EFFECTS OF MESOCLIMATE ON THE YIELD, QUALITY AND PHENOLIC MATURITY OF GRENACHE

M. Nadal[1], F. de Herralde[2], M. Edo[1], M. Lampreave[1], R.Savé[1]
(1) Grup de Recerca Viti-vinicultura. Facultat d'Enologia, Dept. Bioquímica i Biotecnologia, URV
Marcel·lí Domingo s/n. Campus Sant Pere Sescelades. 43007 Tarragona. Spain
montserrat.nadal@urv.cat
(2) IRTA Torre Marimon, Ecofisiologia.
Torre Marimon. 08140. Caldes de Montbui. Spain

ABSTRACT

The potential climate change, due to global change, will increase temperature general and could increase at local level. These changes are not going to be the same in different parts of the world, being especially important in the Mediterranean Basin. Thus, according to the most pessimistic predictions temperature can rise until 4ºC and precipitation can be reduced close to 20% but this would be different according local conditions, being also changes in the distribution. In order to study the differences promoted by these climate differences we compared the phenology, yield and quality parameters of Grenache, grafted onto 110-R in two mesoclimatic areas in Catalonia (Spain), Batea (TA: Terra Alta Appellation) and Caldes de Montbui (CAT: Catalunya Appellation) during two consecutive years 2007 and 2008.

In TA rainfall and potential evapotranspiration (ET0) were higher than in CAT, but accumulated growing degree days (∑GDD) were lower, due to lower maximum temperatures and higher minimum temperatures in winter in CAT. The year 2007 was drier and warmer in both locations. Yield was significantly lower only in CAT2007, being no differences in leaf area, nor pruning weight. Veraison and harvest were advanced in 2007 in both locations. Phenological stages were longer in CAT both years. The length of the period between flowering to veraison, and from veraison to harvest is longer when accumulated rainfall during each period is higher. On the other hand, the higher the average of GDD during the period, the shorter the period was. Probable alcohol degree (PAD), Total Phenol Index (TPI), Color Index (CI), Anthocyanin Content (ANT_T and ANT_E), were higher and Flavan-3-ols content (DMACH) and Seed Maturity (SM) were lower in 2008, in both locations than in 2007, which could indicate that these parameters are very affected by drought, that in 2007 was one of the most dry ripening periods of last century in Catalonia.

KEYWORD
Climate – *Vitis* – grapevine – drought – phenols

INTRODUCTION

The environmental factors and the cultural practices influence the phenological stages of vines, as well as in the accumulation of primary and secondary metabolites in the berry (Cortell *et al*. 2007). Growth measurements give essential information to compare plots under different conditions (Deloire *et al*. 2005). High vegetative density in a vine can modify its microclimate by increasing the shadow of the canes, reducing air circulation, increasing humidity and reducing temperature. On the contrary, vines with scarce vegetation can have an excessive solar exposition (Jackson and Lombard, 1993). Different authors (Bergqvist *et al*. 2001; Coombe, 1987; Smart, 1987) studied the effects of radiation and temperature on the composition and concentration of primary metabolites. During ripening, the evolution of sugar concentration is positively correlated with the anthocyanins concentration and the total polyphenol index (Hardie and Considine, 1976; Hrazdina *et al*. 1984; Río Segade *et al*. 2008), and negatively correlated with the total acidity and malic acid (Barbeau *et al*. 2004). Nevertheless, the phenolic composition in relation with the sugars, evolutions differently along the ripening depending on the edaphoclimatic factors (radiation, temperature, humidity, soil composition, water availability, etc.) genetic factors (variety, clone, rootstock) and cultural factors (training and pruning system, nutrition, wanted degree of berry maturity, etc.) (Jackson and Lombard, 1993; Van Leeuwen *et al*. 2004). The influence of climate on berry composition has been widely studied. Meriaux (1982), Coombe (1987), Bergqvist *et al*. (2001), Spayd *et al*. (2002) founded that higher the temperatures, lower the total acidity and higher the sugar levels. Moreover, usually color (anthocyanins) increases with temperature, proportionally to sugar concentration. Cacho *et al*. (1992), Hermosín and García-Romero (2004), found that the anthocyanin content of berries of the same variety can remarkably vary from vintage to vintage or, within the same vintage, between plots due to the strong influence of climate. Furthermore sugars, organic acids, and phenolic compounds concentrations in must can vary depending on the shape of the vine, since the radiation received by the bunches changes (Smart 1987; Bergqvist *et al*. 2001; Spayd *et al*. 2002; Downey *et al*. 2006; Tarara *et al*. 2008).

MATERIALS AND METHODS

The study was carried out in two different denominations of origin in the North East part of Spain. The first one was located in Batea (41º11'N, 0º21'E; altitude 236 m), in the Terra Alta Apellation (DO) (from now TA). The soil is calcareous of clay-loam texture, with 11% limestone content, 7.7 pH and good content of potassium The average annual temperature is 14.5ºC and the average rainfall of 450 $mm \cdot yr^{-1}$. Grenache (*Vitis vinifera*) vines grafted onto 110-Richter (*V. rupestris* Martin x *V. berlandieri* Resseguier nº2) were 10 years old. Bush vines were pruned in spurs, with a vine spacing of 1.4 x 2.8 m, and grow without any irrigation. The second location was in Caldes de Montbui (41º38'N 2º9'E; altitude 176 m) in the Catalunya Appellation (DO) (from now CAT), where the soil is loam. The average annual temperature is 14.4ºC and the average rainfall of 641 $mm \cdot yr^{-1}$. 3-year-old vines of Grenache grafted onto 110-R, were trained to a bilateral cordon with vertical shoot positioning (VSP) with a vine spacing of 1.5 x 3.0 m, and grow without any irrigation.

From veraison to harvest each year, 500 berries per plot were sampled several times. The berry sample was divided in 3 subsamples in order to do: a) classical maturity controls (berry weight, total acidity and sugar content (OIV, 1990), b) phenolic ripeness was analyzed by the Glories method (Ribéreau-Gayon *et al*. 2000). The easily extractable anthocyanins were extracted at pH 3.6 instead of pH 3.2. We used the pH 1 and pH 3.6 buffer extractions to analyze the following: b1) the total (pH1) and extractable (pH3.6) anthocyanins (analyzed using the bisulphite discoloration method) at 520nm; b2) the total phenols index (A_{280}) and b3) the phenolic potential was calculated as Extractability index $[(\%AE) = (A_{pH1} - A_{pH3.6}) \times 100 / A_{pH1}]$ and Seed maturity index $[(\%SM) = (A_{280(pH3.6)} - (A_{pH3.6} \times 40)/1000) \times 100 / A_{280(pH3.6)}]$; and c) berry skin anthocyanins extracted by acid solution (200 ml HCl: ethanol 800 ml and read at 535 nm). All the analyses were done by triplicate. ANOVA procedure was applied when appropriate. Leaf area was done by leaf count and measuring the length of central nerve (Carbonneau, 1976; Baeza *et al* 1997; Cuevas, 2001)

At harvest we measured yield (kg·vine^{-1}) and pruning weight in winter dormancy (kg·vine^{-1}); and we calculated the Ravaz index.

Weather conditions were monitored during the extent of the experiment through weather stations belonging to the official Agro-meteorological network in Catalunya (XAC), located in the same municipalities than the vineyards.

RESULTS AND DISCUSSION

The two considered locations are representative of different viticultural areas and have different mesoclimates. The two studied years also differed in both places, especially in rainfall amount and distribution (Fig. 1A). In TA, 2007 was 15% drier (384 mm), than the average (450 mm), whereas 2008 was 31% rainier (588mm) than average. In CAT, 2007 was 31% drier (440mm) than the average (641mm) and 2008 16% rainier (742mm). These changes in rainfall amount and distribution were less negative in TA than in CAT. In both years ET_0 was higher in TA, particularly due to higher vapor pressure deficit and wind. The ∑GDD10 did not differ very much between locations but years. 2007 accumulated more GDD from April to the end of the year in CAT than in TA, whereas in 2008 the two locations had an equal GDD value (lower than in 2007) up to harvest time.

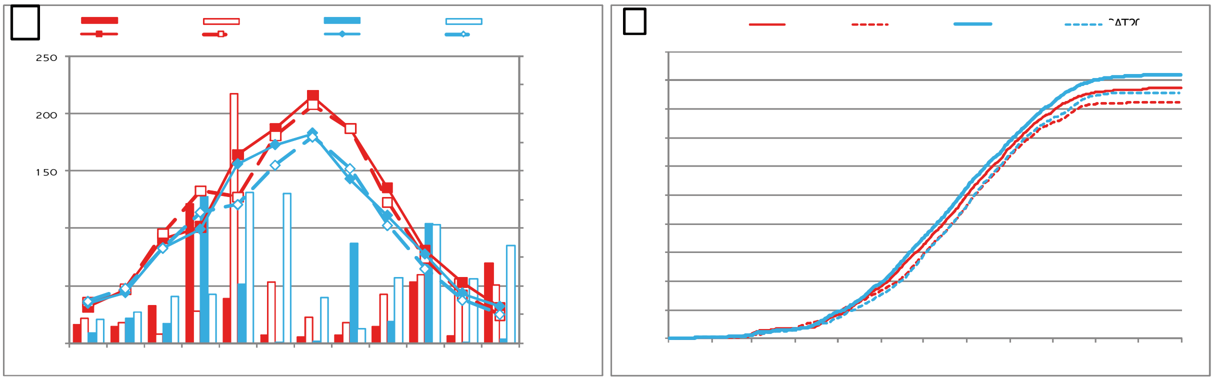

Figure 1. A) Monthly rainfall (mm) and potential evapotranspiration (ET_0 (mm) and B) Accumulated growing degree days (∑GDD (ºC)) in DO Terra Alta (TA) and DO Catalunya (CAT) during 2007 and 2008.

Yield and pruning weight were lower in CAT 2007 than in the others (Tab. 1), due to the youth of the vines. Yield, Leaf area and Ravaz index (Tab. 1) did not show any significant differences between neither places nor years.

The length of the ripening process was different between locations and years. In 2007 it was shortest in TA (33 days), whereas the longest in CAT (46 days), but veraison was set on the same date in both locations. In 2008, veraison and the length of the period in TA resulted similar to 2007 (34 days). In CAT, the veraison was delayed 8 days and moreover the harvest was advanced resulting in a shorter ripening period in CAT. The length of the ripening period had a significant positive relationship with the accumulation of growing degree days ($\sum GDD_{10}$ (ºC)) during this period (r^2=0.88), but not with other parameters such as accumulated rainfall or ET_0 or mean thermal amplitude.

The evolution of classical maturity parameters from veraison to harvest for both locations and years is shown in fig. 2.

In CAT 2007 the berry weight was too high due to the youth of the vines and the poor and not steady fertility. In 2008, berries were significantly higher in CAT than in TA both years. Target PAD was around 14.5º, so harvest date was adjusted to it. In CAT in 2007 was impossible to achieve the level due to intense rainfall around harvest time. In TA 2008 harvest was a bit later than wanted. The total acidity values were similar for all the years and locations.

Table 1. Yield components for Terra Alta (TA) and Catalunya (CAT) plots in 2007 and 2008. Data are mean of n=3 ± **S.E.** Different letters in the same columns indicate significant differences (P≤0.05/ Tukey test)

Location	Year	Pruning weight (kg·vine^{-1})	Leaf area at veraison (m^2·vine-^{1})	Leaf area at harvest (m^2·vine^{-1})	Yield (kg·vine^{-1})	Ravaz Index
TA	**2007**	0,270 ± 0,047b	2,931 ± 0,863	2,586 ± 0,518	2,581 ± 0,199b	9,557 ± 0,199
	2008	0,320 ± 0,010b	2,585 ± 0,438	3,392 ± 0,753	2,872 ± 0,588b	8,978 ± 0,588
CAT	**2007**	0,079 ± 0,016a	2,684 ± 0,335	3,252 ± 0,196	0,465 ± 0,17a	5,877 ± 0,170
	2008	0,385 ± 0,069b	3,004 ± 0,513	3,131 ± 0,355	3,74 ± 0,469b	9,707 ± 0,469
TA		0,295 ± 0,024	2,758 ± 0,44	2,989 ± 0,447	2,726 ± 0,285	9,243 ± 0,285
CAT		0,232 ± 0,061	2,867 ± 0,309	3,183 ± 0,205	2,512 ± 0,664	10,818 ± 0,664
	2007	0,151 ± 0,039	2,808 ± 0,418	2,919 ± 0,289	1,523 ± 0,487	10,105 ± 0,487
	2008	0,361 ± 0,043	2,824 ± 0,332	3,243 ± 0,346	3,415 ± 0,375	9,465 ± 0,375
Global		0,256 ± 0,157	2,817 ± 0,906	3,093 ± 0,81	2,604 ± 1,449	10,182 ± 1,449

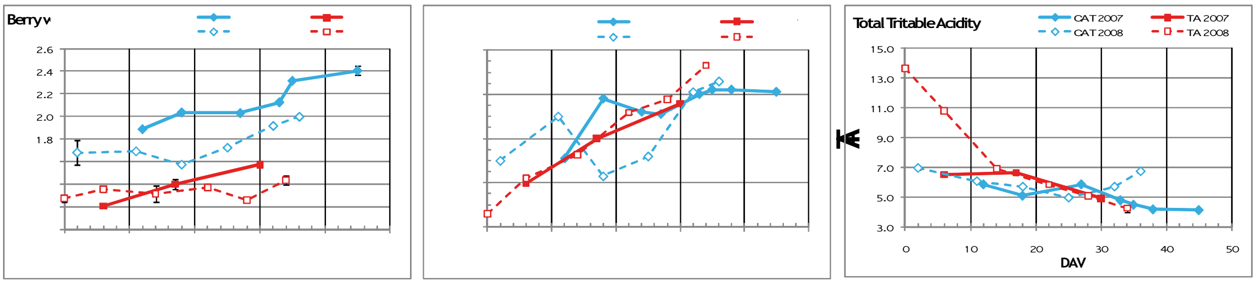

Figure 2. Berry weight (g), Probable alcohol degree (º) and total tritable acidity in DO Terra Alta (TA) and DO Catalunya (CAT) in 2007 and 2008. Horizontal axis is represented in number of days after veraison (DAV) for each location and year.

At harvest TPI, ANT$_T$ and ANT$_E$ were higher in 2008 than in 2007, whereas DMACH was lower. This indicates that 2008 was a better year in terms of polyphenol and anthocyanin accumulation in the berries. Moreover, ANT$_E$ was higher in TA than in CAT, showing a higher value of extractable anthocyanins. The SM at harvest was better in TA than in CAT and in 2008 than in 2007, because of the low values, that indicated less astringency in seeds. The color (CI) showed the highest values in TA2008 and the lowest in CAT2007. Finally AE was much lower in TA 2008 than in the other years and locations. The values of AE match well with extractability of the color (Ribereau-Gayon et al. 2000).

The accumulated rainfall during the veraison to harvest period was much less in TA (2,6 and 21,5 mm in 2007 and 2008 respectively) than in CAT (71,8 and 68,3 mm in 2007 and 2008 respectively). It was positively correlated with BW, PAD, CI, ANT$_T$ and ANT$_E$, and negatively with TTA, DMACH, SM and AE. In TA, where the rainfall was lower these relationships were significant and last all the period. On the other hand, the CAT samples showed the same trend at the beginning of the period, but when it rained intensively at the end of the ripening, the trend was reversed, except in the case of BW and PAD. The rainfall in CAT at the end of the ripening period is characteristic of this mesoclimate due to the sea influence.

Table 2. Phenolic maturity parameters at harvest for Terra Alta (TA) and Catalunya (CAT) plots in 2007 and 2008. From left to right: Total Phenol Index (TPI), Color Index (IC), Total Anthocyanin Content (ANT_T, mg·l^{-1}), Extractable Anthocyanin Content (ANT_E, mg·l^{-1}), Flavan-3-ols content (mg·l^{-1}) (DMACH), Seed maturity index (SM, %), Extractability index (AE, %). Data are mean of n=3 ± S.E. Different letters in the same columns indicate significant differences ($P \leq 0.05$/ Tukey test).

Location	Year	TPI	CI	ANT_T (mg·L^{-1})	ANT_E (mg·L^{-1})	DMACH (mg·L^{-1})	SM (%)	AE (%)
TA	**2007**	53,5 ± 0,5	14,44 ± 0,28b	351,1 ± 33,7	282,6 ± 16,9	243,2 ±14,0	78,89 ± 1,24	19,0 ± 2,8a
	2008	60,2 ± 1,0	20,58 ± 0,44a	453,7 ± 7,9	441,5 ± 5,4	218,6 ± 3,2	70,68 ± 0,21	2,7 ± 0,9b
CAT	**2007**	52,5 ± 3,5	6,19 ± 0,94c	290,6 ± 47,2	226,9 ± 49,9	280,7 ± 6,0	82,91 ± 2,85	23,1 ± 4,8a
	2008	62,0 ± 2,5	17,09 ± 1,02b	420,1 ± 12,4	309,3 ± 8,8	199,1 ± 18,7	79,93 ± 0,97	26,2 ± 2,6a
TA		56,9 ± 1,6	17,51 ± 1,39	402,4 ± 27,7	362,0 ± 36,4a	230,9 ± 8,4	74,78 ± 1,92b	10,8 ± 3,9
CAT		57,8 ± 2,7	13,14 ± 2,29	362,2 ± 32,3	265,4 ± 25,6b	228,0 ± 19,4	81,79 ± 1,34a	26,7 ± 2,4
	2007	53,0 ± 1,6b	10,32 ± 1,90	320,9 ± 29,3b	254,7 ± 26,6b	262,0 ± 10,8a	80,90 ± 1,66a	21,0 ± 2,7
	2008	61,2 ± 1,4a	18,58 ± 0,91	434,5 ± 10,0a	366 ,0± 27,2a	207,5 ± 10,8b	75,97 ± 1,94b	16,1 ± 5,0
Global		57,4 ± 1,6	14,77 ± 1,53	382,0 ± 21,4	314,6 ± 24,3	232,6 ± 10,7	78,24 ± 1,43	18,4 ± 2,9

The response of the quality parameters to the GDD_{10} and ET_0 accumulation during the ripening period was quite similar in sign and significance. BW, PAD and ANTT showed a positive correlation with those parameters. The response of TTA and SM was negative and, when separating by locations and years, the TA2008 data showed a steeper slope. AE only showed a negative correlation with ET_0, but only being significant in TA2008. TPI and CI seemed not to respond to the tested climatic parameters. Nadal et al. (2008) observed less anthocyanin content in berries of vines grown under the sea influence (lower VPD, milder temperatures and higher rainfall).

CONCLUSIONS

In Grenache, a variety with low phenolic potential, the driest years reduce phenol synthesis, especially anthocyanins synthesis. In both years, the evaporative demand in TA was higher than in CAT, increasing the effects of the drought.

In CAT appellation, for both years the quality was reduced due to the rainfall just before harvest, typical in the region. Probable alcohol degree and berry weight increased but anthocyanins were diluted. Rainfall also increases the length of ripening period in CAT compared with TA, due to the sea influence.

Extrapolating at a more global scale, those areas in the future exposed to higher ET_0 and drier summers (in length and amount) seem to be more unfavorable to the color synthesis and extractability and could be a constraint to winegrowing in the future.

ACKNOWLEDGMENTS

The results that appear in this work were partially funded by the Spanish Ministry of Education AGL2005-06927-C02-02 and by National project CDTI with “Unió de Cooperatives” Company.

BIBLIOGRAPHY

Baeza P, Ruiz C, Bartolomé MC, and Lissarrague JR 1997. Differences in gas exchange in cv. Tempranillo (*Vitis vinifera* L) as affected by training system. Acta Horticulturae (ISHS). 526, 145-156.

Barbeau, G.; Bournand, S.; Champenois, R. ; Bouvet, M. ; Blin, A. ; and Cosneau, M. (2004) Comportement de quatre cépages rouges du Val de Loire en fonction des variables climatiques. *J. Int. Vigne Vin*, 38 (1), 35-40.

Bergqvist, J.; Dokoozlian, N. & Ebisuda, N. 2001. Sunlighht exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the Central San Joaquin Valley of California. Am. J. Enol. Vitic, 52:1, 1-7.

Cacho, J.; Fernández, P.; Ferreira, V.; and Castells, J.E. (1992). Evolution of five Anthocyanidin-3-glucosides in the skin of the Tempranillo, Moristel, and Garnacha grape varieties and influence of climatological variables. *Am. J. Enol. Vitic.,* 43 (3), 244-248.

Carbonneau A. 1976. Principes et méthodes de mesure de la surface foliaire. Essai de caractérisation des types de feuilles dans le genre Vitis. Ann. Amélio. Plantes, 26:327-343

Coombe,B.G.1987.Influence of temperature on composition and quality of grapes.Acta Hortic.206:23-35.

Cortell, J.M.; Halbleib, M.; Gallagher, A.V.; Righetti, T.L. & Kennedy, J. A. 2007. Influence of vine vigor on grape (*Vitis vinifera* L. cv. Pinot Noir) anthocyanins. 1. Anthocyanin concentration and composition in fruit. J. Agric. Food Chem., 55, 6575-6584.

Cuevas E. 2001. Estudio de mecanismos de adaptación ecofisiológica de la vid (*Vitis vinifera* L.cv.Tempranillo) al déficit hídrico. Evaluación del consumo de agua y de las respuestas agronómicas en diferentes regímenes hídricos. Tesis doctoral. Universidad Politécnica de Madrid.

Deloire, A.; Vaudour, E.; Carey, V. ; Bonnardot, V. & van Leeuwen, C. 2005. Grapevine responses to terroir: a global approach. J. Int. Sci. Vigne Vin, 39 (4), 149-162.

Downey, M.O.; Dokoozlian, N.K.; and Krstic, M.P. (2006) Cultural Practice and Environmental Impacts on the Flavonoid Composition of Grapes and Wine: A Review of Recent Research. *Am. J. Enol. Vitic*., 57:3, 257-268.

Hardie, W. J.; and Considine, J. A. (1976) Response of grapes to water deficit stress in particular stages of development. *Am. J. Enol. Vitic*., 27, 55-61.

Hermosín Gutiérrez, I.; and García-Romero, E. (2004) Antocianos de variedades tintas cultivadas en la Mancha: perfiles varietales característicos de la uva y de los vinos monovarietales, y evolución durante la maduración de la baya. *Alimentaria*, Abril 04/127-139.

Hrazdina, G.; Parsons, G.F.; and Mattick, L.R. (1984) Physiological and biochemical events during deveopment and maturation of grape berries. *Am. J. Enol. Vitic.* 35 (4), 220-227.

Jackson, J.I. & Lombard, P.B. 1993. Environmental and management practices affecting grape composition and wine quality – A review. Am. J. Enol. Vitic. 44 (4), 409-429.

Nadal M, Mateos S, and Lampreave, M. (2008) Influence de la topographie etdu mésoclimat sur la composition des raisins et rendement dans le terroir del'AOC Priorat, VII CongresInt. terroirs viticoles 19 - 23 mai 2008 Nyon,Suïssa,(2):590-595

Meriaux, S. (1982). La vigne et l´eau dans le Midi méditerranéen. Vignes et Vins, nº especial Septiembre: 23–26.

OIV. (1990). "Récueil des Méthodes Internacionales d'Analyse des vins et des Mouts "; Office Internacional de la Vigne et du Vin: Paris, France.

Ribéreau-Gayon Y, Glories Y, Maujean A. & Dubourdieu D, 2000. Handbook of Enology, Volume 2: The chemistry of wine and stabilization and treatments. John Wiley & Sons Ltd.

Río Segade, S.; Soto Vázquez, E.; and Díaz Losada, E. (2008) Influence of ripeness grade on accumulation and extractability of grape skin anthocyanins in different cultivars. *J. Food Comp. Anal*., 21, 599-607.

Smart, R. 1987. Influence of light on composition and quality of grapes. Acta Hortic. 206:37-43.

Spayd, S.E.; Tarara, J.M.; Mee, D.L.; and Ferguson, J.C. (2002) Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. *Am. J. Enol. Vitic.,* 53:3, 171-182.

Tarara, J.M.; Lee, J.; Spayd, S.E.; and Scagel, C.F. (2008) Berry temperature and solar radiation alter acylation, proportion, and concentration of anthocyanin in Merlot grapes. *Am. J. Enol. Vitic.,* 59:3, 235-246.

Van Leeuwen, C.; Friant, P.; Choné, X.; Tregoat, O.; Koundouras, S.; and Dubourdieu, D. (2004) Influence of climate, soil, and culrivar on terroir. *Am. J. Enol. Vitic.* 55:3, 207-217