Viticultural Performance of Hybrids and Vitis vinifera Varieties Established in Annapolis Valley (Nova Scotia)

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Abstract: (1) Background: Cold-hardy interspecific hybrid grapes (CIHG) are well adapted to the Annapolis Valley edaphoclimatic conditions. The main characteristics of CIHG are the high bud hardness tolerance to winter frost, the short growing cycle, and the good tolerance to cryptogamic diseases. Based on local experience, the Vitis vinifera varieties should be grown in the warmest areas of the Annapolis Valley (Nova Scotia, Canada). Despite this, there is little scientific evidence that shows the viticultural behavior of these varieties under the edaphoclimatic conditions of this valley.

(2) Methods: Thus, the aim of this research was to evaluate the viticultural behavior of two CIHG (L’Acadie and New York Muscat) and three V. vinifera varieties (Chardonnay, Riesling, and Pinot Noir) growing in the Annapolis Valley over three consecutive seasons. (3) Results: The coldest season (2019) produced a delay in grapevine phenology of at least 18 days for budburst compared to the rest of the seasons. The main phenological stages started earlier in L’Acadie than in the V. vinifera varieties. L’Acadie presented lower N petiole content than the V. vinifera varieties, which conditioned shoot growth in the studied seasons. CIHG presented low B petiole levels and produced musts with low malic acid content, while V. vinifera varieties produced musts with high N content. L’Acadie was the only variety that could bud out, and differentially showed the viticultural behavior of these varieties under the edaphoclimatic conditions of this valley.

(4) Conclusions: L’Acadie, and to a lesser extent, Riesling, hold an interesting adaptation to the edaphoclimatic conditions of the Annapolis Valley.

Keywords: cold-hardy interspecific hybrids; Nova Scotia; nutrient status; phenology; shoot growth

1. Introduction

The Nova Scotia (Canada) wine industry was born in the 1980s and is relatively young compared to the rest of the winegrowing regions of the New World [1]. According to the economic impact report of 2015, the wine industry contributes to Nova Scotia’s economy with a business revenue of $154 million, tax revenue of $27.6 million and wages of nearly $37 million. The overall economic impact was $218 million in 2015, which showed an increase of over $22 million since 2011 [2].

The best sites for viticulture in Nova Scotia are those located in areas where the typical winter minimum temperature is above −23 °C and the growing season is above 900 growing degree days [3]. Nova Scotia’s wine industry is greatly based on the production of cold-hardy interspecific hybrid grape (CIHG) varieties, such as L’Acadie, Maréchal Foch, New York Muscat, Seyval, Léon Millot, Lucy Kuhlman, Baco Noir, and Vidal.
Vitis vinifera varieties such as Chardonnay, Riesling, Pinot Noir and Sauvignon Blanc are less cultivated; however, they are becoming more popular [4,5].

CIHG varieties are obtained from the crosses between V. vinifera and North American native Vitis species, such as V. labrusca and V. riparia [6,7]. These hybrids have contributed widely to the expansion of Northern viticultural areas which are characterized by extremely cold winters, short growing seasons, and high fungal disease pressure [8]. Under these conditions, CIHG may provide a high tolerance to cold winters, spring frosts, cryptogamic diseases and having a short growing season [8]. These hybrids are commonly used to produce rosé, red, white, sparkling, port-style and ice wines [7,9–11]. L’Acadie is a flexible variety used for still and sparkling wine production, while New York Muscat is used in blends for still and sparkling wines [1]. Pinot Noir and Chardonnay are used for both still and sparkling wine production. Riesling is used mainly for still wine and occasionally for sparkling and ice wine [9].

Local experience confirms that CIHG varieties are proven performers in Nova Scotia; nevertheless, the production of V. vinifera grapevine varieties should be reserved for exceptional sites and experienced growers. However, to our knowledge, there are no published reports in the scientific literature that demonstrate this hypothesis. In addition, this was part of the first Terroir study developed in Atlantic Canada according to our knowledge. Therefore, the aim of this study was to evaluate the viticultural behavior of two CIHG varieties, L’Acadie and New York Muscat, and three V. vinifera varieties, Chardonnay, Riesling and Pinot Noir cultivated in Annapolis Valley over three consecutive seasons.

2. Materials and Methods

2.1. Site of Study and Plant Material

The field trial was located along the Annapolis Valley, Nova Scotia, Canada, over the 2017, 2018 and 2019 seasons. In 2017, five different experimental vineyards located at a close distance from each other were chosen for the study (Table 1). The selected vineyards are situated in the average latitude of 45°4′37.56” North, and a longitude of 64°29′45.78” West. In two of them, vineyards were planted with cold-hardy interspecific hybrid grapes (CIHG), such as L’Acadie (Cascade × Seyve-Villard 14-287) and New York Muscat (Muscat Hamburg × Ontario). In the other sites, the vineyards were planted with Vitis vinifera varieties, such as Chardonnay, Riesling and Pinot Noir.

Table 1. Study site and plant material information.

| Variety          | Species                        | Season of Planting | Plantation Distance between Rows | Plantation Distance between Plants | Plant Characteristics |
|------------------|--------------------------------|--------------------|----------------------------------|-----------------------------------|-----------------------|
| L’Acadie         | Vitis interspecific crossing    | 2005               | 3.1                              | 0.9                               | Unknown Own rooted     |
| New York Muscat  | Vitis interspecific crossing    | 1997               | 3.0                              | 1.2                               | Unknown Own rooted     |
| Chardonnay       | V. vinifera L., ssp. vinifera  | 2003–2006          | 3.1                              | 1.1                               | 76 3309 Coudere        |
| White Riesling   | V. vinifera L., ssp. vinifera  | 2013–2015          | 2.6                              | 1.4                               | 218 3309 Coudere       |
| Pinot Noir       | V. vinifera L., ssp. vinifera  | 2003–2006          | 3.1                              | 1.1                               | 115 3309 Coudere       |

Three replicates of 30 grapevines in total were arranged randomly within each vineyard. The selected vineyards had adult grapevines that were not irrigated, trained to vertical shoot position system. They were growing in good phytosanitary conditions with an active leaf surface area during the growing season. Phytosanitary treatments in studied V. vinifera grapevines were applied every seven to ten days up to fourteen days depending on climatic conditions, whereas in CIHG every three to four weeks.

2.2. Climate and Soil Conditions

Climate and soil conditions are described by Diez-Zamudio et al. [12]. Briefly, climatic information was recorded using an automatic weather station (AWS) located at most 2 km from each vineyard. Bioclimatic indices such as Winkler Index, Huglin’s Heliothermal Index (HI), Growing Season Temperature (GST) and Cool Night Index (CI) were calculated.
according to the formulas established by the researchers [13–16]. Frost Free period, precipitations and chilling hours in each season were calculated from the information recorded by the AWS (Table 2).

Table 2. Bioclimatic indices calculated each season under study.

| Season | WI | HI | GST (°C) | CI (°C) | Spring | Fall | Frost Free Days | Precipitation mm |
|--------|----|----|----------|---------|--------|------|-----------------|------------------|
| 2017   | 1169 | 1579 | 14.7 | 9.8 | 22 April 2017 | 10 November 2017 | 202 | 683 |
| 2018   | 1143 | 1535 | 14.2 | 7.2 | 5 June 18 | 24 September 18 | 111 | 898 |
| 2019   | 960  | 1515 | 12.5 | 7.7 | 4 May 2019 | 25 October 19 | 174 | 633 |

WI: Winkler Index [13]; HI: Heliothermal Index [14]; GST: Growing Season Temperature [16]; CI: Cool Night Index [15].

Based on physico-chemical analysis of these vineyard soils, in the L’Acadie vineyard, soil pH ranged from 5.9 to 6, organic matter (OM) varied from 4.0 to 5.0% and soil texture was sandy. In the New York Muscat vineyard, soil pH ranged from 6.5 to 6.8, OM varied from 2.8 to 3.5% and soil texture was sandy loam. In the Chardonnay vineyard, soil pH ranged from 6.2 to 6.4, OM varied from 3.0 to 3.5% and soil texture was sandy loam. In the Riesling vineyard, soil pH ranged from 6.0 to 6.5, OM varied from 3.1 to 3.5% and soil texture was sandy clay loam. In the Pinot Noir vineyard, soil pH ranged from 6.1 to 6.7, OM varied from 1.8 to 3.3% and soil texture was sandy loam. In the first season, 2000 kg per ha of lime as dolomitic was applied on every vineyard. In the second and third seasons, it was applied 500 to 1000 kg per ha as calcitic lime. At the beginning of the third season, 50 kg of P₂O₅ and 90 kg of K₂O per ha were applied to the soil. In addition, 1 kg of N per ha, 15 L of seaweed per ha and 100 g per ha of chelate Fe was applied at the beginning of the second and third season as foliar application. In addition, in these seasons, from bloom until veraison, 2 kg of K₂O per ha, 2 kg of Mg per ha, and 4 kg of CaO per ha were foliarly applied. More information about soil nutritional parameters obtained in the first 30 cm of soil and determinations is shown by Diez-Zamudio et al. [12].

2.3. Plant Phenology Determinations

Phenology stages of grapevines were determined weekly on 30 grapevines in each one of the three replicates by variety, according to the method by Gashu et al. [17], which is based on the system developed by Coombe [18]. The timing of four phenological events and the duration of the intervals between them was recorded yearly during 2017–2019 seasons in the five vineyards by replicate. These events included: date of bud break (BB), at E-L 4; when flowering begins (Bl; E-L 19); véraison (Vér; E-L 35); and harvest (Har; E-L 37–38) [18]. The differences in the durations of similar phenological intervals between the varieties was also calculated and defined as the phenological shift based on the method by Gashu et al. [17].

2.4. Viticultural Parameters and Shoot Growth

Bunch weight and weight of 200 berries was measured using an analytical balance (Adam CBK 8a, Oxford, UK). The productivity by grapevine was calculated as the sum of bunches weighted and collected by plant at harvest. Shoot growth was evaluated by the random selection of two buds per plant, which accounted for three hundred shoots per replicate. Grapevine shoots were evaluated from budburst to harvest, measuring them from the shoot base insertion to the apical meristem. The evaluations were carried out with a plastic tape measure (Benchmark 1049-041, Home Hardware, Waterdown, ON, Canada) by following the shoot curvatures during grapevine vegetative growth.

2.5. Plant Water Status and δ¹³C

Stem water potential (ΨStem) was measured using a pressure chamber (PMS Instrument Co., model 615, Corvallis, OR, USA). For this, eight fully expanded and sun exposed
leaves per treatment were wrapped in a plastic transparent film and aluminum foil for at least 2 h, thus achieving an equilibrium between leaf and plant xylem. Stem water potential (ΨStem) measurements were made between 13:00 and 15:00 h once a season after véraison, and δ13C was determined at harvest on grape sugars for each experimental replicate based upon 13C/12C, as performed by Spitzke and Fauhl-Hassek [19].

2.6. Plant Nutrient Status

Leaf petioles located at opposite side of the bunches were collected at bloom in each study season. Sixty to eighty petioles and blades per treatment and per replicate were collected. N, P, K, Ca, Mg, Na, B, Fe and Zn nutrient content were analyzed. The combustion method (Leco CN828, Leco Instruments, Saint Joseph, MI, USA) was used to analyze N content of blades and leaf petioles [20]. The rest of the nutrients were analyzed by Inductively Coupled Plasma Optical Emission Spectroscopy (Varian 725 ICP-OES, Agilent Technologies, Santa Clara, CA, USA), based on the method exposed by AOAC International [21]. Macronutrient concentration was expressed in terms of percentage (w/w), while micronutrients were expressed in ppm.

2.7. Must Determinations

The grapes were harvested from each replicate within the experimental vineyards when the berries reached the following parameters: content of soluble solids of approximately 15–19 °Brix and pH level between 2.8 and 3.2. Subsequently, the bunches were destemmed, the grapes were crushed, and soluble solids, titratable acidity, pH and malic acid in musts were determined by the OIV methodologies [22,23]. For the analysis of yeast assimilable nitrogen (YAN) content of musts, the samples were centrifuged with an Eppendorf Centrifuge model 5702R (Mississauga, ON, Canada) at 3000 × g for 5 min. Then, the supernatants were analyzed by the Fourier transform infrared (FT-IR) analyzer, according to the method proposed by Skoutelas et al. [24]. Organic nitrogen was analyzed by automatized colorimetric method and mineral nitrogen was determined by automatized enzymatic method. The 3-isobutyl-2-methoxypyrazine (IBMP) content in the musts was analyzed based on the methodology exposed by Poitou et al. [25].

2.8. Statistical Analysis

The variables were analyzed considering a completely randomized design with factorial arrangement, accounting five treatments by three study seasons. The variables were subjected to a generalized linear model (type III sums of squares) since the data were unbalanced. This was because some varieties such as L’Acadie, New York Muscat, Riesling, Chardonnay and Pinot Noir were damaged by a spring frost in 2018 and their productivity suffered a total loss. Furthermore, in 2019, due to some technical problems, it was not possible to harvest the Pinot Noir variety. Nutrient content in petioles was subjected to a multifactorial analysis (MANOVA). Generalized linear model and multifactorial analysis were performed using Statgraphics Centurion XVI.I statistical package. The significance of the differences was determined by Duncan’s test (p ≤ 0.05). A principal component analysis (PCA) was performed to determine relationships among variables according to treatment and season, which was performed using InfoStat statistical software (InfoStat, Córdoba, Argentina).

3. Results

3.1. Vine Phenology

The timing of phenological events was significantly affected by variety and season (Table 3). Phenological events, such as budburst, bloom, véraison and harvest occurred earlier in 2017 and 2018 than in the 2019 season. Phenological events shifted by 18–19 days for budburst, 4–6 days for bloom, 11–12 days for véraison and 10–13 days for harvest, comparing 2017 and 2018 to the 2019 season. Budburst in the L’Acadie variety took place before Riesling and Pinot Noir and it also reached the véraison stage before other varieties.
The difference in budburst and véraison between L’Acadie and the *Vitis vinifera* varieties was 4 and 8–12 days, respectively. Bloom in L’Acadie took place before *V. vinifera* varieties with a difference of 5 to 7 days, while the harvest date was earlier in L’Acadie compared to Chardonnay and Riesling, with a difference of 10 and 16 days, respectively.

### Table 3. The average occurrence of phenological stages, expressed in dates, and the length between phenological phases (expressed in days) in cold-hardy interspecific hybrid grapes and *Vitis vinifera* varieties from 2017 to 2019.

| Variety  | Budburst (BB) | Bloom (Bl) | Véraison (Vér) | Harvest (Har) | BB to Bl | Bl to Vér | Vér to Har |
|----------|---------------|------------|----------------|---------------|----------|-----------|-----------|
| L’Acadie  | 23-May ± 0.55 a | 08-July ± 1.05 a | 01-Sept ± 1.32 a | 12-Oct ± 2.11 a | 45.67 a | 55.22 a | 40.89 ab  |
| NY Muscat | 25-May ± 0.88 abc | 12-July ± 1.67 ab | 13-Sept ± 2.10 b | 18-Oct ± 3.37 ab | 47.48 ab | 63.08 b | 35.45 a  |
| Chardonnay | 25-May ± 0.88 abc | 15-July ± 1.67 b  | 9-Sept ± 2.11 b  | 22-Oct ± 3.37 bc | 50.98 b | 56.83 ab | 42.95 ab  |
| Riesling  | 27-May ± 0.67 c  | 15-July ± 1.28 b  | 12-Sept ± 1.62 b | 28-Oct ± 2.58 c | 48.83 ab | 59.00 ab | 46.17 b  |
| Pinot Noir | 27-May ± 0.88 bc | 13-July ± 1.67 b  | 11-Sept ± 2.11 b | 20-Oct ± 3.37 abc | 47.48 ab | 59.33 ab | 38.95 ab  |

Statistical analysis revealed that the duration of phenological events was mostly affected by season factors, except for the véraison to harvest interval, which was not affected by any factor (Table 3). The 2019 season presented the shortest duration interval between budburst and bloom and the longest duration interval between bloom and véraison. Duration between budburst to bloom was shorter in L’Acadie than *V. vinifera* varieties with a difference of 2 to 5 days and no significant differences were found among these varieties in the interval of bloom and véraison stages. New York Muscat presented a longer duration of bloom to véraison than L’Acadie with 8 days of difference.

### 3.2. Petiole Nutrient Content

The nutrient content varied between 0.7 and 1.6% for total N (New York Muscat and Chardonnay, respectively), 1.2 and 1.4% for Ca (New York Muscat and Pinot Noir, respectively), 1.3 and 2.6% for K (Chardonnay and Riesling, respectively), 0.29 and 0.62% for Mg (New York Muscat and L’Acadie, respectively), 0.19 and 0.37% for P, 0.03 and 0.04% for Na, 27 and 42 ppm for B (New York Muscat and Riesling, respectively), 31 and 76 ppm for Fe (New York Muscat and Pinot Noir, respectively), and 32 and 59 ppm for Zn (L’Acadie and Chardonnay, respectively).

Season factor significantly affected N, Ca, and Na petiole content (Table 4). Grapevines contained the highest N petiole content in the 2019 season, while the highest Ca petiole content was in 2017. In 2018, the grapevines presented the highest Na petiole content.

### 3.3. Shoot Growth Developing

The evolution of shoot growth is shown in Figure 1. Generally, at 60–80 days after budburst, shoot growth continues in active development in the *Vitis vinifera* varieties compared to the CIHG (Figure 1). In 2017, initial shoot growth (at 20 days after budburst) was faster in New York Muscat and Chardonnay than in Riesling and Pinot Noir varieties. In 2018, initial shoot growth (at 11 days after budburst) was faster in New York Muscat...
than in L’Acadie, Riesling and Pinot Noir varieties. In the same season, at 81 days after budburst, Riesling presented a higher shoot growth than the CIHG. In 2019, initial shoot growth (at 18 days after budburst) was faster in L’Acadie than in New York Muscat and Riesling varieties. Shoot growth in the 2019 season was higher in L’Acadie and Chardonnay compared to the rest of the seasons, while New York Muscat and Riesling showed the lowest growth of this season.

Table 4. Effects of variety on petiole nutrient content in grapevines growing under cold climate conditions over three consecutive seasons.

| Variety      | N (%) | Ca (%) | K (%) | Mg (%) | P (%) | Na (%) | B (ppm) | Fe (ppm) | Zn (ppm) |
|--------------|-------|--------|-------|--------|-------|--------|---------|----------|----------|
| L’Acadie     | 1.08 a| 1.34 ab| 1.34 a| 0.62 c | 0.37 b| 0.03 a | 30.30 a | 46.18 ab | 32.09 a |
| NY Muscat    | 0.71 a| 1.19 a | 1.68 a| 0.29 a | 0.19 a| 0.04 a | 27.18 a | 31.21 a | 48.73 a |
| Chardonnay   | 1.57 b| 1.26 ab| 1.31 a| 0.41 ab| 0.26 ab| 0.03 a | 36.11 b | 48.46 ab | 58.61 a |
| Riesling     | 1.28 b| 1.31 ab| 2.56 b| 0.46 b | 0.37 b| 0.03 a | 41.71 c | 54.92 ab | 48.61 a |
| Pinot Noir   | 1.48 b| 1.38 b | 1.59 a| 0.54 bc| 0.19 a| 0.03 a | 35.68 b | 76.02 b | 50.41 a |

NY: New York Muscat. Data are the overall mean value (n = 3 replicates by variety). For each parameter, different letters within a column represent significant differences (Duncan’s test p ≤ 0.05). The numbers in red color correspond to significant difference (p-value lower than 0.05).

3.4. Yield and Water Status

Table 5 shows that season factor significantly affected weigh of 200 berries, yield per plant and stem water potential (ΨStem). In 2019, lowest weight of 200 berries and ΨStem was reached, while in 2017, the grapevines showed the highest yield per plant. Variety factor significantly affected bunch weight, weight of 200 berries and yield per plant (Table 5). Chardonnay presented the highest bunch weight, while L’Acadie presented the lowest. New York Muscat presented the highest weight of 200 berries, while L’Acadie presented berries lighter than Chardonnay. This resulted in the L’Acadie and Pinot Noir varieties showing a lower yield per plant compared to Riesling.

3.5. Must Physico-Chemical Parameters

Table 6 shows that season factor significantly affected most of the physico-chemical parameters except for pH and 3-isobutyl-2-methoxypyrazine (IBMP). In 2019, the grapevines reached the lowest soluble solids (°Brix) in musts, while in 2017, the musts presented the lowest total acidity, malic acid, yeast assimilable nitrogen (YAN), organic nitrogen (ON) and mineral nitrogen (MN). Variety factor significantly affected most of the must physico-chemical parameters except for soluble solids. The musts obtained from New York Muscat presented lower total acidity than the musts from the *Vitis vinifera* varieties. New York Muscat musts presented the highest pH and Riesling musts showed the opposite behavior. Musts from the CIHG presented lower malic acid and MN than the *V. vinifera* varieties. In addition, Chardonnay and Pinot Noir musts showed higher YAN and ON than the musts from the CIHG. For its part, Pinot Noir musts presented the highest IBMP content.
Figure 1. Shoot growth development of cold-hardy interspecific hybrid grapes (L’Acadie and New York Muscat) and *Vitis vinifera* varieties (Chardonnay, Riesling, and Pinot Noir) after budburst from 2017–2019 seasons. NY: New York.

3.6. Principal Component Analysis

To classify the different varieties and assess their influence on yield, yield components, water status, petiole nutrient content and must physico-chemical parameters, a principal component analysis (PCA) was performed (Figure 2). Principal component 1 (PC 1) explained 46.8% of the variance and principal component 2 (PC 2) explained 25.1%, representing 71.9% of all the variance. PC 1 was strongly correlated with weight of 200 berries (−), stem water potential (ΨStem) (−), total acidity (+), malic acid (+), mineral nitrogen (MN) (+), N (+), Na (−), B (+) and véraison-harvest duration (+), while PC 2 was strongly correlated with yeast assimilable nitrogen (YAN) (+), P (−) and bunch weight (+). L’Acadie grapevines were positively correlated to P petiole content and negatively with bunch weight, YAN, ON and Zn petiole content. New York Muscat grapevines were positively correlated to weight of 200 berries and negatively correlated to total acidity, Ca petiole content and véraison to harvest duration. Chardonnay and Pinot Noir grapevines were positively correlated to yield per plant, N petiole content, soluble solids, malic acid, MN, and negatively correlated to ΨStem. Riesling grapevines were positively correlated to véraison to harvest duration, Ca, and Mg petiole content, and negatively correlated to weight of 200 berries, Na petiole content and pH.
Table 5. Effect of variety on yield, yield components and water status of grapevines growing under cold climate conditions over three consecutive seasons.

| Variety   | Bunch Weight (g) | Weight of 200 Berries (g) | Yield Per Plant (kg) | $\Psi$Stem (Mpa) |
|-----------|------------------|---------------------------|---------------------|------------------|
| L’Acadie  | 86.09 a          | 289.60 a                  | 1.05 a              | −27.82 a        |
| NY Muscat | 132.19 b         | 598.56 c                  | 1.25 ab             | −28.58 a        |
| Chardonnay| 191.13c          | 344.44 b                  | 2.06 ab             | −27.76 a        |
| Riesling  | 136.06 b         | 325.40 ab                 | 2.13 b              | −28.94 a        |
| Pinot Noir| 110.91 ab        | 297.72 ab                 | 1.07 a              | −28.22 a        |

Varieties: NY: New York Muscat. Data are the overall mean value ($n = 3$ replicates by variety). For each parameter, different letters within a column represent significant differences (Duncan’s test $p \leq 0.05$). The numbers in red color correspond to significant difference ($p$-value lower than 0.05).

Table 6. Effect of variety on must physico-chemical parameters of grapevines growing under cold climate conditions over three consecutive seasons.

| Variety   | Brix         | Total Acidity  | pH | Malic Acid (g L$^{-1}$) | YAN (mg L$^{-1}$) | Organic Nitrogen (mg L$^{-1}$) | Mineral Nitrogen (mg L$^{-1}$) | IBMP |
|-----------|--------------|----------------|----|-------------------------|------------------|--------------------------------|-------------------------------|------|
| L’Acadie  | 17.10 a      | 6.08 ab        | 2.95 b | 4.71 a                  | 176.33 a         | 156.44 ab                      | 20.22 a                       | 0.00 a |
| NY Muscat | 16.86 a      | 4.60 a         | 3.14 c | 4.21 a                  | 207.55 a         | 180.03 bc                      | 19.42 a                       | 0.00 a |
| Chardonnay| 18.09 a      | 7.48 bc        | 2.96 b | 7.06 b                  | 301.55 b         | 233.78 c                       | 67.92 b                       | 0.00 a |
| Riesling  | 17.20 a      | 8.24 c         | 2.74 a | 6.07 b                  | 182.50 a         | 121.17 a                       | 60.83 b                       | 0.00 a |
| Pinot Noir| 18.14 a      | 7.24 bc        | 3.00 b | 7.15 b                  | 312.80 b         | 241.48 c                       | 71.00 b                       | 0.00 a |

Seasons: 2017 133.12 a | 384.68 b | 2.26 b | −28.55 a | −0.41 a | 2018 137.75 a | 402.43 b | 0.88 a | −27.87 a | −0.40 a | 2019 122.96 a | 326.33 a | 1.40 a | −28.37 a | −0.71 b

Significance: Variety: <0.0001 | <0.0001 | 0.0285 | 0.0531 | 0.1971 | Season: 0.3928 | 0.0009 | 0.0058 | 0.2982 | 0.004

NY: New York Muscat. Data are the overall mean value ($n = 3$ replicates by variety). For each parameter, different letters within a column represent significant differences (Duncan’s test $p \leq 0.05$). The numbers in red color correspond to significant difference ($p$-value lower than 0.05).

Pearson’s correlations confirmed some relationships (Supplementary Material), such as that the weight of 200 berries was correlated to bloom to véraison duration ($r = 0.86$), Na ($r = 0.98$), Ca ($r = −0.83$) and Mg ($r = −0.86$) petiole content. Yield per plant was correlated to budburst to bloom duration ($r = 0.90$). $\Psi$Stem was correlated to soluble solids ($r = −0.90$) and Fe petiole content ($r = −0.90$). Soluble solids were correlated to malic acid ($r = 0.87$) and YAN ($r = 0.87$). Total acidity was correlated to pH ($r = −0.91$), malic acid ($r = 0.82$), MN ($r = 0.85$) and véraison to harvest duration ($r = 0.96$). Additionally, pH was correlated to véraison to harvest duration ($r = −0.93$) and P ($r = −0.80$) and B ($r = −0.85$) petiole content. Malic acid was correlated to MN ($r = 0.97$) and B ($r = 0.83$) petiole content. YAN was correlated to organic nitrogen (ON) ($r = 0.84$) and bunch weight ($r = 0.91$). MN was correlated to N ($r = 0.89$) and B ($r = 0.91$) petiole content. Ca petiole content was correlated to Mg ($r = 0.91$), Na ($r = −0.81$) and Fe ($r = 0.85$) petiole content. Mg petiole content was correlated to bloom to véraison duration ($r = −0.80$), P ($r = −0.90$) and Zn ($r = −0.85$) petiole content. P petiole content was correlated to bloom to véraison duration ($r = −0.81$). Na petiole content was correlated to Zn ($r = 0.82$) and bloom to véraison duration ($r = 0.91$). B petiole content was correlated to véraison to harvest duration ($r = 0.88$). Zn petiole content was correlated to bloom to véraison duration ($r = 0.94$). Budburst to bloom duration was correlated to véraison to harvest duration ($r = 0.88$).
Figure 2. Principal component analysis (PCA) performed with the variables obtained from cold-hardy interspecific hybrid grapes (L’Acadie and New York Muscat) and Vitis vinifera varieties (Chardonnay, Riesling, and Pinot Noir) in 2017–2019 seasons. NY: New York. The distribution of variables (black lines) and individual observations according to varieties (blue dots) on PC 1 and PC 2 are shown. Yield/pl: yield per plant; Yl: stem water potential; WB: weight of 200 berries; BW: bunch weight; YAN: yeast assimilable nitrogen; MN: mineral nitrogen; ON: organic nitrogen; TA: total acidity; BB: budburst; Bl: bloom; Ver: véraison; Har: harvest.

4. Discussion

Based on bioclimatic indices, season affected grapevine phenology of cold-hardy interspecific hybrid grapes (CIHG) and Vitis vinifera grapevine varieties (Table 3). In this fashion, hybrids and V. vinifera varieties differentially behaved if extreme climate conditions in a season were present. As expected, the dates of budburst, bloom, véraison and harvest were delayed in the coldest season and presented the lowest heat accumulation in terms of Winkler Index (WI), Heliothermal Index (HI), Growing Season Temperature (GST) and chilling hours (Supplementary Figure S1). However, it is interesting to note that the coldest season presented the shortest budburst to bloom interval and the longest bloom to véraison duration (Table 3). The ripeness cycle is critical in wine production, offering specific characteristics in relation to their origin [26]. Grapes ripen too late in the season in Annapolis Valley and may not reach full ripeness, usually resulting in wines with high levels of acidity and green flavors. Soil temperature has a significant effect on vine phenology [26]. In this fashion, following winter dormancy, a high sum of cumulative heat units absorbed by the soil stimulated root starch and N mobilization and root growth and primary nutrient uptake, with further consequences on canopy growth and altered N partitioning among the plant components [27].

Our results confirmed the difficulty of bringing the harvest to optimal maturity during the coldest season, showing that this area of Nova Scotia is at the edge of the wine production zone [28], and that low-quality vintages must be accepted from time to time. This confirms that the potential for wine in this area is based on cold climate varieties, such as Riesling, Chardonnay, and Pinot Noir, and some CIHG varieties, especially L’Acadie. The latter variety showed the earliest budburst and presented a short ripening cycle (Table 3). Based on previous research, this variety is well distinguished by its winter hardness (−31 °C), consistent short growing season, and low heat unit condition close to 964 heat
units higher than 10 °C [29]. Recent local investigations have shown that the temperature at which 90% of the primary buds will be killed in L’Acadie is around −29 °C. The lineage of L’Acadie includes *Vitis vinifera* (53.5%), *V. rupestris* (22.7%), *V. aestivalis* (8.8%), *V. labrusca* (8.6%), *V. riparia* (3.1%), *V. cinerea* (1.8%) and *V. berlandieri* (1.5%) [29], which may determine its low chilling requirements and fast budburst compared to other varieties [30].

Based on our results, the L’Acadie grapevine may present a higher tolerance to frost damage compared to New York Muscat, Chardonnay and Pinot Noir grapevines since only their secondary and tertiary buds were able to burst and to produce fruit in the 2018 season. The Riesling plot was not impacted with the same intensity compared to the other studied varieties and their shoots stayed with minimum damage. Dormancy and cold hardiness in Riesling is strongly influenced by photoperiod, temperature, and seasonal carbohydrate changes [31,32]. Ferguson et al. [33] showed that Riesling presented the highest bud cold hardness among the *V. vinifera* grapevines. It seems to be that due to their high resistance to cold, the L’Acadie and Riesling varieties could better adapt under the cold conditions of the Annapolis Valley. Spring frost damage probably conditioned bunch weight and yield per grapevine, and the weight of berries of the following season (Table 5).

The studied CIHG and *V. vinifera* grapevines exhibited adequate levels in most of the nutrients analyzed in petioles except for N (Table 4). Excessive levels of N in petioles were found in *V. vinifera* varieties, while NY Muscat reached deficient levels of N (Table 4). N absorption considerably affects shoot development [34]. High N availability, soil moisture, precipitation and low-light conditions stimulated shoot growth and leaf area expansion and delayed leaf senescence [35]. This relationship could be confirmed regarding Figure 1 since CIHG, in addition to presenting low levels of nitrogen in the petioles, also presented a lower shoot growth than *V. vinifera* grapevines. L’Acadie was the only variety that presented adequate levels of N in the petioles. These results are contradictory since it is well known that the hybrids cultivated in Nova Scotia are characterized by their high vigor. Thereby, CIHG vines quickly form their canopy, and their growth stops early in the season, unlike the *V. vinifera* varieties that continue to develop. Based on our data, water status measurement reflected no water deficit of the grapevines measured (Table 5). In addition, these results were confirmed through the $\delta^{13}$C analysis that showed that none of the plots underwent water stress during the whole growing season (Table 5). These findings meant that there was not sufficient water stress to permit grapevines to reduce vigor, in order to finish the shoot growing phase before harvest and, consequently, to improve the ripening process and wine grape quality, especially for red *V. vinifera* varieties. In addition, *V. vinifera* varieties were grafted onto 3309 Couderc rootstock due to their susceptibility to cold injury, while the CIHG were not grafted due to their inherent tolerance to these cold conditions (Table 1). The 3309 C rootstock promotes low to medium vigor to scion, but it induces medium to high accumulation levels of N to the plant tissues [36]. Therefore, cover crop floor management strategies, and organic or industrial waste selection should be used as sources of nutrients or soil conditioners for vineyards in the cool humid climate of Eastern Canada [37]. In addition, the importance of both clone and rootstock selection in cool climate regions where freeze injury may occur also have been proposed by some authors [38].

New York Muscat presented low B petiole levels and produced the weightiest berries, which was negatively correlated to Ca and Mg petiole content (Supplementary Material). Ca deficiency is detrimental to fertilization and fruit set due to its importance for pollen tube growth. Generally, the soils of the selected vineyards in this trial are sandy soils, which display a low quantity of coarse elements, important levels of organic matter, a low to high soil acidity, a generalized potassium deficiency and a medium to high soil compaction in many soil profiles [12]. In some areas of Nova Scotia, the local and most economical source of agricultural lime is from a dolomitic limestone quarry, but as a result, repeated applications of dolomitic lime can cause a build-up of soil Mg level. In this fashion, excessive Mg can lead to poor soil structure and may induce K and sometimes P deficiency, especially toward the end of the growing season. High Ca availability in soils
may induce Mg deficiency due to competition among these cations for root uptake [39]. This competence can be a more pronounced problem in the V. vinifera varieties established in Nova Scotia since the grapevines grafted on rootstocks derived from American Vitis species may be more prone than own-rooted V. vinifera cultivars to such interference of high soil K with Mg uptake [40]. Since Mg is more mobile in the phloem than Ca, Mg deficiency symptoms first become apparent as chlorotic discoloration in the interveinal areas of old leaves as chlorophylls are being dismantled. New York Muscat is a moderately vigorous variety and produces medium-sized and loosely filled clusters, which may be associated with B deficiencies or the genetics of the variety. Reducing N uptake in B-deficient grapevines leads to low leaf N status, sugar, and starch accumulation in the leaves, which can affect the reserve accumulation of the grapevine. This is of utmost importance in grapevines grown in cold climates, especially in CIHG which, according to our study, accumulate a lower content of petiolar B (Table 5). Chardonnay presented the highest bunch weight, which was positively correlated to must yeast assimilable nitrogen (YAN) content. Different authors showed that nitrogen fertilization significantly increased bunch weight [41,42]. Low N availability in grapevines may result in reduced bunch numbers [43,44], while N addition to N-starved grapevines increased the number of seeds and berries and improved fruit set in grapevines [45].

Season considerably influences physico-chemical parameters of musts at harvest (Table 6). The coldest season led to a lower soluble solids content, while the warmest season induced the lowest acidity, malic acid, YAN, mineral N, and organic N content in the musts (Table 6). At similar soluble solids levels in harvest, CIHG musts presented lower malic acid content than the musts obtained from the V. vinifera grapevine varieties (Table 6). The introduction of CIHG adapted to cold climate conditions has allowed the development of the wine industry in Nova Scotia. However, the intrinsic acidity levels in fruits needs to be considered to produce quality wines in cool climates [46–49]. While malic acid content declines steadily after véraison, tartaric acid level is reduced at a much slower rate since it is not used in respiration, nor affected by the growing season’s temperature [46,50]. Despite this, the total acidity of the musts tended to be higher in the studied V. vinifera grapevine varieties compared to the CIHG (Table 6).

In general, the musts from V. vinifera varieties presented higher YAN, mineral and organic N than the musts from CIHG (Table 6). Methyl anthranilate, furaneol (2,5-dimethyl-4-hydroxy-2,3-dihydro-3-furanone), and α-aminoacetophenone, mostly called “foxy” compounds were identified as important contributors to wine aroma in different CIHG [51,52]. More recent studies showed that CIHG cultivated in Québec (Canada) presented high levels of C6 and other fatty acid degradation products, while nonanal, (E,Z)-2,6-nonadienal, β-damascenone, ethyl octanoate and isoamyl acetate showed the highest odor activity values (OAVs) in the wines made from these varieties [7,53]. Some fermentative volatile compounds are produced from the yeast amino acid metabolism in cells and their concentration depends on the YAN content of the must [34]. Higher alcohol content presents an initial increase at low YAN concentration and tends to decrease after a YAN concentration higher than 200–300 mg N L\(^{-1}\) [55]. Ethyl esters production as well as acetate esters, including ethyl acetates that contribute to fruity and floral wine aroma, is generally increased when YAN is up higher than 300 mg N L\(^{-1}\) [55].

5. Conclusions

Viticultural behavior of L’Acadie, New York Muscat, Chardonnay, Riesling, and Pinot Noir cultivated in Annapolis Valley were evaluated over three consecutive seasons. L’Acadie presented the earliest bud burst, bloom and véraison compared to the other studied grapevines, which provides key data for vineyard management decisions, such as frost management. In terms of nutrient uptake, L’Acadie showed the highest Mg content and lower N content compared to Vitis vinifera varieties; the latter condition affects their growth and decreases the growth rate at the end of the growing season, creating more adaptability to the local conditions. Related to their behavior after frost, L’Acadie showed
a good resilience by having a positive second bud burst and even producing a small yield. New York Muscat grapevines had the main phenological stages later compared to L’Acadie; their nutritional uptake based on petiole analysis had the lowest levels of N, Ca, Mg and B. New York Muscat shoot growth had similarities to L’Acadie, diminishing their rate at the end of the season. Although the yield per plant was not the highest, their berries were bigger compared to the other grapevines and the malic acid levels were the lowest compared to other studied varieties. Chardonnay plants had phenological stages later compared to L’Acadie, at petiole analysis their N was highest, and their shoot growth showed high vigor. Their yield per plant and the bunch weight were one of the highest of the studied vines. Riesling and Pinot Noir plants were latest at the phenological stages. Riesling plants had highest levels of K at petiolar analysis and higher N levels compared to CIHG, but overall, the nutritional condition was more balanced. They had a continuous shoot growth. Their yield per plant was the highest in this study. Although they showed the lowest malic acid compared to other studied V. vinifera varieties, their total acidity was the highest of all the studied varieties. Pinot noir showed the lowest P level at petiolar analysis, while Ca and N were the highest. The shoot growth was similar to the other V. vinifera varieties, the bunch weight was the lowest between the grapevines and had the highest malic acid levels. Based on the exposed results, L’Acadie plants, due their growth pattern and resilience to frost, and Riesling, due the nutrient conditions and good yields, showed a good adaptation to the edaphoclimatic conditions of Nova Scotia. L’Acadie is a widely used grape variety in the region, producing wine in different styles and qualities. This study proved its adaptation to the local climatic conditions. Contrary to the bibliography, CIHG presented lower levels of malic acid and total acidity compared to V. vinifera varieties, while V. vinifera showed a high content of N compounds in musts. Related to water demands, no water stress was found in any of the varieties through this study, neither by stem water potential nor δ¹³C analysis. Finally, L’Acadie would be more adapted to cold terroirs and in flat plots, whereas V. vinifera varieties should be established in the warmer sites of the valley and in slope zones.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/horticulturae7090291/s1, Table S1: Pearson’s correlation obtained from principal component analysis of the varieties. Figure S1: Chilling hours accumulation during 2016, 2017 and 2019 season. Figure S2: North Carolina chilling model.

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