Available online at www.sciencedirect.com
SCIENCE DIRECT®
Food Chemistry 86 (2004) 413–419
Food Chemistry
www.elsevier.com/locate/foodchem

Effect of vineyard yield on the composition of sparkling wines produced from the grape cultivar Parellada

M.A. Pozo-Bayón, M.C. Polo, P.J. Martín-Álvarez, E. Pueyo *

Instituto de Fermentaciones Industriales (CSIC), Juan de la Cierva 3, 28006 Madrid, Spain

Received 4 April 2003; received in revised form 16 September 2003; accepted 16 September 2003

Abstract

The influence of vineyard yield on the phenolic, volatile and nitrogen compounds, on the foam characteristics and on the sensory quality of sparkling wines made from grapes of the Parellada variety was studied. Sixteen sparkling wines were manufactured industrially from four base wines. Two of the base wines were manufactured with grapes from a low-yielding vineyard, below 10,500 kg/ha, and the other two with grapes from a higher-yielding vineyard, above 10,500 kg/ha. Significant differences were found, in relation to vineyard yield, for the concentrations of 9 of the 16 phenolic compounds determined, in most of the volatile compounds and in several free amino acids. No significant differences were detected between foam characteristics of wines from low- and high-yield vineyards. The wines from low-yield vineyards were considered, by the tasters, to have better sensory quality than the wines from high-yield vineyards.

Keywords: Vineyard yield; Sparkling wines; Phenolic compounds; Nitrogen compounds; Volatile compounds; Sensory analysis

1. Introduction

Grape quality is one of the factors with the largest influence on wine quality. Its composition depends on the variety, climatic conditions, soil, and cultivation techniques used (Dirninger et al., 1998; Giorgessi, Calò, Sansone, Serra, & Tomasi, 1999; Jackson & Lombard, 1993; Jones & Davis, 2000; Peterlunger et al., 2002). In an attempt to increase the production, cultivation techniques are sometimes used that favour the increase of the vineyard yield. However, these techniques can cause detriment to the grape quality. Some studies have reported reduced grape maturity and impaired grape colour in grapes from vineyards with a high yield (Antonacci & La Notte, 1993) while others did not report these effects so clearly (Ewart, Brien, Soderlund, & Smart, 1985; Riu-Aumatell, López-Barajas, López-Tamames, & Buxaderas, 2002). In some countries, especially in Europe, the legislation specifies an upper limit for vineyard yields if the manufactured wines are to be included in the respective Designations of Origin or Quality. This is the case for *cavas*, sparkling wines manufactured by traditional methods in some Spanish regions in which, not only the grape varieties authorised for wine production are regulated, but also vineyard yield.

Most studies on the relationship between vineyard yield and wine quality have been carried out using Brix, pH and colour as parameters of quality since these are usually aimed at studying grapes for use in the manufacture of red wines. However, it is also necessary to know the influence of vineyard yield on other parameters directly related to the quality of the wines (De Garis, Holzapfel, Rogiers, & Small, 2000). Very few studies exist on the influence of vineyard yield on the quality of white wines and there are no published studies, to date, about how this factor affects the quality of sparkling wines. Therefore, the aim of this research is to detect possible differences in the composition and

* Corresponding author. Fax: +34-91-564-48-53.
E-mail address: epueyo@ifi.csic.es (E. Pueyo).

0308-8146/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2003.09.016

quality of sparkling wines manufactured with grapes of the Parellada variety, the most valued of the ones authorised in Spain to manufacture sparkling wines by the traditional method (*cavas*), proceeding from vineyards with different yields. With this aim, sparkling wines were made from base wines proceeding from grapes cultivated in vineyards with different yields. The main enological parameters, the phenolic, volatile and nitrogen compounds, the foam characteristics and the sensory quality, have been determined. Analysis of variance and multivariate statistical techniques were applied to the data obtained.

2. Materials and methods

2.1. Wine samples

Four base wines were manufactured in one wine cellar from the Penedés region (Catalonia, Spain) and, under identical conditions, two from grapes from traditional low-yield vineyards in the region (between 6000 and 10,500 kg/ha) and the other two from vineyards submitted to cultivation practices aimed at obtaining higher yields (between 10,500 and 17,000 kg/ha). From these four base wines, and under identical conditions, 16 sparkling wines were obtained, 4 of each base wine, with aging times from 9 to 18 months. Nine months is the minimum aging time required for a wine to be classifiable as a *cava.* Since manufacture of the sparkling wines takes place in individual bottles, two bottles of each kind of wine were mixed and homogenized before sampling.

The sparkling wines from base wines of higher-yield vineyards had an average alcohol content of 10.9 g, 0.34 g acetic acid/l (volatile acidity), 3.36 g tartaric acid/l (total acidity) and a pH of 3.3. In these wines, malolactic fermentation took place. The sparkling wines from base wines, proceeding from lower- yielding vineyards, had a mean alcohol content of 10.6 g, 0.13 g acetic acid/l (volatile acidity), 3.64 g tartaric acid/l (total acidity) and a pH of 3.1. Malolactic fermentation did not take place in these wines.

2.2. Determination of phenolic compounds

Phenolic compounds were analysed by high performance liquid chromatography (HPLC) of the extract obtained with diethyl ether and ethyl acetate, following the method described by Peña-Neira, Hernández, García-Vallejo, Estrella, and Suárez (2000). Identification was done by comparing the retention times with those of standard compounds, by the spectral parameters and by mass spectrometry, as indicated in Pozo-Bayón, Hernández, Martín-Álvarez, and Polo (2003).

2.3. Volatile analysis

Analysis of the major volatile compounds was performed by direct injection on a gas chromatograph under the following conditions: Carbowax 20M fused-silica capillary column (30 m $\times$ 0.25 mm ID), coated with a stationary phase of 0.25 μm of thickness (Quadrex, New Haven, USA); split/splitless injector; FID detector; injector and detector temperatures were 220 °C. The initial oven temperature was 40 °C (10 min hold). The temperature gradient was 7–150 °C/min, 30–210 °C/min (2 min hold). The carrier gas was helium (12.5 psi, split 1/15). The compounds determined by this method were: acetaldehyde, ethyl formate, ethyl acetate, methanol, 1-propanol, isobutanol, 2-methyl-1-butanol, 3-methyl-1-butanol and ethyl lactate.

Minor volatile analysis was carried out by gas chromatography (GC) of the head space extract obtained with a 100 μm polydimethylsiloxane (PDMS)-coated fused silica fibre (Supelco, Bellefonte, PA, USA), under the conditions described by Pozo-Bayón, Pueyo, Martín-Álvarez, and Polo (2001). The compounds determined by this method were: 1-hexanol, *cis* -3-hexen-1-ol, isobutyl acetate, isopentyl acetate, hexyl acetate, butyl acetate, ethyl butyrate, ethyl hexanoate, ethyl octanoate, ethyl decanoate, diethyl succinate, hexanoic acid, octanoic acid, decanoic acid and γ-butyrolactone

2.4. Determination of nitrogen compounds

Total nitrogen was determined by the Kjeldahl method with a Tecator Digestion System and a Kjeltec 1030 Auto Analyzer (Tecator AB, Höganäs, Sweden). Free amino acids were determined by HPLC of the derivatives with *o*-phthaldialdehyde under the conditions described by González de Llano (1991). Protein content was determined by the Bradford dye-binding assay (Bradford, 1976).

2.5. Analysis of foam characteristics

For the analysis of the foam characteristics of the wines, equipment developed in the Instituto de Fermentaciones Industriales was used, based on the measurement of the increase in height occurring in a liquid when air is passed through it. The change in the height of the liquid was quantified by means of an emitter-detector of ultrasound waves. The feeding valve to the measurement tube was controlled, and the data gathered, by a personal computer, using software that displays the changes in foam height during experimentation on a screen and stores the data in files for later analysis. The parameter determined was *Plateau H*, the height at which the foam stabilizes. The methodology used has been described by Moreno-Arribas, Pueyo, Nieto, Martín-álvarez, and Polo (2000).

2.6. Sensory analysis

A panel of experts comprising 10 tasters carried out sensory evaluation of the nine-month old wines. The tasting card used was that used by the Instituto Nacional de Denominaciones de Calidad, of the Spanish Ministry of Agriculture, Fisheries and Food. The scores used are penalizing scores, and so better quality wines receive a lower score. The different parameters carry different weight. Visual aspect carries a weight of 1, with a scale from 1 to 9, intensity and quality of aroma and intensity of taste carry a weight of 2, with a scale from 0 to 18, and quality of taste and harmony carry a weight of 3, with a scale from 0 to 27. In evaluation of the visual aspect, special attention was paid, not only to the colour, but also to the observation of foam characteristics, which many consumers consider to be one of the most important characteristics of a sparkling wine. The final scores were reported as the average of the scores of each taster after eliminating those that differed by more than one standard deviation compared to the sample's mean value. The wines were tested individually and not comparatively.

2.7. Statistical analysis

The statistical methods used for the data analysis were: two-way analysis of variance (ANOVA) to test the effect of two factors studied (vineyard yield and aging time) and principal component analysis (PCA) to examine the relationships among the variables. The STATISTICA programme for Windows, version 5.1. (STATISTICA, 1998) was used for data processing. This programme was run on a personal computer.

3. Results and discussion

3.1. Composition of the wines

The results obtained by applying two-way ANOVA to test the significant main effects of the two factors (the interaction and the within-error terms were pooled) revealed that no significant differences existed in most of the compounds determined, due to the aging time factor. For this reason, in order to summarize the results obtained from the individual data of the analysed compounds in the wines, Table 1 shows the mean ± the standard deviation of the data grouped as a function of the vineyard yield, high or low, from which they had come.

Significant differences were not detected in the mean values of the concentrations of any phenolic compound due to different aging times with the yeasts, in agreement with the results reported by Pozo-Bayón et al. (2003). Significant differences were found between the mean values of 9 of the 16 phenolic compounds detected, dues to the vineyard yield (Table 1). The concentrations of most of the phenolic compounds were higher in wines from vineyards with a high yield than in those with a low yield. Significant differences, in relation to vineyard yield were in mean values of gallic acid, *trans*-caffeic, *cis* and *trans*-*p*-coumaric, *cis* and *trans*-caftaric, *cis*-coutaric, *cis*-resveratrol and its glucosylated form. Vanillic and syringic acids, *cis*-fertaric acid and catechin were not detected in any of the wines.

The aging time factor significantly affects only 6 of the 20 volatile compounds detected: 1-propanol, isobutanol, 2-methyl-1-butanol, 3-methyl-1-butanol, ethyl acetate and diethyl succinate. There were significant differences in the mean values of most of the volatile compounds of the wines in relation to vineyard yield (Table 1). In wines from vineyards with a high yield, malolactic fermentation took place spontaneously. It is known (Davis, Wibowo, Eschenbruch, Lee, & Fleet, 1985) that the concentrations of ethyl lactate and acetate increase in this process. Therefore, the differences detected between these two esters, in both groups of wines, could be due to malolactic fermentation and not to the difference in yield of the vineyard where the grapes were produced. The contents of the alcohols methanol, 1-propanol and isobutanol were higher in wines from vineyards of higher yield. However, the content of the alcohols 3-methyl-1-butanol, 1-hexanol and *cis* -3-hexen-1-ol, of the esters isopentyl and hexyl acetate, ethyl butanoate and hexanoate, of hexanoic and decanoic acids and of acetaldehyde, were higher in wines from low-yielding vineyards. Several authors have reported higher concentrations of the esters ethyl butanoate and hexanoate and isopentyl and hexyl acetates in wines from low-yielding vineyards (Jackson & Lombard, 1993) as is the case for these wines. These compounds have an important effect on wine aroma (Ferreira, Fernández, Peña, Escudero, & Cacho, 1995; Lambrechts & Pretorius, 2000), contributing to the flowery and fruity flavours. Since malolactic fermentation took place spontaneously in wines from high-yield vineyards, no conclusion was possible about which factor, either vineyard yield or malolactic fermentation development, would have a higher impact on the changes found in most volatile compounds.

The aging time factor significantly affected ($p < 0.05$) the total nitrogen content while the vineyard yield factor did not affect this content (Table 1). No significant differences were found between the mean protein contents of the wines due to the aging time or the vineyard yield. Riu-Aumatell et al. (2002) found significant differences in the protein contents of Parellada grape juices from low- and high-yielding vineyards. The discrepancy among the results obtained on grape juices and on wines could be related to the changes that occur in proteins during vinification. The mean values of the free amino acids of the wines with different aging times were not

Table 1
Mean ± SD values of phenolic, volatile and nitrogen compounds (mg/l) and of foam characteristics (mV) in sparkling wines, and results of two-way analysis of variance when the interaction and the within-error terms were pooled

	Factor effects		Low yield (<10,500) ($n = 8$)	High yield (>10,500) ($n = 8$)
	Time	Yield	Mean ± SD	Mean ± SD
Phenolic compounds				
Gallic acid	n.s	**	0.29 ± 0.112	0.63 ± 0.178
Protocatechuic acid	n.s	n.s	0.50 ± 0.184	0.54 ± 0.063
p-Hydroxybenzoic acid	n.s	n.s	0.14 ± 0.059	0.16 ± 0.036
Vanillic acid	–	–	n.d	n.d
Syringic acid	–	–	n.d	n.d
trans-Caffeic acid	n.s	***	0.74 ± 0.178	1.29 ± 0.219
trans-*p*-Coumaric acid	n.s	***	0.22 ± 0.057	0.50 ± 0.082
cis-*p*-Coumaric acid	n.s	***	0.27 ± 0.081	0.49 ± 0.082
cis-Caftaric acid	n.s	*	1.57 ± 0.433	1.04 ± 0.285
trans-Caftaric acid	n.s	***	34.0 ± 5.54	14.0 ± 4.80
cis-Coutaric acid	n.s	***	5.02 ± 1.16	7.40 ± 0.847
trans-Coutaric acid	n.s	n.s	2.31 ± 0.549	2.20 ± 0.335
cis-Fertaric acid	–	–	n.d	n.d
trans-Fertaric acid	n.s	n.s	0.31 ± 0.047	0.29 ± 0.037
trans-Resveratrol glucoside	n.s	n.s	0.22 ± 0.094	0.28 ± 0.109
cis-Resveratrol glucoside	n.s	***	0.23 ± 0.067	0.57 ± 0.145
cis-Resveratrol	n.s	*	0.10 ± 0.064	0.20 ± 0.067
Catechine	–	–	n.d	n.d
Tyrosol	n.s	n.s	10.7 ± 2.35	10.6 ± 2.08
Tryptophol	n.s	n.s	1.54 ± 0.483	1.53 ± 0.349
Volatile compounds				
Methanol	n.s	***	30.0 ± 5.65	40.2 ± 5.40
1-Propanol	**	***	19.0 ± 2.39	26.0 ± 2.97
Isobutanol	*	***	26.8 ± 1.70	61.8 ± 5.09
2-Methyl-1-butanol	*	n.s	24.9 ± 5.12	22.2 ± 2.37
3-Methyl-1-butanol	*	***	137 ± 9.67	109 ± 5.57
1-Hexanol	n.s	*	1.75 ± 0.706	1.00 ± 0.561
cis -3-hexen-1-ol	n.s	*	1.18 ± 0.602	0.43 ± 0.260
Ethyl formate	–	–	n.d	n.d
Ethyl acetate	*	***	22.2 ± 2.29	41.9 ± 14.8
Isobutyl acetate	–	–	n.d	n.d
Isopenthyl acetate	n.s	**	0.42 ± 0.152	0.17 ± 0.087
Hexyl acetate	n.s	***	0.04 ± 0.018	0.01 ± 0.002
Butyl acetate	–	–	n.d	n.d
Ethyl butyrate	n.s	*	0.44 ± 0.165	0.16 ± 1.18
Ethyl hexanoate	n.s	*	1.19 ± 0.349	0.85 ± 0.205
Ethyl lactate	n.s	***	39.1 ± 19.8	135 ± 24.5
Ethyl octanoate	n.s	n.s	0.88 ± 0.699	0.93 ± 0.328
Ethyl decanoate	n.s	n.s	0.27 ± 0.252	0.26 ± 0.117
Diethyl succinate	**	n.s	9.87 ± 5.02	9.71 ± 6.16
Hexanoic acid	n.s	**	9.64 ± 4.42	3.85 ± 1.28
Octanoic acid	n.s	n.s	12.5 ± 4.65	9.81 ± 3.06
Decanoic acid	n.s	**	2.45 ± 1.02	1.18 ± 0.199
Acetaldehyde	n.s	***	69.4 ± 17.1	41.1 ± 6.94
γ-Butyrolactone	n.s	–	n.d	n.d
Nitrogen compounds				
Total nitrogen	*	n.s	177 ± 11.538	169 ± 8.65
Protein (mg BSA/L)	n.s	n.s	4.50 ± 1.10	5.73 ± 1.94
Asp	n.s	n.s	13.0 ± 2.73	13.2 ± 1.78
Glu	n.s	n.s	25.80 ± 2.52	25.2 ± 4.43
Asn	n.s	n.s	14.80 ± 2.09	17.5 ± 2.93
Ser	n.s	n.s	5.46 ± 0.811	6.25 ± 0.725
Gln	–	–	n.d	n.d
Hys	n.s	n.s	9.59 ± 1.64	10.9 ± 3.55
Gly	n.s	n.s	14 ± 1.82	14.3 ± 1.48
Thr	n.s	**	3.98 ± 0.969	5.56 ± 0.774
Arg	n.s	n.s	5.65 ± 1.135	6.59 ± 0.822
β-Ala	–	–	n.d	n.d

Table 1 (*continued*)

	Factor effects		Low yield (<10,500) ($n = 8$)	High yield (>10,500) ($n = 8$)
	Time	Yield	Mean ± SD	Mean ± SD
α-Ala	n.s	***	16.9 ± 0.945	27.6 ± 1.90
GABA[a]	n.s	*	14.5 ± 1.66	17.9 ± 2.95
Tyr	n.s	n.s	15.7 ± 2.85	14.4 ± 1.8
α-Aba	n.s	***	9.16 ± 1.49	14.0 ± 1.06
Met	n.s	*	2.64 ± 0.687	3.39 ± 0.651
Val	n.s	n.s	12.4 ± 1.53	11.6 ± 0.975
Trp	–	–	n.d	n.d
Phe	n.s	*	15.6 ± 1.74	13.9 ± 1.11
Ile	n.s	n.s	5.65 ± 0.911	5.50 ± 0.528
Leu	n.s	n.s	18.7 ± 2.25	15.5 ± 5.38
Orn	n.s	n.s	9.16 ± 3.55	8.59 ± 9.35
Lys	n.s	n.s	25.2 ± 3.54	27.0 ± 3.28
Sum of the free amino acids	n.s	n.s	238 ± 25.8	259 ± 17.8
Foam characteristics				
H plateau (n = 5)	n.s	n.s	319 ± 67.7	386 ± 28.3

n.s., not significant differences; n.d., not detected.
* Significant differences ($p < 0.05$).
** Significant differences ($p < 0.01$).
*** Significant differences ($p < 0.001$).
[a] GABA, γ-aminobutyric acid.

significantly different. Neither were different the mean values of most of the free amino acids of the wines coming from grapes grown in vineyards of high or low yield. The content of the amino acids threonine, α-alanine, γ- and α-aminobutyric acids, and methionine were lower in wines from low-yielding vineyards and the phenylalanine content was higher in these wines.

Also, Table 1 shows the mean values of the foam characteristics of 5 wines from each of the groups. No significant differences were detected between the mean values of *Plateau H* of wines from low- and high-yield vineyards or from wines with different aging times. These results agree with the lack of significant differences detected between protein contents of the wines since these compounds have a large influence on the foam characteristics of sparkling wines (Martínez-Rodríguez & Polo, 2003).

3.2. Principal component analysis

Applying principal component analysis to the phenolic compounds, to the volatile compounds and to the nitrogen compounds data, two clearly different groups were obtained: wines from low-yield vineyards and wines from high-yield vineyards. Figs. 1(a)–(c) show the representations of wines as a function of the first two principal components using data of phenolic, volatile and nitrogen compounds, respectively. In the case of phenolic compounds (Fig. 1(a)), the first principal component, that separates the high- and low-yield wines, has a higher and negative correlation with *cis* and *trans*-coumaric acids (−0.949 and −0.943, respectively), with *cis*-coutaric acid (−0.914) and with *cis*-resveratrol glucoside (−0.913) that have significantly higher values in wines from high-yield vineyards (Table 1). The second principal component is more closely related, also negatively, with the tyrosol (−0.802) and tryptophol contents (−0.748).

In Fig. 1(b), the 16 wines are represented in relation to the first two principal components by applying principal component analysis to the volatile compounds data. The first principal component that, as in the case of phenolic compounds, separates the wines from low and high yielding vineyards, is highly and positively related to 3-methyl-1-butanol (0.924), acetaldehyde (0.817) and *cis*-3-hexen-1-ol (0.793) contents and negatively with isobutanol (−0.913). The second principal component is more closely and positively related to ethyl decanoate (0.956) and octanoate (0.796) and also to diethyl succinate (0.778).

Fig. 1(c) represents the wines in the plane defined by the first two principal components when principal components analysis is applied to free amino acid data. The first principal component is more closely related to the sum of the free amino acids (0.949), the lysine content (0.843) and the α-amino butyric acid content (0.761). The second principal component, that separates wines from the high- and low-yield vineyards, is related to the phenylalanine (0.878), valine (0.780) and tyrosine contents (0.778).

3.3. Sensory analysis

Sensory analysis was carried out on the four nine-month old sparkling wines. Nine months is the minimum

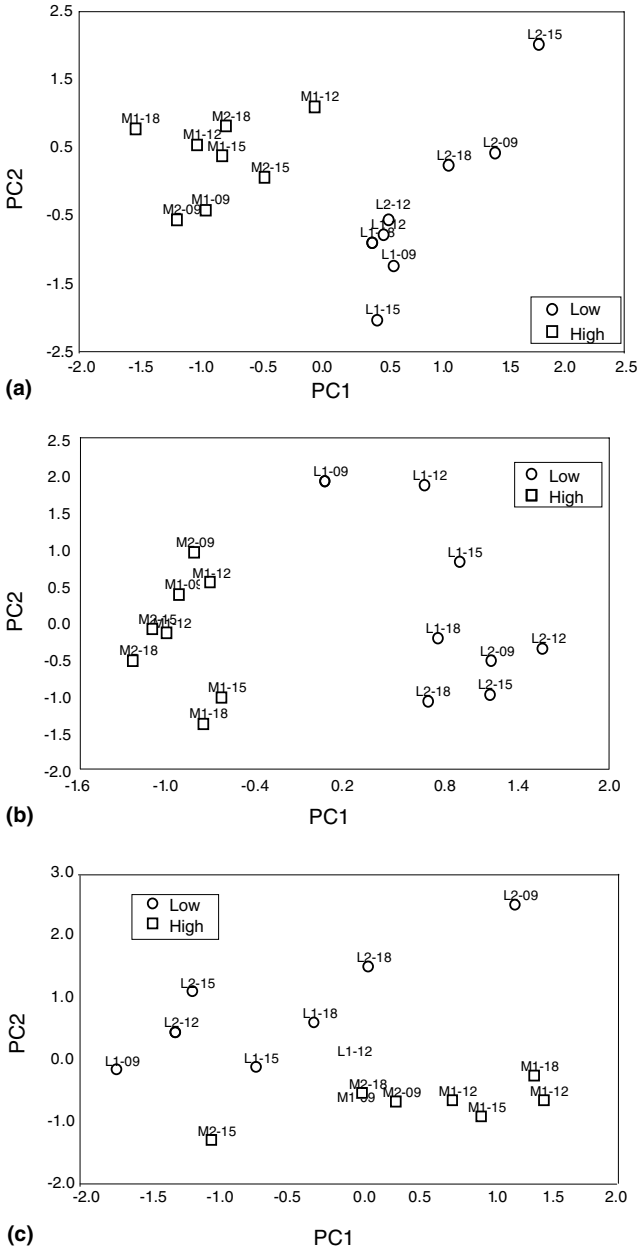

Fig. 1. Plot of the 16 samples of sparkling wines on the plane defined by the two first principal components from data of phenolic compounds (a), volatile compounds (b) and free amino acids (c).

time that a sparkling wine must be in contact with the yeasts to be awarded the Designation of Quality *cava*. Fig. 2 shows the mean values of the results of the sensory analysis of sparkling wines from high- and low-yield vineyards, respectively. A penalising scoring system is used on the tasting card, such that the best quality wines have the lowest scores. Wines from low-yielding vineyards were given a lower score by tasters, i.e., were considered to be of higher quality.

In summary, from the data obtained it can be deduced that the concentrations of most of the phenolic

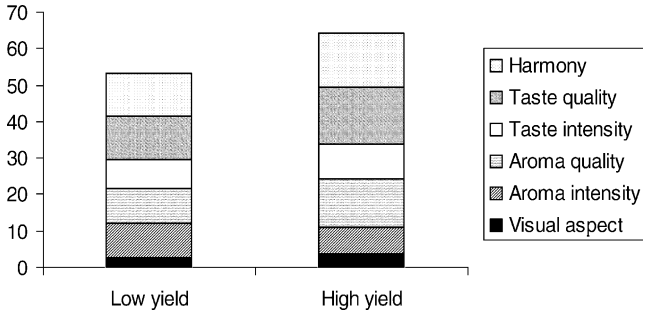

Fig. 2. Results of the sensory analysis of the nine-month-old Parellada sparkling wines.

compounds of sparkling wines obtained from the same grape variety grown in low-yield vineyards, less than 10,500 kg/ha and high-yield vineyards, higher than 10,500 kg/ha, respectively, are different. There were no significant differences between the mean values of most of the nitrogen compounds in wines from the two types of vineyard or in the foam characteristics. Overall, the tasters favoured wines from grapes grown in low-yielding vineyards.

Acknowledgements

This study was supported by the Spanish Comisión Interministerial de Ciencia y Tecnología (Project AGL2000-1569). We are grateful to Castellblanch S.A. (Sant Sadurnid'Anoia, Spain) for manufacturing the wines, especially for the purpose of this research.

References

Antonacci, D., & La Notte, E. (1993). Influence exerted by the increase of the vine production over the wine antocyanic composition and technological considerations. *Rivista di Viticoltura e di Enologia* (3), 3–21.

Bradford, M. M. (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilising the principle of protein-dye binding. *Analytical Biochemistry, 72*, 2248–2255.

Davis, C. R., Wibowo, D., Eschenbruch, R., Lee, T. H., & Fleet, G. H. (1985). Practical implications of malolactic fermentation: A review. *American Journal of Enology and Viticulture, 36*, 290–301.

De Garis, K. A., Holzapfel, B. H., Rogiers, S. Y., & Small, G. (2000). Ripening grapes to specification in the Riverina: The second year. *Australian Grapegrower and Winemaker* (443), 35–36.

Dirninger, N., Duc, D., Schneider, C., Dumas, V., Asselin, C., & Schaeffer, A. (1998). Wine quality and terroirs: Influence of environmental characteristics on the Gewurztraminer flavor profile. *Sciences des Aliments, 18*, 193–209.

Ewart, A. J. W., Brien, C. J., Soderlund, R., & Smart, R. E. (1985). The effects of light pruning, irrigation and improved soil management on wine quality of the *Vitis vinifera* cv. Riesling. *Vitis, 24*, 209–217.

Ferreira, V., Fernández, P., Peña, C., Escudero, A., & Cacho, J. F. (1995). Investigation on the role played by fermentation esters in

the aroma of young spanish wines by multivariate analysis. *Journal of the Science of Food and Agriculture, 67*, 381–392.

Giorgessi, F., Calò, A., Sansone, L., Serra, S., & Tomasi, D. (1999). Importance of planting density on yield and quality control in a viticultural environment of North-East Italy. *Rivista di Viticoltura e di Enologia* (1), 33–57.

González de Llano, D., Polo, M. C., & Ramos, M. (1991). Evolution, isolation and identification of low molecular weight peptides from blue cheeses by high performance liquid chromatography. *Journal of Dairy Research, 58*, 363–372.

Jackson, D. I., & Lombard, P. B. (1993). Environmental and management practices affecting grape composition and wine quality – A review. *American Journal of Enology and Viticulture, 44*, 409–430.

Jones, G. V., & Davis, R. E. (2000). Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux, France. *American Journal of Enology and Viticulture, 51*, 249–261.

Lambrechts, M. G., & Pretorius, I. S. (2000). Yeast and its importance to wine aroma. A review. *South African Journal of Enology and Viticulture, 21*, 97–129.

Martínez-Rodríguez, A. J., & Polo, M. C. (2003). Effect of the addition of bentonite to the tirage solution on the nitrogen composition and sensory quality of sparkling wines. *Food Chemistry, 81*, 383–388.

Moreno-Arribas, V., Pueyo, E., Nieto, F. J., Martín-álvarez, P. J., & Polo, M. C. (2000). Influence of the polysaccharides and the nitrogen compounds on foaming properties of sparkling wines. *Food Chemistry, 70*, 309–317.

Peña-Neira, A., Hernández, T., García-Vallejo, C., Estrella, I., & Suárez, J. A. (2000). A survey of phenolic compounds in Spanish wines of different geographical origin. *European Food Research Technology, 210*, 445–448.

Peterlunger, E., Celotti, E., Da Dalt, G., Stefanelli, S., Gollino, G., & Zironi, R. (2002). Effect of training system on Pinot Noir grape and wine composition. *American Journal of Enology and Viticulture, 53*, 14–18.

Pozo-Bayón, M. A., Hernández, M. T., Martín-Álvarez, P. J., & Polo, M. C. (2003). Study of low molecular weight phenolic compounds during the aging of sparkling wines manufactured with red and white grape varieties. *Journal of Agricultural and Food Chemistry, 51*, 2089–2095.

Pozo-Bayón, M. A., Pueyo, E., Martín-Álvarez, P. J., & Polo, M. C. (2001). Polydimethylsiloxane solid-phase microextraction-gas chromatography method for the analysis of volatile compounds in wines. Its application to the characterization of varietal wines. *Journal of Chromatography A, 922*, 267–275.

Riu-Aumatell, M., López-Barajas, M., López-Tamames, E., & Buxaderas, S. (2002). Influence of yield and maturation index on polysaccharides and other compounds of grape juice. *Journal of Agricultural and Food Chemistry, 50*, 4604–4607.

STATISTICA, program for Windows, release 5.1. (1998). Statsoft Inc., Tulsa, OK.