DOI: 10.1002/jsfa.879

Statistical validation of sensory data: a study on wine

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Abstract: A methodological procedure involving an appropriate statistical validation of sensory data was defined in order to describe the typical sensory profile of a young red wine (Aglianico) destined to aging. A trained panel of eight assessors rated the intensity of nine attributes on 16 products. Sensory data were submitted to statistical validation using a procedure organised in three main steps, namely fixed and mixed models of analysis of variance (ANOVA) and data standardisation. Results of the fixed ANOVA model computed on raw data showed significant differences between the products for all the attributes except *cherry* aroma and *pungent* mouthfeel. However, the results showed inconsistency between assessors. For many attributes, interaction effects were found. When individual differences between assessors were minimised or eliminated using scaled data, results of the fixed and mixed models showed no significant differences ($p \leq 0.05$) amongst the products for any of the sensory attributes. Therefore the differences amongst the products before data handling and before applying the mixed model of ANOVA were due to the assessors' variability. The results after statistical validation showed that the wines are very similar and that all the attributes used to describe the sensory characteristics of the products can be considered, at a qualitative and a quantitative level, as typical descriptors of the Aglianico wine destined to aging.

Keywords: sensory analysis; panel performance; ANOVA; wine

INTRODUCTION

Descriptive analysis has been widely used by researchers to describe the sensory characteristics of food products. It provides qualitative as well as quantitative measures of a product's characteristics. The qualitative component comprises the descriptive terms, called attributes, which define the sensory profile of the product. The quantitative component measures the degree or intensity of each characteristic perceived to be present.[1,2] Therefore descriptive analysis was proposed in order to obtain an objective characterisation of food products by means of selected sensory descriptors.[3,4]

Members of a well-trained laboratory panel are supposed to give small variation in their analytical evaluations.[5] The variations between assessors should be minimised or removed as much as possible before testing, during the selection of panel members or in the training period, but it is very difficult to eliminate the differences completely.[6] When analysing sensory profiling data, several problems occur. Even when panellists have been screened and trained well, variations between assessors exist. There are two main types of variation that influence the total perception: individual differences in the use of the scale and individual differences in sensitivity, motivation and culture.[7–10] Sensory data always contain information about both these variations. The use of scale is most often of little interest for the experimenter. It is considered merely a nuisance effect telling nothing about the product or about the more important part of perception.[11] For instance, two assessors can have the same interpretation of a product and still decide to use different scores. In order to validate the information about product perception and product differences, it is necessary to know the cause of variability between assessors. Nevertheless, separation of the two types of variation between assessors is generally very difficult, because they are always intermingled.[11]

There are, however, ways of arranging or preparing profile data to take the two effects into consideration. One simple way to remove the differences in the use of scale is data standardisation, in which each variable for each assessor is scaled to unit variance (or any other fixed value).[11] After removing the effect of scale, it is possible to start with a thorough data analysis. Analysis of variance (ANOVA) is commonly used to analyse sensory data, but in many research papers a description of the model of the analysis of variance is often ignored or only very briefly mentioned.[5] There are instead two main models of ANOVA: the fixed model, in which the assessors are considered as fixed effects,

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Contract/grant sponsor: European Union; contract/grant number: POM B35
(*Received 13 November 2000; accepted 27 February 2001*)

and the mixed model, in which the assessors are random effects.[12–16] Whether subjects are to be regarded as random or fixed effects depends on whether or not the conclusions need to be extended beyond the panellists tested to the population from which the assessors were drawn.[17] In sensory analysis the conclusions are always concerned with the product's descriptions. This means that the conclusions must be extended to the population from which the assessors were drawn. In fact, the results about food products must be valid in the sense that the results must be the same when redoing the experiment with a new panel.[18] Therefore the assessors must be considered as random effects and the mixed model should be used. However, in sensory analysis it is important to analyse the individual differences between assessors and make a conclusion about panel performance. If the conclusions need to be made about the panel performance, then the fixed model should be used. In fact, in this case, experimenters are interested in the behaviour of specific subjects of a specific panel, and the conclusions must not be extended to a population. Therefore both models are important in the analysis of sensory data: the fixed model should be used to analyse the type of individual differences between assessors, whilst the mixed model should be used to validate product differences.

Several applications of the descriptive analysis technique, applied to alcoholic beverages such as whiskies,[19] beers[20] and Champagne wines,[21] have been published during the last two decades. Descriptive analysis has been used to characterise wines such as Zinfandel,[22] Chardonnay,[23–25] Semillon and Sauvignon,[23] Seyval Blank,[26] Pinot Noir,[27] Riesling and Gewürztraminer[28] and Spanish white wines.[29] Sensory data were analysed by ANOVA, in some cases using the fixed model and in others the mixed model. However, in most of these research papers the results are presented without emphasis on the individual differences between assessors, but with important conclusions drawn about the sensory profile and product differences. It is evident that there is a need to define a statistical approach which combines the two models of ANOVA and eliminates effects due to assessor variability in the sensory evaluation of products. The definition of a methodological procedure is even more important in the case of sensory data associated with typical foods from a defined region which show small differences between productions. In these cases, assessor variability within a panel can strongly affect the sensory descriptor differences between samples.

The aim of this study was to define a methodological procedure in the statistical validation of sensory data in order to describe the sensory characteristics of wines. A young red wine destined to aging was selected as a case study with the purpose to define its typical sensory profile. The methodological approach in statistical validation is based on the use of both fixed and mixed ANOVA models. In order to validate product differences and panel performance, special emphasis is given to the individual differences between the panel members and how to handle them.

MATERIALS AND METHODS

Wines

As described in Table 1, 16 young Aglianico wines from the 1998 vintage were analysed by descriptive analysis. The Aglianico represents a grape variety cultivated in the volcanic area of Vulture situated in the Basilicata region in the south of Italy. This grape provides Aglianico red wine with highly valued characteristics. It has been revealed as one of the most interesting Italian wines and is well suited to aging. The samples were derived from four different zones of Vulture representative of the whole area. In each zone, four wineries were selected.

Subjects

The 16 wines were evaluated in March and April of 1999 by a panel of eight food science and technology students. These panellists had been previously tested for their olfactory and gustatory sensitivity and were selected on the basis of interest and availability from a set of 18 students.

Descriptive sensory analysis

Before starting the study, two preliminary sequences of 10 and six sessions were organised. The first sequence aimed to elaborate the working attribute list. During this sequence all the selected wines were presented to the assessors. Three Aglianico wines were presented to the assessors at each session. Assessors were asked to sniff and then to taste the samples. The assessors individually generated descriptive terms. All terms were put together and discussed with the assessors. In subsequent sessions the panel was provided with standards to aid in the development of a set of

Table 1. Identification and composition of wines

Code	*Zone of origin*	*pH*	*TA*[a]	*Ethanol (% v/v)*
1	Rionero in Vulture	3.65	5.06	12.80
2	Rionero in Vulture	3.48	5.64	12.00
3	Rionero in Vulture	3.47	5.98	12.70
4	Rionero in Vulture	3.26	6.03	12.50
5	Venosa	3.65	4.26	11.60
6	Venosa	3.52	6.60	12.80
7	Venosa	3.45	5.74	13.00
8	Venosa	3.40	5.67	12.00
9	Barile	3.41	5.40	11.50
10	Barile	3.50	5.44	12.90
11	Barile	3.29	6.80	13.00
12	Barile	3.35	5.62	11.50
13	Maschito	3.38	3.76	12.10
14	Maschito	3.30	6.09	12.60
15	Maschito	3.27	5.07	13.00
16	Maschito	3.38	5.88	13.50

[a] Tirtatable acidity (g l^{-1} as tartaric acid).

Table 2. Mean values and standard deviations of selected terms included in final list

Attribute	Mean value	Standard deviation
Aroma		
Rose	54.03	25.12
Cherry	78.22	20.63
Blackberry	46.80	23.52
Taste		
Bitter	43.51	21.37
Sour	74.56	18.16
Flavour-by-mouth		
Cherry	48.29	23.00
Wood	24.15	11.30
Mouthfeel		
Astringent	80.61	31.48
Pungent	50.54	17.31

descriptors. Again, in each section, three samples were presented with a set of standards. After discussing the standards, assessors worked individually and were asked to indicate which of the standard sensations were perceived in the products. Therefore each panellist again recorded all descriptive terms perceived in each wine. A list of 25 attributes was constructed using this procedure.

All terms used during preliminary tasting sessions were put together and discussed with the assessors in order to establish a consensus-based definition. The terms that were synonymous or redundant with other terms and the terms that referred to a preference or a dislike were discarded from the list. The terms showing a high citation frequency, ie perceived by at least six assessors in the same products, were included in the list. Thus a reduced first list of 15 descriptors was generated. Following this, in the remaining four sessions the assessors were asked to rate the intensity of each term on a 100 mm unstructured scale. For this purpose, in each session, four wines were presented to the assessors. The ratings for each wine, each descriptor and each assessor were collected and the means and standard deviations were calculated. The results were then discussed and, by consensus, the most appropriate terms used to define aroma, flavour and mouthfeel of the samples were selected. The descriptors kept for the final list have a mean intensity above 10 and a high standard deviation of the mean (Table 2). The final list of descriptors, with the relevant definitions and composition of the reference standards used, is reported in Table 3. The panel really agreed about the meaning of *cherry* and *wood* flavour and *pungent* mouthfeel, so the relative reference standards were not prepared.

A further six sessions aimed to train and calibrate the panel were carried out. Discrimination and recognition tests were conducted using standard solutions and olfactory standards at various concentration. These standards were prepared in the same way as the reference standards but in different concentrations. Description tests were conducted too in order to train the assessors to rate the perceived intensity of the nine descriptors in wine samples. Four wine samples were presented to assessors. For each descriptor, assessors had to taste the four samples and to rate the perceived intensity on a 100 mm linear scale. Wines samples used for descriptive tests in the training period were the same as used in the study.

The samples were then sensorily analysed by quantitative descriptive analysis. At the beginning of each session the assessors smelled the reference standards and then scored the intensity of each of the aroma and flavour-by-mouth terms for the wines on a 100 mm unstructured scale with anchor points at

Table 3. Descriptive vocabulary of Aglianico wine

Attribute	Definition	Reference composition
Aroma		
Rose	Floral odour of rose	1 mg 2-phenylethanol per 150 ml base wine[a]
Cherry	Odour associated with cherry	20 g cherry jam per 150 ml base wine
Blackberry	Odour associated with blackberry	20 g blackberry jam per 150 ml base wine
Taste		
Bitter	One of the basic tastes caused by aqueous solutions of various substances perceived at the back of the tongue	Aqueous solution of quinine hydrochloride dehydrate, 0.035 g l^{-1}
Sour	One of the basic tastes caused by aqueous solutions of various substances perceived in the central part of the tongue	Aqueous solution of citric acid, 0.25 g l^{-1}
Flavour-by-mouth		
Cherry	Flavour associated with cherry	—[b]
Wood	Flavour associated with wood	—[b]
Mouthfeel		
Astringent	Tactile sensation in which a drying, puckering feeling is perceived throughout the oral cavity	Aqueous solution of tannic acid, 0.25 g l^{-1}
Pungent	Tactile sensation in which a burning is perceived throughout the oral cavity	—[b]

[a] Red wine decoloured and deodorised with activated carbon.
[b] Standard not developed.

each end (0 = absence of the sensation, 100 = extremely intense sensation). Reference standards were smelled as necessary by the assessors during each session. The main trial consisted of 12 sessions needed to evaluate the 16 wines in triplicate. Samples (30 ml) were presented in coded, clear, 170 ml tulip glasses covered with Petri dishes. Four wines were evaluated in each session and were presented at the same time. Within each session the presentation of samples was randomised and balanced for order and carry-over effects.[30] Evaluations were conducted in individual booths under red illumination.

Data analysis

The validation of sensory data included the following steps.

1. A fixed model of ANOVA on the raw data of each of the sensory descriptors evaluated by the panel was performed in order to analyse sample (S), assessor (A) and replicate (R) effects and their interactions (S × A, S × R, A × R). This phase was conducted to get information about panel performance in terms of individual differences amongst assessors. Information about the effect of scale on the sensory data may arise from analysis of A × R interaction effects. In fact, the interaction involving A × R shows a lack of consistency by the assessors in their ratings between replicates. These inconsistencies could be attributed to the different use of the scale by assessors.[28] A part of the S × A interaction is also due to the scale use. The remaining part of the S × A interaction can be due to other individual differences such as differences in sensitivity, motivation and culture.[10] Furthermore, this step was conducted to get information about significant differences amongst the products before handling the sensory data.
2. The sensory data of attributes associated with significant S × A and A × R effects in the first step were normalised in order to validate the sensory data, thereby removing error due to the effect of scale. For these attributes the data were scaled, standardising each assessor by their standard deviation. Then a fixed model of analysis of variance was performed on the scaled data in order to eliminate the A × R interaction effect and part of the S × A interaction effect.
3. A mixed model of ANOVA was performed on scaled data of the sensory attributes associated with a significant S × A interaction effect in the second step. This phase was conducted in order to minimise the remaining part of the S × A interaction effect. Therefore the mixed model[16] of ANOVA was applied to determine and validate the information about the significance of product effects.

The fixed and mixed models of analysis of variance were conducted using the RANDOM statement of PROC GLM in SAS (SAS Institute Inc).

RESULTS AND DISCUSSION

Table 4 shows the fixed ANOVA results for the descriptive analysis data for the 16 samples. The significance of sample (S), assessor (A) and replicate (R) effects and their interactions for each attribute and each product was evaluated in terms of p values. Sample effects were significant ($p \leq 0.05$) for all the attributes except *cherry* aroma and *pungent* mouthfeel. Fixed analysis of variance indicated a significant assessor effect for all the attributes. On the contrary, the replicate effect was not significant for any of the attributes, so replicates were not considered in the subsequent analyses. S × A interactions were significant for all the attributes except *cherry* aroma and *pungent* mouthfeel. For the following attributes a significant ($p \leq 0.05$) A × R interaction was found: *rose*

Table 4. Fixed analysis of variance of raw data

	Samples (S) (df = 15)		*Assessors (A) (df = 7)*		*Replicates (R) (df = 2)*		*S × A (df = 105)*		*A × R (df = 14)*		*S × R (df = 30)*	
Attribute	F *value*	p *value*	F *value*	p *value*	F *value*	p *value*	F *value*	p *value*	F *value*	p *value*	F *value*	p *value*
Aroma												
Rose	2.70	0.0001	16.20	0.0001	1.10	0.3357	2.01	0.0001	2.31	0.0057	1.04	0.4220
Cherry	1.51	0.1600	7.09	0.0001	0.80	0.4294	0.80	0.4200	1.21	0.2790	1.05	0.5302
Blackberry	2.06	0.0300	8.54	0.0001	1.04	0.3465	1.61	0.0019	1.22	0.2614	1.18	0.2478
Taste												
Bitter	2.63	0.0012	19.35	0.0001	1.06	0.3477	1.59	0.0025	0.56	0.8959	0.80	0.7620
Sour	3.65	0.0001	16.70	0.0001	1.15	0.2988	1.73	0.0002	2.13	0.0114	1.30	0.1487
Flavour-by-mouth												
Cherry	3.00	0.0001	39.37	0.0001	1.10	0.3357	1.25	0.0140	2.29	0.0062	1.07	0.3798
Wood	2.32	0.0045	28.05	0.0001	1.08	0.3443	1.31	0.0190	2.40	0.0040	1.14	0.2935
Mouthfeel												
Astringent	3.89	0.0001	8.84	0.0001	1.20	0.2163	2.27	0.0001	1.95	0.0235	1.01	0.4534
Pungent	1.70	0.2000	23.76	0.0001	0.92	0.4018	0.70	0.3100	0.81	0.6592	1.06	0.3917

aroma, *sour* taste, *cherry* and *wood* flavours and *astringent* mouthfeel. There were no significant S × R interactions, so these were not considered in the subsequent analyses. Of all the attributes, only *cherry* aroma and *pungent* mouthfeel showed non-significant interactions. This means that there are no individual differences between assessors in the evaluation of these attributes and it was not necessary to handle their sensory data. Furthermore, only *cherry* aroma and *pungent* mouthfeel showed non-significant sample effects. Therefore the samples are not significantly different with respect to *cherry* aroma and *pungent* mouthfeel. In summary, fixed ANOVA on the raw sensory data showed that the products are significantly different in intensity for all the descriptors except *cherry* aroma and *pungent* mouthfeel. Table 5 shows the mean values of each descriptor for each sample. The calculation of least significant difference (LSD) at 95% significance level allows the different products to be identified; nevertheless, these differences must be verified and validated.

Since, in this first step, interaction effects were found for many attributes, the results for these attributes should be interpreted cautiously. For these attributes it was necessary to define the type of differences between assessors and to verify the products' differences. In particular, before defining the attribute differences across samples, the interaction effects must be eliminated or minimised.

Therefore the sensory data associated with significant S × A and A × R interactions in the previous analysis were normalised in order to remove error due to effects of scale. All the attributes except *cherry* aroma and *pungent* mouthfeel were scaled and then the fixed model of analysis of variance was performed on the scaled data. Table 6 shows the results. After scaling, the sample effect was not significant for the attributes *sour* taste and *cherry* flavour. The assessor effect was not significant for all the attributes ($p = 1$, data not show). The A × R interaction decreased ($p > 0.1$ for all the attributes) and was therefore not significant. The S × A interaction also decreased, although it was still significant for *rose* and *blackberry* aroma, *bitter* taste, *wood* flavour and *astringent* mouthfeel. Only *sour* taste and *cherry* flavour showed no significant S × A interaction. This means that individual differences amongst the assessors in the evaluation of these attributes were due only to the different use of the scale. The panel performed well with respect to these descriptors. Furthermore, after the treatment of the sensory data, *cherry* flavour and *sour* taste showed no significant sample effect: Therefore, before data handling, differences amongst the products were due to assessor variability in the use of the scale, whereas, after scaling the data, it is possible to affirm that the samples are not significantly different with respect to *cherry* flavour and *sour* taste.

Since, after scaling, the S × A interaction decreased, it is possible to affirm that a part of the interaction in the original data was due to the fact that assessors used the scale differently. In order to eliminate the other part of this interaction, a mixed model of analysis of variance was applied on scaled data of *rose, blackberry, bitter, wood* and *astringent*, which were the attributes associated with significant S × A interaction in the previous step. Table 7 shows *F* and *p* values for these

Table 5. Fixed analysis of variance: mean values

	Attribute								
	Aroma			*Taste*		*Flavour-by-mouth*		*Mouthfeel*	
Sample	*Rose*	*Cherry*	*Blackberry*	*Bitter*	*Sour*	*Cherry*	*Wood*	*Astringent*	*Pungent*
1	95.58a	82.90	88.17a	54.83fg	66.58c	58.92cdef	16.50f	72.92e	60.20
2	42.17fgh	85.23	38.75g	48.25g	88.92ab	41.83fg	23.17def	84.46abc	65.80
3	84.75ab	86.20	70.17abcde	63.33bcdefg	89.00ab	62.00bcde	27.42def	90.04abc	64.30
4	69.42bcde	83.25	74.75ab	55.58efg	94.42a	55.00defg	25.50def	93.96ab	65.00
5	61.92cdef	85.92	67.67abcde	83.92ab	79.08abc	42.25fg	41.25abc	100.00a	57.60
6	37.20h	86.70	41.50fg	65.42bcdefg	88.33ab	38.50g	21.17ef	91.67abc	52.10
7	74.75bcd	88.60	71.58abcd	56.42defg	87.75ab	60.83cdef	21.50def	84.33abc	60.40
8	38.50gh	78.45	36.33g	61.00cdefg	82.25abc	46.17efg	26.92def	90.33abc	57.70
9	58.83defg	79.40	50.92defg	56.83defg	81.42abc	43.08efg	30.08def	93.79ab	51.10
10	62.08cdef	80.25	72.17abc	77.25abcd	83.25abc	43.83efg	34.50bcd	97.58ab	57.40
11	66.42bcde	87.92	51.75cdefg	88.58a	73.75bc	75.25abc	45.25ab	99.75a	52.30
12	51.25efgh	78.56	44.00fg	50.75fg	77.50abc	81.75ab	44.42ab	79.67bc	52.90
13	79.42abc	81.12	55.25bcdefg	76.67abcde	89.75ab	81.50a	40.83abc	88.67ab	62.11
14	79.67abc	80.30	49.42efg	72.00abcdef	80.92abc	72.75abcd	46.08ab	82.46abc	56.60
15	61.58cdef	86.33	60.83bcdef	79.75abc	74.17bc	74.58abc	50.83a	100.00a	64.30
16	63.08cde	81.75	43.67fg	61.50cdefg	82.83abc	59.75cdef	42.00abc	91.75ab	68.20
LSD[a]	20.52	—	20.98	21.31	17.22	19.31	13.13	19.69	—

Within each column, mean values followed by the same letter are not significantly different.
[a] Least significant difference at 95%.

Table 6. Fixed analysis of variance of scaled data

Attribute	Samples (df = 15)		S × A (df = 105)		A × R (df = 14)	
	F value	p value	F value	p value	F value	p value
Aroma						
Rose	2.96	0.0001	1.79	0.0002	1.00	0.4676
Blackberry	2.32	0.0052	1.57	0.0030	0.99	0.4783
Taste						
Bitter	2.90	0.0004	1.56	0.0039	0.69	0.7795
Sour	1.36	0.2276	0.89	0.3612	1.23	0.2138
Flavour-by-mouth						
Cherry	1.45	0.2893	0.80	0.4200	0.50	0.8170
Wood	3.12	0.0001	1.58	0.0027	0.89	0.5721
Mouthfeel						
Astringent	4.12	0.0001	1.42	0.0160	1.20	0.2812

attributes. The p values of products were lower in the fixed model than in the mixed model. For all the attributes, p values were greater than 0.05. Therefore, before applying the mixed model of ANOVA, the differences across the samples were due to assessor variability. When individual differences between assessors are eliminated, the results show that there are no product differences. Therefore the wines are very similar even though they came from four different zones and different wineries. These results are probably due to the fact that grape characteristics do not change between zones and strongly affect wine sensory properties of the young wines analysed. Therefore all the attributes used in this study to describe the sensory characteristics of the products can be considered as typical descriptors, both qualitatively and quantitatively, for young Aglianico wines destined to aging.

When data show no significant differences and the *null hypothesis* is accepted, the risk of making a type II error (accepting a false *null hypothesis*) could be considered. Since we are talking about validating a typical sensory profile, it seems appropriate to take into account this kind of risk. In order to avoid a type II error, a less extreme level of significance may be considered. With the level of significance set at 90% ($p \leq 0.1$), the wine population differed in the intensity of attributes such as *astringent* and *bitter* (Table 7). These differences may be due to slight differences in wine-making techniques amongst wineries.

Table 7. Mixed analysis of variance of scaled data

Attribute	Samples (df = 15)	
	F value	p value
Aroma		
Rose	1.47	0.2800
Blackberry	1.60	0.2329
Taste		
Bitter	1.55	0.1007
Flavour-by-mouth		
Wood	1.80	0.1654
Mouthfeel		
Astringent	1.99	0.0970

A graphical representation of the typical sensory profile of the young Aglianico wines is given in Fig 1. The plot shows the mean values for the sensory descriptors. In the sample populations considered in this study, aroma attributes such as *rose* and *cherry*, taste attributes such as *bitter* and *sour* and, above all, the mouthfeel attribute *astringent* are the dominant descriptors in terms of perceived intensity. Flavour of *wood* was minimally perceived, while aroma of *blackberry*, flavour of *cherry* and mouthfeel *pungent* were perceived in moderate intensity.

CONCLUSION

Coupling fixed and mixed ANOVA models provides precise information about both panel performance and product differences. Although much more work is needed in defining statistical methods able to handle assessor × sample interactions and scaling effects, the proposed methodological approach represents a simple strategy in sensory data validation suitable when results from a fixed ANOVA model show interactions comparable with sample main effects.

In particular, the results of the study show that the presented step-by-step approach to analysing sensory data (fixed ANOVA model on raw data, fixed ANOVA model on scaled data and then mixed ANOVA model on scaled data) can be suitable for validating the sensory profile of typical regional food products. In the Aglianico wine case study, interaction and scaling effects were minimised or eliminated. Looking at product differences for each sensory attribute, no significant differences were found with p values lower than 0.05, showing that the intensity of sensory descriptors does not distinguish amongst the products. These results are not affected by assessor discrepancy and so can be referred to the typical sensory profile of Aglianico wine. At a probability level of 90%, samples

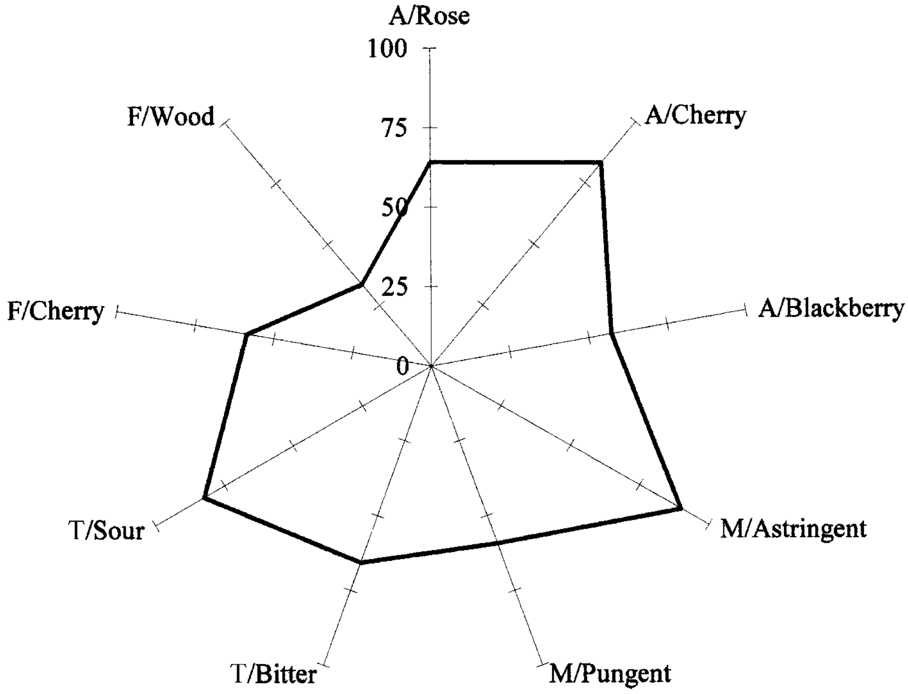

Figure 1. Sensory profile plot of mean intensity rating for descriptors of Aglianico wine.

were significantly different in the intensity of the attributes *astringent* and *bitter*.

ACKNOWLEDGEMENT

The authors are grateful to the European Union project POM B35 for financial support.

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