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Article

Cane Girdling Influence on the Berry Texture Properties of Three Table Grape Varieties

Adrienn Mária Tóth [1,2], Zsolt Zsófi [1,*] and Szilvia Veres [2]

[1] Institute for Viticulture and Oenology, Eszterházy Károly Catholic University, Leányka u. 6, 3300 Eger, Hungary
[2] Department of Applied Plant Biology, Institute of Crop Sciences, University of Debrecen, Böszörményi Str. 138, 4032 Debrecen, Hungary
* Correspondence: zsofi.zsolt@uni-eszterhazy.hu

Abstract: The effects of cane girdling on the berry texture characteristics were studied in three table grape cultivars. The application was carried out at véraison. The total soluble solids (TSS, °Bx) of berry must and berry weight were measured. The berry mechanical properties were investigated by a texture analyser. A double compression test was used to determine berry hardness and its derived parameters. A puncture test was also applied to assess skin hardness, skin elasticity and skin break energy. Skin thickness was also investigated. The sugar concentration of the must and the berry weight after the girdling treatment were significantly higher compared to those of the control. Berry hardness, skin hardness and skin thickness were significantly affected by this technique. The changes in berry mechanical and quality parameters with this application did not show the same pattern as those observed during control ripening. Notably, in our experiment, after the girdling treatments, the higher berry hardness was accompanied with a higher sugar concentration compared to the control. The skin hardness showed lower values as a result of girdling. However, skin thickness was significantly higher in the girdled berries compared to the non-treated vines.

Keywords: girdling; texture profile analysis (TPA); table grapes; berry texture properties

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1. Introduction

The marketability of table grapes is highly influenced by the consumer demand; therefore, the market value of table grapes is mainly linked to berry size, colour and taste [1]. Grapes are among the most important foods and have been used throughout history for making wine or as table fruit. The global production of table grapes doubled between 2000 and 2018, and grapes are grown mainly in warm areas where the climatic conditions are more favourable compared to cool-climate areas [2,3].

Table grape growing is more difficult under cool climate conditions compared to the those of Mediterranean areas. The climatic conditions are warm enough from May to October, but in the case of late-maturity varieties, an early chilling can stop the ripening process at the beginning of October (e.g., Italia, Afuz Ali). In addition, humidity during the ripening process may cause several fungal diseases in table grapes because of the withdrawal of the chemical protection in this period. Therefore, technological applications play an extremely important role in sustaining the economic yield and marketability of table grapes in this region [4].

Several methods, such as phytotechnical applications, exogenous hormone stimulation (i.e., gibberellic acid, [5]), or the combination of these methods, have been already applied to improve table grape quality. Phytotechnical methods in themselves, such as cluster thinning, shoot trimming, and girdling, are also used for this reason. The combined use of these methods seems to be an effective agronomical technique to enhance berry quality and weight [6,7]. However, cluster thinning itself is not always as effective a method as when applied together with girdling [7].

Girdling as a traditional method means the removal of a small ring of the bark (the living phloem cells together with the outer dead cells of the bark) (3–6 mm) from the trunk, bunch, and shoot of a woody plant [4,8]. Usually, a special girdling tool is used for this application, which does not injure the cork of the plant. The wound around the phloem is a physical barrier for the transport of assimilates and hormones from leaves to roots. Consequently, it induces the accumulation of these compounds in certain parts of the plant; meanwhile, water and minerals can be transported from roots to leaves without hindrance. The sugar, auxin (IAA), and abscisic acid (ABA) concentrations increase, while the cytokinin level decreases in plant organs above the girdling wound [8].

Girdling resulted in several positive effects on berry characteristics, depending on the timing of its application [9,10]. For example, during anthesis, it improves the berry set, especially in seedless cultivars, and afterwards, it improves the berry size [9–12]. Furthermore, faster maturity and an enhanced, balanced colouring of the grape berries can be achieved by girdling at véraison [9,10].

Generally, girdling causes the accumulation of several components in the plants above the ringing of the phloem (i.e., clusters) [13] and thus results in an improved [14–16] and earlier harvest by 6–15 days [10]. The typical effects of girdling include increased berry or cluster size and total soluble solids [6,12,17,18] as well as higher total extractability of polyphenols [7]. In addition, this practice accelerates the berry colorization, as shown by previous studies [5,14,15,19]. Using it together with exogenous growing hormones, it is a common practice in the case of seedless cultivars, because the gibberellin synthesis in these varieties is insufficient to produce large berries [5,6,17,18].

Beside sugar concentration, acidity, size and colour, the texture properties of the whole berry and/or the berry skin can be also an important aspect for consumers with respect to grape quality [20]. Several studies have dealt with the description of grape berry textural properties. Bernstein and Lustig [21] conducted the first texture analysis on grape berries from three table grape varieties. They measured differences in berry firmness between the varieties. Recently, several studies have been published regarding grape berry texture profile properties, such as berry and skin hardness, skin thickness, etc. These studies presented further differences among several varieties in the texture properties [20,22–25] and revealed the effect of, e.g., different growing sites, environmental conditions, and harvest times on berry physical parameters [20,26–31]. From a practical point of view, intensive research has been conducted to reveal the relationship between berry skin properties and anthocyanin extractability in different grapevine varieties [28,32]. More recently, the major QTL for berry grape texture characteristics were also investigated [29].

As described above, there are several factors (such as variety, water deficit, growing place, harvest time) that have a significant impact on the quality and texture of the grape berry. Common phytotechnical applications (such as shoot and bunch thinning, defoliation, etc.) and special canopy management (such as early defoliation, girdling) also have great effects on grape quality [33–35]. However, the relationship between canopy management and berry texture has not been studied so far. Indeed, in this context, the physical parameters of the table grape berry are essential. The aim of this study was to reveal the effect of girdling, as a special canopy management, on berry quality and texture properties in three table grape varieties (Áron, Melinda, Muscat Pölöskei) on two consecutive years (2017 and 2018). This is the first study to show the links between a canopy management practice and berry texture.

2. Materials and Methods

2.1. Plant Material Experiment Site and Experimental Design

The treatment was conducted on the Áron, Melinda and Muscat Pölöskei table grape cultivars under commercial field conditions, during the 2017 and 2018 seasons in Abasár, Mátra wine region, Hungary. Each of the examined varieties was bred in Hungary. Áron (*Vitis* interspecific crossing) is a late-ripening white grape variety. Melinda (*Vitis vinifera linné* subsp. *vinifera*) is a blue grape variety and is characterized by second-period ripening.

Muscat Pölöskei is a white cultivar, (*Vitis* interspecific crossing) and usually ripens in early to mid-September.

The vines were planted between 2008 and 2010 with 3 m × 0.9 m row spaces. All vines were cane-pruned in vertical shoot position with 5–8 buds on a horizontal trellis. The crop load was set for two clusters per shoot.

The experiment was set in a randomized block design (three blocks per treatments, ten plants per block). The vines were in similar condition and had the same crop load in all blocks. Cane girdling was performed by a double-bladed tool that removed a 4 mm-wide ring of bark from the cane. The treatment was carried out at the beginning of véraison, as previously described by several authors [8,10,30].

Most of the developmental stages were very similar in 2017 for each grape variety; Melinda was girdled on 15 July, Pölöskei on 22 July, and Áron on 23 July, at the beginning of véraison. The sampling date was determined by the taste and colour of the treated vines. The samples were taken on 30 August (Melinda), 8 September (Muscat Pölöskei), and 22 September (Áron) in 2017. The next year was unusually hot and dry. The average temperature was 11.30% higher, while the annual precipitation was 26.40% lower in 2018 than in 2017 (Figure 1). Therefore, the girdling was conducted earlier in 2018 than in 2017 (Melinda—9 July, Pölöskei—on 18 July, Áron—22 July). The harvest dates were 23 August for Melinda and Muscat Pölöskei and 20 September for Áron.

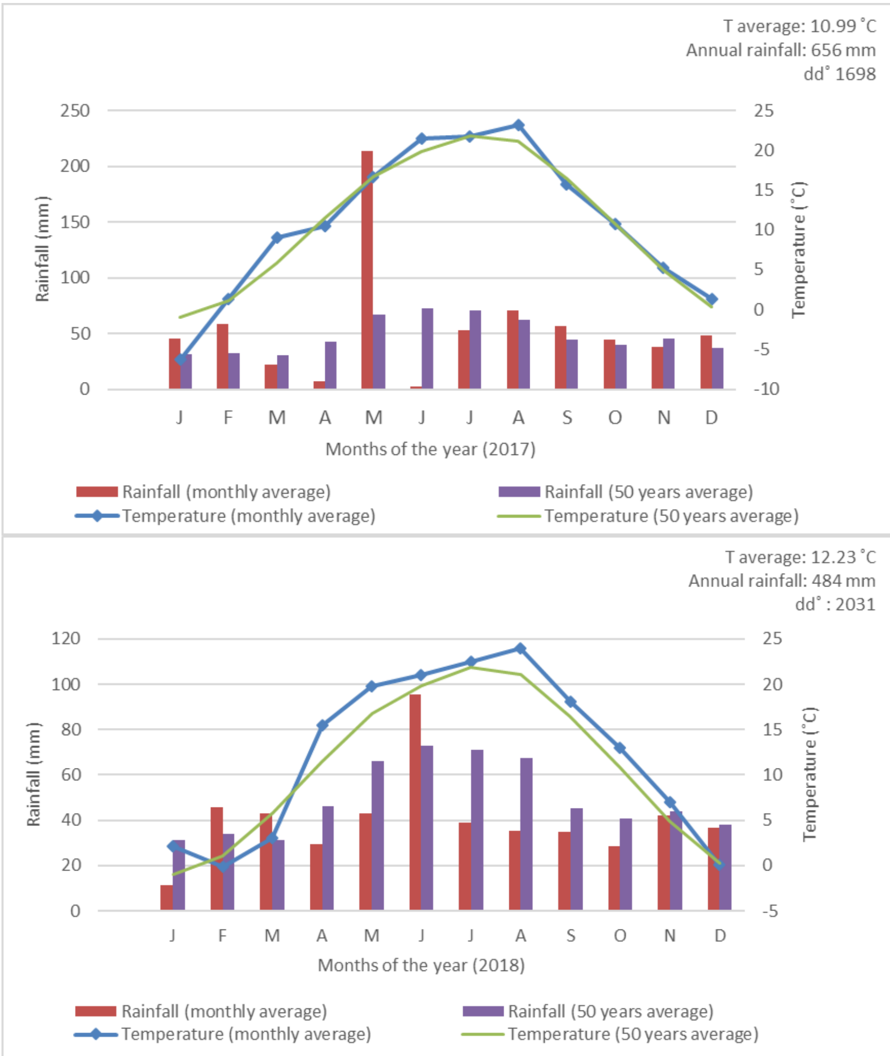

Figure 1. Monthly average air temperature (line) and monthly precipitation (bars) in 2017 and 2018 (Eger, Kőlyuktető).

2.2. Berry Sampling

At harvest, 20 grape bunches per treatment were collected from each cultivar in each block (2 clusters per plant; altogether 60 clusters per treatment). Berries for the measurements were taken from each cluster (5–6 berries/cluster). The berries were removed with pedicels from the same position of the clusters and visually tested before the analysis. Altogether, fifty berries were taken for the texture analyses, and another 100 berries were selected randomly to measure the average berry weight per treatment. The rest of the sample clusters per treatment were crunched and pressed for further measurement. The total soluble solids were determined in three replicates in each treatment. At 20 °C, the total soluble solids (°Bx) were measured using a portable refractometer.

2.3. Texture Analysis

Grape mechanical properties were evaluated using TA.XTplus Texture Analyser (Stable Micro System, Surrey, UK), software version Exponent 6.1.1.0, with an HDP/90 platform and 30 kg load cell. Each type of mechanical measurements required fifty berries. The Exponent 5.1 software was used for data evaluation. Operative conditions were applied according to Letaief et al. 2008 [31] (briefly: the AP/35 probe was used to determine the hardness of the berries (BH, N)). The berry hardness is measured as the force (N) necessary to attain a given deformation [31]. Berries of similar size, with their pedicel carefully removed from the bunch, were placed on the plate of the analyser. They were compressed to 25% of their original diameter. The test speed of the compression was 1 mm s^{-1}. From the force-time curves, more texture properties could be derived from berry hardness, such as berry cohesiveness (BCo—the strength of the internal bonds in the berry), gumminess (BG—the force needed to dissolve a semisolid food ready for swallowing (N)), springiness (BS—the distance between the end of the first bite and the start of the second bite (mm)), chewiness (BCh—the energy needed to chew a solid food until ready for swallowing (mJ)), and resilience (BR—how well a berry fights to resize its original position) [31,36,37]. The values of these parameters were calculated from the force-time curve of the compression test [20]. The berry cohesiveness and resilience are dimensionless parameters.

A P/2N needle was applied to conduct a puncture test. Berries with their pedicel removed from the bunch were laid on the plate of the analyser and then were punctured on the lateral face [32]. The test was carried out at a 1 mm s^{-1} speed. The needle was pushed into the samples to a depth of 3 mm. Skin break force (F_{sk}, N), skin break energy (W_{sk}, mJ), and Young's modulus of the berry skin (E_{sk}, N/mm) were calculated from the puncture test.

Berry skin thickness (S_{psk}, mm) was determined using a P/2 probe with a 2 mm diameter. The test speed was 0.2 mm s^{-1}. For this measurement, about 0.25 cm^2 of skin was removed from the lateral face of the berry. The pulp was carefully and gently peeled from the skin, which was then placed on the platform, and the test was carried out as described by other authors previously [38,39].

2.4. Statistical Analysis

Statistical analysis was accomplished by GraphPad Prism software version 6 (GraphPad Software Inc., La Jolla, CA, USA). Unpaired *t*-test for $p \leq 0.05$ was used to reveal the statistical differences in the mean values of the parameters between the treatments. Vintage differences were detected by GLM analysis of IBM SPSS Statistics version 25.

3. Results

3.1. Berry Weight and Berry Quality Parameters

Significant differences were measured in berry weight among the varieties in both years. The girdled vines presented higher berry weights compared to the control ones. In 2017, the difference between the treatments was about 1.5 g for each variety. By contrast, these differences were strongly reduced the following year (the difference was around 0.9 g in for each variety) (Table 1).

Table 1. Berry fresh weights and total soluble solids (TSS, °Bx) of the grape juices in the experimental years.

	2017			2018		
	Áron	**Melinda**	**Muscat Pölöskei**	**Áron**	**Melinda**	**Muscat Pölöskei**
Total soluble solids (°Bx)						
C	17.47 b	15.8 a	24.17 a	19.43 a	14.20 b	17.30 b
G	20.87 a	18.10 a	25.47 a	20.77 a	17.5 b	20.20 b
p value	<0.001	<0.001	0.26	<0.01	<0.0001	<0.001
Berry weight (g)						
C	4.212 a	7.703 a	3.437 a	4.274 a	6.441 b	3.512 a
G	5.718 a	9.183 a	4.380 a	5.155 b	7.381 b	4.411 a
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Berry weights (n = 100), TSS concentration (n = 3). C: Control, G: Girdled. Average values with different letters within a row indicate significant differences ($p < 0.05$) between the vintages for each cultivar.

The girdled samples presented higher TSS compared to the controls in both years (Table 1). In 2017, the increase of TSS in the girdled samples was 19% for Áron and 15% for Melinda.

In 2018, the highest increase in TSS in the girdled samples compared to the control samples was observed for Melinda (23%), followed by Muscat Pölöskei (18%) and Áron (7%) (Table 1).

Differences were found between the two vintages. The Brix values of the girdled and control samples of the Melinda and Muscat Pölöskei varieties were higher in 2017 than in 2018. Conversely, the control samples of the Áron variety had a higher °Brix in 2018.

3.2. Texture Quality Parameters

In the first year, the berry hardness (BH) of the girdled vines was significantly higher in each variety (Table 2). The mechanical properties of the whole berry such as gumminess (BG), springiness (BS), and chewiness (BCh) (Table 2) showed a very similar pattern to BH. The berry cohesiveness (BCo) of the girdled samples of Áron was significantly lower compared to that of the control berries. In contrast, these values increased by 11% for girdled Melinda samples and, furthermore, there were no significant differences in this parameter between the treatments in the case of Muscat Pölöskei. The gumminess (BG) of the treated berries for Melinda (766.9 mN) and Muscat Pölöskei (477.7 mN) showed significantly higher values compared to the control (636.9 mN for Melinda and 443.3 mN for Muscat Pölöskei). The girdled berries of Áron and Melinda were significantly springier, while the Melinda and Muscat Pölöskei varieties had chewier girdled berries compared to the control. Significant differences in resilience (Br) were found between treatments in all varieties, with Melinda girdled berries presenting higher resilience (0.185) and in Áron (0.219) and Muscat Pölöskei (0.231) berries presenting lower values compared to the control samples (Áron—0.265, Melinda—0.157; Muscat Pölöskei—0.245).

There were significant differences between the treatments in skin break force (F_{sk}) and skin break energy (W_{sk}) in Áron, with lower values observed for the girdled samples compared to the control ones (Table 3). There were no significant differences in Young's modulus (E_{sk}) between the treatments in 2017. In addition, there were no significant differences in skin thickness in Muscat Pölöskei (Figure 2). On the other hand, girdling resulted in a 16% increase in skin thickening in the case of Áron and a 15.7% increase for Melinda samples compared to the control berries.

In 2018, there were no remarkable differences in berry hardness (BH) in Muscat Pölöskei; however, girdling resulted in significantly harder berries in the case of the Melinda and Áron berries compared to the control (Table 2). Interestingly, the girdled samples of Muscat Pölöskei had lower values of berry cohesiveness (BCo). The treated berries of Áron and Melinda cultivars were gummier (BG), and there was no significant difference in berry springiness (BS) in Melinda. In addition, the berry chewiness (Bch) of the girdled samples of those two cultivars differed significantly from that of the control, the berries of the girdled Áron and Melinda varieties being chewier. The springiness resilience values also showed significant differences between the treatments in Muscat Pölöskei.

Table 2. Results of the grape berry texture profile analyses in 2017 and 2018.

2017		**BH (mN)**	**BCo**	**BG (N)**	**BS (mm)**	**BCh (mJ)**	**BR**
Áron	C	956.4 a	0.5507 a	518.0 a	3.660 b	1911 a	0.2647 a
	G	1091 a	0.4838 a	513.5 a	3.836 b	1971 a	0.2187 a
p value		<0.01	<0.001	0.872	<0.01	0.989	<0.0001
Melinda	C	1751 a	0.3675 a	636.9 a	3.852 a	2469 a	0.1566 a
	G	1881 a	0.4078 a	766.9 a	4.033 a	3109 a	0.1851 a
p value		<0.05	<0.01	<0.0001	<0.01	<0.0001	<0.0001
Muscat Pölöskei	C	820 a	0.5427 a	443.3 b	3.413 b	1517 b	0.2449 a
	G	912.9 a	0.5272 a	477.7 a	3.426 b	1638 b	0.2306 a
p value		<0.001	1.000	<0.01	0.805	<0.05	<0.05
2018							
Áron	C	969.6 a	0.4601 b	489.3 b	3.871 a	1672 b	0.1977 b
	G	1047 a	0.4744 a	546.2 a	4.014 a	1962 a	0.2075 a
p value		<0.05	0.683	<0.01	<0.01	<0.01	0.999
Melinda	C	1542 b	0.4205 b	643.4 a	3.874 a	2502 a	0.1855 b
	G	1712 a	0.4220 a	713.7 a	3.865 b	2756 b	0.1862 a
p value		<0.05	0.999	<0.01	1.000	<0.05	0.997
Muscat Pölöskei	C	866.2 a	0.5467 a	471.3 a	3.548 a	1673 a	0.2345 b
	G	905.7 a	0.5263 a	474.3 a	3.697 a	1756 a	0.2242 a
p value		0.827	<0.05	1.000	<0.001	1.000	<0.05

C: Control, G: Girdled. BH: berry hardness; BCo: berry cohesiveness; BG: berry gumminess; BS: berry springiness; BCh: berry chewiness; Br: berry resilience. Average values with different letters within a row indicate significant differences ($p < 0.05$) between the vintages for each cultivar ($n = 50$).

Table 3. Results of the berry skin puncture test in the experimental years (2017, 2018).

2017		**F_{sk} (N)**	**E_{sk} (n/mm)**	**W_{sk} (mJ)**
Áron	C	458.3 a	0.7119 a	0.1933 a
	G	413.3 a	0.7048 b	0.1643 a
p value		<0.05	0.743	<0.05
Melinda	C	410.8 a	1.174 a	0.0956 b
	G	391.4 a	1.126 a	0.0920 b
p value		0.291	0.892	0.064
Muscat Pölöskei	C	556.6 b	0.6394 a	0.2490 a
	G	538.3 a	0.5918 a	0.2496 a
p value		0.346	0.116	0.849
2018				
Áron	C	327 b	0.7138 a	0.1059 a
	G	293.7 b	0.7940 a	0.0787 a
p value		<0.05	<0.05	<0.01
Melinda	C	396.6 a	0.7808 b	0.1340 a
	G	389.1 a	0.8380 b	0.1173 a
p value		0.688	0.690	0.143
Muscat Pölöskei	C	573.8 a	0.5859 a	0.3147 a
	G	499.2 a	0.5327 b	0.2758 a
p value		<0.001	<0.01	<0.001

C: Control, G: Girdled, F_{sk}: skin break force, E_{sk}: Young's modulus of the skin, W_{sk}: skin break energy. Average values with different letters within a row indicate significant differences ($p < 0.05$) between the vintages for each cultivar ($n = 50$).

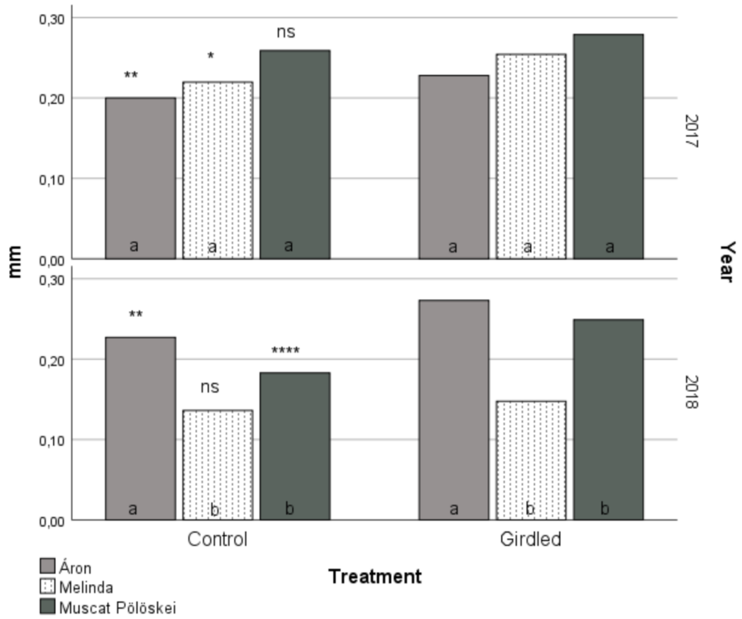

Figure 2. Results of the berry skin thickness test in the experimental years (2017, 2018). (n = 50), * above the columns indicates a significant difference between the treatments in each cultivar; * $p \leq 0.05$, ** $p < 0.01$ and **** $p < 0.0001$, ns = not significant. Different letters within the columns indicate significant differences ($p < 0.05$) between the vintages for each cultivar.

Differences were detected in berry hardness and its derived parameters between the two vintages (Table 2). The berry resilience of the control samples varied significantly between 2017 and 2018 in all three varieties, whereas the berry hardness showed differences in the case of the Melinda control samples. Berry cohesiveness was higher in 2017 than in 2018 in Áron and Melinda control samples. The gumminess and chewiness of the Áron control samples presented higher values in 2017 than in 2018. In the control samples of Muscat Pölöskei, however, the gumminess and chewiness showed lower values in 2017 than in 2018. In addition, the girdled samples of Muscat Pölöskei were significantly chewier in 2018 than in 2017. The girdled berries of the Melinda variety were springier in 2017; meanwhile, the treated and untreated samples of Muscat Pölöskei were less springy in 2017 than in the next year.

The berry skin break force (F_{sk}) and break energy (W_{sk}) were significantly lower in the treated samples of the Áron and Pölöskei varieties (Table 3). The Young's modulus (E_{sk}) of these two varieties was also found to be different; however, the girdled berries had higher values in the case of Áron and lower values in the case of Muscat Pölöskei. No effect of the application was seen in skin break force (F_{sk}), energy (W_{sk}) and Young's modulus (E_{sk}) of the Melinda variety. A significant effect was detected in the Áron and Muscat Pölöskei varieties, with a thicker skin for the girdled berries (Figure 2). The increase in skin thickness of the girdled samples was 18% for Áron and 37% for the Muscat Pölöskei variety.

Vintage differences were found between the berry skin hardness (F_{sk}) of the control and treated samples of Áron and the control samples of Muscat Pölöskei. Both varieties had higher skin hardness (F_{sk}) in 2017 than in 2018; meanwhile, the control samples of Muscat Pölöskei showed lower values of this parameter in 2017 than in 2018. The Young's modulus of elasticity was higher for the Melinda samples (treated and control) and the girdled samples of Muscat Pölöskei in 2017 compared to 2018. However, these parameters for the girdled Áron samples were lower in 2017 than in 2018. The skin break energy value (W_{sk}) of the girdled and control Melinda samples were lower in 2017 than in 2018. In 2017, significantly thicker skin was detected in the cases of Melinda and Muscat Pölöskei berries, both in girdled and control samples.

4. Discussion

Girdling carried out at the beginning of véraison results in faster ripening of table grapes [8,10,40]. It induces enhanced coloration of the berries [10,14,15,17–19] and technological grape berry maturity with lower acidity and higher sugar concentration, as reported in several earlier studies [5,14,17,30].

In our experiments, similar results were obtained. The sugar concentration of the girdled berries was significantly higher compared to that of the control ones. This means that the sugar ripening was faster in the girdled berries compared to the control [10,14,16,30]. In addition, the treatment resulted in significantly larger berries for all cultivars in both years (Table 1). These phenomena were due to the accumulation of carbohydrates and nutrients in the plant organs above the girdle, as reported earlier by Roper and Williams [13].

A texture profile analysis of the berries showed significant differences between the treatments in several berry texture parameters. Many studies [20,24,28,32,37,41] indicated that grape maturity has a significant impact on berry texture properties [20,24,28,32,37,41]. However, environmental conditions such as strength and timing of a water deficit [26,27,38] and vineyard location [28] have a significant impact on the ripening processes as well as on berry texture parameters.

Several studies reported that the lower the berry hardness, the higher the must sugar concentration. Indeed, berry hardness (BH) decreases from véraison to harvest, while the sugar concentration of the berries increases [20,36,42]. In contrast, in our study, the high BH values of the girdled treatment were accompanied with higher sugar concentrations compared to the control in each cultivar (Tables 1 and 2). One possible reason for this phenomenon could be the relationship between berry size and BH, as has been reported previously in other studies [25,26]. In these works, it was concluded that the larger the berries, the greater the berry hardness. Another possible reason for this phenomenon could be the osmoregulation processes above the girdling wound. Water enters the grape berries dominantly through the xylem until véraison, and thereafter this process is mediated by the phloem [43]. The water and minerals in the xylem sap travel upwards to the canopy of the plant, whereas certain assimilates produced by photosynthesis are transported by the phloem downwards to the roots. Consequently, the gap around the bark created by the girdling does not allow the phloem transport to the roots. In parallel, a greater assimilate accumulation can be observed in these plant parts compared to the controls [14,16]. This increased assimilate concentration, as well as the indirect effect of increased ABA, causes leaf stomatal closure, which reduces canopy water loss [13,44,45]. In addition, the travel of phloem water to the berry is osmotically regulated [43], and therefore, the higher sugar concentration of the girdled berries may result in a more intense water influx.

In our experiment, berry gumminess (BG), springiness (BS), and chewiness (BCh) showed a similar pattern to that of berry hardness (Table 2). Other derived parameters of the double compression test such as berry cohesiveness (BCo) and berry resilience (Br) did not show consistent results according to the treatments. The gumminess values were significantly higher in the case of the girdled Melinda variety in both years, and the same phenomenon was observed in Muscat Pölöskei in 2017 and in Áron in 2018. It was reported that the higher gumminess of the treated berries showed a relationship with berry size [25]. However, Río Segade et al. [36] observed a decreasing tendency of the gumminess values during ripening (as the berry sugar concentration increased) in the Mencía, Brancellao, and Merenzao grapevine varieties. In most studies, berry springiness and chewiness decreased when the ripeness increased [36,42]. Furthermore, Rolle et al. [25] observed that the values of berry gumminess, springiness, and chewiness were higher when the berry diameter was greater. These results are supported by our data. Notably, the springiness and chewiness showed an increasing tendency in each variety as a result of girdling, although the differences were not significant in some cases. Indeed, the girdled berries of Melinda were springier and chewier compared to the control in 2017 (Table 2). Similarly, the berries of the Áron variety were springier, and the berries of the Muscat Pölöskei variety were chewier due to this treatment in 2017. Interestingly, only the girdled Muscat Pölöskei had springier berries the next year; however, the chewiness values were higher in the case of the girdled Áron and Melinda berries. Anyway, it seems that BG, BCh, and BS are influenced by the girdling treatments. However, vintage has a great effect on these parameters, as was described earlier by Letaief et al. [31]. In our experiment, vintage also had an effect, especially on the control samples of each variety. The major difference between the two vintages is that 2018 was warmer and dryer than 2017. Due to the climatic conditions, the phenological phases began earlier, and therefore the harvest started earlier in 2018 than in 2017 (personal observation). This might lead to some controversial outcomes regarding the effects of girdling on the berry texture parameters.

The strength of the inner cohesion depends on the cell wall structure of each grape variety [20]. According to previous studies, berry cohesiveness increases during ripening [46] and therefore could be a reliable ripeness indicator [42] and also a useful index for viticultural subzone differentiation [41]. Berry cohesiveness, on the other hand, appears to be influenced by the berry sugar ripeness and is independent from the berry diameter [25,36]. In our study, we did not find significant differences between the treatments, in spite of the significant differences in sugar ripeness. In addition, controversial results were obtained when the differences were significant between the treatments (Table 3). Indeed, the berry cohesiveness of the girdled samples was higher in Melinda in 2017. On the other hand, the girdled berries of Áron in 2017 and Muscat Pölöskei in 2018 were less cohesive than the control ones. These opposite results suggest that this textural parameter may be influenced by variety characteristics, vintage effects, as well as harvest timing. This idea is supported by other authors as well [25,36]. In one of these studies, berry cohesiveness of the Muscat Hamburg variety decreased as the sugar concentration increased, and no differences were found when the data were presented in a normalized form [25]. In contrast, in the case of the Crimson Seedless table grape, Rio Segade et al. [36] reported an increasing trend of BCo normalized values in parallel with the increase of berry sugar concentration. Berry resilience shows ”how well the berry fights to regain its original position” [31] and seems to be independent from berry size [24]. Several studies have found that berry resilience is similar to BCo; however, it appears that the change of this parameter during ripening is primarily determined by the grape variety. Indeed, some decrease was observed in the case of the Mencía and Merenzao grapevine, while no significant changes were found in Brancellao berries [42] during the ripening period. In addition, an increasing trend was observed when the data were normalized in the case of the Crimson Seedless cultivar [36]. In our study, similarly to the BCo data, berry resilience (Br) did not show a relationship with the girdling treatment. No significant differences were found between the treatments in several occasions. Furthermore, controversial results were obtained for the different varieties. Indeed, girdling resulted in higher BR values in Melinda, while, in contrast, the BR of the Muscat Pölöskei girdled samples was lower. Anyway, as a conclusion, it seems that both berry texture properties (BCo and Br) depend more on the variety than on this technological application.

Taking the results of the puncture test, girdling resulted in significant differences in berry skin texture compared to the control berries in several experiments. Some studies suggest that the skin break force (F_{sk}) could be a maturity indicator, as relationships were observed between grape phenolic maturity and skin hardness [39]. However, the trends of this parameter may either change or be steady during ripening. Indeed, in the case of the Nebbiolo cultivar, in the berries of the greatest density class [24,37], F_{sk} increases during the first part of the ripening phase, then slowly decreases until physiological maturity is achieved. In addition, this parameter shows some relationship with berry must pH, as was reported in other studies [42,47]. In our experiment, F_{sk} had lower values after the girdling treatment compared to that measured for the control; however, the difference between the treatments was not significant in any sample (Table 3). These data are in contradiction with other results, if we draw a parallel between skin textural behaviour and berry sugar ripeness. Indeed, in the paper of Rolle et al. [25], a higher skin break force was accompanied with a higher sugar concentration. Anyway, these contradictions suggest that the berry sugar maturation and berry skin texture characteristics do not show a similar pattern on every occasion. Different environmental conditions such as timing of water deficit [19] and cultivation technologies may have a profound effect on the relationships of berry skin texture and ripening processes. Interestingly, we did not find any relationships between the derived parameters of the puncture test (skin break energy, skin elasticity) and the girdling treatment, in spite of the fact that these parameters generally change during the ripening process [39].

Interesting results were obtained in the case of berry skin thickness (S_{psk}) (Figure 2). This parameter is widely studied in the context of berry ripening processes. Indeed, skin thickness and the skin-to-flesh ratio seem to be predictors of grape ripeness as well as water status [35,38,48], inspected it in Red Globe berries with different sugar ripeness. In this study, berry skin thickness increased in parallel with sugar ripeness. In our experiment, girdling resulted in a thicker berry skin, which was probably due to the accumulation of assimilates, and thus to an increase in cell wall metabolism. Furthermore, it seems that, similarly to other studies, there was no relationship between skin break force and skin thickness [26,36].

5. Conclusions

Cane girdling at véraison had a significant effect on grape berry quality parameters and berry texture characteristics. An increase of berry hardness seemed to be a general consequence of this practice. However, some derived parameters of the double compression test showed controversial results. This suggests that the variety and vintage may have a significant effect on these derived parameters. Similarly to berry hardness, skin thickness and skin break force were also influenced by this application. One conclusion of this study is that some texture parameters could be useful indicators of the effect of viticultural technologies and may help us to make the right decisions during the grape growing process (e.g., optimal harvest time). On the other hand, some berry texture parameters of the girdled vines did not show a similar pattern/outcome to those observed during the normal ripening processes (e.g., BH, F_{sk}). This suggests that berry texture can also be manipulated by phytotechnical methods (similarly to other quality parameters, e.g., concentration of sugar, acidity, phenolics). This is a considerable fact, because it is well known that berry physical characteristics play an important role in table grape marketability as well as in quality wine making (such as phenolic extractability). The timing of the special canopy management is also an important aspect of grape quality. Therefore, further studies are needed to show the effect of these specific techniques conducted at different growing stages on berry texture, especially under a cool climate. Additional analytical studies (e.g., chemical compounds, aroma potential) and instrumental measurements (e.g., gas exchange) are required to adequately evaluate the impact of girdling or other precision canopy management. These future research could be important in determining methods to improve the quality of table grapes while also providing economic benefits to the growers in a sustainable way.

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