Sensory properties of premium Spanish red wines and their implication in wine quality perception

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Abstract

Background and Aims: Little is known about the link between quality and the sensory space of premium commercial Spanish red wines. The major aims of the present study were to define the sensory space of these wines and determine the implication of their sensory properties (aroma and in-mouth attributes) in the quality perception of wine professionals.

Methods and Results: Evaluation of wine quality was first studied by a categorisation task. Then, sensory descriptive analysis based on citation frequencies for aroma attributes and conventional intensity scores for taste and mouth-feel properties was performed on individual samples. The general sensory quality was highly positively correlated to astringency and, to a lesser extent, to acidity as well as to fruity, spicy and roasted/woody attributes, and especially highly negatively correlated to aromatic attributes belonging to the animal family.

Conclusions: Categorisation tasks based on quality perception coupled to sensory analysis based on citation frequencies for aroma properties and on classical descriptive analysis for taste and mouth-feel properties could be suitable tools to finely determine sensory quality. The results highlight the importance of in-mouth properties, especially of astringency and acidity, in general quality as well as the relevance of the aromatic profile.

Significance of the Study: This study increases the information on the sensory properties of premium Spanish red wines and the implication of concrete sensory attributes in sensory quality perception. This work provides wine-makers information to be considered when elaborating high quality red wines.

Keywords: *categorisation task*, *citation frequency*, *quality*, *sensory analysis*, *wine*

Introduction

The quality perception of wine is increased when the overall organoleptic sensations, such as alluring aroma, desirable taste and the typical colour of red wines, lead to the pleasure and enjoyment when it is consumed. Sensory evaluation is a scientific discipline used to measure, analyse and interpret reactions to perceived stimuli. Among other applications, sensory analysis techniques have been widely used as an adjunct to quality control and as a diagnostic tool to characterise product differences (Varela and Gambaro 2006, Goldner and Zamora 2007, Campo et al. 2008, Ferreira et al. 2009). Sensory analysis techniques have been applied to wines during recent decades and have become standard practice in order to obtain an objective characterisation and discrimination of products.

The use of correctly trained assessors is a key factor in producing meaningful profiles in sensory analysis. Even with training, judges vary in their perceptions due to obvious individual physiological differences, thus examination of panel performance should be an important routine part of data analysis (King et al. 2001, Campo et al. 2010). To this end, multivariate statistics have been widely used, particularly principal component analysis (PCA), although procluster analysis, correspondence analysis (CA) and cluster analysis have also been used.

Traditionally, conventional descriptive analysis (DA) has been widely used to evaluate a variety of foods, including wine as evidenced by the abundant scientific literature existing to this respect. Nevertheless, the difficulties related to the use of intensity scales when assessing odours make this technique poorly adapted for a precise and reliable description of complex aroma products. The notion that odour judgment in DA is somewhat more difficult than visual, texture and taste judgements (Lawless and Heymann 1998) is particularly true in the case of wine, as most of the odorants are near the olfactory threshold. Campo et al. (2010) have recently shown that the citation frequency-based method can represent a plausible alternative to conventional DA when detailed description of complex aroma products such wine is required. They observed that even if no intensity scale is used by judges, a fine hierarchy of descriptors defining each product can be achieved. Besides, this method presents less risk of having few samples explaining most of the variance in the sensory space because no intensity scores is given to evaluate attributes.

The sensory characterisation of Spanish wines has been the object of few studies in the past years, most of them being carried out in order to define the sensory space of white wines (De La Presa Owens and Noble 1995, Vilanova and Vilarino 2006, Campo et al. 2008, Rodriguez-Nogales et al. 2009), although some sensory description has also been performed on young (Etaio et al. 2008a,b) or oak aged red wines (Aznar et al. 2003, de Simon et al. 2008).

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Recently, a study developed in an attempt to correlate aroma composition and quality revealed that the quality of premium Spanish red wines was primarily related to the absence of defective or negative odorants, and secondarily to the presence of a relatively large number of fruit-sweet odorants (Ferreira et al. 2009). There is also growing recognition that interactions among odorants, perceptual interactions between sense modalities and interactions between the odorant and different elements of the nonvolatile wine matrix can all impact odorant volatility, flavour release, and thus overall perceived flavour intensity and quality (Polaskova et al. 2008, Sáenz-Navajas et al. 2010a,b). These studies reinforce the idea that flavour perception is dynamic and the result of a complex pattern of chemical and physical interactions in wine and in the mouth. All this leads to consideration of the importance of sensory analysis as an important tool to help reach a better understanding of wine sensory quality.

In this context, the aims of this study were to (i) obtain the taste and aroma profile of premium Spanish red wines by means of conventional and citation frequency-based descriptive methods, respectively; and (ii) correlate the quantitative sensory data to the quality assessment carried out by a panel of wine professionals.

Materials and methods

Wines

Twenty-four Spanish red aged wines from 11 different Spanish Denominations of Origin: Rioja (seven samples), Ribera de Duero (five samples), Toro (two samples), one sample from each of Cariñena, Calatayud, Jumilla, Somontano, Priorat, Bierzo, Penedés, Montsant, one 'vi de taula de Balears' and one 'Vino de la Tierra de Castilla'. All the wines were Premium products with a price ranging from 15 to 20 Euro/bottle and were selected attending to sales criteria to obtain a representative sample of the Spanish high quality red wine market. The detailed list of samples, including basic compositional data obtained following standard operating procedures is shown in Table 1.

Analysis of conventional oenological parameters in wines

Conventional oenological parameters of wines were determined in accordance with official International Organisation of Vine and Wine (OIV) practices. Total polyphenol index was estimated as absorbance at 280 nm multiplied by 100 and colour intensity was calculated as the sum of absorbance at 420, 520 and 620 nm multiplied by 10 (Ribéreau-Gayon 1970). The analysis of reducing sugars, ethanol content, pH, titratable and volatile acidities were determined by Infrared Spectrometry with Fourier Transformation with a WineScan™ FT 120 (FOSS®, Barcelona, Spain), which was previously calibrated with the official OIV methods.

Quality assessment by wine professionals

The sensory panel was composed of eight females and ten males, 30–60 years of age, all of them with a long experience as wine tasters but with different backgrounds: five were aroma researchers, four were winemakers, five were sommeliers and four were wine retailers. Each panellist completed one session in individual booths that lasted approximately 60 min. First, the panellists were required to smell and taste each of the 24 wines (20 mL sample was poured into each glass), which were presented randomly in coded clear approved wine glasses (ISO NORM 3591 1977) covered with a petri dish at room temperature, once in the proposed order, in order to minimise any bias introduced by the order of presentation. Afterwards, they could smell and taste the samples as many times as they wanted and in any order. The panellists were asked to sort the wines into groups on the basis of quality (colour, odour and taste). They were asked to form five groups, and to put as many wines as they wished in each group. The groups were: exceptional (scored as 5 during data recording), good or very good (scored as 4), right or approved (scored as 3), poor or disappointing (scored as 2), and defective (scored as 1). The panellists were informed about the general price of the samples before the tasting session, but no more information was disclosed. The overall quality index of each wine was obtained by averaging all the individual scores obtained by each wine after recording. In case a bottle had an obvious bottle-related sensory problem, a second bottle was provided. In those cases in which the problem affected only to the first bottle, this one was discarded and the sensory analysis and further studies were carried out on defect-free bottles. If, however, all the bottles from a sample were defective, the sample was not discarded.

Descriptive analysis by a trained panel

A total of 35 students or staff members from the University of La Rioja (Spain) were recruited on the basis of their interest and their availability during 13 weeks. They were not paid for their participation. Among the 35 panellists, 32 were selected for data analyses (12 males and 20 females from 21 to 62 years old). The selection of panellists was carried out by calculating the reproducibility index (R_i) proposed by Campo et al. (2008) as is described below.

Panellists attended eight descriptive sensory training sessions (c. 1 h per session) over a period of 2 months, during which panellists worked in subgroups led by the same leader and following the same guidelines. They were provided with a list of 110 terms (including 91 specific and 19 more general terms) obtained from the literature (Campo et al. 2008) but with some modifications which are presented in Table 2 along with their corresponding odour reference standards. During training, different reference standards representative of aroma, taste and astringency terms were presented. Aroma standards were mainly natural products (fruits, juices, spices, vegetables, etc.) prepared at the beginning of each session, or odorants taken from 'Le Nez du Vin' (Jean Lenoir, Provence, France). For taste and astringency, solutions containing different concentrations of table sugar (0–12 g/L) for sweetness, tartaric acid (0–1.5 g/L) for acidity, quinine sulphate (0–10 mg/L) for bitterness and potassium and aluminium sulphate (0–5 g/L) for astringency stimuli were presented to the panel to aid with recognition, and discrimination between the different oral sensations.

The training period included two phases: a general and a product specific training phase. During the general training phase (four sessions), panellists became familiar with aroma attributes and with intensity rating of sweetness, acidity, bitterness, astringency, aromatic and global intensity as well as persistence. During a typical session panellists had to evaluate three to five different wines by describing their odour properties by choosing up to five descriptors in the aroma list and by rating sweetness, acidity, bitterness and astringency on a ten-point scale (0 = 'absence', 1 = 'very low' and 9 = 'very high'); aromatic and global intensity on a nine-point scale (1 = 'very low' and 9 = 'very high'); and global persistence on a nine-point scale (1 = 'very short' and 9 = 'very long'). The wines selected for this training phase presented intense and easily recognisable taste and astringency properties and included red, white and rosé wines of diverse grape varieties and origins. The session ended with a discussion during which the panel leader compared the

Table 1. Wines analysed in the experiment including origin, age, varietal composition, oak aging time and some basic compositional parameters.

Wine codes	Denomination of origin	Vintage year	Grape variety	Oak aging (months)	Alcohol %(v/v)	pH	Volatile acidity (g/L)†	Total acidity (g/L)†	Reducing sugars (g/L)	TPI‡	CI§
245	Ribera de Duero	2003	Tempranillo (90%), Cabernet Sauvignon (10%)	18	13.5	3.75	0.56	3.51	1.55	48.3	13.3
662	Ribera de Duero	2004	Tempranillo	14	14.8	3.95	0.73	3.29	3.29	70.1	13.7
239	Ribera de Duero	2005	Tempranillo	15	14.5	3.66	0.63	3.28	3.32	62.0	19.9
301	Rioja	2001	Garnacha, Tempranillo, Mazuelo, Graciano	16	13.5	3.57	0.47	3.75	2.34	61.8	9.4
522	Calatayud	2005	Garnacha (94%), Merlot (6%)	13	14.5	3.37	0.43	4.55	2.9	62.8	16.2
084	Jumilla	2000	Monastrell	18	14.5	3.50	0.41	4.31	3.52	66.3	17.5
170	Somontano	2005	Syrah	16	14.3	3.47	0.49	3.84	3.51	87.7	14.4
454	Rioja	2003	Tempranillo (70%), Garnacha (20%), others (10%)	24	13.5	3.54	0.61	4.22	3.62	57.2	13.4
453	Cariñena	2005	Syrah	14	13.5	3.52	0.45	3.22	3.23	51.6	13.3
487	Rioja	2003	Tempranillo	18	14.4	3.45	0.43	3.80	3.96	79.8	9.3
699	Rioja	2004	Graciano	24	13.2	3.61	0.68	3.93	2.97	93.1	11.5
289	Bierzo	2004	Mencía	15	14.0	3.70	0.54	3.41	1.65	61.0	12.4
521	Rioja	2004	Tempranillo	20	14.5	3.63	0.48	4.12	2.45	62.1	12.7
137	Baleares	2000	Negra Mol	16	14.3	3.73	0.95	3.88	2.87	59.3	9.7
913	Ribera de Duero	2002	Tempranillo	15	14.2	3.86	0.39	3.07	2.76	62.3	10.9
044	Penedés	2001	Cabernet Sauvignon (85%), Cabernet Franc (15%)	24	13.5	3.51	0.50	3.23	2.04	83.9	12.1
984	Montsant	2003	Syrah (50%), Mazuelo (50%)	16	13.5	3.52	0.67	3.56	1.83	68.9	8.8
333	Rioja	2004	Tempranillo (81%), Graciano (15%), Garnacha (4%)	16	14.0	3.77	0.60	3.43	3.03	52.0	9.5
125	Toro	2000	Tinta de Toro	18	14.1	3.48	0.60	3.86	2.24	70.0	11.4
890	Toro	2002	Tinta de Toro	20	14.5	3.58	0.71	3.42	3.07	79.0	12.3
357	Rioja	2002	Tempranillo	20	14.1	3.65	0.51	3.88	3.14	76.7	13.3
823	Ribera de Duero	2000	Tempranillo (90%), Cabernet Sauvignon (10%)	15	13.5	3.57	0.52	3.70	2.14	48.4	7.9
705	Castilla	2002	Cabernet Sauvignon (80%), Merlot (20%)	16	14.5	3.46	0.41	3.99	1.36	51.5	10.2
019	Priorat	2002	Mazuelo (55%), Garnacha (35%), Syrah (10%)	13	14.7	3.40	0.51	3.72	2.16	50.1	8.9

†Expressed as sulfuric acid; ‡Total polyphenol index, expressed in absorbance at 280 × 100; §Color intensity, expressed as ($A_{420} + A_{520} + A_{620}$).

Table 2. Final list of descriptors used for aroma descriptive analysis, with the corresponding odor reference standards presented during panel training.

Descriptor	Odor reference	Quantity or concentration	Descriptor	Odor reference	Quantity or concentration	Descriptor	Odor reference	Quantity or concentration
FRUIT			**BLACK FRUITS**			Mango	Mango nectar, Carrefour	†30 mL
WHITE FRUITS			Blackberry	Blackberry jam, Fruitée Intense Bonne Maman	†five teaspoon in 10 mL of water	**OTHER FRUITS**		
Quince	Fresh quince	†half chopped unit	Blackcurrant	Aromatised blackcurrant water, Volvic gourmande	†30 mL	Candied/cooked fruits	Crystallised fruits	†50 g
Pear	Pear nectar, Carrefour	†30 mL	Blueberry	Blueberry syrup, Védrenne	†5 mL in 10 mL of water	Muscat	Muscat, La sultana	†20 mL
Apple	Apple juice, Carrefour	†30 mL	**DRY FRUITS**			Bitter almond	Bitter almond extract, Vahiné	†10 drops in 30 mL of mineral oil
YELLOW FRUITS			Date	Dry date, Borges	†3 chopped units	Cherries in alcohol	Juice of canned cherries, crushed cherry and Kirsch	†10 mL of juice + 1 cherry + 2 mL Kirsch
Apricot/Peach	Apricot juice, Granini	†30 mL	Fig	Dry fig	†2 chopped units	Cider	Sweet cider, Carrefour	†30 mL
Melon	Essential oil, Natura‡		Prune	Dry prune	†3 chopped units	***FLORAL***		
CITRUS FRUITS			**NUTS**			Acacia	N° 25, Le Nez du Vin‡	
Bergamot	Bergamot candies, Confiserie Stanislas	†2 units in 10 mL of water	Almond	Almond pastry	†10 g	Chamomile	Chamomile, Carrefour	†1 tea sachet in 50 mL of boiling water
Lemon	Lemon extract, Vahiné	†20 drops in 30 mL of water	Walnut	N° 23, Le Nez du Vin‡		Orange blossom	Orange blossom extract, Vahiné	†40 drops in 30 mL of water
Orange	Orange extract, Vahiné	†20 drops in 30 mL of water	Hazelnut	N° 50, Le Nez du Vin‡		Jasmine	Essential oil, Natura‡	
Grapefruit	Grapefruit juice, Granini	†30 mL	**EXOTIC FRUITS**			Lilac	Solution Firmenich	‡200 µg/L
RED FRUITS			Banana/English candy	Banana juice, Granini	†30 mL	Violet	N° 29, Le Nez du Vin‡	
Cherry	Cherry juice, Granini	†30 mL	Pineapple	Pineapple juice, Granini	†30 mL	Lime blossom	Lime, Carrefour	†1 tea sachets in 50 mL of boiling water
Strawberry	Strawberry juice, Granini	†30 mL	Passion fruit	Passion fruit juice, Granini	†30 mL	Rose	Rose	†4 chopped leafs and 4 petals
Raspberry	Raspberry juice, Granini	†30 mL	Lychee	Syrup of canned lychees, Eco +	†30 mL	Honeysuckle	IFF, Dijon France	‡100 µg/L
Redcurrant	N° 17, Le Nez du Vin‡		Coconut	Coconut cream, Blue Dragon	†30 mL	Geranium	Geranium	†4 cutted units
						Honey	Honey Miel de Flores, Carrefour	†2 teaspoon in 10 mL of water

SPICY			**WOODY**			Wet dog	Wet dog hair	†$^1/_2$ flask
Anis/Fennel	Anis, Carrefour organic agriculture	†1 tea sachets in 50 mL of boiling water	Fresh wood	Oak wood,	†1 g in 60 mL of hot water	Leather	4-ethyl-phenol	‡10 mg/L
Licorice	Licorice	†Stick (2 cm × 1 cm)	Smoky	N° 54, Le Nez du Vin‡		Transpiration/sweat	N° 8, Le Nez du Vin, *Les défauts*‡	
Clove	Clove grains	†2 units	***VEGETAL***			Meat fumet	Gallina blanca, meat Avecrem	†one piece in water
Vanilla	Vanillin, Sigma-Aldrich	†30 g/L	**VEGETABLES**			***UNDERGROWTH***		
Nutmeg	Nutmeg, Carmelita	†1 chopped unit in water	Artichoke	Juice of artichoke in conserve, Carrefour	†30 mL	Mushroom	Juice of mushrooms in conserve, Carrefour	†diluted 1/10
Black pepper	Black pepper in powder, Carrefour Ecobio	†Bottom of the flask draped with product	Asparagus	Juice of asparagus in conserve, Carrefour	†1 mL (diluted 1/10)	Humus/earthy	Humus	†10 g
Cinnamon	Cinnamon in powder, Carrefour	†Bottom of the flask draped with product	Cabbage	Juice of cabbage in conserve, Daucy	†5 mL in 5 mL of water	Mould	Moldy bread	†one slice
Curry	Curry, Carmelita	†Bottom of the flask draped with product	Green beans	Juice of green beans in conserve, Carrefour	†5 mL	***OTHERS***		
Juniper	Juniper berries	†6 chopped units	Celery	Celery leaf	†1 chopped leaf	Lactic	Liquid cream, President	†30 mL
Thyme	Thyme in powder, Carrefour	†Bottom of the flask draped with product	Olives	Olive juice, Carrefour	†5 mL	Butter	Butter, Carrefour	†10 g
Laurel	Laurel leafs	†2 chopped leafs	Bell pepper	1 chopped unit	†1 chopped unit	Alcohol	Ethanol, Sigma	†diluted 1/2
Menthol/fresh	Menthol candies	†4 units in 10 mL of hot water	**OTHER VEGETABLES**			Yeast	Bakery yeast, Mandarin	†5 g in 50 mL of hot water
ROASTED/ WOODY			Hay/dry leaf	Dried herbs	a full 120 mL-flask	Chocolate	Pieces of chocolate, Vahiné	†1 teaspoon
ROASTED			Pine/resin	Pine acicules†		Rubber	N° 36, Le Nez du Café, *Passion révélation*‡	
Caramel	Liquid caramel, Carrefour	†30 mL in 30 mL of water	Herbaceous	Cis-3-hexen-1-ol, Sigma	‡100 µL	Tar/bitumen	A piece of asphaltic fabric	Stick (8 cm × 1 cm)
Toasted bread	Fresh bread	†$^1/_2$ crushed toasted slice	Fresh tobacco	Fresh tobacco, Manitou	†1/2 cigarette	Cardboard/dust	Cardboard	†in pieces
Coffee	Coffee, Carrefour	†1 teaspoon	***ANIMAL***			Gun flint/silex	bis (2-methyl-1,3,4-thiadiazolyl)-5,5′-disulfane‡	
			Musk/civet	Standard Sentosphère‡		Sulfur	N° 6, Le Nez du Vin, *Les défauts*‡	
			Cat urine	Sand with cat urine	a full 120 mL-flask			

†Contained in a glass amber flask of 60 mL. ‡Glass amber flask (60 mL) containing an absorbent paper support (5 × 11 cm) impregnated with 5 drops of the odorant solution.

aroma descriptors and the taste intensity scores given by panellists to describe each wine.

The specific training phase consisted of four sessions during which panellists became familiar with the type of samples of the study. During this phase, panellists described odour properties and rated the intensity of sweetness, acidity, bitterness, astringency, aromatic and global intensity, as well as global persistence of red wooded Spanish commercially available wines.

Trained panellists described wines in duplicate. Ten-mL wine samples were presented in dark approved wine glasses (ISO NORM 3591 1977) labelled with three-digit random codes and covered by plastic Petri dishes according to a random arrangement. Each panellist completed five sessions (*c.* 45 min each) over a period of 5 weeks for the analysis of the 48 samples (24 wines × two replicates) from the study (9–10 wines per session). Panellists were asked to smell each wine, rate the aromatic intensity and afterwards to describe their odour by choosing a maximum of five attributes from the list of 110 according to the citation frequency method (Campo et al. 2008). Then, they were asked to rate the sweetness, acidity, bitterness, astringency, global intensity and global persistence of the samples using the above mentioned structured scales for each wine. Trained panellists rated samples using a sip and spit protocol. Ten seconds after wine was sipped, it was expectorated. Ten seconds later, apple pectin solution (1 g/L) was sipped, which was spat out after another 10 s. Between wine–rinse combinations, subjects rinsed twice with de-ionised water for 20 s as described by Colonna et al. (2004).

All wines were served at room temperature and were evaluated in individual booths. Panellists were not informed about the nature of the samples to be evaluated.

Data analysis

Analysis of panel performance. To assess the individual performance, an average reproducibility index (R_i) was calculated for each of the panelists as proposed by Campo et al. (2008):

$R_i = \Sigma[2 \times des_{com} \quad (des_{rep1} + des_{rep2})]/n$ where des_{com} is the number of common terms given by the panellist in the two replicates of a wine, des_{rep1} and des_{rep2} are the number of terms given by the panellist in the first and second repetitions, respectively, and n is the number of wines. The responses from the subjects showing a $R_i < 0.2$ were left out from the study. According to this, 32 panellist were selected and with them a three-way analysis of variance (ANOVA) for the in-mouth attributes involving samples (S), judge (J) and replicate (R) as fixed factors and all first-order interactions were calculated and panel performance was confirmed.

Product characterisation. A one-way ANOVA with repeated measurements was performed on scores (averaged across replicates) derived from the in-mouth attributes and aromatic intensity. Data from the in-mouth and the aroma description were analysed, respectively, by PCA and CA. PCA was performed on the mean ratings over the judges for the in-mouth attributes sweetness, acidity, bitterness, astringency, global intensity and persistence and for each wine (correlation matrix) whereas CA was performed on the contingency table containing the average citation frequency of terms cited by a minimum of five judges (>15% of the panel) in, at least, one wine replicate. In order to choose the number of principal components (PCs) or factors that should be retained, dimensions with an eigenvalue higher than the mean eigenvalue (Kaiser law) were calculated for both PCA and CA spaces.

Hierarchical cluster analysis (HCA) with the Ward criteria was finally applied to the factorial coordinates of the wines in the spaces defined by PCA and CA according to these parameters. The clusters identified by truncating the tree diagram were consolidated by aggregation around mobile centers. In both cases, the terms that best characterised each of the clusters were identified by using the test-value parameter (Morineau et al. 1995). The test-value corresponds to a statistical criterion akin to a standardised variable (zero mean and unit variance). Significance is obtained when the absolute test-value is ≥1.96, which corresponds to an error threshold of 5%. Ranking of the terms according to their test-values provides a quick characterisation of each cluster (Morineau 1984).

To explore the impact of aroma as well as the in-mouth perceptions in the quality perception of wine professionals, two multiple linear regression (MLR) analyses (one for aroma and one for the in-mouth properties) were performed. Therefore, the projection of wines on the CA analysis and on the PCA, respectively, were considered as independent variables and quality as a dependent variable. A stepwise method that allows adding variables one by one to the model was calculated, where the F statistic for a variable to be added must be significant at the 0.05 level. After a variable is added, the stepwise method looks at all the variables already included in the model and deletes any variable that does not produce an F statistic significant at the 0.05 level. All analyses were carried out with SPSS software (version 15.0, SPSS Inc., Illinois, USA).

Finally, partial least-square regression models in order to explain quality scores as a function of sensory scores (aroma and in-mouth attributes) were carried out using PLSR1 with Unscrambler 9.7 (CAMO, Trondheim, Norway). The quality parameters studied to evaluate the prediction ability of the models were the slope of the regression curve between real and predicted Y variables (m), the root mean square error for the prediction (RMSEP), and the percentage of variance explained by the model (%EV).

Results and discussion

Quality assessment by wine professionals

In the present study, the quality of the wine samples was assessed by a panel of experts formed from a diverse group of wine professionals. In spite of their different professional backgrounds, a good correlation was obtained between the scores given by the different groups of professionals ($r^2 > 0.65$). Results of the sensory evaluation are given in Figure 1. Quality score means for the 24 wines range from 1.5 to 4.0, where 1.0 and 5.0 are the minimum and maximum possible scores, respectively. The standard errors of the means ranged between 0.17 and 0.35, and tend to be larger for samples with low scores.

Sensory description of wines by a trained panel

Analysis of panel performance. Ranking of the reproducibility index (R_i) associated to a judge allows one to know how this judge performs with respect to the rest of judges. In the present work the maximum R_i value was found to be 0.52, which corresponds to 52% of common terms between the two replicates for a judge. The minimum value was 0.17 (median = 0.35). The responses from judges showing a $R_i < 0.2$ were left out from the study so that responses of the remaining 32 judges were considered for analysis.

Table 3 shows results from the ANOVAs for each attribute. The judge effect was significant on all attributes. This effect is commonly found in sensory analysis and can be explained by interindividual differences. A wine-by-replicate (W*R) interaction was observed for the term bitterness. However, none of the

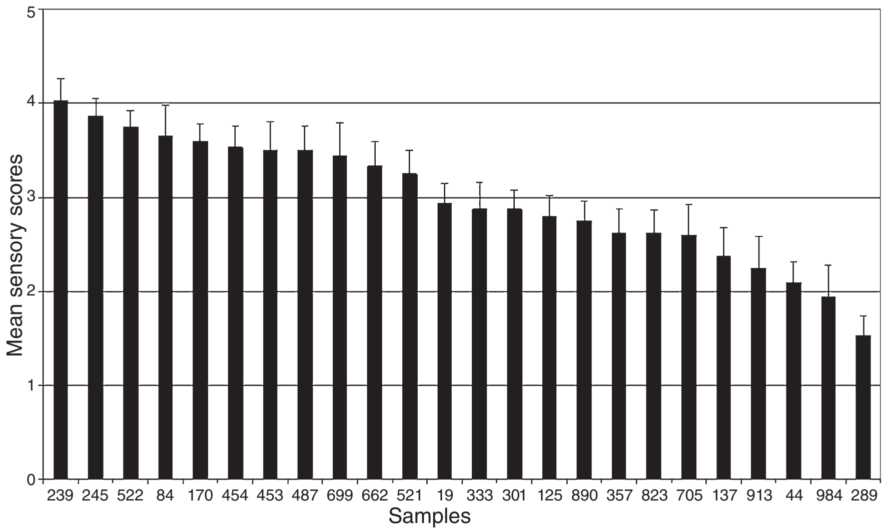

Figure 1. Mean quality scores obtained for the 24 studied wines. Error bars are the standard mean error.

Table 3. Fixed ANOVA model of attribute ratings (32 judges) for the attributes evaluated in mouth (df, degrees of freedom; F, F-ratios; *P*, *P*-values).

Attribute	Judge (J) (df = 31)		Replicates (R) (df = 1)		Wine (W) (df = 23)		W*R (df = 23)		W*J (df = 713)		J*R (df = 31)	
	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Sweetness	74.27	**<0.001**	1.596	0.207	1.515	0.059	1.083	0.359	1.140	0.071	1.083	0.359
Acidity	34.93	**<0.001**	0.010	0.919	3.440	**<0.001**	1.222	0.217	1.121	0.100	1.343	0.131
Bitterness	43.21	**<0.001**	1.380	0.241	1.663	**0.027**	2.532	**<0.001**	1.181	**0.025**	1.439	0.051
Astringency	28.45	**<0.001**	0.813	0.368	13.27	**<0.001**	1.251	0.211	0.988	0.303	1.222	0.233
Aromatic intensity	17.21	**<0.001**	0.277	0.599	2.297	**<0.001**	1.057	0.390	1.022	0.251	0.903	0.501
Global intensity	13.44	**<0.001**	0.160	0.689	8.140	**<0.001**	1.391	0.089	1.166	**0.032**	1.427	0.076
Global persistence	22.87	**<0.001**	0.530	0.467	6.485	**<0.001**	1.372	0.116	1.114	0.112	1.298	0.145

Significant *P*-values (5% level) are highlighted in bold letters.

replicate effect was significant, indicating a consistent assessment of attributes and reflecting the reproducibility of the panel. The wine-by-judge interaction (W*J) was significant for the terms bitterness and global intensity. PCA run on global intensity (judges in columns and wines in rows) revealed that the first component accounted for 61% of the explained variance. For this term the judges' projections were grouped together in the loading plot, thus indicating that interaction was mostly due to scaling disagreements. On the contrary, the judges' projections were spread over the loading plot for bitterness, with the first component accounting for 15% of the explained variance. This indicates that there are differences in the interpretation of the term bitterness and that assessors may need more training with respect to this attribute. Therefore, this term was not considered in subsequent analyses.

Product characterisation. *In-mouth attributes*. According to one-way ANOVA with repeated measurements (judges considered as repetition), the effect of wine was significant at the 5% level for acidity ($F = 2.513$; $P < 0.001$), astringency ($F = 5.359$; $P < 0.001$), global intensity ($F = 13.21$; $P < 0.001$), and persistence ($F = 5.130$; $P < 0.001$), whereas no significant differences were found for the attribute sweetness ($F = 1.475$; $P = 0.071$). This indicates that the attribute sweetness is not useful in characterising differences among this set of wines. Indeed, all are dry wines with residual sugar contents lower than 5 g/L; therefore, in order to avoid giving importance to close-to-hazard differences, this term was not considered in further PCA analysis.

The mean eigenvalue threshold approach suggests that two dimensions should be retained for the PCA. The attributes astringency, acidity, global intensity, and persistence as well as quality (illustrative variable) were taken into account in PCA. The first two PCs accounted for more than 95% of the total variance. Figure 2 shows the PCA bi-plot illustrating the projection of descriptors (Figure 2a) and wines (Figure 2b). The correlation matrix showed that both global intensity and persistence were positively correlated to astringency (91% and 89%, respectively). Besides, global intensity and persistence were highly correlated (93%). These results are in accordance with Sáenz-Navajas et al. (2010a) where it was also confirmed that while global intensity and persistence of white wines were mainly related to volatile molecules, in red wine these compounds play just a secondary role and astringency, intensity and persistence are primarily caused by non-volatile molecules. Peynaud (1987) also supports these results because he stated that what distinguished great wine (and thus its quality) is the length of character of its aftertaste and hence persistence, particularly in the case of red wines where it is mainly related to its phenolic composition which determines their length.

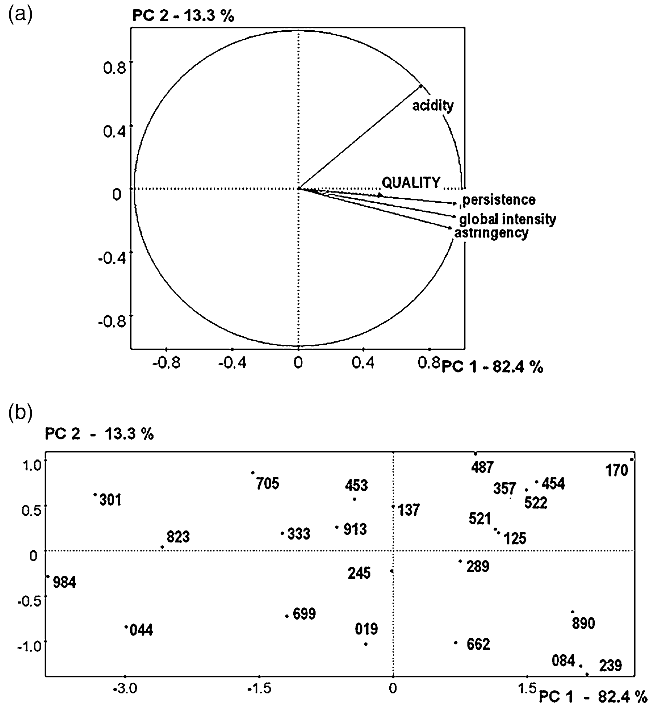

Figure 2. (a) Correlation circle of the PCA. The dotted arrow (illustrative variable) shows quality wines according to the categorization task, (b) projection of the 24 wines on the first two PCs of the PCA.

HCA yielded three clusters, formed by twelve, eight and four samples, respectively. For each cluster, the closest wine to the centre of gravity was identified as the most typical exemplar of the cluster, and therefore, of the related sensory characteristic and such samples were 125 (cluster 1), 913 (cluster 2) and 823 (cluster 3). The first cluster to emerge from the PCA space was characterised by the attributes: astringency, global intensity, persistence and acidity whereas the third cluster was negatively correlated to these attributes. The second cluster was especially not astringent.

Cluster 1 was characterised positively at a confidence level of 90% by the illustrative variable, quality (test-value = 1.54, $P = 0.062$) and contains eight wines (>65%) evaluated with more than 3 points in the assessment of quality by professionals. Clusters 2 and 3 were negatively characterised by the variable quality (test-value = −1.84, and −2.04; $P = 0.033$ and $P = 0.022$, respectively) and more than 75% of wines classified in both clusters were assessed by wine professionals with low scores for the attribute quality, ranging from 1.5 to 2.9. These results suggest that the attributes described in-mouth (astringency, acidity, global intensity and persistence) play an important role in the assessment of quality by professionals.

Besides, in an attempt to explore the impact of the in-mouth attributes assessed in the quality perception of wine professionals, a multiple linear regression analysis was performed where the projections of wines on the PCA analysis were considered as independent variables and quality as a dependent variable. Therefore, two PCs were considered (explaining 95% of the total variance). This multiple linear regression provided a significant model ($F = 7.526$; $P = 0.012$) explained by the first PC. The regression was:

$$\text{Quality} = 2.989 + 0.178 * \text{PC1}$$

The first PC was mainly correlated to persistence (96%), global intensity (96%), astringency (94%), and to a lesser extent, to acidity (74%) and therefore presents a positive correlation with quality.

Both methods, the multiple regression as well as the HCA, confirm that quality is correlated to wines scoring high in astringency, global intensity and persistence and to a lesser extent, to acidity while quality is especially contrary to wines with low scores for the terms evaluated in-mouth. These data reveal the importance of taste, mouth-feel or sensory characteristics evaluated in-mouth in the assessment of quality, what is in accordance with the literature where it is reported that quality evaluated by experts resulted to be linked to sensory characteristics such as long tasting finish (Lecocq and Visser 2006) or astringency (Varela and Gambaro 2006, Buratti et al. 2007). Concerning this last attribute, it is widely acknowledged that high quality red wines have a balance level of astringency and when it is too low the wines may taste flat, insipid and interesting (Gawel 1998).

Aromatic attributes. According to one-way ANOVA, the effect of wine was significant at the 5% level ($F = 1.818$; $P = 0.011$) for the attribute aromatic intensity, and as expected, this term does not present a significant correlation ($F = 0.425$; $P = 0.521$) with the quality evaluated by wine professionals.

Concerning the CA, the first ten factors explained 88% of the total variance and were retained for the HCA. The projection of wines and terms (average of two replications) into a bi-dimensional CA plot can be seen in Figure 3. The interpretation of the dimensions of the CA map was established by statistical indicators measuring the contributions of each term to the inertia on such dimensions. Only those attributes showing a contribution higher than the average were considered. The first factor, explaining more than 34% of the original variability, is mainly defined by 'unpleasant' attributes from the vegetal, animal (leather) as well as the undergrowth families (mushroom, humus/earthy and mould). The second dimension, explaining 12% of the total variance, opposes the animal (leather) and floral (violet) families to the term 'mold' and the vegetable (bell pepper) and fruity families (candied/cooked fruits, and dry fruits-fig). The low eigenvalues observed indicates a rather small dispersion of wines in the aromatic sensory space, which could be explained by the relative sensory proximity of the set of wines.

Concerning the hierarchical clustering (HCA), it revealed that three partition options were the most appropriate from a statistical point of view, the number of clusters in each of these partitions were three, six and eight, respectively. Even if the partition providing with three clusters was the most natural partition of the tree diagram, we chose the partition containing a total of six clusters as it permitted us to obtain more precise descriptions of wines belonging to each group. The terms best characterising samples in each cluster are shown in Table 4. Cluster 1 and 2 were characterised by pleasant attributes from the fruity family, as well as the attributes 'menthol' and 'toasted bread', whereas the other four clusters were mainly described by terms related to unpleasant descriptors (vegetal, undergrowth and animal).

Cluster 1 and cluster 2 were characterised positively by the illustrative variable quality (test-value = 19.78 and 18.54, respectively, and both $P < 0.001$), and 69% of the wines classified in both clusters presented scores higher than 3 points of quality. However, clusters 3, 4, 5 and 6 were characterised negatively by the illustrative variable quality (test-values = −23.36, −20.94, −4.19 and −9.07, respectively, $P < 0.001$), and more than 80% of wines clustered in these four groups were evaluated with quality

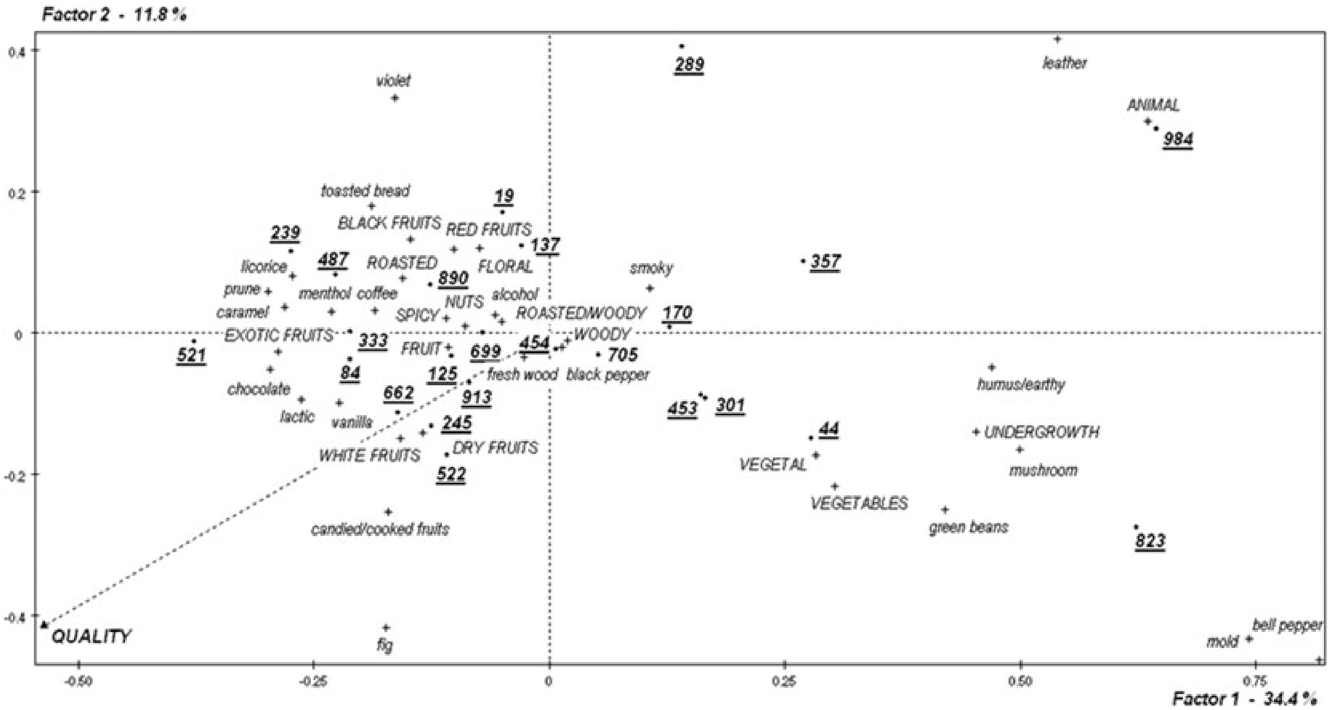

Figure 3. Projection of aroma descriptors and wines in the correspondence analysis space (dimensions 1 and 2). The arrow (illustrative variable) shows wines with quality according to the categorisation task carried out by the panel of wine professionals.

Table 4. Clusters yielded by the HCA for the aromatic attributes.

Cluster	Wine	Positive attribute	Negative attributes
1	239†, 333, 084, 125, 487, 699, 890, 521	Exotic fruit, menthol, toasted bread, *quality*	Animal, leather, undergrowth, mould, vegetables, vegetal, green beans
2	662†, 913, 522, 454, 245	Dry fruits, fig, candied/cooked fruits, *quality*	Bell pepper, animal
3	137†, 019, 357, 170, 301, 705, 289	Animal, leather, undergrowth, humus/earthy	Lactic, bell pepper, candied/cooked fruits, ***quality***
4	984†	Animal, leather	*quality*
5	453†, 044	Vegetal, vegetables, bell pepper	Dry fruits, *quality*
6	823†	Undergrowth, mushroom, mould, humus/earthy, vegetal, vegetables, animal	*quality*

†Wines closest to the centre of gravity of the cluster. Descriptors contributing most to the building of the cluster ($P < 0.05$) and wines belonging to each cluster are listed. The attribute quality is considered as illustrative variable.

scores lower than 3 by wine professionals. This suggests that quality is highly correlated to fruity terms (especially for dry fruits, such as prune or fig, candied/cooked fruits and exotic fruits) as well as to terms such as 'menthol/fresh' (from the spicy family) and 'toasted bread' (from the roasted/woody family). Otherwise, quality was especially contrary to the terms 'leather' from the animal family and 'humus/earthy' from the undergrowth family describing clusters 3 and 4 (test-values = −23.36 and −20.94, respectively). It is important to highlight that an inverse and highly significant correlation ($F = 12.01$; $P = 0.002$) was found between the citation frequencies of the animal and fruity terms in this set of wines, what could be related to the suppression effect of defective odorants from the animal family on fruity aroma already described (Aznar et al. 2003, Ferreira et al. 2009).

In an attempt to explore the importance of aroma attributes in the quality perception by professionals, a multiple linear regression analysis was performed. Therefore, the projections of wines on the CA analysis were considered as independent variables and quality as a dependent variable. Therefore, ten factors were considered (explaining 88% of the total variance) because dimensions with an eigenvalue higher than the mean eigenvalue were retained (Kaiser law). This multiple linear regression provided a significant model ($F = 9.614$; $P = 0.001$) including factors 1 and 2. The regression was:

$$\text{Quality} = 3.020 - 1.420 * \text{F1} - 1.806 * \text{F2}$$

Factor 1 presented significant positive projections (attributes with contributions higher than the average) for the undergrowth (mould, humus/earthy and mushroom), vegetal (veg-

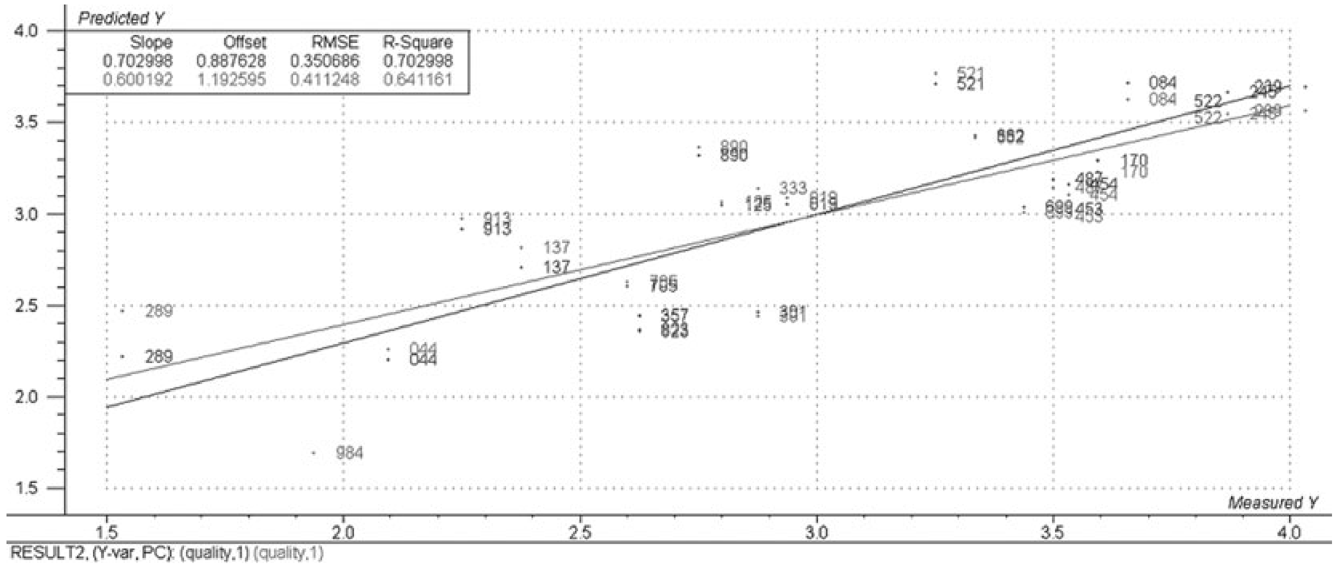

Figure 4. Plot of predicted versus measured quality scores for calibration (in blue) and validation (in red) obtained with the principal least square regression model.

etables, such as green bean) and animal (leather) families, and therefore inversely correlated to quality. On factor 2, dry fruits (fig) showed negative projection, which means that this attribute is positively correlated to the perceived quality.

The results suggest that the perceived quality is not only dependent on the presence of positive attributes such as dry (fig), candied/cooked or white fruits, but also to the absence of 'unpleasant' terms, namely from the animal family (leather), undergrowth (humus/earthy and mushroom) or vegetal (green beans) families.

Link between overall judgment of quality and sensory characteristics

In an attempt to evaluate the role played by the different sensory attributes in the quality perceived by wine professionals, a partial least square (type 1) regression was carried out with both aromatic and in-mouth descriptions. A satisfactory model could be built by introducing only ten descriptors that included aromatic attributes from the fruity, roasted/wooded, spicy and animal families as well as the attributes astringency and acidity. The model is:

$$\begin{aligned}\text{Quality} = {} & 0.211 + 0.0987 * \text{astringency} + 0.0813 \\ & * \text{acidity} + 0.166 * \text{fruity} + 0.112 * \text{white fruits} \\ & + 0.153 * \text{exotic fruits} - 0.123 * \text{animal} + 0.139 \\ & * \text{roasted/woody} + 0.127 * \text{fig} + 0.125 * \text{vanilla} \\ & + 0.114 * \text{menthol/fresh}\end{aligned}$$

This regression model is highly significant ($P < 0.0001$), the total explained variance being 70% (64% by full cross-validation), and the RMSEP is 0.351 as can be observed in Figure 4.

In summary, the model indicates that a major part of the quality of this particular set of red wines depends on both acidity and astringency as well as on their aroma composition, particularly, on those of the fruity (white, exotic and fig fruits), spicy (vanilla, menthol/fresh), roasted/woody and animal families, with this last aroma family being the sole attribute negatively contributing to the model. These data supports again the relevant role played in the assessment of quality of taste and mouth-feel attributes together with the aromatic profile.

Conclusions

The results of this study showed that although the sensory space of this set of premium Spanish red wines is very similar, their sensory quality is highly positively correlated to astringency and to a lesser extent to acidity as well as to fruity (more precisely to white, exotic and dry fruits), spicy (vanilla and menthol/fresh), and roasted/woody (toasted bread) attributes, and particularly highly negatively correlated to attributes from the animal family (leather). Multivariate analysis such as PLS as well as PCA and CA combined with stepwise linear regressions showed that it is possible, to a certain degree, to group these wines into different quality categories, and to predict their quality category membership on the basis of sensory analysis (aroma, acidity and astringency). These facts suggest that a categorisation task based on quality perception coupled to sensory analysis based on citation frequencies and on classical descriptive analysis (using a numeric scale) for taste and mouth-feel properties are suitable tools for classifying samples and finely defining aromatic and in-mouth properties to determine their implication in sensory quality.

The results evidence the importance of the in-mouth properties, especially of astringency and acidity, in the assessment of wine quality as well as the relevance of the aromatic profile. The proposed model shows the sensory quality vector of premium Spanish red wines. The exact role played by each of the attributes will need further study. Thus, in the case of astringency it will be interesting to find the minimum astringency at which a wine is considered as being of medium-high quality in this set of wines.

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