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Relationship between the COI test and other sensory profiles by statistical procedures

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SUMMARY

Relationship between the COI test and other sensory profiles by statistical procedures

Relationships between 139 sensory attributes evaluated on 32 samples of virgin olive oil have been analysed by a statistical sensory wheel that guarantees the objectiveness and prediction of its conclusions concerning the best clusters of attributes: green, bitter-pungent, ripe fruit, fruity, sweet fruit, undesirable attributes and two miscellanies. The procedure allows the sensory notes evaluated for potential consumers of this edible oil from the point of view of its habitual consumers to be understood with special reference to The European Communities Regulation nº2568/91. Five different panels: Spanish, Greek, Italian, Dutch and British, have been used to evaluate the samples. Analysis of the relationships between stimuli perceived by aroma, flavour, smell, mouthfeel and taste together with Linear Sensory Profiles based on Fuzzy Logic are provided. A 3-dimensional plot indicates the usefulness of the proposed procedure in the authentication of different varieties of virgin olive oil. An analysis of the volatile compounds responsible for most of the attributes gives weight to the conclusions. Directions which promise to improve the E.C. Regulation on the sensory quality of olive oil are also given.

KEY-WORDS: Chemometrics - COI test - Fuzzy logic - Sensory Analysis - Sensory wheel - Virgin olive oil.

1. INTRODUCTION

Olive oil is widely known for its delicious taste and aroma and highly prized for its contribution to the basic Mediterranean diet. However, there are many different kinds (extra-virgin, virgin, fine ...) that confused potential consumers as to their quality until The Commission of the European Communities published a standard of quality for these kinds of olive oils in 1991 (E.C., 1991). The standard, the so-called COI-Test, is based on studies performed by the largest association of producer countries –The International Olive Oil Council (COI)– that provided the principal support for the regulation.

The COI-Test was initially developed at the Instituto de la Grasa in the seventies as a result of many years of working with all kinds of olive oils. A refining process allowed the initial large set of attributes to be reduced to those described by the E.C. regulation (E.C., 1991). The methodology is in fact a Quantitative-Descriptive Analysis, henceforth QDA, (Stone et al., 1974) method that can be quickly understood and applied by chemists, farmers, fully trained assessors and apprentices with a minimum of disparity among their evaluations (Aparicio et al., 1991a). Thus, the so-called COI-Test has come to represent a fine sensory "instrument" that has helped in the regulation of trade in this foodstuff and led to the improvement of olive oil quality.

However, the trade in olive oil has spread and now includes relatively new potential consumer countries. For this reason, new attributes have been evaluated, often by non-standard olive oil QDA panels. These new attributes do not correspond semantically to those proposed by the E.C. regulation. This paper studies the evaluation of the same olive oil samples by Dutch and British panels and compares the results with those from Spanish, Italian and Greek panels that observed Regulation nº 2568/91 (E.C., 1991). A non-standard olive oil panel constituted by Italians –traditional consumers of this oil– has been used to determine the possible differences existing between traditional consumers evaluating the product with and without reference to the cited regulation.

The number of sensory notes evaluated by non-standard olive oil panels faced us with the problem of finding solutions to two basic questions, described below. Finding these solutions is the objective of the present work.

A great draw-back in sensory analysis is the apparent disagreement between the evaluations obtained from different panels. Each panel has its own set of attributes which may be quite different from those used by other panels. It is, therefore, appropriate to ask if tasters from different panels are describing the same or a different attribute when they use the same semantic term, and if, when they use different semantic terms, they are describing the same attribute. At this point, the authors wondered if some relationships between inter-panel attributes can be expected and so explain most of the attributes evaluated by these panels.

This paper is an updated version of the one presented at the Symposium.

This paper tries to give answers to these questions by analysing the relationship between COI panels and non-standard olive oil panels consisting of habitual and potential consumers of this foodstuff. Sensory Wheels and Fuzzy Linear Sensory Profiles, in addition to studies of their volatile compounds and sniffing, have been used as these are the most useful tools for achieving the general objective.

As with many standards, problems have arisen during the application of Regulation nº 2568/91 (E.C., 1991). These problems have reached such a point that the Overall Grading Quality (OGQ) is not readily accepted by some farmers and commercial firms, even though they are quite willing to accept the sensory evaluation of the attributes and the methodology described in Regulation nº 2568/91. The differences seen in the overall grading quality of the same samples calculated by different panels, strengthen the arguments against the OGQ. These differences mostly arise because in those studies the panels were not constituted by fully trained expert assessors (Aparicio et al., 1991a).

Alternatives for calculating the OGQ from the attribute scores, instead of using another evaluation supplementing the sensory trials, have already been proposed (Aparicio et al., 1992). The standard, being based on sensory trials, can be affected by the customary cuisine and culture of the assessors. As OGQs were obtained from sensory attributes this problem does not arise.

Finally, the paper describes the conclusions with most significance for the improvement of E.C. Regulation nº 2568/91 (E.C., 1991).

2. MATERIALS AND METHODS

2.1. Samples and sensory trial characteristics.

The data set is made up of 32 samples of virgin olive oil harvested in two consecutive years and collected from Spain, Greece and Italy in perfect sanitary conditions. Table I summarizes the olive characteristics, name, origin, maturity and extraction systems.

The varieties –Arbequina and Picual (Spain), Coratina and Cima di Bitonto (Italy), Koroneiki and Tzunnati (Greece)– were selected as they represent a greater percentage of the bottled olive oil trade (Morettini, 1950; Alonso and Aparicio, 1993). The samples were picked at three stages of maturity: under-ripe, ripe and overripe; the well known suggestions of The Olive Oil Research Department at Mengibar, Spain, (EOC, 1976; Solinas et al., 1987) were followed to collect Spanish samples whilst Good Manufacturing Practices (Hermoso et al., 1991) were strictly applied during olive oil extraction.

Each sample was characterized by non-volatile (Aparicio et al., 1991b; Aparicio and Alonso, 1994) and volatile (Morales et al., 1994) chemical compounds.

Table I
Details on samples used for sensory evaluation

CODE	NAME	RIPENESS	COUNTRY	EXTRACTION
G0101CE	Coroneiki	Unripe	Greece	Centrifugation
G0102CE	Coroneiki	Normal	Greece	Centrifugation
G0103CE	Coroneiki	Over-ripe	Greece	Centrifugation
G0102PE	Coroneiki	Normal	Greece	Percolation
G0202CE	Tzunnati	Normal	Greece	Centrifugation
I0301CE	Coratina	Unripe	Italy	Centrifugation
I0302CE	Coratina	Normal	Italy	Centrifugation
I0303CE	Coratina	Over-ripe	Italy	Centrifugation
I0302PR	Coratina	Normal	Italy	Expression
I0402CE	Cima di Bitonto	Normal	Italy	Centrifugation
S0501CE	Picual	Unripe	Spain	Centrifugation
S0502CE	Picual	Normal	Spain	Centrifugation
S0503CE	Picual	Over-ripe	Spain	Centrifugation
S0601CE	Arbequina	Unripe	Spain	Centrifugation
S0602CE	Arbequina	Normal	Spain	Centrifugation
S0603CE	Arbequina	Over-ripe	Spain	Centrifugation

Five different panels of assessors of different nationalities, assessed 153 sensory notes described in Tables II. Table II.a shows the olfactory-gustatory-tactile sensory notes evaluated by each panel and how they were perceived. 57 names of attributes appear repeated at least once whilst 30 names represent the same attribute evaluated by different perceptions.

Table II.a also displays non-sensory attributes as overall gradings and the appearance attributes. These will not be used in this paper since some samples were not filtered, other were filtered only and the rest were filtered and brightened.

Table II.b shows the attributes calculated from those displayed in Table II.a, plainly justified in the paragraph "First step: Univariate studies of attributes".

Table II.a
Overall Gradings and Attributes evaluated by all panels.
The codes identified the attributes in the paper

PANEL	ATTRIBUTE	PERCEPTION	CODE	PANEL	ATTRIBUTE	PERCEPTION	CODE
Grasa	Olive fruity (green)	Olfactory-gustatory	1	URL	Odour intensity	Smell	79
Grasa	Apple	Olfactory-gustatory	2	URL	Sea breeze on the beach	Smell	80
Grasa	Other ripe fruits	Olfactory-gustatory	3	URL	Prickling	Smell	81
Grasa	Green	Olfactory-gustatory	4	URL	Apple	Smell	82
Grasa	Bitter	Olfactory-gustatory	5	URL	Twig	Smell	83
Grasa	Pungent	Olfactory-gustatory	6	URL	Pine/Harshy	Smell	84
Grasa	Sweet	Olfactory-gustatory	7	URL	Dry wood	Smell	85
Grasa	Winey	Olfactory-gustatory	8	URL	Lemon	Smell	86
Grasa	Rough	Olfactory-gustatory	9	URL	Orange	Smell	87
Grasa	Metallic	Olfactory-gustatory	10	URL	Soft fruits	Smell	88
Grasa	Mustiness	Olfactory-gustatory	11	URL	Candies (fruit)	Smell	89
Grasa	Muddy sediment	Olfactory-gustatory	12	URL	Wild flowers in springtime	Smell	90
Grasa	Fusty ("Atrojado")	Olfactory-gustatory	13	URL	Fermenting fruit	Smell	91
Grasa	Rancid	Olfactory-gustatory	14	URL	Farm	Smell	92
Grasa	Olive fruity (ripe)	Olfactory-gustatory	15	URL	Oil for salads (bean oil)	Smel	93
SSOG	Olive fruity (ripe & green)	Olfactory-gustatory	16	URL	Tallow	Smell	94
SSOG	Other ripe fruits	Olfactory-gustatory	17	URL	Rancid	Smell	95
SSOG	Green	Olfactory-gustatory	18	URL	Cod liver oil	Smell	96
SSOG	Bitter	Olfactory-gustatory	19	URL	Nuts	Smell	97
SSOG	Pungent	Olfactory-gustatory	20	URL	Medicine	Smell	98
SSOG	Sweet	Olfactory-gustatory	21	URL	Earthy	Smell	99
SSOG	"allowable"	Olfactory-gustatory	22	URL	Taste intensity	Taste	100
SSOG	Winey	Olfactory-gustatory	23	URL	Sweet	Taste	101
SSOG	Rough	Olfactory-gustatory	24	URL	Salty	Taste	102
SSOG	Mustiness	Olfactory-gustatory	25	URL	Sour	Taste	103
SSOG	Muddy sediment	Olfactory-gustatory	26	URL	Vinegar	Taste	104
SSOG	Fusty	Olfactory-gustatory	27	URL	Olives	Taste	105
SSOG	Rancid	Olfactory-gustatory	28	URL	Green leaf	Taste	106
SSOG	"unallowable"	Olfactory-gustatory	29	URL	Grass	Taste	107
Eleourgiki	Olive fruity (ripe & green)	Olfactory-gustatory	30	URL	Green banana (not ripe)	Taste	108
Eleourgiki	Apple	Olfactory-gustatory	31	URL	Dried green herbs	Taste	109
Eleourgiki	Other ripe fruits	Olfactory-gustatory	32	URL	Minced pepper	Taste	110
Eleourgiki	Green	Olfactory-gustatory	33	URL	Red chili pepper	Taste	111
Eleourgiki	Bitter	Olfactory-gustatory	34	URL	Cream/butter	Taste	112
Eleourgiki	Pungent	Olfactory-gustatory	35	URL	Rancid	Taste	113
Eleourgiki	Sweet	Olfactory-gustatory	36	URL	Cocos	Taste	114
Eleourgiki	Winey	Olfactory-gustatory	37	URL	Caramel	Taste	115
Eleourgiki	Rough	Olfactory-gustatory	38	URL	Grotty	Taste	116
Eleourgiki	Metallic	Olfactory-gustatory	39	URL	Velvet like	Mouthfeel	117
Eleourgiki	Mustiness	Olfactory-gustatory	40	URL	Sticky	Mouthfeel	118
Eleourgiki	Muddy sediment	Olfactory-gustatory	41	URL	Slightly burned/toasted	Taste	119

PANEL	ATTRIBUTE	PERCEPTION	CODE	PANEL	ATTRIBUTE	PERCEPTION	CODE
Eleourgiki	Fusty	Olfactory-gustatory	42	URL	Ash tray	Taste	120
Eleourgiki	Rancid	Olfactory-gustatory	43	URL	Glue with ethylacetate	Taste	121
Eleourgiki	"unallowable"	Olfactory-gustatory	44	URL	Refinery	Taste	122
Biagini	Tomato	Aroma	45	URL	Metallic	Taste	123
Biagini	Tomato	Flavour by mouth	46	URL	Bitter	Taste	124
Biagini	Ripe black olives	Aroma	47	URL	Astringent	Mouthfeel	125
Biagini	Ripe black olives	Flavour by mouth	48	URL	Green	Aftertaste	126
Biagini	Green olives	Aroma	49	URL	Fruity	Aftertaste	127
Biagini	Green olives	Flavour by mouth	50	URL	Cooling/evaporating	After mouthfeel	128
Biagini	Cut green grassy	Aroma	51	URL	Glue with ethylacetate	Aftertaste	129
Biagini	Cut green grassy	Flavour by mouth	52	URL	Cocoabutter/white choc.	Aftertaste	130
Biagini	Artichoke	Aroma	53	URL	Putty/lineseed oil	Aftertaste	131
Biagini	Artichoke	Flavour by mouth	54	URL	Used frying oil	Aftertaste	132
Biagini	Apple	Aroma	55	URL	Trany	Aftertaste	133
Biagini	Apple	Flavour by mouth	56	URL	Rough	After mouthfeel	134
Biagini	Yeast	Aroma	57	URL	Dry wood	Aftertaste	135
Biagini	Bitter	Taste	58	URL	Dusty	Aftertaste	136
Biagini	Pungent	Mouthfeel	59	URL	Dry	After mouthfeel	137
Biagini	Astringent	Mouthfeel	60	URL	Sharp/etching	After mouthfeel	138
CFDRA	Strength of olive	Odour	61	URL	Pungent/sharp throat	After mouthfeel	139
CFDRA	Strength of olive	Flavour	62	Biagini	Yellow	Appearance	140
CFDRA	Banana skins	Odour	63	Biagini	Green	Appearance	141
CFDRA	Banana skins	Flavour	64	CFDRA	Brightness	Appearance	142
CFDRA	Tomato	Odour	65	CFDRA	Depth of colour	Appearance	143
CFDRA	Tomato	Flavour	66	CFDRA	Yellow	Appearance	144
CFDRA	Sweet	Odour	67	CFDRA	Brown	Appearance	145
CFDRA	Hay/composty	Odour	68	CFDRA	Green	Appearance	146
CFDRA	Hay/composty	Flavour	69	URL	Yellow	Appearance	147
CFDRA	Perfumey	Odour	70	URL	Green	Appearance	148
CFDRA	Perfumey	Flavour	71	URL	Brown	Appearance	149
CFDRA	Grassy	Odour	72	URL	Glossy	Appearance	150
CFDRA	Grassy	Flavour	73	URL	Transparent	Appearance	151
CFDRA	Almond	Odour	74	URL	Particles	Appearance	152
CFDRA	Almond	Flavour	75	URL	Syrup like	Appearance	153
CFDRA	Throatcatching	Mouthfeel	76	Grasa	Overall gradings		154
CFDRA	Thickness	Mouthfeel	77	SSOG	Overall gradings		155
CFDRA	Pungent	Flavour	78	Eleourgiki	Overall gradings		156

Tabla II.b
Attributes evaluated by two different perceptions.

PANEL	ATTRIBUTE	PERCEPTION	CODE	PANEL	ATTRIBUTE	PERCEPTION	CODE
Grasa	"Undesirable"	Olfactory-gustatory	157	CFDRA	Grassy	Olfactory-gustatory	166
SSOG	"Undesirable"	Olfactory-gustatory	158	CFDRA	Banana skins	Olfactory-gustatory	167
Eleourgiki	"Undesirable"	Olfactory-gustatory	159	CFDRA	Almond	Olfactory-gustatory	168
Biagini	Tomato	Olfactory-gustatory	160	CFDRA	Tomato	Olfactory-gustatory	169
Biagini	Ripe olives	Olfactory-gustatory	161	CFDRA	Compost	Olfactory-gustatory	170
Biagini	Green olives	Olfactory-gustatory	162	URL	Rancid	Olfactory-gustatory	171
Biagini	Cut green grassy	Olfactory-gustatory	163	URL	Wood	Olfactory-gustatory	172
Biagini	Artichoke	Olfactory-gustatory	164	URL	Undesirable	Olfactory-gustatory	173
Biagini	Apple	Olfactory-gustatory	165				

From a sensory point of view, all panels are QDA but we may split the panels into two groups on the basis of how each attribute is perceived: olive oil standard panels, which used the so-called COI-Test, and non-standard olive oil panels, Table III. The score for each COI-Test attribute is the result of the whole gustatory-olfactory-tactile perception, whilst the attributes of non-standard olive oil panels are independently evaluated by their different perceptions: smell, taste, odour, mouthfeel, aroma, flavour, etc..

The Spanish panel is constituted by fully trained expert assessors with more than ten years experience in evaluating all kinds of olive oils using the COI-Test (Aparicio et al., 1992). Only some attributes of Regulation nº2568/91 (E.C., 1991), for example acidity and humidity, were not detected in the samples assessed by this panel, in agreement with Aparicio et al. (1992).

Italian SSOG (Stazione Sperimentali per le Industrie degli Oli e dei Grassi) assessors were trained following E.C. directions. The asessors' codes were not reported so we do not know if they changed over the years. The apple attribute was not reported by this panel one year and has been removed from this study.

The panellists of the Greek Eleourgiki panel, who also used the COI-Test, were trained following the olive oil quality standard (E.C., 1991). These panellists work at an olive oil factory and are habitual consumers of this foodstuff. The assessors were the same both years but not all assessors evaluated all samples.

The Italian Biagini assessors were trained using mixtures of different olive oil brands. The assessors were students at an Italian University and changed from one year to the other. The statistical methodology followed to check their abilities has not been given (FLAIR, 1991).

The British CFDRA assessors were trained using different oils (sunflower, nuts, sesame, olive, etc.) which may explain why they evaluated some attributes in virgin olive oil samples that were not evaluated by habitual consumers of this oil during the COI-Test refinement process. Unfortunately, the assessors evaluated different attributes each year, so Table II.a describes those common to both years. Some panellists changed from one year to the other.

The Dutch Unilever (henceforth, URL) assessors were selected using Gitu and Firmenich tests and trained evaluating different olive oil brands (Mojet and Vaessen, 1991). Some of its sensory notes have not been reported during the process of refining the COI-Test nor by Gutierrez et al. (1975), for example. There were also some changes in the panellists from one year to the other.

2.2. Mathematical tools

Two different statistical packages have been used to carry out the mathematical studies: BMDP (Dixon, 1983), SPSS (1986) and SAS (SAS, 1992). The software was run under VMS on a DEC 8550.

Principal Components Analysis (PCA) was applied to analyse the structure of the datasets. Cross-validation (Martens and Naes, 1989), repeated at least four times with a different cancellation matrix, always indicated that the first two significant components were in general enough for this study.

Table III
Basic characteristics of the panels.

INSTITUTION	Biagini	CFDRA	Eleour	I.Grasa	SSOG	URL
Nationality	Italy	UK	Greece	Spain	Italy	Nederland
Nº assessors	11/12	9	14	10	10	10/8
Assessor's level	T	T	T	F	NR	T
Know. Olive Oil	NR	L	C	C	C	L
Consumer	NR	P	H	H	H	P
Pres. samples	NR	Random	NR	Random	NR	Random
Nº attributes	18	27/26	15	15	17/16	68
Type of Panel	QDA	QDA	COI	QDA-COI	COI	QDA
Scale	S	U	S	S	S	U
Scores	1-9	100 mm	1-5	1-5	1-5	130 mm
Replicates	3	3	3	3	NR	3
Data (Years)	2	2	2	2	2	2
Attributes/Taster	1.5	3.0	1.1	1.5	1.7	8.5

Legend:
F/T: Full assesor (>10 years)/Trained for this project.
NR: Not Reported
U/S: Unstructured/Structured.
H/P: Habitual/Potencial.
L/C: Limited/Complete.

On the other hand, a program emulating Multiscale (Ramsay, 1978; Shiffman et al., 1981), Multiple Linear Regression and Canonical Regression Analysis were used to calculate the ellipsoids for the most relevant COI attributes from their standard errors for each coordinate, the sensory wheel sector, stimulus spaces and redundancies among attributes.

Linear Sensory Profiles were made by applying the fuzzy filter algorithm designed by Calvente and Aparicio, programmed in Fortran and run under the MS-DOS Operating System.

AUTOCAD11 (López and Tajadura, 1992), under the Ultrix Operating System, was used to draw all figures except the Fuzzy Linear Sensory Profiles that were plotted using Sigmaplot (1991) under the MS-DOS Operating System.

2.3. State-of-the-art in Sensory Wheel.

It is important to distinguish in Statistics between those programs which basically explore and those which mainly confirm conclusions from datasets.

The former are designed to let the user view datasets in a wide panoply of ways in order to uncover various interesting relationships. The emphasis in such analyses is not so much on decisions or aspects of the data as on displaying what is there.

The aims of this paper are to make decisions about whether the data from many groups can be represented by the same configuration, or whether a basic structure does not abruptly change as new information is added or whether datasets constrained by a projection are the same as the unconstrained information. To achieve these goals, it is assumed that there are a number of aspects of the random variation in the data that have to be taken into account before a procedure can be specified, computed and maximized to obtain maximum likelihood estimates.

The Sensory wheel (Pilgrim and Schutz, 1957; Noble et al., 1987) is widely known for its ability to give rapid solutions to the questions mentioned in the Introduction section of this paper. From a sensory point of view, Noble et al. (1987), for example, proposed that the sectors were made taking into account reference standards though grouping the sectors by the subjective opinions of experts. This procedure, for example, does not consider possible synergy and antagonism between the sectors defined by sensory perceptions and chemical compounds. From a mathematical point of view, it is a non-hierarchical cluster analysis where sensory notes, selected from each cluster, cannot be used to qualify the sensory wheel sectors. Consequently, this procedure has at least one of the following drawbacks:

(i) if the sensory note qualifying each sector is selected by subjective opinions, being sure that all the sensory notes belonging to the cluster have similar meanings, then the limits (angles) of each sector will be different depending on the selected qualifier. Moreover, the subjective opinion used to define the sector will be reflected in the conclusions

(ii) if only cluster or principal components analyses are used, we face at least two problems: (a) the standard deviation of the raw sensory notes will not be taken into account and, in consequence, the limits of the sensory wheel sectors could abruptly change with other information reported; and (b) if there are many sensory notes, then clear sensory wheel sectors are quite impossible, too fuzzy sectors appearing which are not easy to interpret.

2.4. Computing sensory wheel sectors

Another approach is to take into account the effects of synergy and antagonism between attributes and analyse the results applying mathematical algorithms. Thus, in previous, yet unpublished, studies, Aparicio and Morales selected the best attributes and assessors to be used in uni-and-multivariate studies of outliers, repeatability of attributes and product-assessor interaction. The authors calculated the sensory wheel sectors projecting the position of each attribute in the PCA plot onto a circle of radius one and then calculated the circular deviation of the mean of all attributes in the groups predefined by the COI-Test. The results were circles and the tangents from (0,0) to each circle allowed delimitation of each sensory wheel sector as Figure 1.a. shows for the so-called undesirable sector.

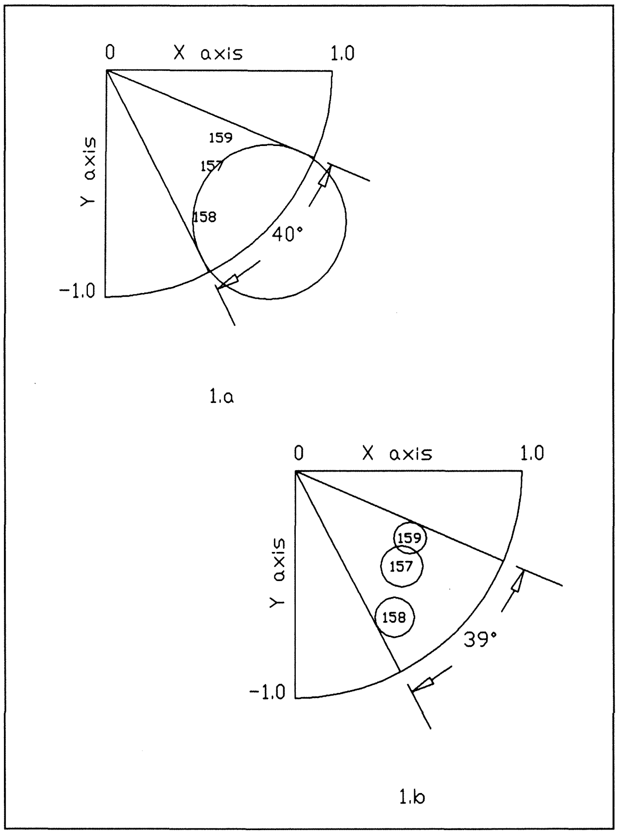

Figure 1
Geometry of the procedure for calculating the sensory wheel sectors. Figure 1.a displays the procedure used applying Mardias. Figure 1.b the results of applying multidimensional scaling.

However, there is disagreement about the pros and cons of segregating or eliminating attributes and assessors because they are in fact outliers (Powers & Ware, 1986; Powers, 1988). For this reason this paper uses another approach in which all attributes and assessors are used and the boundaries of each sensory wheel sector are built from the ellipsoids showing the 95% confidence limits of the most remarkable attributes of COI-Test. These elliptical regions are computed using the standard errors of the estimates for coordinates. The standard errors indicate the relative variability of an attribute with respect to the dimensions or, in other words, a rough idea of how much noise is in the attribute coordinates estimate. The boundaries of each sensory wheel sector are calculated by tangents from (0,0) to the ellipsoids of the most separate attributes inside the group, Figure 1.b. The standard errors have been calculated following the procedure used by Multiscale (Shiffman et al., 1981).

We have applied the results to PCA plots but they would not have changed if we had directly applied such multidimensional scaling procedures Alscal (SAS, 1992) with an adequate selection of the stress variable. The similarity of these statistical procedures have been demonstrated for the present study, while other authors (Williams and Arnold, 1985) have demonstrated their similarity for other purposes.

3. RESULTS

The steps in this study have been divided into six groups following strict mathematical methodology:

(i) previous analysis of data by univariate studies of attributes: skewness and kurtosis, histograms and correlations.

(ii) successive consensus plots of COI panels and habitual consumers of virgin olive oil.

(iii) Sensory Wheels of Italian (Biagini) and British (CFDRA) non-standard olive oil panels from the point of view of the COI-Test, made by the ellipsoids of the 95% confidence limits of the most remarkable COI-Test attributes.

(iv) Dutch panel projection on the sensory wheel.

(v) Sample characterization by the selection of the best attributes of each sensory wheel sector. Results of distinguishing between varieties and stages of maturity of samples in prediction.

(vi) Fuzzy Linear Sensory Profile, a rapid method for displaying the usefulness of attributes characterizing samples.

3.1. First step: Univariate studies of attributes.

A study of skewness and kurtosis on each attribute showed that most of them had an almost normal distribution (Tabachnick and Fidell, 1983), so no transformation had to be applied to them. The rest showed a severe positive skewness, so a transformation was applied before further analysis was performed.

Histograms showed that the value of some attributes evaluated was virtually zero. This was the case for a series of the so-called undesirable attributes of the COI-Test and *the sweet* attribute (nº7, see codes in Tables II). The *sweet* attribute was removed as its average value (0.05) indicates noise rather than a perception (Aparicio et al., 1991c).

The sensory attributes: *winey*, *rough*, *metallic*, *mustiness*, *muddy sediment*, *fusty*, *rancid*, *sour*, *vinegary*, *ferment*, *tallow*, etc., are defined by the COI-Test under the general pseudonym of *undesirable* or *unallowable*. These attributes do not qualify virgin olive oil at all though they may appear as barely perceptible with good repeatability by assessors motivated enough by these attributes.

This study has been performed with olives picked in perfect sanitary conditions, extracted and stored under the best conditions and delivered by courier. Consequently, it is to be expected that those "undesirable" attributes would only be evaluated at their lowest values. A simple analysis of the evaluations made for these attributes confirms this; only 2 out of 22 attributes have a value greater than 0.5 on a scale of 1 to 5.

Multivariate studies of different olive oils (Aparicio et al., 1991a) demonstrated that the "undesirable" attributes were always plotted very close each together as virgin olive oil was evaluated. Their closeness is as much due to their negative correlations with the other attributes as to their low values. However, this series of attributes represents half of the attributes evaluated by the COI-Test and it also causes problems when working with multivariate procedures, as we have a low number of samples and a high number of attributes. As this was not problem for PCA, this method was used for all *undesirable* attributes. They have, however, been grouped into a cluster as when the results from different panels are added the number of attributes can represent a problem in multivariate studies (Shiffman et al., 1981).

On the other hand, the values assigned to each COI-Test attribute is the consequence of its olfactory-gustatory-tactile perceptions, whilst non-standard olive oil panels separately evaluated the perceptions of many of their attributes, for example odour and flavour, or aroma and flavour by mouth. At this point, the authors wondered how olive oil attributes should be perceived: (i) describing perceptions separately or (ii) giving an average of all perceptions from samples.

A correlation analysis of the different sensory perceptions of the same attribute (Table IV) shows that for almost all attributes (89%), separate sensory perceptions of the same attribute do not add relevant information concerning olive oil sensory characterization. In other words, these results support the evaluation methodology proposed by Regulation nº 2568/91 (E.C, 1991). Thus, as the COI-Test suggests, we have gathered those perceptions of the same attribute in one since they have a correlation value greater than 0.80 (2-tail significance at 0.001). Figure 2 shows the results of applying principal components analysis to those attributes evaluated by Biagini and CFDRA panels. The results agree with those shown in Table IV and justify clustering those with correlations greater than 0.80 in successive Principal Components Analysis and/or MultiDimensional Scaling.

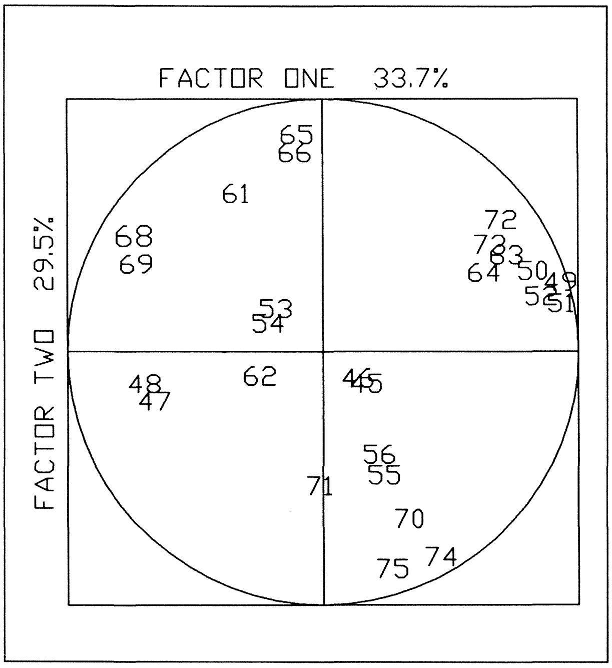

Figure 2
Principal Components Analysis of attributes evaluated by two different perceptions. Panels: CFDRA and Biagini. The closeness of attributes is an indication of similarity in their evaluation.

As has been mentioned, this paper does not describe how the best attributes and assessors of different panels can be selected but an in depth study of this subject has also been developed by the authors (Aparicio and Morales, yet unpublished).

3.2. Second step: Successive consensus plots of COI panels and habitual consumers of virgin olive oil.

Studies carried out at the Instituto de la Grasa for many years suggested that there were clear sensory perceptions defining virgin olive oil though these had not been demonstrated using strict mathematical procedures. Basically, there are four large groups that characterize virgin olive oil : *greens, bitter-pungent-astringent, fruit-fruity* with three possible parts (*green-fruity, ripe-fruity and sometimes sweet-fruity*) and a miscellany of undesirable attributes. There is a cycle that can be *bitter-pungent, green, fruit-fruity, the undesirable* attributes and *bitter-pungent* again. This cycle shows a logical structure from the point of view of sensory analysis though there are definite well-documented exceptions, for instance *rough* and *metallic* (Aparicio et al., 1991a). In fact, most of the groups are well-correlated with non-volatile (Gutierrez et al., 1989) or volatile (Morales and Aparicio, 1993b; Aparicio and Morales, 1994) compounds, or easily detected by sniffing the same samples (Morales et al., 1994) or similar oils (Olias et al., 1978; Olias et al., 1980).

Table IV
Correlations between the different perceptions of the same attribute.

PANEL	FIRST PERCEPCION	CODE	SECOND PERCEPTION	CODE	CORRELATION
Biagini	Ripe olives aroma	47	Ripe olives flavour by mouth	48	0.9822
Biagini	Green olives aroma	49	Green olives flavour by mouth	50	0.8854
Biagini	Cut green grassy aroma	51	Cut green grassy flavour by mouth	52	0.9803
Biagini	Artichoke aroma	53	Artichoke flavour by mouth	54	0.9678
Biagini	Apple aroma	55	Apple flavour by mouth	56	0.9408
Biagini	Tomato aroma	45	Tomato flavour by mouth	46	0.9717
CFDRA	Strength odour	61	Strength flavour	62	0.4795
CFDRA	Grassy odour	72	Grassy flavour	73	0.9301
CFDRA	Banana skins odour	63	Banana skins flavour	64	0.8169
CFDRA	Almond odour	74	Almond flavour	75	0.9260
CFDRA	Tomato odour	65	Tomato flavour	66	0.9035
CFDRA	Compost odour	68	Compost flavour	69	0.8946
CFDRA	Perfumey odour	70	Perfumey flavour	71	0.6500
CFDRA	Pungent odour[1]	–	Pungent flavour	78	0.8216
CFDRA	Oily odour[1]	–	Oily flavour[1]	–	0.8138
URL	Rancid smell	95	Rancid taste	113	0.9107
URL	Dry wood smell	85	Dry wood aftertaste	135	0.9331
URL	Odour intensity	79	Taste intensity	100	0.8897

[1] Attribute evaluated only one year or the first year.

This structure basically remains when analysing all COI-Panels one by one. We only found, for example, a small discrepancy in that the Spanish and Italian panels displayed their attributes in clock-wise and anti-clock-wise directions, respectively, which is due to differences in the level of assessors' training (Aparicio et al., 1991a).

Figure 3 shows the Consensus Space of all COI-Panels by principal components analysis of 43 attributes. The overall grading of each panel has been projected on the plot. Each one of the quadrants could be, more or less, associated with one, and only one, of the four well-documented groups.

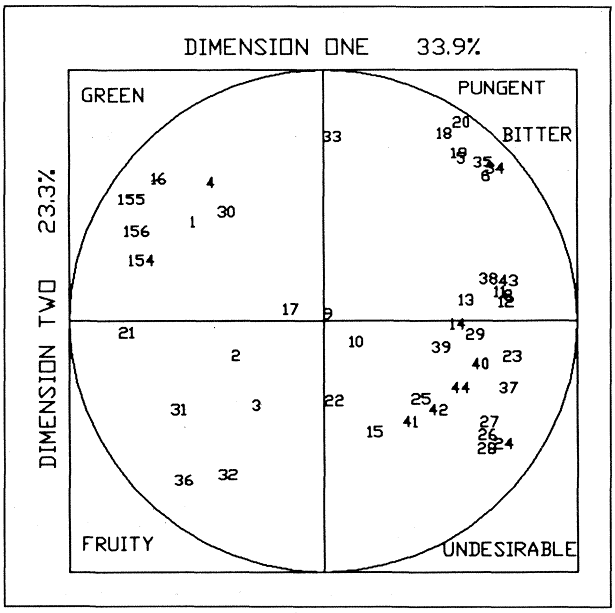

Figure 3
Consensus Space of COI panels: Grasa, SSOG and Eleourgiki.

Half of all the attributes, the so-called undesirable ones, constituted a single cluster, this being placed more or less in the fourth quadrant. The first quadrant belongs to the bitter-pungent group, the second to the green and green-fruity and the third to the miscellany of fruit, sweet and ripe fruits, the initially so-called fruit-fruity. The location of each group in the plot is noteworthy: the undesirable attributes are opposite the green attributes and the bitter-pungent attributes are opposite the fruit-fruity ones. Finally, it is interesting to observe the closeness of the overall gradings and their location very near to the green group and opposite the undesirable attributes.

The most noticeable flaw is the *green* attribute (nº33) evaluated by the Greek panel. This is not close to the green group but rather between the bitter-pungent and green groups, perhaps indicating that Greek assessors consider this attribute as representing a slightly bitter perception.

Once the similarity of the different COI-Panels had been well demonstrated by mathematical tools, we added information from another panel whose evaluations had not been carried out using the E.C. standard though the panel was composed of habitual consumers of this foodstuff.

First of all, we made up our minds to gather undesirable COI attributes from each panel on the one hand and the perceptions of the same attribute, if these had correlations greater than 0.80 (Table IV), on the other. This decision allowed to have an optimum ratio samples to attributes and well balanced number of attributes per panel. The overall gradings have been projected as in previous plots. Figure 4 shows the sensory wheel sectors obtained from the ellipsoids of the most noteworthy COI attributes, following the procedure described above. Thus, this figure allows us to see the sensory evaluations of the non-standard olive oil panel (Biagini), composed of habitual consumers, from the point of view of the COI-Test.

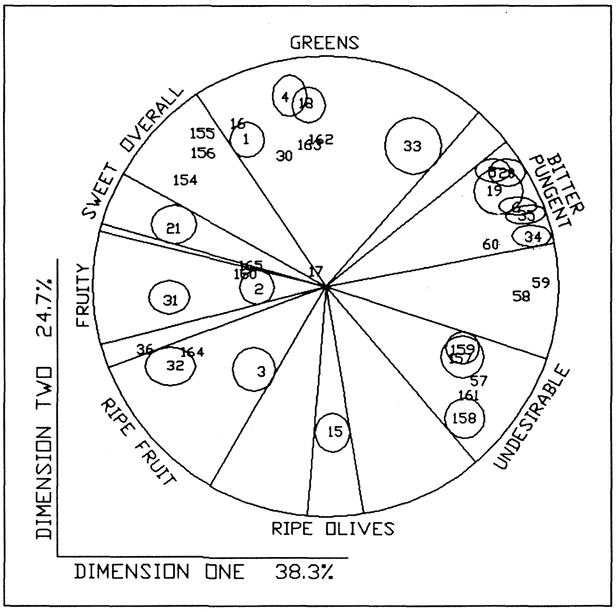

Figure 4
Sensory Wheel Sectors of habitual consumers of virgin olive oil from COI-Test point of view. Panels: Grasa, SSOG, Eleourgiki and Biagini. Ellipsoids (95% of confidence region) of the most important COI-Test attributes.

This new consensus space again shows the four groups which have been perfected since the previous study, where the 'noise' of undesirable attributes did not allow the relationship between the other attributes to be seen clearly. The new attributes, those evaluated by the Biagini panel, were placed in those groups that correspond to their semantic names, for example *cut green grassy* (nº163) and *green olives* (nº162) inside the green group or *astringent* (nº60) in the bitter-pungent group. The new *bitter* (nº58) and *pungent* (nº59) attributes, however, appear rather separated from their group.

Artichoke (nº164) was placed in a group that could be defined as sweet ripe fruit. In order to investigate whether its position in consensus space was a mistake, we crossed our olive oil volatile database with that from other studies (Maarse and Visscher, 1989). The common volatiles are basically: hexanal, 1-hexanol and trans-2-hexenal. These volatiles were associated with fruity and sweet sensory notes by sniffing (Morales et al., 1994) and support the position of artichoke in figure 4.

Ripe olives attribute (nº161) does not apparently represent a serious flaw in this study despite it appearing too close to the undesirable attributes. This was the initial position of *fruity ripe olives* (nº15) as the COI panels were analysed (figure 2). However analysing each year's evaluations, we observed that in the first year it was correlated with attributes *pungent* (nº59), correlation coefficient R=0.04, and with *yeast* (nº57), R=0.34, whilst in the second year it was correlated with *pungent* (nº59), R=0.75, and with *yeast* (nº57), R=0.91. This may indicate a different perception of the same attribute each year. This hypothesis is supported by the sample characterization study in which samples were separated more on the basis of varieties than crops.

3.3. Third step: sensory Wheel from COI-Test point of view

The next challenge was to add the sensory information evaluated by a non-standard olive oil panel, CFDRA, whose assessors are not habitual consumers of this edible oil. Figure 5 shows the results using the same procedure applied to analyse the panels of habitual consumers of virgin olive oil. The structure does not change so that we will only explain where and why some of the new attributes have been placed in the sensory wheel sectors. First of all, the green sector has been delimited to the area determined by most of the green attributes evaluated by habitual consumers. The *green* attribute, numbered 33, evaluated by the Greek panel, has been taken to be an outlier and left between the green and bitter-pungent groups. The authors accept that this is a subjective opinion, although the decision is supported by an outliers' study of all green attributes.

This figure shows another circle of radius 0.5. This circle divides the sensory wheel into two parts: the part enclosed inside this new circle and the other lying between this circle and the old one of radius 1.0. In terms of statistics, we can say that attributes inside the small circle contribute less to the sensory characterization of these olive oil samples than those plotted between both circles. This information should be treated with care but it can be instructive for evaluating uncommon sensory attributes from the point of view of habitual consumers.

Banana skins attribute (nº167) has been placed at the limits of the green group. Banana skins could be associated with 3-hexenyl acetate, 2-penten-1-ol, trans-3-hexen-1-ol and 3-hexenal. The results of the analyses of volatile compounds support the location of this attribute in the sensory wheel.

Almond attribute (nº168) appears in the bitter-pungent sensory wheel sector though it was placed inside the first circle. Panellists possibly referred to a slightly bitter marzipan that could be associated with 2-hexenal (correlation 0.81).

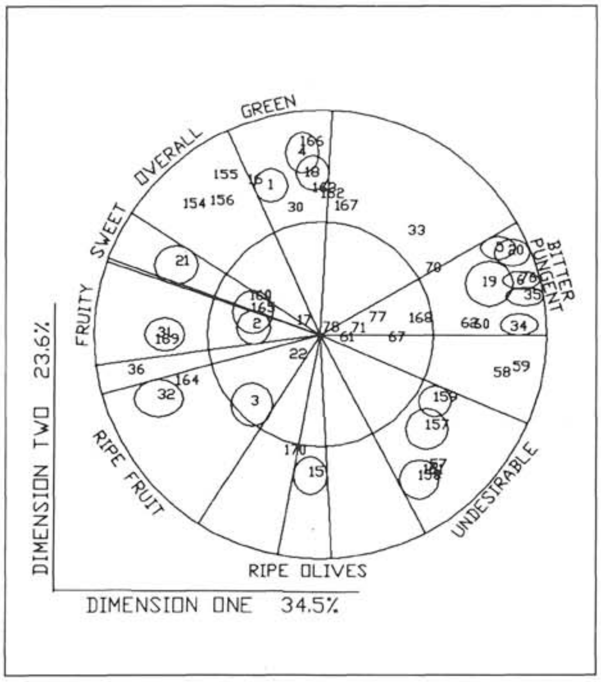

Figure 5
Sensory Wheel Sectors of habitual and potential consumers of virgin olive oil from COI-Test point of view. Panels: Grasa, SSOG, Eleourgiki, Biagini and CFDRA. Ellipsoids (95% of confidence region) of the most important COI-Test attributes.

Perfumey odour (nº70) has been defined as *blossomy/floral* and it appears at the limits of, but outside, the bitter-pungent group.

We have detected two perceptions, concerning *tomatoes* (nº160 and 169). One of these is related to sweet due to 3-methylbutanal, 2-pentenal, 3-pentanone, 1-penten-3-one, ethyl propanoate, etc., and the other is related to fruity due to 1-hexanol, trans-3-hexen-1-ol, trans-2-pentenal, trans-2-hexenal, 2-heptanone, 2-nonanone, etc. The presence of these volatile compounds and their synergy/antagonism could explain the different sensations perceived by assessors of both panels and hence the positions of these attributes in the sensory wheel sectors.

It is significant that the flavour of *strength of olive* (nº 62) appears very close to astringent (nº60). It seems that non-habitual consumers feel bitter-pungent-astringent perceptions to be the most outstanding in virgin olive oil.

Finally, *grassy* attribute (nº166) neatly appears inside the ellipsoid of the *green* attribute (nº4).

3.4. Fourth step: Dutch panel projection on the sensory wheels

Until now, we have analysed the panels with a more or less balanced number of attributes per panel but the Unilever Research Laboratory (URL) panel evaluated 61 attributes (this paper does not analyse the appearance attributes) which is almost more than all the other panels together. On the other hand, we analysed the correlations among *olive* (nº61) perceived evaluating this variety. The high values of the *tomato* (nº169) attribute and the low values of the *pungent* (nº78) attribute could be used to authenticate the Arbequina variety.

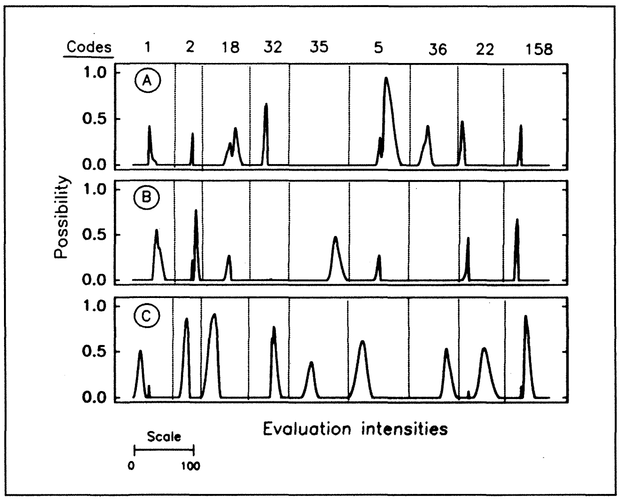

Figure 10
Fuzzy Linear Sensory Profile of stage of maturity: unripe (A), normal ripeness (B) and over-ripe (C). Codes indicate the attributes described in Tables II.

Table V
Sensitivity of attributes to the stages of maturity using the Fuzzy Linear Sensory Profile procedure.

CODE	A	B
1	over-ripe	normal
2	over-ripe	normal
18	over-ripe	unripe
32	unripe	over-ripe
35	over-ripe	normal
5	over-ripe	unripe
36	unripe	over-ripe
22	-	over-ripe
158	unripe	over-ripe

Legend:
A indicates the stage of maturity with the lowest perception intensity for the attributes, and
B indicates the stage of maturity with the highest perception intensity for the attributes.

3.7. A suggestion for improving the COI-Test.

The COI-Test is a suitable method for controlling and improving olive oil quality but when it was designed in 1987 (COI, 1987a) two events had not occurred. The first was the large increase in business developed with potential consumers who have different point of view on the most significant sensory notes of virgin olive oil and the second, the great success of computers in all aspects of Food Technology (Aparicio, 1988; Proc. Use of Computers in the Sensory Lab. Outstanding Symposia in Food Science Technology, 1984).

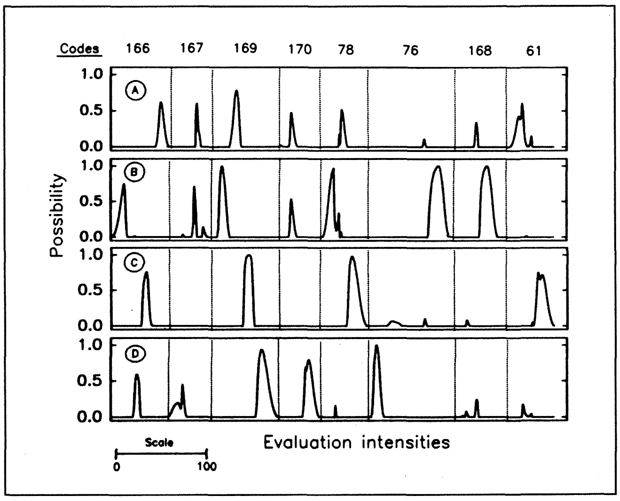

Figure 11
Fuzzy Linear Sensory Profile of Koroneiki (A), Coratina (B), Picual (C) and Arbequina (D). Codes indicate the attributes described in Tables II.

The former event suggests that more attributes should be added to those described in the E.C. Regulation. These, whether they have similar or dissimilar meanings to those described by the COI-Test, should improve its results and help non-Mediterranean consumers to understand olive oil quality. The latter would allow non-structured scales to be applied, at least in the calculation of OGQ, and so disminish the current problems with the quality cut-offs.

The proposal described by Aparicio et al. (1992), and other, yet unpublished, studies by the same authors, concerning a fuzzy linear regression to compute OGQ and the sensory wheel described here, could be a starting point for computing OGQ from attributes, partially obviating the methodology suggested by the E.C. Regulation, but avoiding the current or potential commercial difficulties with the cut-offs of OGQ evaluation.

On the other hand, the combined studies of sensory attributes, sniffing and volatiles (Morales et al., 1994) suggest that the following attributes should be taken into account in future studies of the COI-Test:

(i) "green banana", that could be justified by the volatiles 3-hexenyl acetate, 2-penten-1-ol, trans-3-hexen-1-ol and 3-hexenal;

(ii) "butter", due to 1-hexanol, 3-methylbutanal, cis-2-hexen-1-ol, 2-pentenal, trans-2-hexenal, 2-butanone, 3-pentanone, 1-penten-3-one, 6-methyl-5-hepten-2-one, methyl acetate;

(iii) "tomato", whose volatiles in the sniffing of virgin olive oil has been described above.

(iv) attributes like, for example, "cooling on the palate", "wild aromatic floral" and "astringent" should be evaluated in order to help the non-Mediterranean customers to understand the sensory characteristics of this food.

4. CONCLUSIONS

The sensory wheel supported by this mathematical procedure indicates the flaws in the COI-Test and non-standard olive oil panels, detects sectors where there is no attribute of the COI-test, determines the meaning of the other attributes from COI-Test point of view and selects a set of attributes taking them from the sensory wheel sector for characterizing in prediction the varieties. Thus, a sensory wheel can be seen as an automatic translator of the semantic meanings of the sensory attributes.

The sensory wheel has also allowed us to detect if there is agreement among the different sensory attributes evaluated by all panels from the COI-Test point of view. Sensory attributes that could be considered badly placed could be explained by correlations and sniffing of their most potent odorants. Only a few attributes could not be explained and these should be studied at length in future.

Concerning the sensory wheel sectors, the paper, almost exclusively based on Statistics, has demonstrated that the most remarkable sensory perceptions in virgin olive oil can be explained by the cycle: "Green-bitter-pungent-undesirable-ripe-fruity-sweet". The cycle and the place where attributes were placed seem quite logical from a sensory point of view.

This paper has also analysed possible solutions for improving COI-Test retaining its large experience evaluating all brands and categories of olive oils but removing some of its potential flaws and adding new attributes that would help the potential consumers to understand olive oil sensory quality.

These suggestions may be of interest to olive oil producers, suppliers and retailers and may help the producers, who are basically Mediterranean people and traditional consumers of this food, interpret the attitudes of the potential consumers.

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