agriculture

Article

Effect of Deficit Irrigation on Yield Components and Chemical Composition of Albariño Grapes Grown in Galicia, NW Spain

María Fandiño [1,*], Mar Vilanova [2,3], Marta Rodríguez-Febereiro [1], M. Teresa Teijeiro [1,2], Benjamín J. Rey [1] and Javier J. Cancela [1,2]

1 GI-1716, Proyectos y Planificación, Departamento Ingeniería Agroforestal, Escola Politécnica Superior de Enxeñaría, Universidade de Santiago de Compostela, Rúa Benigno Ledo s/n, 27002 Lugo, Spain
2 CropQuality: Crop Stresses and Their Effects on Quality (USC), Associate Unit of Instituto de Ciencias de la Vid y del Vino (ICVV-CSIC), Rúa Benigno Ledo s/n, 27002 Lugo, Spain
3 Instituto de Ciencias de la Vid y del Vino (ICVV), Consejo Superior de Investigaciones Científicas CSIC, Universidad de La Rioja-Gobierno de La Rioja, Finca la Grajera, Carretera de Burgos, 26080 Logroño, Spain
* Correspondence: maria.fandino@usc.es

Abstract: In the context of climate change, water management is crucial for controlling the reproductive growth and quality of grapes. In this study, we aim to determine the effects of different water regimes on the yield components and chemical composition of grape *Vitis vinifera* Albariño grown in Galicia. Four treatments were tested in the trial: rainfed (T0), irrigated at 30% of ET_o from veraison to harvest (T1), from pea-size to harvest (T2), and throughout the whole vegetative cycle (T6). To analyse the effects of irrigation, measures of stem water potential (Ψ_{stem}) were obtained fortnightly, from flowering to harvest. During the harvest, the average weight per bunch and the number of bunch and yield per vine were determined. In addition, the Ravaz index was also calculated. The grapes from each experimental treatment were subjected to chemical (OIV methods) and volatile composition (GC-MS) analyses. The results indicated a greater yield in the T0 group. The lowest yield was observed for T2 over the three years of the study. The results also showed a stronger influence of year than treatment on Albariño must include chemical composition parameters. Treatment affected malic acid, total acidity, free amino acids (FAN), and assimilable yeast nitrogen (YAN); meanwhile, of the volatile chemical groups analysed, esters, acetates, and volatile acids were affected by the treatment, while the season affected all chemical families of volatile compounds, with the exception of C6 compounds. The interaction effect of Tr × Y was observed on esters, acetates, and total volatile concentration. In the contrast analysis ($p < 0.05$), we observed increases in alcohols and terpenes in T6 vs. T2; however, esters and acetates were increased under rainfed treatment (T0) vs. T6.

Keywords: irrigation schedule; water management; stem water potential; volatile composition

Citation: Fandiño, M.; Vilanova, M.; Rodríguez-Febereiro, M.; Teijeiro, M.T.; Rey, B.J.; Cancela, J.J. Effect of Deficit Irrigation on Yield Components and Chemical Composition of Albariño Grapes Grown in Galicia, NW Spain. *Agriculture* **2022**, *12*, 1522. https://doi.org/10.3390/agriculture12101522

Academic Editor: Pascual Romero Azorín

Received: 31 August 2022
Accepted: 20 September 2022
Published: 22 September 2022

1. Introduction

Global climate change affects viticulture parameters related to the growth of grapes and their quality, modifying the grapevine phenological stages and aromatic compounds [1]. To determine the effects of climate change, multiple studies have developed predictions of climatic conditions based on different climate change scenarios, such as those of Malheiro et al. [2] or, more recently, Cardell et al. [3]. These authors have provided predictions of climatic indices such as the Huglin index [4], which was developed to account for maximum temperatures during the growing season and includes a radiation component, for which a generalised increase can be observed for the entire Iberian Peninsula, including Galicia [2]. This generates the need to apply vineyard management strategies, including efficient water use (irrigation), in vineyards traditionally managed under rainfed conditions. On the other hand, Cardell et al. [3] have predicted the future behaviour integrating parameters related to water status and water use in vineyards, such as real evapotranspiration (RET), calculated using the crop coefficient (K_c) proposed by FAO-56 [5], the

Thornthwaite equation [6], and the water balance (WB; defined as the difference between precipitation and RET), indicating a trend of increased irrigation water requirements in temperate regions, such as Galicia. Studies have recently exposed the current climatic problems in the viticulture field, including the roles of temperature and radiation and possible strategies to provide solutions to viticulturists, among which are irrigation, vegetation management (defoliation), and the adequate management of active vegetation in the row line [7]. In a similar vein, the impact of climate change on viticulture and its possible adaptations have been studied, where soil water management and irrigation have also been included as drought adaptation tools, as well as defoliation as an adaptation alternative under high-temperature conditions [8]. For the specific case of water management in the vineyard, a recent review has presented the main strategies and perspectives for irrigation management, taking into account the limitations imposed by the Denomination of Origen (DOC) and the search for a vegetative–productive balance [9]. Vineyard irrigation is one of the key tools for adapting to climate change in vine cultivation, and its use, combined with other adaptive techniques (e.g., rootstock, cover crops, and so on), is expected to facilitate the achievement of sustainable production [10]. The effects of irrigation on the vineyard and the composition of the berry, as well as water use efficiency, have been considered in previous studies [11,12], generally improving productivity and negatively affecting qualitative aspects, as in the case of aromatic compounds, due to the dilution of those present in the berries. Especially for the cultivar Albariño, drought stress affects yield and quality [11,12]; however, no broad studies focused on this cultivar, including different irrigation strategies along the growing season, have been performed previously. Derived from the complex climatic conditions, it is necessary to carry out studies on the effect of irrigation in vineyards in temperate climates, such as those in Galicia. Our aim was to establish four irrigation strategies during the vineyard season over three years (2016–2018), including a rainfed treatment, in order to assess their effects on vineyard water status, as well as on the production and quality of the grape, paying special attention to the main chemical families of aromatic compounds present in the Albariño variety. This study is based on the hypothesis that irrigation increases production while affecting the qualitative parameters of the must.

2. Materials and Methods

2.1. Study Area and Experimental Design

The experiment was carried out over the 2016–2018 seasons in a commercial vineyard of *Vitis vinifera* L. cv. Albariño located in Lagar de Cervera Winery, O Rosal (41°57′6″ N, 8°49′26″ W, elevation 54 m, and 14.4% slope) in Galicia, Spain [13]. The vineyard was planted in 2006 on 110-Richter rootstock with a spacing of 2 m × 3 m (1667 vines ha^{-1}) [11]. Vines were trained to a *lira* vertical trellis system (H) oriented East-West leaving 28 bud spurs per vine. The irrigation system applied was surface drip irrigation, with a pressure-compensating drip of 2.1 L h^{-1} per emitter, with 0.75 cm separation between emitters.

Climatic conditions and weather data were recorded at the meteorological station of "As Eiras", located 3 km from the plot (41°56′18″ N, 8°47′29″ W, 52 m), and obtained from MeteoGalicia (http://www.meteogalicia.gal/web/index.action, access date: 5 January 2019). Climatic conditions over the three years of the study are shown in Figure 1. Reference evapotranspiration (ET_o) was calculated using the Penman–Monteith equation [5]. The annual rainfall was 1844 mm in 2016 (Figure 1a), 969 mm in 2017 (Figure 1b), and 1500 mm in 2018 (Figure 1c). Rainfall between April 1 and September 30 was 554, 190, and 329 mm in 2016, 2017, and 2018, respectively. Therefore, 2017 was described as a dry season, and 2016 and 2018 were described as wet seasons.

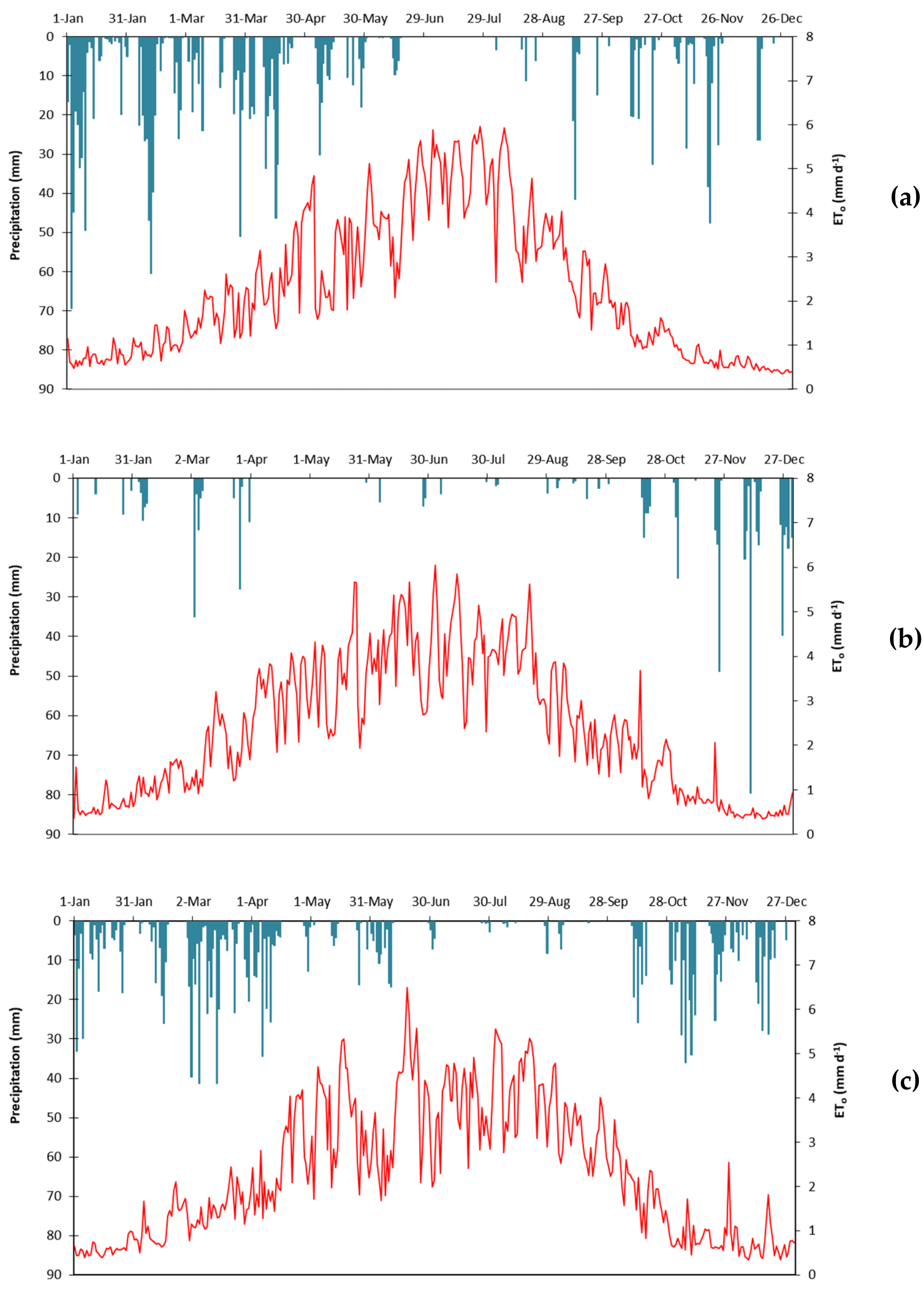

Figure 1. Precipitation (mm, blue bars) and reference evapotranspiration (ET_o, mm d^{-1}, red line) data: (**a**) 2016; (**b**) 2017; and (**c**) 2018.

The experimental design was a completely randomised block layout with four replicates. Each treatment replicate consisted of 21 vines, with the surrounding perimeter vines acting as borders. The treatments established were as follows: T0, Rainfed (0% ET_o); T1, drip irrigated at 30% ET_o from the beginning of veraison to harvest; T2, drip irrigated at 30% ET_o from pea size to harvest; and T6 (control), drip irrigated at 30% ET_o from budburst to harvest (Table 1).

Table 1. Growing season reference evapotranspiration (ET_o, mm), precipitation, and doses (mm), as well as key irrigation dates.

Year	Tr	Irrigation			* Precipitation (mm)	* ET_o (mm)
		Dose (mm)	Start	End		
2016	T0	0.0	-	-	554	652
	T1	31.6	16 August	1 September		
	T2	92.2	11 July	1 September		
	T6	165.2	19 April	1 September		
2017	T0	0.0	-	-	190	655
	T1	81.5	3 August	27 August		
	T2	136.6	15 June	27 August		
	T6	163.3	6 April	27 August		
2018	T0	0.0	-	-	329	642
	T1	22.3	22 August	14 September		
	T2	73.5	28 June	14 September		
	T6	125.0	2 May	14 September		

* ET_o and * Precipitation refer to the period April–September. T0, Rainfed (0% ET_o); T1, drip irrigated at 30% ET_o from the beginning of veraison to harvest; T2, drip irrigated at 30% ET_o from pea size to harvest; and T6 (control), drip irrigated at 30% ET_o from budburst to harvest.

The stem water status (Ψ_{stem}) is considered a reference method to evaluate the effects of different water regimes [9,14]. Therefore, the plant water status was characterised by determining Ψ_{stem} at midday (1130–1230 solar time) on bag-covered leaves from four representative vines per treatment replicate on a weekly basis from May to September, using a pressure chamber (Model 600, PMS Instrument Company, Albany, OR, USA) [15].

2.2. Vine Performance

At harvest, yield components were evaluated on seven vines per treatment replicate. Grape yield (kg vine^{-1}), the number of clusters per vine, and cluster weight (g) were determined for each experimental vine. Pruning weight was obtained, and the Ravaz Index was calculated as the ratio between the yield and pruning weight.

2.3. Must Chemical Composition

Must composition was determined at harvest in two sub-samples weighing approximately 250 g, which came from berries randomly collected from each experimental vine. Musts were physicochemically analysed by determining total soluble solids (TSS, °Brix), pH, titratable acidity (TA), and malic and tartaric acid contents using the official methods of the International Organization of Vine and Wine [16]. Must TSS was determined by refractometry (PR-101, Series Palette, Atago, Tokyo, Japan), while pH and TA were measured with an automatic titrator (Metrohm, Herisau, Switzerland). Juice was titrated with 0.1 N NaOH solution to an endpoint of pH 8.2, and the results are expressed as tartaric acid equivalents. FAN, N Ammonia and YAN were determined using a Foss WineScan FT 120, as described by the manufacturer (Foss, Hillerød, Denmark). All determinations per replicate were performed in triplicate.

2.4. Volatile and Composition of Musts

The extraction of volatile compounds in free and glycosidically bound fractions followed the method described by Oliveira et al. [17], with some modifications [18].

In brief, about 300 mL of must was centrifuged (RCF = 9660; 20 min; 4 °C) and filtered through a glass wool bed. To 75 mL of the juice, 3 µg of 4-nonanol (Merck, ref. 818,773, Darmstadt, Germany) was added as an internal standard and passed through a LiChrolut EN cartridge (Merck, 500 mg, 40–120 µm). The resin was previously preconditioned with 10 mL of dichloromethane (Merck ref. 1.06054), 5 mL of methanol, and 10 mL of an aqueous alcoholic solution (10%, v/v). Free and glycosidically bound fractions were eluted successively with 5 mL of pentane–dichloromethane azeotrope and 7 mL of ethyl acetate, respectively. The pentane–dichloromethane elute was dried over anhydrous sodium sulphate and concentrated to 200 µL by solvent evaporation with N_2 prior to analysis. The ethyl acetate eluate was concentrated to dryness (40 °C) in a Multivapor™ from Buchi (Flawil, Switzerland), then re-dissolved in 200 µL of 0.1 M citrate–phosphate buffer (pH = 5.0). Fourteen milligrams of the enzyme Rapidase Revel Aroma (Erbslbosh, Germany) were added to the glycoside extract, and the mixture was incubated at 40 °C for 14 h. The released aglycons were extracted with pentane-dichloromethane azeotrope after the addition of 3 µg of 4-nonanol as the internal standard. The organic phase was then concentrated to 200 µL with N_2.

The gas chromatographic analysis of volatile compounds was performed using an Agilent GC 6890 N Chromatograph coupled with an Agilent 5975C mass spectrometer (Agilent Technologies, Santa Clara, CA, USA). A 1 µL sample was injected into a capillary column, coated with CP-Wax 52 CB (50 m × 0.25 mm i.d., 0.2 µm film thickness, Chrompack; Agilent Technologies, Santa Clara, CA, USA). The temperature of the injector was programmed to ramp from 20 °C to 250 °C at a rate of 180 °C/min. The oven temperature was held at 40 °C for 5 min, then programmed to rise from 40 °C to 250 °C at a rate of 3 °C /min, then held for 20 min at 250 °C, and finally programmed to go from 250 °C to 255 °C at a rate of 1 °C/min. The carrier gas was helium N60 (Air Liquide, Paris, France) at 103 kPa, which corresponds to a linear speed of 180 cm/s at 150 °C. The detector was set to electronic impact mode (70 eV), with an acquisition range from 29 to 360 *m/z* and an acquisition rate of 610 ms. The semi-quantification of the volatiles such as 4-nonanol equivalents (µL) was performed using the WSearch free software (Wsearch32 v1.6.2005, Australia) by comparing the retention indices with those of the pure standard compounds from Sigma-Aldrich (Darmstadt, Germany) and confirming these by GC-MS.

2.5. Statistical Analysis

The data were subjected to a two-way ANOVA to examine the effects of the treatments (Tr), season (Y), and treatment and season interaction (Tr × Y) using the XLSTAT-Pro software (Addinsoft SARL, Paris, France). As the season exerted a significant influence on most of the studied variables, the mean differences between treatments were calculated separately for each season, according to Tukey's HSD test, with a confidence interval of 95% ($p < 0.05$). Contrast analysis (p-values at 95%) by families of compounds in Albariño musts (mean of three seasons) was conducted.

3. Results and Discussion

3.1. Meteorological Conditions, Irrigation, and Water Relations

The weather conditions over the three years of study were quite variable. This was primarily due to the difference in annual rainfall between the three seasons, with 2016 and 2018 being wet seasons while 2017 was drier (see Table 1).

Measurement of the stem water potential (Ψ_{stem}; MPa) allowed for discrimination of the level of water stress under the different treatments applied (i.e., irrigated and rainfed) throughout the cycle (Figure 2), indicating significant differences between treatments for most of the measurement period, with the irrigation treatments being clearly discriminated from the rainfed treatment (Table 1). From veraison (M), treatments T2 and T6 maintained less water deficit than T1, clearly separated from the rainfed (T0) treatment, especially from the start of irrigation. Due to the rainfall that occurred over the three years prior to the flowering date, the differences between treatments were minimal, although there was a clear difference in the dry year, with lower potential in T0. On the contrary, in veraison, the irrigated treatments showed higher values than the rainfed treatment in all three years, which demonstrates the positive response of the plants to the use of irrigation water.

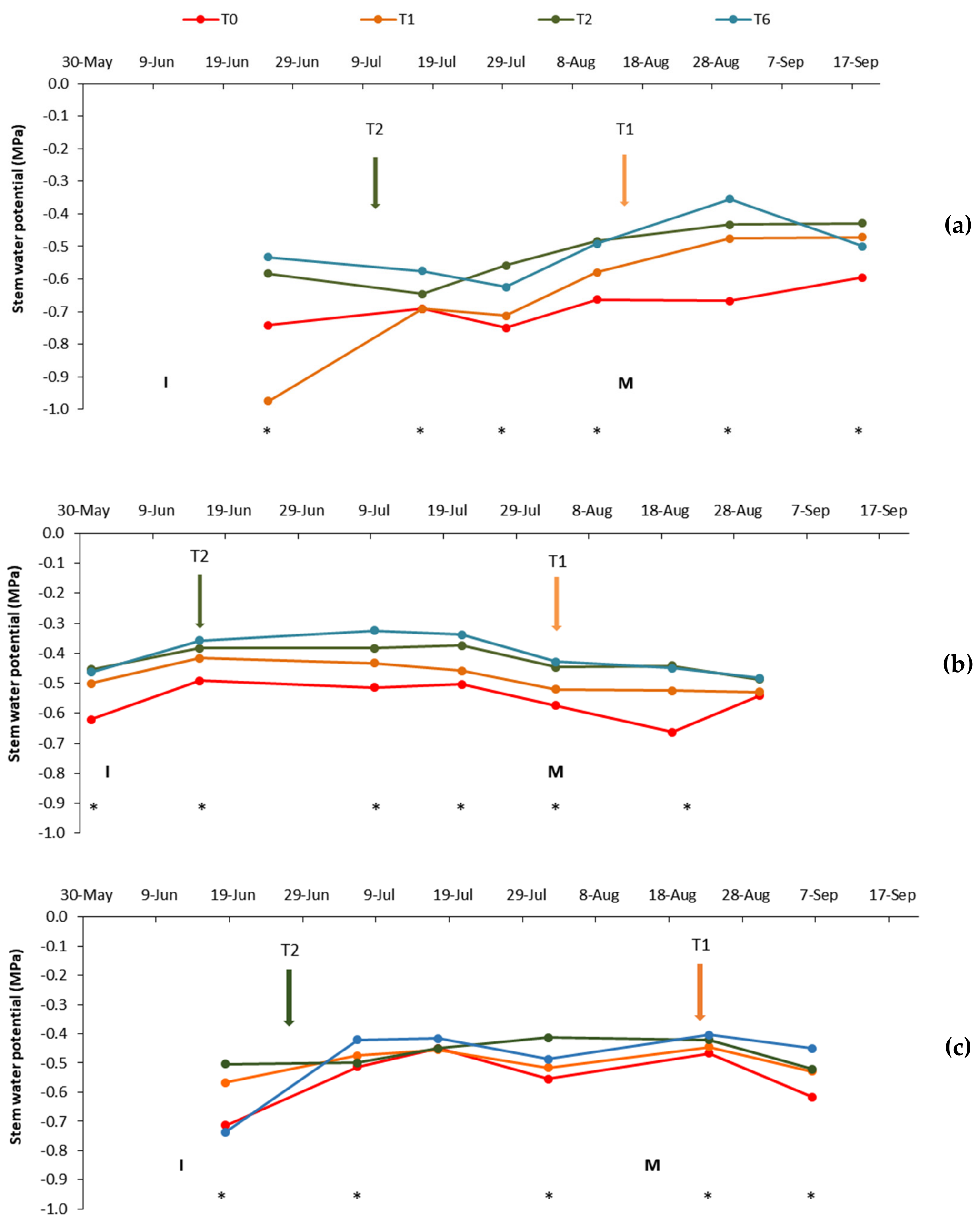

Figure 2. Evolution of stem water potential during the three growing seasons: (**a**) 2016; (**b**) 2017; and (**c**) 2018. Arrows represent the irrigation start date. I, flowering; M, veraison; * indicates significance at $p < 0.05$. T0, Rainfed (0% ET_o); T1, drip irrigated at 30% ET_o from the beginning of veraison to harvest; T2, drip irrigated at 30% ET_o from pea size to harvest; and T6 (control), drip irrigated at 30% ET_o from budburst to harvest.

In 2016, there were significant differences between at least one of the irrigation treatments on all measurement days (Figure 2a). Treatment T6 experienced less water deficit than the other treatments throughout the season, with the exception of the values at the end of July, where the highest Ψ_{stem} values were obtained under treatment T2; in addition, on the last day of the season, the Ψ_{stem} values were homogenous under all treatments, due to previous rainfall. For the 2017 season, the evolution of Ψ_{stem} showed constant behaviour; in particular, T0 showed the most negative values at every measurement date, compared with the higher values of T6, while T1 and T2 were located in-between (T6 > T2 > T1 > T0; see Figure 2b). At the end of May, T2 and T6 showed significant differences in Ψ_{stem} with respect to T0. These two treatments (i.e., T2 and T6) became equal as the season progressed, statistically differing from T0, except for the last day of the measurement cycle (Figure 2b). In 2018, lower variability of the Ψ_{stem} was observed throughout the entire season compared with the previous ones. In the case of T6, the values were higher from the beginning of July to the end of the cycle, except on August 1, presenting significant differences from T0 (Figure 2c). The most negative values throughout the season were obtained for T0, presenting significant differences from all irrigation treatments at the end of the cycle.

The Ψ_{stem} values under T6 were all above −0.6 MPa, the limit for which water stress levels were defined in the vineyard [9,19]. On all measurement days, except at the end of July 2016 (Ψ_{stem} = −0.63 MPa) and at the beginning of 2018 (Ψ_{stem} = −0.74 MPa), no water stress was observed for T6. Similarly, T2 and T1 presented values above −0.6 MPa once the irrigation started, also with no water stress. Finally, T0 obtained the most negative values in the year 2016, with values between −0.6 and −0.9; meanwhile, in 2017 and 2018, the values registered were generally lower in magnitude, thus not presenting water stress, except in the last few days, where the stress level was moderate.

In temperate climates, Ψ_{stem} values are generally low, depending on the variety and local climatic conditions. For the varieties Godello and Treixadura (DO Ribeiro) under rainfed conditions, Ψ_{stem} values of −0.8 MPa and −1.0 MPa have been obtained, while irrigation treatments led to values of −0.6 MPa and −0.8 MPa for the same varieties [20]. These values indicate greater water stress—although moderate—with respect to those obtained for Albariño conducted in Parral [21]. The recorded Ψ_{stem} values of Albariño on trellises were similar to those obtained in Parral [21], although more negative than those reported for Albariño [22] conducted on a trellis in the same study area. The most negative values of Ψ_{stem} stand out: −1.00 MPa was obtained for Albariño at DO Ribeiro under dry conditions [23]. When the results are compared with those from other geographical areas with a continental or Mediterranean climate, the values of Ψ_{stem} in Albariño were higher in all cases; for example, in dry treatments for the Verdejo, Tempranillo Blanco, Airén, and Macabeo varieties, Ψ_{stem} values between −0.97 and −1.42 MPa have been reported [24].

The relevance of using Ψ_{stem} in temperate climates to evaluate the differences between irrigation treatments has also been previously demonstrated [14,15].

3.2. Effect of Water Regime on Vine Performance and Yield

Table 2 details the effects of the treatments (T0, T1, T2, and T6) on yield components. The results indicate a stronger effect of year than treatment on production components. Significant differences were observed for all production parameters when assessing the effect by year; however, pruning weight was not affected by the treatment. The interaction Tr × Y was not observed.

There was a tendency to increase the bunch number under T0 and T1; however, this increase was only significant in the 2016 and 2017 seasons. In contrast, the bunch weight showed a significant increase under T0 and T6 only in the 2018 season. The trend in 2016 and 2017 was to increase the bunch weight in T6 (176.0 g and 160.8 g, respectively). With respect to yield, significant differences were observed in 2016 and 2018, where T0 and T1 led to the highest productions (Table 2). Finally, a significant increase in the Ravaz index was observed under T1 and T2 (28%) in the 2016 season.

In general, higher productions were reached in T0 and T1 in wet years (2016 and 2018); therefore, the climatic conditions of the growing season have an impact on production components, showing a compensatory effect on water-stressed vines. Moreover, the reduction of yield and bunch number appeared to be cumulative over the years (Table 2). Vegetative growth is known to be highly dependent upon vine water status [25].

The yield (kg vine^{1}) was not consistent with the amount of water received in each treatment. It was expected that the greater the amount of water, the greater the production, as other authors have concluded [24,26–28] in semi-arid climates; meanwhile, Cancela et al. [11,21] have reported similar results for Albariño in a temperate climate, which is related with the rainfall distribution during the season and the heterogeneity of soil conditions in the plot. T1 and T0 show the highest productions in the three study seasons, being in 2016 and 2017, the maximum production for T1. Several authors [11,29] have reported a trend towards a greater number of clusters under irrigation treatments. The number of clusters was higher in 2016 and 2017 for the considered Albariño, compared with those reported by the authors cited above, mainly related to the planting framework and pruning carried out. However, the numbers were similar to those determined in Albariño conducted in semi-parral [30].

Table 2. Production parameters, pruning weight, and Ravaz index over three seasons.

Year	Tr	Bunch (nº)	Weight per Bunch (g)	Yield (kg/vine)	Pruning Weight (kg/vine)	Ravaz Index	WUE (kg/m^3)
2016	T0	64.3 a	169.4	10.87 a	1.97	6.12 ab	2.7 a
	T1	62.9 ab	175.8	10.98 a	1.87	6.56 a	2.6 a
	T2	54.9 c	153.1	8.59 b	2.17	4.73 b	1.8 b
	T6	55.8 bc	176.0	9.93 ab	2.11	5.75 ab	2.0 b
Sig.		0.007	0.157	0.006	0.577	0.058	0.000
2017	T0	58.3 ab	153.0	8.66	2.16	4.53	4.5 a
	T1	63.8 a	144.9	9.17	2.12	5.00	3.8 b
	T2	51.4 b	158.9	7.78	2.43	3.69	2.8 c
	T6	56.3 ab	160.8	8.60	2.45	4.28	3.0 c
Sig.		0.026	0.484	0.063	0.473	0.093	0.000
2018	T0	47.1 a	132.3 a	6.26 a	1.99	3.55 a	2.5 a
	T1	45.4 a	111.6 bc	5.06 ab	1.85	3.19 ab	1.9 b
	T2	43.9 a	108.3 c	4.78 ab	2.16	2.49 b	1.6 b
	T6	38.5 b	127.2 ab	5.00 b	1.95	2.88 ab	1.5 b
Sig.		0.040	0.002	0.034	0.503	0.016	0.000
ANOVA							
Treatment (Tr)		***	*	***	ns	***	***
Year (Y)		***	***	***	*	***	***
Tr × Y		ns	ns	ns	ns	ns	ns

Different letters indicate significant differences for Tukey's test at $p < 0.05$. *, ***, and ns indicate significance at $p < 0.05$, 0.001, and not significant, respectively.

The increase in the average weight of the bunch (g) is influenced by the application of a higher amount of irrigation water [27]; however, for the Albariño under study, this trend was not strictly maintained. The highest values of average bunch weight were obtained for T6, except in 2018, the year in which T0 presented the largest values (Table 2). This explains the high productions under T0, together with the number of bunches, when compared with the remaining treatments. The average bunch weights were higher than those determined by other authors for the Albariño variety [11,29,30], although they were similar to those obtained by Vilanova et al. [31]. The irrigation factor showed significant differences in the average bunch weight for the years 2016 and 2018.

The pruning wood values obtained were above those previously reported for Albariño [29], although with a higher density of plantation and simple cordon, while the values reported by Cancela et al. [11] were similar for most years or slightly superior. In the latter case, the planting framework was the same as in the present study. The values obtained in 2016 were within the recommended values for balanced wines (Ravaz Index: 5–10) [32]; meanwhile, in 2017 and 2018, the values (less than 5) were more suitable for cold climates or high vegetative growth, with respect to the production obtained. The Albariño studied in [29] presented a Ravaz index of 2.14 under rainfed conditions, compared with 2.25 under an irrigated treatment; these values are contrary to those obtained in this study.

In relation to water use efficiency (WUE, kg m^{-3})(Table 2), the relationship between yield and water use, taking into account both: irrigation water and precipitation during the growing season, results show the higher values of T0 in the three study years, especially during the dry year (2017). These values are agreed with previous studies in Albariño [11,29], where rainfed treatment showed higher values, which means better use of water by the vineyard in rainfed treatment.

3.3. Effect of Water Regime on Berry Chemical Composition

Table 3 shows the changes in berry chemical composition under the different treatments (T0, T1, T2, and T6). The ANOVA results indicated the stronger effect of year than treatment in Albariño must composition, as more parameters were affected by the year. Among the treatments (Tr), significant differences were observed in malic acid, total acidity, FAN, and YAN. However, significant differences were found for all chemical parameters among years (Y), with the exception of N Ammonia. The interaction Tr × Y was not observed.

Table 3. Chemical Composition of Albariño Musts at Harvest under Different Water Treatments over Three Seasons.

Year	Tr	°Brix	pH	Tartaric Acid (g L^{-1})	Malic Acid (g L^{-1})	AT (g L^{-1})	FAN (mg L^{-1})	N Ammonia (mg L^{-1})	YAN (mg L^{-1})
2016	T0	19.8 b	3.1	1.7	5.2	5.7 b	188.7	77.3	265.7
	T1	21.0 a	3.0	3.9	5.0	6.2 ab	191.7	103.5	294.7
	T2	19.2 b	2.9	3.2	6.7	6.4 ab	374.0	109.0	482.0
	T6	19.3 b	2.7	3.8	6.0	6.7 a	299.7	136.2	436.0
Sig.		0.001	0.562	0.105	0.623	0.025	0.018	0.843	0.086
2017	T0	21.0	3.0	3.4	4.0	7.5	109.5	75.0	184.5
	T1	20.3	3.0	3.5	4.6	7.1	118.0	48.0	166.0
	T2	21.0	3.1	2.9	4.9	7.0	124.0	56.0	180.0
	T6	20.6	3.0	3.2	4.9	7.8	104.0	54.0	158.0
Sig.		0.994	0.341	0.536	0.760	0.745	0.869	0.536	0.890
2018	T0	22.0	3.4	2.7	4.3 b	5.8	146.5	62.0	209.0
	T1	22.2	3.3	1.8	4.4 b	6.8	141.5	54.0	195.5
	T2	21.2	3.4	1.5	5.6 ab	6.3	221.7	98.7	320.3
	T6	21.5	3.4	1.5	7.1 a	7.0	214.0	96.7	312.7
Sig.		0.545	0.582	0.103	0.002	0.099	0.027	0.025	0.022
ANOVA									
Treatment (Tr)		ns	ns	ns	**	*	**	ns	*
Year (Y)		***	***	**	*	**	***	ns	***
Tr × Y		ns	ns	ns	ns	ns	ns	ns	ns

TA, total acidity; FAN, free assimilable nitrogen without proline; YAN, yeast assimilable nitrogen;. Different letters indicate significant differences (Tukey's test, p <0.05). *, **, ***, and ns indicate significance at p < 0.05, 0.01, 0.001, and not significant, respectively.

When the year was analysed separately (Tukey's test, p < 0.05), no significant differences were observed in the driest year, 2017, for any of the chemical parameters analysed; however, different behaviours were observed in the wet seasons (2016 and 2018). In 2016, the highest value of °Brix (21) and total acidity (6.7 g L^{-1}) were observed for T1 and T6, respectively. In contrast, in 2018, significant differences were observed only for malic acid, with the highest value in T6 (7.1 g L^{-1}). In general, malic acid showed a slight tendency to increase in concentration as the amount of irrigation increased, while tartaric acid presented a varying trend among seasons. The treatments with more water availability (T2 and T6) seemed to delay the technological ripeness, as compared with other treatments, as shown by the °Brix, total acidity, and pH. Usually, higher levels of water stress are reported to reduce berry weight and malic acid concentration while increasing sugar contents [33]. Water deficit has been shown to accelerate sugar accumulation and malic acid breakdown in non-irrigated Agiorgitiko must [34]. The acceleration of the ripening process under water deficit is likely related to the indirect effects of water stress, such as reduced vegetative growth and favourable canopy microclimate [34].

3.4. Effect of Water Regime on Volatile Composition of Musts

Water status affects metabolic pathways in berries involved in plant defence and stress response mechanisms. Table 4 presents the influence of different water regimes on must volatile chemical groups (i.e., alcohols, C6 compounds, esters and acetates, volatile acids, terpenes, C_{13}-norisoprenoids, volatile phenols, and lactones) in terms of the sum of both free and glycosidically bound fractions. The effect on total composition (sum of chemical groups) was also evaluated.

Table 4. Total volatile compound concentrations (μg L^{-1}), grouped by chemical families in Albariño musts under different water status treatments over three seasons.

Year	Tr	Alcohols	C6 Compounds	Esters/ Acetates	Volatile Acids	Terpenes	C_{13}-Norisoprenoids	Volatile Phenols	Lactones	Total
2016	T0	395.7	2037.8	546.7 a	1712.5	122.5	687.8	195.3	51.6	5750.0 ab
	T1	417.9	2235.8	581.5 a	1354.4	232.1	690.7	352.0	53.4	5917.8 a
	T2	169.7	1765.7	152.2 b	654.9	123.4	247.5	89.5	23.4	3226.2 c
	T6	352.0	1955.4	219.8 b	1149.7	229.3	338.1	236.3	38.7	4519.1 bc
Sig.		0.118	0.828	0.000	0.272	0.061	0.372	0.259	0.464	0.005
2017	T0	172.1	1639.7	29.4	1635.5	121.4	430.2 a	137.9	31.6	4197.7
	T1	170.7	1222.3	30.1	1145.1	126.7	86.1 b	166.5	20.9	2968.3
	T2	159.9	1957.9	25.0	709.4	99.9	97.0 b	104.3	21.4	3174.9
	T6	230.7	1646.4	44.7	2249.3	161.0	151.3 ab	204.6	19.0	4706.9
Sig.		0.784	0.685	0.579	0.213	0.737	0.015	0.829	0.656	0.536
2018	T0	139.9	1580.9	163.4	376.3 a	112.8	70.9	81.2	5.4	2530.8
	T1	91.7	1801.2	174.9	81.6 b	60.8	18.4	33.2	7.1	2268.9
	T2	126.3	2577.6	215.1	205.1 ab	76.7	73.5	50.4	12.0	3336.6
	T6	161.8	2480.5	247.1	282.9 ab	107.7	100.3	69.0	8.2	3457.5
Sig.		0.229	0.373	0.379	0.036	0.054	0.343	0.239	0.717	0.380
ANOVA										
Tr		ns	ns	**	*	ns	ns	ns	ns	ns
Y		***	ns	***	***	**	**	**	***	***
Tr × Y		ns	ns	***	ns	ns	ns	ns	ns	*

Tr, Treatment; Y, Year; Different letters indicate significant differences for Tukey's test at $p < 0.05$. *, **, ***, and ns indicate significance at $p < 0.05$, 0.01, 0.001, and not significant, respectively.

In the same way as the previous parameters analysed, a stronger effect of year (Y) than treatment (Tr) on must chemical groups was observed, as more volatile groups were affected by the year. Namely, ester, acetate, and volatile acid groups were affected by the treatment (Tr), while all volatile chemical groups (except C6 compounds) varied significantly with the year (Y). The interaction Tr × Y was only significant for the esters and acetates, as well as total composition.

Positive and negative effects of water stress on grape and wine volatile compounds have been reported in previous works. In general, the effect of the irrigation treatment varies depending on the season; therefore, climatic conditions tend to determine the effects of the water regime on grape composition [12,25,35]. In Verdejo wine, lower levels of water availability induced a higher concentration of volatiles [18]. Irrigation significantly altered the concentrations of several volatiles in Albariño wines, which differed between zones and years [36]. In our study, the total volatile composition showed the highest concentrations in the wettest 2016 season for all treatments. However, in 2016, significant differences in total concentration were observed among treatments, where the water regimes with lower irrigation (T1 and T0) presented the highest values (5917.8 μgL^{-1} and 5750.0 μgL^{-1}).

In terms of chemical groups, C6 compounds highly contributed to the free volatile composition of Albariño musts in all seasons and treatments; however, different behaviours were observed among treatments by season. C6 compounds may be considered undesirable due to their contribution to herbaceous aromas in grapes and wine [36–38]. During ripening, the concentration of C6 compounds (hexenols and hexanol) decreases; therefore, a high concentration of C6 compounds is associated with a lack of grape maturity. In our study, the C6 compound group was not affected by either the treatment or the year; however, a trend of increased C6 compound concentration was observed with higher water availability (i.e., T2 and T6) in the 2017 and 2018 seasons in agreement with a lower ripening (°Brix and total acidity). García-Esparza et al. [39] have observed that watering post-veraison at 75% ET_c increased herbaceous aromas in wines, as well as a general trend in a reduction in the skin–pulp ratio when increasing the irrigation regime. In contrast, several studies have suggested that low water availability increased the concentration of some C6 compounds [18,40,41]. In this sense, in the wettest season (2016), T0 and T1 showed the highest values of C6 compounds (2037.8 μg L^{-1} and 2235.8 μg L^{-1}, respectively).

C_{13}-norisoprenoids are products of carotenoid degradation. Negative correlations have been observed between the levels of norisoprenoids and carotenoids during berry development [42]. Carotenoids are mostly synthesised from the first stage of fruit formation until veraison and then degrade to C_{13}-norisoprenoids between veraison and maturity. Several authors have indicated that water supply has a large influence on the degradation of carotenoid contents of grapes, thereby possibly affecting the presence of substances with a high aroma impact at harvest, such as C_{13}-norisoprenoids [43]. The highest concentration of C_{13}-norisoprenoids was observed in the wettest season (2016); however, a trend of reaching the highest values in T0 and T1 was observed. In contrast, a significant effect of treatment was observed in the drier season (2017), where the highest value was also found in T0 (430.2 μg L^{-1}). Water availability promotes canopy growth and, therefore, a decrease in fruit exposure, increasing the concentration of some compounds during ripening [36]. With respect to C_{13}-norisoprenoids, sunshine favours the degradation of carotenoids after veraison, increasing C_{13}-norisoprenoids at maturity in berries exposed to sunshine during a certain period, compared with permanently shaded berries [44]. Other authors have reported that the concentration of free C6 compounds decreased while bound terpene, alcohols, and C_{13}-norisoprenoids increased in berries under severe vine water stress [45]. Therefore, in our study, the increase in fruit exposure due to the effects of water stress may have increased the C_{13}-norisoprenoids concentration under T0.

Esters and acetates showed the highest concentration in the wettest season (2016), where treatments with lower water availability (T0: 547.7 μg L^{-1} and T1: 581.5 μg L^{-1}) increased their concentration with respect to T2 (152.2 μg L^{-1}) and T6 (219.8 μg L^{-1}). Esters in Cabernet Sauvignon wines have been shown to be affected by the water status of vines, where wines produced using grapes from more water-restricted vines resulted in the lowest total amount of esters [46]. In relation to volatile acids, the highest concentrations were also observed in the wettest season (2016); however, significant differences among treatments were only observed in 2018, with the highest concentration found in T0 (376.3 μg L^{-1}). The higher water availability in 2016 may have produced a compensatory effect on water-stressed vines under T0 and T1. Moderate irrigation treatment has been shown to produce wines with higher volatile acid content [46].

Volatile phenols appear to be less influenced by exposure to sunlight [42]. In this sense, a trend to reach a higher concentration of volatile phenols was observed when water was not limited. Thus, the highest concentration of volatile phenols was observed in the wettest season for T1 (352.0 μg L^{-1}) and T6 (236.3 μg L^{-1}), and T6 (204.6 μg L^{-1}) in the dry season (2017).

In general, all chemical groups showed the highest concentration in the wettest season (2016) with a trend to increase their concentration when 30% ET_o irrigation was applied from the beginning of veraison to harvest (T1).

Table 5 provides the volatile composition of Albariño musts as the average of the three seasons. Contrast analysis (p-value < 0.05) was also performed, with the aim to determine the significant differences between control treatment (T6; treatment with the highest water availability) versus treatments T0, T1, and T2. First, significant differences among treatments were observed for all chemical groups, except for C6 compounds and lactones. Total concentrations also presented significant differences among treatments when the season was not considered, showing higher concentrations in T6 and T1. This situation was due to the increases in alcohols, volatile acids, terpenes, C_{13}-norisoprenoids, and volatile phenols in these treatments (T6 and T1).

Table 5. Contrast analysis (*p*-values < 0.05) by families of compounds in Albariño musts (mean of three seasons).

Means TR	Alcohols	C6 Compounds	Esters/Acetates	Volatile Acids	Terpenes	C_{13}-Norisoprenoids	Volatile Phenols	Lactones	Total
T0	235.9 a	1752.8	246.5 a	1241.4 a	118.9 ab	396.3 a	138.1 ab	29.5	4159.5 a
T1	226.8 a	1753.1	262.2 ab	860.4 a	139.9 a	265.1 ab	183.9 a	27.1	3718.4 ab
T2	152.0 b	2100.4	130.8 c	523.1 b	100.0 b	139.3 b	81.4 b	18.9	3245.9 b
T6	248.1 a	2027.4	170.5 bc	1227.3 ab	166.0 a	196.5 ab	169.9 ab	22.0	4227.9 ab
Sig.	0.090	0.700	0.005	0.022	0.107	0.331	0.281	0.583	0.210
				Contrast P-values					
T6 vs. T0	ns	ns	*	ns	ns	ns	ns	ns	ns
T6 vs. T1	ns	ns	ns	ns	ns	ns	ns	ns	ns
T6 vs. T2	*	ns	ns	ns	*	ns	ns	ns	ns

Different letters indicate significant differences for Tukey's test at $p < 0.05$. * and ns indicate significance at $p < 0.05$ and not significant, respectively.

Finally, when we contrasted the higher water availability scenario (T6) with the other treatments, irrigation from budburst to harvest (T6) led to an increase in alcohols and terpenes vs. irrigation from pea size to harvest (T2). However, esters and acetates increased under the rainfed treatment (T0) vs. T6.

These results demonstrate that the application of irrigation during vine growth produces changes in the concentration of grape volatile and bound compounds, affecting the compounds in different ways, depending on their chemical group.

Irrigation has been shown to tend to increase concentrations of volatile fatty acids and decrease some esters and acetates, which could decrease floral and fruity aromas in wine [47,48]. One study, developed in Northwest Spain, has shown that irrigation increased the concentrations of some volatiles that may contribute negative nuances to Albariño wine aromas, such as fatty acids or alcohols while reducing positive compounds such as ethyl esters or terpenes. This effect depended on the climate characteristics of the zone, as more volatiles were affected in the moderately dry zone of Ribeiro than in the humid zone of Rías Baixas [49]. In the same way as this study, our results showed a higher effect of season climatic conditions than treatment on Albariño volatile and bound composition.

4. Conclusions

The amount of irrigation applied does not necessarily positively affect the productive parameters of grapes in a region with abundant rainfall, such as Galicia, even in a dry year (e.g., 2017). The irrigation applied from veraison (T1) generates continuity in terms of traditional production while slightly reducing the yield per hectare in 2018, thus improving the coupling between technological and volatile maturation by allowing a slight delay in the harvest. The trend towards climatic conditions with greater crop water demand in temperate climates has led to a clear interest in the adequate management of irrigation in a sustainable manner (e.g., T1), using small amounts of water that allow a balanced maturation in order to obtain high-quality grapes, adapting to the production limits established in the Denomination of Origin. Rainfed production (T0) is a sustainable management alternative since the production and quality obtained are similar to those shown for T1, especially under temperate weather conditions, as in Galicia (Spain). However, the better water use efficiency (WUE) for all seasons, in T0 recommends not applying irrigation in this vineyard to obtain sustainable production. The research carried out allowed us to determine that higher irrigation over time (T2 and T6) does not improve the productive results while demanding a greater amount of irrigation water. The number of resources available for vineyard irrigation is limited so the results obtained in this study are promising. Through using small amounts of irrigation water (T1), production stability can be attained in both qualitative and productive aspects. The application of deficit irrigation from veraison with lower irrigation depths should be studied, which could allow for an improvement of the WUE for the T1 treatment. Other adaptation techniques to climate change, such as cover crop management and/or leaf defoliation, both early and in the berry ripening phase, should be studied in combination with deficit irrigation. Finally, other irrigation systems, such as sub-surface drip irrigation, could prevent evaporation losses; for this reason, a comparison between surface and sub-surface drip irrigation could help to reduce the water required for irrigation, thus increasing water use efficiency.

Author Contributions: Conceptualization, M.F., M.V. and J.J.C.; methodology, M.F., M.V. and J.J.C.; formal analysis, M.F., M.V., M.R.-F., M.T.T., B.J.R. and J.J.C.; investigation, M.F., M.V., M.R.-F., M.T.T., B.J.R. and J.J.C.; resources, M.V. and J.J.C.; data curation, M.F. and M.V.; writing—original draft preparation, M.F., M.V. and J.J.C.; writing—review and editing, M.F., M.V., M.R.-F., M.T.T., B.J.R. and J.J.C.; visualisation, M.F. and M.V.; project administration, M.V. and J.J.C.; funding acquisition, M.V and J.J.C. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Spanish National Research Institute for Agriculture (INIA) [RTA2014-00049-C05-05] by the Spanish Government.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: To the 'Lagar de Cervera' cellar staff and the colleagues from INIA-2014 for their support and collaboration during the experimental design.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Van Leeuwen, C.; Darriet, P. The impact of climate change on viticulture and wine quality. *J. Wine Econ.* **2016**, *11*, 150–167. [CrossRef]
2. Malheiro, A.C.; Santos, J.A.; Fraga, H.; Pinto, J.G. Climate change scenarios applied to viticultural zoning in Europe. *Clim. Res.* **2010**, *43*, 163–177. [CrossRef]
3. Cardell, M.F.; Amengual, A.; Romero, R. Future effects of climate change on the suitability of wine grape production across Europe. *Reg. Environ. Chang.* **2019**, *19*, 2299–2310. [CrossRef]
4. Huglin, P. Nouveau mode d'évaluation des possibilités heliothermiques de la vigne. *L'académie D'agriculture* **1978**, *64*, 1117–1126.
5. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop evapotranspiration-Guidelines for Computing Crop Water Requirements-FAO Irrigation and Drainage Paper 56*; FAO: Rome, Italy, 1998; Volume 300, p. D05109.
6. Thornthwaite, C.W. An approach toward a rational classification of climate. *Geogr. Rev.* **1948**, *38*, 55–94. [CrossRef]
7. Santos, J.A.; Fraga, H.; Malheiro, A.C.; Moutinho-Pereira, J.; Dinis, L.T.; Correia, C.; Moriondo, M.; Leolini, L.; Dibari, C.; Costafreda-Aumedes, S.; et al. A review of the potential climate change impacts and adaptation options for European viticulture. *Appl. Sci.* **2020**, *10*, 3092. [CrossRef]
8. Van Leeuwen, C.; Destrac-Irvine, A.; Dubernet, M.; Duchêne, E.; Gowdy, M.; Marguerit, E.; Pieri, P.; Parker, A.; de Rességuier, L.; Ollat, N. An update on the impact of climate change in viticulture and potential adaptations. *Agronomy* **2019**, *9*, 514. [CrossRef]
9. Mirás-Avalos, J.M.; Araujo, E.S. Optimization of Vineyard Water Management: Challenges, Strategies, and Perspectives. *Water* **2021**, *13*, 746. [CrossRef]
10. Romero, P.; Navarro, J.M.; Ordaz, P.B. Towards a sustainable viticulture: The combination of deficit irrigation strategies and agroecological practices in Mediterranean vineyards. A review and update. *Agric. Water Manag.* **2022**, *259*, 107216. [CrossRef]
11. Cancela, J.J.; Trigo-Córdoba, E.; Martínez, E.M.; Rey, B.J.; Bouzas-Cid, Y.; Fandiño, M.; Mirás-Avalos, J.M. Effects of climate variability on irrigation scheduling in white varieties of *Vitis vinifera* (L.) of NW Spain. *Agric. Water Manag.* **2016**, *170*, 99–109. [CrossRef]
12. Vilanova, M.; Fandiño, M.; Frutos-Puerto, S.; Cancela, J.J. Assessment fertigation effects on chemical composition of *Vitis vinifera* L. cv. Albariño. *Food Chem.* **2019**, *278*, 636–643. [CrossRef]
13. Fandiño, M. Necesidades de Agua e Influencia de los Sistemas de Riego en *Vitis vinífera* cv. Albariño. Ph.D. Thesis, Universidad de Santiago de Compostela, Santiago, Spain, 2021.
14. Santesteban, L.G.; Miranda, C.; Marín, D.; Sesma, B.; Intrigliolo, D.S.; Mirás-Avalos, J.M.; Escalona, J.M.; Montoro, A.; de Herralde, F.; Baeza, P.; et al. Discrimination ability of leaf and stem water potential at different times of the day through a meta-analysis in grapevine (*Vitis vinifera* L.). *Agric. Water Manag.* **2019**, *221*, 202–210. [CrossRef]
15. Mirás-Avalos, J.M.; Trigo-Córdoba, E.; Bouzas-Cid, Y. Does predawn water potential discern between irrigation treatments in Galician white grapevine cultivars? *OENO One* **2014**, *48*, 123–127. [CrossRef]

16. Rothen, F. International Organisation of Vine and Wine, Compendium of international methods of wine and must analysis. *Paris Int. Organ. Vine Wine* **2015**, *142*, 6–9.
17. Oliveira, J.M.; Oliveira, P.; Baumes, R.L.; Maia, M.O. Volatile and glycosidically bound composition of Loureiro and Alvarinho wines. *Food Sci. Technol. Int.* **2008**, *14*, 341–353. [CrossRef]
18. Vilanova, M.; Rodríguez Nogales, J.; Vila-Crespo, J.; Yuste, J. Influence of water regime on yield components, must composition and wine volatile compounds of *Vitis vinifera* cv. Verdejo. *Aust. J. Grape Wine Res.* **2019**, *25*, 83–91. [CrossRef]
19. Van Leeuwen, C.; Trégoat, O.; Choné, X.; Bois, B.; Pernet, D.; Gaudillère, J.P. Vine water status is a key factor in grape ripening and vintage quality for red Bordeaux wine. How can it be assessed for vineyard management purposes? *OENO One* **2009**, *43*, 121–134. [CrossRef]
20. Trigo-Córdoba, E.; Bouzas-Cid, Y.; Orriols-Fernández, I.; Díaz-Losada, E.; Mirás-Avalos, J.M. Influence of cover crop treatments on the performance of a vineyard in a humid region. *Span. J. Agric. Res.* **2015**, *13*, 907. [CrossRef]
21. Cancela, J.J.; Fandiño, M.; Rey, B.J.; Dafonte, J.; González, X.P. Discrimination of irrigation water management effects in pergola trellis system vineyards using a vegetation and soil index. *Agric. Water Manag.* **2017**, *183*, 70–77. [CrossRef]
22. Cancela, J.J.; Fandiño, M.; Rey, B.J.; González, X.P. Empleo de imágenes térmicas obtenidas mediante UAVs para la determinación del estrés hídrico en *Vitis Vinifera* (cv. Albariño). In Proceedings of the XXIV Congreso Nacional de Riegos, Sevilla, Spain, 7–9 June 2016.
23. Mirás-Avalos, J.M.; Trigo-Córdoba, E.; Bouzas-Cid, Y.; Díaz Losada, E.; Orriols-Fernández, I. Relación entre humedad del suelo y estado hídrico de Albariño bajo condiciones de riego y secano. In Proceedings of the XI Jornadas de Investigación de la Zona no Saturada del Suelo, Lugo, Spain, 6–8 November 2013.
24. Montoro, A.; Uriarte, D.; Fandiño, M.; Cancela, J.J.; Valdés, E.; Vilanova, M.; Garcia-Escudero, E.; Yuste, J. Productive and phisiological response to irrigation of five white *Vitis vinifera* L. varieties cultivated in Spain. In Proceedings of the 20th GiESCO International Meeting (Group of International Experts for Cooperation on Vitivinicultural Systems), Mendoza, Argentina, 5–9 November 2017.
25. Matthews, M.A.; Anderson, M.M.; Schultz, H.R. Phenologic and growth responses to early and late season water deficits in Cabernet franc. *Vitis* **1987**, *26*, 147–160.
26. Nadal, M.; Arola, L. Effects of limited irrigation on the composition of must and wine of Cabernet-Sauvignon under semi-arid conditions. *Vitis* **1995**, *34*, 151–154.
27. Intrigliolo, D.S.; Castel, J.R. Response of grapevine cv. 'Tempranillo' to timing and amount of irrigation: Water relations, vine growth, yield and berry and wine composition. *Irrig. Sci.* **2010**, *28*, 113. [CrossRef]
28. Uriarte, D. Efecto del Riego y el Nivel de Carga de Cosecha en cv. Tempranillo en Condiciones de Clima Mediterráneo Semi-árido. Ph.D. Thesis, Universidad de Extremadura, Badajoz, Spain, 2016.
29. Mirás-Avalos, J.M.; Trigo-Córdoba, E.; Bouzas-Cid, Y.; Orriols-Fernández, I. Irrigation effects on the performance of grapevine (Vitis vinifera L.) cv.'Albariño' under the humid climate of Galicia. *OENO One* **2016**, *50*, 183–194. [CrossRef]
30. Martínez, E.M.; Rey, B.J.; Fandiño, M.; Cancela, J.J. Impact of water stress and nutrition on *Vitis vinífera* cv.'Albariño': Soil-plant water relationships, cumulative effects and productivity. *Span. J. Agric. Res.* **2016**, *14*, 22. [CrossRef]
31. Vilanova, M.; Genisheva, Z.; Tubio, M.; Álvarez, K.; Lissarrague, J.R.; Oliveira, J.M. Effect of vertical shoot-positioned, Scott-Henry, Geneva double-curtain, arch-cane, and parral training systems on the volatile composition of Albariño wines. *Molecules* **2017**, *22*, 1500. [CrossRef]
32. Vance, A.J.; Skinkis, P. Understanding Vine Balance: An Important Concept in Vineyard Management. In *Corvallis, Or: Extension Service*; Oregon State University: Corvallis, OR, USA, 2013.
33. Mirás-Avalos, J.M.; Intrigliolo, D.S. Grape Composition under Abiotic Constrains: Water Stress and Salinity. *Front. Plant Sci.* **2017**, *8*, 851. [CrossRef]
34. Koundouras, S.; Marinos, V.; Gkoulioti, A.; Kotseridis, Y.; van Leeuwen, C. Influence of Vineyard Location and Vine Water Status on Fruit Maturation of Nonirrigated Cv. Agiorgitiko (*Vitis vinifera* L.). Effects on Wine Phenolic and Aroma Components. *J. Agric. Food Chem.* **2006**, *54*, 5077–5086. [CrossRef]
35. Intrigliolo, D.S.; Pérez, D.; Risco, D.; Yeves, A.; Castel, J.R. Yield components and grape composition responses to seasonal water deficits in Tempranillo grapevines. *Irrig. Sci.* **2012**, *30*, 339–349. [CrossRef]
36. Mendez-Costabel, M.P.; Wilkinson, K.L.; Bastian, S.E.P.; Jordans, C.; McCarthy, M.; Ford, C.M.; Dokoozlian, N.K. Effect of increased irrigation and additional nitrogen fertilisation on the concentration of green aroma compounds in *Vitis vinifera* L. Merlot fruit and wine. *Aust. J. Grape Wine Res.* **2014**, *20*, 80–90. [CrossRef]
37. Roujou de Boubee, D. Research on 2-Methoxy-3-Isobutylpyrazine in Grapes and Wine. Ph.D. Thesis, Academie Amorim, Bordeaux, France, 2003.
38. Cullere, L.; Cacho, J.; Ferreira, V. An assessment of the role played by some oxidation-related aldehydes in wine aroma. *J. Agric. Food Chem.* **2007**, *55*, 876–881. [CrossRef]
39. García-Esparza, M.J.; Abrisqueta, I.; Escriche, I.; Intrigliolo, D.S.; Alvarez, I.; Lizama, V. Volatile compounds and phenolic composition of skins and seeds of 'Cabernet Sauvignon' grapes under different deficit irrigation regimes. *Vitis* **2018**, *57*, 83–91.
40. Talaverano, I.; Valdés, E.; Moreno, D.; Gamero, E.; Mancha, L.; Vilanova, M. The combined effect of water status and crop level on Tempranillo wine volatiles. *J. Sci. Food Agric.* **2016**, *97*, 1533–1542. [CrossRef] [PubMed]

41. Wang, J.; Abbey, T.; Kozak, B.; Madilaoa, L.L.; Tindjaua, R.; Del Ninc, J.; Castellarin, S.D. Evolution over the growing season of volatile organic compounds in Viognier (*Vitis vinifera* L.) grapes under three irrigation regimes. *Food Res. Int.* **2019**, *125*, 108512. [CrossRef] [PubMed]
42. Baumes, R.; Wirth, J.; Bureau, S.; Gunata, Y.; Razungles, A. Biogeneration of C13-norisoprenoid compounds: Experiments supportive for an apo-carotenoid pathway in grapevines. *Anal. Chim. Acta* **2002**, *458*, 3–14. [CrossRef]
43. Oliveira, C.; Fereira, A.C.; Pinto, M.M.; Hogg, T.; Alves, F.; Guedes de Pinho, P. Carotenoid compounds in grapes and their relationship to plant water status. *J. Agri. Food Chem.* **2003**, *51*, 5967–5971. [CrossRef] [PubMed]
44. Bureau, S.; Baumes, R.; Razungles, A. Effects of Vine or Bunch Shading on the Glycosylated Flavor Precursors in Grapes of *Vitis vinifera* L. Cv. Syrah. *J. Agric. Food Chem.* **2000**, *48*, 1290–1297. [CrossRef]
45. Song, J.; Shellie, K.C.; Wang, H.; Quian, M.C. Influence of deficit irrigation and kaolin particle film on grape composition and volatile compounds in Merlot grape (*Vitis vinifera* L.). *Food Chem.* **2012**, *134*, 841–850. [CrossRef]
46. Talaverano, I.; Ubeda, C.; Cáceres-Mella, A.; Valdés, E.; Pastenes, C.; Peña-Neira, A. Water stress and ripeness effects on the volatile composition of Cabernet Sauvignon wines. *J. Sci. Food Agric.* **2018**, *98*, 1140–1152. [CrossRef]
47. Rapp, A.; Mandery, H. Wine aroma. *Experientia* **1986**, *42*, 873–883. [CrossRef]
48. Robinson, A.L.; Boss, P.K.; Solomon, P.S.; Trengove, R.D.; Heymann, H.; Ebeler, S.E. Origins of grape and wine aroma. Part 1 chemical components and viticultural impacts. *Am. J. of Enol. Vitic.* **2014**, *65*, 1–24. [CrossRef]
49. Mirás-Avalos, J.M.; Bouzas-Cid, Y.; Trigo-Córdoba, E.; Orriols, I.; Falqué, E. Irrigation effects on the volatile composition and sensory profile of Albariño wines from two different terroirs. *Eur. Food Res. Technol.* **2019**, *245*, 2157–2171. [CrossRef]