horticulturae

MDPI

Communication

First Experience of Late Pruning on Kékfrankos Grapevine (*Vitis vinifera* L.) in Eger Wine Region (Hungary)

Szabolcs Villangó [1,*], András Szekeres [2], György Végvári [1], Gitta Ficzek [3], Gergely Simon [3] and Zsolt Zsófi [1]

[1] Institute of Viticulture and Enology, Faculty of Natural Sciences, Eszterházy Károly Catholic University, Leányka út 12, H-3300 Eger, Hungary; vegvari.gyorgy@uni-eszterhazy.hu (G.V.); zsofi.zsolt@uni-eszterhazy.hu (Z.Z.)

[2] Department of Biotechnology and Microbiology, Institute of Biology, Faculty of Science and Informatics, University of Szeged, Dugonics tér 13, H-6720 Szeged, Hungary; szandras@bio.u-szeged.hu

[3] Department of Fruit Growing, Institute of Horticulture, Hungarian University of Agriculture and Life Sciences, Villányi út 29-43, H-1118 Budapest, Hungary; ficzek.gitta@uni-mate.hu (G.F.); simon.gergely@uni-mate.hu (G.S.)

* Correspondence: villango.szabolcs@uni-eszterhazy.hu

Abstract: Traditional winter pruning in dormancy (BBCH-00) as control (C) and three late pruning treatments, LP1 (wool stage—BBCH-05), LP2 (two leaves folded—BBCH-12), and LP3 (four leaves folded—BBCH-14), were applied on Kékfrankos grapevines. The evolution of the phenological growth stages, grape juice, wine analytical parameters, and phenolic composition were evaluated. The quantitative aspects of the grape berry, bunch, yield, and cane were also assessed. Our goal was to reach a decrease in sugar content and an increase in acidity. Delaying or postponing the phenological phases to bring technological and phenolic ripening closer together was also one of our objectives. These were accomplished, but the negative aspects of late pruning, which resulted in a reduction in the diameter and weight of the canes, should also be taken into account. We also found that, the later the late pruning, the more the yield was reduced. By postponing pruning, the phenological phases were also extended.

Keywords: late pruning; Kékfrankos; grapevine; phenology; wine phenolics

check for updates

Citation: Villangó, S.; Szekeres, A.; Végvári, G.; Ficzek, G.; Simon, G.; Zsófi, Z. First Experience of Late Pruning on Kékfrankos Grapevine (*Vitis vinifera* L.) in Eger Wine Region (Hungary). *Horticulturae* **2024**, *10*, 1223. https://doi.org/10.3390/horticulturae10111223

Academic Editors: Xiangyu Sun, Yu Wang and Xiangyi Li

Received: 13 October 2024
Revised: 6 November 2024
Accepted: 15 November 2024
Published: 19 November 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The negative effects of climate change on viticulture (e.g., increasing annual mean temperatures, uneven rainfall distribution, heat waves, prolonged droughts, floods, sunburn, and hailstorms) are already the subject of numerous studies [1–3]. Therefore, one of the most important topics is the adaptation of vineyards to these issues [3,4]. The investigation of new cultivation techniques or good practices can help us to counteract unfavourable changes in the climate. Reducing the sugar content of grapes and preserving their acidity are among the most important objectives especially in wine regions with a warm or hot climate. However, this problem is also a challenge in cool climate areas, in which extreme warm and/or dry vintages are becoming more and more common and accelerated ripening occurs as an issue [5–7]. In order to mitigate harmful effects in the vineyard, a number of viticultural techniques, as short-term applications, have been applied worldwide (e.g., late pruning, use of kaolin, forced regrowth, defoliation in different phenological phases, and severe shoot trimming) [3,8,9]. In this present research, we focus on late pruning (pruning at bud break and at different phenological stages afterwards). Late pruning could be a good tool to delay the phenological stages and thus slow down the ripening process [10,11]. This allows the grapes to be harvested with a lower sugar content, which can also reduce the potential alcohol content of the wine and maintain acidity, while phenolic maturity is not postponed [12]. Kékfrankos has a tendency toward accelerated sugar development in the Eger wine region, especially in the recent, warm and dry years. Phenolic and sugar

maturity, thus, do not coincide, resulting in disharmonious, often too alcoholic wines. One of the novelties of this study is the selection of the grapevine, as different cultivars, even if they grow under the same conditions, respond differently to this intervention [13]. With Kékfrankos (syn. Blaufränkisch, Lemberger), we still have very limited knowledge about the effects of late pruning, although it is the most widely planted grape variety in Hungary at present [14]. Two studies have already looked at the variety in terms of delayed pruning, but the main objectives were to reduce or avoid frost damage and to detect changes in flavour components [15,16]. In our study, preliminary results on the qualitative and quantitative parameters of the crop are presented, as well as the evolution of the phenological phases. The analysis of wine quality and its chemical composition is also an important task in the case of late pruning. Several studies on red grape varieties have been carried out to address these aspects, including Merlot [17], Sangiovese [18], Malbec [19,20], Syrah [20], Portugieser [21], and Lemberger [15,16]. This present study also deals with the routine analysis and flavonoid composition of Kékfrankos wines.

2. Materials and Methods

2.1. Experimental Vineyard

The unirrigated Kékfrankos (clone A 4-1) vineyard can be found in the Eger wine region, Kőlyuktető, Hungary (lat. 47°52′01.3″ N, long. 20°23′00.1″ E), planted in 2003. The vines are cordon-trained with a single arm on Teleki-Fuhr SO4 rootstock. The shoot positioning is vertical. The inter- and intrarow spacing is 2.4 m × 1.0 m, respectively. During pruning, eight buds were left per vine (four spurs with two nodes). All lateral shoots were removed during the season. A conventional spraying protocol was applied for the experimental blocks. The bunch zone was defoliated on both sides in the beginning of veraison. The height of the canopy was 120 cm. Cluster thinning was not applied.

2.2. Experimental Design

A total of 120 vines were included in the experiment, which were arranged in 3 completely random blocks, which meant 40 plants per block. In each block, all treatments (C, LP1, LP2, LP3) were included, so 10 plants per treatment were present in each of the three blocks. Traditional winter pruning in dormancy (BBCH-00) as control (C) and three late pruning treatments, LP1 (wool stage—BBCH-05), LP2 (two leaves folded—BBCH-12), and LP3 (four leaves folded—BBCH-14), were applied on the vines. The late pruning treatments were carried out when the winter pruned control vines reached the BBCH phenological stage (05; 12; 14, respectively).

2.3. Climatic Data

The data used to characterize the vintage were collected by an automatic meteorological station (Boreas Ltd., Érd, Hungary), located approximately 150 m away from the experimental site.

2.4. Winemaking

Three times 10 kg of grapes from each of the three late pruning treatments and control was used for microvinification. After destemming and crushing, co-inoculation with 20 g/100 L Uvaferm CM (Lallemand Inc., Montreal, QC, Canada) active dry yeast and with 10 mg L^{-1} lactic acid bacteria (Uvaferm Alpha, Lallemand Inc., Montreal, QC, Canada) was carried out in small plastic containers. Punch down was carried out twice a day at 16 °C during the whole fermentation process for 19 days. Pressing was executed between 0.8 and 1.0 bar. Free-run and press wines were blended. After malolactic fermentation, the wines were racked and transported to the laboratory for analysis.

2.5. Phenology

Codes and descriptions for the phenological growth stages of the grapevine (BBCH scale) were used according to Lorenz et al. [22]. Three vines from each block (nine in total)

from all treatments were examined to describe the vines' development status. These were averaged to give the typical phenological growth stages at the time.

2.6. Yield Components

In all, 15 vines (five from each of the three blocks in case of all treatments) were used to determine the average bunch number per vine. To determine the average bunch weight, a bunch was taken from each of the 15 vines. We collected and weighed 100 berries from all 15 harvested clusters for each treatment. The berries were sampled from the upper, lower, middle, sunny, and shady parts of the clusters. To determine the pruning weight, 15–15 vines were also selected from each treatment.

2.7. Cane Properties

For each vine, the total cane weight was measured separately, and one cane per vine was randomly selected to determine the diameter, which means 15–15 canes per treatment. The average diameter of the canes was assessed in the middle third of their total length.

2.8. Basic Chemical Analysis

Clusters were collected from 15 vines (5 vines per block) from which one must sample per block was taken (3 replicates). The juice and wine basic analytical measurements were carried out as per the recommendations of the OIV [23].

2.9. HPLC Measurements of Phenolic Components

The experimental wines were analysed without any treatment on a modular Shimadzu HPLC system (Shimadzu, Duisburg, Germany) equipped with a Kinetex 2.6 µ XB-C18 100A (100 × 4.6 mm) column at a flow rate of 1 mL/min and a Hitachi LaChrom HPLC system (Merck, Budapest, Hungary) coupled with an Hypersil ODS (250 × 4.6 mm, 5 µm) column with the mobile-phase flow rate of 0.8 mL/min. For the separation of different flavonoid compounds, eluent A and B were water and acetonitrile, respectively, both of them supplemented with 1% acetic acid, applying the following gradient program: initially, 0% B; at 16.40 min, 16.3% B; at 16.90 min, 18.4% B; at 20.30 min, 18.4% B; at 24.90 min, 19.4% B; at 27.50 min, 20.4% B; at 27.51 min, 100% B; at 30.4 min, 100% B; at 30.41 min, 0% B; and at 37.0 min, 0% B. The flavonoid contents of the samples [(+)-catechin, (−)-epicatechin, protocatechuic acid, gallic acid, vanillic acid, caftaric acid, *t*-caffeic acid, coumaric acid, quercetin-3-O-galactoside, quercetin-3-glucuronide, kaempferol-3-O-glucoside, and *t*-resveratrol] were identified and quantified using standard reference compounds detected at 280 nm.

2.10. Statistics

Statistical analyses were carried out with GraphPad Prism version 9.5 for Windows (GraphPad Software, San Diego, CA, USA), by one-way ANOVA, after which Tukey's HSD post hoc test was used for mean separation ($p < 0.05$).

3. Results and Discussion

3.1. Vintage Climatic Characteristics

In 2021, the annual mean temperature was 10.6 °C (60-year average: 10.8 °C), and annual rainfall was 408 mm (60-year average: 591 mm) at Kőlyuktető vineyards, of which 207 mm fell during the growing season. Compared with the 60-year average, it can be concluded that the experimental year was slightly cooler and drier.

3.2. Evolution of Phenology

The later the pruning, the more the bud break of the vine is delayed and with it the phenological phases start later during the season [24]. This phenomenon is one of the most powerful effects of late pruning on the plant, and it is mostly pronounced between bud break and veraison [19]. This could have practical and economic benefits. Among these are

the ability to avoid spring frosts by forced re-budding and to postpone the ripening process of the berries to a cooler period [12,24]. The delay in phenological phases was also clearly evident in the case of Kékfrankos (Table 1). For the LP1 treatment, it was necessary to wait until day 194 of the year to catch up with the development of the control vines (BBCH-77—beginning of berry touch). The LP2 treatment reached the control vines on day 215 of the year, when the berry touch was complete (BBCH-79). As expected, the LP3 treatment had the most pronounced effect on slowing down vegetation, as the developmental lag persisted even during the veraison period. Harvesting took place when the control vines exceeded 25 °Brix.

Table 1. Evolution of phenological stages (BBCH scale) for each treatment.

2021	DOY	Principal Growth Stages (BBCH-Code) for Each Treatment			
		C	LP1	LP2	LP3
04 March (Control pruning)	63	0	0	0	0
23 April (Late pruning 1)	113	5 (Wool stage)	5	5	5
29 April	119	7 (Beginning of bud burst)	5	5	5
04 May (Late pruning 2)	124	12 (Two leaves unfolded)	5	5	5
10 May (Late pruning 3)	130	14 (Four leaves unfolded)	9	7	5
17 May	137	19 (Nine or more leaves unfolded)	14	12	9
25 May	145	55 (Inflorescence swelling)	53	14	12
01 June	152	55 (Inflorescence swelling)	53	19	14
08 June	159	57 (Inflorescences fully developed)	55	53	19
15 June	166	61 (Beginning of flowering)	57	55	53
23 June	174	69 (End of flowering)	65	63	60
30 June	181	73 (Groat-sized berries)	71	69	68
07 July	188	75 (Pea-sized berries)	73	73	71
13 July	**194**	**77 (Beginning of berry touch)**	**77**	75	73
22 July	203	79 (Berry touch complete)	79	77	75
03 August	**215**	**79 (Berry touch complete)**	**79**	**79**	77
11 August	223	81 (Beginning of ripening)	81	81	79
19 August	231	83 (Berries brighten in colour)	83	83	81
24 August	236	85 (Softening of berries)	85	85	83
04 October (Harvest)	277	89 (Berries ripe for harvest)	89	89	89

Bolded rows show when each treatment outperformed the control in development. In the case of LP3, this did not happen even at maturation on day 236. DOY = day of year.

3.3. Grape Juice and Wine Analysis

Berries from the first treatment (LP1) had significantly lower sugar content compared with those from the control and the other two treatments (Table 2). For the LP2 treatment, the sugar reduction was not significant. However, the LP3 treatment resulted in an increase in °BRIX compared with the control, which can be explained by a significantly reduced yield (−32% due to reduced bunch number per vine and lower bunch and berry weight, see Table 4). Another possible way to explain this phenomenon is the fact that the leaves of the later-pruned vines are younger than those of the control or earlier treatments, so they may be more photosynthetically active during the ripening period [18]. Interestingly, the alcohol content of the wines was highest for the control, but there was no significant difference between the late pruning treatments in this respect (Table 3). An increased titratable acidity (as tartaric acid equivalent) of the grape juice has been shown (Table 2), which is in accordance with other findings [24]. The lowest values were found in the control vines. The later the pruning, the more acid was retained in the grape berries, with the exception of the difference between LP1 and LP2 treatments. The relationship between late pruning and wine acidity was also observed, to a lesser extent; however, the differences were still significantly different (Table 3). The pH value followed the trend of acidity inversely for both must and wine (Tables 2 and 3). The lowest values were obtained with the LP3 treatments. The malic acid content of the grape juice was also retained at higher levels in the treatments compared with the control, which is in

accordance with other findings [19,25], while the treatments were at the same level (Table 2). The amount of yeast-assimilable nitrogen (YAN) decreased on postponing the pruning to a later date (Table 2). However, the values obtained were below the desirable value (at around 200 mg L^{-1}) even for the control, which can easily result in slow, sluggish, or stuck fermentation if the yeast is not supplemented with external nutrients such as diammonium phosphate (DAP) [26]. This negative aspect should be taken into account when late pruning is applied. The lowering trend in YAN values can be in connection with the physiological consequences of late pruning, namely the vine is forced to another bud break as basal buds remain dormant to a high extent due to apical dominance [27]. In addition, the first bud break with a notable number of buds requires the intensive use of reserved nutrients, and these parts of the cane are removed by late pruning, so the application of late pruning for younger plantations, vines under biotic and/or abiotic stress, or vines with serious trunk disease symptoms should be considered. However, there are also findings that the total non-structural carbohydrates in the trunk, root, and cane were not affected by the application of late pruning [15,28,29].

Table 2. Standard analysis of the grape juices.

Parameter/Treatment	C	LP1	LP2	LP3
°Brix	25.5 ± 0.3 ab	24.9 ± 0.1 c	25.3 ± 0.2 bc	25.8 ± 0.1 a
Titratable acidity (g L^{-1})	6.1 ± 0.1 c	6.9 ± 0.1 b	7.1 ± 0.1 b	7.6 ± 0.1 a
Malic acid (g L^{-1})	3.2 ± 0.1 b	3.9 ± 0.1 a	3.8 ± 0.2 a	3.9 ± 0.2 a
pH	3.38 ± 0.01 a	3.23 ± 0.01 b	3.21 ± 0.01 b	3.17 ± 0.01 c
YAN (mg L^{-1})	135 ± 13 a	117 ± 3 ab	99 ± 7 bc	82 ± 8 c

Each value represents the average ± standard error of 3 replicates ($p < 0.05$). Values marked with different alphabets mean significant differences between treatments.

Table 3. Standard analysis of the wines.

Parameter/Treatment	C	LP1	LP2	LP3
Alcohol (*v*/*v*%)	13.98 ± 0.03 a	13.49 ± 0.04 b	13.52 ± 0.04 b	13.59 ± 0.06 b
Residual sugar (g L^{-1})	1.6 ± 0.2 a	1.7 ± 0.3 a	1.4 ± 0.2 a	1.7 ± 0.2 a
Titratable acidity (g L^{-1})	4.3 ± 0.1 c	4.4 ± 0.1 bc	4.6 ± 0.1 ab	4.8 ± 0.1 a
Malic acid (g L^{-1})	0.35 ± 0.05 b	0.36 ± 0.08 b	0.31 ± 0.07 b	0.51 ± 0.07 a
pH	3.82 ± 0.01 a	3.78 ± 0.02 ab	3.75 ± 0.02 bc	3.72 ± 0.02 c
Volatile acidity (g L^{-1})	0.40 ± 0.08 a	0.32 ± 0.02 a	0.34 ± 0.04 a	0.37 ± 0.05 a

Each value represents the average ± standard error of 3 replicates ($p < 0.05$). Values marked with different alphabets mean significant differences between treatments.

3.4. Change in Yield and Cane Parameters

The bunch number per vine was sensitively affected by the treatment (Table 4). Significantly fewer clusters emerged after late pruning, but all three treatments were at the same level. The average weight of clusters also decreased notably, but it was at the same level for LP2 and LP3. The average bunch weight decreased to below 200 g due to the latest pruning treatment despite the fact that Kékfrankos is a large-bunched variety. The reduction in average berry weight was not as pronounced as the decrease in average cluster weight, and there was no difference between the control and the first treatment. The decrease in yield could occur as a consequence of the reduction of bunches (Table 4) or due to a reduction in the number of berries [18]; however, this parameter was not measured. Previous studies report an ambiguous effect: decreasing [18,25,29], stagnating [30,31], or even increasing [15,32] trends in yield are observed as a result of late pruning. It should be noted, however, that the yield is influenced by numerous growing and experimental conditions (e.g., cultivar, terroir, climate, vintage, viticultural practices, and timing of the pruning). The average cane weight or pruning weight per vine was not affected by the treatments (Table 4). Some other studies have also come to this conclusion [29,33,34]. At the same time, the diameter of the canes was significantly reduced. The thinnest canes were formed on the LP3 treatment.

Table 4. Yield components of the grapevines.

Parameter/Treatment	C	LP1	LP2	LP3
Bunch/vine	12.5 ± 2.0 a	9.7 ± 1.7 b	10.1 ± 1.6 b	9.1 ± 1.6 b
Yield/vine (kg)	2.03 ± 0.33 a	1.94 ± 0.68 a	1.84 ± 0.59 ab	1.39 ± 0.43 b
Bunch weight (g)	362.2 ± 59.8 a	297.9 ± 71.6 b	227.4 ± 48.1 c	174.0 ± 35.7 c
Berry weight (g)	2.42 ± 0.32 a	2.46 ± 0.41 a	2.33 ± 0.34 ab	2.21 ± 0.40 b
Cane weight/vine (kg)	0.47 ± 0.07 a	0.46 ± 0.04 a	0.42 ± 0.05 a	0.44 ± 0.11 a
Cane diameter (mm)	8.5 ± 0.7 a	7.8 ± 0.7 ab	7.1 ± 0.8 bc	6.6 ± 0.9 c

Each value represents the average ± standard error of 15 replicates ($p < 0.05$). Values marked with different alphabets mean significant differences between treatments.

3.5. Flavonoids in the Wines

Among the building blocks of tannins, catechin and epicatechin were investigated (Table 5). The presence of both compounds increased with the late pruning treatment. In the case of epicatechin, the effect was very clear and linear, and there was a significant difference between all the samples. The increase in flavan-3-ols as a result of late pruning has been also confirmed by other studies on other varieties [20,21]. There were no significant changes in resveratrol concentration; however, earlier findings showed contradictory results [20,21]. The treatments had only a marginal effect on caftaric acid, caffeic acid, protocatechuic acid, quercetin-3-O-glucuronide, and kaempferol-3-O-glucoside (Table 5). Quercetin-3-O-galactoside presented a significant increase in LP3. However, there was no difference between the control, LP1, and LP2 treatments in this respect. Among flavonols, quercetin and myricetin are both increased due to the late pruning treatment according to Perin et al. [20]. Anić et al. [21] showed that the effect of late pruning on the total flavonol levels is not very pronounced, but the concentrations of molecules belonging to this group responded selectively and non-uniformly to the treatment. Vanillic acid and coumaric acid showed an upward trend after treatment. The later the intervention, the higher the concentration of these phenolic acids; this trend was also confirmed by Anić et al. [21]. The gallic acid levels were highest during the LP1 treatment and then showed a decreasing trend, while LP3 was at the same level as the control (Table 5). Overall, a smaller berry size may have contributed to an increase in the concentration of these components, resulting in a higher skin-to-mass ratio [35] (Table 4).

Table 5. Flavonoid content in Blaufränkisch wines under different pruning treatments (mg L^{-1}).

Parameter/Treatment	C	LP1	LP2	LP3
Caftaric acid	31.09 ± 0.31 a	31.34 ± 0.47 a	31.00 ± 0.29 a	29.61 ± 0.17 b
Caffeic acid	1.23 ± 0.16 c	2.40 ± 0.03 a	2.37 ± 0.02 a	1.66 ± 0.08 b
Coumaric acid	1.66 ± 0.21 b	3.59 ± 0.69 a	4.04 ± 0.18 a	4.24 ± 0.11 a
Gallic acid	11.57 ± 0.87 c	15.49 ± 0.17 a	14.31 ± 0.05 b	12.36 ± 0.08 c
Protocatechuic acid	4.20 ± 0.35 a	4.86 ± 0.80 a	3.65 ± 0.49 a	3.49 ± 0.41 a
Vanillic acid	6.85 ± 0.53 c	7.74 ± 0.97 bc	8.64 ± 0.17 b	11.25 ± 0.72 a
Catechin	11.70 ± 1.37 b	26.89 ± 4.80 a	31.50 ± 2.74 a	30.69 ± 0.82 a
Epicatechin	2.37 ± 0.22 d	4.31 ± 0.62 c	7.24 ± 0.55 b	10.79 ± 0.34 a
Quercetin-3-O-galactoside	5.21 ± 0.43 b	3.50 ± 1.27 b	4.50 ± 0.15 b	9.32 ± 0.28 a
Quercetin-3-O-glucuronide	5.48 ± 0.29 a	5.47 ± 0.35 a	4.32 ± 0.00 b	5.69 ± 0.47 a
Kaempferol-3-O-glucoside	5.61 ± 0.18 a	5.08 ± 0.53 a	3.99 ± 0.18 a	4.66 ± 1.40 a
Resveratrol	1.36 ± 0.13 a	1.37 ± 0.32 a	0.98 ± 0.08 a	1.45 ± 0.18 a

Each value represents the average ± standard error of 3 replicates ($p < 0.05$). Values marked with different alphabets mean significant differences between treatments.

4. Conclusions

Late pruning (in different phenological stages after bud break) could be used to delay the phenological stages and slow down the ripening process. All three treatments significantly lowered the alcohol content of the wines. The preservation of organic acids in the grape berries during the dry and warm growing seasons is also a key quality issue even

under cool climate conditions. In addition to quality, it is also important to examine (partly also for economic reasons) the quantitative parameters of the crop (e.g., berry weight, bunch weight, and bunch number), which can lead to economic losses due to a reduction in these parameters. However, it is also important to consider how this viticultural practice will affect different varieties and variety/terroir combinations, as they may lead to a deterioration in the vines' condition, which can result in negative changes in cane diameter. Overall, late pruning seems to work successfully in the Kékfrankos variety in terms of delaying ripening and increasing the quality parameters, but further experiments are also needed to find the right time to apply it. If it is implemented too early, the differences may be minimal, but if it is implemented too late, the negative effects may outweigh the benefits.

Author Contributions: Conceptualization, S.V.; methodology, S.V.; software, S.V. and A.S.; validation, G.F. and G.S.; formal analysis, A.S.; investigation, S.V.; resources, G.V.; data curation, A.S.; writing—original draft preparation, S.V.; writing—review and editing, Z.Z.; supervision, Z.Z. All authors have read and agreed to the published version of the manuscript.

Funding: The project financed from the NRDI (National Research, Development, and Innovation) Fund. Title: "Research and development to improve sustainability and climate resilience of viticulture and oenology at the Eszterházy Károly Catholic University" (TKP2021-NKTA-16).

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Droulia, F.; Charalampopoulos, I. Future climate change impacts on European viticulture: A review on recent scientific advances. *Atmosphere* **2021**, *12*, 495. [CrossRef]
2. Droulia, F.; Charalampopoulos, I. A review on the observed climate change in Europe and its impacts on viticulture. *Atmosphere* **2022**, *13*, 837. [CrossRef]
3. Sun, Q.; Granco, G.; Groves, L.; Voong, J.; Van Zyl, S. Viticultural manipulation and new technologies to address environmental challenges caused by climate change. *Climate* **2023**, *11*, 83. [CrossRef]
4. van Leeuwen, C.; Destrac-Irvine, A.; Dubernet, M.; Duchêne, E.; Gowdy, M.; Marguerit, E.; Pieri, P.; Parker, A.; de Rességuier, L.; Ollat, N. An update on the impact of climate change in viticulture and potential adaptations. *Agronomy* **2019**, *9*, 514. [CrossRef]
5. Karvonen, J. Changes in the grapevine's growth cycle in Southern Finland in the 2000s—Comparison between two first decades. *Clim. Change* **2022**, *6*, 94–99.
6. Töpfer, R.; Trapp, O. A cool climate perspective on grapevine breeding: Climate change and sustainability are driving forces for changing varieties in a traditional market. *Theor. Appl. Genet.* **2022**, *135*, 3947–3960. [CrossRef]
7. Schultze, S.R.; Sabbatini, P. Implications of a climate-changed atmosphere on cool-climate viticulture. *J. Appl. Meteor. Climatol.* **2019**, *58*, 1141–1153. [CrossRef]
8. Gutiérrez-Gamboa, G.; Zheng, W.; Martínez de Toda, F. Current viticultural techniques to mitigate the effects of global warming on grape and wine quality: A comprehensive review. *Food Res. Int.* **2021**, *139*, 109946. [CrossRef]
9. Palliotti, A.; Tombesi, S.; Silvestroni, O.; Lanari, V.; Gatti, M.; Poni, S. Changes in vineyard establishment and canopy management urged by earlier climate-related grape ripening: A review. *Sci. Hortic.* **2014**, *178*, 43–54. [CrossRef]
10. Petrie, P.R.; Brooke, S.J.; Moran, M.A.; Sadras, V.O. Pruning after budburst to delay and spread grape maturity. *Aust. J. Grape Wine Res.* **2017**, *23*, 378–389. [CrossRef]
11. Vercesi, A.; Garavani, A.; Parisi, M.G.; Gatti, M.; Poni, S. Vine performance and phenology postponement in cane-pruned Chardonnay vines grown in a temperate climate: The effects of a delayed winter pruning. *Aust. J. Grape Wine Res.* **2023**, *2023*, 1329802. [CrossRef]
12. Allegro, G.; Pastore, C.; Valentini, G.; Filippetti, I. Post-budburst hand finishing of winter spur pruning can delay technological ripening without altering phenolic maturity of Merlot berries. *Aust. J. Grape Wine Res.* **2020**, *26*, 139–147. [CrossRef]
13. Buesa, I.; Yeves, A.; Sanz, F.; Chirivella, C.; Intrigliolo, D.S. Effect of delaying winter pruning of Bobal and Tempranillo grapevines on vine performance, grape and wine composition. *Aust. J. Grape Wine Res.* **2021**, *27*, 94–105. [CrossRef]
14. National Council of the Wine Communities. 2023. Available online: https://www.hnt.hu/wp-content/uploads/2024/03/Magyarorszag.pdf (accessed on 13 October 2024).
15. Persico, M.J.; Smith, D.E.; Centinari, M. Delaying budbreak to reduce freeze damage: Seasonal vine performance and wine composition in two *Vitis vinifera* cultivars. *Am. J. Enol. Vitic.* **2021**, *72*, 346–357. [CrossRef]

16. Persico, M.J.; Smith, D.E.; Smith, M.S.; Hopfer, H.; Centinari, M. Delaying grapevine budbreak to prevent spring freeze damage impacts Lemberger wine flavour compounds under variable weather conditions: This article is published in cooperation with the 22nd GiESCO International Meeting, hosted by Cornell University in Ithaca, NY, July 17–21, 2023. *OENO One* **2023**, *57*, 331–343. [CrossRef]
17. Falginella, L.; Gaiotti, F.; Belfiore, N.; Mian, G.; Lovat, L.; Tomasi, D. Effect of early cane pruning on yield components, grape composition, carbohydrates storage and phenology in *Vitis vinifera* L. cv. Merlot. *OENO One* **2022**, *56*, 19–28. [CrossRef]
18. Gatti, M.; Pirez, F.J.; Chiari, G.; Tombesi, S.; Palliotti, A.; Merli, M.C.; Poni, S. Phenology, canopy aging and seasonal carbon balance as related to delayed winter pruning of *Vitis vinifera* L. cv. Sangiovese grapevines. *Front. Plant Sci.* **2016**, *7*, 659. [CrossRef]
19. Bustos Morgani, M.; Fanzone, M.; Perez Peña, J.E.; Sari, S.; Gallo, A.E.; Gómez Tournier, M.; Prieto, J.A. Late pruning modifies leaf to fruit ratio and shifts maturity period, affecting berry and wine composition in *Vitis vinífera* L. cv. 'Malbec' in Mendoza, Argentina. *Sci. Hortic.* **2023**, *313*, 111861. [CrossRef]
20. Perin, C.; Verma, P.K.; Harari, G.; Suued, Y.; Harel, M.; Ferman-Mintz, D.; Drori, E.; Netzer, Y.; Fait, A. Influence of late pruning practice on two red skin grapevine cultivars in a semi-desert climate. *Front. Plant Sci.* **2023**, *14*, 1114696. [CrossRef]
21. Anić, M.; Osrečak, M.; Štambuk, P.; Ljubičić, L.; Karoglan, M. Impact of late winter pruning of Portugieser grapevines (*Vitis vinifera* L.) on yield components and grape composition. In Proceedings of the 58th Croatian & 18th International Symposium on Agriculture Proceedings, Dubrovnik, Croatia, 11–17 February 2023; pp. 189–194.
22. Lorenz, D.H.; Eichhorn, K.W.; Bleiholder, H.; Klose, R.; Meier, U.; Weber, E. Growth stages of the grapevine: Phenological growth stages of the grapevine (*Vitis vinifera* L. ssp. vinifera)—Codes and descriptions according to the extended BBCH scale. *Aust. J. Grape Wine Res.* **1995**, *1*, 100–103. [CrossRef]
23. OIV. *Compendium of International Methods of Wine and Must Analysis*; International Organisation of Vine and Wine: Dijon, France, 2023.
24. Poni, S.; Sabbatini, P.; Palliotti, A. Facing spring frost damage in grapevine: Recent developments and the role of delayed winter pruning—A review. *Am. J. Enol. Vitic.* **2022**, *73*, 211–226. [CrossRef]
25. Gatti, M.; Pirez, F.J.; Frioni, T.; Squeri, C.; Poni, S. Calibrated, delayed-cane winter pruning controls yield and significantly postpones berry ripening parameters in *Vitis vinifera* L. cv. Pinot Noir. *Aust. J. Grape Wine Res.* **2018**, *24*, 305–316. [CrossRef]
26. Bell, S.-J.; Henschke, P.A. Implications of nitrogen nutrition for grapes, fermentation and wine. *Aust. J. Grape Wine Res.* **2005**, *11*, 242–295. [CrossRef]
27. Keller, M. *The Science of Grapevines*, 3rd ed.; Academic Press-Elsevier: Cambridge, MA, USA, 2020.
28. Thought, M.C.T.; Bennett, J.S.; Boldingh, H.L. Influence of retained cane number and pruning time on grapevine yield components, fruit composition and vine phenology of Sauvignon Blanc vines. *Aust. J. Grape Wine Res.* **2011**, *17*, 258–262. [CrossRef]
29. Palliotti, A.; Frioni, T.; Tombesi, S.; Sabbatini, P.; Cruz-Castillo, J.G.; Lanari, V.; Silvestroni, O.; Gatti, M.; Poni, S. Double-pruning grapevines as a management tool to delay berry ripening and control yield. *Am. J. Enol. Vitic.* **2017**, *68*, 412–421. [CrossRef]
30. Moran, M.A.; Sadras, V.O.; Petrie, P.R. Late pruning and carry-over effects on phenology, yield components and berry traits in Shiraz. *Aust. J. Grape Wine Res.* **2017**, *23*, 390–398. [CrossRef]
31. Zheng, W.; García, J.; Balda, P.; Martínez de Toda, F. Effects of late winter pruning at different phenological stages on vine yield components and berry composition in La Rioja, North-central Spain. *OENO One* **2017**, *51*, 363. [CrossRef]
32. Friend, A.P.; Trought, M.C.T. Delayed winter spur-pruning in New Zealand can alter yield components of Merlot grapevines. *Aust. J. Grape Wine Res.* **2007**, *13*, 157–164. [CrossRef]
33. Moran, M.A.; Bastian, S.E.; Petrie, P.R.; Sadras, V.O. Late pruning impacts on chemical and sensory attributes of Shiraz wine. *Aust. J. Grape Wine Res.* **2018**, *24*, 469–477. [CrossRef]
34. Frioni, T.; Tombesi, S.; Silvestroni, O.; Lanari, V.; Bellincontro, A.; Sabbatini, P.; Gatti, M.; Poni, S.; Palliotti, A. Postbudburst spur pruning reduces yield and delays fruit sugar accumulation in Sangiovese in central Italy. *Am. J. Enol. Vitic.* **2016**, *67*, 419–425. [CrossRef]
35. Ojeda, H.; Andary, C.; Kraeva, E.; Carbonneau, A.; Deloire, A. Influence of pre-and postveraison water deficit on synthesis and concentration of skin phenolic compounds during berry growth of *Vitis vinifera* cv. Shiraz. *Am. J. Enol. Vitic.* **2002**, *53*, 261–267.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.