Washington State Grape and Wine Research Program

FINAL REPORT

1. Summary

Project Title: Grape ripening under a double whammy of heat stress and water deficit

Principal Investigator: Markus Keller

The main objective of this project is to study how plant water status and fruit temperature affect grape berry acidity, pH, and potassium (K^+). We selected two white wine grape varieties in consultation with industry members. Their different juice/wine acidity profiles made Riesling and Chardonnay interesting varieties to study the relationship between acidity, K^+, and pH in Washington. During 2019-2021, field experiments were carried out in the WSU research vineyard at the Irrigated Agriculture Research and Extension Center in Prosser. We tested two irrigation regimes and three light exposure treatments. Moderate water deficit was applied from late July through harvest and compared with a no-stress control. Sun-exposed clusters were generated at the pea-size stage by removing all leaves in the fruiting zone on the east side of the canopy. A portion of these clusters was changed to shaded clusters at veraison by repositioning shoots to create an extra leaf curtain on the east side of the canopy. For control clusters the canopy was left untreated. We installed temperature sensors in the fruiting zone to monitor simulated cluster temperatures. Sun-exposed clusters remained at higher temperatures longer than control clusters in both Riesling and Chardonnay and irrespective of the irrigation regime. Cluster shading after veraison alleviated the high-temperature stress on the clusters only in the vines that were fully irrigated. The changes in fruit zone temperature did not correlate well with any changes in fruit composition. Berries of fully irrigated vines retained higher malate and titratable acidity than those of water-stressed vines. Irrigation treatments did not negatively impact other quality parameters such as total soluble solids, pH, or potassium concentrations. Consequently, irrigation may be more important than canopy management to manipulate acidity in ripening grape berries.

2. **Final Report**

3. **Project Title**: **Grape ripening under a double whammy of heat stress and water deficit – 3 year project 2019-2022**

4. **Principal Investigator/Cooperator(s)**:

PI: Markus Keller, Washington State University, Irrigated Agriculture Research and Extension Center, 24106 N. Bunn Rd., Prosser, WA 99350, (509) 786 9263, mkeller@wsu.edu
Co-PI: Esther Hernández-Montes, WSU-IAREC, Prosser, WA 99350 (*resigned on April 7, 2020*)
Co-PI: James Harbertson, WSU Wine Science Center, Richland WA 99352

5. **Objective(s) and Experiments Conducted to Meet Stated Objective(s)**:
Note: The research for this project was initially conducted by a postdoctoral research associate (Co-PI Esther Hernández-Montes) who resigned in April 2020. Another postdoc (Ben-Min Chang) then maintained the field trial until an MS student (Evan Fritzke) took over in August 2020.

Objective 1: Measure changes in fruit ripening in grapevines exposed to heat and/or water stress.
From 2019 through 2021, a field experiment was carried out using Riesling and Chardonnay wine grapes in the research vineyard at WSU-IAREC. These two varieties were identified by industry stakeholders as the most appropriate to study grape ripening under heat stress and water deficit in Washington. The vineyard has 9' by 6' spacing, north-south row orientation, spur pruning, loose vertical shoot positioning between two pairs of catch wires (spaced 12" apart) 12" and 32" above the cordon wire at 35", and is drip-irrigated. Two irrigation treatments (no water stress and water stress) were applied. Moderate water stress was applied from late July through harvest and compared with a no-stress control. Irrigation scheduling was based on replacing 100% (no stress, using 4-L/h drip emitters) or 50% (moderate stress, using 2-L/h drip emitters) of crop evapotranspiration, using weather data from the AgWeatherNet station near the vineyard. Three light exposure treatments were randomly applied within each irrigation plot, using a split-plot design. Sun-exposed clusters were generated at the pea-size stage by removing all leaves in the fruiting zone (shoot base up to the upper cluster) on the east side of the canopy. A portion of these clusters was changed to shaded clusters at veraison by loosening the upper foliage wire on the east side of the canopy to create an extra leaf curtain. For control clusters the canopy was left untreated. Soil moisture was measured weekly under 3 vines per treatment, using a neutron probe. Midday leaf water potential (Ψ_l) was measured the same day using a pressure chamber. HOBO Pendant® temperature/light data loggers were installed at the cluster level facing east to quantify simulated cluster temperatures and light. Additionally, thermal images were taken using a FLIR ONE®PRO infrared camera connected to an Android cell phone to correlate simulated cluster temperatures against actual, measured cluster temperatures. Berries were sampled repeatedly and equally from both the east side and the west side of the canopy and then pooled and frozen at -80°C for later analysis of titratable acidity (TA), organic acids (malate, tartrate), potassium (K^+), and pH at the WSU Wine Science Center.

Objective 2: Study the relationship between berry respiration, titratable acidity, and organic acids.

Two pot experiments were conducted with Riesling vines in the summer of 2021 to separate the interaction of heat and light and their effects on acidity, and to study the influence of soil K. In experiment 1, vines were subjected to two simulated heatwaves in environmentally controlled growth chambers. Two chambers were used, one to simulate a heatwave and another as a control. Half of the clusters were covered to prevent any light from reaching the berries. The test was conducted before and after veraison and berry samples were taken before and after each of the heatwaves. The chamber simulating the preveraison heatwave (August 5-11) was programmed to a diurnal range of 99/72°F (day/night), and the control chamber was programmed to 86/59°F. The postveraison (September 14-20) heatwave and control chambers were set at 90/68°F and 81/50°F, respectively. Weather data from AgWeatherNet was used to determine reasonable ranges for each of the chambers. Respiration was estimated with a Unisense OX-25 oxygen microsensor inserted into berries on the final days of the second heatwave. The microsensor was calibrated with an aerated water sample and anoxic ascorbate solution in each chamber before testing the berries. Readings at each depth were taken once the signal stabilized. Berry samples were collected before and after each experiment. In experiment 2, vines were potted in Warden coarse-silt soil (with 116 ppm K) without cultivation history, and well-irrigated. Potassium was applied at KCl at three rates (0 g, 0.08 g, 0.8 g of K per pot) to 10 vines each at pea-size and onset of berry softening. Berries were sampled at harvest (20 Brix) for fruit analysis.

Objective 3: Study the influence of organic acids versus potassium on juice pH and buffering capacity.

All berry samples from the field trial were analyzed at the WSU Wine Science Center. Measurements included berry weight, total soluble solids (TSS), titratable acidity (TA), organic acids (malate, tartrate), potassium (K^+), and pH. Correlation analysis was used to determine the influence of each of these parameters on juice pH.

Objective 4: Develop practical recommendations to mitigate heat stress effects.

Recommendations for vineyard management were developed.

6. **Summary of Major Research Accomplishments and Results by Objective:**

Objective 1: Measure changes in fruit ripening in grapevines exposed to heat and/or water stress.

The 2021 growing season was warmer (3049 GDD > 50°F) than the 2020 season (2761 GDD), though both seasons were above the long-term average (2695 GDD). Consequently, vines reached the same phenological stage sooner in 2021 than in 2020. Unlike in 2020, Riesling in 2021 began the season with much higher soil moisture than Chardonnay. In 2020, soil moisture did not begin to reflect the irrigation regimes until the lag phase of berry development, whereas differences were established at bloom in 2021 and maintained for the remainder of the season. Nevertheless, Ψ_l separated by irrigation treatment both preveraison and postveraison in both years; water-stressed vines of both varieties consistently maintained a lower Ψ_l than well-watered vines. Pruning weights, measured after the 2021 season, indicated that even fully irrigated Chardonnay had a 25% smaller canopy than Riesling. Moreover, water deficit reduced the canopy size of Chardonnay more (-57%) than that of Riesling (-42%). In both years, Chardonnay also had lower yields than Riesling, and water deficit decreased berry weights and yields in both varieties.

The canopy management treatments worked as planned: leaf removal on the east side of the canopy opened up the fruit zone to more light exposure, and loosening a foliage wire to provide shade via overhanging shoots at veraison decreased the light exposure. Infrared images demonstrated that leaf removal strongly increased the cluster temperature, and shading via shoot repositioning at veraison reduced it back to control levels for the ripening period (Fig. 1).

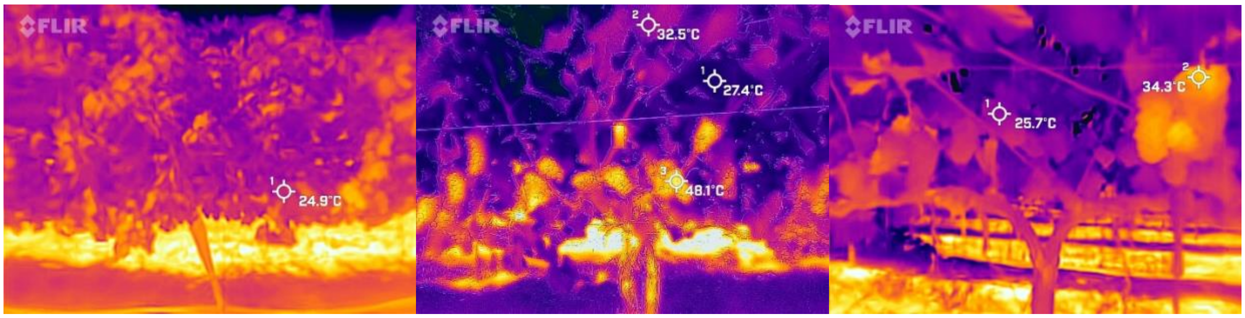

Fig. 1: Infrared images of Riesling control canopy (left), canopy with leaf removal (middle), and canopy with extra shading by shoots (right) in the WSU Roza vineyard. Light colors represent hotter temperatures and dark colors represent cooler temperatures. The ambient air temperature while the images were taken ranged from 22.9°C to 24.2°.

The temperatures registered by the HOBO data loggers were often intermediate between ambient air temperatures and the berry temperatures extracted from the infrared camera. The HOBO data, moreover, were strongly influenced by small shoot and leaf movements and other perturbations. Nevertheless, these data showed that the clusters in control canopies (no leaf removal, full irrigation) accumulated the lowest number of hot hours, i.e., temperatures above 38°C (100°F), above which malate production declines (Lakso and Kliewer 1975). Deficit irrigation increased the number of hot hours across canopy treatments, similar to what we previously found in Cabernet Sauvignon (Keller et al., 2016). Leaf removal strongly increased the number of hot hours (Fig. 2). However, the extra shading provided at veraison did not always reduce heat accumulation, likely due to the localized nature of the HOBO placement. The two varieties did not differ in terms of fruit zone heat accumulation in 2020. The smoke coverage that year effectively changed the sun exposure the berries received, which made it difficult to determine the differences between the canopy treatments. Soon after the shading treatments were applied, the amount of light that the berries received was diminished. In 2021 Chardonnay clusters (especially of deficit-irrigated vines) accumulated more hot hours than Riesling clusters. On a diurnal basis, the simulated cluster temperature closely followed the trends in light intensity (which was also registered by the HOBO sensors) and often exceeded the ambient temperature by more than 10°C (18°F) before noon, indicating that direct sunlight exposure was causing the differences in temperature observed between treatments. Moreover, contrary to its effect during the day, leaf removal decreased the cluster temperature at night by 0.2–0.5°C (0.3–1°F) relative to the control.

Since berries were sampled equally from both sides of the canopy (as a mechanical harvester would do), treatment effects may not have been as pronounced as if sampling had focused on the treated east side only. Neither irrigation nor canopy treatments affected the accumulation of TSS in the berries of either variety, but Chardonnay accumulated TSS more quickly and to higher levels than Riesling. The juice pH and K^+ also increased more, and the TA tended to decline more, in Chardonnay than in Riesling. In 2021, deficit irrigation decreased TA in Chardonnay but not Riesling. Chardonnay tended to have lower tartrate concentrations than Riesling, especially in 2021, but there was no clear treatment effect on tartrate concentrations. Deficit irrigation decreased the malate concentration in Riesling berries in both years, but only in 2021 in Chardonnay. The canopy treatments had no consistent effect on malate. Clearly, the results from the two-year field trial do not support our hypothesis that leaf removal stimulates acid production and subsequent shading of the fruit zone at veraison limits malate degradation. By contrast, the results support the second hypothesis, namely that increased irrigation leads to increased acidity.

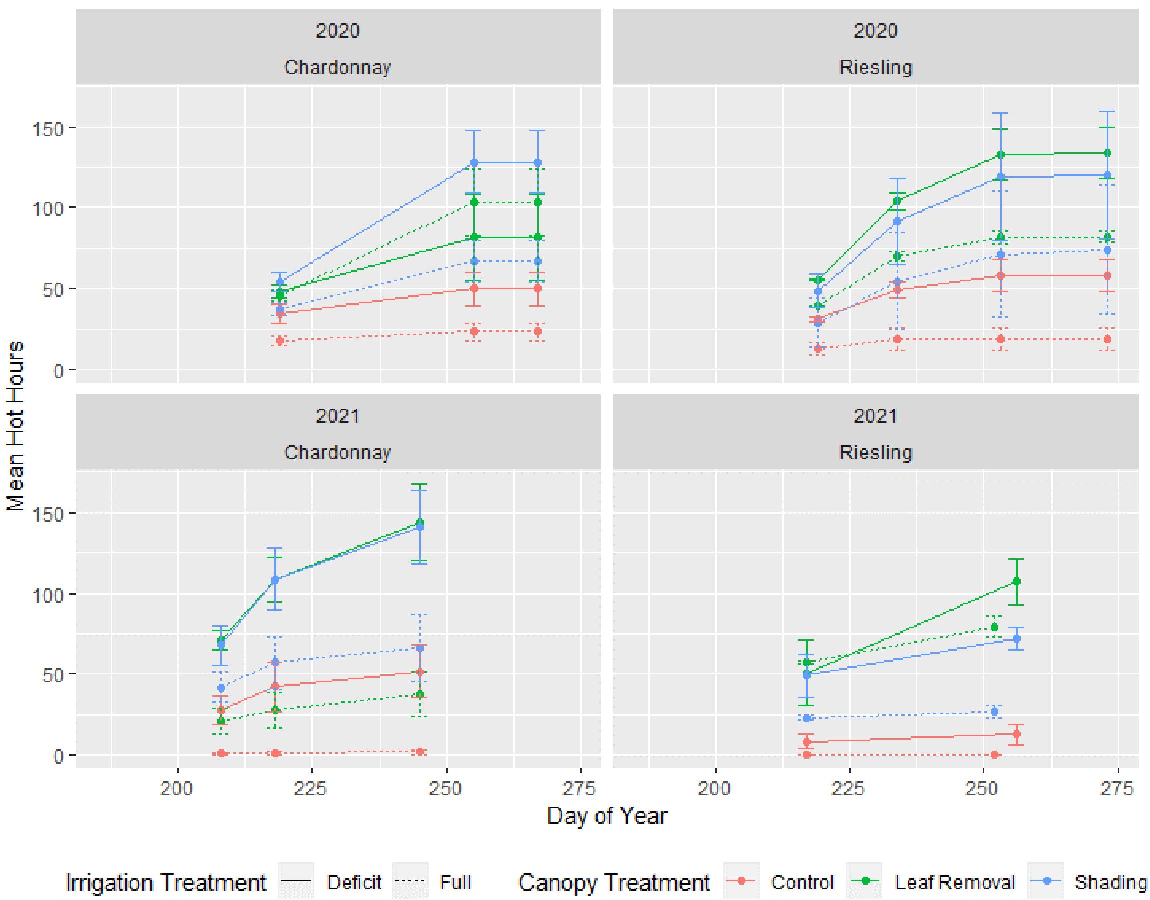

Fig. 2: Accumulation of hot hours (>38°C or 100°F) by HOBO sensors placed in the fruit zone of Chardonnay and Riesling vines in the WSU Roza vineyard under full or deficit irrigation. Symbols show means ± standard errors. Leaf removal occurred on DOY 189 in 2020 and on DOY 182 in 2021; canopy shading occurred on DOY 237 in 2020 and on DOY 214 (Chardonnay) or DOY 222 (Riesling) in 2021.

<u>Objective 2: Study the relationship between berry respiration, titratable acidity, and organic acids.</u>

Oxygen profiling in individual Riesling berries to estimate berry respiration revealed no consistent treatment effects (Fig. 3). Though there were apparent O_2 spikes in some berries exposed to a heatwave, these data do not permit us to conclude that respiration was lower in these berries. We did not consider the O_2 data to be sufficiently reliable to pursue this analysis further. Neither temperature nor light exposure of the clusters consistently altered the accumulation of TSS and potassium, and the increase in pH. The final TA, however, was about 0.9 g/L lower in berries that had experienced two heat waves.

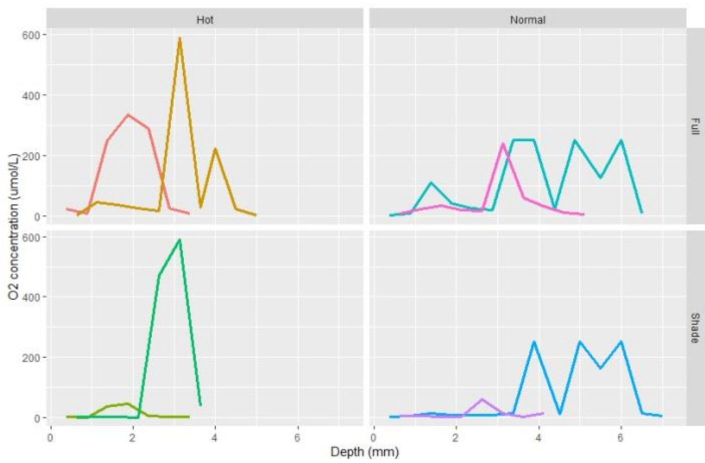

Fig. 3. Oxygen profiles of individual Riesling berries (each line represents a different berry) at varying depths. Postveraison berries were exposed to heatwave (Hot) or control (Normal) conditions with (Shade) and without (Full) cluster shading.

In the K experiment, there was no significant K effect on juice TSS, TA, and pH of Riesling. Contrary to published literature (e.g. Duchêne et al., 2020), however, there was a trend ($p = 0.08$) of increasing TA with increasing soil K. Foliar nutrients remained unaffected by the K treatments, and berries are currently being analyzed. It is possible that the applied K rates were not sufficiently different or that vines might not need supplemental K until lower K concentrations are reached in the soil.

Objective 3: Study the influence of organic acids versus potassium on juice pH and buffering capacity.

For Riesling berries across both years of the field trial there were significant correlations between TSS and TA (r = -0.95), TSS and pH (r = 0.77), TSS and malate (r = -0.77), TSS and tartrate (r = -0.62), TA and pH (r = -0.85), TA and malate (r = 0.87), TA and tartrate (r = 0.64), malate and tartrate (r = 0.78), malate and pH (r = -0.78), and tartrate and pH (r = -0.61). In general, correlations between K^+ and other berry parameters were weak; the strongest of these was K and pH (r = 0.45). Chardonnay berries showed similar trends with correlations between TSS and TA (r = -0.96), TSS and pH (r = 0.89), TSS and malate (r = -0.77), TSS and tartrate (r = -0.29), TA and pH (r = -0.91), TA and malate (r = 0.79), TA and tartrate (r = 0.28), malate and tartrate (r = 0.54), malate and pH (r = -0.86), and tartrate and pH (r = -0.32). However, the correlations between K^+ and pH (r = 0.73), and K^+ and malate (r = -0.62) were much stronger than in Riesling. These results suggest that the two varieties tested may regulate, or buffer, berry acidity differently. Riesling tends to maintain higher concentrations of tartrate throughout ripening, while Chardonnay accumulates more K^+. Consequently, the pH of Chardonnay berries is more dependent on K^+ and less dependent on tartrate than is the pH of Riesling berries.

Objective 4: Develop practical recommendations to mitigate heat stress effects.

Based on the results from both the field and pot experiments, we recommend that irrigation management is a more powerful tool to manipulate the acidity of white winegrape berries than are changes in canopy management, such as fruit zone leaf removal after fruit set and extra shading at veraison, in eastern Washington. Even relatively small decreases in vine water status can be associated with significant increases in fruit zone temperatures that may lead to decreases in berry organic acids and increases in pH. However, even though deficit irrigation limited the canopy size, and increased the fruit zone temperature, of Chardonnay more than those of Riesling, the acidity of Riesling berries was more responsive to irrigation (e.g. 2–3 g/L less malate at harvest with deficit irrigation in both years) than that of Chardonnay berries. Consequently, irrigation may be used with greater success as a tool to alter juice acidity in some varieties than in others.

While altering the temperature of the fruit zone using canopy management treatments is possible, the effects on berry acidity do not appear to be as strong as the effects of irrigation. Nevertheless, the implementation of canopy management treatments could be further refined. Loosening a foliage wire to create an "umbrella" effect with overhanging shoots on the previously defoliated fruit zone led to heterogenous light exposure. If this strategy could be implemented more uniformly, the treatment effects might be amplified. Exploring cost-effective and efficient methods of providing shade postveraison may still prove to be a potential strategy for reducing malate degradation during ripening. For example, in model simulations shade cloth has been shown to be effective in some situations, but not others, at preventing solar heating of berries (Ponce de León and Bailey, 2022).

Another option would be to blend varieties that differ in their regulation of berry acidity. Though Riesling and Chardonnay in our study provide contrasting examples, they are not typical blending partners for winemaking. However, other varieties could be identified that provide acidity (e.g. more tartrate) to wine from varieties that tend to have high pH at maturity, especially when that pH is driven by a propensity of berries to accumulate potassium.

With experience and cooperation with winemakers, growers can develop a sense for which varieties are the most promising candidates for manipulating acidity using irrigation management, canopy management, or blending.

Literature cited:

Duchêne E., Dumas V., Butterlin G., Jaegli N., Rustenholz C., Chauveau A., Bérard A., Le Paslier M.C., Gaillard I., Merdinoglu D. 2020. Genetic variations of acidity in grape berries are controlled by the interplay between organic acids and potassium. Theor. Appl. Genet. 133: 993-1008.

Keller M., Romero P., Gohil H., Smithyman R.P., Riley W.R., Casassa L.F., Harbertson J.F. 2016. Deficit irrigation alters grapevine growth, physiology, and fruit microclimate. Am. J. Enol. Vitic. 67: 426-435.

Lakso A.N., Kliewer W.M. 1975. The influence of temperature on malic acid metabolism in grape berries. I. Enzyme responses. Plant Physiol. 56: 370-372.

Ponce de León M.A., Bailey B.N. 2022. Fruit zone shading to control grape berry temperature: a modeling study. Am. J. Enol. Vitic. 73: 183-197.

7. **Outreach and Education Efforts - Presentations of Research**:

We are disseminating our results to the industry during and after this project, taking advantage of existing outreach and education programs, and collaborating with industry organizations (e.g. Washington Wine Commission, Washington Winegrowers Association, Washington State Grape Society). Key findings will be integrated in the PI's classroom and certificate program teaching materials. Novel scientific knowledge will be published in peer-reviewed journals. To date, results and recommendations have been shared with industry and other stakeholders as follows:

Publications:

Fritzke E. 2022. Canopy and irrigation management effects on grape acidity. MS Thesis, Washington State University.

Fritzke E. 2022: Exploring vineyard management practices for preserving acidity. WSU Viticulture and Enology Extension News, Spring 2022: 6-7.

Posters:

Fritzke E., E. Hernández Montes, B.M. Chang, J. Harbertson and M. Keller. 2022: Canopy and irrigation management effects on grape acidity. WineVit by Washington Winegrowers Association, Kennewick, WA, February 7-10.

Fritzke E., E. Hernández-Montes, B.M. Chang, J. Harbertson and M. Keller. 2021: Heat and water stress effects on acidity during grape ripening. Washington State Grape Society Annual Meeting. Grandview, WA, November 18-19.

Fritzke E., E. Hernández-Montes, B.M. Chang, J. Harbertson and M. Keller. 2021: The effects of heat stress and water deficit on acidity during grape ripening. Washington Winegrowers Association Convention, Virtual, March 15-18.

Hernández-Montes E., Y. Zhang, H. Medrano and M. Keller. 2021: Searching for the drivers that regulate fruit acidity. XI International Symposium on Grapevine Physiology and Biotechnology, Virtual Conference, Stellenbosch, South Africa, October 31 – November 5.

Presentations:

Keller M. 2022: Drought and heat waves coming to a vineyard near you. International Cool Climate Wine Symposium, St. Catharines, ON, Canada, July 17-21.

Keller M. 2022: Effects of climate change in warm/dry areas. Climate Change Symposium, American Society for Enology and Viticulture National Conference, San Diego, CA, June 20.

Keller M. and J. Harbertson. 2022: Riesling production in a warm climate – viticultural and oenological advantages, drawbacks, and challenges. International Riesling Symposium, Eberbach Monastery, Germany, May 9-10.

Keller M. 2021: Mitigating heat stress (with grower panel). Washington State Grape Society Annual Meeting. Grandview, WA, November 18-19.

Keller M. 2021: Thirsty vines: of stresses and varieties. Napa Valley Grapegrowers Sustainable Vineyard Practices Webinar, Napa, CA, March 11.

Hernández-Montes E. 2020: Efecto del estrés por calor y el estrés hídrico sobre el crecimiento, la fisiología de la vid y la composición del mosto. Unified Symposium, Sacramento, CA, February 4-6.

Hernández-Montes E. 2020: Results of different vineyard practices on acidity from academic vineyard trials. Washington Winegrowers Association Convention, Kennewick, WA, March 2-5.

Keller M. 2020, 2021, 2022: Hands-on grapevine physiology. WSU Certificate Program Grape Camp, Prosser, WA, September 11-12.

Keller M. 2020: WAVE Minute, Washington Ag Network and KONA-AM, July 31.

8. **Research Success Statements**:

The outputs generated from this project will help growers and winemakers to understand the main environmental drivers that affect grape acidity, especially in the face of a changing climate with recurring heat waves that impact acidity with potentially negative consequences for wine quality. Continued growth of Washington's wine industry will depend on the industry's ability to adapt to changing scenarios in order to maintain or improve wine quality and economic sustainability. The study of the relationships among organic acids, TA, potassium, and pH, as well as their interaction with environmental factors enables us to develop new adaptation strategies to mitigate the impact of high temperatures on grape and wine quality. The project has also provided educational opportunities for undergraduate and graduate students, and extension programming. For example, four undergraduate students from the WSU Viticulture and Enology Program and two students from Columbia Basin College were trained by participating in the field trial. Moreover, the two postdocs (Esther Hernández-Montes and Ben-Min Chang) who were partly supported by this project both landed competitive positions at research institutions, and the MS student (Evan Fritzke) who was supported by this project was offered, and accepted, an industry job as a viticulturist even before he graduated.

9. **Funds Status**:

A postdoctoral research associate (Esther Hernández-Montes) was hired to conduct this study but resigned effective April 7, 2020. Responsibility for the pot experiments was transferred to another postdoctoral research associate (Ben-Min Chang), and an MS student (Evan Fritzke) was hired, effective August 16, 2020, to continue work on the field experiments. The student defended his thesis on September 16, 2022. Apart from these changes, funds are being spent according to the original budget submitted to the WSGWRP.