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Texture analysis as a method for grape berry characterization

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SUMMARY

The marketability of table grapes is mainly characterized by berry size, color, taste and texture. Mechanical measurements of table grape berries could provide objective information on the textural qualities of grape berries. In addition, this method might be suitable to study the effects of phytotechnical methods (such as girdling) on table grape quality. The aim of this preliminary work was to demonstrate how instrumental testing could be used to examine the effects of girdling on berry grape texture and define the textural characteristics of table grape berries. Cane girdling was carried out at veraison in two table grape varieties. Texture analysis was performed several times during the maturity. Besides this examination another five varieties were analyzed to assess their berry mechanical properties. Double compression test was used to determine berry hardness and its derived parameters. Puncture test was applied to evaluate skin hardness, skin elasticity and skin break energy. Skin thickness was also investigated. Berry hardness, skin hardness and skin thickness of the girdled grapevines were significantly affected by this technique. Most of the textural parameters showed differences among the seven cultivars.

Keywords: *Table-grape; girdling, texture profile analysis (TPA), texture properties*

INTRODUCTION

According to a report issued by the OIV in 2019, the world's wine-growing area was 7.499 million hectares in 2018 (OIV, 2019). In terms of production volume, this represents 77.8 million tons worldwide, of which 57% were wine grapes, 36% table grapes, and 7% raisins. The largest grape variety produced for fresh consumption is Kyoho, which accounts for about 90% of Chinese table grape production. This variety is followed by the Sultanina (aka Thompson Seedless or Kismish), which is found everywhere among major table grape growers, but is mainly produced in larger quantities in the Middle East and Central Asia (OIV, 2017).

Consumer preference for fresh consumption depends on several characteristics of the grape berries. Of these, the visual properties are obviously the primary ones. Furthermore, beside the taste other sensory qualities such as skin thickness, friability, or berry firmness (Rolle et al., 2013) are also important aspects in fresh consumption. Texture analysis can be used to determine many of these properties. Determination the texture properties of individual foods is becoming increasingly popular, because of its objective results (Letaief et al., 2006; Río Segade et al., 2011b). Instrumental measurement can be used to quantify properties such as hardness, strength, adhesion, and extensibility in food raw materials and processed foods, as well as other consumer goods (e.g., cosmetics, medicines, gel adhesives). Compression, penetration, traction, and shear tests can apply for these purposes (Internet 1). Bernstein and Lustig (1981) were the firsts to define elasticity of berries from three different table grape varieties using a compression test. Since their experiment several studies have been performed to see how the method can be applied to characterize different cultivars (Sato and Yamada, 2003; Rolle et al., 2011b, 2013) or reveal textural differences between *Vitis labrusca* and *Vitis vinifera* (Sato et al., 1997). In the case of table grapes, research has mostly focused on to describe the berry textural characteristics of several cultivars (Letaief et al., 2006; Río Segade et al., 2011b; Rolle et al., 2011b, 2013). The method is widely used to study the relationship between berry skin textural properties and anthocyanin extractability (Río Segade et al., 2008). Texture analysis can also be used to study the ripening processes of grape berries (Grotte et al., 2001). Other research activities aimed to describe the effects of water deficit on berry mechanical properties (Zsófi et al., 2014, 2021), as well as phenolic maturity (Villangó et al., 2015).

In order to increase table grape quality, several methods have been used, including phytotechnical treatments (Lukácsy and Zanathy, 2011; Tóth, 2020), exogenous hormone stimulation (i.e., GA3, Reynolds-Savigny, 2004; Ferrara et al., 2014). Cluster thinning, shoot trimming, and girdling are examples of phytotechnical methods used for achieving qualitative changes in the inner content and appearance of the grape berries. Girdling can be carried out at different stages of the berry development depending on the intended result. Application during anthesis enhances berry set, particularly in seedless cultivars (Dokoozlian et al., 1995), and increase the berry size after berry set (Lukácsy et al, 2014; Soltekin et al., 2016). Girdling at veraison may results faster maturation and a more balanced coloration of the grape berries (Yamane and Shibayama, 2006). Girdling induces the accumulation of many components in the plants above phloem rings (i.e. clusters) (Lukácsy and Zanathy, 2011), leading to improved maturity (Yamane and Shibayama, 2006; Abu-Zahra and Salameh, 2012; Keskin et al., 2013; Ferrara et al., 2014; Soltekin et al., 2015) and earlier harvest (Soltekin et al., 2016). The girdling treatment has a variety of impacts, including increased berry or cluster size (Lukácsy et al., 2014), higher total soluble

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solids (Zabadal, 1992; Abu-Zahra and Salameh, 2012, Ferrara et al., 2014; Soltekin et al., 2015, 2016), and higher polyphenol total extractability (Basile et al., 2018). In the case of seedless cultivars, it is common to combine this method with exogenous growth hormones because the gibberellin synthesis of that cultivar's berries is not high enough to develop large berries (Zabadal, 1992; Williams–Ayars, 2005; Abu-Zahra–Salameh, 2012; Ferrara et al., 2014). The relationship between special canopy management and the berry texture of table grapes has not been studied so far. However, the physical characteristics of the table grape berry are essential.

MATERIALS AND METHODS

Plant material experiment site and experimental design

In 2019, two experiments were carried out. The first one aimed to describe the effects of girdling on two grape varieties. The second investigation provides textural data of seven table grape varieties at harvest time in order to demonstrate the differences among the cultivars.

The girdling treatment was conducted on Kozma Pálné Muscat and Melinda table grape cultivars under commercial field conditions at veraison in the Mátra wine region, Hungary. Both varieties were bred in Hungary. Vines were planted between 2008 and 2010 with 3 m x 0.9 m row spaces. All vines were cane pruned in a vertical shoot position with 5–7 buds on a horizontal trellis. The crop load was set for two clusters per shoot. The experiment was planned in randomized block design (three blocks per treatment, ten plants per block). The vines were in similar condition, and they had the same crop load in all blocks. Cane girdling was performed by a double-bladed tool, which removed a 4 mm wide ring of bark from the cane. The treatment was carried out at the beginning of veraison as it was described by several authors previously (Goren et al., 2010; Kaur et al., 2013; Keskin et al., 2013; Soltekin et al., 2015, 2016).

The following varieties were included in the texture analysis at the time of maturity for fresh consumption: Éva, Áron, Kozma Pálné Muscat, Melinda, Pölöskei Muscat, Suzy, Queen of the Vineyard. The planting time and cultivation of the varieties are the same as described above.

Berry sampling

Twenty grape bunches per treatment were collected at harvest time (Brix > 19 – measured by refractometer) from each variety. The same number of bunches were collected from the treated and control vines of Kozma Pálné Muscat and Melinda in different maturity conditions. Further varieties were harvested at full maturity (Brix > 19) for texture profile analysis. The berries were detached with their pedicels from the clusters and visually tested before analysis. Berries were collected from each cluster for measurements (textural analysis: 2–3 berries/cluster). For each texture analysis, thirty berries were taken.

Berry texture profile analysis

The mechanical characteristics of grapes were studied using a TA.XTplus Texture Analyser (Stable Micro System, Surrey, UK) equipped with an HDP/90 platform and a 30 kg load cell. For each sort of mechanical measurement, thirty berries were selected. Data evaluation was performed using Exponent 5.1 software. According to Letaief et al. (2008b, please see *Table 1)*, all operating standards were followed. Berry hardness (BH, N) was assessed using the P/35 probe. Berries about the same size, with their pedicel were carefully cut off from the cluster and placed on the analyzer plate. They were then compressed to 25% of their original diameter. More berry property parameters could be derived from the pressure test such as berry springiness (BS), cohesiveness (BCo), gumminess (BG), chewiness (BCh), resilience (BR) of the berry (Rio Segade et al., 2011, 2013; Rolle et al., 2012). These parameters are calculated form the compression test's force-time curve (Leatief et al., 2008; Rolle et al., 2012), where the first peak indicating the berry hardness and the maximum force required for compression (*Figure 1*). Springiness reveals the value of the distance (D2) (*Figure 1*) between the end of the first bite and the beginning of the next bite by retaining the compressed berry (Letaief et al., 2008, *Table 1*). Cohesiveness (BCo) could be defined as the strength of the internal linkages by evaluating the *A1*, *A1W*, *A2* and *A2W* values (Rolle et al., 2012). Gumminess (N) and chewiness (mJ) give the value of the force and energy requires to chew semisolid and solid foods until swallowing (Leatief et al., 2008; Rolle et al., 2012, *Table 1*). These two parameters are calculated from the BH, BCO, and BS values. Berry resilience is described as the berry's capability to fights back to its original condition (Leatief et al., 2008, *Table 1*).

Berry skin texture properties

A puncture test was conducted using a P/2 N needle. In addition, berries were removed from the cluster with their pedicels and placed on the plate of the analyzer, and penetrated on the lateral face (Letaief et al., 2008a). The samples were removed from the bunch in the same way as in the previous test to determine the skin hardness of the berry (F_{sk}). The samples should be placed on the test platform on their longitudinal axis, exactly as they were for the compression test. The skin hardness test is a penetration test in which a needle breaks through the berry skin. The result of the measurement is given in N by the force required to break through the skin of the berry. The test requires the use of a P/2 N type needle. The skin break energy (W_{sk}, mJ) and Young module of berry skin (E_{sk}, N/mm) were evaluated using data from the puncture test (Letaief et al., 2008a; Zsófi et al., 2014).

Berry skin thickness (S_{psk}) was assessed with of P/2 probe with 2 mm diameter. For this measurement about 0.25 cm^2 skin was peeled from the sidelong face of the berry (Zsófi et al., 2014). The peeled skin was carefully cleaned from pulp, it was placed on the platform and the test was carried out as it was previously reported by other authors (Letaief et al., 2008ab; Río Segade et al., 2008).

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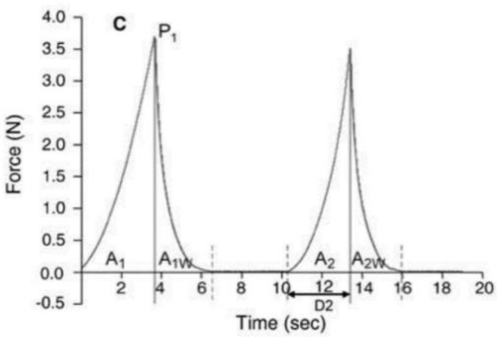
Table 1: **Operative conditions for the measurement of the berry textural characteristics (After Leatief et al., 2008a)**

	Probe	Test speed	Compression	Mechanical property
Berry hardness	P/35 35 mm diameter	1 mm s $^{-1}$	25% of the berry diameter	**BH**: measure of force necessary to attain a given deformation (N) **BCo**: strength of internal bonds **BG**: measure of force needed to dissolve a semisold food ready for swallowing (N) **BS**: measure of the distance between the end of the first bite and start of second bite. (mm) **BCh**: show the energy needed to chew a solid food until ready for swallowing (mJ) **BR**: how well berry fights to resize the original position
Berry skin thickness	P/2 2mm diameter	0.2 mm s $^{-1}$		$\mathbf{S_{psk}}$: berry skin thickness (mm)
Berry skin hardness	P/2N needle	1 mm s $^{-1}$	3 mm	$\mathbf{F_{sk}}$: berry skin break force (N)
				$\mathbf{W_{sk}}$: berry skin break energy (mJ)
				$\mathbf{E_{sk}}$: Young's modulus of the skin (N/mm)

Figure 1: **Schematic of typical curves of the berry hardness test (Rolle et al., 2012)**



Statistical analysis

Statistical analysis was achieved by Graph Pad Prism software version 8.0.1 (GraphPad Software Inc., La Jolla, CA, USA). Unpaired t-test for p≤0.05 was used to reveal the statistical differences in the mean values of the parameters belonging to the treated and untreated berries. One-way Anova analysis was used to define the differed parameters of the compared varieties.

RESULTS AND DISCUSSION

Girdling

Girdled samples presented higher Brix˚ values at both varieties. Due to the girdling treatment, significantly higher BH values were measured in the case of Kozma Pálné Muscat and Melinda in comparison to the control berries (*Table 2*). The treated berries of the Kozma Pálné Muscat cultivar were significantly harder (BH), gummier (BG) and chewier (BCh) and the cohesiveness and resilience values differed from the control berries. In contrast, there were no significant differences in berry springiness values (BS) in the case of Kozma Pálné Muscat between the treatments, however statistically higher springiness was found in the treated berries of the Melinda cultivar (*Table 2*). Nevertheless, the girdled berries of the Melinda were statistically differed from the control ones in case of the cohesiveness and resilience. Based on the berry skin break force (F_{sk}) test the values of the treated grapes of Melinda cultivar were lower than the control samples (*Table 2*). Texture analysis of the berries (berry hardness, skin break force and skin thickness) was performed on the ninth day after veraison in case of both treatments. Significant difference was verified between the girdled and control samples in both varieties even after veraison (*Figure 2, 3, 4*). The treated samples had a greater berry hardness value (*Figure 2*), which corresponds to the measurement conducted during maturity. Values of skin hardness followed the same pattern as it was found at full maturity, particularly, the treated berries had lower F_{sk} values compared to the control (*Figure 3*). In addition, differences were detected after veraison in skin thickness at Melinda variety (S_{psk}) (*Figure 4*).

A texture profile analysis of the berries revealed significant differences in several berry texture parameters between the treatments. According to numerous studies, grape ripeness has a significant

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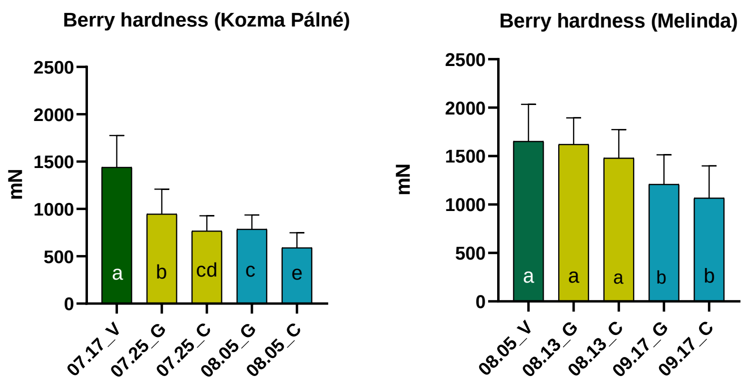
impact on berry textural features (Letaief et al., 2008b, Rolle et al., 2011, 2012, 2013). The lower the berry hardness (BH), the higher the sugar content throughout the ripening phase, according to several research. Berry hardness (BH) was decreasing from veraison to harvest, while sugar content in the berries was increasing (Río Segade et al., 2013). In our investigation, the girdled treatment's elevated BH values were accompanied by increased Brix° in each cultivar. Increased ABA may have an indirect influence on berry hardness by causing leaf stomatal closure, which reduces water loss from the canopy (Düring, 1978; Ezzahouani–Williams, 2001).

Table 2: **Berry textural parameters and Brix-index of the girdled and control berries of Melinda and Kozma Pálné Muscat varieties**

		BH (mN)	BCo(-)	BG (mN)	BS (mm)	BCh (mJ)	BR (-)	F_{sk} (N)	S_{psk} (mm)	Brix
Kozma Pálné Muscat	**C**	0.590	0.536	0.323	3.592	1172	0.256	0.335	0.179	17.8
	G	0.787	0.478	0.397	3.665	1466	0.227	0.326	0.209	19.5
Significance		****	****	****	ns	****	****	ns	*	
Melinda	**C**	1.068	0.478	0.497	3.763	1875	0.213	0.470	0.157	19.3
	G	1.209	0.466	0.545	4.042	2216	0.209	0.386	0.173	20.5
Significance		*	ns	*	***	**	ns	***	ns	

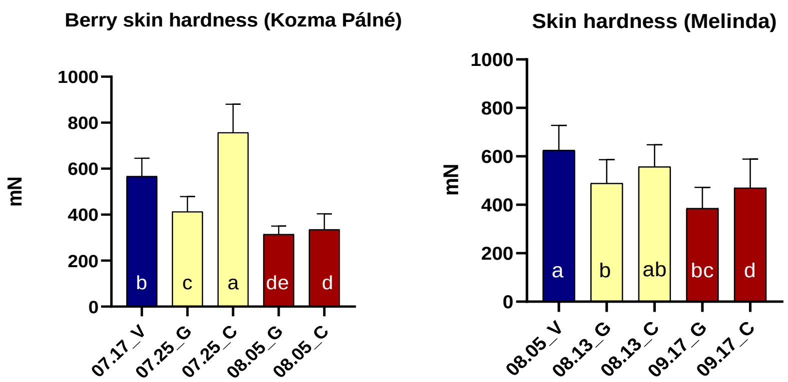
BH: Berry hardness, BCo: berry cohesiveness, BG: berry gumminess, BCh: berry chewiness, BR: berry resilience, F_{sk}: berry skin break force, S_{psk}: berry skin thickness. C: Control, G: Girdled. Statistical analyses were performed by GraphPad 8.0.1 software using unpaired T-test. Different letters within the same column mean significant differences according to t-test (* $p \leq 0.05$, ** $p < 0.01$ and **** $p < 0.0001$, ns = not significant.)

Figure 2: **Berry hardness (BH) parameters of treated and control berries of Kozma Pálné Muscat and Melinda at version (_V), nine days after version and harvest date**



G: Girdled, _C: Control. Statistical analyses were performed by GraphPad 8.0.1 software using Tukey-test (one-way Anova analysis). (n=30, + SD). Different letters within the same column mean significant differences according to Tukey test ($p \leq 0.01$*)*

Figure 3: **Skin break force (F_{sk}) parameters of treated and control berries of Kozma Pálné Muscat and Melinda at version (_V), nine days after version and harvest date**



_G: Girdled, _C: Control. Statistical analyses were performed by GraphPad 8.0.1 software using Tukey-test (one-way Anova analysis). (n=30, ± SD). Different letters within the same column mean significant differences according to Tukey test ($p \leq 0.01$)

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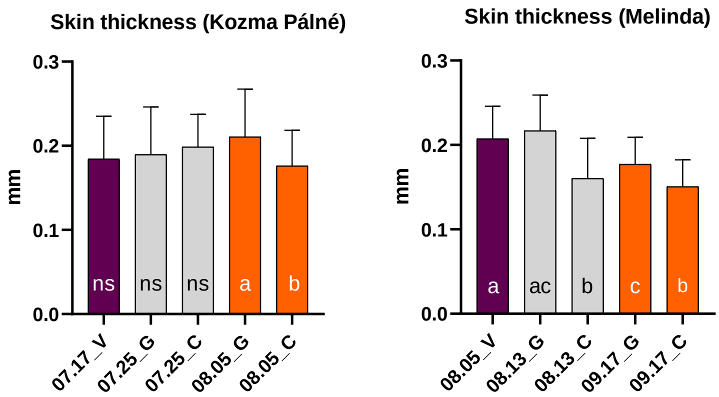
Figure 4: **Skin thickness (S_{psk}) parameters of treated and control berries of Kozma Pálné Muscat and Melinda at version (_V), nine days after version and harvest date**



G: Girdled, _C: Control. Statistical analyses were performed by GraphPad 8.0.1 software using Tukey-test (one-way Anova analysis). (n=30, + SD.). Different letters within the same column mean significant differences according to Tukey test ($p \leq 0.01$)

The cell wall structure of each grape variety determines the strength of the interior cohesion (Rolle et al., 2011). Developing berry cohesiveness in the time of ripening (Le Moigne et al., 2008), providing it as a reliable ripeness indicator (Río Segade et al., 2011). However, it appears that the berry sugar maturity has a stronger influence on this grape berry attribute. (Río Segade et al., 2013; Rolle et al., 2015). The higher value of the berry cohesiveness of the girdled samples in Kozma Pálné Muscat muskotály suggests an advanced stage of maturity in our study (*Table 2*). Berry resilience shows 'how well berry fights to regain its original position' (Letaief et al., 2008b) (Rolle et al., 2011) and shows similar characteristics to berry cohesiveness in several studies. It appears that the variation in this parameter during ripening is the most important factor. In the case of the Crimson Seedless cultivar, there was also an upward tendency. (Río Segade et al., 2013).

Through using the penetration test as a reference, girdling resulted in significant variations in berry skin texture as compared to control berries. Skin break force (F_{sk}) has been recommended as a maturity indicator in some research, particularly when relationships between grape phenolic maturity and skin hardness have been observed (Río Segade et al., 2008). Rolle et al. (2011, 2012) reported that F_{sk} increases during the first part of the ripening phase, then it slightly decreases until the physiological maturity in the case of Nebbiolo cultivar. In our experiment, F_{sk} has lower values in the girdling treatment compared to the control; however, the increased F_{sk} values can be observed after veraison in Kozma Pálné Muscat and Melinda varieties.

In the case of berry skin thickness (S_{psk}) interesting findings were revealed. According to several studies the thickness of the skin and the skin-to-flesh ratio appear to be important indicators of grape maturity and water status (Poni et al., 2006; Zsófi et al., 2014). Berry skin thickness of grape berries developed in line with sugar ripeness in a research by Río Segade et al. (2013). Higher thickness values were linked to the girdled berries' advanced maturation stage in our study.

Varietal differences

Texture profile analysis of the berries showed significant differences among the seven observed varieties. Éva had the hardest, (1.504 N) while Kozma Pálné Muscat had the softest berries (0.697 N) according to the compression test (BH) (*Table 3*). Moreover, these varieties also represented the two extremes of gumminess (BG) and chewiness (BCh), where the Éva had the highest values and the lowest were defined in case of Kozma Pálné Muscat. Queen of the Vineyard has the springiest berries (BS), in contrast, Suzy had the lowest (*Table 3*). Similarly, the lowest cohesiveness and resilience were detected at Suzy and the highest at Queen of the Vineyard varieties (*Table 3*). cohesiveness (BCh) and resilience (BR) are dimensionless parameters. The cohesiveness represents the strengths of the inner bounds, resilience defines how well a berry fights to regain the original position after the first compression (Letaief et al., 2008; Rolle et al., 2011b). Furthermore, Le Moigne et al. (2008) observed that the relation of cohesiveness values and sensory description such as touch resistance and firmness are inversely correlated.

The skin mechanical values of the table grapes indicate differences in skin hardness among the varieties. The hardest berry skin was found in Pölöskei Muscat (0.542 N) (*Table 4*). The lowest F_{sk} values (0.321 N) and W_{sk} (0.123 mJ) were found in Kozma Pálné Muscat, however this variety had the thickest skin (S_{psk}) (0.202 mm). In contrast, Pölöskei Muscat and Éva varieties have the lowest skin thickness (*Table 4*). These results suggest there is no clear relationship between skin hardness and thickness, as it was revealed by other studies (Río Segade et al.; 2013, Zsófi et al., 2016). The skin thickness and the hardness of the berry skin is an important factor of quality for the consumers. In addition, varieties with reduced skin hardness lose

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weight more quickly under postharvest storage (Rolle et al., 2011a).

Interesting findings could be obtained by comparing the results of texture profile analysis with the domestic variety descriptions (Tóth and Pernesz, 2001; Hajdu and Ésik, 2001). Berry texture properties are briefly described using only one or two markers. In the case of the Éva variety, the description defined thin skin and crispy flesh which corresponds to the results of the analysis in our study. Additionally, some of the observed varieties such as Éva and Pölöskei Muscat have adequate properties for packaging and transporting according to Hajdu and Ésik (2001), which corresponds well to the higher F_{sk} values of them.

Table 3: **Berry textural parameters of Éva, Áron, Kozma Pálné Muscat, Melinda, Pölöskei Muscat, Suzy and Queen of the Vineyard varieties**

	(BH, N)		(BCo,-)		(BG, N)		(BS, mm)		(Bch, mJ)		(BR, -)	
Éva	1.504	a	0.479	b	0.703	c	3.452	c	0.245	a	0.227	ce
Áron	1.085	b	0.544	a	0.586	b	3.778	b	2.230	b	0.246	c
Kozma Pálné Muscat	0.697	c	0.536	a	0.323	bc	3.592	d	1.172	abd	0.257	b
Melinda	1.086	b	0.477	b	0.503	b	3.761	c	1.897	b	0.212	a
Pölöskei Muscat	0.796	c	0.553	a	0.434	c	3.575	c	1.547	ad	0.240	ad
Suzy	1.022	bc	0.468	c	0.473	c	3.391	c	1.609	d	0.200	e
Queen of the Vineyard	0.771	c	0.567	a	0.435	a	4.183	c	1.833	ac	0.269	a

Berry hardness, BCo: berry cohesiveness, BG: berry gumminess, BCh: berry chewiness, BR: berry resilience. Statistical analyses were performed by GraphPad 8.0.1 software using Tukey-test (one-way Anova analysis). (n=30). Different letters within the same column mean significant differences according to Tukey test ($p \leq 0.01$).

Table 4: **Berry skin texture parameters of the Éva, Áron, Kozma Pálné Muscat, Melinda, Pölöskei Muscat, Suzy and Queen of the Vineyard**

	F_{sk} (N)		E_{sk} (N/mm)		W_{sk} (mJ)		S_{psk} (mm)	
Éva	0.408	ac	0.816	a	0.136	c	0.127	d
Áron	0.424	a	0.610	c	0.192	b	0.184	ab
Kozma Pálné Muscat	0.321	ade	0.571	ac	0.123	c	0.202	a
Melinda	0.394	c	0.808	b	0.132	bc	0.159	bc
Pölöskei Muscat	0.542	a	0.568	c	0.305	a	0.151	cd
Suzy	0.408	bc	0.639	c	0.164	bc	0.188	ab
Queen of the Vineyard	0.348	d	0.600	c	0.140	bc	0.168	bc

F_{sk}: skin break force, E_{sk}: Young's modulus, W_{sk}: berry skin break energy. Statistical analyses were performed by GraphPad 8.0.1 software using Tukey-test (one-way Anova analysis). (n=30). Different letters within the same column mean significant differences according to Tukey test ($p \leq 0.01$).

CONCLUSIONS

In summary, girdling had a significant effect on berry mechanical properties and that changes can be detected effectively by instrumental texture analysis. According to the performed analysis, girdling induced harder berries and thicker berry skin. However, the variety must always be considered in terms of the timing of the girdling and optimal harvest time. Further analytical investigations are needed (e.i. chemical compounds, aroma potential) to adequately evaluate the changes induced by girdling or other precision canopy management.

Furthermore, to reveal the relationships between texture, sensorial and analytical parameters may help to give a more objective description of table grape varieties.

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