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Susceptibility to Botrytis blight at different floral stages of wild blueberry phenotypes

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Abstract

Botrytis blossom blight is an important disease of wild blueberries with yield losses in excess of 20% frequently occurring. Two field experiments were conducted in 2016 and 2017 to determine the susceptibility of four phenotypes (*Vaccinium angustifolium, V. angustifolium* f. *nigrum, V. myrtilloides* and *V. angustifolium* var. Fundy] at different floral stages [(Bud break (F5); bud prebloom; (F6), corolla fully open (F7), and senescent corolla (F8)] to Botrytis infection. Specific flower clusters on tagged stems from different phenotypes were inoculated with *Botrytis cinerea* conidial suspension (10^6 conidia·ml^{-1}). Disease development were assessed eight days after inoculation. Disease incidence and severity in phenotype ranged from 14.1 to 22.6% and 37.4 to 42.3% in 2016, respectively, and 39.8 to 44.1% and 9.70 to 19.1% in 2017, respectively. Results indicated that *V. angustifolium* was the most susceptible followed by *V. angustifolium* f. *nigrum* and *V. angustifolium* var. Fundy. *Vaccinium myrtilloides* was found to be least susceptible. Incidence and severity on floral stages ranged from 2.95 to 36.4% and 7.81 to 75.5% in 2016, respectively, and 7.28 to 66.9% and 11.1 to 27.1% in 2017, respectively. Floral stage F7 was the most susceptible with incidence up to 66.9% and severity up to 75.5% followed by F6, F5 and F8. Therefore, results from this study indicated that *V. myrtilloides* was less susceptible to *B. cinerea* than *V. angustifolium* phenotypes, and F6 and F7 stages were the most susceptible to Botrytis blight. These results will assist producers in making more informed decisions on Botrytis blight control and as its management practices shift from blanket to precise delivery of disease control products.

Keywords: *Vaccinium angustifolium,* phenotype, *Botrytis cinerea*

Introduction

Wild blueberry (*Vaccinium angustifolium, V. myrtilloides*) production represents a valuable component of the agricultural industry in Atlantic Canada. It is a high-value export crop with approximately 65,000 ha under production representing about 50% of Canada's land area in fruit and nut production (Statistics Canada, 2015).

Wild blueberry production is faced with several challenges including floral and leaf diseases. Botrytis blight caused by *Botrytis cinerea* Pers.:Fr is one important and destructive disease of wild blueberries. The disease causes over 20% crop loss annually on the field (WBPANS 2013, unpublished data; Delbridge and Hildebrand, 1997) but is of less importance post-harvest due to the majority of the berries being processed into individually quick-frozen berries. In blueberries, the pathogen mostly infects flowers at the mid to late bloom. Botrytis-infected tissues turn brown or black and then die with the typical gray mold sign of abundant masses of conidia.

Infection and outbreak of the disease occurs under several hours of wet conditions with moderate temperatures (14 to 28^0C) during bloom (Sapkota et al., 2015; Rivera et al., 2013).

Presently, Botrytis blight is mainly managed through the combination of proper cultural practices such as canopy management, to allow for good air circulation and reduction of humidity within the canopy, and fungicide applications. However, the nature of wild blueberries does not allow the introduction of some these cultural practices recommended for Botrytis control in most crops. Hence, Botrytis control in wild blueberries is solely through the application of fungicides containing the active ingredients fludioxonil, cyprodinil, fluopyram and pyrimethanil. However, these fungicides face the challenge of resistance development among the pathogen population given their polycyclic nature (FRAC, 2014). In addition, improved management practices such as weed control and fertilization has resulted in abundant flower production from 34 million flowers per acre to over 150 million flowers per acre (Percival, 2013). Also, the fairly humid and frequent wetness periods accompanying maritime climate in places such as Nova Scotia create suitable environmental conditions for Botrytis infection. The abundance of flower tissues and fungicide resistant pathogen presents a perfect condition for Botrytis blight outbreak on wild blueberry fields under these frequently wet and humid conditions.

Wild blueberry fields are extremely heterogeneous and with distinctively different phenotypes including *V. angustifolium* Ait., *V. angustifolium* f. *nigrum*, *V. myrtilloides* Michx. and *V. boreale* (Kinsman, 1993; Eck, 1996). *Vaccinium myrtilloides* is a diploid which is densely velvety in nature with heights between 10 – 60 cm. The surface of the leaf margins is entire with frosty blue fruit. Conversely, *Vaccinium angustifolium* is a tetraploid which is densely verrucose in nature with heights ranging between 5-40 cm. Their leaf margins are serrated and have bright blue colored fruit (Tirmenstein, 1990; Camp, 1945). Within the *V. angustifolium*, Nigrum produces bright pink flowers and dark/blackish fruits. Fundy have slightly pubescent stems with glabrous leaves (Hall et al., 1998). The development of the plant varies appreciably depending on the soil and environmental conditions. In spring, dormant buds break, and flowers and leaves emerge. Flower bud break and development begin mostly in late May and attain full bloom in mid-June of the cropping season. Although floral buds break in May, *Vaccinium myrtilloides* are generally late to break bud compared to *V. angustifolium*.

Despite the importance of Botrytis blight in wild blueberry fields and field variability, little is known about the susceptibility of the various phenotypes to the disease. Only one report exists on the susceptibility of floral growth stages to Botrytis infection in wild blueberries (Hildebrand et al., 2001). In the quest to minimize the use of fungicides and improve disease control techniques, information on the host development and susceptibility is important. In view of this, the objectives of this study were to determine (i) the susceptibility of wild blueberry flowers at specific developmental stages, and (ii) the relative susceptibility of various phenotypes to Botrytis blossom blight.

Materials and Methods

Site selection and experimental design

Two field trials were conducted during the crop year of 2016 and 2017 in a commercial wild blueberry field at Debert, Nova Scotia (coordinates = 45°26'35.65 N, 63°27'5.69 W). The annual average temperature for the study site for the last 5 years was 6.0 ^{0}C with average seasonal (May - Aug) temperature of 15 ^{0}C. The average precipitation was 1112.44 mm with an average seasonal (May- Aug) rainfall of 438 mm (http://climate.weather.gc.ca).

Split plot experimental design with four replications were used where the main plots consisted of four phenotypes *V. angustifolium*, *V. angustifolium* f. *nigrum*, *V. myrtilloides* and *V. angustifolium* var. Fundy (Figure 1). Four flower developmental stages consisting of corolla half developed (F5), pink or white bud prebloom (F6), corolla fully open (F7), and senescent corolla/petal fall (F8) (Hildebrand et al., 2001) were the subplot factors (Figure 2).

In 2016, *V. angustifolium* var. Fundy was not included because that phenotype was not available. Also, as flowers developed and the growth stages advanced, the number of flowers in early stages decreased, thus, as flowers approached the F8 stage, the number of flowers in the F2-F5 stages decreased. This posed a challenge in obtaining all of the four stages in 2016. Owing to this observation, the experiment in 2017 was conducted earlier, hence, the F8 stage was excluded. The exclusion of the F8 stage in 2017 was also influenced by the outcome of a pilot trial in 2015 and 2016 experiment which indicated that F8 was least infected by *Botrytis cinerea* after inoculation.

Figure 1. *V. angustifolium* (A), *V. angustifolium* f. *nigrum* (B), *V. myrtilloides* (C) and *V. angustifolium* var. Fundy (D)
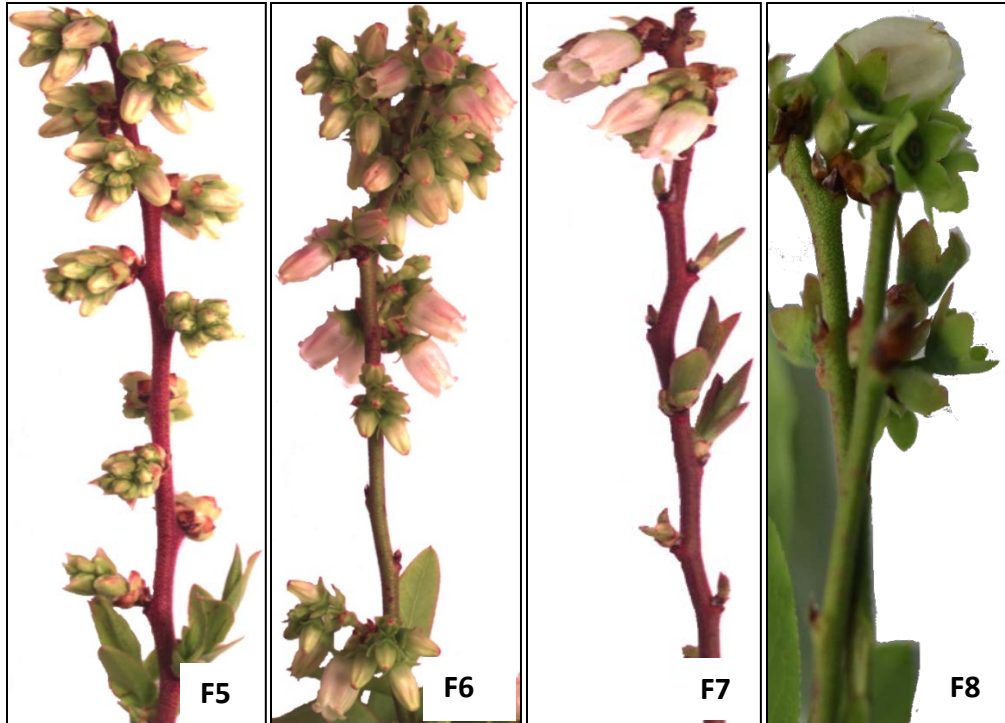
Figure 2. Lowbush blueberry floral bud stages. F5. Bud break; F6. Pink or white prebloom; F7. Anthesis or corolla fully open; F8. Senescent corolla.

Inoculum production and preparation

Single spore *B. cinerea* was isolated from a diseased blueberry flower from the field and cultured on potato dextrose agar (PDA). The cultures were incubated at 22°C in the dark for 10- to 14 days and spore suspension was prepared by washing conidia with sterile distilled water from plates. Spore concentration was estimated using a hemocytometer (BLAUBRAND® Neubauer) and adjusted to 1×10^6 conidia ml^{-1}. Tween 20 (0.04%) was added to the suspension prior to inoculation. The germination percentage of the spore suspension used was $67.5 \pm 2.5\%$.

Plants preparation and inoculation

Ten stems of each split plot with flowers of the specified phenotype at specific growth stage were tagged. Flowers stages other than the specified stage were removed. Only clusters showing uniform flower stages were tagged. *B. cinerea* spore suspension was applied to the flowers using a hand-held pump sprayer to produce very fine evenly distributed droplets on each plant to the point of runoff. Immediately after inoculation, the plots were covered with a hoop structure with row cover (DeWitt Plant & Seed Guard, Halifax seed, NS). The row cover was covered with a 2-mm plastic film for 24 hours to provide favorable conditions, thus prolonged wetness duration for infection to occur after which the plastic film was removed.

Disease assessment and data analysis

Assessment of Botrytis blossom blight was carried out 8 days after inoculation. Disease incidence and severity were recorded, and attention was given to the specific site of infection (corolla, stigmatic surface or ovary). Disease incidence was determined by the percentage of floral buds per stem with visual symptoms/signs of Botrytis blight. Severity was visually estimated as

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the proportion of tissue area of each flower with symptoms of Botrytis blight on a stem. Prior to the data analysis, the data were checked for normality using Minitab statistical software (version 17, Minitab Inc. USA). Data collected from the experiments were analyzed using the PROC GLIMMIX procedure of SAS (SAS institute Inc., Cary, NC, USA) and means were separated by Fisher's LSD test at $\alpha = 0.05$ where there was significant difference.

Results

Following the inoculation of the flowers, significant disease development was observed among the various phenotypes and the various flower developmental stages. Majority of the infections were observed on the corolla, where 98.4% and 98.9% of the total flower infection were observed on the corolla in 2016 and 2017, respectively.

Disease incidence and severity among the phenotypes ranged from 14.1 to 22.6% and 37.4 to 42.3%, respectively in 2016. Incidence was significantly higher in *V. angustifolium* (22.6%) compared to *V. angustifolium* f. *nigrum* (16.6%) and *V. myrtilloides* (14.1%) (Table 1). There was however, no significant difference in disease severity among the phenotypes (Table 2). Disease incidence and severity among flower stages ranged from 2.95 to 36.4% and 7.81 to 75.5%, respectively. In both incidence and severity, F7 had the highest disease with 36.4 and 75.5%, respectively. This was followed by F6 and F5 with F8 having the least disease incidence and severity of 3.32 and 7.81%, respectively (Table 1 and 2). Disease incidence indicated a significant interaction between phenotype and flower stage. Although, significant interaction was observed, there was no difference among F5 and F8 interaction with all the phenotypes. Flower stages F5 and F8 interaction with the phenotypes had the least incidence whereas *V. angustifolium* * F7 had the highest incidence (50.5%) followed by *V. angustifolium* f. *nigrum* * F7 and *V. angustifolium* * F6 (Table 1). There was however, no significant interaction between phenotype and flower stage with respect to severity (Table 2).

Unlike 2016, disease incidence was not significant among the phenotypes in 2017. However, severity was significant whereas it was insignificant in 2016. Disease incidence ranged from 39.8 to 44.1% whereas severity ranged from 9.70 to 19.1 % (Table 3 and 4). Disease severity was significantly higher in *V. angustifolium* var. Fundy (19.1%) followed by *V. angustifolium* f. *nigrum*, and *V. angustifolium* with *V. myrtilloides* having the least severity (9.70%) (Table 3). Among flower stages, a similar trend was observed in 2017 as in the previous year. Incidence and severity ranged from 7.28 to 66.9% and 11.1 to 27.1%, respectively (Table 3 and 4). Incidence and severity had similar trend with F7 (66.9 and 27.1%) being highly susceptible followed by F6 (51.6 and 12.4%) with F5 having the least disease development of 7.28 and 11.1% incidence and severity, respectively (Table 3 and 4).

Significant interactions were observed for both incidence and severity. The interaction of *V. angustifolium* var. Fundy, *V. angustifolium* f. *nigrum* and *V. angustifolium* with F7 was most susceptible whereas interaction of all phenotypes with F5 was the least susceptible (Table 3 and 4). Generally, the interaction between phenotypes and floral stages were low with F5 but increased with increasing flower stage except for *V. mytilloides* * F7 flower stage (Table 3 and 4).

Table 1. Incidence of Botrytis infections on wild blueberry flowers 8 days after inoculation with *B. cinerea* spore suspension in 2016.

	Flower Developmental Stage				
Phenotypes	F5	F6	F7	F8	Main effect (Phenotypes)
V. angustifolium	1.85d	35.9b	50.5a	2.48d	22.6a
V. angustifolium f. *nigrum*	0.630d	24.8c	38.4b	2.50d	16.6b
V. myrtilloides	7.51d	24.9c	20.4c	3.87d	14.1b
Main effect (Flower stages)	3.33c	28.5b	36.4a	2.95c	

% Incidence, where 0 = no blossoms infected and 100 = all flowers infected with at least one lesion. ANOVA: Phenotype * floral bud stage, p<0.0001; Phenotype, p=0.0008; Floral bud stage p<0.0001. Means followed by the same letters in a column/row are not significantly different from each other.

Table 2. Severity of Botrytis infections on wild blueberry flowers 8 days after inoculation with *B. cinerea* spore suspension in 2016.

	Flower Developmental Stage				
Phenotypes	F5	F6	F7	F8	Main effect (Phenotypes)
V. angustifolium	2.36	63.5	80.1	3.75	37.4
V. angustifolium f. *nigrum*	2.50	66.3	77.1	5.00	37.7
V. myrtilloides	19.7	68.3	66.4	14.6	42.3
Main effect (Flower stages)	8.20b	66.0a	75.5a	7.81b	

% Severity, where 0 = no disease and 100% = entire surface area of each flower tissue is infected. ANOVA: Phenotype * floral bud stage = NS; Phenotype = NS; Floral bud stage, p<0.0001. Means followed by the same letters in a column/row are not significantly different from each other.

Table 3. Incidence of Botrytis infections on wild blueberry flowers 8 days after inoculation with *B. cinerea* spore suspension in 2017.

Phenotypes	Flower developmental stage			
	F5	F6	F7	Main effect (Phenotypes)
V. angustifolium	5.55fg	57.0bcd	69.8ab	44.12
V. angustifolium f. nigrum	0g	61.9abc	67.4abc	43.12
V. angustifolium var. Fundy	5.83fg	41.9e	74.3a	40.70
V. myrtilloides	17.7f	45.7de	56.2dc	39.88
Main effect (Flower stages)	7.28c	51.7b	66.9a	

% Incidence, where 0 = no flower infected and 100 = all flower infected with at least one lesion. ANOVA: Phenotype * floral bud stage, p=0.0003, Phenotype = NS, Floral bud stage p<0.0001. Means followed by the same letters in a column/row are not significantly different from each other.

Table 4. Severity of Botrytis infections on wild blueberry flowers 8 days after inoculation with *B. cinerea* spore suspension in 2017.

Phenotypes	Flower developmental stage			
	F5	F6	F7	Main effect (Phenotypes)
V. angustifolium	0.40f	9.05de	23.9b	11.1bc
V. angustifolium f. nigrum	0f	15.7cd	26.9b	14.2b
V. angustifolium var. Fundy	1.93fe	14.6cd	40.9a	19.1a
V. myrtilloides	2.11ef	10.6cd	16.7c	9.78c
Main effect (Flower stages)	11.1c	12.4b	27.1c	

% Severity, where 0 = no disease and 100% = entire surface area of each flower tissue is infected. ANOVA: Phenotype * floral bud stage, p<0.0001; Phenotype, p=0.0001; Floral bud stage, p<0.0001. Means followed by the same letters in a column/row are not significantly different from each other. Analysis of variance (ANOVA) results refer to treatment effects that were either not significant (NS) or significant at p<0.05. Mean separation was completed using LSD test procedure (ά=0.05).

Discussion

Any epidemiological or field infection study is greatly influenced by environmental conditions. The environment is important in disease development, as it affect the survival, growth and development of the pathogen and host. Like any other multiple year field experiments, environmental conditions varied between the two years of the trials. Environmental conditions observed at the research sites in June 2016 was relatively dry with no infection period recorded (data not shown) and this could be a major contributor to the different levels of infection between the two years.

To our knowledge, this is the first study that looks at the susceptibility of wild blueberry phenotypes to Botrytis blossom blight. This study indicated that *V. myrtilloides* was relatively less susceptible to Botrytis blight than *V. angustifolium* phenotypes. The difference among the phenotypes observed in this study could be due to genetic differences among the phenotypes since the conditions and the isolate used were similar. Generally, it can be said that *V. myrtilloides* are less susceptible to Botrytis infection than phenotypes of *V. angustifolium*. In similar study with Monilinia blight, *V. myrtilloides* was found to be less susceptible (Stretch et al., 2001; Ehlenfeldt and Stretch, 2001). These two findings may confirm *V. myrtilloides* as possessing the compositional, structural and temporal characteristics to withstand diseases than *V. angustifolium* phenotypes. The difference between susceptibility of *V. myrtilloides* and *V. angustifolium* may partly be accounted for by the difference in ploidy among the two species: *V. myrtilloides* is a diploid whereas *V. angustifolium* is a tetraploid (Kinsman, 1993). In addition to genetic factors, morphological features could also be a contributing factor towards the difference in susceptibility. *Vaccinium myrtilloides* is well covered with pubescence/ hair-like structures (Kinsman, 1993). These structures have the potential of interfering with direct plant surface contact by conidia. Due to the pubescence, most conidia may land on the pubescence, hence limiting their contact with plant tissues that may be susceptible. Studies have shown that plant species with rough surfaces by means of epicuticular wax, papillae or similar structures retain fewer water droplets, reduce the contact area of water droplets and are much less easily wetted (Massinon and Lebeau, 2012; Puente and Baur, 2011; Wagner et al., 2003). Given the rough surface of *V. myrtilloides,* there may be potential decrease in surface wetness duration, hence reducing the chances of infection.

Furthermore, the difference in the phenology of the phenotypes could contribute to the difference in disease levels. The growth and development of vegetative and floral buds of *V. myrtilloides* is slow compared to *V. angustifolium*, hence making it a late species on wild blueberry fields. In reproduction, it has been pointed out that early flowering species might not have accumulated enough resources unlike late flowering species that might have gained higher capacity (Elzinga et al., 2007). In several plants–pathogen interactions, plants have been reported to be more susceptible to disease in early phase compared to the late phases. This type of resistance is termed as age-related resistance (Kus et al., 2002; Whalen, 2005).

The outcome of this study may partially account for the high levels of Botrytis infections observed within commercial wild blueberry fields because about 80% of the plants are *V. angustifolium* phenotypes.

Studies have revealed that, the susceptibility of flowers is dependent on the environmental conditions and flower developmental stage (Del Ponte et al., 2007; Mertely et al., 2002). In this study, disease development was observed to be very low at the F5 stage but increased with over 85% and 89% more disease at F6 and F7, respectively but decreased drastically at F8 stage. This observation corroborates the reports of Hildebrand et al., (2001) on lowbush blueberry and Smith,

(1998) on highbush blueberry. Hildebrand et al., (2001) reported no infection on flowers at the F4 stage and low disease at F5 stage. From these observations, it may be justified to conclude that the susceptibility of flower tissue begins from F5 and peaks at F7 stage. The decrease in susceptibility at F8 could be attributed to the formation of berries which are resistant to infection. A number of factors have been identified to affect flower infection by pathogens. These include the role, quantities and importance of phenols including resveratrol (Keller et al., 2003); physiological changes, such as increased membrane permeability and increased pollen and pollen exudates (Fourie and Holz, 1998). These are known to ensue in developing flowers, hence could partly influence the increasing susceptibility of flowers as they advance. The outcome of this study suggests little/no influence of phenotype on the floral stage infections. Although significant variations were observed among phenotype infections, flower stages F6 and F7 are the most important developmental stages in Botrytis disease management on wild blueberry fields.

Studies have shown that Botrytis infection is mostly associated with corolla (Rheinländer et al., 2013; Hartill and Campbell, 1974). It is therefore not surprising that over 98% of the infection in this study were observed on corolla. The outcome of this study is also consistent with Hildebrand et al., (2001) who observed that lesions spread from the corolla to the peduncle. This could be due to the large surface area of the corolla which also shield the androecium and gynoecium, hence, it is the first point of contact for inoculum deposition.

Conclusion

This study indicates that the variability among plants and the different flower developmental stages influence the extent of Botrytis infection on the field. Outcome of this study has illustrated that *V. angustifolium* and *V. angustifolium* var. Fundy are the most susceptible phenotypes on wild blueberry fields compared to *V. angustifolium* f. *nigrum,* but *V. myrtilloides* is relatively less susceptible. Finally, flowers are most susceptible at F7 stage when corolla is fully opened for all the phenotypes whiles F5 and F8 were less susceptible to Botrytis infection. Outcome from this study could play a key role in fungicide applications especially when disease management programs are based on weather and plant growth stage. This study has the potential of helping growers make informed decisions on timely and selective application of disease control measures based on plant developmental stages and in the integration of precision agricultural practices in wild blueberry.

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