FINAL REPORT

Washington State Grape and Wine Research Program

PROJECT TITLE: Influence of cultivar, environment and management on grape yield components and quality (Objective 3: Determine weight loss associated with long hang time)

Project Duration: 2014-2016
WRAC Project No.: Unknown

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BUDGET AND OTHER FUNDING SOURCES

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BUDGET *(LIST COMPLETED BUDGET NUMBERS) – NOT APPLICABLE*

	Year 1 FY	Year 2 FY	Year 3 FY
	Jul 14 – Jun 15	Jul 15 – Jun 16	Jul 16 – Jun 17
Item			
Salaries	21,531	22,985	
Benefits	16,675	16,591	
Wages	960	960	
Benefits	93	94	
Equipment			
Supplies	1,000	1,000	
Travel	168	168	
Miscellaneous			
Total	40,427	41,798	0.00
Footnotes: This budget lists figures exactly as presented annually under Objective 3 for this 2-year project.			

Total Project Funding: $82,225
Project Budget Status: Project funding was fully expended by June 30, 2016.

OTHER FUNDING SOURCES/SUPPORT

None.

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Project Summary:

It is becoming increasingly common for wineries to request that wine grapes not be harvested until they reach 26-30 Brix. This is well above the 23-25 Brix that most grapes are able to accumulate through sugar import from the leaves. The higher sugar concentration of such fruit may come at the cost of weight loss through water loss from the fruit. This not only constitutes a potential loss of income for growers, but the long 'hang time' required to achieve such high sugar levels also puts growers at risk from inclement weather (e.g. rainfall, early fall frosts) and disease pressure. Consequently, growers would like to quantify the extent of the potential weight loss for their cultivars. This project therefore studied berry water loss in a range of wine grape cultivars, using grapes from our new research vineyard. Overall, we found that sugar levels above 23-25 °Brix often come at the cost of weight loss from the berries. However, maximum sugar levels and the extent of weight loss varied widely among cultivars. The average daily weight loss of berries at advanced stages of maturity ranged more than 10-fold, from 2.5 mg to 28.3 mg, depending on the cultivar. Similarly, the extent of weight loss for each unit (in °Brix) of late-season gain in sugar varied from insignificant to almost 0.5 g per berry. Much of the weight loss occurred by water evaporation from the berry surface (berry transpiration), which in turn varied more than 30-fold depending on air temperature and humidity. Hot, dry air greatly increased such water loss. In some cultivars, weight loss was accelerated by berry splitting (cracking). Although the present results must be viewed as preliminary, this study has provided important insight into the relationship between hang time and berry weight loss. Growers and wineries may use this information to negotiate a pricing structure that takes desired Brix levels and harvest dates into account, and acknowledges that advanced grape maturity constitutes a potential loss of crop yield and imposes additional risks on the grower.

Project Major Accomplishments:

The objective of this project was to determine the extent of weight loss associated with long hang time. The new WSU wine grape research vineyard planted in 2010 was used for this study. The vineyard is drip-irrigated and spur-pruned, with cultural practices applied as uniformly as possible across the entire block. Grape samples were collected repeatedly during ripening from 25 cultivars (2014) or 27 cultivars (2015) to determine the variation in berry weight, total soluble solids (TSS), organic acids, and transpiration, using established methods (Keller and Shrestha, 2014; Keller et al., 2015; Zhang and Keller, 2015). In 2015, but not in 2014, the vines were thinned at fruit set to a single cluster per shoot. Significant results and conclusions:

The two growing seasons differed markedly with respect to crop yield. The 2014 average yield across all cultivars was 8.2 tons/acre, while cluster thinning reduced the average yield for 2015 to 3.6 tons/acre. In 2014, only four of the 25 sampled cultivars showed a significant late-season decrease in berry weight: Muscat blanc (-20%), Riesling (-15%), Viognier (-21%), and Zinfandel (-20%). None of these cultivars showed visual symptoms of berry shrinkage. Furthermore, only four cultivars reached average TSS levels >25 °Brix: Barbera (25.3 °Brix), Grenache (26.3 °Brix), Nebbiolo (25.4 °Brix), and Viognier (29.7 °Brix). Viognier was also the cultivar with the lowest yield (2.4 tons/acre). The high crop levels in the remaining cultivars increased the need for a longer growing season to ripen the large amount of fruit. In addition, the later portion of the season saw an increase in days with low vapor pressure deficit (VPD), cloudy weather, and repeated rainfall, especially after 9/26/2014. The wet weather, combined with high crop loads, decreased the rate of sugar accumulation, while berry weights fluctuated or continued to increase. In 10 cultivars, the final berry weight at the end of the 79 day postveraison observation period was also the maximum berry weight. Moreover, Grenache showed a high incidence of berry cracking (splitting), and Zinfandel suffered from severe bunch-stem necrosis. However, the heavy crop combined with the somewhat unfavorable weather conditions in 2014 permitted only very limited insight into the issue of late-season berry weight loss.

In 2015, 21 of the 27 cultivars reached TSS levels >25 °Brix, and only Sémillon did not quite reach 24 °Brix, even though Sémillon was the cultivar with the lowest yield (1.7 tons/acre). The average weight loss for red cultivars was 7.6 mg/d, ranging from 3.0 mg/d (Merlot) to 28.3 mg/d (Mourvèdre). The berries of white cultivars lost weight at a rate of 7.0 mg/d, ranging from 2.5 mg/d (Pinot blanc) to 19.8 mg/d (Riesling). Late-season berry weight loss was statistically significant for 16 of the 27 cultivars (Table 1). These results confirm our earlier measurements in Merlot that suggested that the higher sugar concentration of very ripe fruit results from a concentration effect rather than continued sugar accumulation (Bondada and Keller, 2012, 2017). Thus, depending on the cultivar, TSS levels above 23-25 °Brix come at the cost of weight loss through water loss from the berries. Transpiration measurements showed that most of this weight loss may be explained by water loss through berry transpiration, the daily rate of which can vary more than 30-fold depending on ambient VPD. Our earlier work had shown that water evaporation from the berry surface (berry transpiration) is driven by VPD (i.e., air temperature and humidity), and depends on cultivar, berry size, and developmental stage (Zhang and Keller, 2015). Together, these results demonstrate that hot and dry atmospheric conditions during the ripening period are highly conducive to weight loss of grape berries. Yet measurement of berry transpiration on nine cultivars in the present study also revealed a general decrease in transpiration as the berries advanced in maturity to the overripe stage (>24 °Brix). In addition, some cultivars exhibited significant berry cracking which influenced the degree of weight loss and associated shriveling. Of these, Zinfandel had 87% cracked berries by the end of the season, Riesling had 28%, Chardonnay had 12% and Pinot gris had 4 %. Consequently, the extent of berry weight loss varied greatly among cultivars, from not significant to 45% (Table 1). Cracked berries were especially likely to shrink during dry conditions. Similarly, the extent of weight loss for each unit (in °Brix) of late-season gain in TSS varied from not significant to almost 0.5 g per berry (Table 1).

We had shown earlier that there may be a net flow of water from the berries back to the vine under conditions of water deficit and that shriveling symptoms do not become visible until a berry has already lost about 10% of its weight (Keller et al., 2006, 2015). Late-season decreases in the estimated amount of sugar per berry (Keller et al., 2016) in five cultivars (Barbera, Cabernet franc, Nebbiolo, Petit Verdot, Viognier) in the present study further suggested the unexpected possibility that sugar, in addition to water, might also be swept back from the berry to the vine at advanced stages of maturity. This finding, however, should be viewed with caution and requires confirmation in a more detailed analysis. Measurements of organic acids (tartrate, malate, citrate) in nine cultivars (Barbera, Cabernet franc, Cabernet Sauvignon, Grenache, Malbec, Merlot, Nebbiolo, Petit Verdot, Sangiovese) showed that acid levels changed little or not at all during late ripening; tartrate was the major acid (usually at concentrations of two to three times those of malate) in all mature berries. This confirms our earlier observations that malate degradation proceeds rapidly during early ripening and then slows down considerably as the berries approach maturity (Keller and Shrestha, 2014; Keller et al., 2016). In a few cases (Barbera, Nebbiolo), organic acid concentrations increased slightly in overripe (>24 °Brix) berries, probably as a result of a concentration effect due to berry weight loss (Bondada et al., 2017).

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The results from this project must be viewed as preliminary. This is in part because the heavy crop and unfavorable ripening conditions in 2014 did not permit the grapes to ripen adequately for the purposes of the project objective. The 2015 data are more encouraging but insufficient to permit definitive conclusions about the behavior of the range of cultivars investigated. Additional growing seasons and more intense berry sampling would be required to provide definitive and reliable data. Nonetheless, the project has benefited the stakeholders of the Washington state wine industry. Growers and wineries may use the information generated in this study to negotiate a pricing structure that takes desired Brix levels and harvest dates into account, and acknowledges that advanced grape maturity constitutes a potential loss of crop yield and imposes additional risks on growers. The outputs generated from this project have already been shared with grower and winery stakeholders (see the following section). Key findings from this project have already been integrated in the PI's teaching materials in the WSU viticulture and enology program. This program currently has more than 100 enrolled undergraduate students, most of whom will embark on careers in the wine industry upon graduation.

Table 1. Late-season berry weight loss in different wine grape cultivars in 2015.

	Final TSS (°Brix)	Max berry weight (g)	Final berry weight (g)	Max to final berry weight (days)	Weight loss (%)	Weight loss per TSS gain (g/°Brix)	Berry transpiration (mg H_2O/d)
Barbera*[1]	26.0	1.54	1.28	18	17	n/a[2]	33.5
Cabernet franc*	24.4	0.98	0.76	74	23	0.04	23.7
Cabernet Sauvignon*	26.1	1.03	0.83	45	19	0.08	18.4
Grenache	26.1	1.31	1.08	18	17	n/a	33.7
Lemberger	25.0	1.13	0.78	67	31	0.11	
Malbec	24.2	1.11	1.07	52	4	0.05	23.9
Merlot*	25.5	1.02	0.85	61	17	0.13	22.7
Mourvèdre*	26.5	1.41	1.03	11	27	n/a	
Nebbiolo*	26.7	1.19	1.01	11	15	0.27	24.4
Pinot noir*	25.7	1.09	0.70	32	36	0.26	
Petit Verdot*	24.6	1.00	0.82	18	18	0.23	18.2
Sangiovese*	27.8	1.44	1.12	52	22	0.10	26.6
Tempranillo	25.8	1.30	1.10	61	15	0.06	
Zinfandel	30.3	1.96	1.90	11	3	0.03	
Alvarinho*	25.0	1.10	0.85	52	23	0.08	
Auxerrois*	28.2	1.27	0.87	82	31	0.05	
Chenin blanc	25.6	1.53	1.14	62	26	0.09	
Chardonnay*	29.5	1.02	0.77	75	25	0.04	
Gewürztraminer*	27.7	1.24	0.69	75	45	0.09	
Grüner Veltliner	25.0	1.11	0.90	25	19	0.08	
Muscat blanc*	27.7	1.76	1.13	82	36	0.08	
Pinot blanc	24.3	1.16	1.01	62	13	0.11	
Pinot gris	28.7	0.94	0.63	62	33	0.05	
Riesling*	25.1	1.16	0.80	18	31	0.47	
Sauvignon blanc	29.7	1.23	0.73	62	41	0.07	
Sémillon	23.8	1.55	0.94	75	39	0.17	
Viognier*	25.7	0.97	0.64	70	34	0.10	

[1] Asterisk (*) indicates weight loss was significant at $p < 0.05$.

[2] Not calculated because TSS remained constant or decreased.

Information Dissemination, Extension, and Outreach Activities:

Bondada B., E. Harbertson, P.M. Shrestha and M. Keller. 2017: Temporal extension of ripening beyond its physiological limits imposes physical and osmotic challenges perturbing metabolism in grape (*Vitis vinifera* L.) berries. Sci. Hort. 219: 135-143.

Zhang Y. and M. Keller. 2017: Discharge of surplus phloem water may be required for normal grape ripening. J. Exp. Bot. 68: 585-595.

Keller M. 2016: The Science of Grapevines: Anatomy and Physiology. Chinese Translation by J. Wang, C.Q. Duan, F. He and B.Q. Zhu. China Science Publishing & Media, Beijing, China, for Elsevier, New York, NY.

Keller M. 2016: Grape berry ripening: Environmental drivers and spoilers. Keynote presentation. InnoVine International Symposium. Toulouse, France, November 16-17, 2016.

Keller M. 2016: Grape berry ripening: Environmental drivers and spoilers. Oral presentation. Institut des Sciences de la Vigne et du Vin Seminar Series, Université Victor Segalen Bordeaux 2. Villenave d'Ornon, France, November 14, 2016.

Keller M. 2016: Grape berry responses to water stress. Oral presentation. American Society for Enology and Viticulture National Conference. Monterey, CA, June 27-30, 2016.

Keller M. 2016: The time is right: Grape ripening and how to optimize it in the vineyard. Oral presentation. Oregon Wine Symposium. Portland, OR, February 23-24, 2016.

Perez J.C. 2016: Predicting wine grape weight loss. MS thesis, Washington State University (advisor: M. Keller).

Perez J.C., B.M. Chang, Y. Zhang and M. Keller. 2016: Late-season weight loss in wine grapes. Poster presentation. Washington Association of Wine Grape Growers Convention. Kennewick, WA, February 9-11, 2016.

Keller M., P.M. Shrestha, G.E. Hall, B.R. Bondada and J.R. Davenport. 2016: Arrested sugar accumulation and altered organic acid metabolism in grape berries affected by berry shrivel syndrome. Am. J. Enol. Vitic. 67: 398-406.

Molitor D. and M. Keller. 2016: Yield of Müller-Thurgau and Riesling grapevines is altered by meteorological conditions in the current and previous growing seasons. OENO One 50: 245-258.

Zhang Y., J.C. Perez and M. Keller. 2016: Grape berry transpiration: determinant factors, developmental changes, and impacts on berry ripening. Oral presentation. X International Symposium on Grapevine Physiology and Biotechnology. Verona, Italy, June 13-18, 2016.

Keller M. 2015: Managing grapevines to optimize fruit development in a challenging environment: a climate change primer for viticulturists. In Gerling C. (Ed.): Environmentally Sustainable Viticulture – Practices and Practicality. Apple Academic Press, Waretown, NJ, pp. 259-292.

Keller M. 2015: The Science of Grapevines: Anatomy and Physiology. 2nd ed. Elsevier Academic Press, London, U.K.

Keller M. 2015: Deficit irrigation impacts on viticulture. Oral presentation. Washington Association of Wine Grape Growers Convention. Kennewick, WA, February 10-13, 2015.

Keller M. 2015: Grape ripening and how to optimize it in the vineyard. Oral presentation. Southeastern United Grape and Wine Symposium. Dobson, NC, November 5, 2015.

Keller M. and Y. Zhang. 2015: Grapevine water relations and irrigation management. Oral presentation. American Society for Enology and Viticulture National Conference, Portland, OR, June 15-18, 2015.

Perez J.C. and M. Keller. 2015: Late-season weight loss in wine grapes. Poster presentation. Annual Meeting of Washington State Grape Society. Grandview, WA. November 10-11, 2016.

Zhang Y. and M. Keller. 2015: Grape berry transpiration is determined by vapor pressure deficit, cuticular conductance, and berry size. Am. J. Enol. Vitic. 66: 454-462.

Keller M., Y. Zhang, M. Biondi, P.M. Shrestha and B.R. Bondada. 2015: Hydraulic isolation of ripening grape berries: the end of a dogma. Oral presentation. 19th International Symposium GiESCO, Montpellier, France.

Keller M. 2014: Pre-harvest irrigation dilutes grape quality. Really? Oral presentation. Fruition Sciences Vintage Report 2013 Napa Valley. Napa, CA, January 21, 2014.

Keller M., L.J. Mills and M.A. Olmstead. 2014: Fruit ripening has little influence on grapevine cold acclimation. Am. J. Enol. Vitic. 65: 417-423.

Keller M. and P.M. Shrestha. 2014: Solute accumulation differs in the vacuoles and apoplast of ripening grape berries. Planta 239: 633-642.

Keller M. and Y. Zhang. 2014: Changes in berry transpiration and xylem backflow during grape berry development. Oral presentation. 65th American Society for Enology and Viticulture Annual Meeting. Austin, TX, June 23-27, 2014.

Literature Cited:

Bondada B., E. Harbertson, P.M. Shrestha and M. Keller. 2017: Temporal extension of ripening beyond its physiological limits imposes physical and osmotic challenges perturbing metabolism in grape (*Vitis vinifera* L.) berries. Sci. Hort. 219: 135-143.

Bondada B.R. and M. Keller. 2012: Not all shrivels are created equal – Morpho-anatomical and compositional characteristics differ among different shrivel types that develop during ripening of grape (*Vitis vinifera* L.) berries. Am. J. Plant Sci. 3: 879-898.

Keller M. and P.M. Shrestha. 2014: Solute accumulation differs in the vacuoles and apoplast of ripening grape berries. Planta 239: 633-642.

Keller M., P.M. Shrestha, G.E. Hall, B.R. Bondada and J.R. Davenport. 2016: Arrested sugar accumulation and altered organic acid metabolism in grape berries affected by berry shrivel syndrome. Am. J. Enol. Vitic. 67: 398-406.

Keller M., J.P. Smith and B.R. Bondada. 2006: Ripening grape berries remain hydraulically connected to the shoot. J. Exp. Bot. 57: 2577-2587.

Keller M., Y. Zhang, P.M. Shrestha, M. Biondi and B.R. Bondada. 2015: Sugar demand of ripening grape berries leads to recycling of surplus phloem water via the xylem. Plant Cell Environ. 38: 1048-1059.

Zhang Y. and M. Keller. 2015: Grape berry transpiration is determined by vapor pressure deficit, cuticular conductance, and berry size. Am. J. Enol. Vitic. 66: 454-462.

Zhang Y. and M. Keller. 2017: Discharge of surplus phloem water may be required for normal grape ripening. J. Exp. Bot. 68: 585-595.