UNEXPECTED RELATIONSHIPS BETWEEN VINE VIGOR AND GRAPE COMPOSITION IN WARM CLIMATE CONDITIONS

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Abstract

Aim : The purpose of the research was to link vigor with grape composition in a climate change scenario.

Methods and results : This work presents a 4-year study (from 2010 to 2013) in a non-irrigated Tempranillo vineyard located in La Rioja (Spain). It is based on the acquisition of multi-spectral imagery at *véraison* and a subsequent zoning in two different vigor zones based on NDVI (Normalized Difference Vegetation Index). All parameters related to vigor showed significant differences within the zones (total shoot length, leaf area, pruning weight). Unexpectedly, the content in anthocyanins was found to be higher in the highest vigor zone in most of the years of study, a point particularly discussed in this work.

Conclusion : Climatic conditions may affect considerably bunch microclimate and disturb the biosynthetic pathways of major grape components, leading to maturation mismatches. In hotter years, high vigor vines may favor anthocyanin accumulation through shading and protecting effects in the bunch area.

Significance and impact of the study : Many studies have shown a negative relationship between vigor and grape anthocyanins, but in the present research the opposite trend was observed in hot years.

Key words : climate change, grape anthocyanins, vine vigor, NDVI, bunch microclimate

Résumé

Objectif : Cet article a pour objectif d'étudier le rapport entre la vigueur et la composition des raisins dans un contexte de changement climatique.

Méthodes et résultats : L'étude a été menée pendant 4 ans (de 2010 à 2013) dans un vignoble Tempranillo non irrigué situé dans l'AOC Rioja (Espagne). Grâce à l'acquisition des images multi-spectrales à la véraison, la parcelle a été divisée en deux zones différentes de vigueur basées sur le IVDN (Indice de Végétation par Différence Normalisée). Tous les paramètres relatifs à la vigueur (longueur totale du rameau, surface foliaire, poids des bois de taille) présentaient des différences entre les deux zones. D'une manière inattendue, les contenus en anthocyanes étaient plus hauts dans les vignes plus vigoureuses dans la majorité des années d'étude, ce qui est particulièrement discuté dans cet article.

Conclusion : Les conditions climatiques peuvent influer considérablement le microclimat de la grappe et affecter les routes de synthèse des principaux composants du raisin, entraînant des décalages dans la maturation. Dans les années plus chaudes, les vignes plus vigoureuses peuvent favoriser l'accumulation des anthocyanes grâce à l'effet d'ombre et de protection solaire des grappes.

Importance et impact de l'étude : La plupart des études concernant la vigueur et les anthocyanes confirment un rapport négatif entre les deux facteurs. Cependant, dans cette étude, il a été observé l'effet opposé dans les années plus chaudes.

Mots clés : changement climatique, anthocyanes des raisins, vigueur de la vigne, NDVI, microclimat des grappes

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INTRODUCTION

Vineyard spatial variability has always concerned grape growers and has been considered in many recent researches in viticulture. The sources of this variation involve climate, land (topography and soil composition, including water and nutrient availability), and diseases. Previous research has focused on vine vegetative expression and vigor variability, but also on yield and grape characteristics (Tisseyre *et al.*, 2008; Bramley *et al.*, 2011; Arnó *et al.*, 2012).

One of the most easy, fast and feasible tools to assess vineyard variation is remote sensing. Spectral sensors mounted on satellites, or cameras in airplanes or drones, collect information of vegetation reflectance in a range of wavelengths. These data are translated into a single number or index, the most commonly used being the NDVI (Normalized Difference Vegetation Index), which involves infrared and near-infrared wavelength (Rouse *et al.*, 1974). NDVI provides accurate information about photosynthetically active biomass and canopy size (Dobrowski *et al.*, 2003; Hall *et al.*, 2003; Johnson *et al.*, 2003), that is, vegetative expression. Authors have tried to assess NDVI as a predictor of other vineyard characteristics, such as yield (Proffitt and Malcolm, 2005) and grape composition, specially anthocyanins and polyphenols (Johnson *et al.*, 2003; Lamb *et al.*, 2004; Bramley, 2005; Hall *et al.*, 2011; Fiorillo *et al.*, 2012; Martinez-Casasnovas *et al.*, 2012), with variable results.

The effort to relate NDVI as a predictor of grape composition has not always been successful since the factors influencing grape quality are numerous and complex. It is assumed that the ratio between leaf area and yield needs to reach a minimum threshold to assure proper ripening (Kliewer and Dokoozlian, 2005). In this concern, vegetation indices could give valuable information. Regarding anthocyanins, their synthesis and accumulation is highly dependent on temperature and light. In this respect, most of the studies relating vigor and grape quality have revealed that high vigor vines present less anthocyanin content than low vigor vines (Lamb *et al.*, 2004; Stamatiadis *et al.*, 2006; Cortell *et al.*, 2007; Hall *et al.*, 2011; Martinez-Casanovas *et al.*, 2012; Filippetti *et al.*, 2013). This may be explained by the fact that most of these studies have been carried out in rather cold climates, where bunch light exposure and temperature are limiting factors. Moreover, these studies usually analyze anthocyanins in terms of concentration (mg/kg or mL/kg), so berry size has a major influence on these values. Anthocyanins being only present in the skin, the smaller the berry, the smaller the volume (and liquid phase), and thus the higher the skin: pulp ratio, leading to higher anthocyanin concentrations in the obtained musts (Coombe and Iland, 2004). Then, it would be more appropriate to consider absolute anthocyanin synthesis (for instance, mg/cm^2 of skin) for a better comprehension of the synthesis of this compound from a plant physiological point of view. Besides, climate is facing a global warming in which grape growing regions boundaries are changing, and predictions reveal an increase of about +2.5 °C in the next decades (IPCC, 2007). Temperate and warm climates are experiencing unusual temperature increases, causing decoupling between sugars and anthocyanins and altering their accumulation and degradation pathways (Schultz and Jones, 2010).

Thus, several studies reveal that anthocyanin synthesis positively depends on temperature, but it is restrained by temperatures above 26 °C (Kliewer and Torres, 1972; Iland and Gago, 2002; Sadras and McCarthy, 2007). Temperatures above 30°C may lead to less concentration in anthocyanins by impairing their biosynthetic pathways and promoting their degradation (Mori *et al.*, 2005; 2007); it is, moreover, crucial to consider that grape bunches exposed to sunlight may reach 10 °C above air temperature (Pieri and Fermaud, 2005; Pereira *et al.*, 2006).

From this perspective, under very high temperature and sunlight conditions, we can speculate that high vigor vines presenting high leaf density in the bunch area could maintain the grape bunches cooler and protected, accumulating more anthocyanins than low vigor vines. This study focuses on the influence of different vigor levels on the vegetative, productive and grape quality response, and particularly on the anthocyanin content.

MATERIALS AND METHODS

1. Study area

The study was carried out in a commercial vineyard of 14 ha planted with *Vitis vinifera* cv. Tempranillo, located in Laguardia (Alava, Rioja Appellation, North Spain) (ETRS89 UTM 30N, coordinates 531930, 4712532, 570 m altitude) (Figure 1). The vineyard was planted in 1985 with vines grafted on 41B to a row spacing of 2.80 x 1.20 m and was non-irrigated. The canopy was vertically shoot positioned. Rioja-typical spatially uniform

Figure 1 – Location of the study area in Spain.

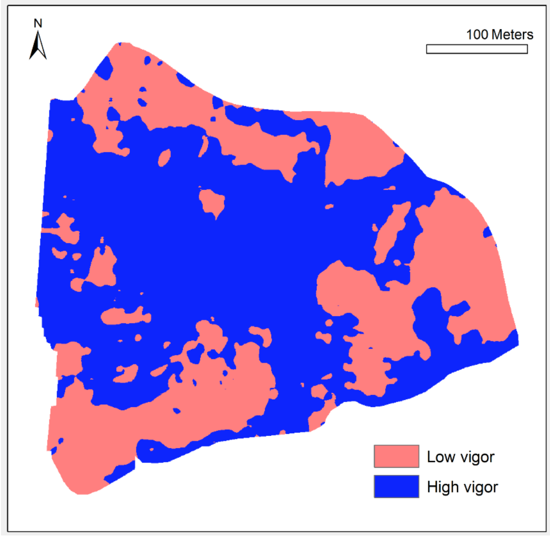

Figure 2 – NDVI clustering in two zones: high vigor and low vigor. Example for year2010.

management was carried out in the whole vineyard: cordon-pruning (12 buds/vine) and shoot thinning to 12 shoots/vine in June.

2. Climate and soil characterization

Climate data were collected from a station nearby the vineyard for the 4 years of study. Average, maximum and minimum temperature, rainfall and average air relative humidity are presented in Table 1.

Two main soil types were described in the different vineyard zones (low vigor hillside and high vigor valley hollow): Vertic haploxerept (with clayey texture and deep cracks in summer) and Aquic haploxerept (with redox depletions with low chroma and saturated with water in some parts, usually in winter and/or spring) (Soil Survey Staff, 2010). The soil profiles were described using the SINERADES handbook (CBDSA, 1983). Samples of all the horizons were analyzed in an external laboratory, using the Olsen method for phosphorus and 1 M ammonium nitrate extraction for potassium and magnesium. Bulk density was calculated by the weight after drying at 105 °C of a soil sample taken with a metallic cylinder (Eijkelkamp, Giesbeek, Holland). Water holding capacity was calculated using a suction plate equipment (Soil Moisture Equipment Corp., Santa Barbara, CA). Results of the soil pits are presented in Table 2.

3. NDVI maps

Multi-spectral airborne remote sensed imagery (0.50-m resolution) was acquired by a commercial provider (SpecTerra Services Pty Ltd, Leederville, Australia) at *véraison* (Lamb *et al.*, 2004) in the 4 years of study: 20th Aug. 2010, 19th Aug. 2011, 13th Aug. 2012 and 4th Sept. 2013. The NDVI was calculated as an indicator of vine vigor (Rouse *et al.*, 1974). Pixels corresponding to soil were removed by means of a threshold NDVI value. NDVI values along the vine rows were interpolated to create a continuous NDVI map for further clustering analysis. Therefore, the study area was classified into two zones using the ISODATA algorithm in ArcGIS (ESRI ArcMAP 9.2, ESRI Inc. Redlands, CA) applied to the continuous NDVI map (Figure 2).
Analysis of variance (ANOVA) and LSD-Fisher comparison was performed for all parameters in order to verify the differences between the two zones. Infostat software (Infostat version 2012, Córdoba, Argentina) was used for those statistical analyses.

4. Vine sampling and measurement of vegetative, yield and grape composition parameters

Based on the differences observed in the field, 42 vines were selected for sampling in the experimental area. The same target vines were sampled during the 4 years. The vines were georeferenced with a Thales Mobile Mapper GPS (Thales Navigation Inc., San Dimas, CA, USA) (accuracy < 1 m after post-processing) and re-checked in the field. Vine sampling was carried out three times per season: at *véraison*, immediately before harvest, and after leaf falling. At *véraison*, vegetation parameters were measured twice in each target vine: total shoot length (as the sum of length of the shoots plus laterals), exposed leaf area, and total leaf area (as the sum of the main leaf area and secondary leaf area). At pre-harvest, yield and grape parameters were measured. Grape yield was

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Table 1 − Average, maximum and minimum temperature, rainfall and average air relative humidity for the 4 seasons of study

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	*Avg*	*Max*	*Min*	*Acc*
Avg Temperature (°C)	***Avg Year***	*5.1*	*6.5*	*9.1*	*10.4*	*14.9*	*18.6*	*20.7*	*21.1*	*17.4*	*13.4*	*8.4*	*5.6*	*12.6*			
	2010	3.6	4.4	7.4	12.3	12.7	16.9	21.4	20.8	17.5	12.3	8.8	3.9	*11.8*			
	2011	5.1	6.7	8.2	13.8	16.3	17.9	17.3	22.0	19.0	14.5	10.4	6.6	*13.2*			
	2012	5.7	3.5	10.2	9.0	15.4	19.3	19.4	22.2	17.5	13.1	8.2	6.5	*12.5*			
	2013	6.2	4.8	8.1	10.3	10.6	15.8	22.4	20.3	17.9	14.6	8.1	4.3	*12.0*			
Max Temperature (°C)	**2010**	12.2	15.1	18.9	27.9	27.4	30.8	34.7	36.6	32.6	28.1	*nd*	15.5	*25.4*	*36.6*		
	2011	15.9	19.4	22.6	29.9	31.6	35.7	31.9	37.7	34.4	30.5	18.4	15.6	*27.0*	*37.7*		
	2012	14.8	20.1	24.4	21.3	30.4	35.2	36.8	39.1	32.2	28.5	16.8	14.7	*26.2*	*39.1*		
	2013	16.1	13.6	18.0	25.9	23.8	30.7	33.5	34.5	29.0	28.3	20.5	14.1	*24.0*	*34.5*		
Min Temperature (°C)	**2010**	-7.0	-3.5	-3.2	1.1	2.6	6.6	8.4	9.0	4.8	1.6	-8.3	-5.9	*0.5*		*-8.3*	
	2011	-4.5	0.0	0.1	2.0	5.5	7.4	9.7	8.6	9.3	1.8	-0.1	-2.3	*3.1*		*-4.5*	
	2012	-4.5	-3.5	0.0	1.3	4.7	8.8	6.2	10.2	6.9	1.1	0.3	-1.8	*2.5*		*-4.5*	
	2013	-0.3	-1.8	-0.5	-0.4	1.9	5.4	12.7	9.5	7.4	2.7	-3.2	-2.3	*2.6*		*-3.2*	
Rainfall (mm)	***Avg Year***	*44.2*	*36.0*	*36.8*	*52.9*	*59.9*	*44.3*	*24.6*	*19.9*	*38.1*	*62.2*	*68.5*	*59.2*				*546.3*
	2010	41.3	12.5	14.1	6.9	39.4	72.8	4.2	0.2	19.0	37.4	46.4	34.1				*328.3*
	2011	21.5	39.7	67.5	46.3	26.6	32.3	20.5	11.0	13.0	14.5	78.3	21.7				*392.9*
	2012	14.0	34.6	7.0	60.8	39.1	23.1	14.4	11.3	36.9	86.6	93.8	25.2				*446.8*
	2013	127.6	86.6	114.7	43.7	30.9	63.7	45.9	4.6	20.7	32.3	74.8	81.2				*726.7*
Avg Humidity (%)	**2010**	74.0	74.0	74.0	74.0	74.0	74.5	71.6	59.5	64.3	69.3	*nd*	75.5	*71.3*			
	2011	78.6	73.8	75.1	67.2	66.9	63.6	75.0	58.4	74.4	63.3	81.4	76.5	*71.2*			
	2012	80.2	67.1	57.5	71.4	63.2	57.6	57.0	52.8	61.1	75.3	80.1	78.3	*66.8*			
	2013	76.5	77.5	73.8	66.8	71.3	69.0	63.6	63.8	68.2	72.0	96.3	29.1	*69.0*			

Abbreviations: Avg = average, Max = maximum, Min = minimum, Acc = accumulated measured as kg/vine, and samples of berries were packed for subsequent analysis. Berry weight was determined by weighting 50 berries randomly selected from each sample. Potential alcoholic degree, as a quantification of sugar content, juice pH and total titratable acidity were determined following the OIV methods. Part of the sampled grapes were frozen (-20 °C) for color analysis (mg/L of extractable anthocyanins) and phenolics at a later date, for which the Glories method (Glories, 1984) was used. Anthocyanin content by skin surface was determined by calculating berry volume from berry weight and considering an average density of 1.1 for 25 °Brix. In each year, in winter, pruning weights were measured on the same target vines after manual pruning.

RESULTS AND DISCUSSION

In order to compare the temperature differences in the 4 years of study, the Winkler Index was calculated (accumulated degrees > 10 °C, Figure 4). Figure 3 shows the extreme temperatures in the years of study. The highest temperatures took place in 2012 throughout the season, but especially from June until harvest. Season 2011 was slightly under 2012 in the ripening period regarding temperatures. Maximum temperatures in 2010 were lower at the beginning of the season but increased from August on. Season 2013 presented the lowest maximum temperatures, with great differences in the ripening period.

The Winkler Index (Figure 4) presented considerable differences amongst the four seasons. Year 2011 was the hottest, followed by 2012. Year 2013 was the coolest, corresponding to a Winkler region I, whilst the other years belonged to a region II. The difference between the coolest and the hottest was 161 degree days.

Climatic data (Table 1) show that the most important months in grape ripening in our region (August and September) were hotter in 2011 and 2012. Rainfall was clearly higher in 2013 (+140 mm on average). Rainfall distribution was also remarkable. Total rainfall in 2010 was not very high but concentrated before *véraison*, in a way that water stress was not very high. Year 2012 was the most affected by droughts, since precipitation in winter was really low and also during the vegetative period. Late rains in October occurred after harvest, so omitting October, it was the driest year. On the contrary, 2013 was very wet during the whole season.

Table 2 – Soil characterization of two soil pits located along the experimental area

	Horizon	Depth (cm)	pH	O.M. (%)	Electric conduct (µS/cm)	Limestone (%)	P ext. (mg/kg)	K ext. (mg/L)	Mg ext. (mg/L)	Bulk dens. (g/cm³)	Water hold. capacity (mm)	Sand (%)	Silt (%)	Clay (%)	Texture class
SOIL PIT 1 *Vertic Haploxerept*	Ap	0 - 20	8.2	1.29	1960	10.40	15	178	130	1.72	16	36.6	34.1	29.4	Clay loam
	B1	20 - 60	8.4	0.54	1960	10.80	1	80	217	1.70	29	35.2	38.2	26.7	Loam
	B2	60 - 112/115	8.6	0.48	1960	10.40	1	60	217	1.59	68	39.4	36.1	24.5	Loam
	2A	112/115-140	8.5	1.03	1960	10.7	2	87	222	1.97	11	39.3	32.9	27.8	Clay loam
	2Bk	140 - 150/+	8.4	0.82	1960	12.3	1	55	137	1.42	13	37.9	38.9	23.1	Clay loam
SOIL PIT 2 *Aquic Haploxerept*	Ap	0 - 14/20	8.3	1.51	1960	8.07	8	257	123	1.75	15	52.6	28	19.4	Sandy loam
	B1	14/20 - 77	8.3	0.88	1960	8.47	2	107	90	1.72	65	51.6	28.6	19.8	Loam
	B12	77 - 95	8.3	0.96	1960	7.05	2	102	99	1.70	33	51.9	24.1	24.1	Sandy clay loam
	2A	95 - 120	8.2	1.76	1960	7.12	2	144	130	1.67	27	42.5	28.9	28.6	Clay loam
	2Bk	120 - 160/+	8.2	0.77	1960	9.5	2	82	83	1.67	63	50.3	28.2	21.6	Loam

Abbreviations : O.M. = organic matter, Electric conduct. = electric conductivity, P ext = extractable phosphorus, K ext = extractable potassium, Mg ext = extractable magnesium, Bulk dens. = bulk density, Water hold. capacity = water holding capacity

Pit 1 (Low vigor hillside, ETRS98 UTM30N coordinates : 531912.09, 4712480.65) and Pit 2 (High vigor hollow : 531902.39, 4712344.32) according to USDA Soil Taxonomy (Soil Survey Staff, 2010).

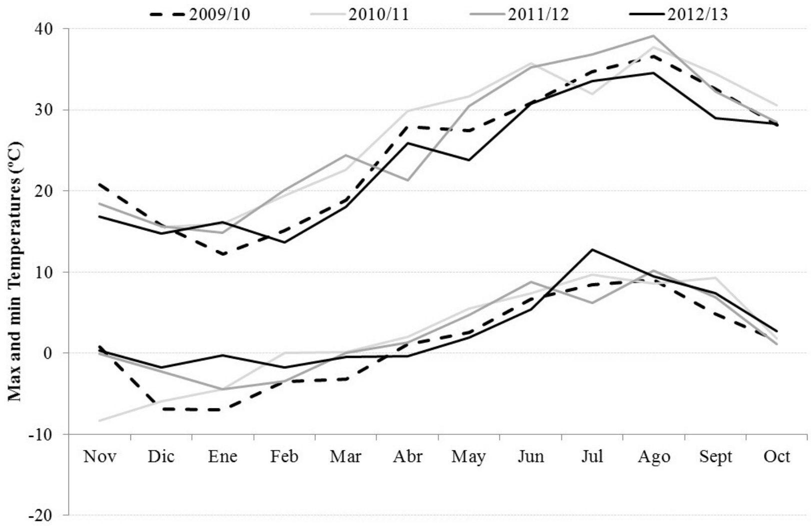

Figure 3 − Maximum and minimum temperatures in the 4 seasons of study.

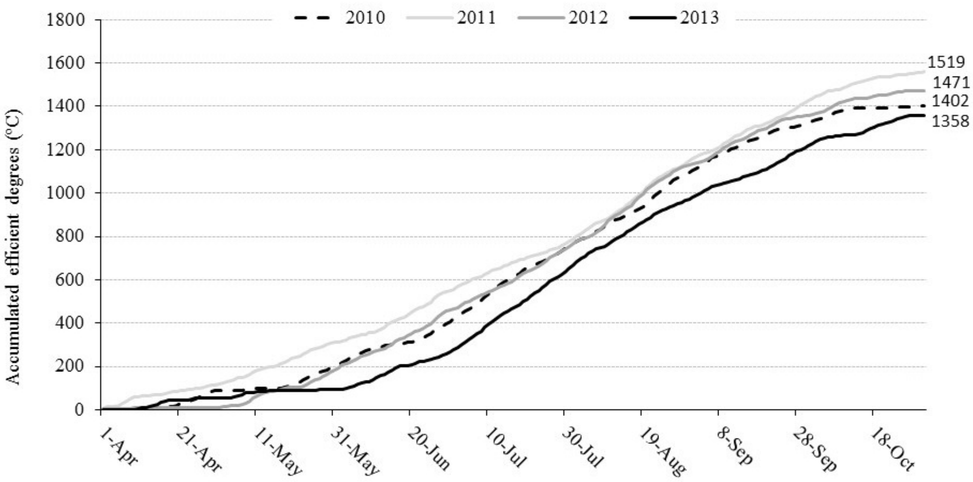

Figure 4 − Winkler Index for the 4 seasons of study.

Regarding soil description (Table 2), the hillside soil presented, in general, less organic matter content and nutrients (P and K). As expected, the water holding capacity was greater in the valley hollow soil (203 vs 137 mm).

Table 3 shows the result of vegetative, yield and grape composition parameters, with the mean of each parameter for every year within the zones resulting from the unsupervised clustering of NDVI interpolated data. All parameters related to vigor showed significant differences within the zones (total shoot length, leaf areas, pruning weight).

Leaf to fruit ratio was always higher in the high vigor zone, due mainly to the bigger vine development rather than to yield variations. In any case, all ratios were always over 1 m^2/kg, which is considered as the threshold for proper grape ripening (Kliewer and Dokoozlian, 2005).

The yield of high vigor vines was greater than that of low vigor ones, although with no significant differences. Bunch weight increased with vigor, as well as berry weight. It could therefore be deduced that bigger berries led to heavier bunches, producing higher yields.

Regarding grape composition parameters, sugar content decreased as vigor increased, being significant only in 2011 and 2012. These results agree with reported reductions in sugar accumulation due to fruit shading and vegetative growth (Kliewer *et al.*, 1967). No differences were found in total acidity, although juice pH was lower in low vigor zones in 2010 and 2012. For an equivalent total acidity, this trend can be explained by a reduction in malic acid concentration and a higher proportion of tartaric acid, which has more acidic power. Low vigor vines usually have less malic acid contents (Smart *et al.*, 1985), due to a decreasing synthesis and also because highly exposed bunches experience high temperatures, which lead to malic combustion (Martínez de Toda and Balda, 2014).

Total phenolics presented no significant differences over the 4 years, although low vigor zones usually had the highest levels. This may be explained by a higher sunlight exposition of the bunches, which is consistent with previous studies where phenolic compounds were found to increase with increasing exposition, even if anthocyanins reached a maximum threshold (Bergqvist *et al.*, 2001; Ristic *et al.*, 2007).

Concerning anthocyanins, high vigor vines presented higher concentrations than low vigor ones in 2010, 2011 and 2012; in 2013, the trend was just the opposite. Many previous studies linking vigor and anthocyanins state that low vigor zones tend to exhibit the highest levels of these compounds. Other authors, in a research in a Sangiovese vineyard in Tuscany (Italy), found that in some years, the highest values of anthocyanins were in the medium vigor block (Fiorillo *et al.*, 2012). According to these authors, these vines may experience moderate water deficit and moderate-high light exposure in the fruiting zone, as compared with the other zones. Conversely, low vigor vines may suffer from strong water deficit, resulting in a severe photosynthesis restriction and ripening downshift (Hardie and Considine, 1976). Given that the leaf to fruit ratio in all vines is high enough to achieve ripeness, differences in anthocyanin contents may be explained by exposure and temperature effects. Some authors have reported that high sunlight exposures may lead to high berry temperatures and reduction of anthocyanin accumulation (Kliewer *et al.*, 1967; Haselgrove *et al.*, 2000; Spayd *et al.*, 2002). Color enzyme activity takes place in a range of 17 to 26 °C (Iland and Gago, 2002; Sadras *et al.*, 2007). After *véraison*, temperatures above 30°C could inhibit anthocyanin synthesis (Kliewer and Torres, 1972; Mori *et al.*, 2007). Bergqvist *et al.* (2001) and Spayd *et al.* (2002) observed that the temperature of fully exposed fruit was 10 °C higher than that of shaded fruit and that the fully exposed fruit was also significantly warmer than the ambient air temperature. Then, high vigor vines, which create more shading effects in the bunch area, may

Table 3 – Analysis of variance for vegetative, grape yield and composition parameters.

	2010			2011			2012			2013		
	Low vigor	High vigor		Low vigor	High vigor		Low vigor	High vigor		Low vigor	High vigor	
Total Shoot Length (cm)	243b	457a	***	158b	411a	***	177b	390a	***	280b	562a	***
Exposed Leaf Area (m²)	2.86b	3.65a	***	2.85b	3.61a	***	2.47b	3.42a	***	2.76b	3.61a	***
Total Leaf Area shoot (m²)	0.50b	0.94a	***	0.32b	0.84a	***	0.36b	0.80a	***	0.57b	1.15a	***
Pruning weight (kg)	0.83b	1.39a	***	0.70b	1.27a	***	0.62b	1.25a	***	0.59b	1.18a	***
Leaf/fruit ratio (m²/kg)	1.56b	2.85a	**	1.63b	3.14a	*	1.08b	2.57a	*	2.63	4.69	ns
Yield/vine (kg)	3.61	4.44	ns	2.55	3.67	ns	3.26	4.09	ns	3.22	3.93	ns
Avg bunch weight (g)	214.5	258.0	ns	183.6b	291.9a	***	237.1b	303.0a	*	232.2b	314.4a	*
Berry weight (g)	2.2	2.4	ns	1.9b	2.6a	***	1.9b	2.3a	**	2.1b	2.4a	*
Sugars (°al)	13.8	13.4	ns	15.4a	14.0b	***	14.8a	13.9b	*	13.9	13.2	ns
Tot. acidity (g/L tartaric acid)	8.04	7.96	ns	6.45	6.14	ns	5.42	5.24	ns	8.91	8.91	ns
pH	3.04b	3.11a	*	3.23	3.30	ns	3.05b	3.18a	**	2.94	2.94	ns
Extract. anthocyanins (mg/L)	319b	454a	**	361b	476a	***	636	695	ns	710	664	ns
Extract. anthocyanins (µg/cm²)	84.0b	114.9a	*	91.3b	129.7a	***	152.5	182.1	ns	179.8	176.2	ns
Total phenolics (AU)	39.0	40.5	ns	41.4	40.0	ns	60.3	55.7	ns	45.9	41.4	ns

Means with different letters are significantly different by the LSD Fisher Test. ns = not significant, *significant at $p < 0.05$, **significant at $p < 0.01$, ***significant at $p < 0.001$
Abbreviations: Extract. anthocyanins = extractable anthocyanins, AU = absorbance units..., °al = probable alcoholic degree

be protecting grapes from high temperatures during the ripening period, leading to higher anthocyanin and color contents (de la Fuente *et al.*, 2007). As stated before, most previous studies consider anthocyanins in terms of concentration in macerated musts (mg/L), the skin : pulp ratio playing a major role in the results. In order to assess the absolute anthocyanin synthesis, results were calculated also on a skin surface basis. The results expressed in these units better reveal these trends.

2013 being a considerably cooler year, light and temperature were limiting factors for anthocyanin synthesis, and thus low vigor vines presented the highest levels. In order to study this, a revision of daily maximum temperatures during the ripening period (after *véraison*) was made for all the years of study (Table 4). This table reflects how intervals of maximum temperature (>35 °C) in this critical period were widely longer in 2012, followed by 2011 and 2010. There were no temperatures over 35 °C in 2013. Another aspect of the issue is the level of vine development or vigor in all the years of study, considering that "a low vigor vine" in a particular year is not the same as in another one. 2011 and 2012 were particularly dry years, where vine development was lower than in 2010 and, mainly, 2013. This can be easily observed in the total shoot length of the four seasons of study in Table 3. In this way, low vigor vines in 2011, and probably in 2012, were more exposed to sunlight and therefore to higher temperatures than low vigor vines in 2010 and 2013, experimenting to a greater extent anthocyanin synthesis downshift and degradation.

In the current climate change scenario, there is a general concern about increasingly high sugar level grapes not accompanied by phenolic maturation. Sugar synthesis enzyme activity ranges stably from 18 to 33 °C, whilst pigment production presents less plasticity (17-26 °C) (Iland and Gago, 2002; Sadras *et al.*, 2007). The increase in the temperatures may favor the northern grape growing regions, but in temperate-warm areas we are assisting a technological, phenolic and aromatic ripeness mismatch (Schultz and Jones, 2010).

Table 4 − Analysis of days and duration of temperatures over 35 ºC after véraison

	No. Days	Duration
2010	3	4h40
2011	3	6h20
2012	7	21h40
2013	0	0

CONCLUSIONS

This research presented the variations in two vigor levels in a Tempranillo vineyard, in terms of vine development, yield and grape composition. From a climate change perspective, the 4 years of study presented opposite climatic characteristics: years 2011 and 2012 were extremely dry and hot, whilst 2010 was moderated, and 2013 was significantly cooler and wetter. As expected, for all the years of study, high vigor vines demonstrated higher vegetative growth, as well as higher berry and bunch weights, which translated into greater yield. Regarding grape characteristics, a sugar/anthocyanin mismatch in the hotter years was found, showing high sugar levels and low anthocyanin contents in the low vigor vines. In all the years except 2013, we found particularly relevant the unexpected positive relationship between vigor and anthocyanin contents, with significance in 2010 and 2011, and similar trend in 2012. This might be due to important environmental influences involving vine microclimate (temperature and exposure), suggesting that in warm areas, anthocyanin accumulation may be favored in high vigor vines through reduced exposure of bunches to sunlight.

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