



Defoliation management and boron application as a strategy to reduce poor fruit set and improve the quality of ‘Merlot’ grapes

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ABSTRACT. ‘Merlot’ grapevines hold significant importance in Brazilian viticulture, particularly within the high-altitude region of Santa Catarina. However, they often experience a physiological disorder known as poor fruit set and shot berries, which results in clusters with few berries, uneven ripening, and reduced productivity. Therefore, this study evaluated the effectiveness of different defoliation and boron application strategies in mitigating poor fruit set. The evaluated treatments included: i) 3 defoliations with boron application at phenological stages 17 (developed inflorescence), 23 (full flowering), and 35 (beginning of maturation); ii) 3 defoliations without boron application at the same phenological stages; iii) 1 defoliation treatment with boron application at full flowering; iv) 1 defoliation treatment with boron application at the beginning of maturation; and v) a control with no defoliation but with boron application. Berry drop evaluations were conducted during the 2023 and 2024 harvests. Our findings showed that performing 3 defoliations at the developed inflorescence, full flowering, and the beginning of maturation stages did not reduce poor fruit set in ‘Merlot’ grapes cultivated in the Serra Catarinense region. However, these treatments were associated with increased total polyphenol and anthocyanin contents, improved color parameters, and enhanced color intensity in the wine. Late defoliation treatments decreased color intensity and anthocyanin and total polyphenol contents in ‘Merlot’ wines.

Keywords: viticulture; polyphenol; calyptra.

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Introduction

Viticulture in the Serra Catarinense region has gained prominence in recent decades, largely due to its favorable climatic conditions and high altitude (above 1,000 m), which have attracted increasing interest from investors. The ‘Merlot’ grape, one of the most globally recognized varieties, is extensively cultivated in this region. However, it is prone to a physiological disorder known as poor fruit set and shot berries, which has been observed in other regions that produce this cultivar (Baby et al., 2016). This disorder, also known as physiological abortion, arises from inadequate flower fertilization, leading to sparse clusters with a limited number of berries. The vine canopy’s microclimate, characterized by a higher humidity and shading, facilitates the retention of the calyptra and contributes to berry abortion (Garrido et al., 2017). Additionally, poor fruit set substantially diminishes grape productivity and quality, which may lead to considerable losses for producers.

The disorder is identified following the onset of flowering, specifically between the 10th and 12th day post-flowering, when a certain number of small berries fail to develop and drop. This deviation significantly undermines the productive potential of grapevine (Dry et al., 2010; Garrido et al., 2017). May (2004) categorized poor fruit sets into millerandage, characterized by the excessive dropping of ovaries or very young fruits, and poor fruit set, which involves small berries intermixed with normal berries within a cluster. Dry et al. (2010) emphasized that the only valid method for measuring fruit set involves counting the number of flowers and the number of berries on a sampled inflorescence or cluster. Various factors, including nutritional imbalances, genetics, and adverse weather conditions, are associated with this disorder (Candolfi-Vasconcelos & Koblet, 1990).

Pötter et al. (2010) highlighted that grapevine defoliation is employed in different regions globally to produce higher-quality grapes. This practice involves removing leaves near the clusters to enhance the temperature, solar radiation, and airflow around the clusters. One hypothesis to counteract this disorder suggests that defoliation before the physiological phenological stage of full flowering, with moderate intensity, and repeating of the process two or three times can significantly decrease the incidence of poor fruit set, yielding better-quality fruit—fruit that achieves ideal harvest points, are healthy, and possesses high levels of technological and phenological ripeness.

Boron is a critical grapevine micronutrient that promotes vegetative growth. Its deficiency can result from dry conditions during the autumn–winter period (from the previous vegetative cycle) or from low temperatures combined with moist soil during spring cold snaps (Porro & Brighenti, 2021). Boron performs several crucial functions in grapevines, contributing to fruit quality and yield and providing a balance among metabolic processes (Melo, 2003; Porro & Brighenti, 2021). Without sufficient boron, fertilization is impaired, leading to clusters with fewer, smaller, seedless berries and berries with lead-colored spots on the fruit pulp. Boron deficiency can also adversely affect wine quality, as it reduces the sugar content in the berry by inhibiting adenosine triphosphate formation (Giovannini, 2004).

Therefore, our study aimed to evaluate the effect of defoliation at 3 different phenological stages—17 (developed inflorescence), 23 (full flowering), and 35 (beginning of maturation), according to the Eichhorn and Lorenz (1977) scale—and boron application in reducing poor fruit set in ‘Merlot’ grapevines.

Material and methods

Experimental area

The experiments were carried out in a commercial vineyard (28°14'00.02" S and 50°03'44.14" W, 1,150 m above sea level) situated in the municipality of São Joaquim (Santa Catarina State, Brazil). The local climate is classified as humid mesothermal (Cfb), according to the Köppen system, and is characterized by evenly distributed rainfall across all four seasons (Peel et al., 2007).

This study focused on ‘Merlot’ grapevines (*Vitis vinifera* L.) grafted onto ‘Paulsen 1103’ rootstock. The plants were spaced at 2.70 × 1.35 m, amounting to 2,743 plants per hectare, and were 19 years old at the time of the study. A bilateral cordon spur-pruned configuration was used for the grapevines. Apart from the experimental treatments, all vineyard operations adhered to the management practices standard for the producer. During winter pruning, each vine was pruned to retain 12 buds. Weather conditions for the 2022 and 2023 harvests within the experimental area were diligently monitored, as recorded by Epagri/Ciram station 2431 (Table 1). The soil conditions were: pH water, 5.20; SMP index, 5.97; Al, 0.25 cmol_c dm⁻³; Ca, 8.83 cmol_c dm⁻³; Mg, 3.63 cmol_c dm⁻³; H+Al, 4.51 cmol_c dm⁻³; CTC (pH 7.0), 17.25 cmol_c dm⁻³; CTC effective, 12.99 cmol_c dm⁻³; K, 110 mg dm⁻³; Bases, 73.86%; Al, 1.92%; Ca, 51.19%; Mg, 21.04%; K, 1.63%; H, 24.70%; Ca/Mg, 2.43; (Ca+Mg)/K, 44.29; OM, 5.7%; clay, 43%; P, 6.0 mg dm⁻³; B, 0.45 mg dm⁻³.

Table 1. Meteorological data for ‘Merlot’ grapevines in the last 4 months of 2022 and 2023 and the flowering period.

2022						
Variable	Leaf wetness	Rainfall [#]	Instantaneous air temp. [*]	Max. temp. [*]	Min. temp. [*]	RH (%)
Month	Monthly sum	Monthly sum	Monthly mean	Monthly max.	Monthly min.	Monthly mean
Sep.	197.73	60.0	12.25	26.77	-1.52	79.94
Oct.	285.44	159.2	15.37	26.71	6.62	82.61
Nov.	182.37	18.0	15.73	27.27	0.09	74.19
Dec.	219.94	128.6	19.31	32.09	7.60	77.70
Mean	221.4	365.8 [†]	15.7	28.2	3.2	78.6
Flowering [‡]	53.1	11.00	17.82	24.61	11.77	69.88
2023						
Sep.	240.11	254.4	16.73	30.86	0.96	81.58
Oct.	256.39	366.4	16.10	27.27	6.78	86.34
Nov.	242.33	319.0	18.17	32.33	4.96	81.18
Dec.	216.53	150.6	20.31	33.02	9.47	81.34
Mean	238.84	1090.4 [†]	15.5	27.7	3.1	80.9
Flowering [‡]	110.79	96.20	17.89	23.84	13.09	80.84

RH: Relative humidity; ^{*}values are given in millimeters (mm); ^{*}values are given in Celsius (°C); [†]sum of data; [‡]mean of the flowering period: Nov. 15 (2022) to Nov. 29 (2022) and Nov. 1 (2023) to Nov. 15 (2023). Source: Epagri/Ciram station 2431.

Treatments

The evaluated treatments are presented in Table 2.

Table 2. Treatments applied in the experiment included the number of defoliation, boron application, and phenological stages.

Treatment	No. of defoliations	Boron application	Phenological stages
1	3	Yes	17, 23, 35
2	3	No	17, 23, 35
3	1	Yes	23
4	1	Yes	35
5	Control	Yes	-

Note: phenological stage 17: developed inflorescence; phenological stage 23: 50% of the flower buds open; full flowering; phenological stage 35: the beginning of maturation, according to Eichhorn and Lorenz (1977).

Treatment 1 consisted of defoliation at 3 phenological stages, according to the Eichhorn and Lorenz (1977) scale. The first defoliation occurred at phenological stage 17, described as “developed inflorescence; separated leaves,” during which up to three leaves near the cordon spur, below the cluster, and low leaves facing the inside of the plant were removed. The primary objective at this phenological stage was to enhance the air circulation of the plant, thereby reducing humidity more swiftly and preventing excessive shading, which is detrimental at the beginning of the cycle. The second defoliation occurred at phenological stage 23, “full flowering,” in which leaves from the cordon spur and any remaining inner leaves up to the cluster’s height were removed. The third defoliation occurred at phenological stage 35, “beginning of maturation,” when any leaves remaining from previous defoliations that could interfere with management and phytosanitary treatments were reviewed and removed to aid in the grape ripening process. At this stage, leaves were removed opposite the cluster, an action prohibited in earlier phenological stages, with caution to avoid removing leaves above the cluster. In this treatment, boron was applied. The standard procedure included two applications of liquid boron (Wiser, Brazil) at a concentration of 10% and a density of 1.32 g mL⁻¹ with a dosage of 100 mL per 100 L of water and a spray volume of 600 L ha⁻¹. The first application occurred at phenological stage 23, followed by a second application 10 days later.

For Treatment 2, all management executions and purposes were the same as in Treatment 1 but without boron application. Treatment 3 involved only 1 defoliation at phenological stage 23, removing the leaves from the cordon spur, internal leaves up to the height of the cluster, opposite the cluster if necessary, and occasionally above it. Treatment 4 was similar to Treatment 3, although defoliation was performed at phenological stage 35. Lastly, Treatment 5 was the control (i.e., no defoliation performed).

The percentage of poor fruit set (assessed over two harvests), productive parameters, technological and phenolic ripeness parameters, and chemical parameters of the wines were evaluated in one harvest, as follows.

Poor fruit set

Flowers were counted in the 2023 and 2024 seasons in 3 marked clusters from different plants per plot; they were expressed in units of flowers per cluster. The fruit set was evaluated by counting the berries from the same three marked clusters used for flower counting per treatment per block and expressed as a percentage.

Productive parameters

The productive parameters were evaluated in 2023. The cluster weight was determined by weighing 10 clusters per replication on an analytical balance (Model LS1, Marte, Brazil) and expressed in grams. The peel weight was measured by weighing the skins separated from the pulp of 30 berries on an analytical balance (Model LS1, Marte, Brazil) and expressed in grams. Berry weight was obtained from 30 berries on an analytical balance (Modelo LS1, Marte, Brazil) and expressed in grams. The cluster length was obtained by measuring 10 clusters per replication with a digital caliper (Model 316119, MTX, Brazil) and expressed in centimeters. As for production, clusters from three plants per treatment per block were weighed, averaged, and expressed in kg per plant. Yield was calculated by multiplying the sum of the cluster weight per plant by plant density and expressed in kg ha⁻¹.

Technological and phenological ripeness parameters

Grapes were harvested on April 3, 2023. Technological ripeness parameters were evaluated through must extraction from 150 berries from each block, according to the (International Organization of Vine and Wine

[OIV], 2020). Parameters included: i) total titratable acidity (meq L^{-1}) by titration; ii) total soluble solids ($^{\circ}\text{Brix}$) measured with a benchtop digital refractometer (MA871, Milwaukee, Brazil); and iii) pH was measured with a pH meter (MP 220 Metler-Toledo, Brazil).

Chemical parameters of wine

Wines were produced in the laboratory with 10 kg of grapes per treatment. The grapes were manually selected, destemmed, and crushed in an automatic machine. During destemming, $25 \text{ mg L}^{-1} \text{ SO}_2$ antioxidant and 0.02 mg L^{-1} pectinolytic enzymes were added. The musts were fermented separately for each treatment using 0.25 g L^{-1} active dry-selected yeast (*Saccharomyces cerevisiae*). Maceration lasted for 5 days with 2 daily *pigeage*. Fermentation was conducted under controlled temperatures (20°C) and monitored by a specific gravity hydrometer. After alcoholic fermentation, the wines were clarified using 0.3 g L^{-1} bentonite. Malolactic conversion was not performed. The treatments underwent cold tartaric stabilization (7 days at 0°C), followed by bottling in 750-mL dark bottles sealed with corks. Post-bottling analyses included total acidity (meq L^{-1}), pH, alcohol content (%v/v), residual sugar (g L^{-1}), density, volatile acidity (meq L^{-1}), free sulfur dioxide (mg L^{-1}), and total sulfur dioxide (mg L^{-1}) following methods from the OIV (2020).

The wine phenolic composition and color parameters were characterized using a UV-Vis spectrophotometer. The total polyphenol content was determined using the Folin–Ciocalteu method, as described by Singleton and Rossi (1965), through a colorimetric reaction and absorbance reading at 760 nm, with results expressed in mg L^{-1} of gallic acid. Color parameters were evaluated as described by Glories (1984) and derived from sample absorbance at wavelengths of 420, 520, and 620 nm. Total monomeric anthocyanins were determined using the differential pH method according to Rizzon (2010). The total polyphenol index and total tannins (g L^{-1}) were analyzed based on methods described by Rizzon (2010), leveraging the property of proanthocyanidins to produce anthocyanins upon heating in an acidic medium.

Experimental design and statistical analysis

The experiments were conducted in randomized blocks, comprising four blocks and five plants per plot, considering only the three interior plants of each plot for evaluation. The results were tested for error normality using the Shapiro–Wilk test, and data not showing normality were transformed using the formula $\sqrt{x+0.5}$. Non-parametric data were analyzed using the Kruskal–Wallis test in Past4.0 software. Normally distributed data were subjected to analysis of variance ($p < 0.05$) and Tukey's test using SISVAR software (Ferreira, 2014). Data spanning two harvests underwent bifactorial analysis (2 harvests $\times$ 5 defoliations). Principal component analysis was also performed using Past software (Hammer et al., 2001).

Results and discussion

The results regarding poor fruit set, presented as fruit set, showed no interaction between defoliation treatments and harvests. Furthermore, no significant differences were observed for the main effects of defoliation and harvest (Table 3), indicating that defoliation performed at various phenological stages—or at a single stage, with or without boron application—had no impact on reducing poor fruit set. These results did not confirm our initial hypothesis, which postulated that implementing 3 defoliations, starting at phenological stage 17 (developed inflorescence), would reduce the poor fruit set. The experiments were conducted over only two productive seasons in a commercial vineyard. Therefore, further evaluation is necessary to confirm the rejection of this hypothesis. This disorder typically occurs more intensely in years characterized by low temperatures and high rainfall during the flowering period (Brighenti et al., 2021). Although there was greater precipitation and leaf wetness during the flowering period in the 2024 harvest compared to 2023, the minimum temperature was slightly higher in 2024 (Table 1). This variation in weather conditions did not significantly affect poor fruit set, as no differences were observed between the two seasons in terms of fruit set. With the exception of the treatment involving 3 defoliations with boron application in 2024, the results from the other treatments in both harvests could not be classified as poor since they were above 30% fruit set. According to Baby et al. (2016), for grapevines, fruit set is considered normal when it exceeds 50%, and fruit set percentages below 30% are deemed poor. In our study, the number of flowers also did not reveal any significant differences.

Table 3. Number of flowers per cluster and fruit set of ‘Merlot’ grapevines subjected to different defoliation and boron strategies in the 2023 and 2024 harvests.

Treatment			Flowers per cluster			Fruit set (%)		
No. of defoliation	Phenological stage	Boron application	2023	2024	Mean	2023	2024	Mean
3	17, 23, 35	Yes	196.4	219.3	207.9 ^{ns}	34.1	29.4	31.8 ^{ns}
3	17, 23, 35	No	184.4	199.0	191.7	31.2	38.6	34.9
1	23	Yes	198.1	207.1	202.6	38.2	36.3	37.2
1	35	Yes	177.6	166.1	171.8	39.3	41.5	40.4
0*	-	Yes	222.6	163.5	193.1	30.4	44.1	37.3
Mean			195.8 ^{ns}	191.0	-	34.6 ^{ns}	38.0	-
CV (%)			20.1			22.3		

* control; ^{ns} not significant.

In the physical analysis of grapes treated with and without boron application and subjected to different levels of defoliation at phenological stage 23 (Table 4), there were no significant differences in cluster weight, peel weight, berry weight, cluster length, production, or yield. This indicates that for the 2023 harvest, neither the defoliation strategy nor boron application had a discernible impact on the physical characteristics of the grapes. The soil had 0.45 mg dm⁻³ of boron, which was below the level recommended by Gatiboni et al. (2016), who found that the adequate boron level in the soil was between 0.6 and 1.0 mg dm⁻³ for grapevines.

Table 4. Cluster weight, peel weight, berry weight, cluster length, production, and yield of ‘Merlot’ grapes with different defoliation timings and boron in the 2023 harvest.

Treatments			Cluster mass ^a	Peel mass ^a	Berry mass ^a	Cluster length [†]	Production (kg plant ⁻¹)	Yield (kg ha ⁻¹)
No. of defoliation	Phenological stage	Boron application						
3	17, 23, 35	Yes	182.1 ^{ns}	19.3 ^{ns}	68.2 ^{ns}	16.6 ^{ns}	3.81 ^{ns}	10432.6 ^{ns}
3	17, 23, 35	No	160.0	25.9	69.9	17.3	3.90	10693.1
1	23	Yes	152.1	21.8	63.3	16.5	4.72	12930.9
1	35	Yes	150.2	23.2	70.1	15.7	3.77	10322.8
0*	-	Yes	148.7	19.6	66.6	16.9	3.49	9574.4
CV (%)			10.3	19.4	6.0	7.9	28.7	28.7

^aValues are given in grams (g); [†]values are given in centimeters (cm); * control; ^{ns} not significant.

Early removal of vine leaves is known to result in a yield reduction. Specifically, if this is done at phenological stage 23 (full flowering), a decrease in productivity is anticipated (Diago et al., 2011; Poni et al., 2006; Würz et al., 2018a). However, this was not observed in the current study, as no statistical difference was noted (Table 4). It is crucial that defoliation practices are executed with care to avoid damaging the plant. Removing leaves increases the temperature, light penetration, and ventilation around the clusters, improving grape ripening. Furthermore, it simplifies manual harvesting and the application of treatments against cluster rot (Giovannini, 2004; Reynier, 2012).

No significant differences in total acidity or pH were observed among treatments (Table 5). The treatments involving three defoliations, both with and without boron application, did not impact the soluble solids content compared to the control group. The highest soluble solids content occurred in the treatment with 1 defoliation at phenological stage 35, which did not significantly differ from the defoliation carried out at phenological stage 23. In research conducted by Würz et al. (2018c), who assessed the impact of varying defoliation timings on the maturation of ‘Cabernet Sauvignon’ grape berries in São Joaquim, different defoliation timings reduced the total titratable acidity.

Density is one of the primary parameters analyzed by winemakers during the wine fermentation process to monitor fermentation progress and confirm its completion. Its value is primarily influenced by the alcohol and sugar contents of the wine (Oliveira et al., 2011). The relative density was lower in treatments involving three defoliations, both with and without boron application, although this did not significantly differ from the treatment involving a single defoliation at full bloom (as shown in Table 3).

The alcohol content plays a crucial role in product quality, affecting sensory properties, maturation, and product stabilization, as it inhibits microbial growth, which is responsible for unpleasant odors. Its formation occurs during the fermentation of sugars present in the must, which is facilitated by yeast (Jackson, 2008; Oliveira et al., 2011; Felippeto et al., 2020). As shown in Table 3, the alcohol content of the wine produced from grapes not subject to defoliation management (control) was the lowest (12.6% v/v) but did not significantly differ from that of treatments involving 3 defoliations without boron application and 1

defoliation at phenological stage 23 with boron. The impact of defoliation timing on the wine alcohol content was more evident in grapes subjected to defoliation at phenological stages 17, 23, and 35 with boron application, which demonstrated a higher alcohol content value (13.9% v/v). Bredun et al. (2021) observed that ‘Merlot’ wines from two vintages made from boron-treated grapes exhibited a higher alcohol content than the control. All treatments adhered to the legislation regarding alcohol content, which specifies a minimum of 8.6% (v/v) and a maximum of 14% (v/v) for fine wines and a minimum of 14.1% (v/v) and a maximum of 16% (v/v) for noble wines (Brasil, 2018).

Table 5. Physicochemical analyses and results of ‘Merlot’ musts and dry red wine subjected to different defoliation times with and without boron application in the 2023 harvest.

Treatment			Must				
No. of defoliation	Phenological stage	Boron application	Total acidity (meq L ⁻¹)	pH	Soluble solids (°Brix)		
3	17, 23, 35	Yes	9.07 ^{ns}	3.52 ^{ns}	20.9 ^b		
3	17, 23, 35	No	8.93	3.49	21.3 ^b		
1	23	Yes	8.80	3.57	21.7 ^{ab}		
1	35	Yes	9.18	3.54	22.5 ^a		
0 ^{**}	-	Yes	9.36	3.54	21.3 ^b		
CV (%)			4.86	1.79	1.46		
Wine							
			Relative density at 20°C (mg L ⁻¹)	Alcohol content (%v/v)	Residual sugar (g L ⁻¹ glucose)	Free SO ₂ (mg L ⁻¹)	Total SO ₂ (mg L ⁻¹)
3	17, 23, 35	Yes	994.0 ^{b*}	13.9 ^a	2.4 ^{ns}	24.5 ^{ns}	60.8 ^{ns}
3	17, 23, 35	No	993.7 ^b	13.0 ^{bc}	2.3	28.3	65.1
1	23	Yes	994.7 ^{ab}	13.0 ^{bc}	2.3	25.1	56.5
1	35	Yes	995.3 ^a	13.4 ^b	2.4	23.5	55.5
0 ^{**}	-	Yes	995.3 ^a	12.6 ^c	2.4	23.5	68.8
CV (%)			0.04	1.28	2.91	12.1	9.89

^aMeans followed by the same letters in the columns do not differ statistically by Tukey's test at a 5% significance level; ^{**} control; ^{ns} not significant.

The wines showed no difference in the residual sugar parameter (Table 5), registering 2.3 g L⁻¹ for treatments with 3 defoliations without boron and 1 defoliation at phenological stage 23 with boron and 2.4 g L⁻¹ for treatments with 3 defoliations plus boron, 1 defoliation at phenological stage 35 plus boron, and the control. According to Brazilian legislation, dry red wines must contain no more than 4.0 g L⁻¹ of sugar (Brasil, 2018), meaning that all samples complied with this requirement. Similarly, there were no significant differences in free and total SO₂, but these levels were within the norms set by Brazilian legislation (Agência Nacional de Vigilância Sanitária [Anvisa], 2016) (Table 5). Legislation dictates that the maximum volatile acidity value should be 20 meq L⁻¹. All wines produced with defoliation and boron treatments conformed to the standards established by legislation (Brasil, 2018) (Table 6). No differences in pH were noted in the wine.

Table 6. Physicochemical analysis and results ‘Merlot’ dry red wine subjected to different defoliation times with and without boron application in the 2023 harvest.

Treatment			pH	Total acidity (meq L ⁻¹)	Volatile acidity (meq L ⁻¹)	Total polyphenols (mg L ⁻¹ GA)	Total monomeric anthocyanins (mg L ⁻¹)	Total tannins (g L ⁻¹)
No. of defoliation	Phenological stage	Boron application						
3	17, 23, 35	Yes	3.0 ^{ns}	115.0 ^{ns}	5.0 ^{ns}	1321.2 ^{a*}	454.7 ^a	63.79 ^{ns}
3	17, 23, 35	No	2.8	108.8	5.4	1314.4 ^{ab}	331.2 ^{ab}	87.30
1	23	Yes	3.0	100.7	5.8	1228.4 ^b	301.5 ^{abc}	84.09
1	35	Yes	3.0	107.0	5.3	1133.1 ^c	260.7 ^{bc}	66.37
0 ^{**}	-	Yes	2.9	108.0	5.4	1057.5 ^c	240.9 ^c	74.10
CV (%)			2.88	4.93	6.76	2.64	29.5	27.6

GA: Gallic acid; ^{*}means followed by the same letters in the columns do not differ statistically by Tukey's test at a 5% significance level, except for total monomeric anthocyanins, which do not differ by the Kruskal–Wallis test at a 5% significance level; ^{**} control; ^{ns} not significant.

Polyphenols are components of qualitative importance for wines. They are primarily found in the peels and seeds of grapes and develop during the grape maturation stage. A high total polyphenol content significantly contributes to the color, texture, and structure of wines (Felippeto et al., 2020). Treatments involving three early defoliations both with and without boron revealed the highest levels of total polyphenols

and anthocyanins, indicating that defoliation at 3 phenological stages, starting at phenological stage 17, positively affected the concentration of these compounds (Table 6). Furthermore, boron application had no significant impact on the total polyphenol and anthocyanin levels.

Würz et al. (2018b) reported that wines from 'Cabernet Sauvignon' grapes without defoliation had a lower total polyphenol content. They also observed that defoliation management increased the total polyphenol content in 'Cabernet Sauvignon' wines grown in high-altitude regions. Pötter et al. (2010) found that defoliation improved the overall quality of wines made from these grapes, particularly because this technique enhances polyphenol production and the color intensity of red wines. Phenolic compounds, including anthocyanins, play a role in DNA protection and defense against photo-oxidative stress (Teixeira et al., 2013). Therefore, early defoliation exposes the fruit to a longer period of solar radiation, inducing the defense mechanism against photo-oxidative stress, as evidenced by increases in the polyphenol and anthocyanin contents compared to later defoliation (stage 35) or no defoliation.

The color parameter is extremely important for red wine quality, as the hue can change as reactions occur over time (Felippeto et al., 2020). As presented in Table 7, there was a difference between the treatments in the color parameters at 420, 520, and 620 nm as well as in color intensity. A positive progression in both results was noted, with the treatment that included 3 early defoliations plus boron application standing out (74.0 nm) and the control showing the lowest value (41.3 nm). Würz et al. (2018b) observed that vine defoliation altered the color of wine (420, 520, and 620 nm) and, consequently, its intensity. In the 2016 vintage, wines from vines not subjected to defoliation or defoliation 15 days after *veraison* had lower color intensity values. Conversely, defoliation performed at full bloom resulted in the highest color intensity of 'Cabernet Sauvignon' wine.

Table 7. Physical analysis for color at the 420, 520, and 620 nm wavelengths, color intensity, L, a*, and b* of 'Merlot' dry red wine subjected to different defoliation times with and without boron application in the 2023 harvest.

Treatment			Wave length			Color variables			
No. of defoliation	Phenological stage	Boron application	420 nm	520 nm	620 nm	Color intensity [#]	L	a*	b*
3	17, 23, 35	Yes	29.6 ^a	31.9 ^a	12.7 ^a	74.0 ^a	1.3 ^{b*}	3.7 ^{ns}	1.7 ^{ab}
3	17, 23, 35	No	26.5 ^{ab}	27.7 ^{ab}	10.9 ^{ab}	65.0 ^{ab}	1.4 ^{ab}	4.9	2.2 ^{ab}
1	23	Yes	25.6 ^{ab}	25.2 ^{bc}	10.0 ^{bc}	60.9 ^{bc}	1.4 ^{ab}	4.7	1.1 ^b
1	35	Yes	23.0 ^b	20.8 ^{cd}	8.6 ^{cd}	52.3 ^{cd}	1.5 ^{ab}	6.2	2.5 ^{ab}
0 ^{**}	-	Yes	17.4 ^c	17.3 ^d	6.6 ^d	41.3 ^d	1.9 ^a	8.2	3.1 ^a
CV (%)			6.53	9.17	8.14	7.66	8.14	34.5	30.3

^{*}Means followed by the same letters in the columns do not differ statistically according to the Tukey test at a 5% significance level; ^{**} control; ^{ns} not significant; [#] the sum of 420 + 520 + 620 nm.

The luminosity parameter showed no significant differences between the control and treatments with 3 early defoliations without boron and 1 defoliation at phenological stages 23 and 35 with boron (Table 7). Nonetheless, the control differed from those with three early defoliations plus boron. The control treatment had the highest L value (1.9), indicating a lighter color. The treatment with three early defoliations plus boron had a lower value, suggesting a darker color. There were no significant differences in a* among treatments. In terms of parameter b*, the control treatment had the highest value (3.1), while the treatment with 1 defoliation at phenological stage 23 with boron had the lowest value (1.1). The lower b* value indicates a shift towards blue, as it ranges from blue to yellow, with higher values representing shades of yellow and lower values indicating shades of blue. The control treatment exhibited higher values for these parameters, suggesting a lighter color with more intense shades of red and yellow. Conversely, the treatment with three early defoliations with boron showed lower values, indicating a darker color with a lower intensity of red and yellow. Dias et al. (2020) observed a higher quality in 'Merlot' wines subjected to different phenological stages (17, 23, and 35). They concluded that super-early defoliation (stage 23) and early defoliation significantly contributed to the production of wine with a higher alcohol content and greater coloration.

Boron application did not significantly affect the physicochemical characteristics of 'Merlot' wine, except for the alcohol content, which was higher under the boron treatment. However, this effect was less pronounced compared to the treatment with 3 early defoliations plus boron, with the only difference being boron application. We observed that defoliations at phenological stages 17, 23, and 35 conferred benefits to wine quality, especially a significant increase in polyphenol content, total monomeric anthocyanins, and improvement in color intensity.

Principal component analysis was performed to provide an overview of the treatments and the evaluated parameters that showed differences (Figure 1). PC1 accounted for 84.6% of the variation in the data, with separation between the control and the defoliation treatments, particularly in treatments with 3 early defoliations. These treatments were more closely correlated with polyphenol content, total monomeric anthocyanins, and color parameters, corroborating the discussion above. For PC1, the control and 1 defoliation at phenological stage 35 with boron application showed a correlation, demonstrating few differences.

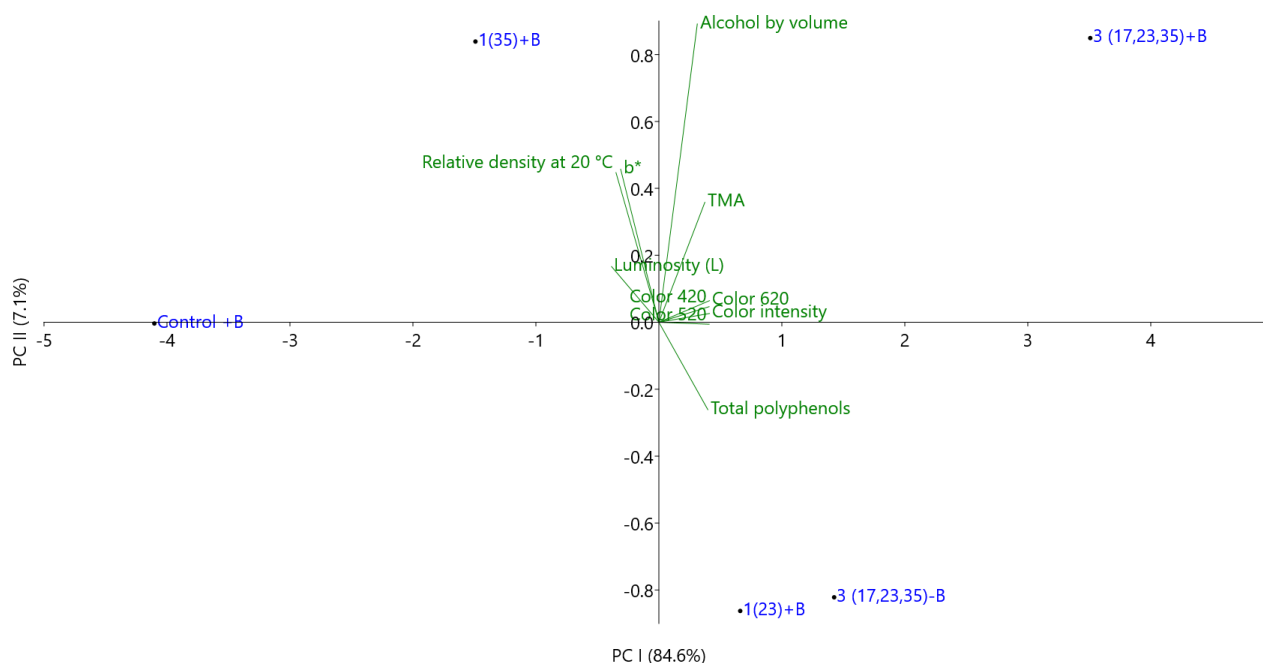


Figure 1. Principal component analysis of ‘Merlot’ wine made from grapes subjected to different defoliation strategies. 3(17, 23, and 35)+B: three defoliations at phenological stages 17, 23, and 35 with boron application; 3 (17, 23, and 35)-B: three defoliations at phenological stages 17, 23, and 35 without boron application; 1(23)+B: one defoliation at phenological stage 23 with boron application; 1(35)+B: one defoliation at phenological stage 35 with boron application; Control+B: no defoliation (control) with boron application. TMA: total monomeric anthocyanins

Conclusion

In the 2023 and 2024 harvests, carrying out 3 defoliations at phenological stages 17, 23, and 35 did not mitigate the poor fruit set in ‘Merlot’ grapes. Conversely, these treatments with three defoliations increased the total polyphenol and anthocyanin content and improved the color parameters and color intensity of the wine. Additionally, boron application alone did not increase the grape quality or, consequently, wine quality, nor did it affect the fruit set.

Data availability

Data are available from the corresponding author upon reasonable request.

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