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Effect of moderate irrigation on grape composition during ripening

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Abstract

The effect of moderate irrigation on berry composition during the ripening of Monastrell grapes and the quality of wines produced from these grapes in a very dry area of southeastern Spain have been studied. The results showed that irrigated grapes reached higher weights but this did not impair sugar accumulation. Titratable acidity and pH were only slightly affected by irrigation, titratable acidity was higher in only one year in the most irrigated grapes at the end of ripening, mainly due to a higher malic acid content. Anthocyanin content in must was slightly lower in irrigated grapes. The results of the sensory analysis of the wines showed that wines made from non irrigated grapes usually obtained the highest scores for quality and intensity of color and aroma although differences were small.

Additional key words: acidity, anthocyanins, berry, sugar content, wine.

Resumen

Efecto del riego moderado sobre la composición de las uvas durante la maduración

Se ha estudiado, durante dos años, el efecto del riego moderado en la vid *(Vitis vinifera* L.) cv. Monastrell, en zonas con un alto déficit hídrico, sobre la evolución de la composición fisico-química de las uvas durante su maduración y la calidad de los vinos obtenidos y los resultados se han comparado con uvas de vides no regadas. Las uvas de vides con un riego moderado alcanzaron pesos de baya más altos, pero el riego no produjo ningún retraso en la acumulación de azúcares en la baya. La acidez total y el pH se vieron poco afectados por el riego. La concentración de antocianos en el mosto fue ligeramente menor en las uvas de vides regadas y consecuentemente, el color de los vinos obtenidos se vio afectado por el riego. Los vinos del tratamiento en secano obtuvieron los resultados mejores en el análisis sensorial, aunque las diferencias fueron pequeñas.

Palabras clave adicionales: acidez, antocianos, azúcares, color, maduración, vino.

Introduction

The chemical composition of grape berries is determined by environmental conditions, maturity level, yield and cultural practices (Morris and Cawthon, 1982; Bravdo *et al.*, 1985; Matthews and Anderson, 1988; Iland, 1989; Nadal and Arola, 1995). Irrigation is one of these practices and may greatly influence grape and vine metabolism. Different irrigation regimes may lead to physiological alterations that will affect vine yield and grape composition (Esteban *et al.*, 1999), therefore influencing the wine produced from them.

In Spain, more than 90% of the vineyards are located in semiarid or arid conditions, with rainfall lower than 450 mm and with a rainfall distribution that does not coincide with maximum vine activity. On the contrary, this maximum activity occurs when water deficits are most intense. If irrigation is adequately applied, excellent results could be obtained, with higher and more constant yields.

Berry solutes that are sensitive to vine water status include organic acids, sugars, anthocyanins and soluble phenolic compounds. Much work has been done concerning the effect of irrigation or water stress on berry solutes and contradictory results have been obtained. Excess irrigation can lead to a very high vegetative growth and crop load (Bravdo *et al.,* 1985; McCarthy, 1985) and, since berry size is increased, a dilution of certain important

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features may occur (Esteban *et al.,* 2001). The sugar content may also diminish due to competition between vegetative growth and fruit development. Severe water stress, on the other hand, tends to decrease vigor but also the sugar and acid content since photosynthetic activity may be compromised (De la Hera Orts *et al.,* 2004). We think that most of the negative effects attributed to irrigation are probably due to excess water supply. We have, therefore, investigated the effect of two moderate watering amounts on the berry composition and wine quality from vines grown in a very dry region.

Material and Methods

A Monastrell vineyard located within the Designation of Origin of Jumilla (Spain) was selected for the study. The vineyard was planted in 1997 on 1103 Paulsen rootstock. The planting density was 2.5 m between rows and 1.25 m between plants. Six one-bud spurs were left at pruning time.

Irrigation treatments have been described previously (De la Hera *et al.*, 2004). Briefly, two drip irrigation treatments and a non-irrigated control were assayed, starting on 15 April and ending on 31 October: NI, non-irrigated vines, no additional water was supplied; T1, additional water supply of 1073 m^3 ha^{-1} $year^{-1}$; T2, additional water supply of 1622 m^3 ha^{-1} $year^{-1}$.

The climatic data of both years are summarized in Table 1.

ET_0 was calculated from the mean values of the preceding 12 years following the method of Pruitt (1986) using the data collected in the meteorological station located in the same vineyard. Vineyard evapotranspiration (Et_{vine}) was estimated using a varying crop coefficient (K_c), based on those proposed by Yañez *et al.* (1996). To apply the crop coefficient (K_c) the season was divided into three periods. The crop coefficient used in each period of the growing season and the watering amounts applied are given in Table 2.

Analytical determinations

A randomized complete block design was used with four replications. Each treatment plot contained 165 vines (512 m^2). In each elementary vineyard plot for each treatment, samples of 100 berries were carefully taken from different parts of several clusters early in the morning and transported to the laboratory at low temperature. Berry sampling began at veraison and continued every 7-10 days until harvest.

Total soluble solids (°Brix) were measured using an Abbé-type refractometer. Titratable acidity and pH were measured using an automatic titrator (Metrohm, Switzerland). Titration was done with 0.1 M NaOH. Tartaric and malic acids were measured using the enzymatic kits from Boehringer Mannheim (Germany).

For the determination of anthocyanins in must, berry samples were homogenized in a blender Coupe GT 500

Table 1. Climatic conditions during 2000 and 2001

Year	Month	Temperature (°C)			Humidity (%)			Rainfall (mm)		Solar radiation (w m^{-2})	ET_o (mm)
		Mean	Max	Min	Mean	Max	Min	Tot	Max	Mean	Mean
2000	April	13.6	18.8	9.8	56.5	95.2	37.4	26.8	14.6	265.1	144
	May	18.3	25.0	13.1	65.8	91.4	42.1	55.0	38.8	300.5	172.4
	June	22.2	28.9	17.3	51.8	76.9	25.8	1.8	1.4	369.9	232.5
	July	24.9	29.3	21.1	47.2	67.3	31.5	11.3	11.3	358.7	238.1
	August	24.6	28.0	21.1	47.0	81.4	24.4	16.7	16.6	305.1	206.7
2001	April	14.9	19.6	10.8	54.6	95.0	30.5	25.1	18.8	300.1	157.8
	May	17.0	22.2	9.9	63.6	94.7	41.0	53.6	17.8	300.1	163.4
	June	23.5	29.0	18.5	43.0	75.2	18.0	2.8	1.9	374.0	241.8
	July	24.7	27.7	21.1	47.3	71.2	23.1	0.5	0.5	346.0	239.3
	August	25.4	28.4	23.2	53.8	77.8	33.4	3.2	3.0	307.2	201.2

T1, T2: treatments as explained in Material and Methods.

Table 2. Crop coefficient (k_c) and irrigation schedule ($m^3\ ha^{-1}$)

Period (Month/day)	T1		T2	
	k_c	$m^3\ ha^{-1}$	k_c	$m^3\ ha^{-1}$
(4/15-6/15)	0.1	235	0.2	470
(6/16-8/15)	0.2	624	0.3	938
(8/16-10/1)	0.1	214	0.1	214
Total		1,073		1,622

(France) for 2 min. Then, 50 g of the homogenate were used to analyze anthocyanins in must and total polyphenols following the method described by Lamadon (1995).

Microvinification procedures

One hundred kilograms of fruit from each irrigation treatment were harvested on the same day. The fruit from each treatment was crushed, destemmed and SO_2 was added (80 mg kg^{-1}). It was then separated into three lots, which were inoculated with selected yeasts. Fermentation temperature was maintained at 25°C. The wine lots were punched down twice daily until the end of alcoholic fermentation (seven days). The skins were pressed off on day 15. Malolactic fermentation occurred without inoculation after the alcoholic fermentation had finished. After the end of the malolactic fermentation, the wines were cold stabilized and bottled.

Chromatic characteristics of the wines

Absorbance measurements were made in a Hitachi 2000 spectrophotometer (Tokyo, Japan) with 0.2 cm path length glass cells.

Color density (CD) was calculated as the sum of absorbance at 620 nm, 520 nm, and 420 nm and tint as the ratio between absorbance at 420 nm and absorbance at 520 nm (Glories, 1984). OD_{280}, expressing the wines total phenol content, and total anthocyanins were determined using the methods described by Ribereau-Gayon *et al.* (1998).

Sensory analysis

The wine-tasters for this analysis were seven well-trained judges from the Jumilla Wine Council. The intensity of each attribute was rated on a scale of zero to nine. A score of zero indicated that the descriptor was not perceived while a score of nine indicated a high intensity.

Statistical data treatment

Significant differences among wines and for each variable were assessed with analysis of variance (ANOVA). This statistical analysis, together with simple regression analyses, was applied using Statgraphics 2.0 Plus.

Results

Berry weight increased from veraison to maturity (Fig. 1). The availability of water led to greater increases in berry weight and, on the last sampling date, berry weight was significantly different among the treatments. The increase was very fast during the first days of Stage III (defined as the period of time from veraison to maturity), especially for the grapes irrigated in the year 2001. In the period between the last two sampling dates, berry weight stabilized or even decreased slightly, probably because of water loss due to evaporation in the berries. Non-irrigated grapes had the lowest weight at harvest.

Sugar accumulation (Fig. 2) was almost lineal during ripening. At the moment of veraison, during the first year of the experiment, NI grapes had the same sugar content as T1 grapes and both were slightly lower than the sugar content of T2, whereas in 2001, the grapes from the three treatments had the same sugar content at veraison, indicating that irrigation did not delay ripening. In both years, around August 7th, the sugar content was almost the same for the three treatments. In 2000, NI grapes showed higher sugar content than

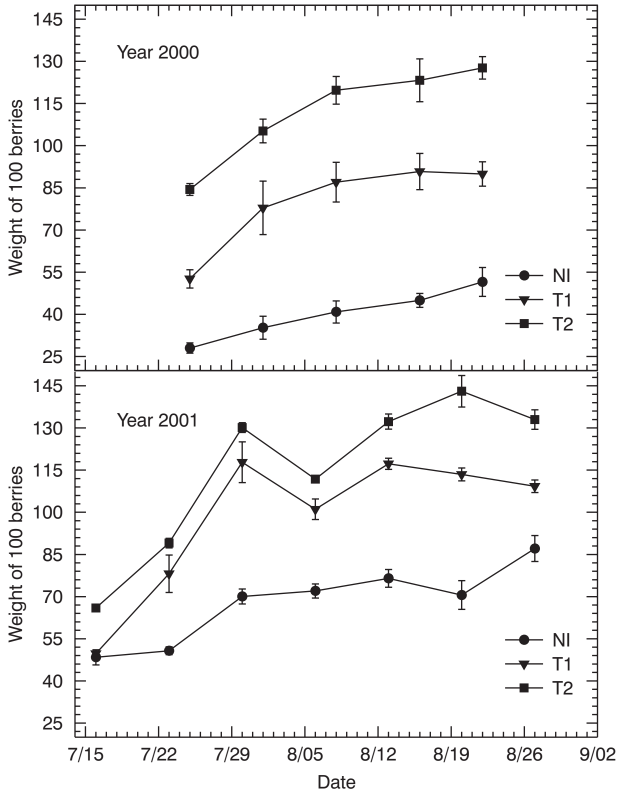

Figure 1. Evolution of berry weight during ripening for the two years of study.

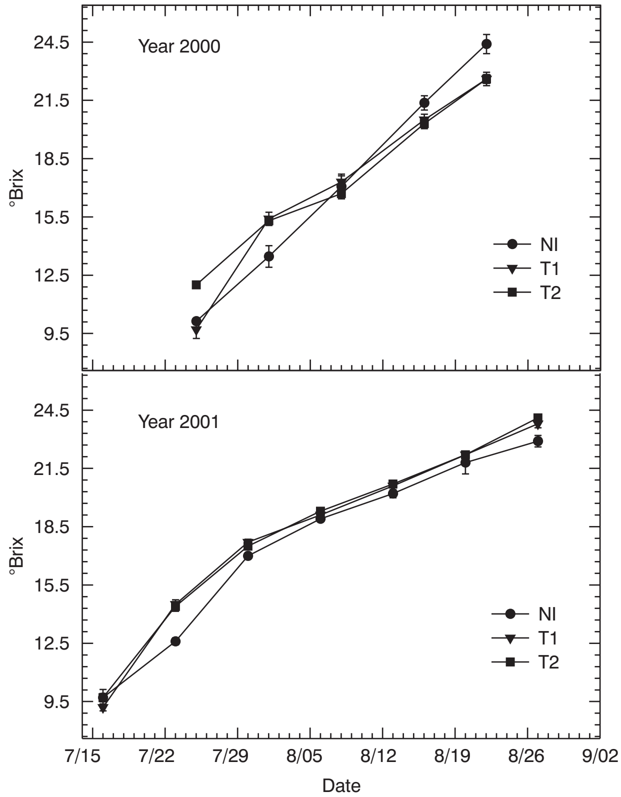

Figure 2. Evolution of sugar content (°Brix) during ripening for the two years of study.

irrigated grapes after this day, but in 2001, the sugar content was lower in NI grapes throughout the entire ripening period and at harvest, although berry weight was greater in irrigated vines, sugar concentration was slightly higher.

Titratable acidity and pH are of great importance for grape juice and wine stability, and both parameters are commonly used as indicators of quality. Their values are shown in Figs. 3 and 4. In 2000, titratable acidity was higher in NI grapes at the onset of stage III, while in 2001 no differences were found. NI grapes had a slow decrease until mid-August, while irrigated grapes experienced a faster decrease in titratable acidity during the same period.

At the time of harvest in both years, titratable acidity levels were very similar for all the grapes. As titratable acidity decreased during ripening, pH values increased, and again, only small differences were found in grapes from the different treatments.

Titratable acidity is mainly due to the presence of tartaric and malic acids. The results (Fig. 5) showed that tartaric acid levels were higher in NI grapes at the beginning of ripening and a slow decrease during the first part of the ripening period was observed. However, at the time of harvest, the content in T1 and T2 grapes was significantly higher than in NI grapes in 2000 and no differences were observed in 2001. Malic acid concentration was very similar between treatments at veraison. A faster decrease in its concentration was observed, compared with tartaric acid and at the end of ripening values were very similar, although a slightly lower concentration was always measured in non-irrigated grapes.

When representing titratable acidity *versus* tartaric and malic acids for all the samples a strong linear correlation was found. Since this was very similar in both years, only the results from 2001 are shown (Fig. 6). Comparing the results for both acids, the main differences found are the slopes of the regression lines. The corresponding slopes were always smaller for tartaric acid than malic acid. Therefore, as titratable acidity decreased, the reduction in tartaric acid was less pronounced than the reduction in malic acid and changes in malic acid affected titratable acidity to a larger extent. This is also reflected in the tartrate/malate ratio. At the beginning of ripening, the

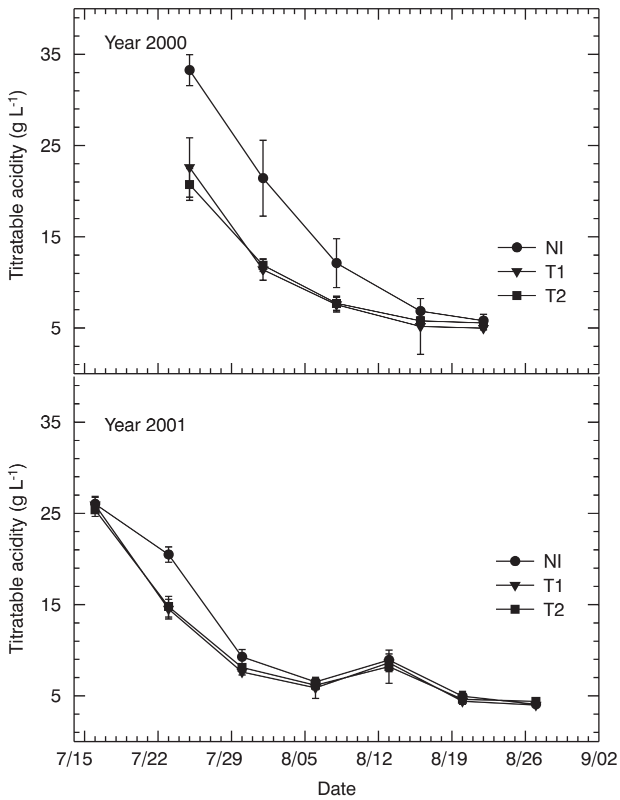

Figure 3. Evolution of titratable acidity (expressed as g L^{-1} of tartaric acid) during ripening for the two years of study.

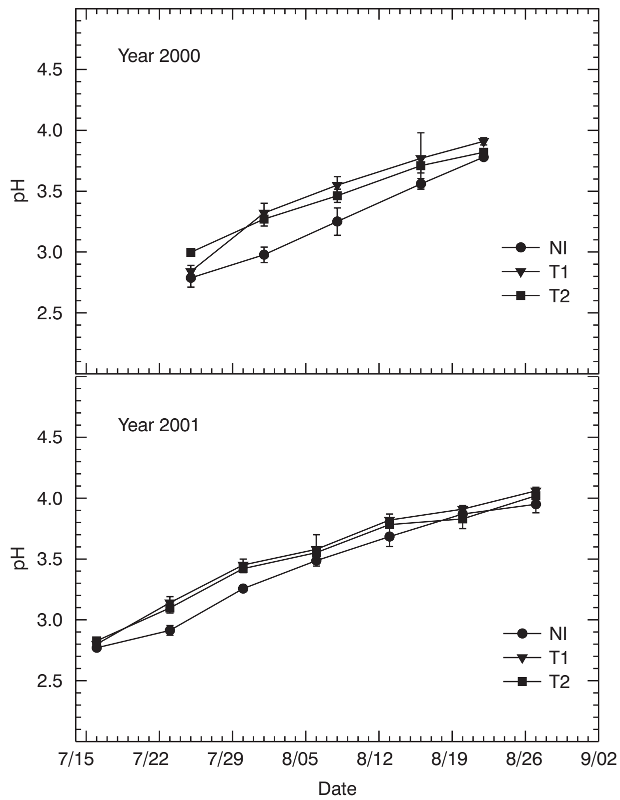

Figure 4. Evolution of pH values during ripening for the two years of study.

tartaric acid/malic acid ratio was low, while at harvest the opposite was true (Fig. 7). This is due to the fact that the decrease in tartaric acid was not as intense as that of malic acid. The highest values of this ratio for non-irrigated grapes are due to a larger degradation of malic acid in these grapes.

The color of grapes is very important for wine quality and the effect of moderate irrigation on the anthocyanin concentration of grapes needs to be assessed. Figure 8 shows the evolution of anthocyanins during ripening. A continuous synthesis was observed during the entire period studied, with total anthocyanins peaking 20-30 days after veraison and then stabilizing. In 2000, a higher concentration of anthocyanins was found in NI berries on the last two sampling dates but in 2001 the evolution of anthocyanins in grapes from non-irrigated and irrigated treatments was very similar and the differences found on the last sampling date were not significant.

Although it is important to evaluate the effect of irrigation on the quality of grapes, our main concern is for the quality of the resulting wines. For this reason,

Table 3. Chromatic characteristics of wines

	2000			2001		
	NI	T1	T2	NI	T1	T2
Color intensity	11.5b	10.4b	8.2a	17.1c	13.2b	12.6a
Total phenols (OD_{280})	71c	59b	55a	65c	58b	53a
Total anthocyanins	425.6b	350.2a	370.2a	558.4b	436.0a	470.5a

Different letters within the same row for each of the years of study mean significant differences according to a LSD test ($p < 0.05$).

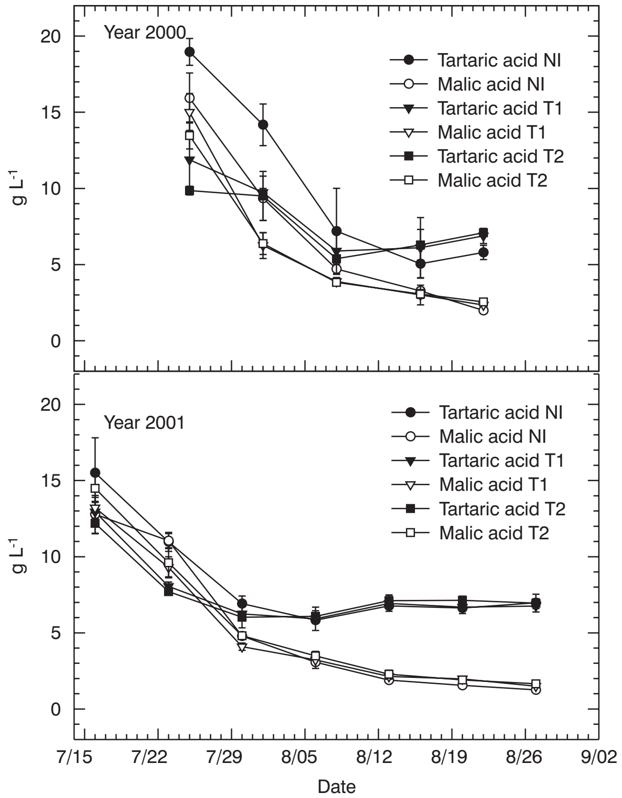

Figure 5. Evolution of tartaric and malic acid concentration in grapes during ripening for the two years of study.

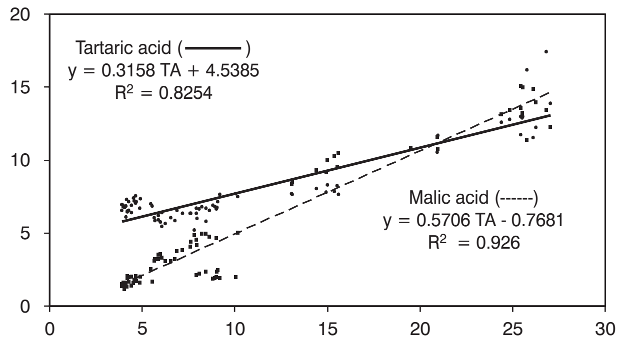

Figure 6. Regression analysis for titratable acidity (TA) *versus* tartaric and malic acid concentrations in 2001.

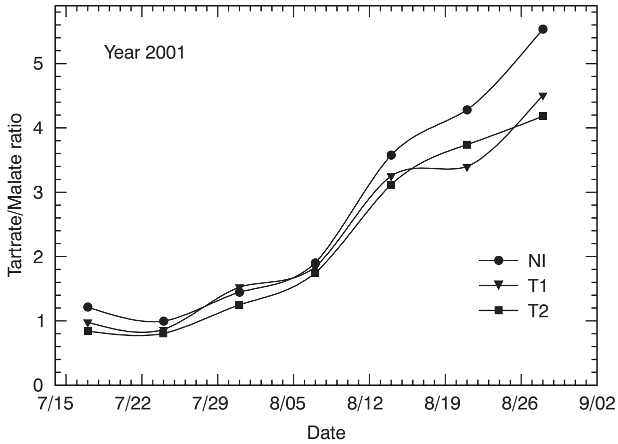

Figure 7. Evolution of the tartrate/malate concentration ratio during ripening in 2001.

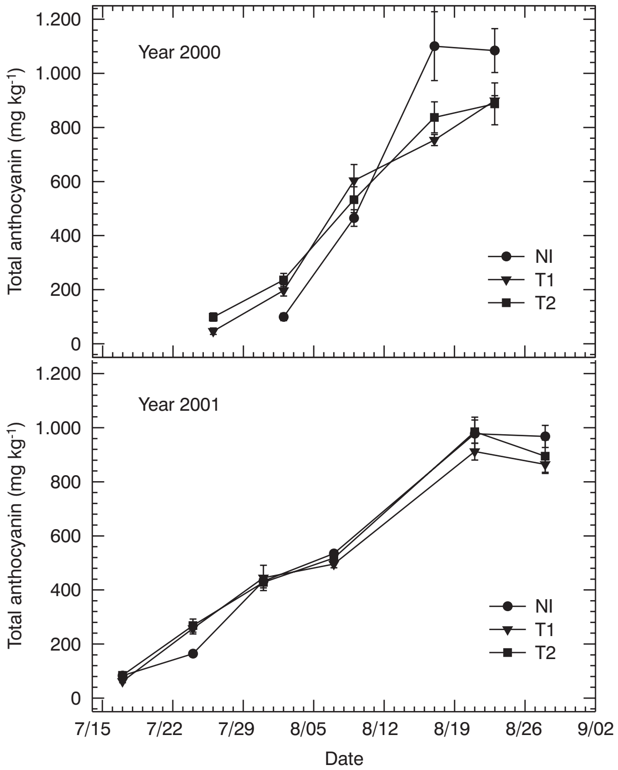

Figure 8. Evolution of must anthocyanins, expressed as mg kg^{-1} of grapes during ripening for the two years of study.

wines elaborated from the grapes of each treatment were submitted to analytical and sensorial analysis. The results showed (Table 3) that irrigation decreased wine color intensity, total polyphenol content and total anthocyanins in wine. Even with the lower doses of irrigation, significant differences were found when comparing wines from irrigated vines with the chromatic data of wine from non-irrigated grapes.

Color and aroma quality and intensity, as assessed by the panelists, are reported in Figure 9. As regards the

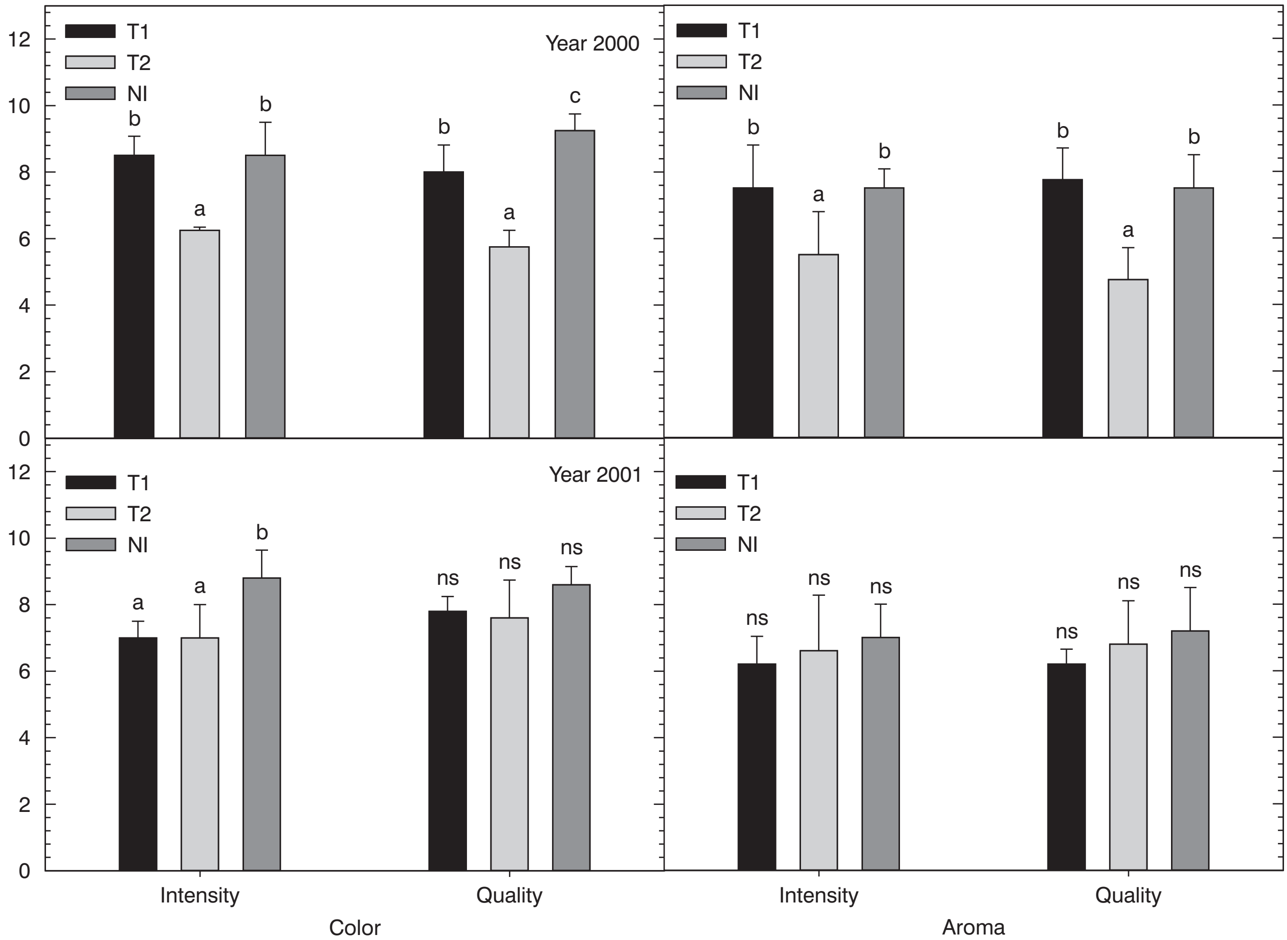

Figure 9. Scores obtained for the wines in the sensory analysis regarding color and aroma characteristics (ns: not significant differences).

color intensity, wines from NI grapes always obtained the highest scores although in 2000, wines from T1 grapes obtained a similar score. The quality of the color was also higher in wines from NI grapes in 2000 but no significant differences were found in 2001 between the wines made from grapes from the different treatments.

Regarding the intensity and quality of the wine aroma, as perceived by the wine-tasters, wines from NI grapes and T1 grapes obtained the same scores in both years. Wines from T2 grapes had a lower aroma intensity and quality in 2000 but no differences could be found in 2001.

Discussion

In dry areas, water is very scarce and expensive and therefore only small volumes can be applied (in the experiment reported here, the water amount applied in the highest irrigation program is the equivalent of 162.2 mm of rainfall in the three periods), and the effect of these moderate irrigation treatments on berry composition needs to be determined.

The increase in berry weight during ripening is determined by the accumulation of solutes, especially sugars and water. The larger berry weight reached by grapes from the irrigated treatments is an effect previously described by several authors (Freeman and Kliewer, 1983; Matthews and Anderson, 1988; García-Escudero and Zaballa Ogueta, 1997; Esteban *et al.*, 1999, 2002). Irrigation may affect the weight of wine grapes both directly and indirectly. The direct effect is manifested in a large number of cells (when there are no water restrictions during stage I of fruit growth) or by a larger cell size (when there are no water restrictions during stage III). A water deficit during stage I (when most cell division and multiplication occur) may impair the final size of the berry, even when there are no water restrictions from veraison to maturity (Bravdo and Naor, 1996). The indirect effect, on the other hand, is due to a larger leaf area on the irrigated vines (De la Hera Orts *et al.*, 2004) and therefore a greater capacity to accumulate photoassimilates (García-Escudero *et al.*, 1991). The berry weight obtained in each irrigation treatment was the productive parameter that most influenced yield as shown in a previous study (De la Hera Orts *et al.*, 2004) where it was found that, in the prevailing climatical conditions of SE Spain, the yield obtained for non-irrigated vines was under 1 kg per vine, making viticulture an activity of low profitability, whereas T2 vines triplicated the yield of non-irrigated vines.

As the results show, sugar accumulation was not impaired by irrigation, as also found by Matthews and Anderson (1988), Bartolome *et al.* (1995), and García-Escudero *et al.* (1995, 1997). Indeed, sugar concentration was even higher in irrigated vines at the time of harvest in 2001. Water availability during ripening is essential for maintaining photosynthesis and ensuring sugar accumulation. Our previous studies (De la Hera Orts *et al.*, 2004) indicated that at veraison, predawn water potentials (Ψpd) in NI vines reached values of around –1.5 Mpa in 2000 and –1.2 Mpa in 2001, compared with –0.9 and –0.7 MPa in T2 vines. The low Ψpd values reached by NI vines reflected the severe water deficit that these vines were suffering. Related with the low Ψpd, large differences in the stomatal conductance and net CO_2 assimilation between irrigated and NI vines were also found, the lowest values corresponded to NI vines. In years of severe heat and drought, irrigation results in an increase in the sugar content, probably by maintaining the functional leaf area of the vines and increasing the photosynthetic activity (Morris and Cawthon, 1982; De la Hera Orts *et al.*, 2004).

However, other authors have found a delay in sugar accumulation associated with irrigation (Nadal and Arola, 1995; Calo *et al.*, 1997). The different results found in the literature may be explained by the different amount of water supplied in the experiments, and the environmental conditions in which the vine is grown. Excess water increases water flow into the berries which may result in excess berry growth (Nadal and Arola, 1995) and dilution of the sugar content (Calo *et al.*, 1997). There may also be an indirect effect of an excess irrigation on sugar concentration, which is excess vegetative growth, resulting in competition for the photoassimilates between the growing shoot tips and the berries (Bravdo *et al.*, 1985).

During ripening, acidity levels decreased more slowly in non-irrigated grapes, in fact, acidity hardly varied until the ripening period was more advanced. Our results on the evolution of titratable acidity also coincide with those of Nadal and Arola (1995). As can be seen, small differences in pH reflect large changes in titratable acidity. Esteban *et al.* (2002) observed that pH increased linearly with berry ripening while titratable acidity decreased exponentially. At the beginning, when titratable acidity is high, a decrease in titratable acidity did not bring about a substantial change in pH; as ripening advanced, the variation in pH became larger. Anyway, the pH values found in the must at maturity were high. A pH level above 3.60 increases the activity of microorganisms, lowers the color intensity of red wines, binds more SO_2 and reduces free SO_2 and adversely affects the ability of wine to age. The pH values forced us to correct the must pH at the moment of winemaking by adding potassium bitartrate.

The decrease in tartaric acid was not as intense as that of malic acid, as also found by Iacono *et al.* (1995). The decrease in titratable acidity during ripening is normally attributed to falling concentrations of malic acid because tartaric acid is considered to be unaffected (Calo *et al.*, 1997), due to its difficulty to metabolize, which is attributed to both its resistance to combustion at high temperatures and its propensity to form salts which are not easily degraded by any known enzyme. The studies of Iland (1987) showed that the tartaric acid is in the acid form at veraison; during ripening, the bitartrate and tartrate salts are formed and these salts are not very soluble. Thus, the decrease during maturity is mainly caused by the tartaric acid changing from acid to salt forms, and by a dilution effect as the berry weight increases (García-Escudero *et al.*, 1995). The loss of malic acid occurs mainly through respiration, and, as shown by the tartaric acid / malic acid ratio, this process is accentuated in non-irrigated grapes, results coincident with those of Hepner and Bravdo (1985), who stated that the loss of malic acid is enhanced in warm temperatures and with water deficits.

Another reported effect of vine irrigation corresponds to a decrease in grape anthocyanin concentration. Since the anthocyanins are synthesized in the skin, larger berry weight results in a lower skin-to-flesh ratio and thus, anthocyanins are diluted. The non significant differences in anthocyanin concentration in the must found in 2001 at the time of harvest, and the fact that the berry weight of T2 grapes was higher than that of NI grapes, could indicate that large synthesis of anthocyanins due to the improvement of physiological status could occur in irrigated grapes. In 2000, the differences found in anthocyanin concentration between irrigated grapes and non-irrigated grapes could be attributed to larger differences in berry weight than those found in year 2001.

The results showed that moderately irrigated grapes reached higher weights, thus improving yields. However, this did not impair sugar accumulation, and in 2001 even the sugar content was higher in irrigated grapes. Titratable acidity and pH were only slightly affected by irrigation. In areas with high temperatures, the final TA of grapes is usually very low due to the high catabolism of malic acid and this can be detrimental for wine quality. In our area, even with irrigation, the values of TA are low at the time of harvest so the acidity must be corrected prior to fermentation if wines with high color and stability are to be obtained.

The results of the chromatic data of wines showed that wine from non-irrigated grapes had the highest color intensity and anthocyanin content. However, such clear differences were not found for the results of the sensory analysis. Although wines from NI grapes usually obtained the highest scores in quality and intensity of color and aroma, the differences between the wines from the three treatments were small in the year 2001, demonstrating that the use of moderate water doses in semiarid regions may improve the physiological status of the vine, leading to better yields and, therefore, economic benefit with no significant loss in wine quality, especially when the lowest water doses were applied.

Acknowledgments

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