CONSEQUENCES OF APICAL LEAF REMOVAL ON GRAPEVINE WATER STATUS, HEAT DAMAGE, YIELD AND GRAPE RIPENING ON PINOT N AND CHARDONNAY

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Abstract:

Context and purpose of the study

Climate change presents a significant challenge to grape growing worldwide as increased temperatures lead to wines with increased sugar and pH levels. Manipulation of the exposed leaf area is a powerful lever governing the assimilation and storage of non-structural carbohydrates in grapevines. Reducing the leaf-to-fruit ratio is now considered as a tool for adapting to hotter and dryer grape growing conditions. The present study documents the effects on grape maturation, yield parameters and on grapevine water status when a substantial portion of the upper canopy is eliminated before and after veraison. Specifically, the relevance of manipulating the leaf-to-fruit ratio is evaluated for its potential to adapt grapevine production to warmer and dryer conditions emerging with climate change.

Material and methods

Six treatments which modified the leaf-to-fruit-ratio through cluster thinning or apical leaf removal were applied on two vineyard plots of Pinot N. and Chardonnay in Burgundy from 2020 to 2023. The percentage of veraison was measured from the onset of veraison until its end. The number of clusters and the yield of each vine were documented at harvest. A random sampling of each experimental unit was used to determine berry weight and to conduct Fourier transform infrared spectroscopy analysis as well as $\delta^{13}C$ isotopic analysis.

Results

Pre-veraison apical leaf removal delayed the date of mid-veraison by 4 to 8 days on average when compared to the control. Apical leaf removal significantly decreased water deficit during grapevine ripening for both cultivars in all three years: $\delta^{13}C$ values decreased from 0.95 ‰ (Chardonnay, 2020) to 1.48 ‰ (Chardonnay, 2022), while significantly limiting the incidence of heat damage for both cultivars in 2020. Apical leaf removal decreased TSS content [potential alcohol level] and pH, with the amplitude and statistical significance of reduction varying according to vintage and cultivar. Our results confirm on CV Chardonnay and Pinot N, the interest of apical leaf removal to adapt to climate change.

Keywords: Grapevine, Pinot N, Chardonnay, climate change, Exposed Leaf Area, Leaf-to-fruit Ratio, grape ripening, water status, apical leaf removal

2. Introduction

The management of the exposed leaf area is a powerful lever for the management of the source/sink relations in the grapevine. A clear relationship exists between the leaf-to-fruit ratio on the assimilation of non-structural carbohydrates and their storage in the different organs of the vine (Zufferey et al., 2012). While the pursuit of training systems aimed to increase the leaf-to-fruit ratio may appear useful in cool climate conditions, its reduction is now considered as a tool for adapting to hotter and dryer conditions, specifically due to contemporary climate change (van Leeuwen et al., 2019). Reducing the leaf-to-fruit ratio improves vine water status and controls the accumulation of sugar content in grapes (Buesa et al., 2019).

To date, cool-climate regions, such as northeastern France, have benefited from the positive effects on grape maturation due to climate change (Duchêne and Schneider, 2005). However, expected climate conditions in these regions by the middle of the 21st century could present challenges to viticulture production, such as strong modifications of wine typicity (Tempere et al., 2019) or excessive water stress (Fraga et al., 2016). Therefore, adaptative strategies are currently needed to prepare for these expected challenges.

This paper details research examining leaf-to-fruit ratio modification through apical leaf removal and cluster thinning implemented in Burgundy from 2020 to 2022. The purpose of this study is to evaluate the effects on grape maturation, yield parameters and on grapevine water status when a large portion of the upper canopy is eliminated before and after veraison. In addition to its contribution to grapevine ecophysiology documentation and knowledge, this study also considers the relevance of manipulating leaf-to-fruit ratio to adapt to warmer and dryer conditions emerging with climate change.

2. Material and methods

2.1 *Experimental design*

The experiment was established in 2020 on one plot (5.001264°E; 47.272172°N) planted with *Vitis vinifera* L. cv. Pinot N (French clone 115) grafted onto the SO4 and on another plot (47.261349°E; 4.986609°N) planted with Chardonnay (French clone 76) grafted on 101-14. The plots are located 8 km south of Dijon, in the Marsannay-la-Côte PDO (Burgundy, France). Both parcels were planted in 2015 at a density of 10,000 vines per hectare (1 m inter-row and 1 m inter-vine spacing) and are characterized by relatively flat terrain with a soil of clay-silty texture, approximately 1 m deep with medium gravel content. The rows are oriented in the East-South-East/West-North-West direction. The plots are trained in vertical shoot positioning (VSP) with simple guyot pruning (2 buds per spur and 6 to 8 buds per cane), with a trunk height of 0.45 m and a foliage height of 0.90 m, i.e., a row height of 1.25 m. No chemical herbicides are applied to the plots; the soil is tilled three or four times during the vegetative season.

Six cluster thinning and apical leaf removal treatments were applied on experimental units composed of 21 grapevine plants (3 adjacent rows of 7 plants). To avoid possible edge effects, measurements were carried out on the 5 vines located in the middle of each 3x7 plant, experimental unit. Treatments were repeated 7 times following a semi randomized-block design.

The treatments which modified the leaf-to-fruit-ratio were compared to a control (CTR) treatment which received no apical leaf removal or bunch thinning. Bunch thinning treatments aimed to increase the leaf-to-fruit-ratio. BT- consisted of moderate bunch thinning while BT+ consisted of severe bunch thinning; the number of bunches to be removed were selected based on a desired distribution of leaf-to-fruit ratio each year. BT+ was not applied for the Chardonnay plot. The apical leaf removal treatments aimed to decrease the leaf-to-fruit-ratio. The LR- treatment consisted of moderate apical stripping. Leaves located 0.4 m or more above the bottom of the canopy were removed. The LR+ treatment consists of severe apical leaf stripping. All leaves located 0.2 m or more above the bottom of the canopy were removed. The BT- and BT+ bunch thinning as well as the LR- and LR+ leaf removal treatments were applied at the "cluster closure" stage, approximately 25 days before the veraison date of the control treatment. The LRL treatment also consisted of a severe leaf removal (all leaves located 0.2 m or more above the bottom of the canopy were removed) but was implemented approximately 10 days after the CTR treatment attained mid-veraison (at average TSS values ranging from 13.8 to 17.6°brix depending on the vintage/cultivar).

For the 2021 vintage, 4 treatments (CTR, LR-/+, LRL) were applied for both Pinot N and Chardonnay. BT-/+ bunch thinning treatments were not applied due to low expected yields from disease pressure and spring frost.

2.2 *Measurements*

The percentage of veraison was measured every 3-5 days from the onset until the end of veraison (visually for Pinot N and tactilely for Chardonnay). The mid-veraison date was estimated by linear interpolation between the two dates for which an average veraison rate of less than and greater than 50% was observed.

In 2020, sunburn on grapes were estimated visually over each cluster of each experimental unit. Total sunburn related damage was estimated as the product of the average proportion of clusters with damage per the average intensity of sunburns (percentage of sunburnt berries) on each grape.

At harvest, the number of clusters were counted, and the harvest of each measurement vine was weighed. A random sampling of 200 berries was conducted on the clusters of the five measurement vines of each experimental unit. Samples were weighed, ground, and analyzed using a specifically calibrated Fourier transform infrared spectroscopy (FTIR, OenoFoss in 2020-2021 and Winescan Flex Auto in 2022, FOSS Analytical). For $\delta^{13}C$ isotopic analysis, a sample of 5 µL of grape juice was pipetted into a tin capsule and placed in an oven at 40°C for 12 hours and analyzed in duplicate on a Vario Micro Cube elemental analyzer coupled in a continuous flow mode to an isotope ratio mass spectrometer (IsoPrime, Elementar). USGS40 (IAEA, Vienna) was used as an internal standard ($\delta^{13}C$ PDB = −26.39 ± 0.04 ‰). $\delta^{13}C$ values are reported in ‰.

2.3 *Statistical analysis*

Results were analyzed by ANOVA followed by a Tukey-HSD post-hoc test. Assumption of ANOVA were tested using Bartlett test for homogeneity of variance and Shapiro-Wilk test for distribution normality evaluations. When the data set did not fit these assumptions, non-parametric tests were applied, i.e. Kruskal-Wallis followed by Fisher-LSD tests. All data statistical analysis was performed using R (R Core Team, 2022).

3. Results and discussion

3.1 *Climate conditions*

The experiment was conducted during three vintages with contrasting climate conditions. 2020 and 2022 exhibited climate conditions during the growing season that were much warmer (summer 2022 was the second warmest summer ever recorded in France, Sorel et al., 2022) and drier (-32% rainfall from April to September 2020 in comparison to 1991-2020 normal) than average. In 2020 there were 9 days (5 in 2022) with recorded maximum temperatures over 35°C during the fruit development and ripening period (July and August).

Conversely, the 2021 vintage was rainy (44% higher than average precipitation during the growing season) and cold (no hot days, average growing season temperature 2.2°C lower than 1991-2020 average). April was remarkably cold. Many vineyards in France where budburst had already occurred were severely damaged by spring frosts (specifically due to a cold surge from April 6th to 8th). This was the case in the study vineyard for Chardonnay (number of clusters in 2021 was half as high as in 2020 and 2022 on the control grapevines). July precipitation was twice as high as normal.

Harvest dates were August 31st 2020, September 23rd 2021, and September 5th, 2022 for Pinot N and September 1st 2020, September 28th 2021 and September 8th 2022 for Chardonnay.

3.2 *Grapevine water status*

Grapevine water status clearly differed over the three vintages and was significantly impacted by the treatments applied. In 2020 the grapevines exhibited severe water deficit according to the classification from Santesteban et al. (2015), with average $\delta^{13}C$ values less negative than -24‰ for all treatments but pre-veraison severe leaf removal (Figure 1). In 2021, water deficit ranged from none to moderate (following the same classification), with average $\delta^{13}C$ values ranging from -25.4 to -27.7 ‰ depending on the treatment and the variety. Severe apical leaf removal significantly decreased water deficit during grapevine ripening for both cultivars in all three years: $\delta^{13}C$ values decreased from 0.95 ‰ (Chardonnay, 2020) to 1.48 ‰ (Chardonnay, 2022). These results were consistent with observations previously made in Spain, on cv Tempranillo in a semi-dry temperate warm region (Buesa et al., 2019). Severe apical leaf removal significantly limited the incidence of heat damage for both cultivars in 2020.

3.3 *Grape production and grape ripening*

Due to rainfall deficit and excessive heat in 2020 and 2022, Pinot N berry and cluster weight were significantly lower than those recorded in 2021 (nearly half in 2020). Chardonnay also exhibited lower berry weight in 2020 and 2022, while cluster weight was only slightly reduced in 2020. Leaf removal treatments had no statistically significant impact on berry and cluster weight. Treatments applied in 2020 and 2021 did not affect cluster quantity per plant in the subsequent year (Table 1).

Pre-veraison severe apical leaf removal delayed the date of mid-veraison by 4 to 8 days on average when compared to the control.

TSS content [potential alcohol level] was reduced by 26.65 g/L [1.57% vol.] for Pinot N (Table 1). and by 11.43 g/L [0.67% vol.] for Chardonnay in 2021. TSS showed no significant difference for Pinot N and Chardonnay in 2020 and 2022. These results support the literature which finds that decreasing the leaf-to-fruit-ratio results in reduced TSS content. In most cases, severe defoliation applied either before or after veraison has been found to reduce sugar content at harvest (Buesa et al., 2019; Palliotti et al., 2013; Poni et al., 2013), except for cultivar Tempranillo under semi-dry conditions.

pH was significantly reduced by 0.35 in 2020, by 0.09 in 2021 and by 0.18 for Pinot N while pH was reduced by 0.07 in 2022 for Chardonnay, consistent with the literature.

Tartrate and malate related results changed according to vintage and cultivar, with no consistency in comparison to what was previously reported in the literature.

4. Conclusions

The results presented in this paper demonstrate that reducing the leaf-to-fruit ratio via apical leaf removal may be a relevant technique to adapt wine production in warmer and dryer conditions, depending on the vintage conditions. Pre-veraison severe apical leaf removal delayed the date of mid-veraison and reduced TSS content and pH. Furthermore, severe apical leaf removal significantly limited water deficit during grapevine ripening with a reduction in $\delta^{13}C$ measured as well as the incidence of heat damage observed on grapes. Developing an understanding of these dynamics and potential long-term consequences could give producers methods to best adapt to climate change.

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6. Literature Cited

Bondada, B., Covarrubias, J.I., Tessarin, P., Boliani, A.C., Marodin, G., and Rombolà, A.D. (2016). Postveraison Shoot Trimming Reduces Cluster Compactness without Compromising Fruit Quality Attributes in Organically Grown Sangiovese Grapevines. Am J Enol Vitic. 67, 206–211. https://doi.org/10.5344/ajev.2016.15058.

Buesa, I., Caccavello, G., Basile, B., Merli, M.C., Poni, S., Chirivella, C., and Intrigliolo, D.S. (2019). Delaying berry ripening of Bobal and Tempranillo grapevines by late leaf removal in a semi-arid and temperate-warm climate under different water regimes. Australian Journal of Grape and Wine Research 25, 70–82. https://doi.org/10.1111/ajgw.12368.

Duchêne, E., and Schneider, C. (2005). Grapevine and climatic changes: a glance at the situation in Alsace. Agronomy for Sustainable Development 25, 93–99. https://doi.org/10.1051/agro:2004057.

Fraga, H., Garcia de Cortázar Atauri, I., Malheiro, A.C., and Santos, J.A. (2016). Modelling climate change impacts on viticultural yield, phenology and stress conditions in Europe. Global Change Biology 22, 3774–3788. https://doi.org/10.1111/gcb.13382.

van Leeuwen, C., Pieri, P., Gowdy, M., Ollat, N., and Roby, J.-P. (2019). Reduced density is an environmental friendly and cost effective solution to increase resilience to drought in vineyards in a context of climate change: OENO One 53, 129–146. https://doi.org/10.20870/oeno-one.2019.53.2.2420.

Palliotti, A., Panara, F., Silvestroni, O., Lanari, V., Sabbatini, P., Howell, G. s., Gatti, M., and Poni, S. (2013). Influence of mechanical postveraison leaf removal apical to the cluster zone on delay of fruit ripening in Sangiovese (Vitis vinifera L.) grapevines. Australian Journal of Grape and Wine Research *19*, 369–377. https://doi.org/10.1111/ajgw.12033.

Poni, S., Gatti, M., Bernizzon, F., Civardi, S., Bobeica, N., Magnanini, E., and Palliotti, A. (2013). Late leaf removal aimed at delaying ripening in cv. Sangiovese: physiological assessment and vine performance. Australian Journal of Grape and Wine Research 19, 378–387. https://doi.org/10.1111/ajgw.12040.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Santesteban, L. g., Miranda, C., Barbarin, I., and Royo, J. b. (2015). Application of the measurement of the natural abundance of stable isotopes in viticulture: a review. Australian Journal of Grape and Wine Research 21, 157–167. https://doi.org/10.1111/ajgw.12124.

Sorel, M., Mittelberger, S., & Kreitz, M. (2022). Un été 2022 extrêmement chaud. *La Météorologie*, *119*, 99‑115. https://doi.org/10.37053/lameteorologie-2022-0095

Tempere, S., Pérès, S., Espinoza, A.F., Darriet, P., Giraud-Héraud, E., and Pons, A. (2019). Consumer preferences for different red wine styles and repeated exposure effects. Food Quality and Preference 73, 110–116. https://doi.org/10.1016/j.foodqual.2018.12.009.

Zufferey, V., Murisier, F., Vivin, P., Belcher, S., Lorenzini, F., Spring, J.-L., and Viret, O. (2012). Carbohydrate reserves in grapevine (Vitis vinifera L.'Chasselas'): the influence of the leaf to fruit ratio. Vitis 51, 103–110.

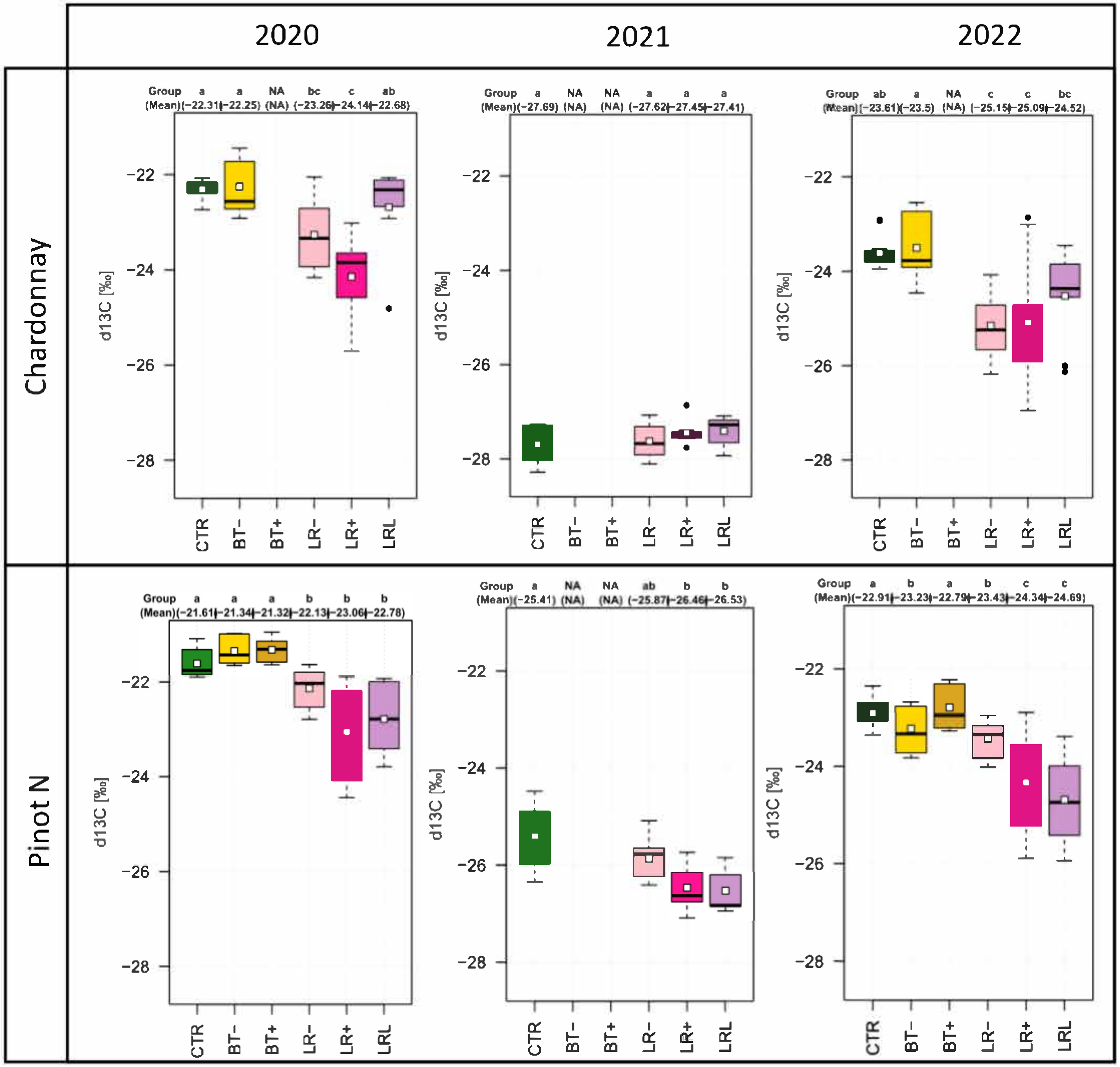

Figure 1. Distribution of δ^{13}C of berry juice at harvest for the 6 treatments, for Chardonnay (top) and Pinot N (bottom) varieties. Letters on the top of each boxplot correspond to statistically identical groups (following Tukey HSD or Fisher LSD methods). NA = not available (not sufficient data to perform the test or treatment not applied). Values between parentheses correspond to treatment average δ^{13}C.

Table 1. Compiled harvest data with post hoc test groupings for the 5 treatments, for Chardonnay (top) and Pinot N (bottom) varieties. Treatment average values at harvest are reported for berry weight [g], cluster quantity, cluster weight [g], sugar content [g/L], potential alcohol [% vol.] and pH. Letters on the right of each value correspond to statistically identical groups (following Tukey HSD or Fisher LSD methods). NA = not available (not sufficient data to perform the test or treatment not applied).

		Mod	2020		2021		2022			Mod	2020		2021		2022	
Chardonnay	**Berry weight [g]**	CTR	1.12	a	1.50	a	1.22	a	**Sugar Content [g/L]**	CTR	216.69	ab	205.21	a	205.45	a
		BT-	1.1	a	NA		1.20	a		BT-	223.86	a	NA		205.57	a
		LR-	1.22	a	1.50	a	1.30	a		LR-	215.24	ab	197.29	ab	201.07	a
		LR+	1.71	a	1.44	a	1.24	a		LR+	205.44	b	**187.79**	**c**	194.02	a
		LRL	1.1	a	1.45	a	1.22	a		LRL	211.20	b	**191.14**	**bc**	206.37	a
	Cluster quantity	CTR	10.05	a	5.50	a	10.61	ab	**Pot. Alcohol [% vol.]**	CTR	12.87	ab	11.40	a	12.20	a
		BT-	**5.25**	**b**	NA		7.52	b		BT-	13.30	a	NA		12.22	a
		LR-	9.74	a	5.56	a	10.75	ab		LR-	12.79	ab	10.96	ab	11.95	a
		LR+	9.29	a	4.33	a	11.36	a		LR+	12.21	b	**10.43**	**c**	11.55	a
		LRL	8.51	ab	5.22	a	9.48	ab		LRL	12.55	ab	**10.62**	**bc**	12.25	a
	Cluster weight [g]	CTR	52.9	a	63.94	a	73.65	a	**pH**	CTR	3.65	a	3.16	a	3.35	ab
		BT-	50.7	a	NA		71.33	a		BT-	3.73	a	NA		3.37	a
		LR-	59.6	a	66.91	a	69.06	a		LR-	**3.47**	**b**	3.17	a	3.28	b

		LR+	59.5	a	63.84	a	63.40	a		LR+	**3.40**	**b**	3.19	a	3.27	b
		LRL	55.1	a	67.35	a	59.69	a		LRL	3.65	a	3.18	a	3.36	ab
		Mod	**2020**		**2021**		**2022**			**Mod**	**2020**		**2021**		**2022**	
Pinot N	**Berry weight [g]**	CTR	0.95	a	1.75	a	0.83	a	**Sugar Content [g/L]**	CTR	199.01	a	219.5	a	211.34	bc
		BT-	0.98	a	NA		0.90	a		BT-	209.80	a	NA		218.53	ab
		BT+	0.95	a	NA		0.85	a		BT+	211.51	a	NA		**224.00**	**a**
		LR-	1.00	a	1.75	a	0.84	a		LR-	203.96	a	**213.2**	**b**	209.39	c
		LR+	0.99	a	1.67	a	0.87	a		LR+	194.51	a	**192.9**	**d**	200.99	c
		LRL	1.11	a	1.63	a	1.00	a		LRL	197.81	a	**205.8**	**c**	205.51	c
	Cluster quantity	CTR	7.88	b	7.00	a	12.24	a	**Pot. Alcohol [% vol.]**	CTR	11.83	a	13.04	a	12.54	abc
		BT-	**5.86**	**c**	NA		10.72	a		BT-	12.47	a	NA		13.00	ab
		BT+	**4.99**	**c**	NA		**7.24**	**b**		BT+	12.57	a	NA		13.29	a
		LR-	8.45	ab	6.51	a	10.79	a		LR-	12.12	a	**12.67**	**b**	12.44	abc
		LR+	9.39	ab	6.55	a	10.29	a		LR+	11.56	a	**11.46**	**d**	11.93	c
		LRL	**9.96**	**a**	8.06	a	11.88	a		LRL	11.76	a	**12.23**	**c**	12.20	bc
	Cluster weight [g]	CTR	48.4	a	84.38	a	66.99	ab	**pH**	CTR	3.85	ab	3.60	a	3.71	ab
		BT-	51.5	a	NA		70.44	ab		BT-	3.93	ab	NA		3.75	ab

		BT+	50.2	a	NA		83.00	a		BT+	4.02	a	NA		3.90	b
		LR-	45.0	a	83.78	a	63.39	b		LR-	3.72	bc	3.54	ab	3.62	b
		LR+	49.3	a	92.33	a	71.61	ab		LR+	**3.50**	**c**	3.51	ab	3.53	b
		LRL	51.41		88.09	a	79.11	ab		LRL	3.67	bc	**3.49**	**b**	3.54	b