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Technical Note

Leaf-to-Fruit Ratios in *Vitis vinifera* L. cv. "Sauvignon Blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah" Growing in Maule Valley (Chile): Influence on Yield and Fruit Composition

Gastón Gutiérrez-Gamboa [1], Irina Díaz-Galvéz [2], Nicolás Verdugo-Vásquez [3] and Yerko Moreno-Simunovic [1,]*

[1] Centro Tecnológico de la Vid y el Vino, Facultad de Ciencias Agrarias, Universidad de Talca, Av. Lircay S/N, Talca 3460000, Chile
[2] Instituto de Investigaciones Agropecuarias, INIA Raihuén, Casilla 34, San Javier 3650000, Chile
[3] Instituto de Investigaciones Agropecuarias, INIA Intihuasi, Colina San Joaquín s/n, P.O. Box 36-B, La Serena 1760000, Chile
* Correspondence: ymoreno@utalca.cl; Tel.: + 56-71-201556

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Abstract: A trial was conducted during the 2005–2006 season in order to determine the effects of different leaf-to-fruit ratios on yield components and fruit composition in four *Vitis vinifera* L. cultivars. The treatments consisted of selecting shoots of four lengths (>1.3 m, 1.3–0.8 m, 0.8–0.4 m, and <0.4 m) with two crop levels (1–2 clusters/shoot), which allowed defining eight ratios. Berry composition and yield components were measured. The treatments affected the accumulation of soluble solids in "Sauvignon blanc", "Cabernet Sauvignon", and "Syrah", delaying it as the ratio decreased. All yield components were affected in "Sauvignon blanc", while bunch weight and the number of berries per bunch were altered without a clear trend. None of the yield components were affected in "Cabernet Sauvignon", while the lowest ratio presented the lowest number of berries per bunch in "Syrah". Total polyphenol index (TPI) was affected in "Carmenère" without a clear trend. A highly significant correlation was found between shoot length and leaf area in all studied cultivars. As the ratio increased, the shoot lignification increased in "Sauvignon blanc". However, studies must be conducted during more seasons to establish better conclusions about the effects of leaf-to-fruit ratios on yield and fruit composition.

Keywords: crop load; leaf area; leaf-to-fruit ratio; lignification; phenolic composition

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1. Introduction

The balance between the crop load (sink) and the photosynthetic leaf area (source) is a determinant factor that widely affects productiveness and fruit quality in most *Vitis vinifera* L. cultivars, which subsequently influence the final wine quality [1]. Based on this, the main source of carbohydrates supplying the fruit comes from the leaf photosynthesis [2]. "Overload" is produced when this relationship is exceeded. Based on this, the exposed leaf surface is not able to synthetize enough carbohydrates to supply the grapevine's needs. Therefore, the grapes from these grapevines do not reach an optimum ripening, and remain smaller than the grapes produced from balanced grapevines. This results in a low content of soluble solids, low pH, high total acidity, little color development, and low glutathione and thiol content in grapes [2–5].

Certain authors proposed different leaf area values to reach an optimum ripening of berries [2]. Currently, most studies focus on understanding their effects on grape quality as a strategy to mitigate the unfavorable effects of high temperatures as a result of climate change. Parker et al. [6] reported that restricting potential carbohydrate sources in "Pinot noir" and "Sauvignon blanc" during post-flowering allowed delaying veraison stage, while crop removal scarcely affected the evaluated parameters. Verdenal et al. [5] reported that, in *Vitis vinifera* L. cv. "Chasselas", an excessive leaf area reduced the low yeast assimilable nitrogen status in the musts. A deficient nitrogen level for yeast can lead to stuck or sluggish alcoholic fermentations [7]. Šuklje et al. [3] showed that the highest leaf-area-to-yield ratio presented a high glutathione content in musts and a high concentration of thiols in "Sauvignon blanc" wines. This report also showed that the wines from the highest ratio treatment were best scored for overall quality, presenting tropical aromas. On the other hand, recent researches [6,8,9] showed that, by altering the leaf-to-fruit ratio, it is possible to modify the date of veraison, delaying the grape sugar accumulation. This management was proposed as a viticultural strategy to mitigate the effects of climate change on the maturity of the berries.

Based on this, it is important to define a correct balance between the vegetative and productive relationship in different grapevine cultivars, varying in their edaphoclimatic conditions, in order to increase yield, improve the physico-chemical composition of the grape, and reduce production costs, among other considerations. To our knowledge, this is the first report that studies leaf-to-fruit ratios in grapevine cultivars cultivated in Chile. Therefore, the aim of this work is to study the effect of different leaf-to-fruit ratios performed on "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah" on yield and fruit composition.

2. Materials and Methods

2.1. Experimental Site and Plant Material

The research was performed during the 2005–2006 season, in two commercial vineyards located in San Rafael and San Javier, Maule Valley, Chile, spaced 15 km apart, as shown in Table 1. San Javier presents a clay loam soil, which is characterized by a sedimentary soil in the alluvial terrace position, with a flat topography and good drainage and permeability [10]. The effective soil depth is 55 cm. San Rafael presents a soil loam texture, characterized by a sedimentary soil in the position of the intermediate remnant terrace, resting on a volcanic tuff that constitutes a sandstone. The phreatic surface is observed between 20 and 40 cm of depth, and the development of roots reaches 30 cm of depth [10]. Climatic data of the season under study (2005–2006) were obtained from a representative automatic weather station located between both vineyards, which is administered by the General Water Management of Chile (www.dga.cl).

Table 1. Characteristics of the studied vineyards planted in Maule Valley (cv. "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah").

	Sauvignon Blanc	Carmenère	Cabernet Sauvignon	Syrah
Location	San Rafael	San Javier	San Javier	San Javier
Geographic coordinate	35°31′ SL; 71°53′ WL	35°37′ SL; 71°46′ WL	35°37′ SL; 71°46′ WL	35°37′ SL; 71°46′ WL
Planting year	2002	2000	2001	2001
Surface (ha)	3.20	1.37	2.10	3.22
Planting distance (m)	2.2 × 1.5	2.5 × 1.5	2.5 × 1.5	2.5 × 1.5
Plant density (vines)	3030	2666	2666	2666
Pruning system	Cane pruning	Spur pruning	Cane pruning	Spur pruning
Training system	Vertical shoot system	Vertical shoot system	Vertical shoot system	Vertical shoot system
Orientation	North to south	North to south	North to south	North to south
Irrigation system	Drip irrigation	Drip irrigation	Drip irrigation	Drip irrigation
Rootstock	Own-rooted	Own-rooted	Own-rooted	Own-rooted

SL: South Latitude; WL: West Latitude.

2.2. Treatments and Statistical Design

The treatments consisted of selecting shoots of four lengths (>1.3 m, 1.3 to 0.8 m, 0.8 to 0.4 m, and <0.4 m) with two crop levels (1–2 clusters/shoot) during the veraison stage. The grapevines were not topped; therefore, shoots that naturally had one or two bunches and the corresponding length were selected. This allowed establishing eight different leaf-to-fruit ratios per grapevine cultivar as shown in Table 2. The treatments were arranged in a completely random experimental design (CRD). In total, 26 replicates were selected per treatment, where each replicate corresponds to a shoot. In each grapevine, a maximum of two shoots were selected, applying the same treatment. In this way, each treatment covered a maximum of 13 grapevines. It is important to note that, in each grapevine, the other shoots were not intervened.

Table 2. Leaf-to-fruit ratios (cm^2/g) in cv. "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah" according to length of shoot and crop load.

Leaf-to-Fruit Ratio (cm^2/g)	Sauvignon Blanc	Carmenère	Cabernet Sauvignon	Syrah
T1: 2 bunches per shoot >1.3 m	11.2 ^{cd}	8.3 ^{bc}	10.2 ^{c}	4.8 ^{b}
T2: 1 bunch per shoot >1.3 m	23.8 ^{e}	12.2 ^{c}	13.9 ^{d}	9.3 ^{c}
T3: 2 bunches per shoot 1.3–0.8 m	8.9 ^{bc}	5.5 ^{ab}	8.2 ^{b}	4.7 ^{b}
T4: 1 bunch per shoot 1.3–0.8 m	13.7 ^{d}	6.3 ^{abc}	12.0 ^{c}	8.4 ^{c}
T5: 2 bunches per shoot 0.8–0.4 m	5.7 ^{ab}	3.6 ^{a}	3.6 ^{a}	2.6 ^{a}
T6: 1 bunch per shoot 0.8–0.4 m	8.2 ^{bc}	9.0 ^{bc}	8.0 ^{b}	5.9 ^{b}
T7: 2 bunches per shoot <0.4 m	2.5 ^{a}	2.6 ^{a}	2.9 ^{a}	2.1 ^{a}
T8: 1 bunch per shoot <0.4 m	4.2 ^{a}	7.2 ^{b}	4.8 ^{a}	2.9 ^{a}
Significance	**	**	**	**
Coefficient of variation (%)	21.1	27.2	29.0	29.1

For each parameter, different letters in the same row indicate significant differences among treatments (** $p \leq 0.01$).

2.3. Sample Evaluations

2.3.1. Leaf Area, Shoot Length, and Degree of Shoot Lignification

With the aim of obtaining the leaf area, after the harvest of the bunches, all the leaves of each shoot were manually extracted. Subsequently, the obtained leaves were introduced into a leaf area meter (LI-COR, LI-3100 C, Lincoln, NE, USA) with the aim of analyzing leaf area. Shoot length was measured with a 2-mm tape at the phenological stage of veraison. Bunches of the same shoot were used for the subsequent analysis of yield and physico-chemical parameters, as shown in Tables 3–5. Degree of shoot lignification (%) for "Sauvignon blanc" was determined taking 10 shoots per treatment. This parameter was calculated as the relationship between the length of the lignified shoots and the total length of the shoots multiplied by 100.

2.3.2. Productivity and Physico-Chemical Parameters

For each cultivar, the date of harvest was determined when the vineyard in general presented optimum technological maturity, as defined by the winegrower (22 °Brix for Sauvignon blanc and between 23 and 24 °Brix for red-wine cultivars). Bunch and berry weight were measured using an analytical balance (Cubis®Precision Balance, Sartorius, Göttingen, Germany). Physico-chemical parameters such as °Brix, pH, and total acidity (g/L of sulfuric acid) were analyzed in grapes, according to the methodology established by OIV [11]. For the previous analyses, one bunch was randomly chosen from each shoot (in the case of treatments with two bunches), and two berries were sampled at the top, middle, and bottom of each bunch (total of six berries per bunch and 78 berries per treatment).

2.3.3. Phenolic Composition

Total polyphenol index (TPI) was determined by spectrophotometric absorbance at 280 nm after previous dilution of the samples according to the methodology proposed by Ribéreau-Gayon and

Stonestreet [12]. Extractable anthocyanins (%) and seed maturity (%) were analyzed based on the methodology proposed by Glories and Agustin [13].

2.4. Statistical Analysis

The statistical analysis in relation to parameters analyzed was performed using variance analysis (one-way ANOVA), with Statgraphics Centurion XVI.I (Warrento, Virginia, United States). Differences between samples were compared using the Tukey test at the 95% probability level.

3. Results and Discussions

3.1. Climate Conditions

Climatic characteristics (precipitation, and minimum and maximum temperature) are shown in Figure 1. Precipitation was registered mainly during autumn and winter (85%). Precipitation during the growing season (September to April) reached 139 mm (15% of the total), highlighting the almost complete absence of rainfall during the veraison–harvest period. With respect to temperature, average minimum temperature during the growing season (September to April) was 9.3 °C, while the average maximum temperature during this period was 24.8 °C. The highest temperatures were registered at the end of January and the beginning of February, coinciding with the veraison period of the four cultivars under study. These climatic characteristics (high temperatures and the absence of significant rainfall during the veraison–harvest period) are representative of the environmental conditions of the Maule region (Chile) [14].

3.2. Leaf-to-Fruit Ratios

Table 2 shows the leaf-to-fruit ratios (cm^2/g) defined in "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah" cultivars. As expected, the leaf-to-fruit ratios were low in the treatments that presented shorter shoots and high crop load. In "Sauvignon blanc", the leaf-to-fruit ratios ranged from 2.5 to 23.8, and the highest ratio was obtained in the treatment which was defined as one bunch per shoot >1.3 m (T2). The treatments with shorter shoot lengths (T7 and T8) presented lower leaf-to-fruit ratios than the rest of the treatments, except for the treatment which was defined as two bunches per shoot of 0.8–0.4 m (T5). In "Carmenère", the leaf-to-fruit ratios varied from 2.6 to 12.2, and little difference was found in leaf-to-fruit ratios among the treatments. Thus, leaf-to-fruit ratio was higher in T2 than in the treatment defined as two bunches per shoot of 0.8–0.4 m (T3), as well as T5, T7, and T8 treatments. In "Cabernet Sauvignon", the leaf-to-fruit ratios ranged from 2.9 to 13.9, and the highest ratio was obtained in the T2 treatment. Furthermore, T5, T7, and T8 treatments presented lower leaf-to-fruit ratios than the rest of the treatments. In "Syrah", the leaf-to-fruit ratios varied from 2.1 to 9.3. For this cultivar, T2 treatment and the treatment defined as one bunch per shoot of 0.8–0.4 m (T4) presented higher ratios than the rest of the treatments. Additionally, T5, T7, and T8 treatments showed lower leaf-to-fruit ratios than the rest of the treatments. A significant correlation (Figure S1, Supplementary Materials) was found between shoot length and leaf area in "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah" grapevines (r^2 values of 0.98, 0.94, 0.97, and 0.98, respectively).

Table 3. Effects of the leaf-to-fruit ratios (cm^2/g) on must enological parameters in cv. "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah".

	Sauvignon Blanc			Carmenère			Cabernet Sauvignon			Syrah		
	°Brix	pH	Total Acidity [a]	°Brix	pH	Total Acidity [a]	°Brix	pH	Total Acidity [a]	°Brix	pH	Total Acidity [a]
T1: 2 bunches per shoot >1.3 m	22.5 [b]	3.1	5.4 [b]	24.3	3.7	2.8	24.7 [b]	2.8	3.7	23.5 [b]	2.9	3.5
T2: 1 bunch per shoot >1.3 m	22.8 [b]	3.2	4.4 [a]	24.5	3.7	2.7	24.9 [b]	2.9	3.8	24.4 [c]	3.0	3.4
T3: 2 bunches per shoot 1.3–0.8 m	22.4 [b]	3.2	4.6 [a]	24.3	3.7	2.7	24.9 [b]	2.9	3.7	24.0 [c]	2.9	3.4
T4: 1 bunch per shoot 1.3–0.8 m	22.8 [b]	3.1	4.7 [a]	24.3	3.7	2.8	24.7 [b]	2.8	3.7	23.9 [bc]	3.0	3.4
T5: 2 bunches per shoot 0.8–0.4 m	22.6 [b]	3.2	5.1 [ab]	24.2	3.7	2.6	24.4 [b]	2.7	3.8	22.6 [ab]	2.9	3.5
T6: 1 bunch per shoot 0.8–0.4 m	22.6 [b]	3.1	4.6 [a]	24.4	3.7	2.5	24.1 [b]	2.8	3.8	23.8 [bc]	2.9	3.4
T7: 2 bunches per shoot <0.4 m	21.2 [a]	3.1	4.5 [a]	24.2	3.7	2.5	21.9 [a]	2.7	3.8	21.9 [a]	2.9	3.3
T8: 1 bunch per shoot <0.4 m	21.8 [ab]	3.2	4.5 [a]	24.4	3.7	2.5	24.1 [a]	2.8	3.8	23.4 [b]	3.0	3.4
Significance	*	NS	*	NS	NS	NS	**	NS	NS	**	NS	NS
Coefficient of variation (%)	7.1	3.6	16.1	6.2	4.1	14.1	5.1	12.3	3.8	5.9	13.5	3.2

For each parameter, different letters in the same row indicate significant differences among treatments (* $p \leq 0.05$, ** $p \leq 0.01$, NS—not significant). [a] Values are g/L of sulfuric acid.

Table 4. Effects of the leaf-to-fruit ratios (cm^2/g) on yield parameters in cv. "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah".

	Sauvignon Blanc			Carmenère			Cabernet Sauvignon			Syrah		
	Bunch Weight (g)	Berry Weight (g)	Number of Berries per Bunch	Bunch Weight (g)	Berry Weight (g)	Number of Berries per Bunch	Bunch Weight (g)	Berry Weight (g)	Number of Berries per Bunch	Bunch Weight (g)	Berry Weight (g)	Number of Berries per Bunch
T1: 2 bunches per shoot >1.3 m	155.6 [b]	1.86 [b]	79 [ab]	167.3 [b]	1.08	106 [ab]	95.7	0.92	104	321.3	1.03	156 [b]
T2: 1 bunch per shoot >1.3 m	145.1 [b]	1.66 [ab]	71 [ab]	155.4 [b]	1.20	120 [b]	106.4	0.95	112	192.2	1.08	178 [bc]
T3: 2 bunches per shoot 1.3–0.8 m	131.4 [ab]	1.85 [b]	84 [ab]	161.9 [b]	1.13	121 [b]	103.6	0.95	109	185.2	0.98	189 [c]
T4: 1 bunch per shoot 1.3–0.8 m	131.9 [ab]	1.71 [ab]	94 [b]	152.1 [b]	1.28	110 [ab]	100.0	0.98	102	173.2	0.99	175 [bc]
T5: 2 bunches per shoot 0.8–0.4 m	125.4 [ab]	1.66 [ab]	79 [ab]	146.4 [b]	1.12	104 [ab]	115.4	1.03	112	340.0	1.00	170 [bc]
T6: 1 bunch per shoot 0.8–0.4 m	111.4 [a]	1.67 [ab]	67 [ab]	131.4 [ab]	1.04	113 [ab]	96.0	0.98	98	203.4	1.13	180 [bc]
T7: 2 bunches per shoot <0.4 m	108.1 [a]	1.54 [a]	63 [a]	100.2 [a]	1.01	80 [a]	95.1	0.98	97	247.6	0.96	129 [a]
T8: 1 bunch per shoot <0.4 m	113.1 [a]	1.57 [a]	66 [ab]	106.7 [a]	1.08	96 [ab]	98.0	1.00	98	329.1	1.05	157 [bc]
Significance	*	**	*	*	NS	*	NS	NS	NS	NS	NS	**
Coefficient of variation (%)	29.1	11.5	31.2	27.7	19.2	28.7	19.6	14.2	25.9	28.1	18.1	27.2

For each parameter, different letters in the same row indicate significant differences among treatments (* $p \leq 0.05$, ** $p \leq 0.01$, NS—not significant).

Table 5. Effects of the leaf-to-fruit ratios (cm^2/g) on phenolic maturity in cv. "Carmenère", "Cabernet Sauvignon", and "Syrah".

	Carmenère			Cabernet Sauvignon			Syrah		
	Total Polyphenol Index	**Extractable Anthocyanins (%)**	**Seed Maturity (%)**	**Total Polyphenol Index**	**Extractable Anthocyanins (%)**	**Seed Maturity (%)**	**Total Polyphenol index**	**Extractable Anthocyanins (%)**	**Seed Maturity (%)**
T1: 2 bunches per shoot >1.3 m	37.0 [a]	48.9	68.2	34.5	45.2	74.5	35.7	48.3	67.5
T2: 1 bunch per shoot >1.3 m	46.2 [ab]	47.9	77.1	44.2	46.5	86.1	33.3	53.6	61.0
T3: 2 bunches per shoot 1.3–0.8 m	52.6 [ab]	48.5	73.7	35.1	39.6	73.8	34.9	50.9	71.6
T4: 1 bunch per shoot 1.3–0.8 m	41.7 [ab]	39.9	70.9	37.1	49.3	79.2	30.1	47.9	65.4
T5: 2 bunches per shoot 0.8–0.4 m	44.5 [ab]	50.9	73.3	34.4	38.9	77.1	29.9	44.0	58.7
T6: 1 bunch per shoot 0.8–0.4 m	40.9 [ab]	43.6	71.8	44.3	44.2	88.8	33.4	50.7	63.9
T7: 2 bunches per shoot <0.4 m	49.6 [ab]	59.6	75.1	45.2	44.3	76.3	32.2	42.2	60.2
T8: 1 bunch per shoot <0.4 m	55.2 [b]	42.9	77.3	38.9	37.6	87.5	33.3	46.9	70.1
Significance	*	NS	NS	NS	NS	NS	NS	NS	NS
Coefficient of variation (%)	19.7	12.6	4.2	14.9	18.0	10.6	15.5	16.5	8.2

For each parameter, different letters in the same row indicate significant differences among treatments (* $p \leq 0.05$, NS—not significant).

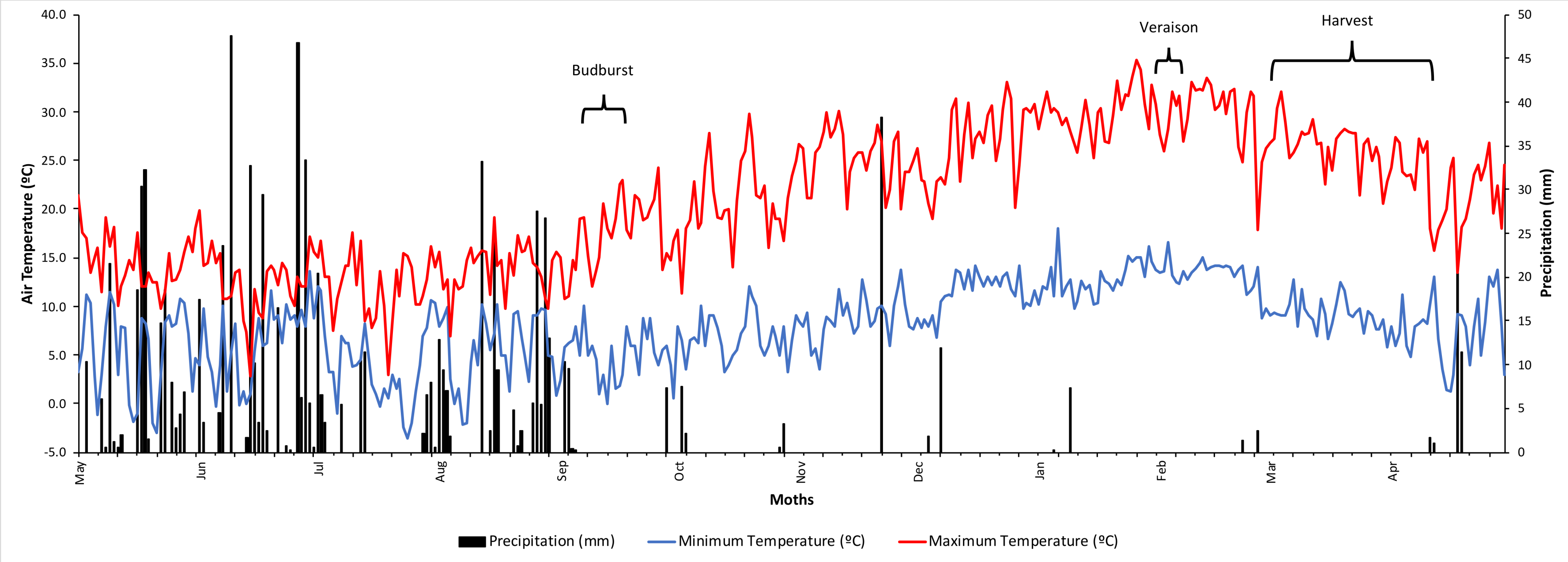

Figure 1. Precipitation (mm), and minimum and maximum temperature (°C) during the 2005–2006 season. Budburst, veraison, and harvest show the periods of occurrence of the main phenological stages for the four cultivars under study.

3.3. Physico-Chemical Parameters

Table 3 shows the effect of the leaf-to-fruit ratios (cm^2/g) on must physico-chemical parameters from "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah". Leaf-to-fruit ratio did not affect pH in "Sauvignon blanc", "Cabernet Sauvignon", and "Syrah". None of the physico-chemical parameters in "Carmenère" were affected by the treatments. Moreover, total acidity content was not affected in "Cabernet Sauvignon" and "Syrah". In general, the leaf-to-fruit ratios affected the accumulation of soluble solids in "Sauvignon blanc", "Cabernet Sauvignon", and "Syrah", delaying it as the ratio decreased. Soluble solids in "Sauvignon blanc" ranged from 21.2 to 22.8 °Brix. In this cultivar, T7 treatment showed lower °Brix than the rest of the treatments, except than the T8 treatment. In "Cabernet Sauvignon" soluble solids varied from 21.9 to 24.9 °Brix. In this cultivar, the treatments that presented shorter shoot lengths, which reached low leaf to fruit ratios (T7 and T8) showed lower °Brix than the rest of the treatments. In "Syrah", soluble solids ranged from 21.9 to 24.4 °Brix. In this cultivar, T7 treatment showed lower °Brix than the rest of the treatments, except for the T5 treatment. In "Sauvignon blanc", total acidity varied from 4.5 to 5.4 g/L of sulfuric acid. In this cultivar, the treatment defined as two bunches per shoot >1.3 m (T1) presented higher total acidity than the rest of the treatments, except for T5 treatment. A significant non-linear relationship between leaf-to-fruit ratios and soluble solids was found for "Sauvignon blanc", "Cabernet Sauvignon", and "Syrah", while, for "Carmenère", the relationship was linear (Figure S2, Supplementary Materials). The differences between cultivars for this relationship may be due to differences in the harvest dates. "Carmenère" is a very vigorous cultivar, characterized by a late entry into production, presenting also a low fertility in basal buds [15,16]. "Carmenère" cultivar shows a tendency to fruitlet abscission that seriously affects its yield [17]. This problem, in which there is an incomplete fertilization in fruit set, leads to grape bunches containing berries with a wide variability of size and maturity [17]. Therefore, soluble solids may have been affected by different variables, such as dehydration or the variability on berry maturation, which might have led a decrease in the effect of the performed treatments. This may explain the fact that there were no significant differences in the soluble solids for the "Carmenère" cultivar (Table 3).

Based on the leaf-to-fruit ratios, in "Sauvignon blanc" grapevines cultivated under the Maule Valley edaphoclimatic conditions, a leaf-to-fruit ratio higher than 8.2 cm^2/g allowed reaching enough content of soluble solids, while, in "Carmenère" grapevines, all leaf-to-fruit ratios reached high values of soluble solids. In "Cabernet Sauvignon" grapevines, a leaf-to-fruit ratio higher than 8.0 cm^2/g allowed reaching an optimal value of soluble solids, while, in "Syrah" grapevines, a leaf-to-fruit ratio higher than 5.9 cm^2/g allowed reaching enough content of soluble solids. Kliewer and Dokoozlian [2] reported that, for the "Cabernet Sauvignon" cultivar, values of leaf-to-fruit ratio between 9 and 11 cm^2/g were adequate for obtaining an optimum maturity at harvest, in agreement with the results found in this research. These authors also found that, for different cultivars established in a single-canopy trellis system, values between 8 and 12 cm^2/g were necessary to obtain fruit with an optimum harvest maturity. If we compared the results obtained in this research, for the case of the "Syrah" cultivar, the optimum value of leaf-to-fruit ratio to obtain fruit with optimum harvest maturity was lower than that presented in the rest of the red varieties. Hochberg et al. [18] showed that "Syrah" cultivar presented higher water uptake and stomata conductance than "Cabernet Sauvignon" cultivar, presenting also a near anisohydric behavior. Additionally, these authors reported that "Cabernet Sauvignon" presented higher water-use efficiency, as well as photosystem II photochemical potential at drought. Schultz [19] reported that maximum stomatal conductance and maximum photosynthesis of "Syrah" were less sensitive to drought than "Grenache". This report also showed that "Syrah" stressed grapevines presented similar sugar concentration to irrigated "Syrah" grapevines. The tension in the xylem created by transpiration aids in extracting water from the soil, attracting nutrients which can then be taken up by the roots [20]. Therefore, it is possible that, due to these particularities, the "Syrah" grapevines can reach an optimum technological maturity at low leaf-to-fruit ratios compared to other red grapevine cultivars.

3.4. Shoot Lignification in cv. Sauvignon Blanc

Figure 2 shows the effect of the leaf-to-fruit ratios (cm^2/g) on the percentage of shoot lignification in cv. "Sauvignon blanc". A quick increase in shoot lignification was observed from 2.5 to 5.7 cm^2/g. Subsequently, the percentage of shoot lignification in cv. "Sauvignon blanc" increased gradually. According to Figure 2, as leaf-to-fruit ratio increased, the percentage of lignification became more developed. Additionally, there was a clear delay in the accumulation of reserves by those shoots lacking leaf area, such as in the T7 and T8 treatments (Figure 2). This can lead to negative consequences in flower initiation and, subsequently, in their productiveness, since low carbohydrates accumulated by the buds can lead to an irregular bud break. Verdenal et al. [5] showed that an oversized canopy decreased total nitrogen in all organs and decreased yeast assimilable nitrogen (YAN) in musts. These authors proposed a leaf-to-fruit ratio between 1.0 and 1.2 m^2/kg (10 to 12 cm^2/g) to guarantee grape maturity, YAN accumulation, and nitrogen recovery in the reserve organs for "Chasselas" grapevines.

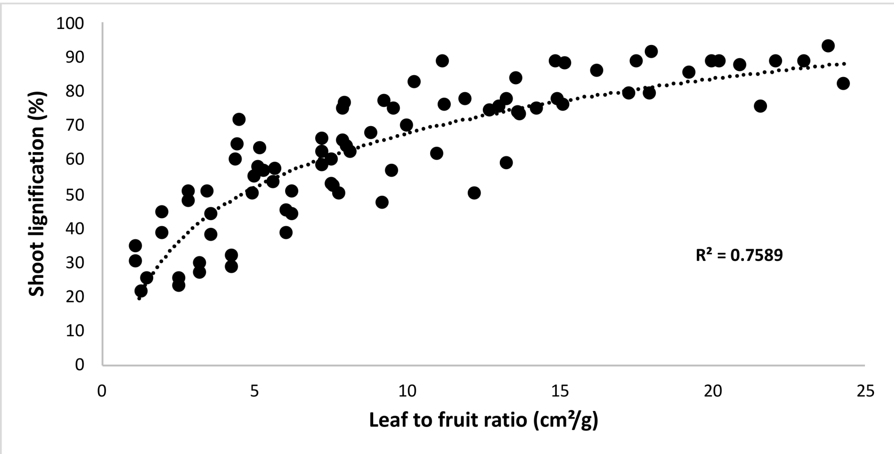

Figure 2. Effects of the leaf-to-fruit ratios (cm^2/g) on the percentage of shoot lignification in cv. "Sauvignon blanc".

3.5. Yield Parameters

Table 4 shows the effect of the leaf-to-fruit ratios (cm^2/g) on yield parameters in cv. "Sauvignon blanc", "Carmenère", "Cabernet Sauvignon", and "Syrah". The treatments did not affect yield parameters in "Cabernet Sauvignon". Berry weight was not affected by the different leaf-to-fruit ratios in "Carmenère" and "Syrah", while the treatments did not affect bunch weight in "Syrah". In "Sauvignon blanc", bunch weight ranged from 108.1 to 155.6 g, and the treatments with lower leaf-to-fruit ratio (T7 and T8), together with the treatment defined as one bunch per shoot 0.8 to 0.4 m (T6), presented lower bunch weight than the treatments that presented the highest shoot length (>1.3 m: T1 and T2). Berry weight varied from 1.54 to 1.86 g. In this cultivar, berry weight was lower in T7 and T8 treatments than in T1 and T3 treatments, while the number of berries per bunch, which ranged from 63 to 94, was higher in the T4 treatment than in the T7 treatment. In "Carmenère", bunch weight varied from 100.2 to 167.3 g. In this cultivar, T7 and T8 treatments showed lower bunch weight than the rest of the treatments, except for T6 treatment, while T7 treatment presented a lower number of berries per bunch, which ranged from 80 to 121, than T2 and T3 treatments. In Syrah, T7 treatment presented the lowest number of berries per bunch. This parameter varied from 129 to 178 for this same cultivar. Therefore, there is not a clear trend between the increase in leaf-to-fruit ratios and berry weight or bunch weight. It seems to be that the bunch weight and number of berries per bunch decrease when the leaf-to-fruit ratio is low, depending on the studied cultivar. The results of the number of berries per cluster are unexpected since this parameter is determined at fruit set, normally several days after flowering, and largely before veraison. Therefore, treatments of leaf-to-fruit ratio at veraison would not be expected to modify the number of berries per bunch. Poni et al. [21] showed that pre-bloom defoliation of the first six basal leaves on main shoots in "Barbera" and "Lambrusco" (*Vitis vinifera* L) cultivars reduced fruit set and yield per shoot, likely as a result of increased leaf-to-fruit ratios. Trimming at two nodes per shoot reduced bunch number, bunch weight, and vine yield and could be applied as alternative to cluster thinning in different stages until one month after blooming [9]. Additionally, Auzmendi and Holzapfel [4] reported that the leaf area necessary to obtain maximum berry weight was more variable than that for sugar concentration and anthocyanin content.

3.6. Phenolic Composition

Table 5 shows the effect of the leaf-to-fruit ratios (cm^2/g) on phenolic maturity in cv. "Carmenère", "Cabernet Sauvignon", and "Syrah". Leaf-to-fruit ratios did not affect phenolic composition in terms of total polyphenol index (TPI), extractable anthocyanins (%), and seed maturity (%) in all the studied grapevines. However, TPI was affected by the leaf-to-fruit ratios in "Carmenère". This parameter ranged from 37 to 55 (T8 and T1 treatments, respectively). In this way, the treatment defined as one bunch per shoot of <0.4 m (T8) showed lower TPI than the treatment defined as two bunches per shoot of >1.3 m (T1). There was no clear trend between the increases in leaf-to-fruit ratios and the accumulation of phenolic compounds in grapes. Based on this, Auzmendi and Holzapfel [4] reported that a greater ratio of leaf area to fruit weight was required to maximize anthocyanin content than that for sugar concentration. Additionally, trimming at two nodes per shoot at G–H and I physiological stages, according to the Baillod and Baggiolini system [22], improved the anthocyanin accumulation and tended to maintain high level of total acidity in grape berries during the first season of treatment [9]. It is important to mention that the non-effects of the leaf-to-fruit ratio on the phenolic composition may be due to the phenological state when the treatments were performed (veraison). Poni et al. [21] found differences in total anthocyanins and total phenols in two red cultivars ("Barbera" and "Lambrusco") when leaf removal was done early in the season (pre-flowering).

3.7. General Comments

It is important to note that this study considered only one season; therefore, the values of leaf-to-fruit ratio proposed that allow obtaining an optimum ripeness to harvest should continue to be assessed in future seasons. The effect of the leaf-to-fruit ratio on the induction of the floral bud of the following season [23] and the effect on the accumulation of reserves in the permanent structures should also be considered [24,25]. The above considerations will allow determining the sustainability of the proposed leaf-to-fruit ratio for a given cultivar. On the other hand, it is important to mention that there were shoots under evaluation (treatments) and shoots without evaluation in the same grapevine with different leaf areas. Therefore, the carbohydrates could be easily transported from one shoot (e.g., high leaf-to-fruit ratio in the shoot) to another shoot with a lower leaf-to-fruit ratio, as mentioned by Pallas et al. [26]. Consequently, the carbon transport between shoots will minimize the effects of the leaf-to-fruit ratio. Finally, we must consider the phenological stage in which the adjustment of the leaf-to-fruit ratio is made, since the current tendency is to perform the adjustment early in the season (pre-flowering or flowering) [8,21] in order to mitigate the negative effects of climate change on the maturity on grape berries.

4. Conclusions

The different leaf-to-fruit ratios affected yield parameters and berry composition, depending on the cultivar. Low leaf-to-fruit ratios were reached in the treatments defined as short shoots with high crop load. A high relationship was found between the shoot length and the leaf area for all the studied grapevines. The leaf-to-fruit ratio considerably affected the percentage of lignification in "Sauvignon blanc" grapevines, increasing as the leaf-to-fruit ratio increased. As the leaf-to-fruit ratio decreased, the accumulation of soluble solids was delayed in "Sauvignon blanc", "Cabernet Sauvignon", and "Syrah" cultivars. Leaf-to-fruit ratios did not affect the accumulation of soluble solids in "Carmenère". In this cultivar, all leaf-to-fruit ratios allowed reaching values of soluble solids higher than 24 °Brix.

The leaf-to-fruit ratio to reach an optimum content of soluble solids was 8.2 cm^2/g for "Sauvignon blanc", 8.0 cm^2/g for "Cabernet Sauvignon", and 5.9 cm^2/g for "Syrah". Yield parameters were affected by the leaf-to-fruit ratio without a clear trend. However, bunch weight and the number of berries per bunch decreased when the leaf-to-fruit ratio was low, depending on the cultivar. Phenolic composition was scarcely affected by the treatments. However, little difference was found in total polyphenol index in "Carmenère". These results are important for defining an optimal fruit load according to the cultivar in different grapevines planted along the Maule Valley. However, more studies must to be carried out to establish better conclusions in relation to the effects of the different leaf-to-fruit ratios on yield parameters and berry composition.

Supplementary Materials: The following are available online at http://www.mdpi.com/2077-0472/9/8/176/s1.

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