Article

Disease susceptibility of interspecific cold-hardy grape cultivars in Northeastern U.S.A.

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Abstract:

Susceptibility to economically-important diseases of grapes is critical to the evaluation of germplasm recommended for commercial production and for development of sustainable production systems. In 2018-2019, nine cold-hardy grape cultivars including 'Brianna', 'Crimson Pearl', 'Itasca', 'Louise Swenson', 'Marechal Foch', 'Marquette' 'Petite Pearl', 'St. Pepin', and 'Verona' were evaluated on non-treated vines for susceptibility to downy mildew, powdery mildew, black rot, anthracnose, *Phomopsis* leaf spot and fruit rot, and *Botrytis* bunch rot. No cultivars were consistently disease-free, and all exhibited some degree of black rot and powdery mildew infection. Relative susceptibility to disease was not consistent across both years, but 'Brianna' had greater incidence of black rot and 'Louise Swenson' showed lower incidence of powdery mildew in both years. The relatively new cultivars 'Crimson Pearl' and 'Verona' exhibited comparatively moderate disease susceptibility overall. Growers typically manage diseases with fungicides on commercial farms, so cultivar susceptibility is just one component of a sustainable pest management and production system.

Keywords: *Vitis* spp.; interspecific hybrid grapes; cultivar evaluation; Integrated Pest Management; disease resistance.

1. Introduction

Winegrapes are an emerging and expanding crop throughout the New England states in the northeastern U.S.A. and the recent introduction of several new cold-tolerant cultivars now allows production in regions where low winter temperatures previously precluded cultivation [1]. According to a 2014 NASS report where grapes were singled out as a crop for the first time in New England, there were 360 ha of grapes grown in New England yielding an average of 5.6 MT * ha^{-1} [2]. The value of the utilized production for the area was $4,200,000, resulting in an average of $11,600 per acre. This figure does not take into consideration any of the value-added income potential of turning these grapes into wine. Vermont grape acreage doubled from 2007 to 2012 [3] and increased again by 34% by 2017 [4].

Grape production requires a long period of 3-4 years from planting until attaining any substantial marketable production, and high establishment costs of about US$20,000 per hectare exclusive of land costs makes production capital-intensive and risky in the short-term [5]. Most vineyards in Vermont are managed using Integrated Pest Management (IPM) methods, but an increasing number of vineyards have adopted 'natural' production methods that include practices used in organic and biodynamic production systems [6]. In a 2016 survey of grape producers from Vermont and surrounding states, disease management was ranked among the greatest threats to their operations [1].

In both IPM and 'natural' production systems, cultivar resistance to disease is a critically important component of sustainable fruit production. Because grape production is relatively new in the region and made possible only by recently-bred cultivars, continued breeding and germplasm evaluation has contributed to turnover in recommended and planted cultivars. Public coordinated evaluation programs including NE-1020/1720 Multistate Evaluation of Winegrape Cultivars and Clones [7-11] and Northern Grapes Project [12] have assisted the relatively rapid collection and dissemination of performance metrics for new winegrape cultivars. The research presented in this paper is a product of that effort.

Grapes can be difficult to grow in the humid northeast and the complex of fungal diseases that attack foliage and fruit clusters is particularly challenging. Diseases in Vermont vineyards can include black rot (*Guignardia bidwellii*), *Phomopsis* leaf spot and fruit rot *(P. viticola)*, powdery mildew (*Uncinula necator*), downy mildew (*Plasmopora viticola*), anthracnose (*Elsinoe ampelina*) and *Botrytis* (*B. cinerea*) bunch rot and blight among others. In slightly warmer regions of the central and eastern Northern United States, such as Finger Lakes, New York; Niagra Peninsula, Ontario; and portions of Michigan and other states with favorable proximity to the Great Lakes, relatively cold-hardy *V. vinifera* grape cultivars of Eurasian origin such as 'Riesling' and 'Cabernet Franc' are grown among other, more cold-hardy hybrid and North American-native cultivars with lower risk for crop loss from cold damage [13]. In those regions where cold-hardy *V. vinifera* and interspecific hybrids are grown in proximity to one another, the relative disease resistance of the hybrids is apparent, as growers typically apply 8-12 fungicide sprays annually for the former compared to 5-6 for the latter [14].

In addition to selection for cold hardiness, the recent inter-specific grape cultivars have also been bred for disease resistance. The majority of cultivars grown in the colder regions of upper Midwest and Northern U.S. where *V. vinifera* production is unreliable were developed in three breeding programs located in Minnesota or adjacent Wisconsin. Each of these breeding programs has used *V. vinifera*, included for its juice quality for winemaking, and native North American species, particularly *V. labrusca* and *V. riparia*, which impart cold hardiness to the crosses [15,16]. Because the North American species co-evolved with disease-causing organisms native to the region, and *V. vinifera* co-evolved with many plant pathogens originating in Eurasia, these interspecific hybrids tend to have lower overall disease susceptibility than more commonly-grown commercial cultivars.

In 2007-2015, eight interspecific winegrape cultivars were evaluated in South Burlington, VT, USA (lat. 44.43162, long. -73.20186) for horticultural and juice quality characteristics [9]. Among those cultivars, 'Traminette' and 'Vignoles' were removed from the planting for exhibiting poor cold hardiness and crop yield and are not grown commercially in Vermont. A recent industry survey indicated that 'Corot Noir' has never been commercially planted in Vermont, 'Prairie Star' is planted on very little acreage, and 'Frontenac' is being removed by commercial growers in favor of cultivars exhibiting enhanced wine quality [1]. Since winegrape production is so new in the region; older cultivars continue to be considered for suitability to the regions' soil and climate; and new cultivars continue to be released, comprehensive evaluation of horticultural, juice quality, and pest susceptibility is necessary to reduce risk in planting and managing this long-term, perennial crop.

2. Materials and Methods

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Research site

The research vineyard was planted in 2016 at the University of Vermont Horticulture Research Center in South Burlington, VT, U.S.A. (lat. 44.43162, long. -73.20186, USDA hardiness zone 5a, Köppen-Geiger classification Dfb) located in the Lake Champlain valley. The soil type is a well-drained Adams Windsor loamy sand (USDA NRCS, 2016) with pH 7.2. The nine own-rooted cultivars were planted following NE-1720 trial protocols. Vines of the cultivars 'Crimson Pearl', 'Itasca', 'Petite Pearl', 'St. Pepin', and 'Verona' were planted in a randomized complete block design of six blocks with two-vine plots of each cultivar per block at 1794 vines/ha density. In addition, vines of 'Brianna', 'Louise Swenson', 'Marechal Foch', and 'Marquette' were planted in solid rows at the same density adjacent to the mixed rows of other cultivars (Table 1). Similar proximity within the vineyard, vine age, and management practices applied to both the randomized NE-1720 section and the adjacent vines were considered when including all cultivars in the same trial for the purpose of this study.

Vines were trained from two trunks per vine to a 1.8 m high-wire dual unilateral cordon spur-pruned system. Drip irrigation was applied when soil water potential was below 25 kPa based on soil tensiometer readings. The vineyard received mineral nutrients as determined by soil and petiole nutrient analysis, and weekly vineyard scouting [17,18]. The research vineyard was located immediately adjacent to a previous planting in which disease presence has been recorded [19], and within 50 m of wild, unmanaged grape vines that grow in an adjacent tree canopy and typically show some level of disease. Therefore, we assume that disease inoculum is sufficiently present to evaluate new vines for diseases commonly found in area vineyards. No fungicide or insecticide treatments were applied in 2018 or 2019 in order to evaluate natural cultivar susceptibility to disease.

Table 1. Breeding program origination for nine winegrape cultivars evaluated in South Burlington, VT, USA

Cultivar	Wine color	Year released	Breeding program[1]
Brianna	White	2001	Swenson
Crimson Pearl	Red	2015	Plocher
Itasca	White	2017	UMN
Louise Swenson	White	2001	Swenson
(Marechal) Foch	Red	1951[2]	Kuhlmann
Marquette	Red	2006	UMN
Petite Pearl	Red	2009	Plocher
St. Pepin	White	1986	Swenson
Verona	Red	2015	Plocher

[1]Kuhlmann = private breeder Eugène Kuhlmannin, Alsace, France; Plocher = private breeder Tom Plocher, Hugo, MN, U.S.A.; Swenson = private breeder Elemer Swenson, Osceola, WI, U.S.A.; UMN = University of Minnesota, Chanhassen, MN, U.S.A.

[2] Release year in USA.

2.1 Foliage assessment

Foliar incidence (presence/absence) and severity (area infected) assessments were performed annually and included: downy mildew; powdery mildew; black rot; *Phomopsis* leaf spot; and anthracnose. For cultivars 'Brianna', 'Louise Swenson', 'Marquette', and 'Foch', the center two vines in a four-vine panel were sampled. For cultivars 'Crimson Pearl', 'Itasca', 'Petite Pearl', 'St. Pepin', and 'Verona', both vines of the two-vine panel were sampled. Six two-vine replications were assigned per cultivar.

Twenty-five leaves were randomly selected for disease assessment from each two-vine panel on 27 August 2018 and 4 September 2019 cultivar. Foliage samples were held in plastic bags at 2.2^{0} C until examined in the laboratory. Foliar disease incidence and severity were determined by visually assessing both surfaces of twenty leaves randomly selected from each two-vine panel per cultivar. A dissecting microscope was used for further examination if needed. Each leaf was assessed for the incidence and severity of the following diseases: downy mildew, powdery mildew, black rot, anthracnose, and *Phomopsis* leaf spot. Diseases were identified using standard diagnostic tools and protocols [20,21].

2.2 Fruit cluster assessment

Fruit clusters from each cultivar-replicate were collected annually for evaluation prior to harvest on 12 September 2018 and between 23 September and 14 October 2019, depending on the cultivar. 'Marquette' fruit cluster samples were not collected in 2019. Clusters were held in plastic bags at 2.2^{0} C until examined. Fruit disease incidence and severity were determined by visually assessing ten randomly selected clusters for each cultivar. A dissecting microscope was used for further examination if needed. Each cluster was assessed for the incidence and severity of the following diseases: downy mildew, powdery mildew, black rot, *Phomopsis* fruit rot, *Botrytis* bunch rot, and anthracnose. The Horsfall-Barratt scale (Table S1) was used to rate disease severity on foliage and clusters. If a specific disease was present, the end-point of the Horsfall-Barratt disease range (e.g., 3, 6, 12, 25, etc.) was recorded on the data sheet to indicate the area affected [22].

2.3 Statistical analysis

Data were analyzed separately by year with cultivar as the treatment variable. Analysis of variance (PROC GLM) was completed using SAS 9.4 software (SAS, Inc., Cary, NC, U.S.A.). If the overall effect from treatment was significant at α=0.05, Tukey's Honest Significant Difference (HSD) test was used to make pairwise comparisons of effects by cultivar at overall α=0.05.

3. Results

No downy mildew was observed on fruit or foliage and no anthracnose observed on fruit during the study, and those data are not further presented.

3.1 Foliage assessment

In 2018, incidence of powdery mildew ranged from 95.0-22.5% (Table 2). 'Marquette' had greatest incidence of the disease which was greater than all other cultivars except 'St. Pepin' and 'Verona'. 'Itasca', 'Brianna', and 'Louise Swenson' had the lowest incidence of powdery mildew in that year. However, in 2019, 'Marquette' and 'Louise Swenson' both had 100% incidence of powdery mildew on leaves, followed by 'Brianna', 'Petite Pearl', 'St. Pepin', and 'Verona' which had 75.8-89.2% incidence. Foliage infected with powdery mildew was lowest (22.5%) in 'Louise Swenson' in 2018 yet in 2019, this same cultivar had the highest incidence (100%). 'Foch' had 50% incidence and 'Itasca' had lowest incidence with only 22.5% of leaves affected. Disease severity trends generally followed incidence and were not consistent between years for some cultivars. In particular, disease severity on 'Louise Swenson' was lowest in 2018, but among the highest in 2019, and a similar pattern was observed for 'Foch'.

Black rot on foliage (Table 3) varied within years, and some trends were apparent. 'Brianna' had among the highest incidence of foliar black rot in both years, and in 2019, incidence of disease on that cultivar, with 83.3% of leaves affected, was substantially greater than the other cultivars, which had incidence of 0.8-28.3% of foliage with the disease. 'Itasca', 'Marquette', and 'Verona' had similar incidence of black rot to 'Brianna' in

2018 (range 13.3-18.3%). 'Foch' and 'Louise Swenson had among the lowest levels incidence and severity of foliar black rot in both years.

Phomopsis and anthracnose symptoms on foliage (Table 4) were not common in either year, with a few exceptions. In 2018, Phomopsis was only observed on 'Verona' with 1.7% of leaves affected and only 0.04% severity; in 2019, no Phomopsis was observed on that cultivar, but 20% of 'Brianna' and 8.3% of 'Foch' foliage had incidence of the disease, and severity was very low for both. No anthracnose was observed on any foliage in 2018, but in 2019, 45% of assessed 'Brianna' foliage had anthracnose symptoms, and no other cultivars had the disease.

3.2 Fruit cluster assessment

Powdery mildew incidence (Table 2) was high on fruit in both years. In 2018, incidence ranged 56.7% - 100% with no statistical separation among cultivars. In 2019, all assessed cultivars had 100% incidence of the disease on fruit. Severity was different among cultivars, and 'Brianna' had greatest severity and 'Crimson Pearl', 'Foch', 'Louise Swenson', 'Marquette', 'Petite Pearl', and 'Verona' had among the lowest severity of powdery mildew on fruit. As with foliar powdery mildew severity, that trend did not continue in 2019, when 'St. Pepin', 'Louise Swenson', and 'Petite Pearl' had among the highest severity of the disease.

In 2018, incidence of black rot (Table 3) was highest in 'Marquette' (85.0% of fruit affected) followed by 'Brianna' (73.3%). 'Petite Pearl' had moderately high incidence (48.3%), followed by 'Itasca' (30.0%) and 'St. Pepin' (20.0%). 'Louise Swenson' and 'Verona' had lowest incidence of black rot on fruit (1.7-3.3%) among all cultivars, and severity followed a similar trend to incidence in that year. Black rot incidence and severity were greater overall in 2019, with all cultivars having incidence above 94% except 'Louise Swenson' which had 69.1% of fruit affected. There was a greater range in severity of black rot damage among cultivars: 'Foch' had the most severe black rot on fruit, followed by 'St. Pepin' and 'Verona'. 'Crimson Pearl', 'Louise Swenson', and 'Petite Pearl' had the lowest severity of the disease on fruit in that year.

Although no symptoms of the disease were observed on foliage of 'Foch' and 'Petite Pearl' in 2018, Phomopsis incidence (Table 5) was observed for 1.7% and 3.3% of fruit on those cultivars, respectively. No other cultivars had incidence of the disease that year, and this low overall incidence across all cultivars did not generate statistically significant differences. In 2019, 'Petite Pearl' was the only cultivar with *Phomopsis* symptoms on fruit, and 16.7% of fruit were affected by the disease and severity was 0.4% of area affected. *Botrytis* fruit rot (Table 5) was relatively low in 2018 with no significant differences observed at α=0.05. Of the nine cultivars evaluated in that year, 'Brianna', 'Crimson Pearl', 'Marquette', and 'Petite Pearl' had incidence from 1.7-6.7%, but severity was well below 1% of fruit surface affected. In 2019, *Botrytis* bunch rot affected 51.7% of assessed 'Foch' fruit; all other cultivars had below 11.7% fruit affected. Severity was greatest on 'Foch', with 1.6% of surface affected, and below 1% damaged cluster area for the remaining cultivars.

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Table 2. Comparison of percent incidence and severity of powdery mildew symptoms on grape foliage and clusters in 2018 and 2019.

	Powdery Mildew [1]																			
	2018										2019									
	Foliage				Cluster						Foliage				Cluster					
Cultivars	% Inc. [2]		% Sev. [2]		% Inc.		% Sev.				% Inc.		% Sev.		% Inc.		% Sev.			
Brianna	35.83	de	1.54	bcd	88.33		20.51	a			75.83	ab	4.93	bc	100.00		14.26	bcd		
C. Pearl	51.67	cde	2.00	bcd	70.00		3.08	b			41.67	bc	1.85	c	100.00		17.18	bcd		
Foch	59.17	bcd	1.85	bcd	56.67		2.26	b			50.00	bc	17.60	abc	100.00		11.48	cd		
Itasca	38.33	de	0.98	cd	95.00		8.55	ab			22.50	c	0.53	c	100.00		6.21	d		
L. Swenson	22.50	e	0.55	d	63.33		2.65	b			100.00	a	21.91	ab	100.00		24.67	ab		
Marquette	95.00	a	3.22	ab	86.67		7.03	b			100.00	a	34.17	a	-		-			
Petite Pearl	74.17	bc	1.87	bcd	100.00		3.24	b			86.67	ab	2.48	c	100.00		19.63	abc		
St. Pepin	80.83	ab	5.05	a	85.00		9.02	ab			75.83	ab	13.03	bc	100.00		34.63	a		
Verona	76.67	ab	2.24	bc	60.00		7.58	b			89.17	ab	4.82	bc	100.00		17.16	bcd		

[1] Values represent the mean from 6 replicate, two-vine plots per cultivar of disease incidence on 20 leaves or 10 clusters per plot. Disease severity (area infected) was rated using the Horsfall-Barratt scale and converted to percentages using the Elanco's conversion tables. Means followed by the same letters within columns are not significantly different according to Tukey's Honest Significant Difference (HSD) Test ($p \leq 0.05$).

[2] Inc. = Incidence; Sev. = Severity

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Table 3. Comparison of percent incidence and severity of black rot symptoms on grape foliage and clusters in 2018 and 2019.

	Black rot [1]							
	2018				2019			
	Foliage		Cluster		Foliage		Cluster	
Cultivars	% Inc. [2]	% Sev. [2]	% Inc.	% Sev.	% Inc.	% Sev.	% Inc.	% Sev.
Brianna	16.67 ab	0.39 a	73.33 ab	3.16 b	83.33 a	2.71 a	98.33 a	5.50 cd
C. Pearl	0.00 b	0.00 b	11.67 d	0.27 cd	28.33 b	0.66 b	94.44 a	3.42 d
Foch	0.00 b	0.00 b	16.67 cd	0.43 cd	0.83 e	0.02 e	100.00 a	48.39 a
Itasca	15.00 a	0.35 a	30.00 bcd	0.82 bcd	12.50 bcd	0.29 bcd	100.00 a	11.91 c
L. Swenson	2.50 ab	0.06 ab	3.33 d	0.08 cd	2.50 de	0.06 de	69.07 b	2.17 d
Marquette	18.33 a	0.43 a	85.00 a	9.02 a	8.33 cde	0.23 bcde	-	-
Petite Pearl	2.50 ab	0.06 ab	48.33 bc	1.44 bc	6.67 cde	0.16 cde	98.33 a	3.24 d
St. Pepin	0.00 b	0.00 b	20.00 bcd	0.47 cd	15.83 bc	0.37 bc	100.00 a	26.25 b
Verona	13.33 ab	0.31 ab	1.67 d	0.04 d	19.17 bc	0.51 bc	100.00 a	34.09 b

[1] Values represent the mean from 6 replicate, two-vine plots per cultivar of disease incidence on 20 leaves or 10 clusters per plot. Disease severity (area infected) was rated using the Horsfall-Barratt scale and converted to percentages using the Elanco's conversion tables. Means followed by the same letters within columns are not significantly different according to Tukey's Honest Significant Difference (HSD) Test ($p \leq 0.05$).

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Table 4. Comparison of percent incidence and severity of *Phomopsis* and Anthracnose symptoms on grape foliage in 2018 and 2019.

	Phomopsis [1]						Anthracnose [1]					
	2018		2019				2018		2019			
Cultivars	% Inc. [2]	% Sev. [2]	% Inc.		% Sev.		% Inc.	% Sev.	% Inc.		% Sev.	
Brianna	0.00	0.00	20.00	a	0.59	a	0.00	0.00	45.00	a	3.06	a
C. Pearl	0.00	0.00	0.00	b	0.00	b	0.00	0.00	0.00	b	0.00	b
Foch	0.00	0.00	8.33	ab	0.31	a	0.00	0.00	0.00	b	0.00	b
Itasca	0.00	0.00	0.00	b	0.00	b	0.00	0.00	0.00	b	0.00	b
L. Swenson	0.00	0.00	0.00	b	0.00	b	0.00	0.00	0.00	b	0.00	b
Marquette	0.00	0.00	0.00	b	0.00	b	0.00	0.00	0.00	b	0.00	b
Petite Pearl	0.00	0.00	0.00	b	0.00	b	0.00	0.00	0.00	b	0.00	b
St. Pepin	0.00	0.00	0.00	b	0.00	b	0.00	0.00	0.00	b	0.00	b
Verona	1.67	0.04	0.00	b	0.00	b	0.00	0.00	0.00	b	0.00	b

[1] Values represent the mean from 6 replicate two-vine plots per cultivar of disease incidence on 20 leaves per plot. Disease severity (area infected) was rated using the Horsfall-Barratt scale and converted to percentages using the Elanco's conversion tables. Means followed by the same letters within columns are not significantly different according to Tukey's Honest Significant Difference (HSD) Test ($p \leq 0.05$). [2] Inc. = Incidence; Sev. = Severity

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Table 5. Comparison of percent incidence and severity of *Phomopsis* fruit rot and *Botrytis* bunch rot symptoms on grape fruit clusters in 2018 and 2019.

	Phomopsis fruit rot [1]						*Botrytis* bunch rot [1]					
	2018		2019				2018		2019			
Cultivars	% Inc. [2]	% Sev. [2]	% Inc.		% Sev.		% Inc.	% Sev.	% Inc.		% Sev.	
Brianna	0.00	0.00	0.00	b	0.00	b	6.67	0.16	0.00	b	0.00	b
C. Pearl	0.00	0.00	0.00	b	0.00	b	1.67	0.04	0.00	b	0.00	b
Foch	1.67	0.04	0.00	b	0.00	b	0.00	0.00	51.67	a	1.60	a
Itasca	0.00	0.00	0.00	b	0.00	b	0.00	0.00	5.00	b	0.12	b
L. Swenson	0.00	0.00	0.00	b	0.00	b	0.00	0.00	0.00	b	0.00	b
Marquette	0.00	0.00	-		-		5.00	0.12	-		-	
Petite Pearl	3.33	0.08	16.67	a	0.39	a	1.67	0.04	1.67	b	0.04	b
St. Pepin	0.00	0.00	0.00	b	0.00	b	0.00	0.00	11.67	b	0.27	b
Verona	0.00	0.00	0.00	b	0.00	b	0.00	0.00	6.67	b	0.16	b

[1] Values represent the mean from 6 replicate two-vine plots per cultivar of disease incidence on 10 fruit clusters per plot. Disease severity (area infected) was rated using the Horsfall-Barratt scale and converted to percentages using the Elanco's conversion tables. Means followed by the same letters within columns are not significantly different according to Tukey's Honest Significant Difference (HSD) Test ($p \leq 0.05$).

[2] Inc. = Incidence; Sev. = Severity

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4. Discussion

Fungal diseases are often a limiting factor in grape production in the humid northeastern U.S.A. and were variable between the years of this study. Overall, we observed that disease incidence on foliage and fruit clusters was lower in 2018 compared with 2019, which was likely a result of the drier weather in the growing season (May through September) of 2018 which had combined 31.95 cm rainfall compared with 43.36 cm recorded for the same months in the research plots in 2019 (Table S2). Total hours of leaf wetness were also considerably lower in 2018 (534 hours) compared with 2019 (1,018). Powdery mildew incidence was higher in 2018 averaged over all cultivars: most likely a result of the higher number of hours over 90% humidity recorded in 2018 (521 hours from May-September) when compared to 209 hours recorded in 2019.

It is rare that commercial grape producers would not apply fungicides, whether synthetic or organically-approved, to manage diseases in their vineyards. However, information on relative susceptibility of cultivars to disease is critical to developing IPM programs that reduce unneeded pesticide applications overall. Many grape cultivars also exhibit phytotoxic symptoms to copper and/or sulfur products, which are the most commonly-used fungicides in organic production systems [23,24]. Furthermore, because most materials that are suitable for use in organic production systems are less effective and often may require more applications than synthetic materials while also delivering less effective results, selection of resistant cultivars is critical to success when adopting such a management program.

At the time of this writing, there were no reports on disease susceptibility found in the literature for the cultivars ‘Crimson Pearl’ and ‘Verona’, which are both relatively new releases from a private breeding program. ‘Petite Pearl’, which was also recently released from that program, has had limited disease evaluation conducted and reports collated in a recent literature review were generated primarily from Extension and observational reports [25]. ‘Itasca’, the next-most recently released cultivar (2017), was featured in a HortScience article upon its release, where relative resistance to powdery mildew was reported [26]. Of the remaining cultivars, several have been available for planting and testing for twelve to seventy years (Table 1) and thus have had varying levels of rigorous disease susceptibility assessment completed. Among the older cultivars in this trial, ‘Marquette’ has been evaluated in Vermont as part of a prior trial [19,27]. Finally, the Swenson-bred cultivars ‘Brianna’, ‘Louise Swenson’, and ‘St. Pepin’ have been included in a number of comparison studies that included vine growth and juice quality considerations, but little comprehensive disease evaluation has been conducted on any of them.

Among the significant disease reported on these cultivars, black rot is the primary disease affecting fruit in the northeastern U.S.A. and neighboring Canada, with powdery mildew following close behind. Powdery mildew is relatively easily managed by use of sulfur-based fungicides [18,23], but black rot in not easily managed with sulfur or copper materials used in organic production systems. Black rot is one of the most serious diseases of grapes in the eastern United States and can cause substantial crop loss under conducive weather conditions. Disease severity and inoculum from the previous year, current weather conditions and varietal susceptibility all play a role in the impact and losses due to the disease. Managing inoculum and choosing the most black rot-resistant cultivars are important priorities for growers and often result in cost savings by decreasing the number of fungicide sprays necessary to manage a disease that occurs to some extent every season.

Powdery mildew is an important disease of grapes worldwide. Because the disease only requires high humidity, as opposed to leaf wetness, for infection, it may be a problem in dry but humid years when other diseases are less present [20]. Therefore, powdery mildew management may involve a different fungicide program than one which targets black rot, *Phomopsis*, and other diseases that proliferate in wet conditions [18]. Sulfur is a widely-used, inexpensive fungicide that is acceptable for use in organic production systems, and has excellent efficacy against this disease [23]. However, many grape cultivars

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are sensitive to sulfur and may exhibit phytotoxic responses to its application, which can be severe in some cases [24]. Of the cultivars rated in this study, 'Brianna' and 'Foch' have shown substantial phytotoxicity resulting from sulfur applications, whereas 'Marquette' and 'Petite Pearl' have not shown significant sulfur injury in previous research [24]. In Cadle-Davidson et al.'s review of *Vitus* species' susceptibility to powdery mildew in New York, with similar climate to Vermont, 'Foch' exhibited moderate to high susceptibility to the disease [28]. Importantly, *V. vinifera* selections showed greater susceptibility to powdery mildew than *V. labrusca* or *V. riparia* overall, which suggests that resistance may be greater in cultivars which include those species in their parentage. While incidence of powdery mildew in this study was relatively high on untreated vines, severity varied substantially, both by year and by cultivar. By developing an understanding of both the susceptibility of untreated cultivars to powdery mildew as well as the potential damage caused by sulfur application, a producer may make sound decisions on cultivar selection and development of organic or other pest management systems to minimize both disease and abiotic damage resulting from powdery mildew management.

Downy mildew can be a devastating disease that can completely and prematurely defoliate affected vineyards, thus lowering fruit quality, vine growth, and cold hardiness. This disease is native to eastern North America, and thus interspecific hybrids including those in this study that have parentage including *V. riparia* and *V. labrusca* which coevolved with the pathogen *Plasmopara viticola*, tend to exhibit resistance to the disease [16,29]. This was observed in previous work that included these cultivars [5,7,9,12,30], and this study supported those prior findings, as no downy mildew was observed on any of the cultivars.

Anthracnose has become an increasingly common disease of grapes grown in Vermont. Work by Carisse and Lefebvre just to the north of this study site in Quebec, Canada surveyed a number of cold-hardy cultivars, including 'Louise Swenson', 'Marquette', and 'St. Pepin' which are in this study, for susceptibility to that disease [31]. In that work, most evaluated cultivars were rated as "resistant to slightly susceptible", with 'Louise Swenson' rated as "susceptible" and 'Marquette' exhibiting the highest severity of anthracnose among all tested cultivars and rated as "highly susceptible". Anthracnose incidence on leaves was low overall in this study, even on 'Marquette', and no affected fruit were observed on any cultivar. That may be attributed to low inoculum or to weather conditions during the study period that were not conducive to disease development.

The grape and wine industry in Vermont and similar cold-climate regions in midwestern and eastern North America is relatively new, in many cases in existence less than twenty or thirty years[32]. The cultivars grown in the region are a changing mix of selections that may have been evaluated regionally or in more established production areas. Often this mix includes both older selections that have been evaluated through research and on farms and newly released cultivars from breeding programs. [1]. In many cases, materials that offer recommendations or ratings for cultivar disease susceptibility and other important characteristics are based on anecdote, general observation, and sometimes limited replicated field trials [25,33-35]. The collective, co-created knowledge generated from formal and informal research and farming networks can be highly useful in developing planting systems and management programs for a disease-susceptible, perennial crop with a high investment cost and long period of return, but quantitative and replicated research and validation of prior observations are critical to successful crop production.

Wines are produced from fruit, and disease-affected fruit may be completely unusable for wine production, whereas foliar disease may be present in a vineyard, depending on type and severity, and a marketable crop still produced. After cold hardiness and acceptability for winemaking, susceptibility to common fruit diseases may be the most important criteria for selection of a suitable cultivar. In this study, cluster disease severity was variable among cultivars in each year, and not consistent over the course of the two-years. All cultivars showed some level of powdery mildew and black rot in fruit clusters on non-treated vines in both years, and relative susceptibility to those two diseases may be key determinants in cultivar selection. However, no single cultivar was consistently more resistant to all the foliar or cluster diseases in this study and the ranking of cultivar susceptibility varied depending on the growing season and the disease. It is important to note that all cultivars had powdery mildew and black rot infections on fruit in both years.

5. Conclusions

This study has shown disease incidence ratings vary among cultivars and disease ratings of cultivars are not always consistent in a two-year project. It is critical to increase the length of time for this type of study to track trends in disease incidence and severity over several years. In addition to increasing the number of years for these studies, yield data should be incorporated in future research, giving growers additional critical data to select the most productive disease resistant cold hardy grape cultivars.

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Data Availability Statement: Data files and SAS code are available at: xxx.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Figure S1: title, Table S1. Horsfall-Barratt disease range used for data collection; Table S2. Weather conditions during the growing season.

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References

1. Bradshaw, T.L.; Hazelrigg, A.; Berkett, L.P. Characteristics of the cold-climate winegrape industry in Vermont, U.S.A. *Acta Hort* **2018**, *1205*, 469-476, doi:10.17660/ActaHortic.2018.1205.57.
2. NASS. Annual Bulletin, New England Agricultural Statistics, 2014. Available online: http://www.nass.usda.gov/Statistics_by_State/New_England_includes/Publications/Annual_Statistical_Bulletin/2014%20New%20England%20Annual%20Bulletin.pdf (accessed on 5/31/2021).
3. USDA National Agricultural Statistics Services. 2012 Census of Agriculture. Available online: https://www.nass.usda.gov/AgCensus/ (accessed on 05/31/2021).

4. USDA National Agricultural Statistics Services. 2017 Census of Agriculture. Available online: https://www.nass.usda.gov/AgCensus/ (accessed on 5/31/2021).
5. Cannella, M.P. *2015 Vermont Vineyard Feasibility Study*; University of Vermont Extension: FBRR 014, 2015; https://blog.uvm.edu/farmvia/files/2013/03/FBRR014-2015-VineyardFeasibilityStudy.pdf.
6. Holiman, E.C. The Vermont Wine Industry: The Emergence of Cold Climate Viticulture and The Uncertain Future in the Face of Climate Change. B.S. Honors Thesis, University of Vermont, Burlington, VT, 2020.
7. Nonnecke, G.; Domoto, P.; Cochran, D. *NE-1020 Cold Hardy Wine Grape Cultivar Trial*; Iowa State Research Farm Progress Reports 2173; Ames, IA, 2015; http://lib.dr.iastate.edu/farms_reports/2173.
8. Read, P.E.; Gamet, S.J. Sixteen years of cold-climate cultivar evaluation. *Acta Hort* **2016**, 23-28, doi:10.17660/ActaHortic.2016.1115.4.
9. Bradshaw, T.L.; Berkett, L.P.; Kingsley-Richards, S.L.; Foster, J.A. Horticultural Performance and Juice Quality of Cold-Climate Grapes in Vermont, U.S.A. *Eur. J. Hortic. Sci.* **2017**, *83*, 42-48, doi:10.17660/eJHS.2018/83.1.6.
10. Hatterman-Valenti, H.M.; Auwarter, C.P.; Stenger, J.E. Evaluation of cold-hardy grape cultivars for North Dakota and the North Dakota State University germplasm enhancement project. *Acta Hort* **2016**, *1115*, 13-22, doi:10.17660/ActaHortic.2016.1115.3.
11. NERA. NE1020: Multi-state Evaluation of Winegrape Cultivars and Clones. Available online: https://www.nimss.org/projects/view/SAES/4034 (accessed on 5/31/2021).
12. Martinson, T.E.; Mansfield, A.K.; Luby, J.J.; Gartner, W.C.; Dharmadhikari, M.; Domoto, P. The Northern Grapes Project: integrating viticulture, enology, and marketing of new cold-hardy wine grape cultivars in the Midwest and Northeast United States. *Acta Hort* **2016**, *1115*, 3-12, doi:10.17660/ActaHortic.2016.1115.2.
13. Cattell, H. *Wines of Eastern North America*; Cornell University Press: Ithaca, NY, 2014.
14. Hazelrigg, A.; Kingsley-Richards, S. *Pest Management Strategic Plan for Grapes in the Northeast*; Northeast IPM Center: Ithaca, NY, 2017; https://ipmdata.ipmcenters.org/documents/pmsps/Grape-PMSP-for-Northeast-2017.pdf.
15. Hemstad, P.; Breeder, G. Grapevine breeding in the Midwest. In *Grapevine breeding programs for the wine industry: Traditional and molecular techniques*, Reynolds, A., Ed.; Woodhead Publishing: Cambridge, UK, 2015; pp. 411-425.
16. Swenson, E.P. Wild Vitis Riparia from northern US and Canada--breeding source for winter hardiness in cultivated grapes--a background of the Swenson hybrids. *Fruit Varieties Journal* **1985**, *39*, 28-31. https://www.pubhort.org/aps/39/v39_n1_a10.htm.
17. Bradshaw, T.; Berkett, L. *An Initial IPM Strategy for New Cold Climate Winegrape Growers*; UVMFRT004; University of Vermont Extension: Burlington, VT, 2017; https://www.uvm.edu/~orchard/fruit/pubs/Factsheets/UVMFRT004_initialIPMStrategy.pdf.
18. Weigle, T.; Muza, A., (Eds.) *New York and Pennsylvania pest management guidelines for grapes*. Cornell University: Ithaca, NY, 2016.
19. Hazelrigg, A.; Bradshaw, T.L.; Berkett, L.P.; Maia, G.; Kingsley-Richards, S.L. Disease Susceptibility of Cold-Climate Grapes in Vermont, U.S.A. *Acta Hort* **2018**, *1205*, 477-482, doi:10.17660/ActaHortic.2018.1205.58.
20. Wilcox, W.F.; Gubler, W.D.; Uyemoto, J.K. *Compendium of grape diseases, disorders, and pests*; APS Press, The American Phytopathological Society: St. Paul, MN, 2015.
21. Jones, D.S.; McManus, P.S. Distinctive Symptoms and Signs of Downy Mildew on Cold-Climate Wine Grape Cultivars. *Plant Health Progress* **2017**, *18*, 192-195, doi:10.1094/PHP-01-17-0009-DG.
22. Horsfall, J.G., Barratt, R.W. An improved grading system for measuring plant diseases. *Phytopathology* **1945**, *35*, 655.
23. Weigle, T.; Carroll, J., (Eds.) *Organic Production and IPM Guide for Grapes*. NYS IPM: Geneva, NY, 2016; Volume 224.
24. McManus, P.S.; Kartanos, V.; Stasiak, M. Sensitivity of cold-climate wine grape cultivars to copper, sulfur, and difenoconazole fungicides. *Crop Protection* **2017**, *92*, 122-130, doi:10.1016/j.cropro.2016.10.027.

 doi:10.20944/preprints202106.0084.v1

25. Pedneault, K.; Provost, C. Fungus resistant grape varieties as a suitable alternative for organic wine production: Benefits, limits, and challenges. *Scientia Horticulturae* **2016**, *208*, 57-77, doi:10.1016/j.scienta.2016.03.016.
26. Clark, M.; Hemstad, P.; Luby, J. 'Itasca'Grapevine, a New Cold-hardy Hybrid for White Wine Production. *HortScience* **2017**, *52*, 649-651, doi:10.21273/HORTSCI11692-16.
27. Berkett, L.; Bradshaw, T.; Kingsley-Richards, S.; Griffith, M. *Disease evaluation of selected cold climate wine grape cultivars in Vermont, USA*; 105; International Organisation for Biological Control: Zürich, Switzerland, 2014; pp. 29-33
28. Cadle-Davidson, L.; Chicoine, D.R.; Consolie, N.H. Variation within and among Vitis spp. for foliar resistance to the powdery mildew pathogen Erysiphe necator. *Plant Disease* **2011**, *95*, 202-211, doi:10.1094/PDIS-02-10-0092.
29. Hemstad, P.; Luby, J. Utilization of Vitis riparia for the development of new wine varieties with resistance to disease and extreme cold. *Acta Hort* **2000**, *528*, 487-496, doi:10.17660/ActaHortic.2000.528.70.
30. Jones, D.S.; McManus, P.S. Susceptibility of cold-climate wine grape cultivars to downy mildew, powdery mildew, and black rot. *Plant disease* **2017**, *101*, 1077-1085, doi:10.1094/PDIS-01-17-0022-RE.
31. Carisse, O.; Lefebvre, A. Evaluation of northern grape hybrid cultivars for their susceptibility to anthracnose caused by Elsinoe ampelina. *Plant Health Progress* **2011**, *12*, 9, doi:10.1094/PHP-2011-0805-01-RS.
32. Trzaskos, T. *Wines of Vermont: A History of Pioneer Fermentation*; The History Press: Mount Pleasant, SC, 2015.
33. Delate, K.; Friedrich, H. Organic apple and grape performance in the Midwestern US. *Acta Horticulturae* **2004**, *638*, 309-320, doi:10.17660/ActaHortic.2004.638.42.
34. Bradshaw, T.L.; Hazelrigg, A.; Berkett, L. *Relative Disease Ratings for Wine Grape Varieties Grown in Vermont*; UVMFRT003; UVM Extension: Burlington, VT, 2020; https://www.uvm.edu/~fruit/grapes/gr_ipm/UVMFRT003_2020RelativeGrapeDisease.pdf.
35. Reisch, B.; Pool, R.; Peterson, D.; Martens, M.-H.; Henick-Kling, T. *Wine and juice grape varieties for cool climates*; Information Bulletin 233; NYSAES: Geneva, NY, 1993; https://hdl.handle.net/1813/17814.