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Impact of climate change on grape cluster structure, grape constituents, and processability

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Abstract. Over the last 20 years in the Pfalz region of Germany, GDD were highest in the vintages 2018-2020. To visualize the effect of climate change for the Pfalz region of Germany, the development of TSS and TAwere documented during Pinot noir grape ripening for the vintages 1998-2021. It was observed that climate change causes sooner and accelerated ripening, however, sooner or accelerated ripening were not connected with each other. The presented study investigated the impact of vintages on berry physiology development, ripening heterogeneity in grape clusters, changes in grape constituent concentrations and their extractability with progressing grape maturity. Pinot noir and Cabernet Sauvignon, both cultivated in the Pfalz region, were compared during three consecutive vintages. Different maturities were considered in the range of 17-25 Brix and berry size distribution was documented. The changes in grape constituent concentrations and their extractability with progressing grape maturity were analyzed using HPLC-DAD/FD, LC-QToF-MS and protein precipitation assay. It was revealed that tannin extractability differs for grape varieties and vintages and progressing maturity seemed to have only a small influence on the extractability of anthocyanins.

1 Introduction

Understanding the potential impacts of climate change on viticulture has become increasingly important for the wine industry. A study by Duchêne and Schneider (2005) has shown a significant increase in temperatures for the vintages 1972-2002 and that the period between budburst and harvest has become both earlier and shorter [1]. In a long-term (1952-1997) climatology study in Bordeaux, Jones and Davis (2000) observed that phenological events such as budburst, floraison, véraison tended to occur earlier with a shortening of those intervals. Cabernet Sauvignon and Merlot tended to produce higher sugar to total acid ratios which was shown to have an influence on Bordeaux vintage quality [2]. Several studies have shown that musts with higher sugar levels due to higher temperatures in the growing interval caused a stress reaction in the yeast metabolism and that higher pH had an influence on the microbial ecology, enhancing the chances for off-flavors and related loss in wine quality [3]. To extend on those findings, our study aims to visualize the effect of climate change in the Pfalz region of Germany for the vintages 1998-2021, using the traditional grape maturity parameterstotal soluble solids and titratable acidity. It was investigated whether climate change has an impact on the kinetics of berry ripening and the ripening heterogeneity within grape clusters. The tannin and anthocyanin contents in Pinot noir and Cabernet Sauvignon grapes at different maturities were investigated for the vintages 2018-2020 and compared to the tannin and anthocyanin contents in wine. Besides the extractability of phenolics, the phenolic composition of wines was examined to discuss future process options in times of climate change.

2 Materials and methods

2.1 Growing degree days

To visualize climate change, the growing degree days (GDD) were calculated with data from an on-site weather station at the Weincampus Neustadt (lat. 49°24’ N; long. 8°11’ E) for the vintages 2008-2021 according to Method 1 by McMaster and Wilhelm (1997) [4]. The GDD were used as explanatory variable for plotting the day-of-year when reaching 20 Brix.

2.2 Basic grape juice parameters

Pinot noir berries were sampled weekly, starting at 7 Brix, from 10 vineyards located in the Pfalz region of Germany for the vintages 1998-2021. Total soluble solids (TSS) and titratable acidity (TA) were measured by Fourier transform infrared spectroscopy (FT-IR) (Wine Scan™ FT120 Basic, FOSS GmbH, Hamburg, Germany) using a calibration method provided by the manufacturer.

2.3 Berry physiology, constituents, and processability

2.3.1 Vineyard site

The investigation of berry physiology, constituents, and processability was conducted during the 2018-2020 vintage at the Weincampus Neustadt experimental vineyard located in the Pfalz region of Germany (lat. 49°24’ N; long. 8°11’ E). *Vitisvinifera*L. cv. Pinot noir (PN; clone Mariafeld on SO4 rootstock) was planted in 1987 with a vine by row spacing of 1.88 m × 1.20 m and *Vitisvinifera*L. cv. Cabernet Sauvignon (CS; clone 1Gm

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on Binova 1Opp rootstock) was planted in 2008 with a vine by row spacing of 2.00 m × 1.20 m.

2.3.2 Berry analysis

Pinot noir and Cabernet Sauvignon berries were collected at three different time points in the range from 17 to 25 Brix. Lots of 500 berries per time point and grape variety were cut from the rachis using scissors to obtain intact berries (*n* = 3 experimental replicates). The berries were sorted into three size categories of different diameters (PN: < 13 mm, 13-15 mm, > 15 mm; CS: < 11 mm, 11-13 mm, > 13 mm). The grape constituent concentrations were measured using the protein precipitation assay by Harbertson et al. (2002, 2003, 2015) [5-7].

2.3.3 Wine production

Pinot noir and Cabernet Sauvignon grape bunches were harvested manually in the aforementioned TSS range. After destemming, grapes were crushed, transferred into 100 L experimental stainless-steel fermenters (70 kg each) and inoculated with 200 mg/L ZYMAFLORE® RB2 yeast. At day 5 coinoculation with 10 mg/L *Oenococcusoeni* VP41 (ZEFÜG GmbH & Co. KG, Bingen, Germany) was done. After maceration, wines were <1 g/L residual sugar. Fermentations were carried out in triplicate.

2.3.4 Wine analysis

Phenolic contents of the wines were analysed using HPLC-DAD/FD, LC-QToF-MS and protein precipitation assay by Harbertson et al. (2002, 2003, 2015)[5-7].

3 Results and Discussion

Over the last 20 years, GDD in the Pfalz region were highest in the vintages 2018-2020. The day-of-year when reaching 20 Brix in PN was calculated for the decades 2002-2011 and 2012-2021, as well as the individual vintages. As shown by the correlation in Figure 1, the increase in GDD causes grapes to reach 20 Brixsooner. This observation indicates climate change in the region.

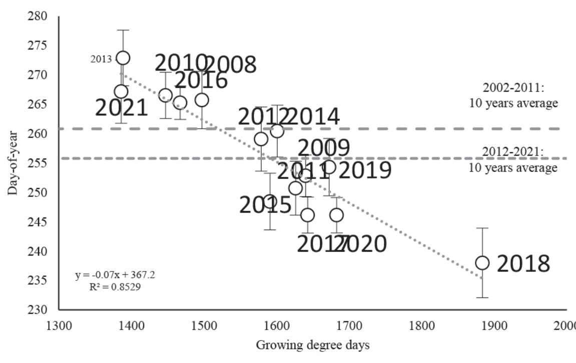

Figure 1. GDD in relation to day-of-year when reaching 20 Brix in Pinot noir (*n* = 10 vineyards in the Pfalz region; mean ± SD) for the vintages 2008-2021.

Besides TSS, winemakers consider the decrease in TA when determining their harvest time points. To evaluate whether climate change only causes a sooner maturity or accelerates the pace of ripening, the decrease in TA was related to the increase in TSS. This ratio is shown for the vintages 2008-2021 in Figure 2. As shown by the linear regressions of the ratio of TSS/TA, climate change causes sooner and accelerated ripening. However, sooner or accelerated ripening do not necessarily have to be connected with each other.

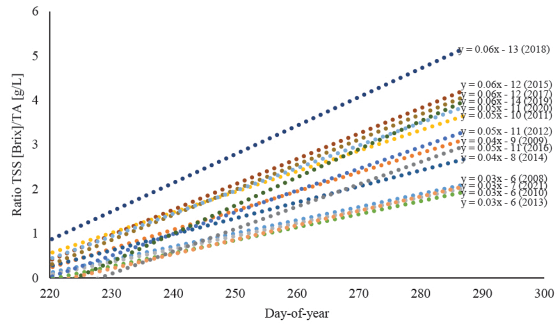

Figure 2. Linear regressions on the ratio of TSS/TA with day-of-year for PN of the vintages 2008-2021 (*n* = 10 vineyards in the Pfalz region).

To examine whether the observed differences in grape constituent contents are an effect of dilution or concentration, changes in berry size distribution need to be considered. The evolution of berry size distribution in PN and CS as a possible indicator of ripening heterogeneity was investigated for the vintages 2019 and 2020. In both grape varieties and both vintages, berry size distribution did not significantly change with progressing maturity (Fig. 3). The proportion of <13 mm PN berries was higher in 2020 than in 2019, indicating a higher heterogeneity, which is most likely due to rainfall near flowering of PN, as observed by Zhu et al. (2020) [8]. In contrast, CS berries tended to be larger in size in 2020 than in 2019. The contrasting observations indicate that changed weather conditions manifest differently in different grape varieties.

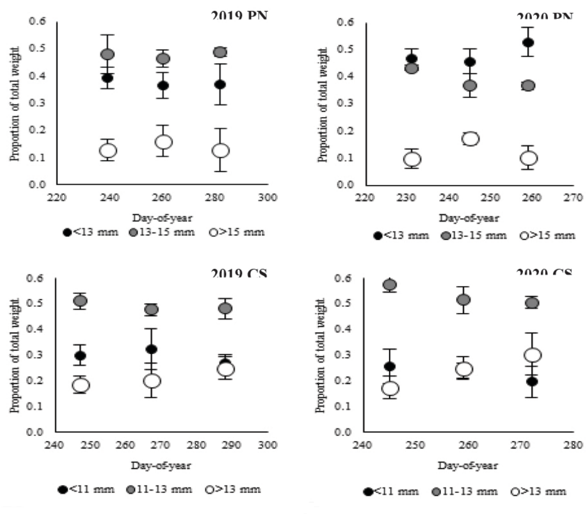

Figure 3. Berry size distribution of Pinot noir (PN) and Cabernet Sauvignon (CS) at different time points in the vintages 2019 and 2020. (*n* = 3 experimental replicates; mean ± SD).

Since wine quality cannot be defined solely by TSS and TA, the concept of phenolic maturity was introduced [9]. Recent research suggests that phenolic composition may be used to monitor grape maturity and predict wine composition and style [10].

The phenolic composition of PN and CS berries and resulting wines at three different maturities in two consecutive vintages was analysed in order to investigate the influence of grape maturity and vintages on the processability of the grapes. Tannin and anthocyanin contents in berries and resulting wines are shown in Figs. 4 (PN) and 5 (CS).

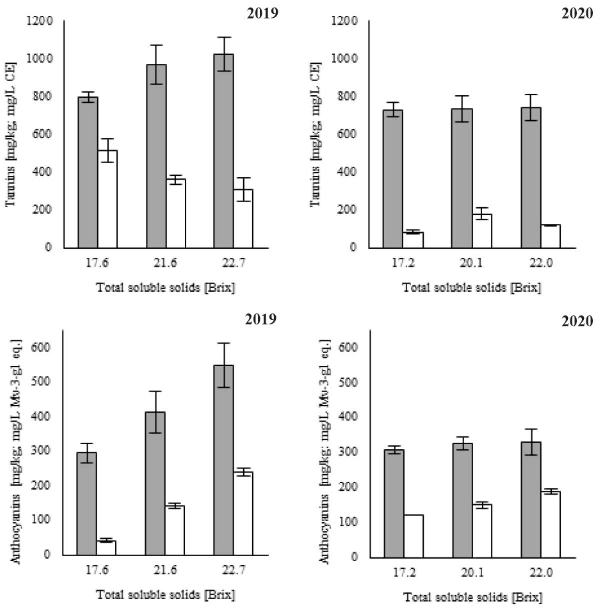

Figure 4. Tannin and anthocyanin content in PN berries (grey) and wine (white) at different time points in the vintages 2019 and 2020. (n = 3 experimental replicates; mean ± SD).

Irrespective of the vintage and grape variety, tannin and anthocyanin content was higher in berries than in wine. This can be explained by incomplete extraction and multiple reactions of phenolic compounds in the winemaking and ageing process. Tannin content in 2019 PN berries (Fig. 4) increased with progressing grape maturity, the tannin content in the corresponding wine decreased, indicating that tannins are more readily extracted in unripe PN berries. This trend could not be observed in the 2020 vintage. Tannin content in both, berries and wine, did not change with progressing grape maturity.

In CS on the other hand, tannin content in berries did not show a trend with progressing grape maturity (Fig. 5). In wine, however, tannin content increased with progressing grape maturity in both vintages, indicating that tannins have a higher extractability with progressing grape maturity. Therefore, the extractability of tannins is influenced by grape variety and grape maturity.

Irrespective of the vintage and grape variety, anthocyanin content in berries and wine (Figs. 4 and 5) increased with progressing grape maturity, indicating that the extractability of anthocyanins was not influenced by grape maturity.

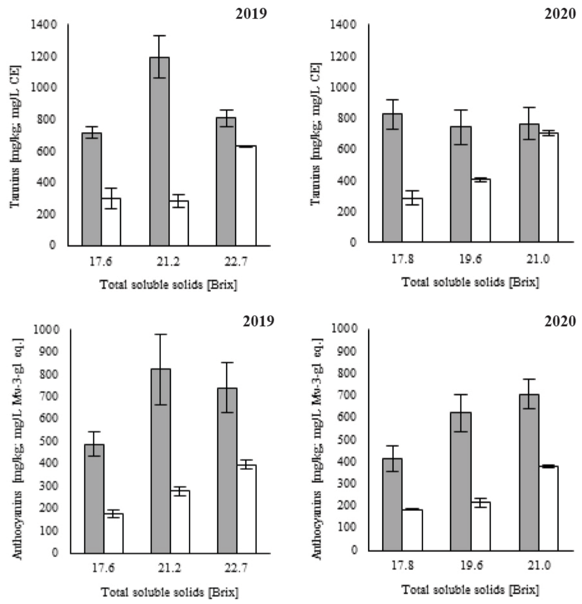

Figure 5. Tannin and anthocyanin content in CS berries (grey) and wine (white) at different time points in the vintages 2019 and 2020. (n = 3experimental replicates; mean ± SD).

Many other phenolic compounds than tannins and anthocyanins contribute to the berry and wine composition, such as phenolic acids and proanthocyanidins. Also newly formed phenolic compounds, such as polymeric pigments, which result from reactions during winemaking and ageing, can be found in wine.

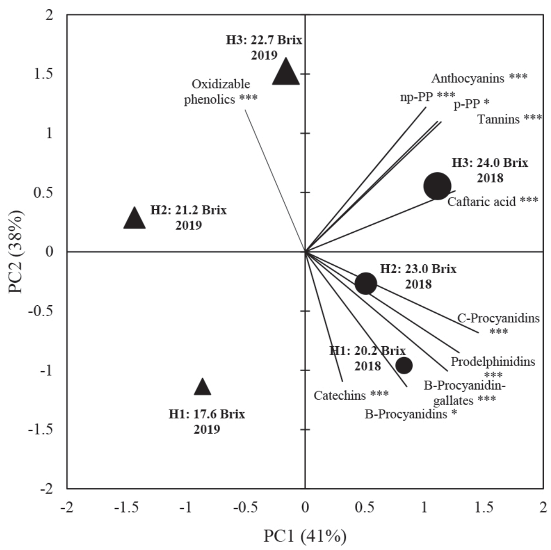

Figure 6. PCA for Cabernet Sauvignon wines produced from grapes at different harvest time points in two consecutive vintages (2018 circles, 2019 triangles). PCA space was calculated on the thirteen displayed chemical attributes. (n = 3 experimental replicates; * significant at $p < 0.05$, ** significant at 0.01, *** significant at 0.001).

A PCA was performed for the phenolic composition of CS wine in two vintages at different maturities (Fig. 6). The first PC segregated the wines by vintages. 2018 vintage wines were positively loaded on PC1 which is explained by higher contents of caftaric acid, C-procyanidinsand prodelphinidins. PC2 segregated the wines by maturity. H1 wines were negatively loaded on PC2 which is explained by higher contents of catechins and B-procyanidins. H3 wines were positively loaded on PC2 which is explained by higher contents of oxidizable phenolics, polymeric pigments (np-PP and p-PP), anthocyanins and tannins.

Progressing maturity has a great influence on the phenolic composition of wine. However, the difference between vintages was neither enhanced nor reduced by progressing maturity. Accordingly, earlier or later harvest could not compensate for the inter-annual ripening differences as indicated by TSS and TA. Changing weather conditions due to climate change require adaptions in viticulture and enological processing.

4 Conclusion

The effect of climate change on viticulture in the Pfalz region could be shown by relating GDD to TSS. Higher GDD resulted in an earlier and faster increase in TSS in Pinot noir, indicating that climate change causes sooner and accelerated ripening (TSS/TA). The study also revealed that sooner and accelerated ripening are not necessarily connected to each other. Although not significantly changing from 17 to 23 Brix, changing weather conditions over the years affect the grape cluster structure. The extractability of tannins was strongly influenced by progressing maturity and also by different vintage conditions. For anthocyanins, extractability differed for grape varieties and vintages, but progressing maturity seemed to have only a small influence. The processability of PN and CS grapes seems to be strongly affected by changing conditions due to climate change.

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