Agro-Thermal Heat Treatment of Grapevines in the Okanagan Valley

PROJECT REPORT

Okanagan, British Columbia, 2022

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Funding for this project has been provided by the Governments of Canada and British Columbia through the Canadian Agricultural Partnership, a federal-provincial-territorial initiative. Additional funding has been provided by Quails Gate Winery and The University of British Columbia. The program is delivered by the Investment Agriculture Foundation of BC.

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The project team would like to thank Carl Bogdanoff of Agriculture and Agri-Food Canada, Summerland; Lynn Bremmer of Mount Kobau Wine Services, Oliver, BC; Judy Wanbon, Jordan Guthrie, Kailee Frasch and J.P. Fowler of Quails’ Gate; and Wesley Zandberg of UBC Okanagan. Thank you also to Naitong Chen, Shirley Cui, Shannon Edie and Dr. Lang Wu for help with the statistical analysis as part of the UBC Vancouver STAT500 class in 2020/21.
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Agro-Thermal Heat Treatment of Grapevines in the Okanagan Valley: Project Report
1. Executive summary

The effects of short bursts of hot air into the canopy of grapevines was evaluated in the semi-arid environment of the Okanagan Valley during the growing seasons of 2019 and 2020. Heat therapy is thought to be a sustainable management practice to decrease the use of pesticides by controlling grapevine pests, increase fruit set and yield and enhance wine quality. Heat was applied 3-6 times during each growing season into three vineyards (Merlot, est. 1998; Chardonnay, est. 2008; Chardonnay, est. 2014) using the Agrotherm XT™ machine from AgroThermal Systems® (Napa, CA).

The effects on grapevine phenology and performance, berry and wine quality and crown gall incidence were monitored. Few effects were observed; heat treatment decreased the average number of berries and decreased leaf greenness. Pruning weight, berry weight, soluble solids and fruitfulness increased and heat treatment affected 50% bloom. Heat treatment had no effect on crown gall incidence or the abundance of Allorhizobium vitis in the vineyard soil. Total wine phenolics and residual sugar increased in the heat-treated Merlot wine and sensory analysis observed differences in wine taste, although only one wine batch for each treatment was analyzed.

In conclusion, few positive or negative effects of heat therapy in vineyards were observed and investing in heat equipment may not be beneficial for Okanagan Valley grapevine growers.

2. Introduction

The British Columbia (BC) wine industry contributes over $2.8 Billion annually to the economy and the grape-growing region includes more than 10,260 acres under production, with 84% of the acreage located in the Okanagan Valley (Wine Growers of British Columbia). The region has a semi-arid climate with hot, dry summers and cool winters. Compared to the Napa Valley, the Okanagan Valley is warmer and more arid and receives nearly two hours more sunlight per day during the peak growing season.

Sustainable grape and wine production has become increasingly important for business owners, but also consumers and tourists visiting the region. One strategic pillar laid out in the Wine BC 2030 Long-Term Strategic Plan is to advance sustainability (Wine BC 2030: British Columbia Wine Industry Long-Term Strategic Plan).

Climate change may increase the risk of variable temperature and precipitation that impact critical grapevine phenological stages which determine fruit-set and final yield. As vineyards and other specialty horticultural crops are developed in cooler sites, higher elevations and
northern locations to mitigate the impacts of a warming climate, they are exposed to an increasing climatic risk for production.

Variable weather patterns also increase fungal disease pressure, specifically botrytis bunch-rot and powdery mildew, resulting in the need for increasing chemical fungicide applications at a time when resistance to agro-chemicals and to their modes of action is also increasing. In addition, the severity of bacterial diseases, such as crown gall of grapevines, is directly related to extreme winter freezing events. Alternative and sustainable practices and technologies are needed to address these issues.

An Agrotherm XT™ machine (AgroThermal Systems®, Napa, CA) uses heat as a sustainable strategy for vineyard management. The Agrotherm XT™ machine is a gas-operated, hydraulic fan heater system that can be used to treat trellised row-type crops including cane berries, currents, apples, peaches, plums, nectarines, olives, herbs, tomatoes and grapes (Figure 1). Heat is applied at different crop growth stages throughout the growing season. The machine is towed by a tractor, weighs 3,086 lbs with a full gas cylinder and can be used in crop rows that are at least 6 feet apart from each other. The maximum permitted speed is 15 mph and operating speed is 3 mph (AgroThermal Systems®). Fans are located on both sides of the machine to simultaneously apply heat to the canopy of two rows and are adjustable to target different canopy heights.

Agro-Thermal heat treatment in vineyards is thought to decrease the use of pesticides by controlling pests, increase fruit set and yield and enhance wine quality (AgroThermal Systems®). A study conducted by Tome’ M. Martin-Duvall (Caltec Ag Inc, Modesto, CA) showed that three heat applications controlled powdery mildew (Erysiphe necator) significantly better than the chemical control (Mettle® 125 ME fungicide, IsagroS.p.A., Milan, Italy). Case studies conducted by AgroThermal Systems® in 2018 showed that grapevine cluster weights, the number of berries per cluster and berry and rachis weight was increased with heat treatment in red and white cultivars. AgroThermal Systems® customers report increased wine quality and additionally, heat can be used to dry crop off after a rain event to prevent the development of fungal diseases.

To our knowledge there are few peer-reviewed studies of Agro-Thermal heat treatment in vineyards available. Gohil and Moyer (2014) found that heat treatment did not affect vine phenology, fruit set or berry quality in Merlot and Syrah vineyards in eastern Washington State (Gohil et al., 2014). Treptow et al. 2017 found that heat treatment increased anthocyanins in one, but not another year in Tannat grapes in Brazil. Some berry phenolic compounds were increased by heat in a Pinot Noir vineyard in Oregon; however, the study did not include biological replicates in the first two years (Manduri et al., 2017).
3. Objectives

The objective of the study was to explore sustainable solutions to three significant issues currently facing the wine industry. Extreme and variable seasonal climate patterns of temperature and precipitation impact critical grapevine phenological stages that determine fruit-set and yield, increase fungal disease pressure, such as botrytis bunch rot, and extreme winter freezing events increase the severity of bacterial diseases, such as crown gall disease of grapevines.

The specific objectives were to assess Agro-Thermal heat treatment in three different vineyards over two growing seasons in a semi-arid environment in the Okanagan Valley in British Columbia to evaluate the impact on:

- Grapevine performance, phenology and berry quality
- Botrytis bunch rot of wine grapes
- Crown gall of grapevines, caused by *Allorhizobium vitis*
4. Materials and Methods

4.1 Vineyards and experimental design

All vineyards belong to a commercial winery (Quails’ Gate Winery) located in the Okanagan Valley in Kelowna, British Columbia, Canada. The Merlot and Chardonnay 1 vineyards are located in West Kelowna and the Chardonnay 2 vineyard is located in East Kelowna. Vineyard characteristics are listed in Table 1.

The vertical shoot positioned (VPS) trained vines were drip-irrigated, leaves in the fruit zone were removed and all other vineyard management used standard practices conducted by the winery.

The Merlot vineyard was divided into six blocks consisting of four rows each. Treatments (heat application or no-heat = control) were assigned randomly to two rows in each block with the treated vine rows adjacent to each other. Five treatment vines were chosen randomly in one treated and one control row for a total of 60 treatment vines.

Chardonnay 1 vineyard was laid out similarly, with the difference that five blocks were assigned and four treatment vines per row chosen for a total of 40 vines. In addition, each block consisted of three treatments:

- Control (no heat + conventional botryticide),
- Heat (heat + conventional botryticide), and
- No-botryticide (heat + no botryticide).

Botryticides control the development of botrytis bunch rot. The third treatment was included to determine if heat can reduce botrytis development.

Chardonnay 2 vineyard was heavily infected with grapevine crown gall and was laid out in a randomized block design with six blocks (rows). Each row consisted of five 5-vine plots with three treatment vines in the middle and two guard vines on either end of each plot. Treatments were heat application and control, and three different composts that were part of another experiment and are not considered here.

All three treatment vines from each plot were used to collect data for a total of 36 vines sampled. Data were collected from the same flagged treatment vines across both years in all vineyards.
Table 1: Vineyard information

<table>
<thead>
<tr>
<th>Location</th>
<th>Year established</th>
<th>Cultivar</th>
<th>Rootstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merlot</td>
<td>49.84°N, 119.57°W</td>
<td>1998</td>
<td>Merlot 347</td>
</tr>
<tr>
<td>Chard 1</td>
<td>49.84°N, 119.57°W</td>
<td>2008</td>
<td>Chardonnay 95</td>
</tr>
<tr>
<td>Chard 2</td>
<td>49.82°N, 119.47°W</td>
<td>2014</td>
<td>Chardonnay 99</td>
</tr>
</tbody>
</table>

4.2 Weather data

ADCON weather stations were located within the Merlot and Chard 2 vineyards. Data were processed using the ADCON advantage Pro 6.6 program. Data were collected from April 2019-June 2021 in Chard 2 and from April 2019-December 2020 in the Merlot vineyard. Growing degree day (GDD) accumulation was calculated from April 1st – October 31st for 2019 and 2020 using 10°C (50°F) as base temperature.

Maximum and minimum temperatures were similar between the vineyards (Figure 2). Cumulative growing degree days in October 2019 and 2020 were 1511 and 1467 GDD (Merlot), and 1301 and 1276 (Chard 2).

Figure 2: Daily maximum and minimum temperatures in °C in the Merlot vineyard.
4.3. Agro-Thermal heat application

Heat was applied according to guidelines of the manufacturer using the Agrotherm XT™ machine from AgroThermal Systems® (Napa, CA, Figure 2). The recommendation was to start applications pre-flowering, and then every 7-10 days through until verasion. The tractor pulled the machine at a speed of 3mph and 300 °F hot air was emitted directly into the canopy. The fan on one side was turned upwards to prevent heat treatment of non-target areas of the vineyard. Heat was applied throughout the whole row. Application dates in the growing seasons of 2019 and 2020 are listed in Table 2.
<table>
<thead>
<tr>
<th></th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May</td>
<td>Jun</td>
</tr>
<tr>
<td>Merlot</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>Chard 1</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>Chard 2</td>
<td>6</td>
<td>18</td>
</tr>
</tbody>
</table>

### 4.4 Grapevine performance measurements

- **50% bud break**: The date where half of the buds of each vine showed separation of the first leaf from the bud was determined by visual rating at least four times over a two-week period. Total number of buds and number of open buds per vine were recorded and used to calculate 50% bud break by regression analysis.
- **Shoot and cluster counts**: Shoots and clusters on each vine were counted when shoots were about 15 cm long.
- **Bud fruitfulness**: Bud fruitfulness was expressed as the number of clusters per shoot.
- **50% bloom**: The date where half of the flowers have lost their caps was determined by visual rating at least three times in a two-week period and 50% bloom calculate by regression analysis.
- **50% veraison (Merlot only)**: The date where half of the grapes per vine underwent a color change from green to red (50% veraison) was assessed similarly to 50% bloom.
- **Leaf greenness**: Leaf greenness was measured using a Soil Plant Analysis Development (SPAD) chlorophyll meter (Spectrum Technologies, Plainfield, IL, USA). Ten fully expanded and exposed leaves per vine were measured 2 cm from the leaf edge and the values averaged.
- **Crown gall**: Severity was rated visually and the trunk area in % that was covered with fresh galls (galls that developed during the current season) recorded.
- **Ravaz index**: Crop load was determined by dividing yield by pruning weight.
- **Pruning weight**: Pruning weight was collected in the winter for each treatment vine.
Heat application in 2019 started after bloom had occurred, and leaf greenness was the first measurement in that year. Therefore, other spring data (50% bud break and bloom, fruitfulness) were assessed again in 2021 in order to obtain two years data from each variable and because the number of clusters in 2021 buds was determined during the 2020 growing season, when heat treatment was applied.

Because of extensive winter freeze injuries in the experimental plot, 50% bud break and bloom, and fruitfulness could not be assessed in 2021 in the Merlot. Specific dates for all data collections are provided in Table 3.
Table 3: Data collection dates for all three vineyards

<table>
<thead>
<tr>
<th></th>
<th>Merlot</th>
<th></th>
<th></th>
<th>Chard 1</th>
<th></th>
<th></th>
<th>Chard 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>50% bud break</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>na</td>
<td>na</td>
<td>-</td>
<td>May 6,</td>
<td>10, 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8, 10, 12</td>
<td>4, 7, 11, 18</td>
</tr>
<tr>
<td>Shoot and cluster counts</td>
<td>-</td>
<td>May 20</td>
<td>-</td>
<td>na</td>
<td>na</td>
<td>-</td>
<td>May 28</td>
<td></td>
</tr>
<tr>
<td>50% bloom</td>
<td>-</td>
<td>Jun 25, 29; Jul 1</td>
<td>-</td>
<td>na</td>
<td>na</td>
<td>-</td>
<td>Jun 22, 24, 26, 29</td>
<td>Jun 17, 19, 21</td>
</tr>
<tr>
<td>Leaf greenness</td>
<td>Jul 26</td>
<td>Aug 6</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>July 26</td>
<td>Aug 6</td>
<td>na</td>
</tr>
<tr>
<td>50% veraison</td>
<td>Aug 23, 27</td>
<td>Aug 31, Sept 2, 5</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>A. vitis rating</td>
<td>-</td>
<td>-</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>Jul 26</td>
<td>Aug 6</td>
<td>na</td>
</tr>
<tr>
<td>Soil sampling</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>Oct 28</td>
<td>Oct 20</td>
<td>n.a</td>
</tr>
<tr>
<td>Harvest</td>
<td>Oct 18</td>
<td>Oct 17</td>
<td>na</td>
<td>Sep 24</td>
<td>Sep 30</td>
<td>Sep 30</td>
<td>Oct 6</td>
<td>na</td>
</tr>
<tr>
<td>Pruning weight</td>
<td>na</td>
<td>Mar 12</td>
<td>Mar 8</td>
<td>na</td>
<td>na</td>
<td>Dec 17</td>
<td>na</td>
<td>Jan 5</td>
</tr>
</tbody>
</table>

Note: Only yield data was assessed in Chard 1, as this site was used to study the effects of heat treatment on Botrytis disease development.

4.5 Yield and berry analysis

At harvest, all true clusters were counted for each vine and weighed using a field scale (Ranger 4000, Ohaus, Parsippany, NJ, USA) to determine total yield (kg) and to calculate average cluster weight (kg). Thirty berries were randomly collected from each vine (2-3 berries from each cluster), weighed and average berry weight (g) and the average number of berries per cluster calculated.

Berries were submitted for berry analysis to the Summerland Research and Development Center (Carl Bogdanoff, Summerland, BC) in 2019 and to Mount Kobau Wine Services (Oliver, BC) in 2020.
In 2020, 100 berries instead of 30 berries were submitted for analysis. Berries were crushed with a mortar and pestle at 18-22°C and the released juice passed through cheesecloth. An ATAGO pocket refractometer PAL-1 (Atago, Saitama, Japan) with automatic temperature compensation and zeroed with distilled water was used to determine % total soluble solids (Brix). Titratable acidity (TA, g/L) of berry juice was determined by titrating 5 ml of grape juice with 0.1 N NaOH to a pH endpoint of 8.2. pH was measured on settled grape juice without dilution, refrigeration or freezing, using an Orion STAR A111 pH meter with automatic temperature compensation (Thermo Scientific, Waltham, MA, USA).

Figure 6: Collecting yield in the Merlot vineyard

4.6 Soil sampling and A. vitis quantification

Soil from Chardonnay 2 vineyard (infected with grapevine crown gall) was sampled from underneath the dripline 20 cm away from the trunk using a 30 cm soil probe. One soil core from the right and left side of the trunk were combined. DNA was isolated from 0.25 g soil using the
MoBio Powersoil® DNA extraction kit, according to the manufacturer’s instructions (MoBio, Carlsbad, CA, USA). DNA was eluted in 100 μl elution buffer provided with the kit.

Concentrations and absorbance ratios were determined by Nanodrop spectrophotometry (Thermo Scientific, Wilmington, DE, USA). Aliquots of nucleic acids were stored at -20°C until use. Two μl were used as template for droplet digital PCR (ddPCR), a molecular methodology to quantify genes. DdPCR was performed as outlined in Voegel et al., 2018.

4.7 Wine analysis

Two wines were made from the Merlot vineyard in 2020; one from all of the heat-treated grapevines, and one from all the control vines, according to standard procedure of Quails’ Gate Winery. Phenolic compounds (total phenolics, tartaric esters, flavonols, anthocyanins, mg/ml) were analyzed by Wes Zandberg (UBC Okanagan) using UV absorbance at differing wavelengths for each class of compound according to the lab’s standard procedures.

Wines were analyzed by Quails’ Gate for pH, TA (g/L) by Hannah HI84502-50 Mini Titrator, alcohol (%) by DE-EVO automatic distillator then density metre, and residual sugar (g/L) by enzymatic assay using Megazyme kits. Wine sensory analysis was conducted at Quails’ Gate according to the usual practices of the winery.

4.8 Statistical analysis

Censored data for 50% bud break, bloom and veraison were visualized using Kaplan-Meier survival plots and a Cox Proportional Hazards (Cox PH) model was used to investigate treatments effects. Covariates in the model included treatment, block and the interactions of the factors. All other data were visualized by side-by-side boxplots and each response variable analyzed separately using two-way ANOVA. Covariates in the model included treatment, block and the interactions of the factors.

Levene test was used to test for equal variance across all treatment/block combinations and QQ plots were used to test for normality. If data were violating the assumptions of two-way ANOVA, a non-parametric Aligned Rank Transform (ART) ANOVA model was used. All statistical analyses were conducted in R statistical software version 3.6.1 (R Foundation for Statistical Computing, Vienna, Austria).

4.9 Study limitations

Whenever field-based research is conducted in commercial settings, unfortunately there are challenges of the real world which can interact with the trials. This project has been no
different, particularly concerning labour shortage in the agricultural sector due to the restrictions faced by the COVID-19 pandemic during the 2020 growing season. This meant some canopy management tasks were not completed in a timely fashion to allow tractor passes through blocks at various times, causing delays in timing of applications.

Also, due to the nature of the growing season, some tasks were prioritized over heat treatment applications by tractors and operators to ensure we maintained the vineyards to the highest quality standards. Mechanical breakdowns, either from the tractor or the machine, also contributed to some delays in timing of applications.

In addition, the application of heat during only two seasons and in only two different cultivars may have limited this study and heat may have been lost when emitted until it reached the grapevine canopy.

5. Results and Discussion

5.1 Treatment effects in Merlot

During 2019, the average number of berries slightly decreased by 14 from 109 to 95 berries per cluster with heat treatment ($p = 0.05$) and there was a small interactive effect between location of the block and treatment ($p = 0.06$), indicating that the location of the blocks affected the results (Table 4). Berry pH in the same year slightly increased under heat from pH 3.3 to pH 3.34 ($p = 0.03$) and there was a strong block:treatment interaction ($p < 0.001$). Although statistically significant, the pH difference is likely not important from a winemaking point of view.

During 2020, heat treatment decreased leaf greenness from 38.9 to 37.6 ($p = 0.05$). Leaf greenness is an indirect measure of leaf chlorophyll and tends to be lower in stressed plants, indicating that heat treatment may have a negative effect on plant health. Pruning weight increased from 0.18 to 0.27 kg ($p = 0.03$) indicating increased vigor in plants where heat was applied. However, crop load (yield/pruning weight) was not different between treatments. Increased vigor can have negative effects on grapevine health, as new leaves are more susceptible to develop powdery mildew disease.

In addition, increased vigor late in the season can prevent the grapevines from effective hardening-off and increase chances of freeze injuries during winter. However, because this vineyard experienced winter damage in the previous year, an increase in pruning weight due to heat treatment can be considered beneficial.
Table 4: Effects of heat treatment on grapevine phenology and berry quality in a Merlot vineyard

<table>
<thead>
<tr>
<th></th>
<th>2019</th>
<th>2020</th>
<th>Effect</th>
<th>2019</th>
<th>2020</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heat</td>
<td>Control</td>
<td></td>
<td>Heat</td>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>Fruitfulness&lt;sup&gt;a&lt;/sup&gt;</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>0.62 ± 0.11</td>
<td>0.42 ± 0.09</td>
<td>ns</td>
</tr>
<tr>
<td>50% bloom&lt;sup&gt;b&lt;/sup&gt;</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>27.8 ± 0.3</td>
<td>27.5 ± 0.3</td>
<td>ns</td>
</tr>
<tr>
<td>Leaf greenness</td>
<td>39.7 ± 0.4</td>
<td>40.3 ± 0.5</td>
<td>ns</td>
<td>37.6 ± 0.5</td>
<td>38.9 ± 0.6</td>
<td>*</td>
</tr>
<tr>
<td>50% veraison&lt;sup&gt;c&lt;/sup&gt;</td>
<td>18.1 ± 1.3</td>
<td>21.5 ± 0.9</td>
<td>ns</td>
<td>29.7 ± 0.8</td>
<td>28.0 ± 1</td>
<td>ns</td>
</tr>
<tr>
<td># of clusters</td>
<td>17.8 ± 1</td>
<td>19.3 ± 1</td>
<td>ns</td>
<td>6.6 ± 0.9</td>
<td>5.9 ± 1.1</td>
<td>ns</td>
</tr>
<tr>
<td>Yield (kg)</td>
<td>2.4 ± 0.2</td>
<td>2.9 ± 0.2</td>
<td>ns</td>
<td>0.93 ± 0.11</td>
<td>0.99 ± 0.25</td>
<td>ns</td>
</tr>
<tr>
<td>Cluster weight (kg)</td>
<td>0.13 ± 0.01</td>
<td>0.15 ± 0.01</td>
<td>ns</td>
<td>0.12 ± 0.01</td>
<td>0.11 ± 0.01</td>
<td>ns</td>
</tr>
<tr>
<td>Berry weight (g)</td>
<td>1.40 ± 0.03</td>
<td>1.35 ± 0.03</td>
<td>ns</td>
<td>1.23 ± 0.04</td>
<td>1.18 ± 0.05</td>
<td>ns</td>
</tr>
<tr>
<td># of berries/cluster</td>
<td>94.8 ± 6</td>
<td>108.5 ± 6</td>
<td>*</td>
<td>101.6 ± 7.1</td>
<td>91.2 ± 7.7</td>
<td>ns</td>
</tr>
<tr>
<td>Berry soluble solids (°Brix)</td>
<td>24.6 ± 0.1</td>
<td>24.3 ± 0.2</td>
<td>ns</td>
<td>25.0 ± 0.3</td>
<td>25.5 ± 0.2</td>
<td>ns</td>
</tr>
<tr>
<td>Berry tritratable acidity (TA, g/L)</td>
<td>7.1 ± 0.2</td>
<td>7.3 ± 0.24</td>
<td>ns</td>
<td>8.2 ± 0.2</td>
<td>8.2 ± 0.3</td>
<td>ns</td>
</tr>
<tr>
<td>Berry pH</td>
<td>3.34 ± 0.02</td>
<td>3.30 ± 0.01</td>
<td>*</td>
<td>3.22 ± 0.02</td>
<td>3.23 ± 0.02</td>
<td>ns</td>
</tr>
<tr>
<td>Pruning weight (kg)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.26 ± 0.02</td>
<td>0.27 ± 0.04</td>
<td>ns</td>
<td>0.27 ± 0.04</td>
<td>0.18 ± 0.03</td>
<td>*</td>
</tr>
<tr>
<td>Ravaz index&lt;sup&gt;e&lt;/sup&gt;</td>
<td>11.1 ± 1.2</td>
<td>13.6 ± 1.3</td>
<td>ns</td>
<td>3.8 ± 0.7</td>
<td>3.9 ± 0.7</td>
<td>ns</td>
</tr>
</tbody>
</table>

<sup>a</sup>fruitfulness = clusters/shoots  
<sup>b</sup>number represents date in June  
<sup>c</sup>number represents date in August  
<sup>d</sup>pruning weight was assessed in early spring the year after  
<sup>e</sup>Ravaz index = yield/pruning weight  
<sup>f</sup>Values are means (n=30) followed by the standard error  
<sup>g</sup>* indicates significant effect at p = 0.05  
ns: not significant  
na: data not available

5.2 Treatment effects in Chard 1

Only yield data was assessed in this vineyard, as this experimental site was primarily used to study the effects of heat treatment on Botrytis disease development. However, no natural
botrytis infection occurred in any study year, and we were not able to collect botrytis infection data. There were no effects of heat treatment in either year on any of the other data assessed (Table 5).

**Table 5: Effects of heat treatment on grapevine harvest in a Chardonnay 2008 vineyard**

<table>
<thead>
<tr>
<th></th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heat</td>
<td>Control</td>
</tr>
<tr>
<td># of clusters</td>
<td>30 ± 1.9</td>
<td>32 ± 1.3</td>
</tr>
<tr>
<td>Yield (kg)</td>
<td>5.9 ± 0.5</td>
<td>6.2 ± 0.3</td>
</tr>
<tr>
<td>Cluster weight (kg)</td>
<td>0.20 ± 0.01</td>
<td>0.19 ± 0.01</td>
</tr>
</tbody>
</table>

*Values are means (n=20) followed by the standard error
ns: not significant

### 5.3 Treatment effects in Chard 2

In 2019, and similar to the Merlot data in 2020, heat decreased leaf greenness from 38 to 36.4 ($p = 0.007$) and increased pruning weight from 0.31 to 0.38 kg/vine ($p = 0.007$, Table 6). In 2020, leaf greenness was also lower in heat treated vines (from 34.2 to 33.1; $p = 0.008$). Heat treatment delayed 50% bloom by one day from June 24 to June 25 ($p = 0.001$), however, this change is not significant from a viticultural perspective. Heat increased berry weight from 1.2 to 1.4 g ($p = 0.002$) and soluble solids content from 18 to 18.6°Brix ($p = 0.04$).

In 2021, heat increased fruitfulness from 1.1 to 1.4 ($p = 0.006$) and 50% bloom was two days earlier in heat treated vines (June 15 compared to June 17). This is opposite from the effects in 2020, where heat delayed bloom by one day, however, this effect was dependent on the location of the experimental blocks within the vineyard ($p = 0.003$). A one-day increase or decrease of 50% bloom will not affect overall vineyard health or berry quality.
### Table 6: Effects of heat treatment on grapevine phenology and berry quality in a Chardonnay 2014 vineyard

<table>
<thead>
<tr>
<th></th>
<th>2019&lt;sup&gt;a&lt;/sup&gt;</th>
<th>2020&lt;sup&gt;b&lt;/sup&gt;</th>
<th>2021&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heat</td>
<td>Control</td>
<td>Effect&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
<tr>
<td>50% bud break&lt;sup&gt;a&lt;/sup&gt;</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Fruitfulness&lt;sup&gt;b&lt;/sup&gt;</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>50% bloom&lt;sup&gt;c&lt;/sup&gt;</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Leaf greenness</td>
<td>36.4 ± 0.4</td>
<td>38.0 ± 0.4</td>
<td>**</td>
</tr>
<tr>
<td># of clusters</td>
<td>21.1 ± 1.4</td>
<td>19.7 ± 1.6</td>
<td>ns</td>
</tr>
<tr>
<td>Yield (kg)</td>
<td>2.5 ± 0.2</td>
<td>2.1 ± 0.2</td>
<td>ns</td>
</tr>
<tr>
<td>Cluster wgt (kg)</td>
<td>0.12 ± 0.01</td>
<td>0.12 ± 0.01</td>
<td>ns</td>
</tr>
<tr>
<td>Berry weight (g)</td>
<td>1.3 ± 0.0</td>
<td>1.3 ± 0.1</td>
<td>ns</td>
</tr>
<tr>
<td># of berries/cluster</td>
<td>87.5 ± 4.9</td>
<td>90.9 ± 6.2</td>
<td>ns</td>
</tr>
<tr>
<td>Berry soluble solids (*Brix)</td>
<td>22.2 ± 0.1</td>
<td>22.0 ± 0.1</td>
<td>ns</td>
</tr>
<tr>
<td>Berry titratable acidity (TA, g/L)</td>
<td>7.9 ± 0.1</td>
<td>7.9 ± 0.2</td>
<td>ns</td>
</tr>
<tr>
<td>Berry pH</td>
<td>3.1 ± 0.0</td>
<td>3.2 ± 0.0</td>
<td>ns</td>
</tr>
<tr>
<td>Pruning weight (kg)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.38 ± 0.02</td>
<td>0.31 ± 0.03</td>
<td>*</td>
</tr>
<tr>
<td>Ravaz index&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.6 ± 0.6</td>
<td>8.5 ± 1.6</td>
<td>ns</td>
</tr>
</tbody>
</table>

<sup>a</sup>Number represents date in May  
<sup>b</sup>Fruitfulness = clusters/shoots  
<sup>c</sup>Number represents date in June  
<sup>d</sup>Pruning weight was assessed in early spring the year after  
<sup>e</sup>Ravaz index = yield/pruning weight  
<sup>f</sup>Values are means (n=17) followed by the standard error  
<sup>g</sup>*, **, and *** indicate significant effect at p = 0.05, p = 0.01, and p = 0.001 respectively  
<sup>h</sup>Values are means (n=16 for control, n=17 for heat) followed by standard error  
<sup>i</sup>Values are means (n=18 for control, n=17 for heat) followed by standard error  
<sup>ns</sup>: not significant  
<sup>na</sup>: data not available

Agro-Thermal Heat Treatment of Grapevines in the Okanagan Valley: Project Report 16
No visible damage to any parts of the grapevines was observed after heat application in either vineyard. Overall, there were few effects of heat treatment on grapes. Most effects only occurred during one, but not both study years, except for leaf greenness. However, a decrease in leaf greenness and increase in pruning weight with heat were observed in both vineyards Merlot and Chardonnay 2014. From a viticultural perspective, increases in pruning weight, berry weight and Brix may have positive implications for the winery.

5.4 Wine analysis

Merlot wine analysis suggested the heat-treated wine had higher total phenolics residual sugar compared to the control wine (Table 7).

Table 7: Analysis of heat-treated and control wines

<table>
<thead>
<tr>
<th></th>
<th>Total phenolics (mg/ml)</th>
<th>Tartaric esters (mg/ml)</th>
<th>Flavonols (mg/ml)</th>
<th>Anthocyanins (mg/ml)</th>
<th>pH</th>
<th>TA (g/L)</th>
<th>Alcohol (%)</th>
<th>Residual sugar (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat(^1)</td>
<td>0.36 ± 0.01</td>
<td>0.42 ± 0.01</td>
<td>0.22 ± 0.001</td>
<td>0.44 ± 0.004</td>
<td>3.63</td>
<td>5.67 ± 0.09</td>
<td>14.7</td>
<td>0.41 ± 0.01</td>
</tr>
<tr>
<td>Control</td>
<td>0.34 ± 0.01</td>
<td>0.4 ± 0.005</td>
<td>0.22 ± 0.003</td>
<td>0.45 ± 0.01</td>
<td>3.65</td>
<td>5.7 ± 0.12</td>
<td>14.7 ± 0.06</td>
<td>0.38 ± 0.004</td>
</tr>
</tbody>
</table>

\(^1\text{numbers are average (n=3) followed by the standard error}

Wine sensory analysis at Quails’ Gate Winery found differences in the heat-treated vs control wines:

- **Heat-treated Merlot:**
  - Blueberry, blackberry, spice, plum, vanilla, black pepper, medium minus intensity, medium mouthfeel, round dry mid, astringent finish

- **Control Merlot:**
  - Bell pepper, green leaf, blue fruit, leather, dusty, less fruit, white pepper, medium mouthfeel, chalky tannins, astringent finish

Although there seem to be differences between both wines, care needs to be taken with the interpretation of the data, as there were no biological replications to perform a statistical analysis (only one batch of wine from each treatment was made). Differences are likely due to variations in the wine making process and not necessarily because of the heat treatment.
5.5 Effect of heat on grapevine pathogens

There was no effect of heat treatment on either crown gall incidence or *Allorhizobium vitis* soil abundance in the Chardonnay 2014 vineyard. This indicates that heat treatment is not effective to prevent crown gall disease of grapevines, likely because the short bursts of heat may not be enough to reach the location of the bacteria within the xylem and do not result in an induction of systemic response of the grapevine.

Because no natural botrytis infection occurred in the Chardonnay 2008 vineyard in either year, and no botrytis bunch rot developed in either treatment, the effects of heat treatment on botrytis bunch rot could not be assessed.

5.6 Cost benefit analysis

Below is a calculation of the overall return per acre per season for the 2019 season Chardonnay 2 trial block which showed a 16% increase in yield. While yield increase was not consistent between sites and seasons, for the 2019 growing season a significant increase in revenue was achieved.

Purchase price: $65,700
- Total acres treated: 32 (across all sites)
- Running cost per season (incl. labor): $8,500
- Cost/acre/season: $265
  - Over 5 applications = $53/application

2019 Chardonnay yield
- Control: 2.1 T/a
- Heat treatment: 2.5 T/a
  - = 16% increase

Chardonnay price per ton $2,250
- Control at 2.1 T/a would return $4,725 per acre
- Heat treatment at 2.5 T/a would return $5,625 per acre
  - = increase of $900

Total per acre revenue increase ($900) – Total cost/acre/season ($265) = Total per acre return of $635
5.7 Recommended next steps

Shortening of the interval between heat applications and increase of total applications could be explored to adapt to the short growing season in the Okanagan valley. The trial can also be extended to include other grapevine cultivars of varying age.

While not part of this study, heat treatment was applied to an organic vineyard that Quails’ Gate inherited with a substantial degree of residue powdery mildew, Ucinula necator. An alternating spray schedule of sulphur and heat treatment, every 7-10 days throughout the growing season not only managed to arrest the residue powdery mildew issue, but produced very clean fruit and canopy. The use of heat treatment in conjunction with a reduced fungicide program to control powdery mildew, whether conventional or organic, has potential and could be further explored.

6. Conclusions

Because effects of heat treatment were not consistent in each year and vineyard, and because the effects on grapevine phenology, wine quality and crown gall incidence were small, heat treatment may not be applicable for wineries in the Okanagan Valley to improve plant growth or health.

However, an increase in pruning weight from a vineyard with winter damage, increased berry weight and Brix are positive effects. This study was not able to evaluate heat treatment effects on botrytis bunch rot or insect diseases, but possibilities to control grapevine pathogens using heat therapy exist.

Our study confirms the results observed by Moyer and Gohil 2014, which found that heat treatment did not affect vine phenology, fruit set or berry quality in Merlot and Syrah vineyards in eastern Washington State (Gohil et al., 2014).
References


Wine BC 2030: British Columbia Wine Industry Long-Term Strategic Plan, Artemis Group, O’Donnell Lane, LLC, 2019