine grape has gained increased recognition within the cold-climate wine grape industry for producing high quality dry red wines. The first commercial batches of wine made from this cultivar appeared in regional markets in 2012, making this grape among the newest cold-climate grapes available. Production of quality dry red wine has previously proved to be extremely challenging for the cold-climate grape industry. Tannin content, a critical component of high quality red wine, is lacking in many other popular cold-climate red wine cultivars. Additionally, non-*vinifera* flavors associated with *Vitis labrusca* and other hybrid grapes cultivars can often creep into the taste profile of cold-climate red wines. Petite Pearl has lower acidity and higher tannin levels than most hybrids, making this grape more similar to *Vitis vinifera*, and has already been used to create award-winning wines in spite of its recent introduction. Frequently compared in flavor and profile to vinifera wines, this cultivar figures to be a major player in the cold-climate industry and will likely continue to increase in popularity in coming years. Unlike other cultivars listed in this chapter, Petite Pearl was included in this study for just one season in one vineyard. Therefore, ratings for disease susceptibility are less certain. In 2016 we found Petite Pearl moderately susceptible to powdery mildew and minimally susceptible downy mildew. However, it was highly susceptible to black rot and phomopsis cane and leaf spot. Strengths against downy mildew and powdery mildew may make this cultivar an ideal candidate for reduced spray programs, but susceptibility to black rot and phomopsis cane and leaf spot will make well-timed sprays early in the growing season critical.

Downy Mildew. We found Petite Pearl to be minimally susceptible to downy mildew. Foliage can experience light infection, particularly late in the season, and fruit are not affected by the disease. Premature defoliation from downy mildew did not occur on this cultivar. The extent of downy mildew damage is similar to Marquette, Frontenac, and Frontenac gris. This cultivar carries a full, healthy canopy through the end of the growing season in spite of light spore production.

MAY, JUNE: Petite Pearl was not damaged by downy mildew in May or June in our trials.

JULY:

Figure 1: Downy mildew “oil spots” on the upper surface of a Petite Pearl leaf.

Figure 2: Like Marquette, Frontenac, and Frontenac gris, downy mildew spore production can be difficult to observe on Petite Pearl. When present, it is sparser than what is found on most other cultivars.

AUGUST:

Figure 3: Downy mildew "oil spots" on the upper surface of a Petite Pearl leaf.

Figure 4: Minimal downy mildew spore production on the lower surface of the leaf pictured at left.

Figure 5: Downy mildew lesions on Petite Pearl can be a faint black-brown color, similar to those found on Leon Millot. These symptoms are particularly common near the end of the growing season on old, fully expanded leaves within the fruiting canopy.

Figure 6: Downy mildew Spore production on the lower surface of the leaf pictured at left.

Powdery Mildew. We found Petite Pearl to be moderately susceptible to powdery mildew. Foliage experienced light infection late in the season. However, loss of leaves and fruit due to damage from this pathogen did not appear to be a concern for this cultivar.

MAY, JUNE: Petite Pearl was not damaged by powdery mildew during May or June in our trials.

JULY:

Figure 7: Powdery mildew on the upper surface of a Petite Pearl leaf.

AUGUST:

Figure 8: Late season powdery mildew on the upper surface of a Petite Pearl leaf. Fungal infection tends to be concentrated on older leaves in the fruiting canopy.

SEPTEMBER:

Figure 9: Severe powdery mildew on the upper surface of a Petite Pearl leaf.

Figure 10: Powdery mildew damage on a Petite Pearl cane.

Figure 11: Extensive powdery mildew throughout the canopy of Petite Pearl.

Black Rot. Petite Pearl was highly susceptible to black rot in 2016. The number of clusters damaged per vine for the growing season was among the largest of any cultivar during the growing season at any site. The severity of damage to each individual cluster was also among the greatest of any cultivar in our trials.

MAY, JUNE:

Figure 12: Symptoms on leaves advance rapidly on this cultivar. Entire leaves become covered in lesions early in the season.

JULY:

Figure 13: Black rot appears early in the season on Petite Pearl, damaging the first two to three fully expanded leaves on shoots.

AUGUST:

Figure 14: Black rot lesions become particularly common at main and axillary shoot tips as leaves within the fruiting canopy become fully expanded and less susceptible to infection.

Figure 15: Lesions can coalesce into larger dead regions on severely diseased Petite Pearl leaves.

Figure 16: Mummified Petite Pearl berries. Clusters damage from the black rot pathogen can be extensive.

SEPTEMBER:

Figure 17: Clusters affected by black rot tend to be almost entirely destroyed by the end of the growing season.

Phomopsis cane and leaf spot: Petite Pearl is highly susceptible to Phomopsis cane and leaf spot. Cane lesions were evident throughout the growing season. Severe damage to clusters was common, as was damage to rachises.

AUGUST, SEPTEMBER:

Figure 18: Left: Phomopsis cane and leaf spot can cause severe damage to both canes and rachises. These symptoms are common at the base of shoots near the spur and cane junction. *Phomopsis viticola* also causes severe fruit rot on this tight-clustered cultivar when not properly managed. The tiny black dots covering the infected fruit are spore-producing structures of the fungus. Above: Phomopsis leaf spot. These symptoms are common on the first two to three fully expanded leaves near the base of each cane, and are commonly found in combination with the cane, rachis, and fruit symptoms pictured at left.

St. Croix

St. Croix was developed by Elmer Swenson and released in the 1980s. It is known for its low acid and distinct flavor profile as a red wine grape. Although this wine grape lacks tannin, its other merits make it a popular choice for northern growers. St. Croix has proven to be reliably winter hardy and fruitful from year to year in our trials, although its downward growth habit makes it a poor choice for the VSP training system used in our trial blocks. St. Croix is highly susceptible to foliar downy mildew and moderately susceptible to powdery mildew. Berries are not visibly susceptible to downy mildew. St. Croix is minimally susceptible to black rot and highly susceptible to Phomopsis cane and leaf spot/fruit rot.

Downy Mildew. St. Croix leaves were damaged by downy mildew in July and August at both field sites in 2015 and 2016 This cultivar appeared to be relatively resistant to disease early in the season, but symptoms developed as the season progressed. Severity of damage varied between sites and years. St. Croix was minimally damaged at PARS in both 2015 and 2016, and at WMARS in 2015. However, it was severely defoliated at WMARS in 2016. Berries were not damaged by the disease.

MAY: St. Croix was not damaged by downy mildew in May 2015 or 2016 in our trials.

JUNE:

Figure 1: Downy mildew oil spot on the upper surface of a St. Croix leaf. St. Croix displays prominent oil spots throughout the growing season.

Figure 2: Downy mildew spore production on the lower surface of a St. Croix leaf.

Figure 3: Downy mildew lesions on the upper surface of a St. Croix leaf. Oil spots will become dead tissue within several days.

Figure 4: Spore production is frequently still visible on the underside of dead lesions on leaves of St. Croix.

JULY:

Figure 5: Oil spots on the upper surface of a St. Croix leaf. If not properly managed, disease progresses rapidly on St. Croix under conducive environmental conditions.

Figure 6: Downy mildew spore production on the lower surface of a St. Croix leaf.

Figure 7: Downy mildew lesions on St. Croix can be large, particularly on young foliage at growing tips. Large lesions often develop shot-hole symptoms as they die.

Figure 8: Although dead tissue is extensive, spore production is still visible at the edges of shot-holed lesions.

AUGUST:

Figure 9: Downy mildew lesions on the upper surface of a St. Croix leaf. Older leaves in the canopy can be heavily damaged by the pathogen, but defoliation is not typical, even at this level of disease.

Figure 10: Downy mildew Spore production on the lower surface of a St. Croix leaf.

SEPTEMBER:

Figure 11: Downy mildew damage on the upper surface of a St. Croix leaf. Downy mildew can cause numerous areas of dead tissue on St. Croix late in the season. Note that the lesions may follow the veins.

Figure 12: Downy mildew spore production on the lower surface of a St. Croix leaf. Unlike many other cultivars, spore production remains dense and easily observed through the duration of the growing season, making downy mildew easier to identify on St. Croix than on several other cultivars.

Figure 13: Oil spots continue to develop on tip growth through the end of the growing season.

Figure 14: Leaf death is common on severely diseased leaves within the fruiting canopy. Dead spots eventually coalesce into large areas of dead leaf tissue, ultimately resulting in leaf death and premature defoliation of vines.

Powdery Mildew. Overall, St. Croix appears to be moderately susceptible to this disease. However, St. Croix can be severely damaged by powdery mildew, particularly late in the season in dry conditions. Both leaves and fruit are damaged by the disease.

MAY, JUNE, JULY: St. Croix was not damaged by powdery mildew in May, June, or July in 2015 or 2016 in our trials.

AUGUST:

Figure 15: Early stages of powdery mildew on St. Croix. Powdery mildew on St. Croix is not easily seen in the early stages, so holding leaves in direct sunlight is a useful strategy tool when scouting for this disease.

Figure 16: Younger leaves of St. Croix affected by powdery mildew can become distorted, with patches of yellow. Flipping the leaf over to inspect the lower side with a hand lens reveals the powdery mildew fungus, with characteristic spore-producing structures late in the season.

SEPTEMBER:

Figure 17: Powdery mildew on the rachis of a St. Croix cluster.

Black Rot. St. Croix was consistently among the least damaged cultivars by this disease in both 2015 and 2016. Fruit damage was particularly minimal compared to other cultivars.

MAY: St. Croix did was not damaged by black rot in May 2015 or 2016 in our trials.

JUNE:

Figure 18: Black rot lesion on a St. Croix leaf. As is the case with other cultivars, leaf lesions are heavily concentrated on the first two to three fully expanded leaves in the spring.

JULY:

Figure 19: Black rot damage on St. Croix berries. Note the characteristic "bull's-eye" pattern on berries on the left and mummified berry to the right.

AUGUST, SEPTEMBER:

Figure 20: While fully expanded leaves become resistant to black rot, younger leaves at growing tips and on axillary shoots can continue to develop black rot lesions as the season progresses.

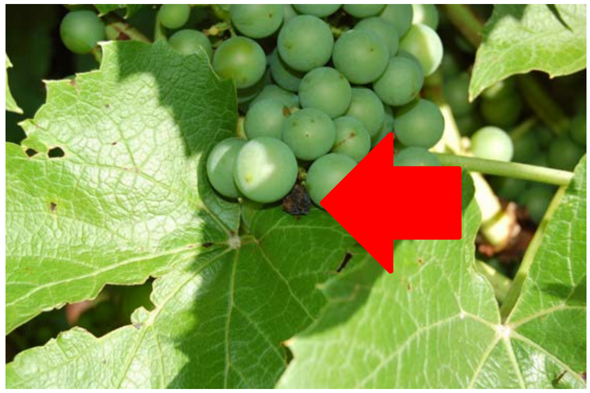

Figure 21: Black rot mummy on a St. Croix cluster.

Phomopsis. St. Croix is highly susceptible to Phomopsis cane and leaf spot/fruit rot. In spite of conventional maintenance prior to 2015 and absence of Phomopsis outbreaks in most other cultivars, St. Croix experienced severe fruit damage from Phomopsis fruit rot in our trials in 2015. Symptoms were even more severe in 2016, and were further contrasted by the absence of this disease in other cultivars. Although leaf lesions were observed throughout the season, damage was particularly evident at harvest. Loss of the side arm of the rachis was common in both 2015 and 2016. Berries containing *Phomopsis viticola* spore-producing stuctures and spores were recovered from damaged clusters. Canes were also visibly damaged by the disease, particularly in 2016.

MAY, JUNE: Phomopsis cane and leaf spot damage was not observed in May or June 2015 or 2016 in our trials.

JULY, AUGUST:

Figure 22: Early season loss of the side arm of the rachis prior to veraison. This is a characteristic symptom of Phomopsis fruit rot.

Figure 23: Stem lesions caused by *Phomopsis viticola*.

:

SEPTEMBER:

Figure 24: Side arm death just before harvest. Collapse of the rachis halts ripening of grapes attached to the damaged tissue.

Figure 25: The small circular scar on the stem of this cluster marks the loss of the side arm of the rachis.

Figure 26: Side arms killed by phomopsis will often leave small, brown stumps prior to falling off entirely.

Figure 27: Side arm death can occur while berries are ripe, shortly before harvest. The berries and dead rachis fall off easily if touched, leading to further crop loss.

Valiant

This cold-climate cultivar out of South Dakota State University is not typically used for wine production (Smiley et al. 2015). Rather, the cultivar was developed for production of juice and jelly in northern climates with extremely low winter temperatures that otherwise eliminate the possibility of producing grapes. It has been recorded to survive winter temperatures of below -40 degrees Celsius without suffering damage (Smiley et al. 2015), and has been reliably winter hardy and fruitful in our trials, frequently setting as many as five or six clusters per shoot if left un-thinned in the spring. Valiant was included in our studies as a “check” cultivar due to previous observations of severe susceptibility to downy mildew, powdery mildew, and black rot (Smiley et al. 2015). We found that the downy mildew and black rot reports were valid. Valiant is highly susceptible to foliar and fruit downy mildew and black rot. Downy mildew can cause complete loss of the fruit and much of the canopy on this cultivar. Black rot also causes extreme foliar and fruit damage if not properly managed. It is slightly susceptible to powdery mildew. Production of Valiant grapes in the wet humid conditions favorable to downy mildew and black rot will prove to be extremely challenging without a meticulous management program.

Downy Mildew. Valiant is highly susceptible to both foliar and fruit downy mildew. Complete loss of fruit and premature defoliation were common in 2015 and 2016. Downy mildew can completely defoliate the canopy and eliminate the crop on this cultivar. Susceptibility of fruit is unique to Valiant among the eleven cultivars included in our study.
MAY: Downy mildew did not damage Valiant fruit or foliage in May 2015 or 2016 in our trials.

JUNE:

Figure 1: Downy mildew appears on Valiant berries almost as soon as fruit are set. Infected berries initially turn pale green-yellow, and become covered in spore-producing structures.

Figure 2: Downy mildew spore production becomes more evident as berries continue to swell. Clusters take on a hooked shape as rachis expansion is hindered due to infection by the pathogen.

Figure 3: Lesions are initially yellow and slowly turn brown.

Figure 4: Downy mildew spore production on the lower surface of a Valiant leaf.

Figure 5: Valiant clusters are highly susceptible to downy mildew, displaying symptoms and fungal structures early in the season shortly after fruit set. Downy mildew can result in complete loss if not managed.

Figure 6: Rachises and fruit may become infected early in the season. Even berries that continue to look green may have internal infections that become evident as the season progresses.

Figure 7: Valiant is among the first of the cold climate cultivars to show active spore production for downy mildew. Spore production on this cultivar is dense and reliably distributed underneath oil spots.

Figure 8: Oil spots on Valiant leaves.

JULY:

Figure 9: As berries develop to full size, downy mildew continues to cause significant damage on Valiant. Premature red pigmentation occurs when berries are internally infected with the pathogen. Production of white spores continues on smaller, less developed fruit.

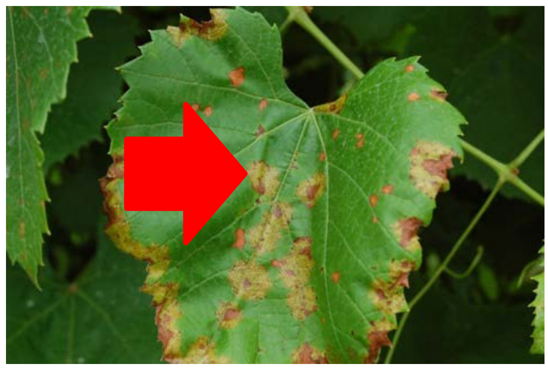

Figure 10: Downy mildew oil spots on the upper surface of a Valiant leaf (red arrow). (Black rot lesions are also pictured).

Figure 11: Downy mildew spore production on the lower surface of a Valiant leaf. Spore production is particularly heavy on younger foliage at this time of the season. Spore production on older leaves is typically sparser.

Figure 12: Downy mildew spore production on a developing cluster. The pink fruits in the background are also a result of downy mildew infection.

Figure 13: Large lesions are common on young developing foliage at this time of year. Lesions on older leaves in the canopy are smaller.

Figure 14: Spore production on the lower surface of dead downy mildew lesions.

AUGUST:

Figure 15: Advanced downy mildew symptoms on the upper surface of a Valiant leaf. Severely infected leaves begin to display dead tissue at the edge of the leaf. The death of tissue progresses inward, ultimately killing the leaf and causing it to drop.

Figure 16: Spore production on old lesions on old leaves is less pronounced than on younger leaves.

Figure 17: Premature yellowing caused by downy mildew on an old leaf in the fruiting zone of the canopy. These leaves will drop prematurely.

Figure 18: Downy mildew in the fruiting zone of the canopy of Valiant.

Figure 19: Downy mildew on tip growth of Valiant. Note the larger size of lesions at growing tips than those found on older leaves, pictured above.

Figure 20: Spore production on the lower surface of a Valiant leaf.

Figure 21: While some berries may reach maturity, those affected by downy mildew will remain hard and pink-red in color.

Figure 22: Yellowing and thinning of Valiant canopy caused by downy mildew.

Figure 23: Advanced downy mildew on a Valiant leaf. Note that tissue death starting at the leaf edge has worked its way inward, causing the leaf to curl. Leaf drop follows shortly after this level of severity is reached.

Figure 24: Valiant is distinguished from other cold climate cultivars by its high susceptibility of fruit to downy mildew. Other cultivars experience foliar damage, but none of the other cultivars that we studied had visible damage to fruit. This image shows a ripe Brianna cluster growing undamaged by downy mildew surrounded by Valiant clusters that are damaged by the disease.

Figure 25: Like LaCrosse and La Crescent, Valiant experiences defoliation that starts at the fruiting zone of the canopy and proceeds upward. Note that all leaves in the canopy have dropped, leaving fruit fully exposed.

Powdery Mildew.

MAY, JUNE, JULY: Powdery mildew did not damage Valiant in May or June 2015 or 2016 in our trials.

AUGUST, SEPTEMBER:

Figure 26: Powdery mildew on the upper surface of a Valiant leaf. Early symptoms and fungal structures are difficult to see without direct sunlight.

Black Rot. We found Valiant to be highly susceptible to both foliar and fruit black rot. Valiant is one of the first cultivars to display symptoms in the spring, and both leaf and fruit infections progress rapidly. Both fruit and foliage were severely damaged by the end of both growing seasons.

MAY

Figure 27: Black rot symptoms were recorded for the first time in mid-June in 2015 on Valiant. One year later, after a season without a management program, symptoms were recorded in mid-May, just after the first leaves had fully expanded.

Figure 28: Valiant clusters affected by black rot are often completely mummified, making the presence of overwintering mummies in the trellis likely.

JUNE:

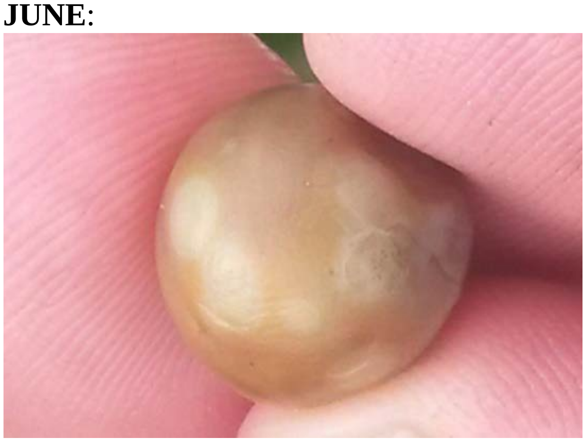

Figure 29: Early symptoms of black rot on a Valiant berry. Berries turn brown with small cream-colored circles scattered across the berry. These berries later develop spore-producing structures and shrink down to mummies. This stage of black rot is easily mistaken for anthracnose, or “bird’s eye spot.”

Figure 30: Leaves, leaf stems, and stems can all be heavily damaged by black rot early in the growing season.

Figure 31: Top left: Berries with black rot beginning to mummify. Bottom left: black rot lesions on leaves at a variety of developmental stages. Right: fully mummified berries. Wholesale loss of clusters is common in Valiant infected by black rot.

AUGUST:

Figure 32: Black rot mummies. Note that all berries in the cluster have been destroyed. This is common in Valiant if proper management is not practiced.

Figure 33: Foliage of Valiant is highly susceptible to black rot. When disease is severe, lesions often begin to coalesce and leaves will die.

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GLOSSARY

Axil: The angle between the upper side of a leaf or stem and the stem or branch to which it is attached. A bud is usually found in the axil.

Axillary shoot: a shoot produced at the axil of a leaf.

Bull cane: a shoot that is excessively vigorous, typically displaying long internodes (5-6 inches or more), and a large diameter (>one-half inch). Bull canes are less fruitful and less cold-hardy than normal canes, and make poor selections for cordons and trunks during establishment.

Bull's eye: cream colored spot surrounded by a tan to brown colored ring. A common early symptom of black rot on grape berries.

Calcareous: containing calcium carbonate.

Defoliate (verb) or **defoliation** (noun): to lose leaves; loss of leaves.

Lesion: a localized area of diseased or damaged tissue.

Mummy: dehydrated, hardened fruit covered with fungal spore-producing structures. Mummies are created by several species of fruit rotting fungi, and function as an overwintering structure for these pathogens.

Oil spot: shiny, yellow lesion commonly found on the upper surface of leaves affected by downy mildew.

Petiole: the stalk that attaches a leaf to a stem.

Rachis: specialized stem that holds grape berries and attaches them to the cane.

Spore: a reproductive unit of a pathogen, capable of being dispersed.

Terminal shoot: growing tip at the end of a shoot that does not develop from the axil of a leaf.