Disease Susceptibility in Cold- Climate Grape Cultivars of the North Central Region

Final Report for GNC15-210

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Project Information

Summary:

Lack of knowledge regarding the susceptibility of cold-climate wine grape cultivars may be leading to the overuse of fungicides and under-utilization of plant host resistance to combat disease in the northern U.S. To provide new insight on diseases of cold-climate cultivars and to update management recommendations, disease was evaluated in three vineyards containing eight cultivars that were not sprayed with fungicides in 2015 and 2016. Disease incidence and/or severity of downy mildew (*Plasmopara viticola*), powdery mildew (*Erysiphe necator*), and black rot (*Guignardia bidwellii*) were measured from bud break until 2 weeks after harvest. Cold-climate cultivars ranged widely in susceptibility to different diseases, and while several cultivars were relatively resistant to two diseases, no cultivar was highly resistant to all three diseases. Additionally, a difference between foliar and fruit susceptibility for all three diseases was noted in several cultivars. These data provide a foundation for developing low-spray and certified organic disease management strategies for cold-climate wine grapes based on susceptibility to disease.

Introduction:

Wine grape cultivation has historically focused on the European wine grape, *Vitis vinifera*. While *V. vinifera* cultivars produce notable wines, they lack the cold tolerance needed to survive winter temperatures below -5˚C to -10˚C. This lack of cold tolerance in wine grapes has limited large-scale wine production to regions where *V. vinifera* reliably survives winter temperatures. Over the past two decades however, both public and private grape breeders have released several “cold-climate cultivars” that are crosses of cold-hardy native American grape species (e.g., *Vitis riparia, Vitis aestivalis, Vitis cinerea, Vitis labrusca*) with the European wine grape. The cold-climate cultivars can tolerate winter temperatures of -16 ˚C to -37 ˚C and produce high quality wine. The introduction of these hybrids has resulted in a rapid expansion of the wine grape industry in the Upper Midwest, Great Plains, and Northeast U.S., areas largely devoid of wine grape cultivation previously (Tuck and Gartner 2013). As of 2011 the industry accounted for nearly 400 hectares and contributed over $400 million and 12,000 jobs annually to the economies of states in those regions, with further economic impact predicted as newly planted vineyards mature (Tuck and Gartner 2013). A survey in 2012 revealed that over 60% of vineyards in these regions had been established in the previous 15 years, and 82% of respondents planned on continuing the expansion of their businesses (Tuck and Gartner 2013). Growers surveyed also rated disease as one of the most significant threats to their businesses (Tuck and Gartner 2013). Downy mildew (*Plasmopara viticola*), powdery mildew (*Erysiphe necator*), and black rot (*Guignardia bidwellii*) are particularly widespread diseases that can reduce yield and winter hardiness. The season-long use of fungicides to manage these diseases is expensive, and carries risks to the health of applicators, consumers, and the environment. A more recent survey reported a 63% increase in cold-climate grape acreage since 2011, and that further expansion is expected among existing businesses in coming years (Gartner 2016). This continuing growth trend underscores the need for more knowledge on diseases and host resistance in cold-climate cultivars.

In the Upper Midwest wild grape species such as *Vitis riparia* are endemic, and high humidity and summer rains favor disease development; therefore, economically challenging grape pathogens are likely to be present in most regions where commercial vineyards are established. Although previous efforts have been made to rate and categorize disease susceptibility of cold-climate cultivars (Bordelon et al. 2016), we are aware of no such studies performed in vineyards in which cultivar blocks were replicated, randomized, and left not sprayed with fungicides.

Project Objectives:

The objectives of this research were to determine: (i) the relative susceptibility of commercially important cold-climate cultivars to downy mildew, powdery mildew, and black rot; (ii) whether foliage and fruit on a given cultivar differ in disease susceptibility, as this distinction may have significant implications for development of reduced spray programs; and (iii) determine the validity of using potted vines exposed to field inoculum and artificial humidification as a useful comparison to field vineyard trials. Experiments were conducted at two locations over two growing seasons with cultivars that collectively account for approximately 58% of cold-climate wine grape acreage (Gartner 2016). Based on the results of this study, the use of host resistance to reduce fungicide inputs in cold-climate wine grape production is discussed.

Cooperators

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Research

Materials and methods:

Field sites. Trials were conducted in 2015 and 2016 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, USDA zone 5b). These two locations represent significant regions for cold-climate viticulture in Wisconsin. Each site had a vineyard, designated WMARS and PARS 1 consisting of 200 vines (eight cultivars on their own roots ´ five randomized replicates ´ five vines per replicate) established in 2012. White grape cultivars at each site were ‘Brianna,’ ‘Frontenac gris,’ ‘La Crescent,’ and ‘LaCrosse’ and red grape cultivars at each site were ‘Frontenac,’ ‘Marquette,’ ‘St. Croix,’ and ‘Valiant.’ ‘Valiant’ was previously reported to be highly susceptible to downy mildew, powdery mildew, and black rot (Smiley et al. 2015) and was included in this study as a disease indicator. An additional vineyard at PARS, designated PARS 2, was included in the study in 2016, and consisted of 96 vines (six cultivars on their own roots ´ four randomized replicates ´ four vines/replicate) established in 2008. The cultivars in this vineyard were ‘Brianna,’ ‘Frontenac,’ ‘Frontenac gris,’ ‘La Crescent,’ ‘LaCrosse,’ and ‘Marquette.’ No fungicides were applied to WMARS and PARS 1 during either growing season. Likewise, when PARS 2 was added to the study in 2016, fungicides were withheld. Aside from the absence of fungicide applications, the vineyards were managed 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. Vines were hedged as needed, sucker sprouts were removed, and bird netting was used to prevent damage during berry ripening. Insecticides were applied as needed at both sites 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. Daily high and low temperatures and rainfall were measured at WMARS with a Spectrum WatchDog 1000 Series Micro Station (Spectrum Technologies, Inc., Aurora, IL) and at PARS with a CR 1000 Measurement and Control Datalogger (Campbell Scientific, Logan, UT).

Trap Plants. Once per month, from May through August 2015, 48 potted plants (six cultivars replicated eight times) were placed in randomized fashion underneath grapevine canopies in the two WMARS and PARS vineyards being studied that year. The cold-climate cultivars used were ‘Brianna,’ ‘Frontenac,’ LaCrosse,’ ‘Maréchal Foch,’ and ‘Marquette.’ ‘Cabernet Sauvignon,’ a *Vitis vinifera* cultivar known to be susceptible to the three diseases of interest, was included as a positive control. A total of eight of these assays were conducted, one assay at both WMARS and PARS 1 in May, June, July, and August 2015. The trap plants were planted in six-inch standard pots as dormant rooted cuttings, pruned down to three to six buds, and grown out in a greenhouse for 4 weeks before being placed in the field. Prior to planting, rooted cuttings were stored in a cooler throughout the season to hold dormancy until they were removed and grown out for assays. As such, all groups of trap plants that went out in to the field throughout the growing season were the same age, 4 weeks past bud break. No fungicides or other pesticides were sprayed on the trap plants at any point during the greenhouse production of the vines or the assay itself. ‘Cabernet Sauvignon’ and ‘Maréchal Foch’ were included to help relate disease susceptibility data from newer cold-climate cultivars to the disease susceptibility of established cultivars. Two six-plant groups of trap plants were held back from the field each month at both sites as controls. One group was placed directly in a humidified greenhouses equipped with misters to maintain high relative humidity (>90%) with the plants that had been placed in the vineyard, and then after 7 days, transferred to the cold frame with them. The second control group was held in the greenhouse for the duration of the study and was never placed outside or in contact with plants that had been placed in the field. Both control groups were rated on the same days as the plants that had been placed in the vineyard. The scale used to rate all trap plants was the same 1 to 4 rating system used on the field trials (Chapter 2). After being collected from the field, humidified, and placed outside in cold frames, each group of trap plants was rated at 2-week intervals. These ratings were conducted on each group of trap plants three times.

Disease assessment. Beginning when leaves unfolded in the spring, all vineyards were scouted at least once 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 three diseases of interest had been reported previously at WMARS and PARS, and therefore no inoculum was added artificially. In 2015, damage to leaves and fruit by downy mildew, powdery mildew, and black rot was rated on three vines per replicate using a visual scale of 1 to 4. A rating of 1 indicated no disease (0%), a rating of 2 indicated light disease (<25% of leaves and clusters with symptoms), a rating of 3 indicated moderate disease (26-50% of leaves and clusters with symptoms), and a rating of 4 indicated severe disease (>50% of leaves and clusters with symptoms). Separately, the incidence of downy mildew on fruit clusters (percent of fruit clusters damaged) was estimated visually on 13 July at WMARS and 14 August at PARS 1 in 2015. In 2016, downy mildew, powdery mildew, and black rot were rated on three vines per replicate with the same scale, and incidence of downy mildew damage to fruit clusters was recorded; however, a distinction between foliar and fruit damage was added for powdery mildew and black rot in 2016. Percentage of fruit clusters damaged by disease was determined on three vines per replicate for all cultivars in 2016. Percentage of fruit clusters damaged by downy mildew was measured on 13 July and 10 August at WMARS and 14 July and 11 August at PARS 1 and PARS 2. Percentage of fruit clusters damaged by powdery mildew was measured on 10 August and 6 September at WMARS and 12 August and 8 September at PARS 1 and PARS 2. The rating of black rot was modified to describe both the incidence and severity of disease. On 15 August at WMARS and 20 August at PARS 1 and PARS 2, the percentage of clusters with black rot (incidence) was determined by counting, and the percentage of berry surface affected (severity) was estimated by visual assessment.

Data analysis. Data were subjected to statistical analysis using SAS Statistical Software version 9.4 (SAS Institute Inc., Cary, NC). Data from each of the vineyards were analyzed separately for each year and each rating date. The SAS RANK procedure was used to create a set of ranked data points. A non-parametric one-way analysis of variance was applied to the data generated by the RANK procedure (this procedure is equivalent to the Kruskal-Wallis k-sample test). A least significant difference (LSD) test was also conducted for each date to determine significant differences between cultivars in the incidence or severity of each disease.

Research results and discussion:

Susceptibility to downy mildew. In 2015, severity of downy mildew on foliage was significantly different ($P<0.05$) between cultivars on 13 of 17 rating dates at WMARS and 9 of 16 rating dates at PARS 1 (Fig. 1A and B). In general, disease was more severe and developed earlier in the season at WMARS than at PARS 1. ‘Valiant,’ the indicator cultivar, had both severe foliar and fruit damage in 2015 and was the only cultivar that had fruits visibly damaged by downy mildew, with > 80% of fruit clusters affected at both WMARS and PARS 1 (data not shown). ‘LaCrosse’ leaves were highly susceptible at WMARS and PARS 1. ‘La Crescent’ leaves were highly susceptible at WMARS and moderately susceptible at PARS 1 in 2015, but disease developed later in the season than it did on ‘Valiant’ or ‘LaCrosse.’ All three of these cultivars were severely defoliated by downy mildew by the end of the season, a response that was not recorded on the other five cultivars. ‘St. Croix’ ‘Brianna,’ ‘Frontenac,’ and ‘Frontenac gris’ leaves were moderately to highly susceptible at WMARS and minimally susceptible at PARS 1 in 2015. ‘Marquette’ leaves were minimally susceptible at WMARS and PARS 1 in 2015. In spite of abundant inoculum produced on nearby vines of other cultivars, sporulating downy mildew lesions were not observed on ‘Marquette’ at either site in 2015. However, pale yellow lesions resembling “oil spot” symptoms of downy mildew were observed on older foliage of ‘Marquette’ near the end of the growing season.

In 2016, severity of downy mildew on foliage was significantly different ($P<0.05$) between cultivars on 11 of 17 rating dates at WMARS, 8 of 13 rating dates at PARS 1, and 8 of 13 rating dates at PARS 2 (Fig. 1C, D, and E). ‘Valiant’ had severe foliar and fruit damage in 2016, and was again the only cultivar that had fruit visibly damaged by downy mildew, with > 80% of fruit clusters affected at both WMARS and PARS 1 (data not shown). ‘LaCrosse’ and ‘La Crescent’ leaves were highly susceptible at WMARS, PARS 1, and PARS 2. As in 2015, these cultivars were defoliated by the end of the season. ‘St. Croix’ leaves were highly susceptible at both WMARS and PARS 1 in 2016, and the cultivar was defoliated by the end of the season at WMARS. ‘Brianna’ leaves were highly susceptible at WMARS and moderately susceptible at PARS1 and PARS 2, but ‘Brianna’ was not prematurely defoliated. ‘Frontenac’ and ‘Frontenac gris’ were minimally susceptible at WMARS, PARS 1, and PARS 2 in 2016. As in 2015, light sporulation was consistently observed on both cultivars late in the season, particularly on older leaves. ‘Marquette’ leaves were minimally susceptible at WMARS, PARS 1 and PARS 2. Light sporulation occurred sporadically on foliage at growing tips, and “oil-spot” lesions were observed on older leaves near the end of the growing season.

Susceptibility to powdery mildew. In 2015, severity of powdery mildew was significantly different ($P<0.05$) between cultivars on 6 of 17 rating dates at WMARS and 7 of 16 rating data at PARS 1 (Fig. 2A and B). Leaves of all eight cultivars were minimally susceptible to powdery mildew at WMARS in 2015 except ‘LaCrosse,’ which was slightly susceptible. At PARS 1, all cultivars were highly susceptible except ‘La Crescent’ and ‘Valiant.’ ‘La Crescent’ was moderately susceptible and ‘Valiant’ was slightly susceptible. Although our ratings did not quantify disease on leaves versus fruit in 2015, differences were observed in several cultivars.

In 2016, severity of powdery mildew on foliage was significantly different ($P<0.05$) between cultivars on 2 of 17 rating dates at WMARS, 7 of 13 ratings dates at PARS 1, and 7 of 13 rating dates at PARS 2 (Fig. 2C, D and E). ‘Frontenac,’ and ‘Frontenac gris’ were slightly susceptible at WMARS, and other cultivars were not damaged by powdery mildew in 2016. ‘Brianna,’ ‘Frontenac,’ ‘Frontenac gris,’ and ‘Marquette’ were moderately to highly susceptible at PARS 1 and PARS 2. ‘La Crescent,’ ‘LaCrosse,’ ‘St. Croix,’ and ‘Valiant,’ were slightly susceptible at PARS 1 and PARS 2.

A rating distinction between fruit clusters and foliage was made in 2016. No powdery mildew damage to fruit clusters was recorded at WMARS in 2016 (data not shown). At PARS 1, ‘Brianna,’ ‘Frontenac,’ and ‘Frontenac gris’ clusters were moderately to highly susceptible to powdery mildew (Fig. 3A and B). ‘La Crescent,’ ‘LaCrosse,’ ‘Marquette,’ and ‘St. Croix’ were slightly susceptible, and ‘Valiant’ was not susceptible. At PARS 2, ‘Brianna,’ ‘Frontenac,’ and ‘Frontenac gris’ fruit clusters were moderately to highly susceptible to powdery mildew (Fig. 3C and D). ‘LaCrosse’ clusters were slightly susceptible, and ‘La Crescent’ and ‘Marquette’ were not susceptible. Powdery mildew was observed primarily on the rachises of ‘La Crescent,’ ‘Frontenac,’ ‘Frontenac gris,’ ‘Marquette,’ and ‘St. Croix,’ while disease was observed on both berries and rachises of ‘Brianna’ and ‘LaCrosse.’

Susceptibility to black rot. In 2015, severity of black rot was significantly different (*P*<0.05) between cultivars on 11 of 17 rating dates at WMARS and 8 of 16 rating dates at PARS 1 (Fig. 4A and B). ‘Brianna’ and ‘Marquette,’ were slightly susceptible to black rot at WMARS in 2015. ‘La Crescent,’ ‘Frontenac,’ ‘Frontenac gris,’ and ‘St. Croix,’ ‘LaCrosse’ and ‘Valiant’ were minimally susceptible. ‘Frontenac’ was slightly susceptible to black rot at PARS 1 in 2015, while ‘Brianna,’ ‘La Crescent,’ ‘LaCrosse,’ ‘Frontenac gris,’ ‘Marquette,’ ‘St. Croix,’ and ‘Valiant’ were minimally susceptible.

In 2016, black rot severity on foliage was significantly different (*P*<0.05) between cultivars on 13 of 17 rating dates at WMARS, 9 of 13 rating dates at PARS 1, and 9 of 13 rating dates at PARS 2 (Fig. 4C, D and E). At WMARS, leaves of ‘Marquette’ and ‘Valiant’ were moderately susceptible to black rot. Leaves of ‘Brianna,’ ‘La Crescent, ‘LaCrosse, ‘Frontenac,’ ‘Frontenac gris,’ and ‘St. Croix’ were minimally susceptible. At PARS 1, leaves of ‘Valiant’ were highly susceptible to black rot. Leaves of ‘LaCrosse,’ ’Frontenac,’ ‘Frontenac gris,’ ‘Marquette,’ and ‘St. Croix’ were moderately susceptible, while ‘Brianna’ and ‘La Crescent’ were minimally susceptible. At PARS 2, leaves of ‘Marquette,’ ‘Brianna,’ ‘Frontenac,’ ‘Frontenac gris,’ ‘La Crescent,’ and ‘LaCrosse’ were minimally susceptible.

Trends in black rot incidence on fruit clusters generally paralleled trends in severity in all three vineyards (Fig. 5). At WMARS, ‘Marquette’ had the highest incidence of cluster damage, at approximately 40%, and ‘Valiant’ had the second highest incidence, at approximately 20% (Fig. 5A). Disease severity was greatest on ‘Marquette’ and ‘Valiant,’ averaging approximately 30% of cluster area affected on each cultivar (Fig. 5B). Incidence of cluster damage on other cultivars was less than 5%, and severity ranged from about 5% to 20%. At PARS 1, incidence of cluster damage was highest on ‘Valiant,’ with 84% of clusters damaged (Fig. 5C). ‘Frontenac,’ ‘Frontenac gris,’ ‘LaCrosse,’ and ‘Marquette’ averaged between 25% and 45% of clusters damaged, while ‘Brianna,’ ‘La Crescent,’ and ‘St. Croix’ averaged less than 20% of clusters damaged. Disease severity was greatest on ‘Valiant’ with about 60% of cluster area affected (Fig. 5D). Disease severity was approximately 25% to 45% on ‘Frontenac,’ Frontenac gris,’ ‘LaCrosse,’ and ‘Marquette,’ and approximately 20% or less on ‘Brianna,’ ‘La Crescent,’ and ‘St. Croix.’

At PARS 2, ‘Marquette’ and ‘Frontenac gris’ had the highest incidence of cluster damage at approximately 15% to 20% (Fig. 5E). Incidence of cluster damage on ‘Brianna,’ ‘La Crescent,’ ‘LaCrosse,’ and ‘Frontenac’ was less than 10%. Disease severity was greatest on ‘Marquette’ and ‘Frontenac gris’ at approximately 30% of cluster area affected (Fig. 5F). Disease severity was approximately 20% on ‘LaCrosse’ and less than 20% on ‘Brianna,’ ‘La Crescent,’ and ‘Frontenac.’

Trap Plants: The eight assays conducted with trap plants in 2015 did not show disease development that different from the control groups (p>0.05). It was also noted that what little disease that did appear was also not representative of disease measured on adult vines at either of the field sites. For example, the average rating for foliar downy mildew between 'Brianna,' 'Frontenac,' and 'Marquette' was not significantly different in any of the trap plant assays. Conversely there was a significant difference between susceptibility of these three cultivars at WMARS, PARS 1, and PARS 2 in both 2015 and 2016. Powdery mildew and black rot damage was minimal in all eight trap plant assays, which was also different from what was observed on these same cultivars in the field. More powdery mildew was recorded on the control groups that never left the greenhouses than was recorded on trap plants placed in the field, and no cultivar received a rating of greater than "2" for black rot in any of the eight trap plant assays. Cultivars that displayed moderate to severe susceptibility to powdery mildew and black rot in the field (Chapter 2, Figures 2, 3, 4, and 5), such as 'Marquette,' would not have been detected using the trap plant assay. These differences illustrate the reduced separation observed between cultivars during the trap plant study for all three diseases of interest. While this assay did succeed in generating ratings for disease, the results did not separate cultivars in a way that was consistent with what was recorded in the field trials, and missed several important distinctions in susceptibility between cultivars that were detected in the field trials.

There are several possible explanations for why the trap plant assay did not provide the results that we had anticipated. It is possible that the trap plants grown in the greenhouse were less susceptible to disease than their field-grown counterparts due to a differential formation of cuticle, leaf expansion, or physiological "age" at the time of field placement. It is also possible that the cold-frame environment that the grapes were placed in following humidification was not similar enough to the conditions that the pathogens in the field were experiencing to generate the same disease development. Grape canopies are dense during the summer months, minimizing air flow and allowing leaves to stay wet for a longer period of time. The trap plants were 1 year old, and as such had a sparse canopy. The cold-frames that they were placed in following the humidification treatment faced south, so it is possible that the minimal canopy and intense sunlight resulted in a less favorable environment for the three pathogens of interest.

In spite of the possibility to correct several of these potential issues, the failure of this assay highlights the necessity for the study of these pathogens under field conditions in future work, or at the very least to accompany such studies with field subjects. Disease did appear on the trap plants, but it was at low levels or inconsistent and also encompassed several diseases that never appeared in the vineyard, such as *Botritis cinerea,* which showed up on the leaves of several of the plants. Disease assays that are conducted using plants outside of vineyard conditions may not generate susceptibility results that are consistent with what occurs on adult vines in field conditions for the duration of a growing season, particularly given the variability between up to three sites in field conditions.

Discussion. We report here disease susceptibility of popular cold-climate wine grape cultivars in multiple randomized field trials over two growing seasons. The low susceptibility to downy mildew, powdery mildew, or black rot that was observed in several cultivars sets the stage for development of reduced spray and organic production strategies for the cold-climate wine industry in the northern U.S. Distinctions between foliar and fruit susceptibility to disease in these cultivars will provide additional flexibility as these strategies are developed. Avoidance of highly susceptible cultivars, particularly among growers wishing to minimize fungicide use, will be critical to the growth, sustainability, and profitability of the cold-climate wine grape industry.

Across years and locations, there were trends in the susceptibility of cultivars to foliar and fruit downy mildew that were highly consistent (Fig. 1), allowing us to rank cultivars from most to least susceptible: Valiant = LaCrosse > La Crescent > St. Croix > Brianna > Frontenac = Frontenac gris > Marquette.

Downy mildew is capable of destroying fruit of many well-known cultivars of *V. vinifera*, the European wine grape (Kassemeyer et al. 2015). Even when this disease does not directly destroy fruit, premature loss of foliage can cause fruit to fail to ripen (Kassemeyer et al. 2015). Our data suggest less risk for many of the cold-climate cultivars, even in absence of fungicide applications. All of the cultivars that were included in this study except 'Valiant' were resistant to downy mildew on fruit clusters, even when fruit were surrounded by leaves with sporulating lesions and during periods of rainy weather that were highly conducive to disease. Further, many cultivars sustained light or moderate foliar infection without a premature loss of leaves. Thus, on some cultivars, there is potential to reduce fungicide use substantially by foregoing sprays early in the season and focusing specifically on preventing defoliation in middle to late summer on an "as-needed" basis. Fewer sprays for downy mildew control would reduce costs to growers and would also reduce the risk for the development of fungicide resistance, a serious concern as resistance to QoI (strobilurin) fungicides has already been documented in the grape downy mildew pathogen in several locations in the U.S. (Colcol and Boudoin 2016; Ward-Gauthier and Amsden 2014; Wong and Wilcox 2000).

Across years and locations, there were consistent trends in the susceptibility of cultivars to foliar and fruit powdery mildew, allowing us to rank cultivars from most to least susceptible (Fig. 2 and 3): Brianna = Frontenac = Frontenac gris > Marquette > LaCrosse > St. Croix > La Crescent = Valiant. Susceptibility to both fruit and foliar powdery mildew appears to be more common among the cold-climate cultivars than what we observed for downy mildew and black rot, posing a potential challenge for the development of reduced spray programs. Heavy powdery mildew damage can result in poor fruit ripening, uneven fruit sizing, fruit cracking, and loss of photosynthesis late in the season (Gadoury et al. 2015; Lasko et al. 1982). Our data suggest that future testing of reduced spray programs may need to pay particular attention to powdery mildew, since this disease can cause significant direct damage to fruit and rachises of cold-climate cultivars. A possible complicating factor in our trials is the effect that one disease might have on another disease. For example, we observed low severity of powdery mildew on 'La Crescent' and 'Valiant,' but it is possible that extensive downy mildew damage to leaves made these cultivars less ideal hosts for powdery mildew. Since both the downy mildew and powdery mildew pathogens are obligate biotrophs, reduction of healthy leaf tissue by either pathogen could reduce the possibility of infection by the other.

Across years and locations, there were consistent trends in the susceptibility of cultivars to foliar and fruit black rot, allowing us to rank cultivars from most to least susceptible (Fig.4 and 5): Valiant > Marquette > Frontenac = Frontenac gris > Brianna = LaCrosse = St. Croix > La Crescent. Of the eight cultivars that were studied, foliar black rot was severe on only 'Valiant' and 'Marquette,' and even severely damaged vines were not defoliated prematurely by the disease. However, black rot caused severe damage to fruit on several cultivars despite low levels of foliar disease.

There was a significant increase in the severity of black rot in 2016 compared to 2015 at both WMARS and PARS 1, and also a greater degree of separation among the eight cultivars in 2016. This suggests a tendency of black rot to build up following a year of poor management. ‘La Crescent’ was less susceptible to black rot compared to other cultivars, making it a possible candidate for organic vineyards, since fungicides approved for use in organic production are generally ineffective in controlling black rot (Weigle and Carroll 2016). By contrast, ‘Marquette,’ ‘Frontenac,’ ‘Frontenac gris,’ and ‘Valiant’ were all highly susceptible to black rot on fruit and moderately to highly susceptible to foliar black rot, making them less practical choices for organic production.

Berries of *Vitis labrusca* some and interspecific hybrids have a window of peak susceptibility to black rot beginning at bloom and extending about 4 weeks after bloom (Hoffman and Wilcox 2002; Hoffman et al. 2004). In our trials, most black rot lesions developed on leaves later in the season, with severity ratings < 2 until mid-July to early August for most cultivars in most trials. However, if berries of cold-climate interspecific hybrids become resistant to infection by 4 weeks after bloom, then they would not be damaged by conidia released from lesions that develop after that time. Fruit mummies, particularly those that overwinter in the trellis, are a significant source of black rot inoculum (Hoffman and Wilcox 2002; Wilcox and Hoffman 2015). Therefore, it may be possible to achieve good control of black rot in less susceptible cold-climate cultivars with two or three sprays starting just before bloom and ending at 3 to 4 weeks after bloom if fruit mummies are removed each year prior to bloom.

Participation Summary

Educational & Outreach Activities

PARTICIPATION SUMMARY:

Education/outreach description:

Journal Publications currently in review:

1.) Jones, D.S. and McManus, P.S. Susceptibility of Cold-Climate Wine Grape Cultivars to Downy Mildew, Powdery Mildew, and Black Rot. Submitted to Plant Disease 2017.

2.) Jones, D.S. and McManus, P.S. Signs and Symptoms of Downy Mildew on Cold-Climate Wine Grape Hybrids. Submitted to Plant Health Progress, 2017.

Extension Publications:

1.) Jones, D.S. and McManus, P.S. 2015. Grape Downy Mildew. Northern Grapes News. Volume 4, issue 4. November 2015

http://northerngrapesproject.org/wp-content/uploads/2015/11/NG-News-Vol4-I4-Nov-2015.pdf

2.) Jones, D.S. and McManus, P.S. 2016. Profile of Current Grape Pathology Work.

Wisconsin Fruits Newsletter 2016, Issue 1.

3.) Jones, D.S. and McManus, P.S. 2016. Reducing Disease Pressure Through Vineyard Sanitation. Wisconsin Fruits Newsletter 2016, Issue 2.

4.) Jones, D.S. and McManus, P.S. 2016. Early Season Black Rot Management. Wisconsin Fruits Newsletter, Issue 3.

5.) Jones, D.S. and McManus, P.S. 2016. Wisconsin Grape Disease Updates. Wisconsin Fruits Newsletter, Issues 4, 5, 6, 8, 9, 10, 11.

6.) Jones, D.S. and McManus, P.S. 2016. Late Season Downy Mildew Management. Wisconsin Fruits Newsletter, Issue 12.

7.) Jones, D.S. and McManus, P.S. 2016. Susceptibility to Downy Mildew, Powdery Mildew, and Black Rot: New Management Applications for Cold-Climate Wine Grape Growers. Wisconsin Fruits Newsletter, Special Grape Supplemental Issue.

Extension and Outreach Activities:

1.) Jones, D.S. and McManus, P.S. Cold Climate Wine Grape Disease Research Update and Future Directions. Wisconsin Grape Growers Association Summer Vineyard Walk, July 2015.

2.) Jones, D.S. and McManus, P.S. Downy Mildew Susceptibility in Cold-Climate Grape Hybrids. Wisconsin Fresh Fruit and Vegetable Conference. Wisconsin Dells, WI, January 2016.

3.) Jones, D.S. and McManus, P.S. Discussion of Disease in Cold Climate Wine Grapes and 2015 Season Research Synopsis. Wisconsin Grape Growers Association Vineyard Walk, July 2016.

4.) Jones, D.S. and McManus, P.S. Disease Susceptibility Screening in Cold Climate Wine Grapes. American Phytopathological Society Annual Meeting Poster Session. Orlando, FL August 2016.

5.) Jones, D.S. and McManus, P.S. Susceptibility to Disease and Sensitivity to Copper and Sulfur: New Management Applications for Cold-Climate Wine Grape Growers. Great Lakes Fruit Workers Exposition, December 2016.

6.) Jones, D.S. and McManus, P.S. Integrated Disease Management Based on Cultivar Susceptibility and Fungicide Sensitivity. USDA Northern Grapes Project Webinar Series. January 2017.

7.) Jones, D.S. and McManus, P.S. Susceptibility of Cold-Climate Wine Grape Cultivars to Downy Mildew, Powdery Mildew, and Black Rot. Wisconsin Fresh Fruit and Vegetable Conference, January 2017.

Project Outcomes

Project outcomes:

1.) The relative susceptibility to downy mildew, powdery mildew, and black rot of eight cold-climate cultivars has been categorized, and will serve as a basis for the development of reduced spray and organic systems that incorporate host plant resistance into disease management strategies. These systems will allow for more sustainable and economically viable production of cold-climate wine grapes throughout the North Central region and a continued push away from calendar based spray programs. This information also allows growers to understand the relative disease risks associated with growing specific cultivars, providing valuable insight into seasonal disease issues that may arise. It also gives growers better insight on what problems may arise when establishing a planting of a new cultivar, allowing growers to avoid cultivars with severe susceptibility to problematic diseases at time of establishment.

2.) New information on the susceptibility of cold-climate wine grape cultivars has and will continue to be distributed to the growers using multiple educational outlets, including regional and national conference presentations, regional and national newsletters, and peer-reviewed publication. This information will help both researchers and growers incorporate disease susceptibility information into future work concerning the cold-climate wine grape industry.

3.) New distinctions in disease symptoms and organ-specific susceptibility to disease in cold-climate cultivars have been categorized with both data and images. For example, we found that only one of the seven cultivars studied is susceptible to downy mildew damage on fruit clusters, a distinctive trait from traditionally grown *Vitis vinifera* cultivars with important management applications. This information will be incorporated into diagnostic guides and photographic manuals for growers, leading to new discussions on management decision making throughout the North Central region.

Economic Analysis

Farmers will see economic benefit from this research in several ways over time. Selection of less susceptible cultivars to downy mildew, powdery mildew, or black rot could result in spray savings. Additionally, heightened awareness of risks associated with cultivars that are already in the ground may allow for more targeted, cultivar specific management choices. Growers will continue to see economic benefit in years to come as the information in this research is used to develop reduced spray programs for specific cultivars. These programs will give farmers more economically sustainable practices to produce

Farmer Adoption

Cold-climate grape growers have been given the information generated by this work through the variety of venues listed previously, and adoption of disease management practices that take advantage of cultivar susceptibility to disease will continue as more information is generated. At this time, cultivar selection at time of establishment is a crucial strategy that can be employed throughout the North Central region to promote more sustainable management strategies. Conversely, avoidance of cultivars with severe susceptibility to a disease that has caused previous economic hardship at a vineyard site can be employed to minimize the potential for problems in the future.

Recommendations:

Areas needing additional study

1.) Spray Reduction Programs (i-iii). Our data indicate that there are several cold-climate varieties, including Frontenac, Frontenac gris, and Marquette that perform well against downy mildew in the absence of fungicides. While it is unlikely that grapes can be produced in an economically sustainable manner in complete absence of fungicides, it seems plausible that reduced rates of fungicides could be a sustainable and viable option for growers in the north given observed high performance of these cultivars in no-spray conditions. Diseases such as downy mildew, which primarily affect vegetative growth in these cultivars, currently cause growers to spray heavily. However, our findings indicate that foliar downy mildew does not tend to damage these cultivars to the point of causing premature leaf drop or impaired fruit ripening, and that fruits are not susceptible to the disease. Furthermore, research has shown that peak fruit susceptibility to black rot occurs between 3-4 weeks after bloom (Hoffman and Wilcox 2002), and could be controlled with timely application of fungicides early in development, with a reduced program targeting foliar pathogens as the season progresses.

i.) Conventional Spray Reduction Programs: Data indicating minimal risk of foliar damage from downy mildew makes it reasonable to suggest that 2-3 timely sprays starting just before flower opening and ending 3-4 weeks post bloom to control black rot (Hoffman and Wilcox 2002) combined with an “as needed” approach to spraying for foliar pathogens such as powdery mildew and downy mildew could achieve acceptable management throughout a growing season for Marquette, Frontenac, and Frontenac gris. Petite Pearl, a popular cultivar that we observed in just one year, also appeared to be similarly resistant to damage from downy mildew and would be worth including in further trials. Reduction or elimination of sprays directed at foliar infections would represent an enormous savings in spray programs in the region, as most vineyards are sprayed every 1-2 weeks from bud break through fruit ripening at present. Any pathogen that causes foliar disease is currently seen as a danger to the success of the vineyard and the season’s crop, and addressed as such. However, our data suggest that the foliage of several cold-climate varieties is in little danger of being significantly harmed by downy mildew to the point of economic loss, and that fruits are rarely at risk of being damaged by this disease. This is particularly important given the vigor of the cold-climate varieties. Excess vigor means that growers have to annually thin leaves, hedge, and otherwise push back growth of the vines. Therefore, it stands to reason that light disease may not tax vines to a level where fruit quality is impaired.

ii.) USDA Certified Organic Spray Reduction Programs: Alternatively, there are several cultivars that appear to be less susceptible to black rot than others, though several are severely susceptible to downy mildew. Black rot is one of the most challenging diseases for organic growers to manage, as it is not sensitive to sprays containing copper (Ellis and Mizuho 2014). Copper-based sprays are among the few effective fungicides that organic growers have available to them. For this reason, spray reduction programs targeted at organic production may need to be built on cultivars that are minimally susceptible to black rot rather than downy mildew. Our trials indicate that La Crescent and St. Croix are both minimally susceptible to black rot, displaying lower levels of foliar and fruit damage than other cultivars in both 2015 and 2016. Additionally, both cultivars are only moderately susceptible to powdery mildew. Although both are severely susceptible to downy mildew, copper-based sprays provide excellent downy mildew control, and are available to organic growers (Carroll and Weigle 2016). A program that incorporates dormant lime sulfur applications and removal of mummified combined with timely sprays of copper-based fungicide to manage downy should be compared to a conventional system. Vineyard sanitation is particularly critical from an organic production standpoint, as previous research shows a significantly higher risk for black rot damage when mummies are retained within the trellis as opposed to falling to the ground or being removed altogether (Hoffman and Wilcox 2002). Because this program would aim to minimize sprays against black rot, sanitation would be among the most effective tools for reducing inoculum present within the vineyard.

iii.) Spray Reduction Comparisons: There are several important factors related to both the quality and the quantity of a crop that need to be analyzed in order to determine whether low spray alternative systems using cultivar selection to minimize disease are a viable option for Wisconsin growers. The total weight of harvested crop should be compared to controls maintained in a conventional manner. In addition to measuring harvest weights, additional fruit characteristics critical to winemaking should be measured, including a final reading of brix (soluble sugars) and titratable acidity. The malic acid to tartaric acid ratio should also be compared. Finally, the timing of fruit ripening should be closely monitored using brix and titratable acidity. If disease causes fruit in low-spray systems to lag behind conventional systems, this could be problematic in cool or short growing seasons. For example, in 2016 at WMARS, ripening of La Crescent lagged over a week behind the conventional a block at WMARS due to defoliation in the no-spray block, making it clear that there is a certain damage threshold beyond which ripening is impaired.