Interspecific Hybrids versus *Vitis vinifera* L. Bud Hardiness, Viability, and Postfreeze Pruning Implications in Cane-Pruned Vines

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**Abstract**

**Background and goals**

Winter temperature inversions in 2020 and 2022 saw much of Nova Scotia drop below -20°C, with the coldest vineyards registering below -25°C. With sizable plantings of both interspecific hybrids and *Vitis vinifera* L., we examined both in terms of bud hardiness, viability, and the regional historical frequency of like events. A pruning study using one hybrid and one *V. vinifera* site tested whether minimal pruning should remain the recommendation in a highly damaged cane-pruned system.

**Methods and key findings**

Bud hardiness measurements using differential thermal analysis across 44 sites, 16 cultivars, and two years showed regional hybrids to be 3°C harder, on average, than *V. vinifera*. Pre- and postfreeze bud viability data reflected this difference. Historical data indicates that the frequency of winter events equal in severity or worse than recent damaging winter events has decreased from occurring annually 100 years ago, to once every five years today. Pruning trials using a range of pruning severities showed that no treatment produced a marketable crop in the more damaged Chardonnay, while retaining extra canes was as effective as minimal pruning in Vidal blanc. Minimal pruning reduced vigor, limited pruning options, and greatly increased pruning time the following year. Carryover treatment effects in year two were nuanced and nominal in both cultivars.

**Conclusions and significance**

A reduction in winter damage risk resulting from warming is being offset by an increase in plantings of less-hardy *V. vinifera* cultivars in the region. Results from the pruning trials challenge the notion that minimal pruning after a damaging freeze event is universally the best practice in a cane-pruned system.

**Key words:** Chardonnay, climate change, cold hardiness, cool climate, freeze stress, Vidal blanc

**Introduction**

One of the most significant factors determining whether winegrapes can be grown in a region, as well as what cultivars can be grown, is the absolute minimum temperature experienced each winter (Willwerth et al. 2014, Shaw 2017). A single lethal low temperature event can determine whether a vineyard will produce a crop that year or not. The rapid growth of the Nova Scotian winegrape industry over the last two decades coincides with a general warming trend and a rapid expansion into less-hardy *Vitis vinifera* cultivars. After several years of relatively mild winters, lethal, winter low-temperature events have occurred in several vineyards in Nova Scotia in two of the last three years. On 15 Feb 2020 and on 22 Jan 2022, temperatures dropped below -20°C across much of Nova Scotia, and in some vineyards, below -25°C. Different winegrape cultivars possess a wide range of dormant bud hardiness levels. The buds of most hybrid cultivars, which normally include some level of American *Vitis* species parentage crossed with *V. vinifera*, typically freeze at colder levels, and therefore are more winter hardy than most European *V. vinifera* cultivars (Dami et al. 2012, Willwerth et al. 2014). Winegrape regions with a low risk of winter damage typically focus on *V. vinifera* cultivars, while regions with cold winters and a high risk of winter damage often rely on hybrids. The modern Nova Scotia winegrape industry is now somewhere in the middle, with sizable commercial plantings of both hybrids and *V. vinifera*.

The extracellular regions of woody perennials, including grapevines, are the first to freeze and generally do so routinely throughout the winter in cool climate regions. While the formation of extracellular ice is harmless, the formation of intracellular ice is lethal (Keller 2015, Rende et al. 2018). The tissues that make up the grapevine buds are the least tolerant of winter low temperatures, and the larger primary bud is typically the most vulnerable of the buds contained in the compound bud (Zabadal et al. 2007, Willwerth et al. 2014).
Bud hardiness is a complex and dynamic process, which is influenced by a number of factors including climate, cultivar, and horticultural practices. In general, hardiness levels track the temperatures experienced in the region during the dormant period. Vines acclimate and become hardier in the fall, reach maximum cold hardiness in the winter, and then start to deacclimate in the late winter and early spring (Willwerth et al. 2014). Preformed inflorescences found within the primary bud and, to a lesser extent, the secondary and tertiary buds, hold the potential for the crop in the following growing season. The loss of these buds results in crop losses for a given year. An otherwise healthy vine will respond to the loss of its primary buds by instead pushing less fruitful secondary or tertiary buds, if they remain viable, or largely unfruitful latent buds. The effect of severe winter freezing events can go beyond bud mortality and include vascular damage—especially phloem damage—resulting in delayed and asynchronous budbreak, cane dieback, an increase in shoots from the base of the trunk, and even vine death (Moyer et al. 2011, Gonzalez Antivilo et al. 2020).

While several postfreeze studies predate this one, this study offers a detailed account of the vine hardiness and viability over a range of hybrid and V. vinifera cultivars from a region with sizable plantings of both. In the context of these previous studies, as well as two notable damaging winter freeze events that occurred over the previous three years, pruning trials were conducted with the objective to challenge the conventional wisdom and literature suggesting that minimally pruning severely damaged vines is universally the best practice. In a cool climate region that heavily favors cane pruning over the more common spur-pruning systems, a range of pruning treatments were applied to two severely damaged plots: one V. vinifera and one hybrid. Questions surrounding yield and vine architecture pertinent to a cane-pruned system were addressed using a range of both minimal (i.e., the previous year’s fruiting canes retained) and maximal (i.e., the previous year’s fruiting canes removed) pruning treatments.

Materials and Methods

Three different activities were associated with this study: a bud hardiness survey conducted over a range of hybrid and V. vinifera cultivars over two years (2019 to 2020 and 2020 to 2021), at 44 sites located within 120 km of the Kentville Research and Development Centre (KRDC) (45°04’N; 64°28’W; Kentville, Nova Scotia, Canada); a bud viability survey conducted in a subset of the bud hardiness sites both before and after the 15 Feb 2020 and 22 Jan 2022 freeze events; and a post-deep-freeze pruning trial in one hybrid (Vidal blanc) and one V. vinifera cultivar (Chardonay) located within the KRDC vineyard after the 15 Feb 2020 freeze event.

Temperature data

A logging-capable temperature sensor (HOBO MX2304) was placed in or near all sites associated with the 2019 to 2020 bud viability survey sites in 2019 for a total of 12 sensors (some sensors served double-duty for more than one cultivar site when sites were adjacent to one another) with a 15-min scan interval. These sensors remained in place through the 2021 to 2022 dormant season. Within the KRDC vineyard, a tower was installed ≈5 m outside the vineyard along the middle of the east side row in 2019. Type T thermocouple sensors mounted in radiation shields were located along the length of the tower at heights of 0.1, 1, 2, 4, 6, 8, and 9 m to detect temperature inversions. Data were recorded using a VersaLog VI-TC (Accsense). In addition, two temperature (HOBO MX2304) and wind (WindLogger, Logic Energy) sensors were placed in the vineyard—one on both the north and south ends toward the middle of the block using a 10-min interval. These sensors were located to the west and downslope of the tower (Supplemental Figure 1). All temperature sensors described above were mounted 2 m above ground level in a radiation shield. Finally, an Environment and Climate Change Canada (ECCC) weather station was also located at the KRDC ≈750 m from the KRDC vineyard described above. Weather data, including daily minimum and maximum temperatures, have been recorded from this same site since 1913.

Bud hardness survey

The 44 bud hardness survey sites consisted of 23 hybrid sites across nine cultivars (Baco noir, Geisenheim 318-57, L’Acadie blanc, Leon Millot, Lucie Kuhlmann, Marquette, New York Muscat, Seyval blanc, and Vidal blanc) and 21 V. vinifera sites across seven cultivars (Chardonnay, Chenin blanc, Ortega, Pinot gris, Pinot noir, Riesling, and Sauvignon blanc). The survey was conducted in early February, a period of peak winter hardiness in the region, in both 2019 and 2020. The 2020 survey was conducted 10 days prior to the 15 Feb 2020 deep freeze event. Bud hardiness was estimated using low-temperature exotherms (LTEs) via differential thermal analysis (DTA) (Wolf and Pool 1987, Wolf and Cook 1994). Five canes were randomly selected from each cultivar site each year; nodes three to seven were removed for DTA analysis (i.e., a total of 440 canes and 2200 buds analyzed across all sites and years). This survey included five Chardonnay sites and two Vidal blanc sites, which are the focus of our pruning trial. Using programmable freezers (T20-AWF4, Tenney Environmental), the temperature was lowered from 0 to −45°C at a rate of 4°C/hr. Freezing buds placed on a Peltier plate generated LTEs that were measured as voltage spikes using a multimeter data acquisition system (Keithley Instruments). Bud hardiness values were expressed as the median temperature at which 50% of the buds died (LTE50).

Bud viability survey

A bud viability survey was conducted every four weeks in a subset of the bud hardness survey’s 44 sites in 2020, 2021, and 2022. However, this report focuses on the dissections and assessments taken just before and after the singular deep freeze events that took place in February 2020 and January 2022 (Supplemental Table 1). In 2020, five 10-node canes were sampled from each site and time point: 31 sites...
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(before + after) × 5 canes = 155 canes and 1550 compound buds assessed. In 2021 and 2022, ten 10-node canes were sampled from each site and time point: in 2022, 36 sites (before + after) × 10 canes = 360 canes and 3600 compound buds assessed (Supplemental Table 1). The health of the primary and secondary bud of each compound bud was assessed for each site and time point as described by Moyer et al. (2011) (Supplemental Figure 2). Finally, in the weeks following the deep freeze event, an assessment was also performed on the two cultivars of interest in the 2020 postfreeze pruning trial—Chardonnay and Vidal blanc—located in the KRDC vineyard. One cane from the head and fruiting cane were randomly sampled from 10 vines for each cultivar (i.e., a total of 40 canes and 400 buds assessed).

KRDC vineyard / postfreeze pruning site

The KRDC vineyard, ≈1 ha in size, was established in 2016 at the KRDC. Rows are oriented north-south with 1.2-m vine spacing and 3-m row spacing; posts were spaced 4.8 m apart (i.e., four vines per panel, the distance between posts). The row length was 92 m. The vineyard slopes gently to both the south and the west. The pruning trial involved two cultivars: Vidal blanc, a white hybrid grape (Vitis spp.) and Chardonnay (clone 96) (V. vinifera). Both cultivars were grafted onto 3309C rootstock. The KRDC vineyard included four adjacent rows of each cultivar of interest, separated by four adjacent rows of a third cultivar. All vines were pruned using a flat bow, cane-pruned (two canes retained per vine and six or seven nodes per cane) style trained using a vertical shoot positioning system in the years preceding the freeze event, as well as in the subsequent year.

Postfreeze pruning trial

In two separate, but adjacent, plots, the postfreeze pruning trials were set up using a randomized complete block design for each cultivar. Each cultivar plot was made up of 24 panels located in two lengths of 12 consecutive panels centered in two 19-panel rows (Supplemental Figure 1). Each plot was further divided into three blocks (eight panels per block). Two individual full-panel replicates of four different pruning treatments were randomly assigned within each block (Figure 1A). The four pruning treatments, ranging from minimum to maximum pruning, were: ‘10-node cane’ (10-NC) (multiple vertical canes) (Figure 1B; minimum pruning), ‘three-node spur’ (3-NS) (Figure 1C), ‘four-cane horizontal’ (4-CH) flat bow cane (Figure 1D), and vine pruned back to the ‘head only’ (HO) (Figure 1E; maximum pruning). The four treatments consisted of two minimally pruned treatments (10-NC + 3-NS), each of which retained the previous year’s fruiting canes (=two-year-old wood), and two maximally pruned treatments (4-CH + HO), each of which removed the previous year’s fruiting canes (Figure 1). Pruning treatments were implemented in late March 2020. In year two, all vines were returned to their previous cane pruning system (i.e., Figure 1D, but with only two canes retained). Each Chardonnay fruiting cane was pruned to seven nodes, and each Vidal blanc cane to six nodes. This difference was because of internode length and cropping considerations. No shoot or cluster thinning was performed over the course of this study, aside from mechanical hedging and topping, which was applied equally to both cultivars in each year. Vine performance measured both in the year

Figure 1  Schematics representing the range of pruning severity treatments applied to cane-pruned, vertical shoot-positioned-trained vines in the year of the deep freeze event: A) unpruned (not included as a pruning treatment), B) 10-node cane (10-NC) (vertical canes) (minimum pruning), C) three-node spur (3-NS), D) four-cane horizontal (4-CH) (typical cane pruning approach, but with four as opposed to two canes retained), E) pruned back to the ‘head only’ (HO) (maximum pruning). The four treatments are further classified into minimal (10-NC + 3-NS) and maximal (4-CH + HO) pruning treatments.
of the deep freeze (2020) and the subsequent year (2021) included the following: yield; cane number (head and fruiting canes); weak shoots (defined as shoots that failed to reach the height of the second set of catch wires due to lack of vigor); cane diameter (diameter of the largest cane on each vine, both from the head and fruiting canes, where applicable, as measured between nodes one and two); and dormant cane pruning mass (the previous year’s growth, less than one-year-old wood). Older wood (greater than one-year-old) was measured separately. In the second year, the variables assessed in year one were again assessed and the following vine and fruit composition variables were added: % shootless nodes, cluster number (from the head and total), average 100 berry mass (in grams), total soluble solids (TSS; Atago digital refractometer), and titratable acidity (TA, g/L tartaric acid; HI 84502, Hanna Instruments). Fruit composition variables were performed on the must generated from a 100-berry sample. All variables were assessed on a per-vine basis, but averaged over the panel, except for the fruit composition variables and dormant pruning weights, which were collected and measured on a per-panel basis.

### Statistical analysis

All statistical analyses were performed using R version 4.1.1 (R Development Core Team 2022). Single factor analysis of variance (ANOVA) was used to separately analyze each of the two pruning trials. The constant variance and normal distribution assumptions were tested using a residual versus fits plot and a normal quantile-quantile plot, respectively. For significant main effects, treatment means were compared using Tukey’s pairwise comparison test (emmeans package). Year-to-year and varietal differences described were analyzed with a t test. Hybrid versus V. vinifera hardiness was analyzed with ANOVA. For the postfreeze bud viability assessment, regression analysis was performed on site-specific minimum temperature versus primary bud viability broken down by type, i.e., hybrids versus V. vinifera.

### Results

#### Temperature data

The KRDC ECCC site temperature reached a minimum of -21.7°C during the 15 Feb 2020 event, and -22.3°C during the 22 Jan 2022 event (i.e., = -22°C for both). During both events, the temperature in the KRDC vineyard measured ≥3°C colder than at the KRDC ECCC site (i.e., ≤ -25°C); both were temperature inversion events. A plot of the temperatures at the KRDC vineyard (the site of the post-deep-freeze pruning trial) during the 14 to 15 Feb 2020 event is shown in Figure 2A. The minimum temperature across all sites that were monitored for viability on 15 Feb 2020 averaged -21.4°C, but ranged from -15.6 to -25.5°C. The same sites measured on 22 Jan 2022 averaged -22.6°C and ranged from -19.0 to -25.8°C. Regression analysis using historical data (1913 to 2022) from the KRDC ECCC site indicates the mean annual temperature increased by 0.018°C per year ($p < 0.001$), for a total of 1.9°C over this time period, while the minimum temperature increased by 0.055°C per year ($p < 0.001$), for a total of 5.9°C, over the same range. The 10-year moving average indicates that the frequency of a winter freeze event comparable to or greater than the 2020 and 2022 events (i.e., ≤ -22°C) has decreased, with a temporary deviation from the overall trend from 1950 to 1980, from annually (100%) in 1923 to once every five years (20%) in 2022 (Figure 2B).

#### Bud hardness

In a multicultivar, multiple-site survey conducted near peak hardiness (early February) over two years, hybrid cultivars were on average 3°C harder than V. vinifera cultivars, based on their LTE50 values ($p < 0.01$). A plot of the individual

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**Figure 2** A) Kentville Research and Development Centre vineyard temperatures at 1 m and the difference between 1 and 9 m on 14 to 15 Feb 2020; B) the 10-year moving average showing the frequency that the annual minimum temperature reaches ≤ -22°C (the equivalent or more damaging than the 2020 and 2022 events) at the Kentville Environment and Climate Change Canada site using data from 1913 to 2022.
cultivars shows a wide range of hardness values (Figure 3). When ranked from most to least hardy, cultivars naturally divided into hybrids (hardier) and \textit{V. vinifera} (less hardy), although adjacent cultivars in Figure 3 (e.g., Geisenheim 318-57 and Pinot noir) were not necessarily significantly different. Vidal blanc, which is moderately hardy for a hybrid, was ≈2.0°C harder than Chardonnay (Figure 3).

**Bud viability**

Data from the combined 2020 and 2022 surveys showed bud viability to be high before the respective, and similar, deep freeze events: \textit{V. vinifera} primary and secondary buds were 94.1% and 90.5% viable, respectively; hybrid primary and secondary buds were 94.6% and 96.4%, respectively. In 2021, a year without a damaging freeze event, the primary and secondary buds of both \textit{V. vinifera} and hybrids remained in excess of 90% viable until budbreak in the spring: \textit{V. vinifera} (93.3% and 94.9%, respectively) and hybrids (93.5% and 96.9%, respectively). In the years with comparable, damaging freezes (2020 and 2022), average postfreeze primary and secondary bud viability values dropped to 61.1% and 64.9% for \textit{V. vinifera} and 73.8% and 85.2% for hybrids, respectively. Damage was dependent on individual site temperature and cultivar. Regression analysis (site minimum temperature versus postfreeze primary bud viability) indicated a difference ($p < 0.001$) between the slope of the linear model fitted to the hybrid cultivars [viability = (0.03831 × min. temp) + 1.6037] compared with the \textit{V. vinifera} model [viability = (0.1251 × min. temp) + 3.3212]. If the minimum temperature recorded at the Kentville ECCC weather site in both 2020 and 2022 (i.e., -22°C) is used in the above formulas, the resulting predicted bud viability for the average hybrid and \textit{V. vinifera} vine at that temperature would be 76% and 57%, respectively. Because of the difference in slope between the two vine types, the margin of difference in bud viability increases as minimum temperatures decrease. However, that margin will then start to shrink at progressively colder temperatures after the average \textit{V. vinifera} bud viability level reaches zero.

The side-by-side viability assessment conducted in the KRDC vineyard after the 2020 deep freeze event, in connection with the postfreeze pruning trial, indicated that the primary and secondary Chardonnay buds were both <1% viable. There was no difference in canes selected from the head of the vine versus the fruiting canes. For the hardier Vidal blanc hybrid vines, the primary and secondary bud viability levels averaged 15% and 22%, respectively, with no difference between head versus fruiting canes in terms of primary or secondary bud viability.

**Postfreeze pruning**

For both Chardonnay and Vidal blanc, more severe pruning resulted in lower yields in the year of the freeze, but differences were largely the result of the lower crop in the maximum HO pruning treatment, with no difference noted in the remaining three treatments. For Chardonnay, even the highest yielding treatment, 10-NC, produced only 150 g/vine (less than the mass of a typical single cluster). Canes emanating from the horizontal fruiting canes (HO treatment excepted) averaged 3.0 canes per vine for the 4-CH

![Figure 3](image-url)  

**Figure 3.** A plot showing a survey of the midwinter (early February) average bud LTE50 (low-temperature exotherm) hardness values and standard deviation of some of the most common hybrids and \textit{Vitis vinifera} grown in Nova Scotia. The cultivars are ranked from the hardiest (Marquette) to the least hardy (Chenin blanc). The number of sites included in the survey for each cultivar is shown in parentheses. Averages (n) are made up of individual cane median LTE values; five canes were selected per site per year over two years: e.g., for two sites: five canes × two sites × two years = n = 20 canes.
treatment and 6.7 for the 10-NC and 3-NS treatments combined across cultivars. In contrast, for both cultivars, the two minimal pruning treatments (10-NC + 3-NS) produced fewer canes, and of a smaller diameter, from the head of the vine than the two maximal pruning treatments (4-CH + HO) (Table 1). Across both cultivars, wood that was more than one-year-old (HO treatment excepted) was greater in the two minimally pruned treatments (0.40 kg/vine) compared to the 4-CH treatment (0.22 kg/vine). While the HO treatment produced the lowest average cane pruning mass for both cultivars, this differed only in Chardonnay (Table 1). There were no treatment differences in the number of weak canes (unsuitable to be retained) emanating from the head in Chardonnay (mean 1.2/vine) and Vidal blanc (mean 0.9/vine). There were no treatment differences in the maximum cane diameter in the canes emanating from the fruiting canes (as opposed to from the head of the vine, HO treatment excepted) in Chardonnay (11.3 mm) or Vidal blanc (11.9 mm). Maximum cane diameter was larger in canes emanating from the head than fruiting canes for both cultivars (Table 1).

There were fewer response variable pruning treatment differences in the year after the freeze after all vines were returned to their original two horizontal, flat bow, cane pruning system (Table 1). Chardonnay and Vidal yields averaged 4.2 and 8.3 kg/vine, respectively, across all treatments with no treatment differences (Table 1). There appeared to be a slight residual effect in the cane numbers emanating from the head of the vine from the previous year’s pruning treatment and response, at least in the Vidal (Table 1). The diameter of the largest cane emanating from the head of the vine averaged 10.5 and 12.5 mm for Chardonnay and Vidal blanc, respectively, across all treatments with no treatment differences. There was no difference across treatments for wood more than one-year-old for Chardonnay (0.17 kg/vine) and Vidal blanc (0.14 kg/vine). Dormant cane mass (wood less than one-year-old) showed no difference between treatments for Chardonnay, but there were some differences in Vidal blanc (Table 1). There was no treatment difference in the number of weak canes emanating from the heads in either Chardonnay (2.3/vine) or Vidal blanc (1.5/vine) in year two. However, a paired t test showed both these values were higher in year two than in the year of the freeze for both Chardonnay (p = 0.02) and Vidal blanc (p = 0.02). There were no treatment differences in the maximum cane diameter in the canes emanating from the fruiting canes (not from the head) in the Chardonnay (11.3 mm) or the Vidal blanc (12.1 mm) in the year after the freeze, and no difference from the previous year (data not shown). There was no treatment difference in the percentage of shootless nodes; however, there were more shootless nodes in Chardonnay (13%) than in Vidal blanc (5%) (p = 0.005) in year two.

Despite there being no difference in overall yield (Table 1) or berry size across treatments in the year after the freeze, cluster numbers did vary (Supplemental Table 2). Differences were primarily governed by the number of clusters on shoots emanating from the head of the vine, which were either low in vines minimally pruned the previous year, or high in vines that received the most severe pruning (Supplemental Table 2). Fruit composition levels (TSS and TA) varied little after the vines were converted back to a two-cane pruning system in year two, except for

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year 1 (freeze damage / pruning treatments)</th>
<th>Year 2 (subsequent year / standard cane pruning)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield (kg)</td>
<td>Cane no.</td>
</tr>
<tr>
<td>Chardonnay</td>
<td></td>
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</tr>
<tr>
<td>10-NC</td>
<td>0.15 a</td>
<td>3.5 b</td>
</tr>
<tr>
<td>3-NS</td>
<td>0.11 ab</td>
<td>3.5 b</td>
</tr>
<tr>
<td>4-CH</td>
<td>0.06 ab</td>
<td>6.0 a</td>
</tr>
<tr>
<td>HO</td>
<td>0.03 b</td>
<td>7.2 a</td>
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<tr>
<td>Sig.</td>
<td>*b</td>
<td>***</td>
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<tr>
<td>Vidal blanc</td>
<td></td>
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</tr>
<tr>
<td>10-NC</td>
<td>2.9 a</td>
<td>3.1 b</td>
</tr>
<tr>
<td>3-NS</td>
<td>2.9 a</td>
<td>3.6 b</td>
</tr>
<tr>
<td>4-CH</td>
<td>2.1 ab</td>
<td>5.4 a</td>
</tr>
<tr>
<td>HO</td>
<td>1.3 b</td>
<td>6.1 a</td>
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<td>Sig.</td>
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</table>

- Numbers in relation to canes emanating from the “head” (Figure 1A and 1E) of the vine only, excludes fruiting canes.
- b, **, *** NS: significant (Sig.) at p < 0.05, 0.01, 0.001, or not significant, respectively. Letter groupings as measured via a Tukey pairwise multiple means comparison.
- c+ indicates a trend at ≤ 0.1.
that of the Vidal blanc HO treated vines, which had lower TA values than the remaining three treatments (Supplementary Table 2).

Six of 192 vines (i.e., 3.1%) died during the course of this two-year study. Only one vine died in the year of the freeze: a 10-NC Vidal blanc vine. Five vines died in the following year: two 10-NC and one HO vine in the Chardonnay, and one 10-NC and 4-CH in the Vidal blanc.

**Discussion**

**Hybrid versus V. vinifera** bud hardiness and viability

While the appropriate bud hardiness ranking of each individual cultivar, including where the hybrids and V. vinifera meet (Geisenheim 318-57 and Pinot noir), is not conclusive, the finding that hybrids as a whole are harder than V. vinifera is conclusive (Figure 3). This finding was reinforced by the higher bud viabilities observed in the hybrid versus V. vinifera cultivars after the 2020 and 2022 freeze events. While such a finding is not new (Vandal 1986, Dami et al. 2012), the cultivar hardiness range and ranking provide interesting information from a region that grows both hybrids and V. vinifera in high numbers. The range in peak hardiness differed between the two vine types: hybrids -5.6°C, V. vinifera -1.7°C (Figure 3). This result is dependent on the basket of hybrid and V. vinifera cultivars grown in this region. The lower extent of the hybrid hardiness range could have been extended if some additional hardier hybrids (e.g., several relatively recent releases from Minnesota: Frontenac, La Crescent, Petite Pearl) had been included in this survey. While these cultivars are grown in Nova Scotia, their plantings are more limited. Additionally, despite adequate hardiness levels, some hybrids are not well suited to the Nova Scotian climate because of their heat and season length requirements. Regional climate limitations are a greater factor in determining which V. vinifera cultivars are suitable for the area. Less-hardy V. vinifera (e.g., Malbec, Merlot, or Syrah) are missing from this list because they are not grown in numbers in the region. Finally, while the general trends observed in Figure 3 would largely reflect those found in other regions, it should be noted that cold temperatures are needed to drive a vine to its peak hardiness and that the relative hardiness of some cultivars may also be dependent on the region in which they are grown (Howell 2000, Ferguson et al. 2014).

**Temperature inversion variability, climate change trends, and winter damage risk**

The 2020 and 2022 deep freezes were both temperature inversion events. Despite similar low-temperature averages in both years with damaging low temperatures, there were distinct differences in individual site temperature minima across years. This is characteristic of temperature inversions, where cool, dense air is allowed to settle near the ground, often concentrating in low areas or against tree lines, and warmer air is found above. A range of static and more dynamic variables determine the temperature minima experienced at each site. Several Nova Scotia vineyards are located near the Bay of Fundy, home to the highest tides in the world; these tides, which may exceed 16 m, can move huge volumes of air, influencing temperatures at the local level. The stratification of cold and relatively warmer air (Figure 2A) suggests that air mixing strategies, such as the use of wind machines, may have helped increase the temperature at the level of the vine and reduced damage in both 2020 and 2022 (Fraser et al. 2014).

The finding that the warming trend is being disproportionately driven by an increase in minimum temperatures is consistent with other studies (Jones 2005, Shaw 2017, Hewer and Gough 2020, 2021). The average annual extreme minimum temperature—a factor in determining a region's “hardiness zone”—is considered one of the most important factors in determining where more sensitive cultivars can be grown (Willwerth et al. 2014, Shaw 2017). The frequency of damaging deep-freeze temperatures, like those experienced in both 2020 and 2022, has dropped dramatically, most markedly since ~1980 (Figure 2B). However, the reduction in risk from low-temperature frequency would be tempered by reduced hardiness in the vines related to warmer winter temperatures and the trend in planting less-hardy V. vinifera cultivars. This same trend has been observed in other Canadian grapegrowing regions (Hewer and Gough 2020, 2021). While growing V. vinifera is now commonplace in the region, a large cultivar evaluation trial that occurred in the 1960s did not include V. vinifera and even concluded that the region was unsuitable for most hybrids due to insufficient heat (Bishop et al. 1970). However, it is important to note that the timing of this trial coincided with a period of climatic cooling in Nova Scotia (Figure 2B) and that production methods, cultivar choice, and wine styles may now be better suited to the region.

**Pruning implications for yield and vine architecture**

Despite some differences on account of the degree of freeze damage, V. vinifera (Chardonnay) and hybrid (Vidal blanc) vines responded similarly to the four postfreeze pruning treatments (Table 1). However, increased fruitfulness (a hybrid trait) in Vidal blanc secondary buds relative to Chardonnay, may also have been a factor. For both cultivars, the yield was inversely correlated with the amount of pruning material removed. However, only the HO treatment (maximum pruning) was different from the other three pruning treatments (Table 1). In principle, this finding agrees with the conventional advice that the amount of pruning material removed should be inversely proportional to winter damage (Keller and Mills 2007, Moyer et al. 2011, Dami et al. 2012, Willwerth et al. 2014). Fruitful primary buds are typically the first to freeze in a lethal winter event, increasing the odds that the shoots that emerge in the current growing season will be less fruitful secondary, tertiary, or lesser latent buds (Khanduja and Balasubrahmanyam 1972,
In practice, however, no pruning treatment resulted in a crop worth harvesting in the more damaged Chardonnay. Retaining four as opposed to two canes (i.e., 4-CH—the second highest amount of pruning material removed in this study) was nearly as effective as bolstering yield in damaged vines as the 10-NC and 3-NS treatments (i.e., minimal pruning). Furthermore, there was capacity to retain five or six canes (Table 1), which would have further bolstered the crop. In light of this finding, further metrics should be explored to see if there are other reasons to recommend minimal pruning (i.e., 10-NC and 3-NS) in the case of severely damaged cane-pruned vines.

For both cultivars in the year of the freeze damage, pruning strategies that increased the number of shoots arising from the previous year’s canes and spurs (i.e., minimal pruning treatments: 10-NC and 3-NS) did so to the detriment of the number of shoots emanating from the head. Canes emanating from the head of the vine are important in a cane-pruned system as the source of the following year’s fruiting canes but are less important in spur-pruned systems. The two minimal pruning treatments had lower vigor (i.e., lower maximum cane diameter) and below normal cane numbers at the head of the vine (as compared to the year after the freeze), with roughly half the number emanating from the head (mean = 3.5 canes) as the two maximal pruning strategies (4-CH and HO) (mean = 6.2 canes) (Table 1). This finding aligns with the classic work of Winkler et al. (1974), which describes pruning response in undamaged vines as an interplay between vine vigor and capacity. Pruning more severely may lower overall capacity, and this was observed as lower total cane mass in the maximum HO treatment, but it increases the vine capacity-to-aboveground wood ratio in the remaining structure, as evidenced by more and larger canes emanating from the head (Table 1). It is speculation that a higher vine capacity-to-wood ratio could benefit the recovery from vascular damage. Dami et al. (2012) found that pruning mass increased with pruning severity on winter damaged vines, which differed from the results of the present study. The difference may be the degree of winter damage and the degree to which the capacity was dwarfed by the crop. Pertinent to cane-pruned vines, all pruning treatments in the present study averaged approximately one weak cane (unsuitable for use as a fruiting cane) arising from the head. This suggests that for the two minimal pruning treatments, there were few to no options for these vines when selecting two canes to be retained in the subsequent year.

In the year after the freeze, there was little carryover effect from the previous year’s pruning treatments (Table 1) after all vines were converted back to a two-cane system (Figure 1D), the regional norm. The relationship between pruning treatment and cluster number in shoots emanating from the head did not affect overall yields (Table 1). This finding could reflect a subtle carryover in shoot number from the previous year (Table 1). However, differences in the unmeasured carbohydrate status at the head could also be a factor. The greater vigor (cane diameter) and cane number at the head (Table 1) indicate a greater concentration of resources in this part of the vine in the 4-CH and HO treatments. Other studies have found that the fruitfulness of the buds may be correlated with the carbohydrate status of the vine (Lebon et al. 2008, Jones et al. 2013). It is uncertain whether the carryover treatment differences in pruning mass (Table 1) and in the lower TA values in the HO treatment—both only found in Vidal blanc—were statistical anomalies or had some basis in physiology.

Finally, in agreement with Dami et al. (2012), converting the minimally pruned vines (10-NC and 3-NS) back to a cane pruning system took more time than the pruning required for the maximally pruned treatments (4-CH and HO). The large amount of wood greater than one-year-old that was removed from the minimally pruned vines was two to three times more than that found in a normal cane-pruned system. Furthermore, the poor placement of canes in the minimally pruned vines (e.g., at the top of a vertical 10-node cane [Figure 1B]) often resulted in long, horizontal canes that became entangled with neighboring vines. The minimally pruned treatments also required larger cuts to be made (greater than two-year-old wood) than maximally pruned vines (less than two-year-old wood) when vines were converted back to cane pruning in year two. Larger pruning cuts are associated with increased levels of fungal infection and trunk diseases (Gubler et al. 2005, Pouzoulet et al. 2017, Wine Australia 2019). It was further speculated that in cases where winter damage was severe enough to include vascular damage, reducing vine size through increased pruning could reduce the type of vine collapse that occurs when the amount of growth on the plant outpaces the ability of the damaged vascular system to provide water and nutrients. Vine mortality was primarily observed in the year after the freeze event (five vine deaths), when vine mortality rose above average levels, but not in the year of the freeze event (one vine death). Anecdotally, the highest level of vine mortality was found in the minimal 10-NC treatment (accounting for four out of six vine deaths spread evenly across the two cultivars). Previous studies did not find a link between pruning strategy following winter injury and vine survival and future performance (Keller and Mills 2007, Dami et al. 2012), but they were challenged by the same limitations as the present study.

Conclusion

In both hybrid and V. vinifera vines, primary and secondary bud viability levels remain high (>90%) throughout the dormant season, unless subjected to a damaging freeze event. Regional hybrid cultivar bud hardiness levels are 3°C hardier, on average, than V. vinifera cultivars; however, hybrid hardiness levels especially range greatly and are dependent on the cultivar. For trials involving cane-pruned Vidal blanc and Chardonnay severely damaged by low winter temperatures, results were similar for both vine types. Minimally pruning vines in a manner that retained the previous
year's horizontal fruiting canes (i.e., 10–NC and 3-NS) is not justified by a substantial increase in crop load relative to retaining extra canes from the head of the vine in a cane-pruned, as opposed to a spur-pruned, system. Additionally, minimally pruning vines reduces the number of canes emanating from the head and limits cane pruning options in both cultivars in the following year. Finally, the degree and frequency of winter minimum temperatures has declined greatly in the region over the past century. However, the reduced risk associated with warming winter minima may be partially offset by reduced acclimation and hardness and the trend to grow less-hardy cultivars.

Acknowledgments

We would like to thank Katherine Benedict and Sophie Visser for their technical support. We would also like to acknowledge the assistance provided by information specialist André Gionet in tracking down some of the literature referenced in this manuscript. This work was supported by a Canadian Agricultural Partnership (CAP) project (ASC-12 Wine Grape Cluster Activity?), the Canadian Grapevine Certification Network (CGCN), the Grape Growers’ Association of Nova Scotia (GGANS) and the Nova Scotia Department of Agriculture (NSDA).

Supplemental Data

The following supplemental materials are available for this article at ajevonline.org:

Supplemental Table 1 A breakdown of the bud viability sites assessed shortly before and after the damaging freeze events that occurred in 2020 (15 Feb) and 2022 (22 Jan). Site numbers (n) are shown in brackets after vine type (hybrid versus Vitis vinifera) and cultivar. All “after” assessments include all “before” assessment sites plus additions.

Supplemental Table 2 Year two (subsequent year after damaging freeze and pruning) vine cluster number and fruit composition across vines previously pruned using 10-node cane (10-NC) (minimum pruning), three-node spur (3-NS), four-cane horizontal (4-CH), and head only (HO) (maximum pruning) pruning treatments for both Chardonnay and Vidal blanc. All vines were pruned using standard cane pruning (two canes retained). TSS, total soluble solids; TA, titratable acidity.

Supplemental Figure 1 A schematic of the Kentville Research and Development Centre vineyard showing the location of the Chardonnay and Vidal blanc pruning plots and treatment panels, the 9 m tower equipped with type T thermocouples, and the temperature sensors and anemometers located on the north and south ends of the vineyard. 10-NC, 10-node cane (multiple vertical canes); 3-NS, three-node spur; 4-CH, four-cane horizontal flat bow cane; HO, vine pruned back to the head only.

Supplemental Figure 2 A Chardonnay bud following the 15 Feb 2020 winter freeze (-25°C) event with a damaged, but still viable, secondary bud (left) and a nonviable primary bud (right).

Citation


References

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