Meteorological Conditions: Influence on Yield, Sanitary Status and Grape Composition

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***Abstract*—** *The current study aimed to establish which meteorological conditions have the strongest impact on grapevine yield, sanitary status and berry composition, as well as checking their relative importance in relation to management practices and grapevine variety. Weather data was correlated to yield, sanitary status and grape composition of three varieties (Cabernet-Sauvignon, Merlot and Tannat) under two trellis systems (lyre and vertical shoot positioning), with or without yield control (pruning type and cluster thinning) over four seasons throughout the south of Uruguay. Principal component analysis showed that weather variables explained, respectively, 57.3%, 64.3% and 57.8% of the variance in yield, sanitary status and grape composition within the studied dataset. Hierarchical Clustering grouped years, confirming that the relevance of weather interannual variability was greater than that of genetics and management practices. Yield depended on bunch number, which was determined by rainfall and temperature. Water statuses during the first stage of the growing cycle are determinant for bunch rot infection, as well as thermal and hydric conditions that prevail during maturation. Grape compounds were positively correlated to thermal sum at the beginning of the growing cycle and negatively with high temperatures and water availability in maturation. Our results suggest that the favourable intervals of atmospheric conditions for yield and bunch rot are different from those for berry quality.*

Keywords*— *Berry quality, climate, genotype, viticultural practice, yield components.

I. INTRODUCTION

The main climatic elements that explain variations in grapevine performance and oenological quality are sunlight, temperature and precipitation. Among these, temperature and precipitation have the most marked effect on yield components and berry composition, which are sensitive to their magnitude, variations and distribution over the crop cycle [1,2]. Bunch number per plant explains about 60-70 % in the interannual variation in grapevine yield [3]. Initiation – induction of inflorescences and floral differentiation take place in the period of budbreak - fruit set, in two consecutive seasons, hence temperature and water availability during this phase are determinant factors for quality and yield in two harvests [4-6]. Water deficits in the season previous to harvest produce yield declines by reduction in number of bunches per plant. For the harvest year, water deficit influences the differentiation of flowers, fruit set or abortion of flowers, fruit, and berry size, leading to variations in yield [4, 7]. Vine water requirements depend on phenological stage, being flowering - veraison (48.2 %) the most demanding period over a total of 750 mm required during the growing season [8]. *Botrytis cinerea* is a serious threat to grapevine and has a negative impact on grape and wine quality. Weather conditions during pre-harvest (frequent precipitations, high relative humidity, mild temperatures and low wind intensity) are key elements for the development of this disease [9,10]. Meteorological conditions accounted for 88 % of the total variability on grape composition, a higher percentage than that explained by variety or soil [11]. Wine grape quality between years depends on temperature variability that determines whether grape ripening would be completed, due to its impact on sugar content, acidity degradation and berry anthocyanins balance [12]. The optimum diurnal temperature ranges from 25°C to 30°C. Values over 37°C inhibit sugar accumulation and induce a negative balance in anthocyanins; while the respiration of malic acid accelerates starting from 35°C [12, 13]. During maturation, optimal levels of acidity and a positive balance in anthocyanins require a temperature range night / day of 16 / 25°C; lower temperatures promote high levels of malic acid [13]. Meanwhile, thermal sum in that period, expressed as degree-day base 10ºC, is strongly associated with anthocyanin content [1]. In general, it is recognized that a progressive and moderate water stress from flowering to fruit set favors the accumulation of sugars and anthocyanins, and decreases the acidity associated with the reduction of vegetative growth in the fruit ripening stage [2,14]. Post veraison water stress is responsible for the largest increase in polyphenolic content.

In this context, the current study aimed to establish which meteorological conditions have the strongest impact on grapevine yield, sanitary status and berry composition. An additional objective was to assess when and how weather interannual variability affects grapevine yield and berry quality, as well as checking its relative importance in relation to management practices and variety.

II. MATERIAL AND METHOD

2.1 Description of the study sites

Ten plots distributed throughout the south of Uruguay (34°35'12.43" S; 56°15'2.26'' W), which comprises 76.4% of vineyard surface in the country (INAVI, 2013), were established in commercial vineyards. The climate of this area is Temperate warm, with Temperate nights and Moderately dry according to the Multicriteria Climate Classification [MCC, 15,16]. To cover the full range of situations representative of the conditions present in the region, during four years (2001-2004), three different *Vitis vinifera* L. varieties were studied: Tannat, Cabernet Sauvignon and Merlot (accounting for 47.2% of the surface of red varieties). They were either trellised to lyre or Vertical Shoot Positioning (VSP), representing 98% of vineyard trellis systems in the area, and subjected to yield control: with or without cluster thinning at veraison or type of pruning (spur or cane pruned). Row orientation was north to south and the rootstock was SO4 in all plots For data collection, three rows with ten vines each were randomly selected within the whole vineyard, for each situation. Each individual vine was considered as an experimental unit (30 repetitions). In those plots were cluster thinning was undertaken, the number of clusters left on the vines was 50% of those left in the unthinned vines. Cluster thinning was always performed when grapes attained 5% veraison [Eichhorn-Lorenz Stages, 35 E-L]. In order to make all the plots comparable, the number of buds left at winter pruning was the same (Table 1).

TABLE 1
PLOTS USED IN THE CURRENT STUDY AND ABBREVIATIONS USED FOR REFERRING TO EACH ONE OF THEM

Variety	Management practices	Year of plantation	Plant density (vines/ha)	Abbreviation (*)
Merlot	Lyre spur pruned and no cluster thinning	1994	3300	ML year
Merlot	Lyre spur pruned and cluster thinning	1994	3300	MLT year
Merlot	VSP spur pruned and no cluster thinning	1996	3200	MV year
Merlot	VSP spur pruned and cluster thinning	1996	3200	MVT year
Cabernet-Sauvignon	Lyre spur pruned and no cluster thinning	1994	3320	CSL year
Cabernet-Sauvignon	VSP spur pruned and no cluster thinning	1996	4000	CSV year
Cabernet-Sauvignon	VSP spur pruned and cluster thinning	1996	4000	CSVT year
Tannat	Lyre spur pruned	1992	3472	TLS year
Tannat	Lyre cane pruned	1992	3472	TLC year
Tannat	VSP spur pruned	1996	3478	TVS year

(*) Year refers to the studied season: 2001, 2002, 2003 or 2004.

2.2 Climate conditions

Weather data for the years 2001 to 2004 were collected at a meteorological station (34°40'S - 56°20'W; 32 m above sea level, Davis Instruments, Hayward, CA, USA) located at about 5 km from the studied plots. Historic meteorological data (years 1972-2002) were used for determining the climate class, according to MCC, adapted by Ferrer [16] using specific conditions for Uruguay (growing cycle from September to February and available soil water of the studied plots). Hence, three synthetic and complementary climatic indices were computed: Heliothermal index (HI), Dryness index (DI) and Cool Night index (CI) [15]. Pre-dawn leaf water potential (ΨPD) was determined with a pressure chamber (Soil moisture equipment, Santa Barbara, CA, USA). These measurements were made before dawn at fruitset, veraison and harvest, in 20 adult, healthy leaves per plot. Threshold ΨPD values to evaluate the level of water stress (WS) experienced by vines were: -0.2 MPa no WS; -0.2 MPa > ΨPD ≥ 0.4 Mpa mild to moderate WS; -0.4 > ΨPD ≥ - 0.6 MPa moderate WS; ΨPD < -0.6 MPa severe to high WS.

2.3 Yield components and bunch rot incidence determinations

At harvest, the yield of the 30 plants per plot was individually weighed, the number of clusters was counted and the average weight per bunch was calculated by dividing yield per vine to the number of clusters. Rot incidence was estimated by weighing separately bunches with at least 5% of berries affected and expressed as percentage from the total yield per vine.

2.4 Grape samples and analysis

The harvest was done at "technological maturity" for each treatment, considering pH values, the relation between sugar content and titratable acidity of grapes, and berry weight. These parameters were analyzed periodically according to OIV [17] methods. For this purpose, replicated 250-berry samples from all vines in each plot were collected weekly from veraison to harvest. Berry composition was determined after manually destemming the berries and obtaining the juice by crushing the pulp with an electric blender (HR2290, Phillips, The Netherlands). Sugar contents were measured using a refractometer (Atago N1, Atago, Tokyo, Japan); pH was determined with a pH meter (HI8521, Hanna instruments, Villafranca Padovana, Italy) and acidity, expressed as g sulfuric acid/L juice, was measured by titration. The potential in total (ApH1) and extractable anthocyanins (ApH 3.2) was measured according to the spectrophotometric method (Shimadzu UV-1240 Mini Shimadzu, Japan) proposed by Ribéreau-Gayon and Stonestreet, [18]. The phenolic richness of the grapes (A280) were determined by measuring the absorbance at 280 nm of the pH 3.2 extract according to Glories and Augustin [19]. The indexes were calculated considering the respective dilution of the grape extracts, according to González-Neves et al. [20].

2.5 Statistical analyses

Data were analyzed using multivariate techniques, such as Principal Component Analysis (PCA) and Hierarchical Clustering (HC), to determine significant correlations between meteorological conditions and yield, berry composition and sanitary status. Moreover, a correlation analysis was performed using Pearson's correlation coefficient. Analysis of variance was performed on the surveyed composition variables, followed by the Tukey test for mean separation. All the statistical analyses were carried out using the InfoStat software.

2.6 Variables used in the study

For every variable, the corresponding abbreviation is listed in Table 2.

TABLE 2
ABBREVIATIONS OF THE VARIABLES USED IN THE CURRENT STUDY

Variable	Abbreviation
Rainfall during growing season (mm , 1 september -28 february)	RG
Rainfall from 1 september to harvest (mm)	Rsh
Rainfall from budbreak to fruitset (mm)	Rbf
Rainfall from 1 september to flowering (mm)	Rsfl
Rainfall at flowering stage (mm)	Rfl
Rainfall from budbreak to veraison (mm)	Rbv
Rainfall from budbreak to veraison of previous year (mm)	Rbv-1
Rainfall from veraison to harvest (mm)	Rvh
Rainfall during january (mm)	RJ
Rainfall during february (mm)	RF
Rainfall during ripening period (mm)	Rm
Rainfall 10 days before harvest (mm)	Rh-10
Rainfall 20 days before harvest (mm)	Rh-20
Rainfall 30 days before harvest (mm)	Rh-30
Dryness index during growing season (mm)	DIG
Water deficit of growing season (mm, september at february)	WD
Water deficit during ripening period (mm, january and february)	WDm
Pre-dawn leaf water potential at fruitset (bars)	Ψf
Pre-dawn leaf water potential at veraison (bars)	Ψv
Pre-dawn leaf water potential at harvest (bars)	Ψh
Heliothermal Index (°C, september at february)	HIG
Heliothermal Index from budbreak to veraison (°C)	HIbv
Heliothermal Index from veraison to harvest (°C)	HIvh
Minimum temperature from veraison to harvest (°C)	Tmvh
Cool night Index (°C, Minimum temperature 15 february –15 march)	CI
Maximum temperature at bloom stage (°C)	TMbl
Minimum temperature at bloom stage (°C)	Tmbl
Maximum absolute temperature in January (°C)	TMJ

Maximum average temperature in January (°C)	TMxJ
Minimum temperature in January (°C)	TmJ
Maximum temperature in February (°C)	TMF
Minimum temperature in February (°C)	TmF
Maximum temperature 10 days before harvest (°C)	TMh-10
Maximum temperature 20 days before harvest (°C)	TMh-20
Maximum temperature 30 days before harvest (°C)	TMh-30
Minimum temperature 10 days before harvest (°C)	Tmh-10
Minimum temperature 20 days before harvest (°C)	Tmh-20
Minimum temperature 30 days before harvest (°C)	Tmh-30
Relative Humidity at bloom stage (%)	RHb
Relative Humidity during ripening period (%)	RHr
Wind from veraison to harvest (m/s)	W
Yield/ha (kg)	Y
Clusters number/vine	CN
Cluster weight (g)	Cw
Berry weight at veraison (g)	Bwv
Berry weight at harvest (g)	Bwh
Bunch rot (% yield)	By
Sugar content (g/L)	S
Total acidity (g/L H2SO4)	TA
Total anthocyanins (ApH1)	ApH1
Extractable anthocyanins (ApH3.2)	ApH 3.2
Phenolic richness (ua 280)	A280

III. RESULTS

3.1 Climatic conditions

The classification of each one of the years studied, according to MCC, showed that two years (2001 and 2003) were different from the rest.

2001: Temperate warm, Warm nights, Humid.

2002: Temperate warm, Temperate nights, Moderately dry.

2003: Temperate warm, Temperate nights, Sub-humid.

2004: Temperate warm, Temperate nights, Moderately dry.

Over the 2001 and 2003 growing seasons, HIG values were on the threshold between the Temperate-Warm and the Warm classes (>2400 ºC). The cool night index was lower than the normal value (1972-2002) in three out of the four years studied; however, in 2001, it was higher, corresponding to the class of Warm nights. In 2001 and 2003, the dryness index was higher than the historical average for the site, corresponding to Humid and Sub-humid classes, respectively. When calculated between veraison and harvest, HIvh varied amongst years and in respect to the historical average. In 2002, this index was 17.7% lower than the historical average, whereas in 2004 this reduction was 2.6%. In contrast, the historical value was surpassed by 24.9% in 2001 and no deviations were observed in 2003. Veraison to harvest represented 48.7% of the heat accumulated over the whole growing season (HIvh/HIG) in 2001 (higher than the historical average that is 41.1%), whereas it represented 32.6%, 38.4% and 38.9% in 2002, 2003 and 2004, respectively.

The average maximum temperature in January and the absolute maximum temperature in 2002 and 2004 were below historical values, while they were higher in 2001 and 2003, respectively.

Historical records of rainfall over the growing season (RG) and during fruit ripening were 586.6 mm and 205.5 mm, respectively. In the years of study, RG exceeded the historical average in 2001 by 41.4%, in 2002 by 4.0%, in 2003 12.0% and 24.0% in 2004. In flowering-veraison, rainfall accounted for 26.8% of the cycle in 2001 and between 46.4% and 48.1% in the other 3 years studied. Rainfall during fruit ripening exceeded the historical record in 2001 by 125.0%, while the other three years were below this record. Water deficit over the growing season was higher than the historical record for 2004 and lower for the rest of the studied years. During grape ripening in 2001 there was no WDm deficit, whereas the rest of the years exceeded the historical deficit for this period; in more than 65 mm in 2002 and 2004 Vine water status reflects the evolution and accumulation of soil water content. At bloom - fruitset, Ψ_{PD} showed values of no WS, a situation that continued in 2001 during the whole growing season. Vine water status at veraison and harvest (Ψv_{PD}, Ψ_{HPD}) varied depending on the year. In 2003, the ranks of restriction registered were of no WS at veraison and mild to moderate WS at harvest. At veraison, in 2002, values of moderate to severe WS were recorded, evolving to no WS at harvest. In 2004 at veraison, mild to moderate WS was recorded, evolving to severe and high WS at harvest (Table 3).

TABLE 3
CLIMATE CONDITIONS OF THE STUDIED YEARS AND NORMAL VALUES FOR THE 1972-2002 PERIOD

Year	HIG (°C)	HIvh (°C)	CI (°C)	DIG (mm)	TMxJ (°C)	TMJ (°C)	RG (mm)	Rm (mm)	WD (sep at feb) (mm)	WDm (mm)
2001	2390	1136.3	18.8	157.1	29.2	35.6	829.4	462.3	-117.5	90.2
2002	2306	751.4	16.0	35.3	27.9	34.1	610.0	111.5	-309.3	-240.5
2003	2391	918.1	15.3	120.3	29.5	38.8	657.0	169.4	-282.0	-198.6
2004	2285	889.3	14.2	47.4	28.6	34.0	715.8	152.0	-336.9	-242.9
1972-2002	2220	913.0	16.75	47.5	28.9	34.8	586.6	205.5	-313.4	-172.5

3.2 Yield components

The first two principal components (PC) explained 57.3% of the total variance in the dataset; PC1 and PC2 accounted for 37.6% and 19.7%, respectively. Load vectors of yield and its components contributed to PC2. Load vectors of climatic elements (CE) contributed to the highest values of PC1. The plots of 2001 are separated in PC1 (CE) and those of 2003 in PC2 (lower CN), while those from 2002 and 2004 are relatively close (Fig. 1)

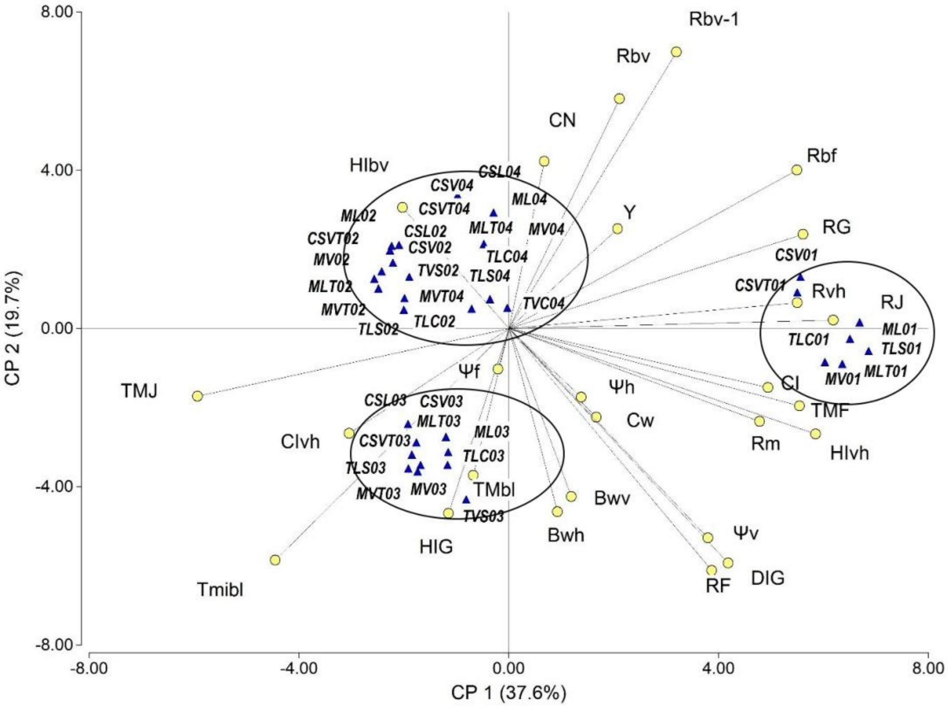

FIGURE 1: PRINCIPAL COMPONENT ANALYSIS OF THE STUDIED PLOTS ACCORDING TO YIELD COMPONENTS AND CLIMATE ELEMENTS. ABBREVIATIONS OF THE VARIABLES ARE LISTED IN TABLES 1 AND 2

The yield and its components were positively correlated with the hydric conditions of the current cycle and of the previous cycle and negatively with the thermal conditions.

Cluster number (r= 0.56, p < 0.001) and bunch weight (r = 0.49, p < 0.001) were the overriding factors contributing to yield variation. Nevertheless, berry weight at veraison or harvest did not show correlation with yield. The years 2003 and 2004 had a significantly different number of clusters per plant (16.50 vs 25.45, respectively) and the hydric and thermal conditions were also different in those years; 2004 recorded higher volumes of rainfall compared to 2003. In contrast, 2004 thermal conditions were cooler compared to 2003.

It was noticed that 2002 and 2003 were the most similar years, while 2001 was the most different amongst the four (Fig. 2), confirming the PCA results. In addition, within each year, the effect of variety on yield was greater than that of crop management.

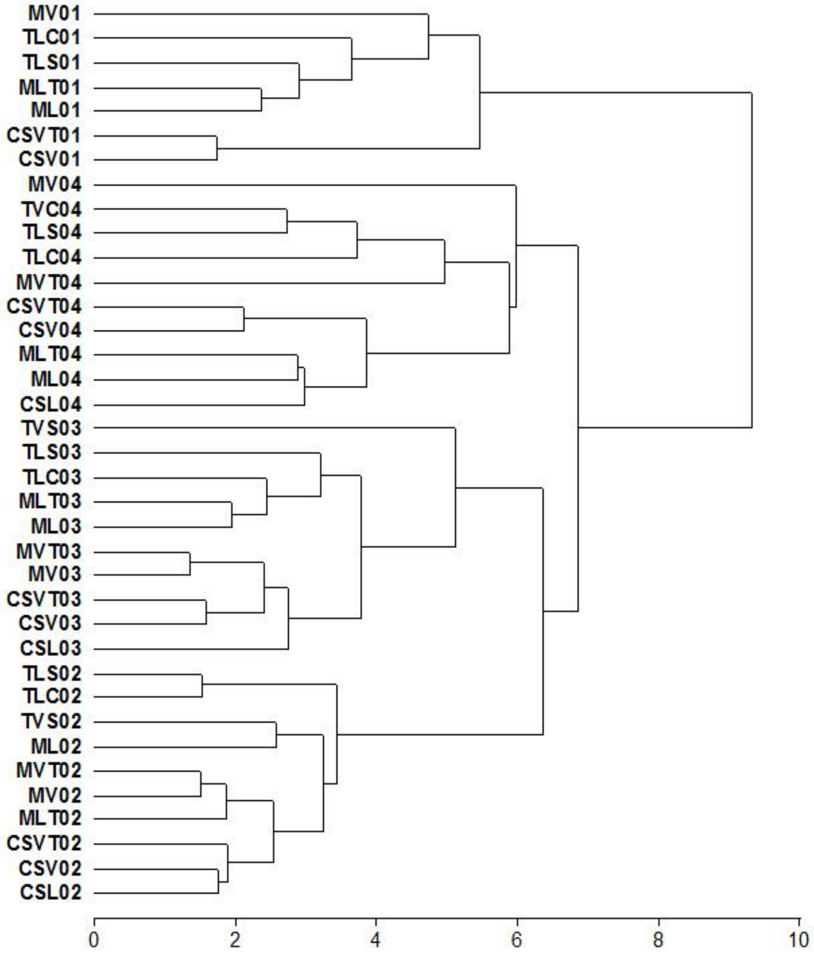

FIGURE 2 ASCENDING HIERARCHICAL CLASSIFICATION (EUCLIDIAN MEAN) WHICH REGROUPS THE YEARS - VARIETY-CULTIVATION TECHNIQUES FOR SIMILARITY OF YIELD AND ITS COMPONENTS. ABBREVIATIONS ARE LISTED IN TABLE 1

3.3 Berry sanitary state: rot incidence

The clusters affected by rot contributed significantly in reducing grape yield (r = -0.79, p < 0.001). The first two PC included 64.3% of the total variance in the dataset. Respectively, PC1 and PC2 explained 46.6% and 17.7% of the variance in the data set. The vector load bunch rot incidence (By) contributed to PC2. The plots of 2001 are clearly separated from the rest in PC1. PC2 separated plots of 2004 from the rest, while the plots of 2002 and 2003 were relatively close and had the lowest incidence of bunch rot (Fig. 3). Load vectors of thermal and hydric conditions of the month prior to harvest and the period from September to flowering contributed positively to PC1 with the highest values. September rainfall at harvest, the minimum temperatures in January and relative humidity during ripening contributed positively to PC2.

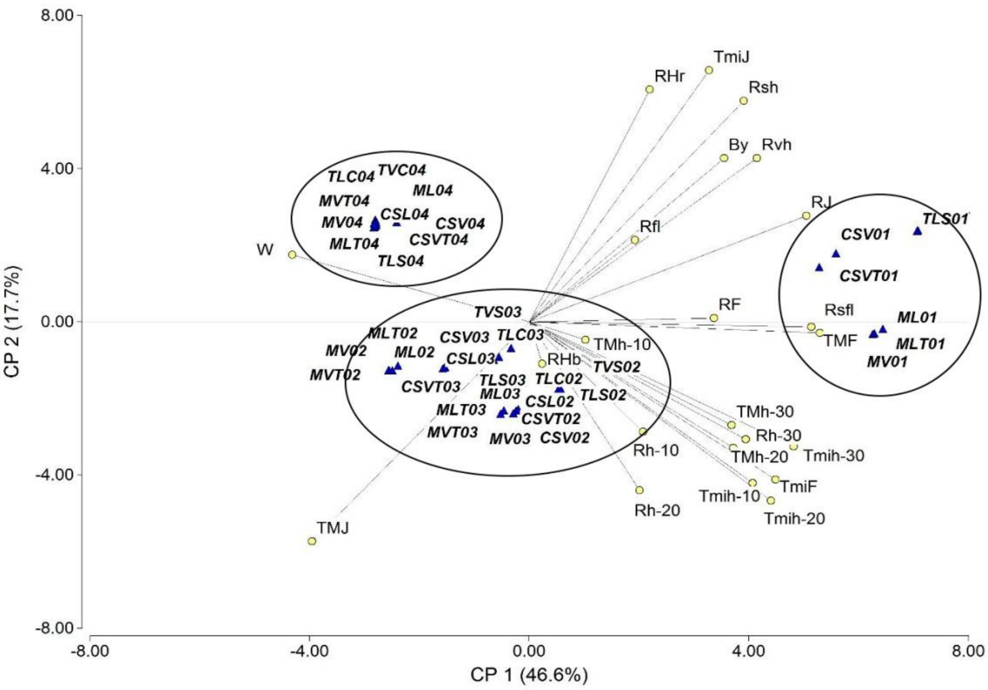

FIGURE 3: PRINCIPAL COMPONENT ANALYSIS .DISTRIBUTION OF PLOTS DEPENDING ON WEATHER AND BUNCH ROT INCIDENCE. ABBREVIATIONS OF THE VARIABLES ARE LISTED IN TABLES 1 AND 2

In 2001 there was a significantly higher incidence of bunch rot (53.4%) compared to 2003 (6.0%). In 2001, weather conditions related to rainfall exceeded to their corresponding values in 2003. In contrast, thermal conditions were higher in 2001 when compared with 2003. However, wind intensity during the ripening period of 2001 was lower than in 2003.

The four years studied were clearly differentiated in the cluster analysis (Fig. 4). In addition, within each year, the plots of a given variety are perfectly grouped, differing from other varieties. The plots of 2001 are those separated by a greater distance from the rest.

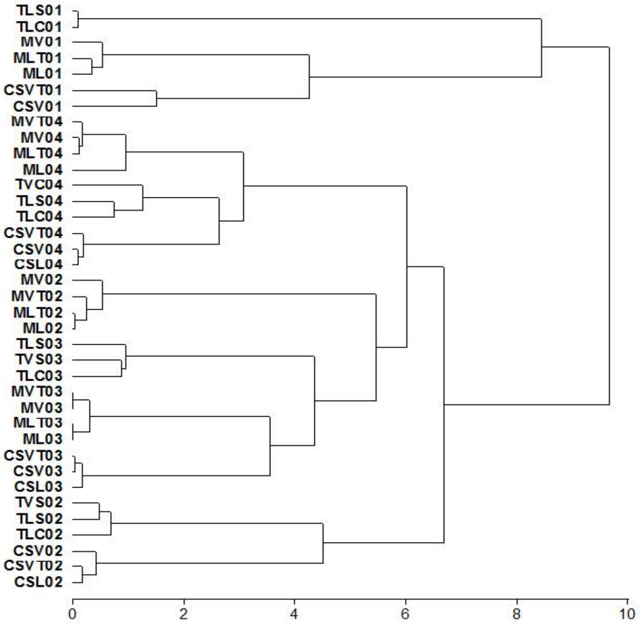

FIGURE 4 ASCENDING HIERARCHICAL CLASSIFICATION (EUCLIDIAN DISTANCE) WHICH REGROUPS THE YEARS - PLOTS BY SIMILARITY OF BUNCH ROT INCIDENCE. ABBREVIATIONS OF THE VARIABLES ARE LISTED IN TABLE 1

3.4 Berry composition

Load vectors of the chemical attributes of grape composition contributed to PC2 (Fig. 5).

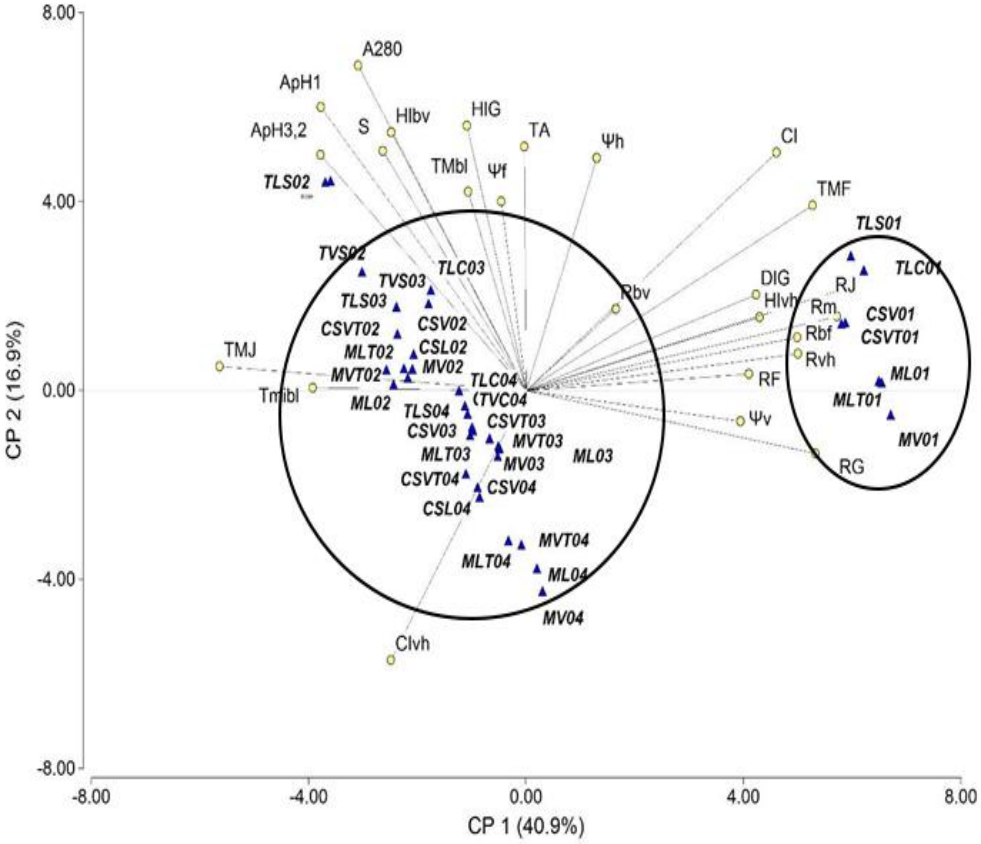

FIGURE 5: PRINCIPAL COMPONENT ANALYSIS. DISTRIBUTION OF PLOTS ACCORDING TO BERRY COMPOSITION AND CLIMATE ELEMENTS. ABBREVIATIONS OF THE VARIABLES ARE LISTED IN TABLES 1 AND 2.

The first two main components include 57.8% of the overall variance of the dataset. PC1 explains 40.9% and PC2 16.9% of the variance. As in previous cases, the plots of 2001 are clearly separated from the rest through PC1. In contrast, the plots of 2002, 2003 and 2004 are grouped. Load vectors of hydric and the TMF contributed negatively to PC1 with the highest values, whereas TMJ did it positively. Vector load of thermal sums and vine water status at harvest contributed positively with the highest values to the PC2, whereas night temperatures contributed negatively. All of the considered grape composition attributes were significantly higher in 2002 than in 2001, except for titratable acidity (Table 4).

TABLE 4
GRAPE COMPOSITION ATTRIBUTES AT HARVEST AS A FUNCTION OF YEAR.

Year	S (g/L)	TA (g/L)	ApH1 (mg/L)	ApH3.2 (mg/L)	A280
2001	202.6 a	4.6 ns	984.9 a	587.0 a	42.7 a
2002	220.8 b	4.50 ns	2270 d	1200 c	70.1 b
2003	211.3 b	4.25 ns	1853.5 c	977.2 b	61.0 b
2004	217.2 b	4.53 ns	1584.3 b	994.0 b	48.1 a

Abbreviations of the variables are listed in Tables 2

In 2002 the maturation occurred in cooler and drier conditions than in 2001, as evidenced by the values of the thermal and hydric conditions. The HC according to grape composition (Fig. 6), as in the previous cases, separated the four years, being 2001 the one with a greater distance from the rest.

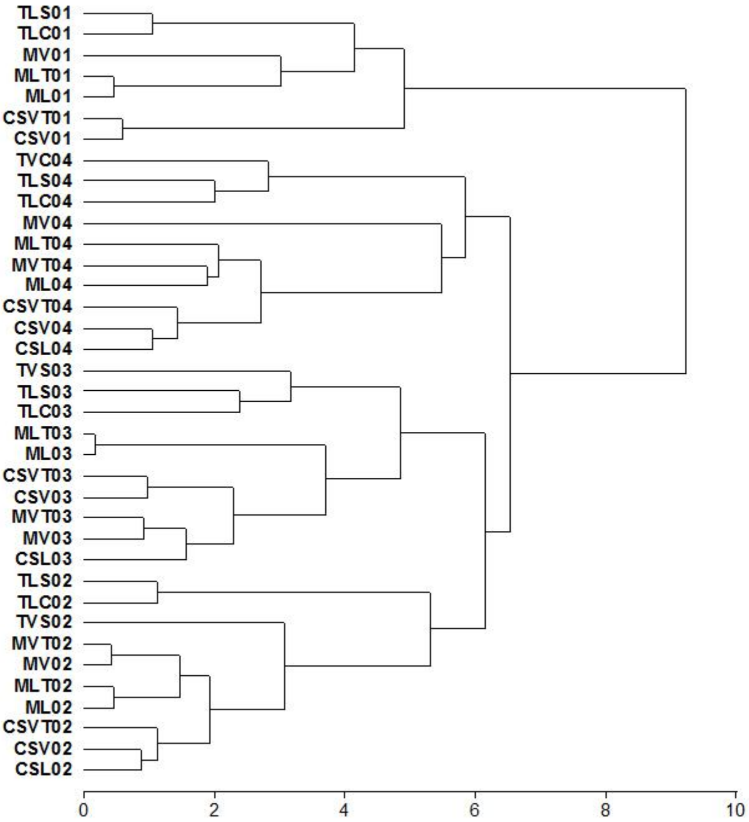

FIGURE 6 ASCENDING HIERARCHICAL CLASSIFICATION (EUCLIDEAN DISTANCE) WHICH REGROUPS THE YEARS - PLOT ACCORDING TO SIMILARITY OF THE GRAPE COMPOSITION. ABBREVIATIONS OF THE VARIABLES ARE LISTED IN TABLE 1

IV. DISCUSSION

Weather interannual variability was evidenced by different thermal and hydric conditions amongst years and with respect to historical values. This proved that MCC is a good method to characterize the climate of a given region, as suggested by Santos et al. [5].

4.1 Yield components

The two variables with the greatest influence on yield were cluster number and weight, in accordance with Dry et al.[2] Clingeleffer [3], and Jones et al. [21]. A positive correlation was detected between cluster number and rainfall over the growing season, rainfall between budbreak and veraison occurred on the previous cycle and the same period of the current season; whereas this relationship was negative for the thermal conditions of the current season. Warm temperatures, high solar irradiation and adequate water availability are needed for induction, formation and development of inflorescences, as well as for fruit set [4-6,36]. Appropriate water availability favors root activity, which has an essential role in the aforementioned stages [22]. Jones et al. [21] reported that temperatures higher than 15ºC favor cell division in the inflorescences. In the current study, the low yield observed in 2003 was a consequence of a low number of clusters; caused by water deficits during the two aforementioned phenological stages (Rbv -1 and Rbv), as well as minimum temperatures (11.1°C) under the appropriate values for the correct development of the inflorescences. According to Cuevas et al.[8], vine water requirements during flowering - veraison in 2003 were not satisfied (48.2% of the required over total growth).

Cluster weight, which also explained part of the variation in yield, was positively correlated with berry weight. The link between cap fall and germination of the pollen provides a possible explanation for the fact that weather conditions at flowering influence fruit set since they determine its percentage and also the number of seeds, two traits directly related to berry weight [4,7]. As shown in the present study, weather conditions were appropriate for fruit set, since maximum temperatures (between 20-25ºC) and rainfall (greater than 25.9 mm) values were in accordance with those reported by Heazlewood et al. [23]. These conditions also occurred during the year with the lowest yields, although it showed the greatest berry and cluster weight when compared with the rest of the years, this was not enough for compensating the low yield caused by a low number of clusters.

Berry weight at harvest was significantly correlated with that at veraison, in accordance with Ferrer [16] and Ollat et al.[24]. In this study, berry weight was positively related to water availability before veraison, as reported by Ferrer et al. [25] and Niculcea et al.[26]. In the years when berry weight was high (2001 and 2003), no water restrictions were detected at veraison, and the dryness index was higher than the historical average. During this stage of maturation, the negative effect of maximum temperature of January on berry weight can be explained by berry dehydration, in accordance with Rogiers et al. [27]. In our study, this effect was likely attenuated because the highest temperatures occurred in years with high water availability (2001 and 2003).

It was expected that HIG would be positively correlated with yield and its components, due to its positive influence on the induction process and on the number of clusters, as reported by Jones et al. [21]. However, we found a negative effect of the thermal sum in the first stage of the season (HIbv), accompanying the negative effect of high temperatures reported by Santos et al.[5]. From veraison onwards, this index (HIvh) was positively correlated with yield and cluster and berry weights.

The effect of year prevailed over those of the variety and the management practices, as shown by HC; however, within the same year, the effect of the variety on yield and its components was greater than that of the management practices. This can be explained by the differences in components such as cluster number and weight. In Australia, Dry et al. [2] reported that Merlot and Cabernet Sauvignon present a high bunch number and a low bunch weight; whereas Ferrer et al. [28] found that, for Uruguayan conditions, Tannat showed a high bunch number and weight, in accordance with the findings of the current study.

4.2 Berry sanitary state: rot incidence

Bunch rot reduces grape yield and quality affecting vineyard economic revenues [10]. In the current study, in years of low yields (2002 and 2003) the incidence of this disease was lower compared with that observed in years of high yields (2001 and 2004), because, presumably, high yields facilitate the spread of bunch rot or water condensation within bunches, thus creating a favorable microclimate for fungal colonization [9].

Diseased berries at harvest may be the result of latent infections that occur during bloom and early stages of berry growth or direct infections during ripening. In both periods, rainfall and relative humidity were strongly correlated with bunch rot incidence, in accordance with Fermaud et al. [9] and González-Domínguez et al. [29].

Wind intensity was negatively correlated with bunch rot incidence because as wind speed increases, relative humidity is reduced. Wind speed at maturation in the year of greatest bunch rot incidence was, on average, below that of the rest of the years (0.85 m/s vs. 1.53 m/s).

Maximum temperature of January was negatively related with bunch rot incidence since it surpassed the threshold for being favorable to fungus development [9,29]. However, the minimum temperatures of the same month and those of the maturation period were positively correlated with bunch rot incidence and they were between the intervals reported as favorable by the same authors (Table 3).

Within the same year, the tested varieties showed different behavior in relation to bunch rot infection. On average for the four years, 26.2%, 5.6% and 7.4% of clusters were infected for Tannat, Merlot and Cabernet Sauvignon, respectively. These results are in agreement with the susceptibility ranking to bunch rot reported by Ferrer et al. [28]. This different sensitivity associated to variety can be explained by combined effects, such as cluster compactness [30] and resveratrol content [31]. Tannat clusters are more compact than those of Merlot and Cabernet Sauvignon [28]. In addition, Merlot grapes presented higher resveratrol content than Cabernet Sauvignon and the lowest content was observed for Tannat.

4.3 Berry Composition

The compounds that responded more markedly to the atmospheric conditions of the year were total poliphenols, total and extractable anthocyanins, as well as sugars and titratable acidity, in accordance with van Leeuwen et al. [11]. Meteorological conditions during ripening determine berry composition at maturity. Rainfalls after veraison and during maturity were negatively correlated with total and extractable anthocyanins, total polyphenols and sugars. The dilution effect explains the reduction in compounds linked to berry enological quality [2,14], whereas water restriction showed a positive correlation because of its related impact on phenolic biosynthesis. This response is related to the competition for photo-assimilates between vegetative and berry growth [33]. Appropriate water availability during maturation maintains vegetative growth and, consequently, this competes with the accumulation of sugars and other chemical compounds in the berries [2,14]. A positive correlation between grape composition and spring temperatures, as well as with the sum of degree days between flowering and veraison was established in accordance with Nicholas et al.[34]. In the current study, total soluble solids were strongly correlated ($p < 0.001$) with those traits accounting for quality (ApH1 $r = 0.79$; ApH3.2 $r = 0.79$; A280 $r = 0.77$), in accordance with Keller [4]. Temperature during the last stage of maturation was negatively correlated with grape composition, as previously reported [1,12]. However, this relationship was positive with temperature of January. Therefore, it can be suggested that flowering thermal conditions, which are strongly correlated with maturation temperatures, would exert a great influence on berry composition. In a previous research, Gonzalez-Neves et al. [35], indicated that Tannat grapes had the highest sugar contents and titratable acidity during all years. Merlot and Cabernet Sauvignon grapes did not differ between them in the majority of the years. On the other hand, Tannat grapes are characterized for the highest values of phenolic richness and total anthocyanin potential. Moreover, anthocyanin potentials were significantly higher in Cabernet Sauvignon than Merlot grapes in all the years studied. These might be the reasons why the effect of the variety prevailed over that of the management practices within the same year.

V. CONCLUSIONS

Annual variability on grapevine performance, sanitary state and berry composition was greater than that produced by variety and management practices. The number of clusters was the main component of the annual variation in yield; this number was defined by thermal and hydric conditions occurred in the first stage of the previous growing cycle and those of the current year.

Hydric conditions during the first stage of the growing cycle were determinant for bunch rot infection, as well as thermal conditions and water availability during maturation.

Compounds related to berry quality were positively influenced by thermal sum during the first stage of the growing cycle and negatively affected by high temperature and water availability during maturation.

Within each year, the effect of the variety was more relevant for yield, sanitary status and berry composition than that of the management practices considered in this study.

Our results suggest that the intervals of atmospheric conditions that favor yield and bunch rot are different from those that favor berry quality

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