Color and Phenolic Compounds of a Young Red Wine. Influence of Wine-Making Techniques, Storage Temperature, and Length of Storage Time

E. Gómez-Plaza,*,† R. Gil-Muñoz,† J. M. López-Roca,‡ and A. Martínez†

Centro de Investigación y Desarrollo Agroalimentario, Ctra. La Alberca s/n, 30150 Murcia, Spain, and Unidad de Tecnología de los Alimentos, Facultad de Veterinaria, Universidad de Murcia, Campus de Espinardo, 30071 Murcia, Spain

The purpose of this work was to determine the influence of vinification technique (maceration temperature and clarification method), storage temperature, and length of storage time on the phenolic compounds and color of young red wines. Multivariate analysis of variance and principal component analysis pointed to significant differences among all of the variables according to vinification technique and length of storage time. Storage temperature did not cause significant differences between some of the variables. The best color characteristics were obtained when low-temperature maceration wines were clarified with polyvinylpyrrolidone. Color quality also improved with lower storage temperature.

Keywords: *Color; phenolic compounds; red wine; multivariate analysis*

INTRODUCTION

A wine's color depends on several parameters such as the grape variety, the vinification techniques used, and the numerous reactions that take place during storage (Auw et al., 1996).

The most rapid changes in color composition occur during the first year of storage (Somers and Evans, 1986), when the purple-red color, which is typical of young red wines, changes to orange-red. These changes are mainly caused by the displacement of the monomeric pigments of anthocyanins by more stable oligomeric forms. Although oxidative influences surely occur, recent studies have indicated that the principal phenolic interactions, which begin in the early stages of vinification and continue through wine storage, are essentially anaerobic, temperature being a more important influence than oxygen concentration (Somers and Pockock, 1990), a conclusion also reached by Dallas and Laureano (1994).

The effect of various vinification techniques (two different maceration temperatures and two different clarification treatments), storage temperature, and length of storage time on the color and phenolic compound content of a young red wine is studied in this paper.

The influence of vinification conditions on the evolution of a wine's color is still poorly understood (Gao et al., 1997), although it is known that the maceration temperature greatly affects the transfer of polyphenols from skins to must. Dupleiss (1973) stated that for the same contact time, an increase in maceration temperature from 15 to 35 °C may increase the polyphenol content of the must as much as 300 times.

Clarification also affects wine quality. Fining agents such as polyvinylpyrrolidone (PVPP), gelatin, or bentonite have been shown to reduce phenolic levels and alter the color and sensory characteristics of wines. Data found in the literature show that gelatin has little influence on young red wines because it affects only the colloidal compounds, whereas PVPP typically binds and removes smaller molecular weight phenolic compounds (Sims et al., 1995), and bentonite, which is a volcanic aluminum silicate clay with exchangeable cationic components, is used to reduce the protein content of wines (Main and Morris, 1991). Bentonite also absorbs polyphenol oxidase, phenols, and other positively charged molecules (Main and Morris, 1991).

Storage temperature influences pigment degradation and polymerization and is, according to Somers and Evans (1986) and Somers and Pocock (1990), the primary environmental factor that influences changes in the color characteristics of red wine. The length of storage is the other factor influencing wine color because most of the changes occurring during wine storage are time dependent (Dallas and Laureano, 1994).

The final objective of this study was to find the best conditions for elaborating and storing young red wines which could ensure that the best quality characteristics were maintained during several months of storage. Principal component analysis (PCA) was applied to check whether it was possible to differentiate the wines after 12 months of storage. In recent years, color analysis has been used to characterize wines according to browning and aging status. In this way, Heredia et al. (1997) presented a multivariate characterization of aging status in red wines based on chromatic parameters; Mayen et al. (1997) applied multivariate statistical analysis to study changes in phenolic compounds during accelerated browning in white wines, and Fernán-

* Address correspondence to this author at the Unidad de Tecnología de los Alimentos, Facultad de Veterinaria, Universidad de Murcia, Campus de Espinardo, 30071 Murcia, Spain (telephone 34-968-364707; fax 34-968-364147; e-mail encarnag@fcu.um.es).

† Centro de Investigación y Desarrollo Agroalimentario.

‡ Unidad de Tecnología de los Alimentos.

10.1021/jf9902548 CCC: $19.00
Published on Web 02/10/2000

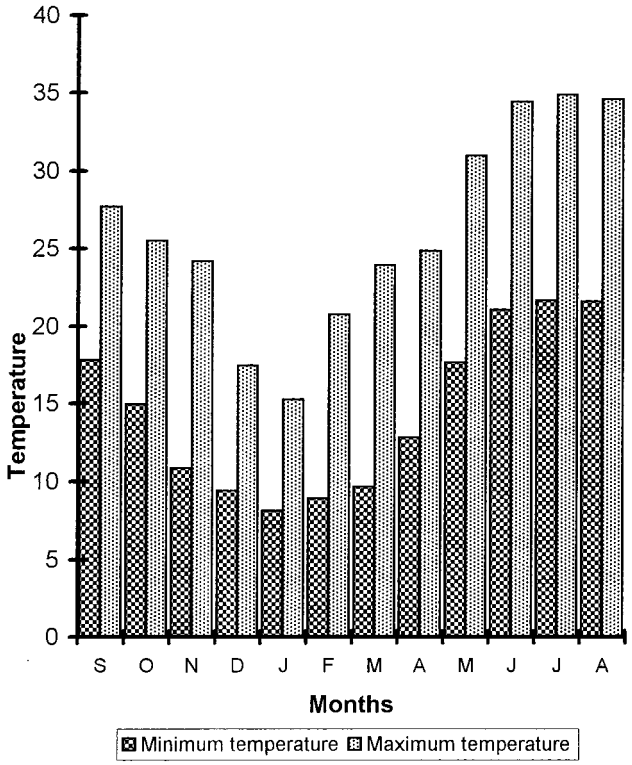

Figure 1. Monthly evolution of the maximum and minimum temperatures registered in the warehouse where wines were stored (T1).

dez-Zurbano et al. (1995) used multivariate statistical analysis to predict oxidative browning.

MATERIALS AND METHODS

Grapes from *Vitis vinifera* var. Monastrell, cultivated in Jumilla (southeastern Spain) were harvested at optimum maturity in 20 kg boxes and transported to the winery. Two different lots were prepared from these grapes. One lot was processed immediately (normal-temperature maceration, NTM) while the other lot was cooled to 10 °C (low-temperature maceration, LTM). Both lots were processed in the same way. The maceration at low temperature occurred only the first days of the vinification process. After 5 days, the temperature was the same in both musts because no attempt was made to cool the must and the fermentation reaction itself increased the must temperature.

The vinifications were carried out in a large scale experimental winery. SO_2 was added after crushing (50 mg/kg of grapes). For the clarification treatments two different fining agents were used: PVPP (Polyclar VT, Gaf Chemical Corp.) at a concentration of 45 g/100 L and a combination of bentonite plus gelatin (BG) at concentrations of 2 and 45 g/100 L, respectively. Bentonite (Volclay, Medical Colloid Co.) and gelatin (J. Laffort, San Sebastian, Spain) were previously prepared by dissolving them in water (10 g/100 mL of water at 25 °C and 5 g/100 mL of water 80 °C, respectively), during 24 h. After the fining treatments, wines were cold stabilized at −4 °C for 1 month. No selected yeasts were used. The first racking was done 1 week after alcoholic fermentation and then every 15 days.

After cold stabilization, the wines were bottled and stored in two different conditions: (i) one lot of bottles was stored in a partly open warehouse in which the bottles were subjected to the temperature variations (both daily and seasonal) as shown in Figure 1 (T1) and (ii) the other lot of bottles was stored in a cellar where temperature oscillated all year between 15 and 20 °C (T2). Wines were stored for 12 months. Samples (three bottles of each wine) were taken at the moment of bottling and then every three months.

Extraction, Identification, and Quantification of Phenolic Compounds. All analyses were made in triplicate. Fractionation of the phenolic compounds involved raising the pH of the samples to 7.0 prior to extraction with ethyl acetate, to separate neutral from acidic polyphenols (Mayén et al., 1995). For the fractionation of neutral phenolic compounds, a preconditioned C_{18} Sep-Pak cartridge (Waters Associates, Philadelphia, PA) was used according to the method of Lee and Jaworski (1987). The neutral polyphenols retained in the cartridge were eluted using 16% acetonitrile at pH 2 to collect flavan-3-ol derivatives. Because phenolic acid derivatives were not fixed in this cartridge at pH 7, another cartridge conditioned to pH 2 was used. The absorbed phenolic acids derivatives were eluted using methanol.

Anthocyanins were isolated directly from the wine by passing 2 mL of wine through a Sep-Pak cartridge previously conditioned to pH 7. Anthocyanins were eluted with 16% acetonitrile at pH 2.

Each fraction was evaporated to dryness and redissolved in 2 mL of methanol before injection into the chromatographic system.

Chromatographic Analysis. Quantification and Identification. A 25 μL aliquot of each fraction was injected into a Hewlett-Packard 1050 high-performance liquid chromatograph equipped with an UV−vis detector and quaternary pumps. The phenolic compounds were separated by a Hewlett-Packard C18 column (250 × 0.4 mm, 0.5 μm particle size). Chromatographic conditions are shown in Table 1.

The different phenolic compounds were identified and quantified by comparing their retention times with those of pure standards, when possible. Caffeoyl tartaric acid (caftaric acid) and coumaroyl tartaric acid (coutaric acid) were isolated according to the method described by Singleton et al. (1978). The anthocyanin concentration was expressed as malvidin 3-glucoside, which was isolated using the method described by Wulf and Nagel (1978). Procyanidins were identified and quantified by means of standards, donated by Dr. Santos Buelga (University of Salamanca, Spain).

Spectrophotometric Determinations. Absorbance measurements were made in a Hitachi 2000 spectrophotometer (Tokyo, Japan) with 0.2 cm path length glass cells. The samples were clean and contained no CO_2, which was eliminated by means of ultrasound and agitation.

Color density (CD) was calculated as the sum of absorbance at 520 and 420 nm and tint as the ratio between absorbance at 420 nm and absorbance at 520 nm (Sudraud, 1958).

Wine color (WC), total color of pigments (WCA), polymeric pigment color (PPC), and chemical age (CA) were calculated according to the methods of Bakker et al. (1986). WC was determined by adding 20 μL of acetaldehyde to 2 mL of wine and measuring absorbance at 520 nm after 45 min. WCA was determined by adding 9 mL of 0.1 N HCl to 1 mL of wine to obtain a pH <1 and measuring the absorbance at 520 nm after 4−5 h. PPC was determined by adding 15 mg of $NaHSO_3$ to 5 mL of wine and measuring absorbance at 520 nm after 1 min.

CA was calculated as PPC × 100/WCA. Total polyphenols (TP) were calculated using the Folin−Ciocalteu reagent and expressing the results as milligrams per liter of gallic acid.

Data Design. These investigations were carried out using an experimental design that included the following factors: vinification technique (two different maceration temperatures and two different fining agents), storage temperature, and storage length.

Statistical Data Treatment. A multivariate analysis of variance (MANOVA) was performed to study the effects of vinification, temperature, and time on all of the constituents measured in the wines. Significant differences among wines and for each variable were assessed with analysis of variance (ANOVA). These statistical analyses, together with PCA, were performed using Statgraphics 2.0 Plus.

RESULTS AND DISCUSSION

To study separately the effects of vinification, temperature, and time, the MANOVA was applied.

Table 1. Chromatographic Conditions

	phenolic acids	flavan-3-ols	anthocyanins
mobile phase	A = CH_3CN; B = AcH 2%	A = CH_3CN−HCOOH 4.5% (10:90 v/v); B = COOH 4.5%	A = CH_3CN; B = COOH 5%
flow rate (mL)	1.15	1.5	1.10
detection (nm)	280	280	520
elution program	% CH_3CN	% CH_3CN−HCOOH 4.5%	% CH_3CN
0 min	0	0	5
5 min	5	1.7	9
10 min		3.4	
15 min	5	6.6	
20 min	15	13.0	
25 min		25.5	
30 min	15	50.0	
40 min	100	100	15
50 min			20
60 min			
70 min			30
75 min			30
77 min			5

Table 2. Probability Values of Statistical Analysis for the Spectrophotometric Data

		ANOVA test ($p < 0.01$)						
effect		CA	WC	WCA	CD	tint	PPC	TP
simple effect	vinification (V)	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$
	temperature (T)	$p < 0.01$	0.080 (ns[a])	0.002	0.254 (ns)	$p < 0.01$	$p < 0.01$	0.600 (ns)
	time (t)	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$
second-order effects	V × T	$p < 0.01$	$p < 0.01$	$p < 0.01$	0.004	0.007	0.04 (ns)	0.120 (ns)
	V × t	$p < 0.01$	$p < 0.01$	$p < 0.01$	0.02 (ns)	$p < 0.01$	$p < 0.01$	0.002
	T × t	$p < 0.01$	$p < 0.01$	0.002	0.005	0.004	0.09 (ns)	0.05 (ns)

[a] ns, not significant.

Table 3. Probability Values of Statistical Analysis for the Phenolic Compounds

		ANOVA test ($p < 0.01$)										
effect		catechin	epicatechin	B4	B2	B5	caftaric	coutaric	delphidin	peonidin	petunidin	malvidin
simple effect	vinification (V)	$p < 0.01$	$p < 0.01$	0.008	0.123	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$
	temperature (T)	0.550 (ns[a])	$p < 0.01$	0.613 (ns)	$p < 0.01$	0.035 (ns)	0.004	0.014 (ns)	0.001	$p < 0.01$	0.925 (ns)	$p < 0.01$
	time (t)	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$
second-order	V × T	0.004	0.035 (ns)	0.224 (ns)	0.003	0.200 (ns)	0.005	0.741 (ns)	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$
effect	V × t	$p < 0.01$	$p < 0.01$	0.014 (ns)	0.02 (ns)	0.001	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$
	T × t	0.541 (ns)	0.008	0.354 (ns)	0.465 (ns)	$p < 0.01$	0.190 (ns)	0.015 (ns)	0.014 (ns)	0.025 (ns)	$p < 0.01$	$p < 0.01$

[a] ns, not significant.

Table 4. Mean Values of the Spectrophotometric Data (ANOVA Analysis)

		ANOVA test ($p < 0.01$)						
effect		CA	WC	WCA	CD	tint	PPC	TP
vinification	LTM-PVPP	13.20^{b}	3.92^{c}	9.65^{b}	5.39^{b}	0.77^{a}	1.17^{b}	1158.77^{ab}
	LTM-BG	13.07^{b}	3.70^{b}	9.53^{ab}	5.42^{b}	0.82^{c}	1.16^{b}	1224.44^{b}
	NTM-PVPP	12.13^{a}	3.68^{b}	9.77^{b}	5.13^{a}	0.80^{b}	1.14^{b}	1088.57^{a}
	NTM-BG	11.99^{a}	3.60^{a}	9.15^{a}	5.11^{a}	0.82^{c}	1.05^{a}	1109.89^{a}
temperature	T1	13.12^{b}	3.74^{a}	9.37^{a}	5.29^{a}	0.81^{b}	1.16^{b}	1165.13^{a}
	T2	12.08^{a}	3.71^{a}	9.68^{b}	5.24^{a}	0.80^{a}	1.10^{a}	1125.70^{a}
time	0 months	8.53^{a}	6.65^{d}	11.53^{d}	5.31^{bc}	0.77^{a}	0.90^{a}	1024.38^{ab}
	3 months	10.43^{b}	3.33^{c}	10.27^{c}	5.11^{ab}	0.78^{ab}	1.09^{b}	1305.77^{c}
	6 months	12.79^{c}	3.11^{b}	9.57^{b}	5.48^{c}	0.78^{ab}	1.19^{c}	1271.05^{c}
	9 months	14.80^{d}	2.80^{a}	8.11^{a}	5.49^{c}	0.83^{c}	1.20^{c}	1006.66^{a}
	12 months	16.44^{e}	2.74^{a}	8.15^{a}	5.92^{a}	0.86^{d}	1.26^{c}	1119.21^{b}

Tables 2 and 3 show the p values for each factor (vinification, storage temperature, and time). Significant differences were found for all of the spectrophotometric data with respect to vinification and length of storage, whereas storage temperature was not significant for WC or CD, although significant interactions were found with vinification and length of storage in these cases. With regard to the phenolic compounds, storage temperature was not significant for catechin, procyanidins B4 and B5, coutaric acid, or petunidin. These findings did not agree with the results of Somers and Pocock (1990) and Sims and Morris (1984), who found that storage temperature had a strong influence on browning and color evolution, although perhaps the difference of temperatures and the length of storage used in our experiment did not differ sufficiently for the wines to be clearly differentiated.

Influence of Vinification. The vinification technique was a source of variation when MANOVA was applied. ANOVA for the spectrophotometric data (Table 4) showed that normal-temperature maceration together with the use of bentonite plus gelatin as fining agents produced a poor wine color, with low WC, WCA, CD, and TP and high tint. On the other hand, wines produced after low-temperature maceration and clarified with PVPP resulted in more colored and less brown

Table 5. Mean Values for Phenolic Compounds (Milligrams per Liter) According to Four-Way ANOVA Analysis[a]

effect		catechin	epi-catechin	B2	B4	B5	caftaric acid	coutaric acid	delphidin	peonidin	petunidin	malvidin
vinification	LTM-PVPP	6.32[b]	2.82[c]	3.02[a]	2.20[a]	2.49[a]	154.05[d]	131.55[d]	14.52[b]	24.59[c]	25.21[b]	153.94[b]
	LTM-BG	4.96[a]	2.38[b]	3.38[a]	2.42[a]	2.96[b]	125.43[c]	94.96[c]	14.60[b]	22.73[b]	26.89[c]	152.49[b]
	NTM-PVPP	5.93[b]	3.02[c]	3.21[a]	2.35[a]	2.61[ab]	109.10[b]	73.60[a]	13.29[a]	20.82[a]	24.49[b]	154.14[b]
	NTM-BG	7.14[c]	2.02[a]	3.05[a]	2.40[a]	2.38[a]	99.96[a]	82.89[b]	13.50[a]	20.03[a]	22.72[a]	141.49[a]
temperature	T1	6.13[a]	2.77[b]	2.97[a]	2.33[a]	2.51[a]	125.04[b]	98.11[a]	13.69[a]	22.68[b]	24.84[a]	154.17[b]
	T2	6.05[a]	2.41[a]	3.38[a]	2.35[a]	2.71[a]	119.25[a]	93.39[b]	14.26[b]	21.40[a]	24.81[a]	146.86[a]
time	0 months	11.88[e]	4.96[d]	0.00	0.00	0.00	165.33[e]	169.66[e]	20.93[e]	31.13[e]	36.25[e]	220.43[e]
	3 months	6.07[d]	3.23[c]	2.65[a]	2.15[a]	2.43[a]	131.09[d]	107.39[d]	14.34[d]	24.23[d]	26.86[d]	162.20[d]
	6 months	5.09[c]	2.28[b]	3.03[a]	2.25[a]	2.52[a]	120.46[c]	85.85[c]	12.81[c]	21.10[c]	23.90[c]	143.69[c]
	9 months	4.27[b]	1.32[a]	3.96[b]	2.70[b]	3.05[b]	103.57[b]	65.83[b]	11.41[b]	18.70[b]	19.38[b]	125.37[b]
	12 months	3.14[a]	1.01[a]	3.05[a]	2.27[a]	2.45[a]	90.28[a]	50.03[a]	10.41[a]	15.04[a]	17.75[a]	100.88[a]

wines. In a previous work (Gil-Muñoz et al., 1997) we found that wines prior to bottling already showed some differences in color characteristics depending on the vinification technique used and especially depending on the clarification method. Wines clarified with PVPP had higher WC and WCA and lower tint value at the moment of bottling. Less pronounced differences were found for the maceration temperature. Although it might be expected that maceration at low temperatue would promote more differences in color characteristics of wine, Gil-Muñoz et al. (1997) showed that grape temperature strongly affected the rate of phenolic compound extraction during the first days of alcoholic fermentation. After that, the fermentation process itself raised the temperature of the must, and the differences became much less pronounced as vinification progressed.

With regard to the phenolic compounds, data consistent with the spectrophotometric results were found (Table 5). Thus, wines elaborated after maceration at normal temperature and clarified with bentonite and gelatin had the lowest anthocyanin and hydroxycinnamic acid derivatives concentrations, whereas high concentrations of catechin, which are correlated to browning (Moutounet et al., 1988), were found. The formation of anthocyanins−catechin polymeric compounds stabilizes and improves wine color, but if there are high concentrations of monomeric flavan-3-ols, which will not participate in the formation of polymeric compounds, then poor-quality color (low anthocyanin content) and browning effects (high catechin levels) will occur.

Low-temperature maceration wines produced wines with a high content of anthocyanin and hydroxycinnamic acid derivatives. Caftaric and coutaric acids are easily oxidized during maceration because they are the principal substrates for polyphenol oxidase enzyme. The lower maceration temperature probably afforded these compounds a certain protection. Caftaric acid is known to be responsible for the initiation of enzymatic browning in must; however, it does not seem to have such a marked effect on chemical browning (Mayen et al., 1997). Fernandez-Zurbano et al. (1995) stated that all hydroxycinnamic acid derivatives showed a low correlation to chemical browning.

Influence of Storage Temperature. Several of the parameters studied were not affected by the storage temperature (WC, CD, and TP), whereas those parameters affected by temperature behaved as was to be expected: higher temperature led to wines with higher CA, tint, and PPC, that is, more polymerized wines, and with lower WCA.

Catechin, procyanidins, and petunidin were not affected by temperature. Epicatechin and caftaric and coutaric acid were higher at T1 as well as peonidin and malvidin.

Table 6. Percent of Variance Explained by the First Six Principal Components

component	eigenvalue	% of variance	cumulative %
1	5.84	32.47	32.47
2	3.27	18.21	50.68
3	2.06	11.45	62.13
4	1.59	8.84	70.97
5	1.14	6.37	77.35
6	1.05	5.88	83.24

Influence of Length of Storage Time. WC and WCA suffered a strong decrease with time. Bakker et al. (1993) found that all model solutions containing anthocyanins exhibited a logarithmic decrease in total anthocyanins during storage, together with a hypsochromic change in λ_{max}. With regard to the phenolic compounds, the evolution of anthocyanins was consistent with the spectrophotometric data, their concentration falling during storage. Catechin and epicatechin also disminished with time. These substances may suffer oxidations and polymerizations (Singleton, 1980) and be involved in the formation, through Baeyer-type condensations, of polymeric compounds together with anthocyanins (Timberlake and Bridle, 1977).

CD levels decreased from 0 to 3 months but increased from 3 to 12 months. The formation of anthocyanin−acetaldehyde−catechin polymers produces highly colored intermediates with an increase in the maximum of absorbance (Timberlake and Bridle, 1977; Bakker et al., 1993). CA and PPC increased as did tint. All three data are related with polymeric compounds, and they are known to increase with time. CA measures the relation between monomer compounds and polymeric compounds and PPC the polymeric compounds, those that are not discolored by SO_2. Hydroxycinnamic esters markedly decreased with time.

PCA. PCA, which was applied to the data of the wines after 12 months of storage, permitted a clear differentiation among samples with regard to their color quality.

Reliable statistical analysis results require variance in the data, and therefore the initial data set should be checked for constant and redundant variables before multivariable techniques are attempted. We checked the variables with high correlation coefficient values, obtained from the pooled within matrix. Because only coefficients close to 1.00 can be considered equivalent or redundant, the variance of our data was tested.

Table 6 despicts the cumulative percentage of the total variance explained by the first six principal components (those having eigenvalues >1.00). The first two factors retained 50% of the variance. The contribu-

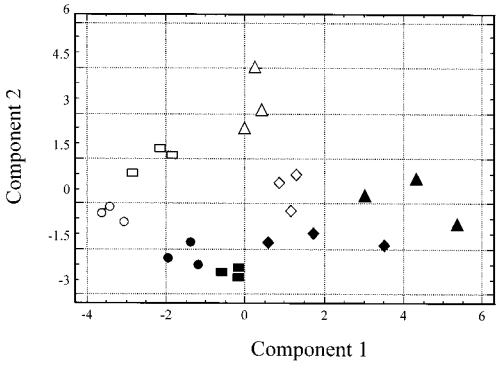

Figure 2. Distribution of wines in the two-dimensional coordinate system defined by the first two principal components: (▲) LTM-PVPP-T1; (△) LTM-PVPP-T2; (◆) LTM-BG-T1; (◇) LTM-BG-T2; (■) NTM-PVPP-T1; (□) NTM-PVPP-T2; (●) NTM-BG-T1; (□) NTM-BG-T2.

Table 7. Component Weights

	component 1	component 2
CA	0.336	−0.148
WC	0.062	0.451
WCA	−0.240	0.321
CD	0.390	0.076
tint	−0.092	−0.408
PPC	0.357	−0.040
TP	0.084	0.284
catechin	−0.098	0.226
epicatechin	0.109	0.033
B2	−0.031	0.136
B4	−0.133	−0.144
B5	−0.013	0.040
caftaric acid	0.303	0.250
coutaric acid	0.200	0.350
delphidin	0.232	0.170
peonidin	0.313	−0.051
petunidin	0.328	−0.197
malvidin	0.309	−0.256

tion of the variables of the first two principal components is shown in Table 7. CD, TP, CA, and anthocyanins were the variables that contributed mostly to the positive first axis, whereas WC was the one that contributed mostly to the positive and tint to the negative second axis.

Some grouping could be observed in the space formed by the two first components (Figure 2). Low-temperature maceration wines were located in the positive part of PC1, whereas normal-temperature maceration wines were located in the negative part. The higher CD and anthocyanin content of low-temperature maceration may lead to more evolved wines with, probably, greater color stability.

Also, some differences regarding storage temperature could be observed. T2 wines were mainly found in the positive part of PC2 and T1 wines in the negative; negative values in PC2 are closely related with high tint values.

Conclusions. Vinification technique and length of storage time were the main factors influencing the color and phenolic compounds in wines. Some of the variables showed no temperature-related variations, probably because the storage temperatures were not extreme or sufficiently different to create any clear differentiation between wines. However, PCA did allow us to differentiate among wines to a certain extent, according to storage temperature. T1 wines were mainly located in the negative axis of PC2, where the weight of the variable tint was very high.

To obtain young red wines with the best color characteristics which will last during storage, the most suitable vinification conditions involve the use of low-temperature maceration and PVPP as fining agent and storage temperatures <20 °C.

ABBREVIATIONS USED

LTM-PVPP, low-temperature maceration wine, clarified with PVPP; LTM-BG, low-temperature maceration wine, clarified with bentonite and gelatin; NTM-PVPP, normal-temperature maceration wine, clarified with PVPP; NTM-BG, normal-temperature maceration wine, clarified with bentonite and gelatin; CD, color density; WC, wine color; WCA, total color pigments; PPC, polymeric pigment color; CA, color age; TP, total polyphenols; MANOVA, multivariate analysis of variance; ANOVA, analysis of variance; PCA, principal component analysis.

ACKNOWLEDGMENT

We are grateful to Dr. Santos-Buelga and Dr. Rivas-Gonzalo for supplying the procyanidin standards.

LITERATURE CITED

Auw, J. M.; Blanco, V.; O'Keefe, S. F.; Sims, C. A. Effect of processing on the phenolics and color of Cabernet Sauvignon, Chambourcin and Noble wines and juices. *Am. J. Enol. Vitic.* **1996**, *47*, 279−286.

Bakker, J.; Preston, N.; Timberlake, C. The determination of anthocyanins in aging red wines: comparison of HPLC and spectral methods. *Am. J. Enol. Vitic.* **1986**, *37*, 121−126.

Bakker, J.; Picinelli, A.; Bridle, P. Model wine solutions: colour and composition changes during aging. *Vitis* **1993**, *32*, 111−118.

Dallas, C.; Laureano, O. Effects of pH, sulphur dioxide, alcohol content, temperature and storage time on colour composition of a young portuguese red table wine. *J. Sci. Food Agric.* **1994**, *65*, 477−485.

Du Pleissis, C. S. Browining of white wines. *Die Wynboer* **1973**, *499*, 11−13.

Fernández-Zurbano, P.; Ferreira, V.; Peña, C.; Escudero, A.; Serrano, F.; Cacho, J. Prediction of oxidative browning in white wines as a function of their chemical composition. *J. Agric. Food Chem.* **1995**, *43*, 2813−2817.

Gao, L.; Girard, B.; Mazza, G.; Reynolds, A. Changes in anthocyanins and color characteristics of Pinot Noir wines during different vinification processes. *J. Agric. Food Chem.* **1997**, *45*, 2003−2008.

Gil-Muñoz, R.; Gómez-Plaza, E.; Martínez, A.; López-Roca, J. M. Evolution of the CIELAB and other spectrophotometric parameters during wine fermentation. Influence of some pre and postfermentative factors. *Food Res. Int.* **1997**, *39*, 699−705.

Heredia, F. J.; Troncoso, A. M.; Guzmán-Chozas, M. Multivariate characterization of aging status in red wines based on chromatic parameters. *Food Chem.* **1997**, *60*, 103−108.

Lee, C.; Jaworsky, A. Phenolic compounds in white grapes in New York. *Am. J. Enol. Vitic.* **1987**, *38*, 277−281.

Main, G.; Morris, J. Color of Riesling and Vidal wines as affected by bentonite, cufex and sulfur dioxide juice treatments. *Am. J. Enol. Vitic.* **1991**, *42*, 354−357.

Mayen, M.; Merida, J.; Medina, M. Flavonoid and non-flavonoid compounds during fermentation and post-fermentation standing of musts from Cabernet Sauvignon and Tempranillo grapes. *Am. J. Enol. Vitic.* **1995**, *46*, 255−261.

Mayén, M.; Barón, R.; Mérida, J.; Medina, M. Changes in phenolic compounds during accelerated browning in white wines from cv. Pedro Ximenez and cv. Baladi grapes. *Food Chem.* **1997**, *58*, 89−95.

Moutounet, M.; Cheynier, V.; Rigaud, J.; Souquet, J. M. Flavonoides et dérivés hydroxycinnamiques des vins blancs. *Bull. Liason Groupe Polyphenols* **1988**, *14*, 355−356.

Sims, C.; Eastridge, J.; Bates, R. Changes in phenols, color and sensory characteristics of Muscadine wines by pre- and post-fermentation additions of PVPP, casein and gelatin. *Am. J. Enol. Vitic.* **1995**, *46*, 155−158.

Singleton, V. L. Grape and wine phenolics; background and prospects. In *Proceedings of the University of California, Davis, Grape and Wine Centennial Symposium*; Weeb, A. D., Ed.; University of California Press: Berkeley, CA, 1980.

Singleton, V.; Timberlake, C.; Lea, A. The phenolic cinnamates of white grapes and wine. *J. Sci. Food Agric.* **1978**, *29*, 403−410.

Sommers, T. C.; Evans, M. E. Evolution of red wines. Ambient influences on color composition during early maturation. *Vitis* **1986**, *25*, 31−39.

Somers, T.; Pocock, K. Evolution of red wines. III. Promotion of the maturation phase. *Vitis* **1990**, *29*, 109−121.

Sudraud, P. Interpretation des courbes d'absortion des vins rouges. *An. Technol. Agric.* **1958**, *7*, 203−208.

Timberlake, C.; Bridle, P. Anthocyanins colour augmentation with catechin and acetaldehyde. *J. Sci. Food Agric.* **1977**, *28*, 539−544.

Wulf, L.; Nagel, C. W. High-pressure liquid chromatographic separation of anthocyanins. *Am. J. Enol. Vitic.* **1978**, *29*, 42−49.

Received for review March 3, 1999. Revised manuscript received December 2, 1999. Accepted December 6, 1999. Financial support from the Fundación Séneca (Comunidad Autónoma de Murcia) for the realization of this work is gratefully acknowledged.

JF9902548