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Research Article

Effect of viticultural practices on yield and volatile composition of 'Cabernet Sauvignon' grapes

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Abstract

'Cabernet Sauvignon' is a vigorous grapevine that develops herbaceous aromas in grapes. Canopy management practices can impact grapevine physiology, and as consequence the photosynthesis, fruit yield, and grape composition, and improve the quality of the fruit. Leaf removals and apical leaf removals on grapevines have been shown to reduce herbaceous aromas. However, little is known, about the effect of the use of girdling on the concentration of volatile compounds in grapes. Thus, the objective of this study was to evaluate the effect of basal leaf removal (BLR), girdling, and girdling plus cutting the apical regions of the canopy (girdling + CAC), on the concentration of volatile compounds of 'Cabernet Sauvignon' grapes. Fruit yield, chemical composition, and volatile compounds were analysed in all treatments. Girdling + CAC showed a reduction in grape yield, and total acidity, however, increases in total soluble solids, and fruity aromas were observed in comparison to BLR and the control (no-canopy treatment). Controls showed the highest concentration of volatile compounds related to herbaceous and unripe fruit characteristics aromas. On the other hand, BLR showed increases in volatile compounds in the grapes related to floral character. These results suggest that grapevine canopy management modifies the chemical composition of 'Cabernet Sauvignon' grapes, and girdling techniques and increase the fruity aromas.

Keywords: aroma compounds; berry quality; canopy management; *Vitis vinifera*

Introduction

Vitis vinifera L. var. 'Cabernet Sauvignon' is a grape that originated in Bordeaux France and is cultivated in many areas around the world by its adaptability to different climatic conditions (Yao *et al.*, 2021). Different climatic factors and viticultural practices determine the quality of the grapes, and their wines (Alem *et al.*, 2019).

Viticultural practices on grapevine canopy originate microclimates that mitigate extreme temperatures, and irradiance changes that improve the chemical characteristics of the fruit (Viguié *et al.*, 2014). Basal leaf removal (BLR), and apical leaf removals are common agronomical practices to balance foliar area and fruit load, these practices increase fruit light exposure, which modifies the synthesis of biomolecules like amino acids and

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fatty acids that act as some volatile compound precursors involved in the aroma of many fruits including grapes (Song *et al.*, 2015; Zhang *et al.*, 2017; Grebneva *et al.*, 2022). Furthermore, it has been reported that BLR and apical leaf removals have been carried out on 'Syrah' grapevines when the accumulation of total soluble solids reached 15 °Brix, so it can be considered a viticultural practice (Zhang *et al.*, 2017).

Different canopy management in the vineyard impacts the concentration of volatile compounds responsible for negative and positive aromas in grapes. For example, the concentration of methoxypyrazines, which generate negative aromas of bell pepper, asparagus, green grass, and vegetable aromas, decreases when grapes are exposed to light as a result of reducing the foliage around the bunches (Mosetti *et al.*, 2016; Alem *et al.*, 2019). Some studies have shown that the concentration of 3-isobutyl-2-methoxypyrazine in 'Cabernet Franc' grapes decreased by approximately 50% due to leaf removal (Ryona *et al.*, 2008; Mosetti *et al.*, 2016).

On the other hand, leaf removal in grapevine has been shown to increase the concentration of volatile compounds considered positive. Leaf removal of 'Pinot noir' grapevines, increased the concentration significantly of β-damascenone in their fruits, a molecule that provides floral aromas in wines (Feng *et al.,* 2015). Similarly, BLR in 'Tempranillo' grapes significantly increased the concentration of ethyl octanoate, 3-methylbutyl acetate, and other volatile compounds that promote fruity aromas in wines (Vilanova *et al.*, 2011).

On the other hand, girdling is another agronomic technique that consists of cutting a part of the bark of the trunk or shoot, or at the beginning of the bunch, to block the return of phloem flow from the aerial part of the plant to the roots. This effect increases the concentration of photosynthates in the fruit but does not affect the conduction of water and nutrients from the roots to the rest of the plant (Ferrara *et al.*, 2014; Li *et al.*, 2015; Soltekin *et al.*, 2015). Girdling the trunk and branches is a common practice in the production of some fruits such as apples, prunus fruit, and some table grapes to increase fruit quality (Matsumoto *et al.*, 2021; Piccolo *et al.*, 2021; Grebneva *et al.*, 2022). Girdling has an impact on the chemical composition of grapes. Girdling grapevine shoots have also been proven to increase concentrations of total soluble solids, anthocyanins, and the size and weight of apples, red plum fruit, and table grapes (Abu-Zahra, 2010; Gatti *et al.*, 2012; Eltom *et al.,* 2013; Piccolo *et al.*, 2021).

Unfortunately, little is known about the effects of girdling, the CAC, and the combination of both on grapevines, and on the concentration of volatile compounds in grapes. Consequently, the objective of the present study was to evaluate the effect of BLR, girdling, and girdling + CAC on the chemical composition and concentration of volatile compounds in 'Cabernet Sauvignon' grapes.

Materials and Methods

Plant material

The study was carried out in 2020 in an experimental vineyard of the University Autonomous of Chihuahua, Mexico (latitude 28° 26' 50''). The average maximum and minimum environmental temperature during the growth and ripening period were 28 °C, and 12.5 °C respectively. The accumulated rainfall during the period from veraison to harvest was 154 mm. 'Cabernet Sauvignon' vines on '110-R' rootstock with 'Royat' system conduction were used, the vineyard space established between plants was 1 m and 3 m between rows. Six vines were used per treatment; plants were considered as experimental units. Girdling was done by removing a 1-cm strip of bark from the branch (T2), BLR consisted in removing a 10-cm section of basal leaves from around the bunches during veraison (T3), and the combination of girdling + CAC of grapevine (T4) was done when fruits reached 18 °Brix (237 GD). The control group consisted of grapevines that were not defoliated, CAC, or girdled (T1).

Psychochemical characterization of 'Cabernet Sauvignon' grapes

Grapes were collected from the veraison, every eight days until harvest time. 300 berries per treatment were randomly collected from the middle part of 40 bunches. The grapes were crushed and macerated in a closed bottle glass of 10 L. for 20 minutes at 4 °C temperature. Three samples of must per treatment were collected in 20 mL vials and kept at a temperature of –80 °C until their volatile compound content was evaluated.

In the most obtained from the grapes crushed were determined, the total soluble solids (TSS) content was evaluated by digital refractometry (ATAGO Co. Ltd., Osaka, Japan), total acidity (TA) by titration with 0.1 N NaOH, and pH by potentiometry (HANNA Instruments Inc., Woonsocket, USA). During harvest, the yield and weight of bunches were evaluated to calculate the yield.

Isolation of free volatile compounds from Cabernet Sauvignon musts

Prior to analysis, musts were centrifuged at 2 °C (15,000 rpm, 30 min). Must (2 mL) was placed in a 4 mL vial with 0.65 g of NaCl. Volatile compounds were recovered from the headspace by adsorption for 1 h in a silica fiber covered by polydimethylsiloxane/divinylbenzene (0.65 µm) by solid-phase microextraction (SPME, Supelco, Co, Bellefonte, PA, USA). The desorption of volatile compounds was carried out within the injector in a Gas Chromatography-Mass Spectrometry (GC-MS, Agilent Technologies 7890B with a mass detector 5977A MSD) keeping the fiber in the injector in splitless mode at 200 °C for 15 min. Volatile compounds were separated in a DB-WAX column (60 m × 0.250 mm I.D., 0.25 µm film thickness, Agilent, USA). Helium (99.999 %) was used as a carrier gas at a flow rate of 30 cm $\cdot$ s^{-1}. The initial oven temperature was maintained at 33 °C for 5 minutes, it was increased to 50 °C at a rate of 2 °C $\cdot$ min^{-1}, then it was increased to 250 °C at a rate of 5 °C $\cdot$ min^{-1}, and finally, was maintained at 250 °C for 6.50 min. Mass spectra were obtained by electronic ionization at 70 eV. The temperatures for the transfer line were 250 °C and for the ion trap 180 °C. To identify volatile compounds, mass spectra were compared against those reported in the standardized database of the NIST library (chemistry WebBook) and the chromatogram of some C6-aldehyde, C6-alcohols and esters standards (Sigma-Aldrich, St. Louis, Mo, USA). The results were expressed in relative concentration percentages, which were calculated as the area of each compound divided by the sum of the areas of all identified compounds as described by Mauriello *et al.* (2009), Garde-Cerdán *et al.* (2018), and Gutiérrez-Gamboa *et al.* (2019), with similar results. Each analysis was performed in triplicate.

Statistical analysis

The experiment was performed under a completely randomized block design. The data were analysed by a one-way ANOVA after testing the normality and homoscedasticity of the data. An a posteriori test was performed using a Tukey test ($p \leq 0.05$) using the SAS V 9.0 statistical package (SAS Institute. Inc. Cary, N.C., USA, 2002).

Results

Yield and bunch weight

Flowering started at 382 growing degree days (GDD), the fruit set was observed at 451 GDD, and the veraison appeared at 967 GDD for all treatments. On the other hand, maturation (> 18 °Brix) in the control was observed at 1,221 GDD, while harvest for all treatments was conducted at 1,494 GDD. On the harvest day, all treatments had reached total soluble solids levels above 21 °Brix. Total yield and bunch weight fluctuated significantly ($p < 0.05$) between the different management treatments in relation to the control (Figure 1). Total yield was duplicated for the control compared to the rest of the treatments of canopy management. In the vines that were girdled, and added the CAC, bunch weight decreased by approximately 70% ($p < 0.05$), while the weight of bunches with BLR treatment decreased 50% compared to the control.

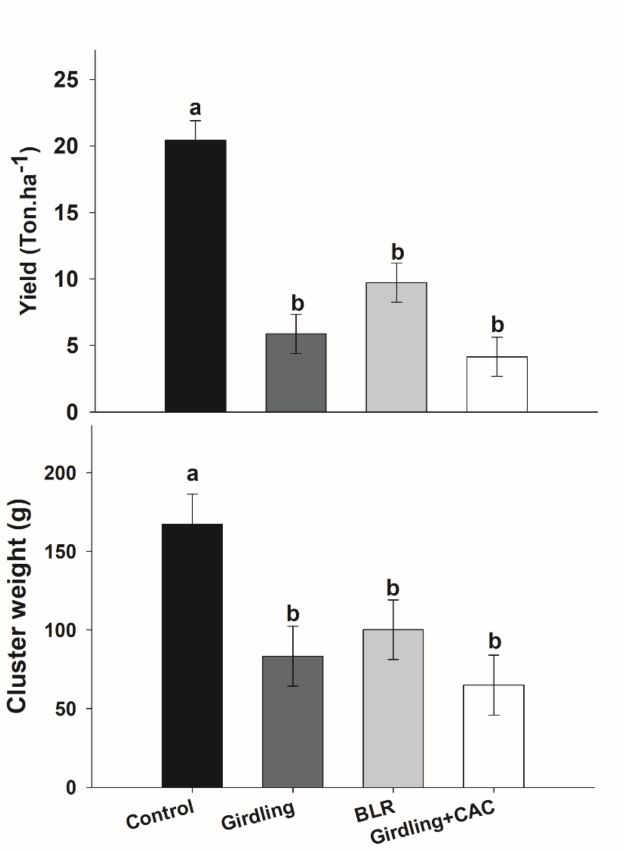

Figure 1. Effect of girdling, basal leaf removal (BLR), and girdling + cutting the apical region of canopy (CAC) on the weight of bunches and yield in 'Cabernet Sauvignon' grapes
Different letters showed significate differences (p<0.05) between treatments.

Psychochemical and maturity parameters of 'Cabernet Sauvignon' grapes

The chemical characteristics of grapes fluctuated significantly depending on the canopy management treatment (Figure 2). The TSS content was significantly higher ($p < 0.05$) from week four (1300-degree days) of sampling, until harvest time at week eight (1500-degree days), especially in the grapevines that were girdled or combined girdled + CAC, while a lower concentration of TSS was showed in the control and the grapevines with BLR. Total acidity was relatively similar for all treatments throughout the maturation period; however, controls showed the highest acidity levels ($p < 0.05$) when compared to the BLR or girdling treatments.

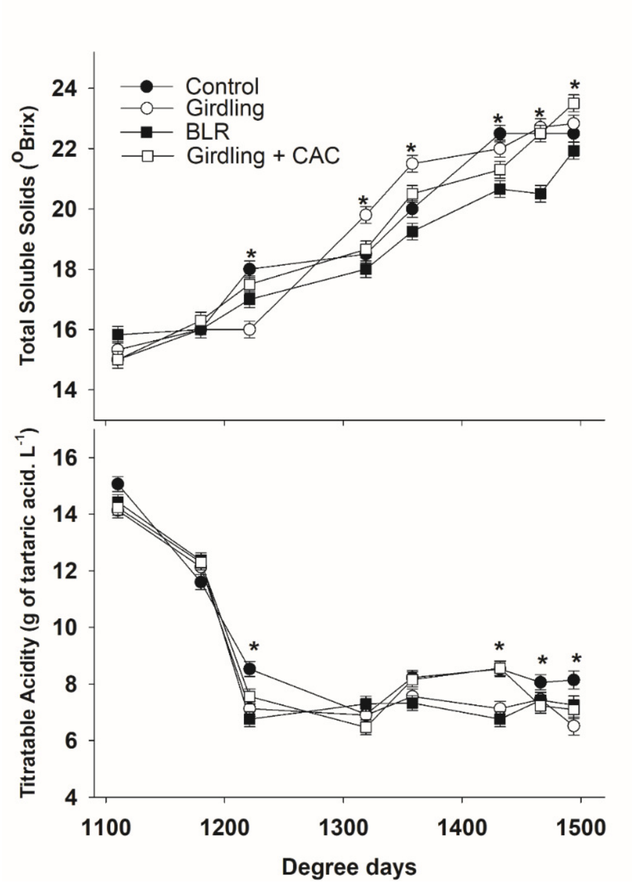

Figure 2. Influence of the different canopy management treatments on physicochemical parameters of 'Cabernet Sauvignon' grapes during ripening

*Differences between treatments on the same date of sampling.

On the other hand, Table 1 shows the results of the calculations of the maturity indexes of 'Cabernet Sauvignon' grapes based on the physicochemical parameters (TSS, pH, TA) of the different treatments used in this study at harvest time. The results demonstrate that TSS was significantly higher for all treatments with management on the canopy, but specifically for the treatment girdling + CAC, which showed the highest values of 23.5 °Brix, compared with the BLR and girdling treatments with 22.5 and, 21.9 °Brix for the control. In contrast, in TA, the results showed the highest value of 8.1 g · L^{-1} in the grapes control compared with de values of 7 or 6 g · L^{-1} in the canopy management treatments. In addition, the grape maturity parameter of TSS/TA, showed a better maturity index for treatments related to BLR, girdling, and girdling + CAC. Furthermore, the calculation of another parameter index such as TSS x pH, and TSS x pH^2, interestingly showed once again the best maturity index in 'Cabernet Sauvignon' grapes harvested from grapevines with treatments girdling, BLR, and girdling + CAC.

Table 1. Maturity index parameters calculated from 'Cabernet Sauvignon' grapes at harvest time for treatments of canopy: Control, Girdling, BLR (basal leaf removal), and, Girdling + CAC (cutting the apical regions of canopy)

Harvest time (Degree days)	Treatments	'Cabernet Sauvignon' grapes maturity parameters					
		TSS (°Brix)	TA (g · L^{-1})	TSS/TA	pH	TSS (°Brix) x pH	TSS (°Brix) x pH^2
1500	**Control**	21.9 ± 0.278c	8.10 ± 0.319a	2.70 ± 0.147c	3.20 ± 0.02c	70.08 ± 3.85c	224.56 ± 15.77b
	Girdling	22.4 ± 0.278b	6.20 ± 0.319c	3.61 ± 0.147a	3.50 ± 0.02a	78.42 ± 3.85a	274.41 ± 15.77a
	BLR	22.5 ± 0.278b	7.20 ± 0.319b	3.12 ± 0.147b	3.40 ± 0.02b	76.50 ± 3.85b	260.10 ± 15.77a
	Girdling+ CAC	23.5 ± 0.278a	7.10 ± 0.319b	3.31 ± 0.147a	3.40 ± 0.02b	82.25 ± 3.85a	271.66 ± 15.77a

Different letters in the same column indicate significant differences between treatments ($p<0.05$). TSS: Total soluble solids; TA: Total acidity (expressed as g tartaric acid · L^{-1} must).

Analysis of grape volatile compounds by HS-SPME-GC-MS

Sixteen volatile compounds belonging to different chemical groups were identified the must obtained from 'Cabernet Sauvignon' grapes (Table 2). Five aldehydes, four alcohols, four esters, and three molecules from other groups (oxyme methoxy-phenyl, oxalic acid, and 1-hydroxy-2-propanone) were identified. C6-aldehydes 1-hexenal, (E)-2-hexenal; C6-alcohols such as (E)-2-hexen-1-ol and (Z)-3-Hexen-1-ol, 3-methyl-1-butanol; and the esters 2,2,4-trimethyl-1,3-pentanediol-diisobutyrate, and 2-methylpropanoic acid (isobutyric acid) were found in all treatments, including the control. However, the aldehydes hydroxyacetaldehyde dimer, furfural, the ester hexanoic acid, hexyl ester (ethyl hexanoate), and 1-hydroxy-2-propanone (α-hydroxyketone) were identified in vines only vines with girdling + hedging. Finally, 5-hydroxymethylfurfural and oxime methoxy phenyl were present only in grapes from the control.

Table 2. Volatile compounds identified in the different treatments (Control, Girdling, BLR, and Girdling + CAC.), and their descriptive odor notes of 'Cabernet Sauvignon' grapes

Group	**Volatile compound**	**Time retention (min)**	**Diagnostic Ions (m/z)**	**Treatments where the volatile compound was found**	**Odour descriptive**	**Reference**
Aldehydes	1-hexanal	18.35	44(999) 56(819) 41(690) 43(550) 57(380)	Control, girdling, BLR, and girdling+CAC	Unripe, Green apple, grass-like	Dixon & Hewett, 2000
	(E)-2-hexenal	24.07	41(999) 42(580) 39(521) 83(504) 69(468)	Control, girdling, BLR, and girdling+CAC	Green-sharp	Dixon & Hewett, 2000
	Hidroxyacetaldehyde	27.25	31(999) 32(485) 29(404) 28(127) 60(71)	girdling+CAC	Green/Sharp	Dixon & Hewett, 2000
	Furfural	31.69	96(999) 95(991) 39(644) 38(226) 29(201)	girdling+CAC	Sweet, caramel, fruity, floral odor	Niu et al., 2011; Meng *et al.*, 2011; Yao *et al.*, 2021
	5-hydroxymethyl furfural	53.44	97(999) 126(779) 41(732) 39(358) 69(326)	Control	liquorice	Yao *et al.*, 2021
Alcohols	(E)-2-hexen-1-ol	30.11	57(999) 41(432) 27(205) 82(205) 44(182)		Green fruity	Larsen & poll, 1992
	(Z)-3-hexen-1-ol	29.49	41(999) 67(700) 55(351) 39(314) 82(303)	Control, girdling, BLR, and girdling+CAC	Strong fruity odor	Meng *et al.*, 2011

	2-methyl-1-butanol	23.57	57(999) 41(877) 56(877) 29(700) 70(423)	Control, girdling, BLR, and girdling+CAC	Chesse odor, nail polish	Feng et al., 2015; Meng *et al.*, 2011
	4-methyl-1-hexanol	20.17	70(999) 69(950) 41(910) 29(410) 55(400)	BLR	------	
Esters	2,2,4-trimethyl-1,3-pentanediol-di-isobutyrate	42.04	71(999) 43(316) 159(122) 243(107) 111(100)	Control, girdling, BLR, and girdling+CAC	Sickly sweet smell of emulsion paints	Yu & Kim, 2010
	Ethyl acetate (ethyl ethanoate)	9.04	43(999) 61(153) 45(146) 29(124) 70(118)	girdling, BLR, and girdling+CAC	Fatty ester odor, fruity	Zhang *et al.*, 2007: Yao *et al.*, 2021
	Hexanoic acid, hexil ester (hexil hexanoate)	35.57	43(999) 117(491) 56(474) 99(444) 84(415)	girdling+CAC	Fruity/apple	Dixon & Hewett, 2000
Others	2-methylpropanoic acid (Isobutyric acid)	41.55	43(999) 41(391) 73(258) 27(244) 42(98)	Control, girdling, BLR, and girdling+CAC	Fruity, silage sour	Larsen & Poll, 1992
	Oxime methoxy phenyl	38.57	133(999) 151(649) 135(262) 73(167) 42(165)	control	-------	
	Oxalic acid	31.82	45(999) 46(583) 29(200) 44(161) 28(140)	Control, BLR, and girdling+CAC	-------	
	1-hydroxy-2-propanone (α-hydroxyketone)	26.78	43(999) 31(169) 74(98) 15(86) 29(55)	girdling+CAC	Alcoholic-fruity, malty	Niu *et al.,* 2011

The relative concentrations of volatile compounds showed significant differences in 'Cabernet Sauvignon' grapes from the different treatments (Table 3). The concentration of aldehydes 1-hexanal and (E)-2-hexenal, were ten and three times on average for control than the treatments on canopy respectively, and 5-hydroxymethylfurfural was detected only in control 'Cabernet Sauvignon' grapes. In contrast, the volatile compounds hydroxyacetaldehyde, and furfural, were shown in treatment girdling + CAC. On the other hand, for the alcohols group, the (Z)-3-hexen-1-ol showed six times higher concentration in cabernet sauvignon BLR grapes, compared to the rest of the treatments, and the compound 4-methyl-1-hexanol only was observed in grapes with BLR treatment.

The esters and other volatile compounds showed relative concentration differences, for example, the ethyl acetate was approximately higher in the grapes from the combined treatment of girdling + CAC (4.63) when compared to the rest of the treatments (0.59-0.68). And 1-hydroxy-2-propanone (α-hydroxy-ketone) was observed only for girdling + CAC Cabernet Sauvignon grapes, while Oxime methoxy phenyl was observed only for control grapes.

Table 3. Influence of the different canopy management treatments (Control, Girdling, BLR, and Girdling + CAC) on the volatile composition relative area (/10^3) of 'Cabernet Sauvignon' grapes

Volatile compounds	Treatments			
	Control	Girdling	BLR	Girdling+CAC
Aldehydes				
1-hexanal	199.74 ± 28.67a	12.75 ± 28.67 b	28.28 ± 28.67 b	12.72 ± 28.67 b
(E)-2-hexenal	13.23 ± 1.31 a	5.53 ± 1.31 b	3.08 ± 1.31 b	3.24 ± 1.31 b
Hydroxyacetaldehyde	ND	ND	ND	1.88 ± 0.25
Furfural	ND	ND	ND	0.45 ± 0.11
5-hydroxymethylfurfural	0.37 ± 0.02	ND	ND	ND
Alcohols				
(E)-2-hexen-1-ol	8.09 ± 3.71 a	9.72 ± 3.71 a	15.26 ± 3.71 a	12.32 ± 3.71 a
(Z)-3-hexen-1-ol	1.33 ± 2.99 b	1.35 ± 2.99 b	7.79 ± 2.99 a	1.14 ± 2.99 b
2-methyl-1-butanol	1.88 ± 0.73 a	2.13 ± 0.73 a	1.28 ± 0.73 a	2.99 ± 0.73 a
4-methyl-1-hexanol	ND	ND	0.10 ± 0.002	ND
Esters				
2,2,4-trimethyl-1,3-pentanediol-diisobutyrate	3.73 ± 1.43 a	3.40 ± 1.43 a	5.15 ± 1.43 a	3.49 ± 1.43 a
Ethyl acetate (ethyl ethanoate)	ND	0.68 ± 0.96 b	0.59 ± 0.96 b	4.63 ± 0.96 a
Hexanoic acid, hexil ester (hexyl hexanoate)	ND	ND	ND	0.39 ± 0.001
Others				
2-methyl propanoic acid (isobutyric acid)	5.82 ± 2.12 a	4.86 ± 2.12 a	7.67 ± 2.12 a	5.56 ± 2.12 a
Oxime methoxy phenyl	0.32 ± 0.07	ND	ND	ND
Oxalic acid	1.33 ± 0.55 a	2.01 ± 0.55 a	1.59 ± 0.55 a	ND
1-hydroxy-2-propanone (α-hydroxy-ketone)	ND	ND	ND	1.06 ± 0.005

Different letters in the same row indicate significant differences between treatments ($p<0.05$).

The relative concentration of C6-aldehydes, C6-alcohols, and esters varied significantly between treatments (Figure 3). Aldehydes were the most abundant chemical group in grapes. The highest percentage of aldehydes was found ($p > 0.05$) in control grapes (213) compared to those obtained from the different canopy treatments (18.28 - 31.1). Finally, the concentration of C6-alcohols was superior in grapes with BLR treatment (24.4) and lower in the control (11.3).

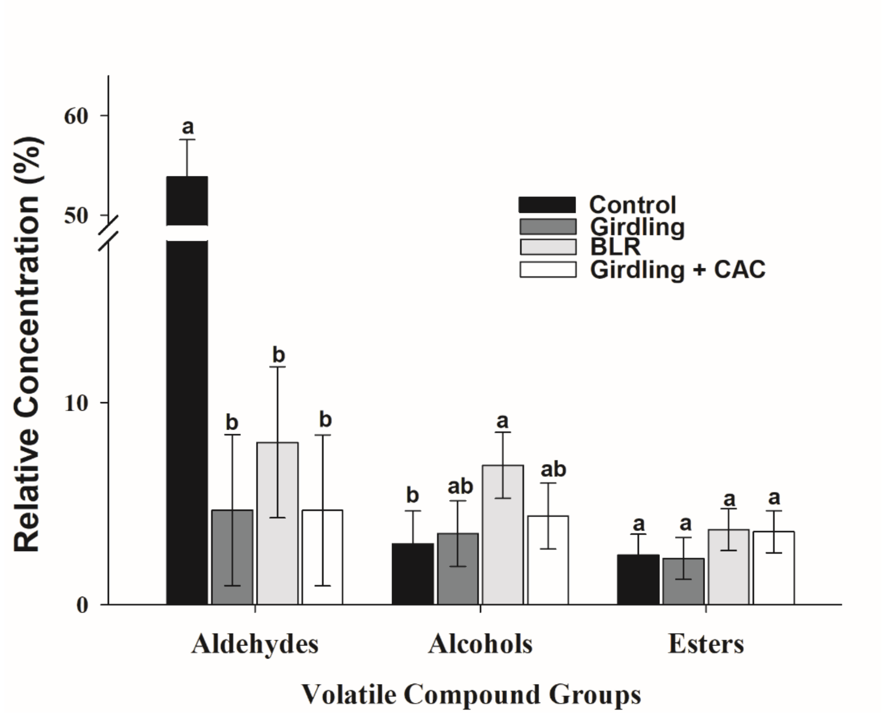

Figure 3. Comparison of the effect of control girdling, BLR (basal leaf removal), and, Girdling + CAC (cutting the apical region of canopy) on the relative concentrations of groups of aldehyde, alcohols, and esters found in 'Cabernet Sauvignon' grapes

Discussion

Yield components

This study demonstrates that yield and physicochemical composition of the grapes can be modified as a result of canopy management. The results of this study are consistent with those obtained in other studies. The decrease in weight and yield of the 'Cabernet Sauvignon' grapes observed here was similar to that observed in 'Italia', 'Red globe', 'Sovereign Coronation', and 'Flame seedless' grapes that were girdled on the bunches (Williams *et al*., 2000; Reynolds and Savigny, 2004; Ferrara *et al*., 2014; Soltekin *et al*., 2015). Similarly, BLR of 'Riesling', 'Sangiovese', and 'Nero d'Avola' results in a reduction of yield and berry weight (Poni *et al.,* 2006; Almanza-Merchán *et al*., 2011; Gatti *et al*., 2012; Verzera *et al*., 2014). Grapevine defoliation and shoot removal reduces foliar area, which increases sunlight exposure, and causes increase of temperature in bunches (English *et al.,* 1989; Spayd *et al*., 2002; Soltekin *et al*., 2015). The temperature of the Zinfandel grape bunches, for example, increased up to 2 °C at noon in grapevines with BLR with respect to non-defoliated (English *et al*., 1989). Just like BLR, can increase light incidence and increase bunch temperature. This rise in temperature potentially increases the evaporation rate in grapes, which results in the observed reduction in berry weight and yield.

'Cabernet Sauvignon' grape maturity parameters

The highest concentrations of TSS and reduction of TA observed in the present study for grapes with treatments on canopy were consistent with those observed in other studies. Girdling techniques increase TSS and decrease TA in 'Red globe', 'Sovereign Coronation', and 'Flame Seedless' (Reynolds and Savigny, 2004; Soltekin *et al*., 2015; Soltekin *et al*., 2016). The girdling of the trunk or shoots prevents phloem translocation and increases photosynthates accumulation in the foliar area. These photosynthates eventually concentrate in the grapes (William *et al*., 2000; Soltekin *et al*., 2015; Böttcher *et al*., 2017). In 'Riesling' and 'Concord' grapes, for example, girdling the grapevine shoots resulted in a reduction of the grape set or bunching (Intrigliolo *et al.*, 2017). Similarly, treatments of defoliation reduce foliar area, and increase exposure to sunlight with less weight of bunches and high TSS accumulation (Spayd *et al*., 2002; Soltekin *et al.*, 2015). Therefore, the TSS increase and TA decrease observed in this study for the treatments of BLR, girdling or the girdling + CAC treatments where results were the result of the weight reductions, and the increase of photosynthates in the foliar area to synthesize these metabolites for the grapes.

Nevertheless, the analytical determination of the ripening indexes gives some information on the evolution of chemical compounds in grapes during ripening, the most significant being the concentration of sugars and acids. It has been proven that, during the ripening period, the concentration of sugars is continuously increasing. In contrast, total acidity decreases progressively. When both components remain constant for a few days, this moment corresponds to technological or industrial ripening (Boulton *et al*., 1996). According to the results, the control, girdling, and BLR treatments showed the lowest values of total soluble solids (TSS), probably due to the conditions of the vineyard treatments, while girdling + CAC was the highest (23.5), recommended for optimum harvest maturity. Regarding total acidity (TA), T1 showed the highest value (8.10 $g \cdot L^{-1}$), followed by BLR, and girdling + CAC, and the lowest value was for girdling (6.20 $g \cdot L^{-1}$). In the case of pH, all treatments showed values between 3.20-3.50. In attention to the maturity indexes, TSS/TA index mentions that a value of 3.1 is considered optimal for grape harvest (Palomo *et al*., 2007); BLR and girdling + CAC treatments are close to this value, while treatments control (2.60) and girdling (3.61) have values outside the index, so this may be due to the degree of ripening of the grapes at the time of harvest.

Boulton *et al.* (1996) mentioned that the optimum value for the °Brix x pH index is between 85, and 95, and the °Brix x pH^2 index lies between 200, and 270 for optimum harvest maturity. No correlation was found for the °Brix x pH index for all treatments, and for the °Brix x pH^2 index, only treatments control (224.5) and BLR (260.1) were within the mentioned range. The use of maturity indexes to predict wine quality is limited, so the aroma is considered one of the most critical factors related to wine quality. Therefore, the volatile composition is an essential parameter for assessing the optimum stage of maturity of grapes (Du Plessis *et al*., 1982).

Volatile composition of 'Cabernet Sauvignon' grapes

Canopy treatments on the Cabernet Sauvignon vine altered the volatile composition of the grapes considering also that the volatile composition of skins has been studied as compounds ceded to the must. BLR, impact the primary and secondary metabolites, and as consequence the fruit composition (Alem *et al*., 2019). BLR in this work, increased concentrations of volatile compounds classified as C6-alcohols, whereas the combination of girdling + CAC influenced esters composition specifically on ethyl acetate concentration that provides fruity aroma. However, C6-aldehydes concentration such as 1-hexanal and (E)-2-hexenal decreased with both treatments with respect to those of the control, these volatile compounds are characteristics of unripe, grass or green aromas, therefore the untreated grapes (control), developed higher concentration of green aromas. Despite the lack of knowledge on the effect of girdling or the combination of girdling + CAC on the volatile compounds of 'Cabernet Sauvignon' grapes, these results are consistent with the concentrations of C6-alcohols and esters found in other studies with BLR in 'Tempranillo' and 'Nero d'Avola' grapevines (Vilanova *et al*., 2011, Verzera *et al*., 2014; Moreno *et al*., 2016). Likewise, techniques of BLR, and CAC has also resulted in increased ester concentrations observed in Syrah grapes (Zhang *et al*., 2017). These increase in C6-alcohols and esters have been shown to be the result the microclimate under the canopy, including quality and quantity of irradiance on bunches, relative humidity, temperature, etc. (Moreno *et al*., 2016). (E)-2-hexen-1-ol and (Z)-3-hexen-1-ol are formed from long-chain fatty acids in the grape and increase during berry ripening; they are also increased by berry breakdown mechanisms and skin contact before fermentation (Baumes *et al*., 1989).

'Cabernet Sauvignon' grapes can synthesize herbaceous aromas or unripe fruit that are characteristic of C6-aldehydes (Dixon & Hewett, 2000; Noble *et al*., 2012; Mozzon *et al.,* 2016), while alcohols provide floral aromas (Espino-Diaz *et al*., 2016). In this study, Cabernet Sauvignon control, and BLR treatments showed high concentrations of C6-aldehydes and alcohols respectively. Other studies use as a technique BLR on grapevines to reduce herbaceous aromas in 'Merlot' and 'Cabernet Sauvignon' grapes (Verzera *et al.*, 2014; Song *et al.,* 2015). In this work, Girdling + CAC was the most effective treatment in reducing the concentration of type C6-aldehydes and alcohols. In addition, girdling + CAC increased the synthesis of aldehydes such as furfural, esters, and ketones that are related to fruity aromas (Dixon and Hewett, 2000; Zhang *et al*., 2007; Verzera *et al*., 2014; Yao *et al*., 2021). The reduction of concentration in aldehydes showed in the canopy treatments of this study (BLR, girdling, and girdling + CAC) is due to the result of the increased light exposure, bunch aeration, and in the girdling treatments, the increases of photosynthates in the foliar area which promote changes in the composition of aromatic compounds in grapes (Feng *et al*., 2015; Alem *et al*., 2019). Likewise, an increase of light exposure of bunches increases the synthesis of lipids, which are the main volatile compound precursors to the β-oxidation pathway, lipoxygenase (LOX) pathway, and even by the synthesis of terpenes in several fruit trees (Espino-Díaz *et al*., 2016; Zhang *et al*., 2016; Maya-Meraz and Pérez-Leal, 2019).

This study demonstrated that the combination of girdling + CAC impact the synthesis of four additional volatile compounds, including two aldehydes, an ester, and a ketone (hydroxyacetaldehyde dimer, furfural, hexanoic acid hexyl ester, and 1-hydroxy-2-propanone), compared to the rest of the treatments. However, the synthesis of 4-methyl-1-hexanol was observed in grapes harvested from the BLR treatment. Finally, it was observed that the different treatments on the canopy of this study can inhibit the synthesis of the oxyme methoxy phenyl compound.

Conclusions

Grapevine canopy management impact 'Cabernet Sauvignon' grapes composition. The leaf removal treatment showed positive effects on the aromatic composition because it increases the groups of volatile C6-alcohols, all the while decreasing the content of TSS in berries. On the other hand, the combined girdling + CAC treatment decreased yield components; however, berries from this treatment showed better balance of TSS accumulation and the same concentration of volatile ester compounds as the leaf removal treatment. These results demonstrate that the combined girdling + CAC technique could be useful for vigorous varieties that in some climates do not accumulate enough TSS. Furthermore, this technique positively influences the concentration of volatile compounds because it increases positively molecules of fruit aromas in grapes while decreasing the concentrations of herbaceous aromas in the berries and possibly in their wines. Information about the free aroma fraction of this variety may help the selection of the best culture practices and the optimum date of harvest, as well as the development of an adequate wine-making technology.

Authors' Contributions

Conceptualization: IOMM, Methodology: NASS, IOMM; Validation: NASS, RPL; Formal analysis: IOMM, RPL, NASS; Funding acquisition: NASS, RPL; Investigation: IOMM, RPL, NASS, RAV; Methodology: NASS, IOMM; Writing: IOMM, RPL, RAV; Writing - review and editing; IOMM, RPL, RAV. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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