Chapter 3

Evaluation of the Cultivar Effect on Wine Grape Fungal Diseases with a Use of a Low-Input Fungicide Regimen in Southeastern Virginia, USA

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Additional information is available at the end of the chapter

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Abstract

Wine grape cultivar selection was examined as a use of biotechnology and a part of integrated plant disease management in grape and wine production. The efficacy of 18 wine grape cultivars against various wine grape diseases was examined using a relatively low-input fungicide regimen to determine whether these diseases can be managed under hot and humid southeastern Virginia conditions over 5 years. Disease developments of black rot, Botrytis bunch rot, downy mildew, Phomopsis cane and leaf spot, and powdery mildew was evaluated. Although overall level of disease was low in each year, we observed a significant ($P \leq 0.05$) effect of cultivar in many cases, indicating the importance of cultivar selection. Cultivars such as 'Norton', 'Noire', 'Traminette', 'Vidal blanc', and 'Viognier' were found to be less susceptible to the major diseases under Virginia environmental conditions.

Keywords: grape cultivar selection, low input disease management, Southeastern US, Norton, Noiret

1. Introduction

The state of Virginia (VA) is in the mid-Atlantic region of the USA. Currently, VA ranks fifth in wine grape production in the US with 1100 hectares of wine grape acreage (*Vitis vinifera*, inter- or intraspecific hybrids, and *V. labrusca*) and over 230 wineries [1, 2]. An annual economic impact of VA wine industry was estimated to be $740 million in 2010 [2], which represents a 106% increase from 2005.

VA is known for its diverse climate with five different climate regions (**Figure 1**): Tidewater, Piedmont, Northern Virginia, Western Mountain, and Southwestern Mountain regions [3]. Some localities, such as Charlottesville in the Central VA, are preferred for commercial wine grape production due to long growing seasons and relatively lower risk of winter temperature extremes. On the other hand, winters on the north of the Blue Ridge mountains (which is a part of the Appalachian Mountains, the border between Northern and Western Mountain in **Figure 1**) in Northern VA can be very severe.

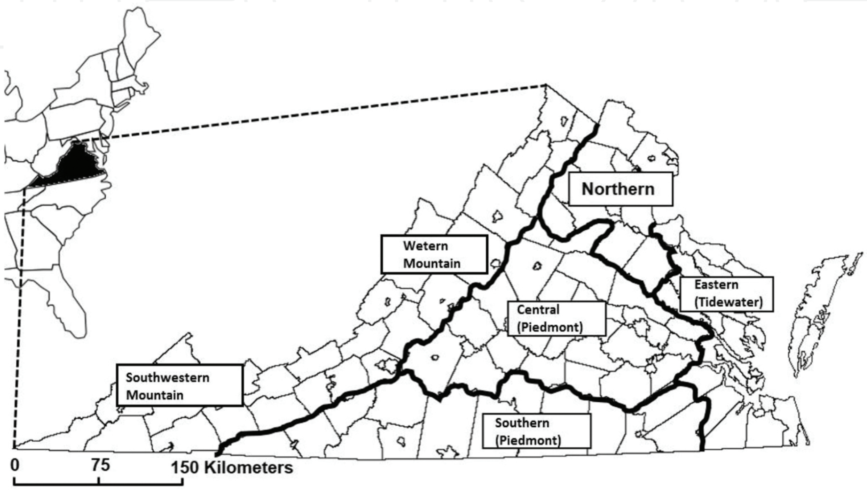

Figure 1. Map of the state of Virginia (adapted with permission from [4]).

Annual rainfall totals can vary from 838 mm in the Shenandoah Valley, which is located the west of the Blue Ridge mountains, to more than 1500 mm in the mountains of southwestern Virginia [3]. The Gulf Stream in the Atlantic Ocean and moist air coming from the Pacific Ocean are the primary drivers for precipitations in VA. Storms resulted from warm and humid air generally moves from the west to the east in the continental US. At the East coast, the storms are pushed toward the northeast by moist air that comes from the south, following the Gulf Stream. The meeting of two air masses often results in frontal storms coming from the west to produce rainfalls, especially along the western side of the Appalachian Mountains. In addition to the frontal storms, tropical storms, which typically come to VA in late August to early October, provide 10–40% of the annual rainfall [3]. When these storms become very intense and/or take more westward pass, the strong winds that hit the mountain range result in heavy rainfalls on the Blue Ridge. However, often time, these tropical storms come from the southern US, cross the East coast to the south of Virginia, and then exit out to the Atlantic. In such cases, the heaviest rain usually falls in southeastern VA.

Southeastern VA is traditionally known for tobacco production since the first tobacco planting in the US in 1612 near the James River, which runs through VA [5]. However, due to a recent increase in cheaper tobacco import from foreign countries, the tobacco industry is struggling [6]. Thus, many growers are seeking for alternative crops. Since labor and land cost is relatively low, cash crops such as wine grapes are often considered as a crop of choice [7]. Traditionally,

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Central VA and Northern VA have been the major wine grape growing regions in VA; however, based on 2013 information, 64 farm wineries are located in the lower half of VA where relatively lower price of land allows growers to plant more vines (www.virginiawine.org).

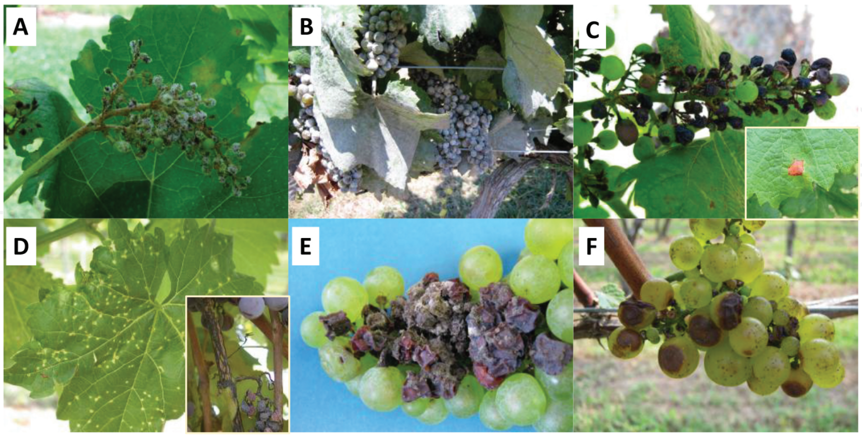

Figure 2. Symptoms commonly found grapevine fungal diseases in Virginia. Panel (A) Downy mildew on a cluster and leaf, (B) powdery mildew on clusters and leaves, (C) black rot on clusters (and on a leaf in the lower right insert), (D) phomopsis cane and leaf spot on a leaf, (and on a shoot and rachis in the lower right insert), (E) Botrytis bunch rot, and (F) ripe rot, pictures courtesy of the author.

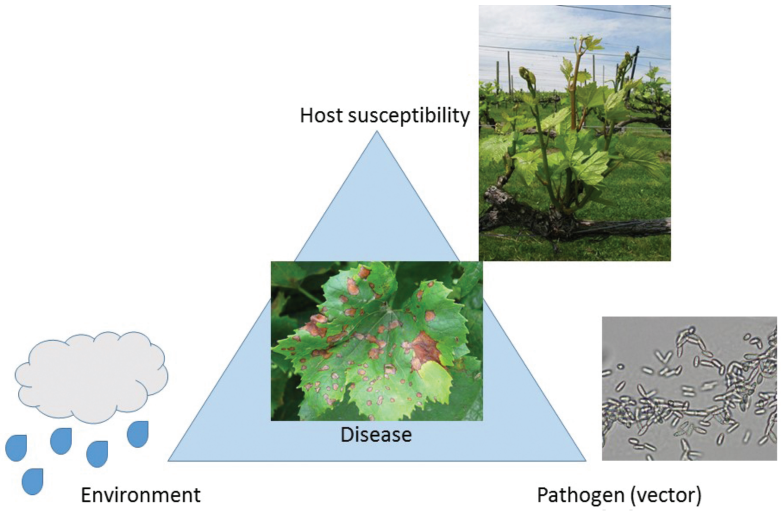

Figure 3. Disease triangle adapted with permission from Agrios [9], pictures courtesy of the author.

Frequent rainfalls in the spring and summer create environmental conditions that favor development of various diseases [8]. Common summer time diseases in Virginia are downy mildew (caused by *Plasmopara viticola*) (**Figure 2A**), powdery mildew (caused by *Erysiphe necator*) (**Figure 2B**), black rot (caused by *Guignardia bidwellii*) (**Figure 2C**), and Phomopsis cane and leaf spot (caused by *Phomopsis viticola*) (**Figure 2D**). As the berries mature, late season rots such as Botrytis bunch rot (also known as Botrytis gray mold, caused by *Botrytis cinerea*) (**Figure 2E**), ripe rot (caused by *Colletotrichum acutatum* and *C. gloeosporioides* species complexes) (**Figure 2F**), and sour rot (caused by several bacteria and yeast species) become more common.

Development of plant disease is often described with a concept called the disease triangle [9]. Three components (environment, susceptible host, and presence of pathogen) have to be met in order for any plant disease to develop (**Figure 3**). The frequent rain events in VA produce the environment for many summer diseases, as well as late season rots. In addition, growers often select cultivars based on their marketing needs, rather than viticultural decisions, such as disease resistance [10]. In VA, cultivars such as 'Chardonnay', 'Merlot', and 'Cabernet Sauvignon' are commonly grown commercially [8]. These cultivars are relatively susceptible to the diseases mentioned above, when you compared with some of intraspecific hybrid cultivars, such as 'Vidal blanc' or 'Traminette' [8].

The high risk of disease development often results in more frequent applications of fungicides [9, 10]. This decision is often made not based on the facts (i.e., components of the disease triangle), but based on the fear of losing the crop. The unnecessary fungicide applications not only cost growers as out of pocket expenses, but also cause significant environmental impacts, such as increased risk of fungicide drift, fungicide resistance, soil compaction due to more traffic, more CO_2 emission, etc. [9]. The over use of the materials often resulted in the misuse of them, which can increase the risk of fungicide resistance [10, 11]. The frequent application of fungicides also increases the concern on the over use of "hard" materials such as mancozeb and captan, which are used frequently because of their broad target pathogen ranges and low fungicide resistance risks [8, 9]. Heavy reliance on mancozeb can results in increased European red mite population [9], and captan is known as an eye irritant [12].

This chapter will focus on cultivar selection as a use of biotechnology and a part of integrated plant disease management in grape and wine production. The efficacy of 18 wine grape cultivars against various wine grape diseases was examined using a relatively low-input fungicide regimen to determine whether these diseases can be managed under hot and humid southeastern VA conditions over 5 years.

2. Materials and methods

A research vineyard at Virginia Polytechnic Institute and State University's Southern Piedmont Agricultural Research and Extension Center (SPAREC) (latitude = 37.0754205, longitude = −77.8670789) was utilized for the experiment. Research plots were completely randomized design with 6 replications of 18 cultivars (**Table 1**). Each replication consisted of three vines of the same cultivar. Disease incidence and severity were visually assessed twice in the season (approximately at bloom and veraison) on leaves and clusters for five major diseases for the area (black rot, Botrytis bunch rot, downy mildew, Phomopsis cane and leaf spot, and Powdery mildew). The vineyard was evaluated for 5 years (2009–2013).

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Cultivar	Short names used in this chapter
Aleatico	Aleatico
Cabernet Franc clone #1	CabF1
Cabernet Franc clone #313	CabF313
Cabernet Sauvignon clone #337	CabS337
Chardonnay clone #96	Chard96
Mourvedre	Mourvedre
Muscat blanc	MuscatB
Norton	Norton
NY73.0136.17 (Noiret)	NY73 (Noiret)
Petit Manseng	PetitM
Petit Verdot	PetitV
Roussanne	Roussanne
Tannat	Tanna
Tinta Cao	TintaCao
Touriga nacional	TourigaN
Traminette	Traminet
Vidal blanc	VidalB
Viognier	Viognier

Table 1. Cultivars tested at SPAREC, Blackstone, VA, USA, 2009–2013.

Fungicides were applied 10–11 times per year (**Table 2**) with a low-cost and low-chemical input in mind. Applications were made based on a 14-day interval schedule with an exception of “at bloom” application that could be applied less than 14 days of the previous application. During 2009 and 2010, the first application was not applied, thus, there were a total of 10 applications. In general, mancozeb (Dithane Rainshield 75DF, Dow Agro Science, Indianapolis, IN, USA) and sulfur (Microthiol Disperss, United Phosphorous Inc., King of Prussia, PA, USA) were applied until prebloom. Boscalid + pyraclostrobin (Pristine, BASF Corporation, Research Triangle Park, NC, USA) were applied at bloom and bunch closure. After the second cover, mancozeb was replaced with a potassium phosphite (Prophyt, Helena Chemical, Collierville, TN, USA). All were applied with a 100 gallon (379 L) air blast sprayer (John Bean, Durand-Wayland Inc., GA, USA). The one exception was the cultivar ‘Norton’ that was not treated with any fungicides during the 5 years.

The effect of cultivar on the mean leaf and cluster disease incidence and severity was analyzed using a generalized linear mixed model (PROC GLIMMIX, SAS, ver. 9.4, SAS Institute, Cary, NC, USA). The GLIMMIX model utilized the log it link function for the mean leaf and cluster disease incidences and identity for the mean leaf and cluster disease severities. When the effect of cultivar was found to be significant, differences among cultivars were compared using Fisher's least square difference (LSD) method.

Application number	Growth stage	Material and rate per hectare[a]	
1	3″	Mancozeb (3.4 kg)	+ sulfur (3.4 kg)
2	10″	Mancozeb (3.4 kg)	+ sulfur (3.4 kg)
3	Prebloom	Mancozeb (3.4 kg)	+ sulfur (3.4 kg)
4	50% bloom	Pyraclostrobin + boscalid (0.88 kg)	
5	1st cover	Mancozeb (3.4 kg)	+ sulfur (3.4 kg)
6	Pea (2nd)	Mancozeb (3.4 kg)	+ sulfur (3.4 kg)
7	Pea (3rd)	Potassium phosphite (3.5 L)	+ sulfur (3.4 kg)
8	Berry touch	Pyraclostrobin + boscalid (0.88 kg)	
9	Veraison	Potassium phosphite (3.5 L)	+ sulfur (3.4 kg)
10	Preharvest	Potassium phosphite (3.5 L)	+ sulfur (3.4 kg)
11	Preharvest	Potassium phosphite (3.5 L)	+ sulfur (3.4 kg)

Note. [a]Materials used were Mancozeb (Dithane Rainshield 75DF, Dow Agro Science, Indianapolis, IN, USA), sulfur (Microthiol Disperss, United Phosphorous Inc., King of Prussia, PA, USA), pyraclostrobin + boscalid (Pristine, BASF Corporation, Research Triangle Park, NC, USA), and a potassium phosphite (Prophyt, Helena Chemical, Collierville, TN).

Table 2. Fungicide application program used at SPAREC, Blackstone, VA, USA 2009–2013.

3. Results

Weather data were obtained from a weather station (ET106, Campbell Scientific, Logan, UT, USA), located approximately 50 m east of the experimental vineyard. The average precipitation per year between 2009 and 2013 was 1250 mm. The average temperature from April to August varied from 13 to 23°C, and total precipitation varied from 378 to 646 mm (**Table 3**).

Year	Average temperature (C)	Total precipitation (mm)
2009	21.6	515.1
2010	13.0	438.4
2011	22.0	582.2
2012	21.1	378.7
2013	23.1	645.9

Table 3. Average temperature in Celsius and total precipitation in mm from April to August, SPAREC, Blackstone, VA, USA, 2009–2013.

Although a consistent level of precipitation was recorded each year, overall development of diseases during 2009–2013 was lower than expected (**Table 4**). Consistent development of both black rot and downy mildew was observed each year; however, other than 2011 when the mean downy mildew disease incidence and severity was 61% and 5%, respectively, we did not observe any major development of the other four diseases on leaves. In many cases, disease incidence was less than 10% and disease severity was less than 0.2%. There was a higher level of Phomopsis cane and leaf spot observed in 2013. These higher levels of downy mildew and Phomopsis cane and leaf spot probably were probably due to more precipitations observed in 2011 and 2013 (**Table 3**). Botrytis was not recorded because leaf symptom development was rarely observed.

Disease incidence	**2009**		**2010**		**2011**		**2012**		**2013**	
Black rot	1.72	(0.21)	8.41	(0.45)	4.81	(0.36)	1.72	(0.21)	0.47	(0.11)
Downy mildew	5.19	(0.36)	0.48	(0.11)	61.00	(0.81)	5.19	(0.36)	1.03	(0.17)
Phomopsis	0.11	(0.05)	0.24	(0.08)	0.19	(0.07)	0.11	(0.05)	2.75	(0.27)
Powdery mildew	0.03	(0.03)	7.23	(0.42)	2.58	(0.26)	0.03	(0.03)	0.19	(0.07)
Disease severity	**2009**		**2010**		**2011**		**2012**		**2013**	
Black rot	0.019	(0.003)	0.141	(0.011)	0.093	(0.009)	0.019	(0.003)	0.005	(0.001)
Downy mildew	0.084	(0.009)	0.008	(0.003)	5.367	(0.14)	0.084	(0.009)	0.01	(0.002)
Phomopsis	0.001	(0.001)	0.003	(0.002)	0.002	(0.001)	0.001	(0.001)	0.115	(0.017)
Powdery mildew	<0.001	(0)	0.162	(0.017)	0.081	(0.015)	<0.001	(0)	0.002	(0.001)

Table 4. The mean and standard error (in parentheses) of leaf disease incidence and severity at veraison, SPAREC, Blackstone, VA, USA, 2009–2013.

Disease incidence	**2009**		**2012**		**2013**	
Black rot	1.75	(0.38)	1.75	(0.38)	0.08	(0.08)
Botrytis	0.08	(0.08)	0.08	(0.08)	0.00	(0)
Downy mildew	0.17	(0.12)	0.17	(0.12)	0.08	(0.08)
Phomopsis	0.00	(0)	0.00	(0)	0.00	(0)
Powdery mildew	0.00	(0)	0.00	(0)	0.25	(0.15)
Disease severity	**2009**		**2012**		**2013**	
Black rot	0.027	(0.008)	0.027	(0.008)	0.004	(0.004)
Botrytis	0.001	(0.001)	0.001	(0.001)	0	(0)
Downy mildew	0.005	(0.004)	0.005	(0.004)	0.004	(0.004)
Phomopsis	0	(0)	0	(0)	0	(0)
Powdery mildew	0	(0)	0	(0)	0.003	(0.001)

Table 5. The mean and standard error (in parentheses) of cluster disease incidence and severity at veraison, SPAREC, Blackstone, VA, USA, 2009, 2012, and 2013.

		Disease incidence[a]			Disease severity[a]		
Year	Disease	*F*	*P* > *F*		*F*	*P* > *F*	
2009	Black rot	1.0	0.50		1.6	0.07	
	Downy mildew	10.6	<0.001	**	8.9	<0.001	**
	Phomopsis	0.7	0.40		2.0	0.01	**
	Powdery mildew	0.0	0.94		0.9	0.56	
2010	Black rot	15.0	<0.001	**	22.2	<0.001	**
	Downy mildew	1.7	0.11		4.1	<0.001	**
	Phomopsis	2.0	0.11		3.4	<0.001	**
	Powdery mildew	6.3	<0.001	**	4.6	<0.001	**
2011	Black rot	10.4	<0.001	**	18.7	<0.001	**
	Downy mildew	32.0	<0.001	**	61.5	<0.001	**
	Phomopsis	0.4	0.76		2.1	0.01	**
	Powdery mildew	3.2	<0.001	**	4.9	<0.001	**
2012	Black rot	1.0	0.50		1.6	0.07	
	Downy mildew	10.6	<0.001	**	8.9	<0.001	**
	Phomopsis	0.7	0.40		2.0	0.01	**
	Powdery mildew	0.0	0.94		0.9	0.56	
2013	Black rot	0.8	0.60		1.7	0.04	*
	Downy mildew	3.3	<0.001	**	5.8	<0.001	**
	Phomopsis	7.7	<0.001	**	14.7	<0.001	**
	Powdery mildew	0.3	0.92		1.7	0.04	*

Note. [a] *F* statistics and *P*-values from ANOVA (PROC GLIMMIX in SAS 9.4) results are shown. One and two asterisk(s) following the number represent 95 and 99% confidence level, respectively.

Table 6. Effect of cultivar on leaf disease incidence and severity at veraison, SPAREC, Blackstone, VA, USA, 2009–2013.

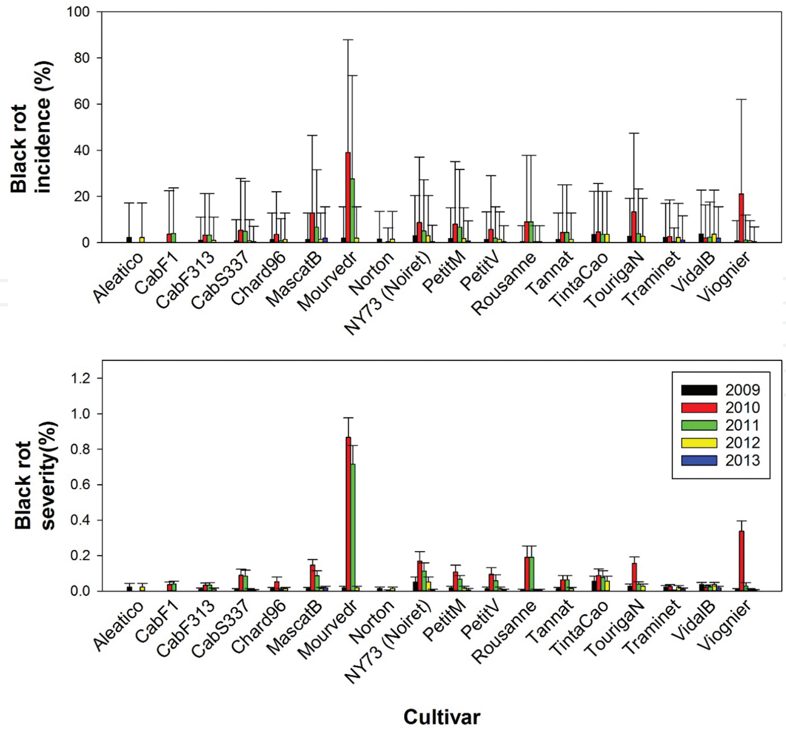

Figure 4. Leaf disease incidence and severity of black rot among 18 cultivars examined at SPAREC, Blackstone, VA, USA, 2009–2013 (note: The *Y*-axis scale of each panel is different).

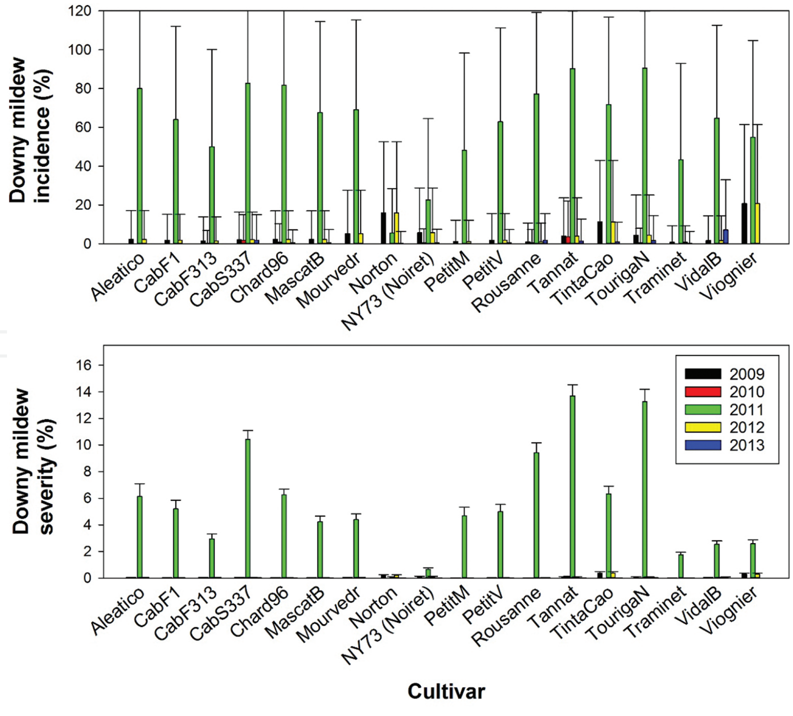

Figure 5. Leaf disease incidence and severity of downy mildew among 18 cultivars examined at SPAREC, Blackstone, VA, USA, 2009–2013 (note: The *Y*-axis scale of each panel is different).

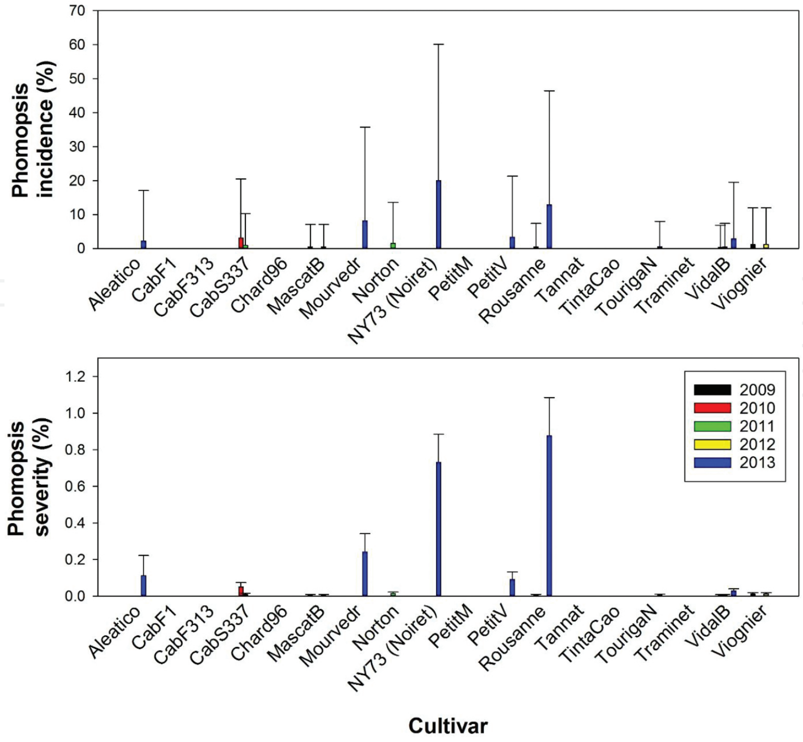

Figure 6. Leaf disease incidence and severity of Phomopsis cane and leaf spot among 18 cultivars examined at SPAR-EC, Blackstone, VA, USA, 2009–2013 (note: The *Y*-axis scale of each panel is different).

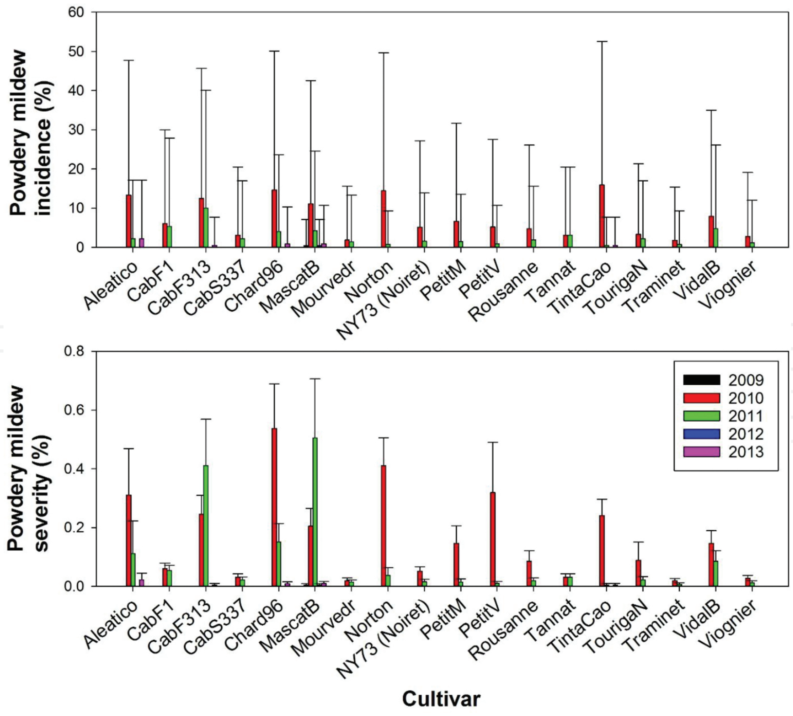

Figure 7. Leaf disease incidence and severity of powdery mildew among 18 cultivars examined at SPAREC, Blackstone, VA, USA, 2009–2013 (note: The *Y*-axis scale of each panel is different).

Cluster disease incidence and severity were measured in 2009, 2012, and 2013. The majority of clusters were lost due to bird damages in 2010 and 2011. As in leaf disease incidence and severity, the overall disease levels in these 3 years were very low (**Table 5**). The highest disease development was black rot on 2009 and 2012, but disease incidence was less than 2% and disease severity was less than 0.03%. To our surprise, there were very limited developments of Botrytis. Most likely due to very low development of cluster diseases, the effect of cultivar on cluster disease incidence and severity on all five diseases was not significant ($P > 0.05$) for all 3 years. Thus, data shown hereafter are on leaf disease incidence and severity.

Cultivara[a]	**Black rot 2010**[b]				**Downy mildew 2011**[b]			
	Incidence (%)		**Severity (%)**		**Incidence (%)**		**Severity (%)**	
Aleatico	0	G	0	CDEF	80.00	ABCD	6.13	CD
CabF1	3.64	EFG	0.04	EF	64.00	EF	5.21	CD
CabF313	3.33	G	0.03	F	50.00	GH	2.94	EF
CabS337	5.33	DEFG	0.09	CDEF	82.67	B	10.42	B
Chard96	3.56	FG	0.05	DEF	81.78	B	6.25	C
MascatB	12.89	C	0.15	CDE	67.62	DE	4.23	DE
Mourvedre	39.05	A	0.87	A	69.05	CDE	4.39	DE
Norton	0	G	0	F	5.56	J	0.07	H
NY73 (Noiret)	8.72	CDE	0.17	CD	22.56	I	0.65	GH
PetitM	8.00	CDEF	0.11	CDEF	48.15	GH	4.67	D
PetitV	5.71	DEFG	0.10	CDEF	62.86	EF	5.00	CD
Roussanne	9.05	CD	0.19	C	77.14	BC	9.41	B
Tannat	4.44	DEFG	0.06	DEF	90.22	A	13.7	A
Tinta Cao	4.62	DEFG	0.09	CDEF	71.79	CDE	6.33	C
TourigaN	13.33	C	0.16	CDE	90.56	A	13.26	A
Traminet	2.59	G	0.03	F	43.33	H	1.75	FG
VidalB	2.08	G	0.02	F	64.76	DE	2.54	F
Viognier	21.18	B	0.34	B	54.90	FG	2.59	F

Note. [a]See **Table 1** for actual names of cultivars.
Note. [b]Least square means from GLIMMIX results are shown. Different letters following the number indicate significant ($P \leq 0.05$) difference based on LSD.

Table 7. Effect of cultivars on black rot in 2010 and downy mildew in 2011, SPAREC, Blackstone, VA, USA.

In spite of low development of diseases, there are many cases where significant effect of cultivar ($P \leq 0.05$) on disease incidence and severity were observed (**Table 6**). In many cases, it was one or two cultivars that resulted in relatively higher or lower level of disease incidence or severity (**Figures 4–7**, **Tables 7** and **8**). For example, "Mourvedre" and "Viognier" resulted in higher disease incidences and severities of black rot than other cultivars examined (**Figure 4**, **Table 7**). Leaf downy mildew disease incidences and severities of 'Tannat', 'Touriga nacional', 'Cabernet Sauvignon clone 337', 'Chardonnay clone 96', and 'Roussanne' were higher than others in 2011 (**Figure 5**, **Table 7**). Mourvedre, NY73.0136.17 ('Noiret'), and Roussanne were more susceptible to Phomopsis cane and leaf spot than others in 2013 (**Figure 6**, **Table 8**). Interestingly, these three cultivars resulted in relatively lower powdery mildew incidence than other cultivars (**Figure 7**, **Table 8**). 'Aleatico', 'Cabernet Franc clone 313', Chardonnay clone 96, 'Muscat blanc', Norton, and 'Tinta Cao' resulted in relatively higher powdery mildew incidence in 2010 (**Figure 7**, **Table 8**).

Cultivara[a]	**Phomopsis 2013**[b]				**Powdery mildew 2010b**[b]			
	Incidence (%)		**Severity (%)**		**Incidence (%)**		**Severity (%)**	
Aleatico	2.22	AB	0.11	BC	13.33	ABCD	0.31	ABCDEF
CabF1	0	B	0	C	6.06	CDEF	0.06	DEF
CabF313	0	B	0	C	12.50	AB	0.25	BCD
CabS337	0	B	0	C	3.11	FGH	0.03	EF
Chard96	0	B	0	C	14.67	A	0.54	A
MascatB	0	B	0	C	11.11	ABC	0.20	CDE
Mourvedre	8.21	AB	0.24	B	1.90	GH	0.02	EF
Norton	0	B	0	C	14.44	A	0.41	AB
NY73 (Noiret)	20.00	A	0.73	A	5.13	DEFGH	0.05	DEF
PetitM	0	AB	0	C	6.67	BCDEF	0.15	CDEF
PetitV	3.33	AB	0.09	BC	5.24	DEFG	0.32	BC
Roussanne	12.86	AB	0.88	A	4.76	EFGH	0.09	DEF
Tannat	0	B	0	C	3.11	FGH	0.03	EF
Tinta Cao	0	B	0	C	15.90	A	0.24	BCD
TourigaN	0.56	B	0.01	C	3.33	EFGH	0.09	DEF
Traminet	0	B	0	C	1.85	H	0.02	F
VidalB	2.86	AB	0.03	C	7.92	BCDE	0.15	CDEF
Viognier	0	B	0	C	2.75	FGH	0.03	EF

Note. [a]See **Table 1** for actual names of cultivars.
Note. [b]Least square means from GLIMMIX results are shown. Different letters following the number indicate significant ($P \leq 0.05$) difference based on LSD.

Table 8. Effect of cultivars on Phomopsis cane and leaf spot in 2013 and powdery mildew in 2010, SPAREC, Blackstone, VA, USA.

4. Summary and concluding remarks

As noted earlier, plant disease requires three conditions to develop: host susceptibility, pathogen (or vector with pathogen) availability, and conducive environmental condition (**Figure 2**). This study examined the choice of cultivars as a use of biotechnology in the vineyard, and challenge it with a low-input fungicide regimen under severe weather conditions in the southeastern VA. The results showed that a proper selection of cultivar coupled with a relatively simple disease management plan can prevent the majority of foliar and cluster diseases of wine grapes.

There was significant cultivar effect on the development of each disease, and each cultivar resulted in different level of susceptibility to five of diseases we measured, with an exception of Botrytis that only showed limited development during the course of 5 years. Some cultivars, such as Norton and Noiret (NY73), resulted in very low level of diseases regardless of the very limited use of fungicide. Noiret is one of the newer red-fruited interspecific hybrid cultivar that was introduced in 1994 from the New York State Agricultural Experiment Station, Cornell University [13]. It is a cross of 'Chancellor' and 'Steuben', and it is rated moderately resistant to powdery mildew and Botrytis bunch rot. Our results also support that Noiret is more resistant to powdery mildew than other cultivar examined. Although a report from Cornell University [13] suggested that downy mildew can be an issue with Noiret, our results demonstrated that it is less susceptible than other tested cultivars. However, it seemed that Noiret is susceptible to Phomopsis cane and leaf spot.

Norton (syn. 'Cynthiana') is an intraspecific red-fruited hybrid cultivar, which was developed by Dr. Daniel Norborne Norton of Richmond, Virginia, around 1820 [14, 15]. It is considered a cross between *Vitis aestivalis* and *V. vinifera*, but with some traits of other *Vitis* species (*V. labrusca*, *V. cinerea*, and *V. cordifolia*) from previous crossing [15] were also speculated. It is also known for strong resistance level against many pathogens [15, 16]. In our study, Norton vines did not receive any fungicides over 5 years, yet, resulted in very low level of disease development. There was a relatively high level of powdery mildew development in 2010, and a low level of downy mildew development in 2011, but we did not observe any major outbreak of disease. Growers in VA recognize the advantage of the cultivar and a total of 51 hectares of Norton is grown in VA in 2015 [17]. One of growers produce more than 16 hectares of Norton, which is a very large hectarage for VA [15]. It is often described that Norton only requires 20–25% of pesticides when you compared with *V. vinifera* cultivars [15].

Five years of observation revealed characteristics of each cultivar. For instance, Traminette, Vidal blanc, and Viognier were another set of cultivars with low level of overall disease development. Viognier is designated as the state's signature grape in 2011 by the Virginia Wine Board, a state-sponsored trade association that promotes Virginia wine. Probably because of the promotion, more than 138 hectares of Viognier are grown in VA in 2015 [17]. Viognier is known to be susceptible to Phomopsis cane and leaf spot; however, results from this study did not show the same trend. Disease incidence of Phomopsis cane and leaf spot of grapes tend to aggregated among previously infected vines [18], thus, our results may be due to the lack of infected vines nearby Viognier subplots. Traminette and Vidal blanc are two intraspecific white-fruited hybrid cultivars that are commonly grown in VA. Traminette is a cross between Joannes Seyve 23-416 and Gewurztraminer and was introduced from New York State Agricultural Experimental Station in Geneva in 1996 [8]. Traminette is known for excellent wine quality as well as good disease resistance [8], as shown in our study. Vidal blanc is a cross between Ugni blanc and Seibel 4986, and known for good resistance against downy mildew, Botrytis and black rot [8, 16]. As of 2015, 46 and 65 hectares of Traminette and Vidal blanc, respectively, are grown in VA [17].

Other cultivars to be noted are 'Cabernet sauvignon clone #337', 'Tinta Cao', and 'Touriga nacional', which resulted in relatively low powdery mildew development. Powdery mildew is considered as one of the most important diseases among VA and mid-Atlantic regions [8], thus, it is important to know that these cultivars are less susceptible to it. Mourvedre was another cultivar with low powdery mildew; however, it was shown to be more susceptible to black rot and Phomopsis than other cultivars, therefore, Mourvedre may not be the best cultivar for the southeastern VA. Also, it should be noted that although the overall disease level was low with Noiret, it was very susceptible to Phomopsis cane and leaf spot, thus a specific protective application for this cultivar may be required.

Weather conditions varied among 5 years of experiment, and the development of diseases showed the influence of these weather events. For example, the lack of Botrytis development during the 5 years of experiment can be explained by the lack of conducive environmental conditions because *Botrytis* cinerea has a very wide host range, and some of cultivar, such as Chardonnay, is known to be susceptible to Botrytis. In 2011 and 2013 when the total amount of precipitation was higher than other years, there were more prominent developments of both downy mildew and Phomopsis cane and leaf spot. In this study, the fungicide application schedule was predetermined, and it was not altered based on weather conditions. In reality, any grower would change/modify their fungicide application schedule or chemicals based on weather conditions. For example, under rainy weather conditions we observed in 2011 or 2013, growers would have used downy mildew-specific material with curative activity (e.g., metalaxyl, potassium phosphite, etc.), in addition to the planned fungicides used in this study, or mix one of them with one of the applications. Thus, very low downy mildew incidences and severities shown with Noiret, Norton, Viognier, Traminette, and Vidal blanc with our fungicide program shows that these cultivars can be managed with lower fungicide inputs against downy mildew.

The advent of fungicide resistance has been documented in many modes of action groups in VA and surrounding states [19–21]. Moreover, risks of fungicide resistance development from the reliance on curative fungicide application have been discussed [11]. Therefore, the demonstrated efficacy of a relatively low-input protective fungicide program helps us to reduce unnecessary fungicide applications.

The information obtained from this study will be used to select proper cultivars for hot and humid growing conditions in the southeastern Virginia, and to develop a backbone fungicide application program to manage major fungal diseases with a relatively simple, and low-input program.

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