Food Chemistry 141 (2013) 2906–2915

Contents lists available at SciVerse ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Analytical Methods

Analytical characterisation of *Negroamaro* red wines by "Aroma Wheels"

Simonetta Capone *, Maria Tufariello, Pietro Siciliano

National Council of Research, Institute of Microelectronics and Microsystems (C.N.R.-I.M.M.), Via Monteroni, Campus Ecotekne, 73100 Lecce, Italy

A R T I C L E I N F O

Article history:
Received 25 June 2012
Received in revised form 25 February 2013
Accepted 22 May 2013
Available online 4 June 2013

Keywords:
Negroamaro wine
Volatile analysis
Aroma Wheel
Odour Activity Value (OAV)

A B S T R A C T

In this work we characterised *Negroamaro* red wines, made by an autochthonous cultivar of Southern Italy, by linking volatile composition to aroma properties. This linking was carried out by picturing "Aroma Wheels", built by Odour Activity Values (OAVs) of all the identified volatile compounds grouped in "aromatic series" belonging to 13 classes of sensory descriptors. The 18 most active odorants with OAV > 1 were mainly alcohols, fatty acids and their ethyl esters. The "OAVs' Aroma Wheels" showed that the classes of sensory descriptors are first fruity and floral, next fatty and pungent and minor nutty and caramelised notes. Principal Component Analysis displayed correlations between sensory descriptors and wine samples; the main 7-fruity and 5-floral sensory features of *Negroamaro* wines have negative values of PC1 and they are negatively correlated with the second main sensory feature, i.e. 13-fatty, falling at positive value of PC1; this fit the aroma perception of this varietal.

1. Introduction

Wine aroma and flavours are some of the main organoleptic characteristics that contribute to typicality concept (Cadot, Caillé, Samson, Barbeau, & Cheynier, 2010; Maitre, Symoneaux, Jourjon, & Mehinagic, 2010); they define the differences among an amazing number of wines and wine styles produced throughout the world. They are formed by hundreds of different volatile compounds, belonging to different chemical categories (alcohols, esters, aldehydes, ketons, fatty acids, terpenes, etc), covering a wide range of concentration (from 1 ng/L to several g/L), polarity, solubility, volatility, and pH (Ortega-Heras, Gonzalez-San Jose, & Beltran, 2002). Wine volatile compounds can be distinguished in: (1) primary (or varietal) compounds, that are aroma compounds found in undamaged cells of the grapes released only by crushing, or produced by enzymatic interactions at crush; (2) pre-fermentative and fermentative secondary compounds, the firsts formed during the processing of the grapes and by chemical, enzymatic and thermal reactions in grape-must, and the latter during the alcoholic fermentation, and (3) tertiary compounds that constitute the maturation "bouquet" caused by chemical reactions during maturation of the wine in the bottle (Pisarnitskii, 2001; Styger, Prior, & Bauer, 2011).

Wine aroma perception is really a intricate matter due to complex matrix effects, and oral human physiological variables; recent research advances in understanding aroma perception are beyond the aim of this work (Muñoz-González, Rodríguez-Bencomo, Moreno-Arribas, & Pozo-Bayón, 2011; Polášková, Herszage, & Ebeler, 2008). As simplification, the contribution of a specific volatile compound to wine aroma perception can be related to its odour threshold (OTH), which is defined as the lowest concentration that can be detected by smelling. OTHs of wine volatiles are estimated by odour threshold sensory tests (Janusz et al., 2003) in synthetic wine and reported in literature (Rocha, Rodrigues, Coutinho, Delgadillo, & Coimbra, 2004; Gómez García-Carpintero, Sánchez-Palomo, Gómez Gallego, & González-Vĩnas, 2011).

Another parameter, commonly used to assess the contribution of each compound to wine aroma, is the aroma index (I), also known as "Odour Activity Value" (OAV), defined as concentration/OTH ratio. The concept of "odour activity value" is a useful measure to assess the relative importance of individual chemical components present in a sample. Among all the volatiles present in wine volatile fraction, only a limited number of volatiles can be found in wines at concentrations high enough to be perceived (compounds with OAV $\geqslant$ 1) (Gil, Cabellos, Arroyo, & Prodanov, 2006; Gòmez-Miguel, Cacho, Ferreira, Vicario, & Heredia, 2007). Obviously, these compounds are the would-be active odorants that will primarily make-up the aroma features of a wine.

The issue of wine aroma characterization is generally dealt with chemical-analytical or sensory descriptive methodologies (Muñoz-González et al., 2011; Saurina, 2010; Sumby, Grbin, & Jiranek, 2010; Swiegers & Pretorius, 2005). The first is normally based on gas chromatographic methods (as GC/MS), that extract, separate, identify and quantify the whole set of volatile compounds released from wine and that may determine the perception of its aroma; hence, it provides a complete chemical profile of wine volatile fraction, that can be represented by a radar plot as a "Volatiles' Aroma Wheel" (Fig. 1A). The second is based on wine expert panel, who provides a sensory profile of wine, that can be represented by a

* Corresponding author. Tel.: +39 0832 422507; fax: +39 0832 422552.
E-mail address: simona.capone@le.imm.cnr.it (S. Capone).

0308-8146/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.foodchem.2013.05.105

radar plot as a "Sensory Aroma Wheel" (Fig. 1B); the panel use specific descriptive sensory tests and sensory descriptors of perceived wine attributes according to the definition of a common method and a consensual flavours lexicons (Drake & Civille, 2002; Esti, González Airola, Moneta, Paperaio, & Sinesio, 2010; Murray, Delahunty, & Baxter, 2001). Quantitative sensory aroma wheels can be also generated if ratings (panel scores) for each sensory descriptor are evaluated by panel (Barata et al., 2011; Jackson, 2009). "Volatiles' Aroma Wheel" and "Sensory Aroma Wheel" are schematically reported in Fig. 1A and B, respectively for a generic wine.

Another analytical methodology for detecting and identifying odour-active compounds in wine is GC-olfactometry, i.e. the coupling of gas chromatography (GC) with the human nose of an individual as a detector. This instrumental-sensory methodology provides a GC-aromagram and may establish which aroma components can be perceived (Bowen & Reynolds, 2012; Craig & Heresztyn, 1984; Francis & Newton, 2005; Lee & Simpson, 1990; Lee & Simpson, 1993).

The role of each volatile compound as odorant in the multiplicity of wine aroma components can be described in terms of one or several sensory descriptors (Franco, Peinado, Medina, & Moreno, 2004). In addition, as reported in several works (Gòmez-Miguez et al., 2007; Muñoz, Penaido, Medina, & Moreno, 2007; Penaido, Mauricio, & Moreno, 2006), odorant (or aromatic) series can be defined by grouping all the volatile compounds with similar sensory descriptor, and a generalised Odour Activity Value (generalised OAV) for each aromatic series can be calculated by adding the OAV of each aromatic series component. In such a way an odour profile of wine can be established by plotting in a radar graph the generalised OAV of all the aromatic series; the resulting "OAVs' Aroma Wheel" allows to link quantitative information get by chemical analysis to sensory perceptions, and provides a valid tool to compare the wine aroma profiles (Fig. 1C).

The aim of the present study is principally to quantify free volatile compounds in monovarietal wines, made from *Negroamaro* grapes grown in Apulia region, relating them to aromatic series and offering a simple method representative of potential aroma profile of this variety by graphing "OAVs' aroma wheels". Moreover, this work enters in an oenological wine promotion context, where it is highly felt the need to promote regional productions, giving a contribute to picture the typical aroma profile of *Negroamaro* wines through the chemical analysis of their volatile composition in relationship to odour descriptors. However, the proposed method hasn't the ambition to become a reference and standardized methodology to describe wine typicality concept, but it should be considered as a tentative "to portrait" the aroma profile of a wine in a first, simple and easy approach without the use of a more advanced and acknowledged sensory analysis, that remains the method commonly used within the framework of the typicality cryptic concept (Cadot et al., 2010; Perrin et al., 2008). According to *Sauvageot*, when the concept of typicality is applied to enology, it represents wine characteristics on the whole, resulting from type of vine, soil, and wine making process (Sauvageot, 1994). Thus, the typicality includes sensory, technical, and environmental dimensions and can be defined as a set of properties of belonging and distinction (Casabianca et al., 2005).

2. Materials and methods

2.1. Wine samples

A total of 10 different commercial monovarietal red wines, produced exclusively from *Negroamaro* cultivar, were considered. Moreover, in order to compare the aroma composition of the different wine samples, without considering the aroma evolution due to wine ageing, all the wine samples, considered in our experimental campaign, came from the same vintage, i.e. 2007. All the

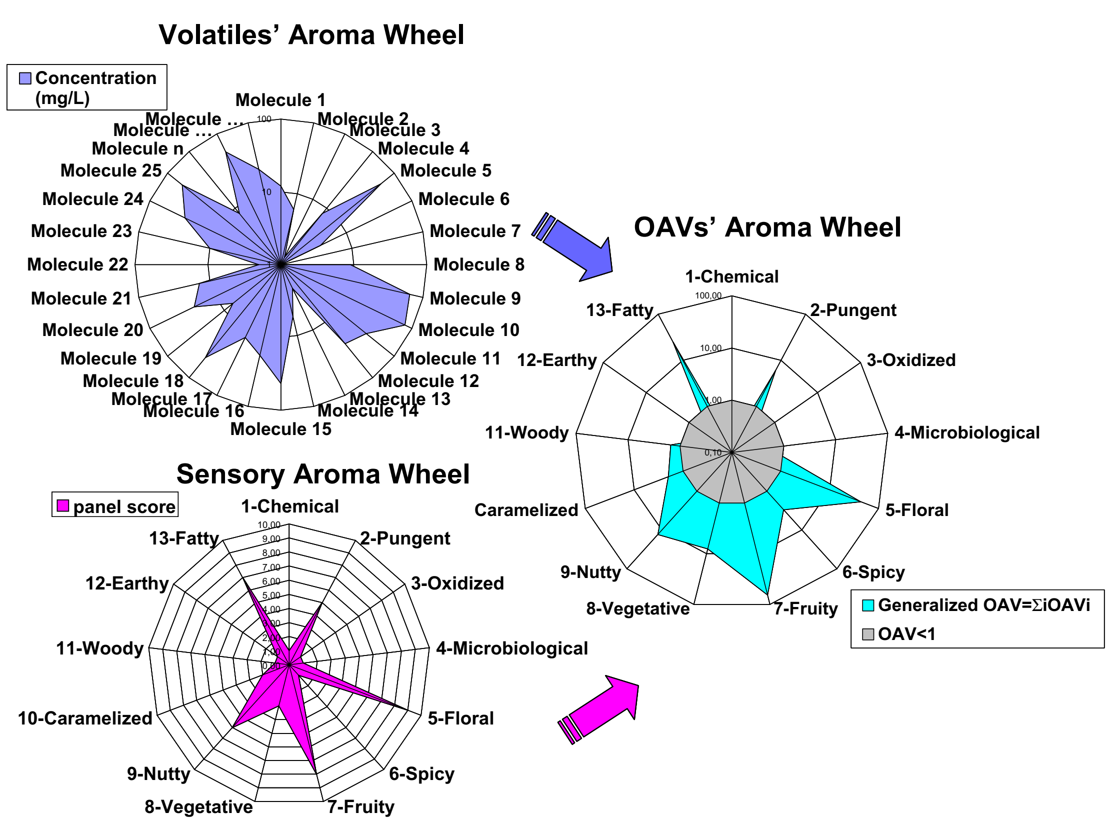

Fig. 1. Building of OAVs' Aroma Wheel starting from Volatiles' and Sensory Aroma Wheels for a generic wine.

selected wine samples had also a Denomination of Controlled Origin (D.O.C.) certification mark, that guarantees the quality and the geographical origin of the *Negroamaro* wines produced in *Salento* (southern area in Apulia region, Italy). In order to protect proprietary interests, winery identities have not been reported. The 10 Negroamaro wine samples were numbered with the following identification codes: NA1, NA2, . . ., NA10. All samples were stored at 4 °C until analysis.

2.2. Reagents and standards

All reagents were of analytical grade and all solvents were of HPLC grade. Methanol and ethanol 96% were purchased from J.T. Baker (Phillipsburg, NJ, USA); dichloromethane were purchased from Carlo Erba Reactive (Rodano, Italy). Pure water was obtained from a Milli-Q purification system (Millipore, USA). Identification and quantification of the volatile compounds by GC/MS was obtained by using an Internal Standard (I.S.), i.e. a chemical added to the sample at a constant concentration with a distinct retention time to the analyte, and by commercial pure chemical standards. Both the I.S. (octan-2-ol) and commercial pure chemical standards with purity superior of 98% were supplied by Sigma–Aldrich. Hence, a 200 mg/L hydro-alcoholic solution (1:1, v/v) of the I.S. (200 ppm_V I.S. in liquid), was prepared. Moreover, different standard solutions were prepared by dissolving exact volume of the chemical standard compounds in ethanol at concentration three order of magnitude higher than the typically found in wines. Next, for each chemical standard, the standard solution was diluted with water and ethanol adjusting the final alcohol content to 12% (v/v) in order to prepare a set of six standard mixtures containing known concentrations of the chemical standard, covering the typical concentration range found in wine. All the synthetic standard solutions used in the calibration graphs were 6 g/L of tartaric acid and pH 3.2 also adjusted. All these solutions were stored at 4 °C (Tufariello, Capone, & Siciliano, 2012).

2.3. Extraction of volatile compounds

The aroma compounds were separated by adsorption/desorption on preconditioned divinylbenzene cartridges (Strata™-X polymeric SPE sorbents prepacked in 500 mg/6 mL cartridges, Phenomenex).

To 50 mL of each wine sample and to each standard solution were added 400 μL of I.S. solution. The extraction of volatile compounds was carried out by Solid Phase Extraction (SPE), using polymeric sorbents and dichloromethane as elution sorbent; a method developed by Piñeiro et al. (2006), suitably modified in this work, was followed. For the extraction of the wine volatile fraction a Vac Elut 20 station equipment from Varian (Palo Alto, USA) was used. Strata™-X polymeric SPE were first rinsed with 4 mL of dichloromethane, 4 mL of methanol and, finally, 4 mL of a water–ethanol mixture (12%, v/v). Each liquid sample was passed through the SPE cartridge at around 2 mL/min. Afterwards, the sorbent was dried by letting air pass through it. The volatile compounds were recovered by elution with 4 ml of dichloromethane, and concentrated to a final volume of 500 μL under a stream of pure nitrogen (N_2). An aliquot of 2 μL of each extracted wine sample was injected into the GC/MS in splitless mode and analysed for identification and quantification of the volatile compounds contained in the extracted volume. The analyses were performed in triplicate and mean values were used in further data processing.

2.4. GC–MS conditions and quantitative analysis

A 6890N series gas chromatograph (Agilent Technologies) with an Agilent 5973 mass spectrometer selective detector (MSD) and equipped with a DB-WAX, polyethylene glycol capillary column (60 m × 0.25 mm I.D × 0.25 μm film thickness, Agilent Technologies) was used. The carrier gas was helium at a flow rate of 1.0 ml/min. The injection of the wine extract was made in splitless mode, the injector temperature was 250 °C. The column oven temperature was initially held at 40 °C, then it was programmed to 200 °C at 4 °C/min, with a final holding time of 20 min. Spectra were recorded in the electron impact mode (ionisation energy, 70 eV) in a range of 30–500 amu at 3.2 scans/s. A solvent delay time of 10 min was used to avoid overloading the mass spectrometer with solvent.

The identification of the volatile compounds was achieved by comparing mass spectra with those of the data system library (NIST 98, $P > 90\%$), with the retention data of commercially available standards and MS data reported in the literature.

Quantification analysis is based on the principle that the area under a peak is proportional to the amount of the analyte present in the sample. The quantification was carried out following the internal standard quantification method. The different sets of standard mixtures, previously prepared and containing known concentrations of the chemical standard ($C_{analyte}$) and the I.S. concentration ($C_{I.S.}$), were analysed and their peak areas ($A_{analyte}$) recorded. For each chemical standard, a six points calibration graph of relative peak area ($A_{analyte}/A_{I.S.}$) versus analyte concentration ($C_{analyte}$) was drawn to confirm a linear detector response and from which the amount of the analyte can be determined. The unknown concentration of an analyte ($C_{analyte,\ x}$) is calculated according to the interpolation of the calibration plots:

$$C_{analyte,x} = \left(\frac{A_{analyte,x}}{A_{I.S.}}\right) \cdot \frac{C_{I.S.}}{DRF_{analyte}} \quad (1)$$

where $DRF_{analyte}$ is the Detector Response Factor for an individual analyte. The concentration of volatile compounds for which there was no pure reference chemical standard available, was obtained by using the same calibration plot as one of the compounds with the most similar chemical structure belonging to the same molecular family. The obtained coefficients of regression (R^2) were >0.999 ad the relative standard deviations (RSD) were <5%.

2.5. Statistical analysis

To reveal the relationship among the *Negroamaro* wine samples based on compositions of volatile fraction, and to identify the constituents that are the chemotypical factors, the composition data matrix of ten samples was analysed using Principal Component Analysis (PCA) with STATISTICA 7.0 software package. Two-dimensional PCA biplots, including both wine samples and chemical compounds, were produced as results.

3. Results and discussion

3.1. Active odorants (impact aromatic molecules)

The results reporting the concentrations of wine volatiles have been published in a previous work (Tufariello et al., 2012). In this work, we extended the characterization of *Negroamaro* wines by combining the chemical-analytical analysis to the study of the would-be active odorants. In order to identify the most important wine odorants of *Negroamaro* wines, the aroma index (I), i.e. the Odour Activity Value (OAV), defined as the ratio between the concentration of the volatile compound (C_{odour}) and its odour perception threshold, was calculated for all the identified chemical species (Table 1). On the basis of their odour description and OAV, the most active odorants in the analysed *Negroamaro* wines were determined. As can be seen in Table 1, only 18 (pointed by arrows in the table) of the 51 identified have an OAV ⩾ 1. Volatiles with OAV ⩾ 1 are commonly considered the most important compounds contribute to wine aroma (Ferreira, Lòpez, & Cacho, 2000; Gil et al., 2006; Gòmez-Miguez et al., 2007; Romano, Suzzi, Domizio, & Fatichenti, 1997; Styger et al., 2011), although interactions between the different aroma components may occur. Compounds with high OAVs may be suppressed due to masking by other components (antagonistic effects), whereas compounds with lower OAVs can be revealed due to additive or synergic effects of the volatile components in the wine matrix. Therefore, the identification of the most active odorants only on the basis of their OAVs should be considered as a tentative study (Francis & Newton, 2005; Gómez García-Carpintero et al., 2011; Gòmez-Miguez et al., 2007).

In *Negroamaro* wine samples, the would-be impact odorants (i.e. those with OAV ⩾ 1), are some compounds generated during alcoholic fermentation, already known to be the most important contributors to the aroma of young red wines with limited varietal aroma potential (Gomez-Miguez, Vicario & Heredia, 2007; Ferreira, Fernandez, Pena, Escudero, & Cacho, 1995; Gomez-Miguez, Cacho, Ferreira, Vicario & Heredia, 2007; Falqué & Fernández, 1995). As exception we registered the contribution of 1-hexanol, which proceeds from the grapes (Baumes, 2000); its concentration in the wines depends on the conditions of fermentation, the composition of the must and the yeast biota.

Among compounds with high odour activities, we identified some alcohols (our code: A4, A5, A11), several esters (code: B2, B3, B4, B5, B12) and acids (code: C2, C3, C5, C6, C7, C8), a few aldehydes (code: E1, E2, E3), and one sulphur compound (code: G1).

Alcohols are reported to contribute the wine odour intensity (Etievant, 1991; Styger et al., 2011); isoamyl-alcohols (code A4), phenylethanol (code A11) and 1-hexanol (A5) were the only ones found contributing to the analysed *Negroamaro* wines. The first two are fusel alcohols, which are usually present in wines as a result of yeast metabolism during alcoholic fermentation. Concentrations above 300 mg/L in these alcohols have an adverse impact on wine aroma and flavour (specifically, a pungent smell and taste) (Rapp & Versini, 1991); on the other hand, concentrations below that level can have a positive impact by imparting the wine with fruity and floral notes. 1-hexanol (code A5) exhibits an small herbaceous and greasy odour (Kotseridis and Baumes (2000)) (OAV slightly higher to 1). Esters are responsible for the fruity aroma in wines, particularly acetate esters are correlated with the freshness and fruitiness of young wines (Rapp, 1990) (28 < OAV < 114) and their origin being mainly fermentative. Esters formation during fermentation is influenced by several factors, such as the physicochemical composition of musts and fermentation conditions (Ugliano & Henschke, 2009). In *Negroamaro* wines this class of odorous compounds is well represented by different active species, as for example isoamyl acetate (code B4) with its characteristic "banana" odour and ethyl hexanoate (code B5) with its characteristic green apple odour. Within the family of fatty acids, 2-methylpropanoic, 2+3 methylbutyric, hexanoic and octanoci acids were notable for their high concentrations in all wines. Fatty acids production is governed by the initial composition of the must and by fermentation conditions (Schneider, 1979) and have been described with fruity, cheese, fatty, and rancid notes (Rocha et al., 2004). Among acids (28 < OAV < 114), we mention as relevant active odorants 2+3-methylbutyric (code C5), butyric (code C3) and octanoic (code C7) acids. In recent studies on Bordeaux red wines carried out by Kotseridis and Baumes (2000), the importance of fatty acids as impact odorants were reported. In particular, they found that 2+3-methylbutyric acid was very intense at the sniffing port, and its odour descriptors were fatty, rancid and cheesy, whereas butyric and isobutyric acids were associated with, cheesy odour descriptors (Table 1). Finally, we point put the relevant content of the aldehyde vanillin (code E3) in the *Negroamaro* samples NA1 and NA4, in which they impress a sensorial contribution described as vanilla, sweet, chocolate.

The presence of these 18 potential aroma-contributing substances in Negroamaro sample corroborates the typical fruity and floral main nuances associated to this wine, perceived together to fatty and pungent notes as well as a distinctive but pleasant bitterish note. However, it should be highlighted that the balance and relative amount of aroma compounds present in a wine, rather than the presence of specific impact odorants is important.

3.2. OAV's Aroma Wheel

In order to link volatile composition to aroma descriptors, we designed an approach based on picturing a tentative odour profile representative of wine aroma characteristics. In particular, likewise to the approach used by other authors (Muñoz et al., 2007; Penaido et al., 2006), we propose a method that groups odorous compounds with similar sensory descriptors into classes (aromatic series). In Table 1 for each compound we affiliated one or more membership sensorial classes. As sensory classes we considered the standardized classes of sensory descriptors used in the well known "*Aroma Wheel*", developed at the University of California at Davis by Ann C. Noble in the early Eighties, as a standard used to describe wine in uniform, non-judgmental terms (http://winearomawheel.com/). The "Aroma Wheel" provides a visual graphic of the different categories and aroma components that one can encounter in wine. It consists of three concentric circles divided into segments for different classes of both bouquet and aroma. The terminology used is standardized for use by both professionals and amateur wine tasters. The wheel breaks down wine aromas into 12 basic categories and then further sub-divided into different aromas that can fall into those main categories. In our opinion an additional thirteenth category (13-fatty) has to be integrate in the aroma wheel to complete the organoleptic description of wine volatile fraction.

Afterward, in reference to the 13 defined standardized classes of sensory descriptors, an Odour Activity Value for each class of sensory descriptors (i.e. generalised OAV) was calculated by adding up the OAVs of all the compounds that form that class. In this computation, also the compounds with OAV < 1 were considered in agreed with the acknowledged theory that sub-thresholds compounds may also contribute to wine aroma through additive effects of compounds with similar structure or odour (Francis & Newton, 2005). Finally, we graphed them in a radar plot called "OAVs' Aroma Wheel", since it is based neither on chemical analytical data (i.e. compound concentrations get by chromatographic quantification) nor on sensory data based on intensity marks given by panel judgments, but on hybrid chemical/sensory parameter as generalised OAV is. A radar chart is a useful graphical method of displaying multivariate data in the form of a *n*-dimensional chart of *n*-quantitative variables represented on axes (rays) starting from the same point. This gives the plot a star-like appearance. In this case the variables are the thirteen classes of sensory descriptors and the quantitative input values are the generalised OAVs of each sensorial class. It's evident how such type of plots are useful to answer the following questions: a) what sensory classes are dominant for a given wine sample?, b) which wine samples are most similar, c) are there outliers?.

Fig.2 shows both the individual Analytical Aroma Wheel for each *Negroamaro* wine sample and a global Analytical Aroma Wheel overlapping the radar plots of all the *Negroamaro* wine samples. In particular, we chose a logarithmic scale in order to enhance minor variables flattened by predominant variables. The organoleptic profile of *Negroamaro* wine obtained by this method is compatible with the popular *Negroamaro* characteristics, focused on the name itself literally meaning "black" and "bitter", to emphasise both the deep colour of the grape and the wine, as well as its

Table 1
Odour Activity Value (OAV) of the would-be impact odorants of *Negroamaro* wines.

				Odour description (ODE)	Odour threshold (OTH)	Ref.	OAV = C_{odou}^OTH										Classes of sensory descriptors
LRI	code	Peak	Compounds		mg/L		NA1	NA2	NA3	NA4	NA5	NA6	NA7	NA8	NA9	NA10	
			(A) Alcohols														
1060	A1	4	1-Propanol	Alcohol, ripe fruit	306	b	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0,1	7
1214	A2	5	2-Methyl-propanol	Alcohol, solvent	40	h	0.36	0.32	0.31	0.21	0.33	0.32	0.37	0.29	0.27	0.25	2, 1
1142	A3	7	1-Butanol	Medicinal, phenolic	150	b	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1
1221	A4	8	2 + 3 Methyl-1-butanol	Fusel, alcohol, sweet, fruity	30	g	4.40	4.10	4.23	3.53	3.97	6.33	6.17	3.77	2.37	3.62	7, 2
1282	A5	12	1-Hexanol	Herbaceous	4.8	a	0.83	1.54	1.06	1.10	1.23	0.77	0.80	0.73	<0.1	0.41	8
1296	A6	13	cis- 3-Hexen-1-ol	Plant, fruity, aromatic	0.4	g	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8, 7
1545	A7	19	(D,L)-butan-2,3-diol	Fruity	150	b	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	7
	A8	21	(R,S)-butan-2,3-diol	Fruity	150	b	0.03	0.01	0.01	0.02	<0.1	<0.1	<0.1	0.03	0.01	0.03	7
1888	A10	33	Benzyl alcohol	Flowery, sweet	200	g	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.02	<0.1	5
1892	A11	34	Phenylethanol	Flowery, rose, Honey	10	a	4.63	6.00	4.85	4.68	3.00	4.95	4.06	4.36	4.00	2.86	5
			(B) Esters														
	B1	1	Ethyl propanoate	Fruity	1.8	b	0.45	0.40	0.44	0.37	0.44	0.56	0.74	<0.1	0.37	<0.1	7
	B2	2	Ethyl isobutyrate	Fruity, apple	0.02	c	43.50	35.00	44.00	38.50	35.00	<0.1	49.50	<0.1	<0.1	<0.1	7
1080	B3	3	Ethyl butyrate	Floral, fruity	0.02	c	44.00	38.00	56.50	41.50	40.00	50.00	62.50	40.50	<0.1	49.00	5, 7
1145	B4	6	3-Methyl-1-butanol acetate	Banana	0.03	e	35.33	29.00	30.67	50.00	55.00	58.33	35.67	30.67	28.33	43.67	7
1185	B5	9	Ethyl hexanoate	Fruity, green apple	0.014	e	35.71	13.57	50.00	42.86	50.00	35.71	<0.1	57.14	100.00	114.29	7
1326	B6	11	Ethyl lactate	Lactic	154.6	h	0.12	0.11	0.13	0.11	0.10	0.14	0.17	0.10	0.02	0.06	4
1436	B7	14	Ethyl octanoate	Ripe fruits, pear, sweety	0.24	a	<0.1	<0.1	0.96	<0.1	<0.1	0.13	0.04	0.08	<0.1	0.67	7
1499	B8	17	Ethyl 3-hydroxybutyrate	Fruity	20	g	0.03	0.03	0.03	0.03	0.03	<0.1	0.04	<0.1	0.04	0.04	7
1702	B9	27	Diethyl succinate	Fruity, wine; Cheese, earthy, Spicy	200	g	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	7, 4
2070	B10	39	Diethyl malate	Fruity	10	d	0.07	0.05	0.03	<0.1	0.05	0.01	0.05	0.02		0.01	7, 4
2331	B11	46	Ethyl hydrogen succinate	Chocolate	N/A		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	4, 10
2676	B12	49	Ethyl vanillate	Vanilla, chocolate	0.99	g	<0.1	0.05	<0.1	0.08	<0.1	0.03	<0.1	2.73	0.04	<0.1	4, 10
2543	B13	50	Methyl vanillate	Vanilla	3	i	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10
1936	B14	30	2-Phenyl ethyl acetate	Floral	0.25	c	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5
			(C) Acids														
1426	C1	15	Acetic acid	Vinegar	200	c	0.01	0.09	0.06	0.05	0.04	0.03	0.03	0.05	0.08	0.08	1
1583	C2	20	2-Methyl propanoic acid	Fatty, rancid	2.3	i	<0.1	1.91	1.52	1.47	1.33	1.28	1.39	1.52	1.28	2.00	13
1600	C3	22	Butyric acid	Fatty-rancid, cheesy, sweaty	0.4	a	7.08	7.50	8.83	7.98	7.18	19.75	8.20	6.93	6.95	7.50	13
1642	C5	26	2+3-Methyl butyric acid	Fatty-rancid, cheesy	0.25	c	<0.1	14.40	<0.1	<0.1	<0.1	18.40	14.00	16.60	16.40	13.20	13
1816	C6	31	Hexanoic acid	Rancid, grass, fruity	6.7	a	0.82	0.72	1.38	0.88	0.63	0.99	0.76	0.75	1.03	0.78	13, 7
2024	C7	40	Octanoic acid	Fatty acid, dry, dairy	2.2	a	2.05	1.82	3.40	2.24	1.68	3.36	2.82	2.18	<0.1	2.45	13
2289	C8	44	n-Decanoic acid	Fatty acid, dry, woody	1.4	a	<0.1	<0.1	<0.1	<0.1	<0.1	2.71	2.46	<0.1	2.01	<0.1	13
2378	C9	47	Benzoic acid		N/A		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	13
1929	C10	36	2-Hexenoic acid		N/A		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	13
LRI	code	Peak	Compounds		mg/L		NA1	NA2	NA3	NA4	NA5	NA6	NA7	NA8	NA9	NA10	
			(D) Phenols														
1882	D1	32	2-Methoxyphenol	Smoky, burning, sweet, phenolic	0.075	a	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	11
	D2	35	2-Methoxy-4-methylphenol	Phenolic	N/A		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	11
	D3	38	4-Ethyl-2-methoxyphenol	Phenolic	0.033	f	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	11
2189	D4	42	4-Ethylphenol	Phenolic	0.44	g	<0.1	0.068	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.30	11
2219	D5	43	2-Methoxy-4-	Black pepper, species	0.38	a	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4211	11

			vinylphenol													
2424	D6	45	2,6-Dimethoxyphenol	Phenolic	0.57		0.12	0.63	0.33	0.70	0.04	0.37	0.05	0.02	0.14	0.12	11
			(E) Aldehydes													
1458	E1	16	Furfural	Caramel	3		0.167	0.09	1.07	0.8	1.3	0.8	2.233	0.627	1.53	0.97	10
1503	E2	18	Benzaldehyde	Bitter almond	0.35	[i]	1.71	1.11	1.43	1.71	1.66	1.43	1.71	1.14	1.14	1.11	9
2511	E3	48	Vanillin	Vanilla	0.2	[c]	12.50	<0.1	<0.1	14.80	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10
			(F) Terpenes													
2007	F1	41	3,7-Dimethyl,1,7-octanediol	Floral	N/A		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5
1715	F2	28	a-Terpineol	Floral	0.25	[e]	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5
			(G) Sulphur compounds													
1725	G1	29	3-Methylthio-1-propanol	Potato, baked cabbage	0,5	[c]	0.42	0.96	0.60	0.24	1	0.12	1	0.40	<0.1	0.14	8
			(H) Lactones													
1635	H1	23	Butyrolactone	Sweet, buttery	20	[c]	0.18	0.17	0.23	0.20	0.18	<0.1	0.16	0.46	0.19	0.24	11
1974	H2	37	cis-Methyl-octanolide	woody	0.067		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	11
			(I) Ketons													
	I1	10	Acetoin	Buttery	155	[c]	0.09	0.12	0.05	0.01	<0.1	0.02	<0.1	0.04	0.10	0.13	10
2685	I2	51	Acetovanillon	Caramel, vanilla	1	[g]	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10

Notes: LRI: linear retention index on a DB wax column.
Peak: numbering peak according to elution time.
Code: identification code assigned to each compound following the numbering inside the classes (A-Alcohols; B-Esters; C-Fatty acids; D-Phenols; E-Aldehydes; F-Tepernes; G-Sulphur compounds; H-Lactones; I-Ketons).
Odour Description (ODE) and Odour Threshold (OTH) as reported in the literature references (Ref.):
Odour Activity Value (OAV): defined as ratio between odour concentration (C_{odour}) and OTH.
Each compound was attributed to 1 or more classes of the following 13 classes of sensory descriptors: 1, chemical; 2, pungent; 3, oxidised; 4, microbiological; 5, floral; 6, spicy; 7, fruity; 8, vegetative; 9, nutty; 10, caramelized; 11, woody; 12, earthy; 13, fatty.

[a] Rocha et al. (2004).
[b] Penaido et al. (2006).
[c] Guth (1997).
[d] Moyano, Zea, Moreno, and Medina (2002).
[e] Günata, Bayonove, Baumes, and Cordonnier (1985).
[f] Vilanova and Sieiro (2006).
[g] González Álvarez, González-Barreiro, Cancho-Grande, and Simal-Gándara (2011).
[h] Gómez-Míguez et al. (2007).
[i] García-Carpintero et al. (2011).

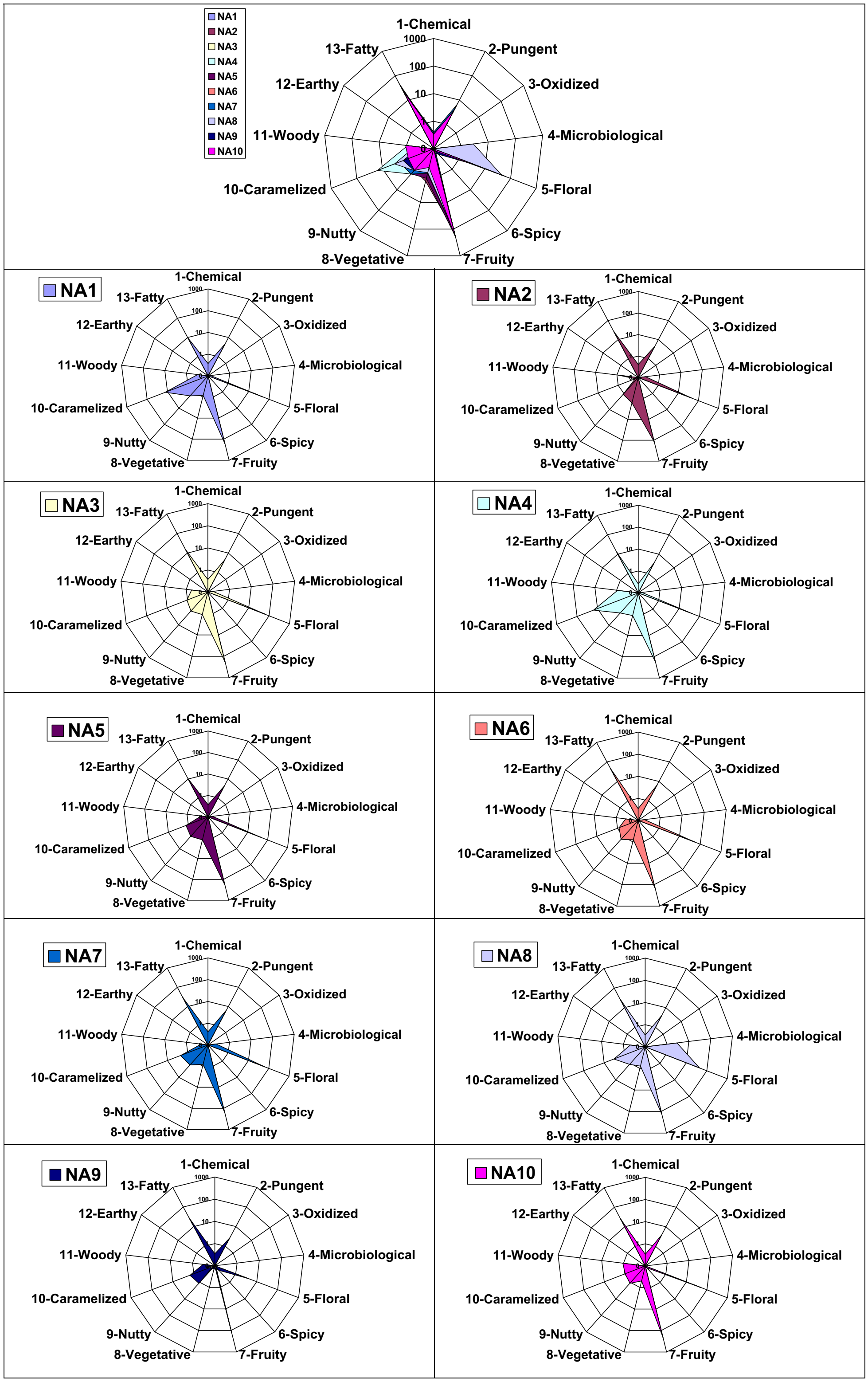

Fig. 2. Analytical "Aroma Wheel" of the *Negroamaro* wines based on the OAVs values of each class of sensory descriptors.

basically bitter flavour. Indeed, as can be observed all the analytical aroma wheels of *Negroamaro* wines show high 7-fruity and 5-floral characteristics, as well as typical 13-fatty and 2-pungent sensory classes with minor harmonious 10-caramelised and 9-nutty features. Of course some differentiations among the analysed *Negroamaro* wines are visible.

The proposed method based on "OAVs' aroma wheel" doesn't aim to become a reference and standardized methodology to describe wine aroma characteristics, but it could be used by chemical analysts to draw the aroma fingerprint of any wine by linking the chemical information to sensory parameters (i.e. Odour Thresholds-OTHs reported in literature). This fast and simplified

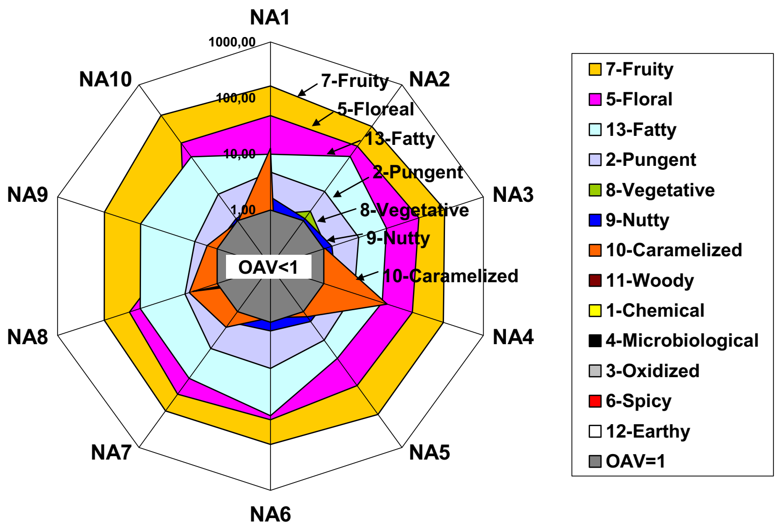

Fig. 3. Radar plot of the OAVs of the 13 standardized classes of sensory descriptors for the different *Negroamaro* wines analysed in this work.

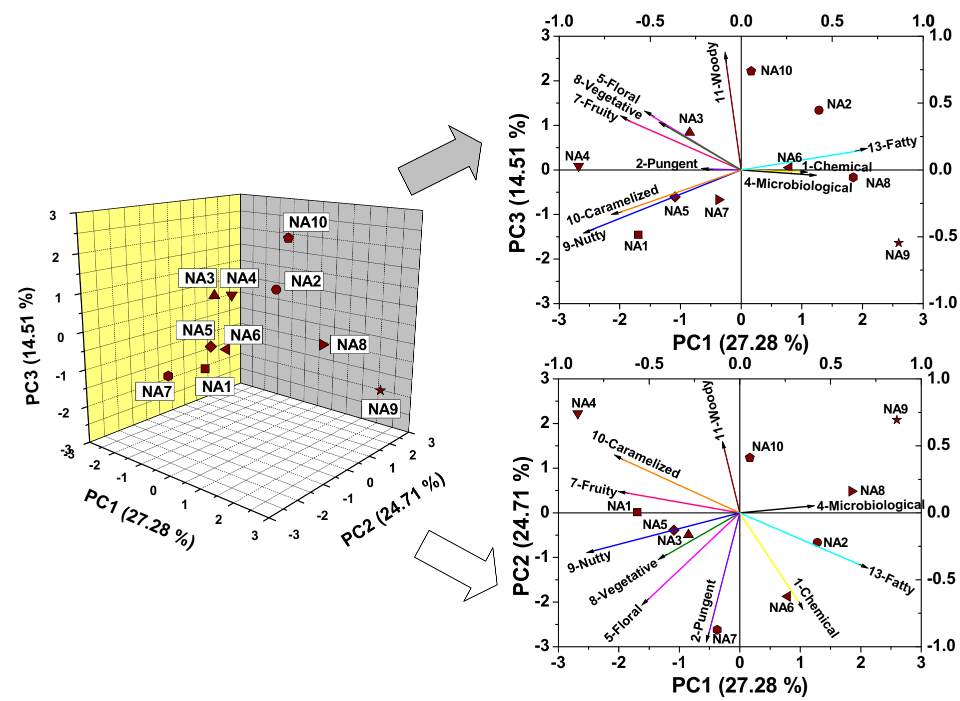

Fig. 4. PCA results based on the generalized OAVs of the 13 sensory descriptors. Left: 3-D score plot of the different Negroamaro wines; right: 2-D biplots on PC1-PC2 and PC1-PC3 plane overlapping scores and loadings.

comparison between wines is not substitutive of pure sensory analysis, but it is preliminary to it. It could become useful in many contexts where a sensory analysis isn't available or affordable and a first raw fingerprint of wine aroma peculiarity has to be sketched.

Moreover, in Fig. 3 we graphed an inverse radar plot by using the 10 analysed *Negroamaro* samples as variables and the 13 classes of sensory descriptors as samples. Here, it can more easily seen which are the prevalent classes of sensory descriptors and the classes with insignificant sensory impact falling inside the OAV < 1 area.

3.3. Principal Component Analysis

Principal Component Analysis (PCA), was the multivariate data analysis technique used for dimensionality reduction and display relationships/correlations between the 13 standardized classes of sensory descriptors and the considered *Negroamaro* wine samples. PCA was applied to the data matrix containing the generalised OAVs of each aromatic series.

Fig. 4 (left) shows the PCA score plot in the space of the first three Principal Components (PCs). An only class of data was explored by PCA; no clear clustering of *Negroamaro* wine samples according to local areas of *Salento* was observed. This is consistent with the aroma profile typicity of a generic *Negroamaro* wine, that seems not depend on the microarea of production inside *Salento* geographical macroarea. Data related to the different *Negroamaro* wines resulted rather spread since seven Principal Components were extracted explaining 100% of the total variance of the initial data set. The first three PC1, PC2 and PC3 accounted for 66.50% of total variance and they were considered sufficient for further discussion.

The little dissimilarities/similarities (mainly due to the diversification of the wine-making process operated by the different producers) among the different *Negroamaro* wine samples can be better resolved by reporting score plots combined with loadings plots (biplots), since in such a way it's more easy to display correlations between the 13 standardized sensory descriptors and the wine samples, and between the sensory descriptors and the PCs. Fig. 4 right shows the biplot on the PC1-PC2 and PC1-PC3 planes. As can be seen, the main 7-fruity and 5-floral sensory features of *Negroamaro* wines have negative values of PC1 and they are negatively correlated with the second main sensory feature, i.e. 13-fatty, falling at positive value of PC1; this fit the traditional and known aroma perception of this varietal. Wine samples NA8, NA9, NA10 are the only wines with minor correlation with the main *Negroamaro* aroma notes, being scattered in the I and IV quadrant in both PC1–PC2 and PC1–PC3 plane. NA10 seems also characterised by 11-woody notes, NA2 is more correlated to 13-fatty notes compared to the other wines whereas NA6 to 1-chemical notes. Among the wines falling in the II and III quadrant, we highlight samples NA1 and NA4 that show characteristic correlations with 10-caramelised notes. Moreover sample NA5 has typical correlated with 9-Nutty nuances, whereas sample NA7 with 2-pungent notes.

4. Conclusions

In conclusions, the results obtained by SPE-GC/MS analysis on *Negroamaro* red wines (an Italian indigenous grape varietal grown mainly in *Salento* area in *Apulia* Region) showed that the aroma composition of these monovarietal wines is dominated by different categories of compounds originating from different fermentation processes, mainly alcohols, ethyl esters and fatty acids. Other classes of compounds found in minor percentage were: ketons, aldehydes and lactons. Based on the sensory OTH values of each compound, the Odour Activity Values (OAVs) of all the quantified volatile compounds were calculated and eighteen would-be impact odorants (with OAV > 1) were determined. The identified key odorants of *Negroamaro* wines are associated with fruity (ranging from dark plum to prune and blackberries with a distinctive peppery note), floral, fatty and pungent notes with a pleasantly bitterish vein, that represents the known main characteristic aromatic feature of *Negroamaro* wines.

In this work the chemical analysis by GC–MS on *Negroamaro* wines was functional to the development of a method to built up "volatile/sensory aroma wheels" as pictures of odour wine tipicality. We get *Negroamaro* organoleptic profile in a more objective way by relating the quantitative information get by chemical analysis to OTHs. The comparison of the volatile/sensory aroma wheels of different wines may be a easy method to discriminate wines that differ for: cultivar, area growing, wine making, *terroir*, ageing, etc.

Principal Component Analysis (PCA), applied to the data matrix containing the generalised OAVs of each aromatic series, was used for dimensionality reduction and allowed us to display and discuss relationships/correlations between the 13 standardized classes of sensory descriptors and the considered *Negroamaro* wine samples.

Acknowledgements

This work was founded by a Strategic Project of the research founding program of *Apulia* Region government: "Innovative biotechnological approaches to improve quality and safety of typical *Apulian* wines" – acronym INNOWINE.

References

Barata, A., Campo, E., Malfeito-Ferreira, M., Loureiro, V., Cacho, J., & Ferreira, V. (2011). Analytical and sensorial characterization of the aroma of wines produced with sour rotten grapes using GC-O and GC–MS: identification of key aroma compounds. *Journal of Agricultural and Food Chemistry, 59*, 2543–2553.

Baumes, R. (2000). Los constituyentes volatiles de la etapa fermentativa. In C. Flanzy (Ed.), *Enologıa: fundamentos cientıficos y tecnologicos, A.M.V.* (pp. 147–158). Madrid: Mundi-Prensa.

Bowen, A. J., & Reynolds, A. G. (2012). Odor potency of aroma compounds in riesling and vidal blanc table wines and icewines by gas chromatography–olfactometry–mass spectrometry. *Journal of Agricultural and Food Chemistry, 60*, 2874–2883.

Cadot, Y., Caillé, S., Samson, A., Barbeau, G., & Cheynier, V. (2010). Sensory dimension of wine typicality related to a terroir by quantitative descriptive analysis, just about right analysis and typicality assessment. *Analytica Chimica Acta, 660*, 53–62.

Casabianca, F., Sylvander, B., Noel, Y., Beranger, C., Coulon J.B., & Roncin, F. (2005). *INRA-INAO, Colloque International de restitution des travaux de recherches sur les indications d'origine géographiques, 199*, Paris (France).

Craig, J. T., & Heresztyn, T. (1984). 2-Ethyl-3,4,5,6-tetrahydropyridine – an assessment of its possible contribution to the mousy off-flavor of wines. *American Journal of Enology and Viticulture, 35*, 46–48.

Drake, M. A., & Civille, G. V. (2002). Flavour lexicons, comprehensive reviews. *Food Science and Food Safety, 2*, 33–40.

Esti, M., González Airola, R. L., Moneta, E., Paperaio, M., & Sinesio, F. (2010). Qualitative data analysis for an exploratory sensory study of grechetto wine. *Analytica Chimica Acta, 660*, 63–67.

Etievant, P. X. (1991). Wine. In H. Maarse (Ed.), *Volatile compounds of food and beverages* (pp. 483–546). New York: Dekker.

Falqué, E., & Fernández, E. (1995). Vinification effects in white wine flavour composition. *Deutsche Lebensmittel-Rundschau, 95*, 107–110.

Ferreira, V., Fernandez, P., Pena, C., Escudero, A., & Cacho, J. F. (1995). Investigation on the role played by fermentation esters in the aroma of young spanish wines by multivariate analysis. *Journal of the Science of Food and Agriculture, 67*, 381–392.

Ferreira, V., Lòpez, R., & Cacho, J. F. (2000). Quantitative determination of the odorants of young red wines from different grape varieties. *Journal of the Science of Food and Agriculture, 80*, 1659–1667.

Francis, I. L., & Newton, J. L. (2005). Determining wine aroma from compositional data. Microbial modulation of wine aroma and flavour. *Australian Journal of Grape and Wine Research, 11*, 114–126.

Franco, M., Peinado, R. A., Medina, M., & Moreno, J. (2004). Off-vine grape drying effect on volatile compounds and aromatic series in must from Pedro Ximénez grape variety. *Journal of Agricultural and Food Chemistry, 52*, 3905–3910.

Gil, M., Cabellos, J. M., Arroyo, T., & Prodanov, M. (2006). Characterization of the volatile fraction of young wines from the denomination of origin "Vinos de Madrid" (Spain). *Analytica Chimica Acta, 563*, 145–153.

Gómez García-Carpintero, E., Sánchez-Palomo, E., Gómez Gallego, M. A., & González-Vĩnas, M. A. (2011). Effect of cofermentation of grape varieties on aroma profiles of La Mancha red wines. *Journal of Food Science, 76*, 1169–1180.

Gomez-Miguez, M. J., Cacho, F. J., Ferreira, V., Vicario, M. I., & Heredia, F. J. (2007). Volatile compounds of Zalema white wines. *Food Chemistry, 100*, 1464–1473.

Gómez-Míguez, M. J., Vicario, I. M., & Heredia, F. J. (2007). Assessment of colour and aroma in white wines vinifications: Effects of grape maturity and soil type. *Journal of Food Engineering, 79*, 758–764.

González Álvarez, M., González-Barreiro, C., Cancho-Grande, B., & Simal-Gándara, J. (2011). Relationships between Godello white wine sensory properties and its aromatic fingerprinting obtained by GC–MS. *Food Chemistry, 129*, 890–898.

Günata, Y. Z., Bayonove, C., Baumes, R., & Cordonnier, R. (1985). The aroma of grapes. Extraction and determination of free and glycosidically bound fractions of some grapes aroma components. *Journal of Chromatography Science, 331*, 83–90.

Guth, H. (1997). Identification of character impact odorants of different white wine varieties. *Journal of Agricultural and Food Chemistry, 45*, 3022–3026. <http://winearomawheel.com/>.

Jackson, R. S. (2009). *Wine tasting: A professional handbook. Food science and technology, international series* (second ed,). 978-0-12-374181-3. Academic Press, © Elsevier.

Janusz, A., Capone, D. L., Puglisi, C. J., Perkins, M. V., Elsey, G. M., & Sefton, M. A. (2003). (E)-1-(2,3,6-trimethylphenyl)buta-1,3-diene: A potent grape-derived odorant in wine. *Journal of Agricultural and Food Chemistry, 51*, 7759–7763.

Kotseridis, Y., & Baumes, R. (2000). Identification of impact odorants in Bordeaux red grape juice, in the commercial yeast used for its fermentation and in the produced. *Journal of Agricultural and Food Chemistry, 48*, 400–406.

Lee, T. H., & Simpson, R. F. (1990). Cork and oak taints in wine. In *Proceedings of the New Zealand grape and wine symposium: Present and future, symposium held 5–6 November, Auckland, New Zealand* (pp. 43–47). Wellington, New Zealand: New Zealand Society of Viticulture and Oenology.

Lee, T. H., & Simpson, R. F. (1993). Microbiology and chemistry of cork taints in wine. In G. H. Fleet (Ed.), *Wine microbiology and biotechnology* (pp. 353–372). Chur, Switzerland: Harwood Academic Publishers.

Maitre, I., Symoneaux, R., Jourjon, F., & Mehinagic, E. (2010). Sensory typicality of wines: How scientists have recently dealt with this subject. *Food Quality and Preference, 21*, 726–731.
Moyano, L., Zea, L., Moreno, J., & Medina, M. (2002). Analytical study of aromatic series in sherry wines subjected to biological aging. *Journal of Agricultural and Food Chemistry, 50*, 7356–7361.
Muñoz, D. M., Penaido, R. A., Medina, M., & Moreno, J. (2007). Biological aging of sherry wines under periodic and controller microaerations with *Saccharomyces cerevisiae* var. capensis: Effect of odorant series. *Food Chemistry, 100*, 1188–1195.
Muñoz-González, C., Rodríguez-Bencomo, J. J., Moreno-Arribas, M. V., & Pozo-Bayón, M. Á. (2011). Beyond the characterization of wine aroma compounds: looking for analytical approaches in trying to understand aroma perception during wine consumption, review. *Analytical and Bioanalytical Chemistry, 401*, 1497–1512.
Murray, J. M., Delahunty, C. M., & Baxter, I. A. (2001). Descriptive sensory analysis: Past present and future. *Food Research International, 34*, 461–471.
Ortega-Heras, M., Gonzalez-San Jose, M. L., & Beltran, S. (2002). Aroma composition of wine studied by different extraction methods. *Analytica Chimica Acta, 458*, 85–93.
Penaido, R. A., Mauricio, J. C., & Moreno, J. (2006). Aromatic series in sherry wines with gluconic acid subjected to different biological aging conditions by *Saccharomyces cerevisiae* var. capensis. *Food Chemistry, 94*, 232–239.
Perrin, L., Symoneaux, R., Maître, I., Asselin, C., Jourjon, F., & Pages, J. (2008). Comparison of three sensory methods for use with the Napping procedure: Case of ten wines from Loire valley. *Food Quality and Preference, 19*, 1–11.
Piñeiro, Z., Natera, R., Castro, R., Palma, M., Puertas, B., & Barroso, C. G. (2006). Characterisation of volatile fraction of monovarietal wines: Influence of winemaking practices. *Analytica Chimica Acta, 563*, 165–172.
Pisarnitskii, A. F. (2001). Formation of wine aroma: Tones and imperfections caused by minor components (review). *Applied Biochemistry and Microbiology, 37*, 552–560.
Polášková, P., Herszage, J., & Ebeler, S. E. (2008). Wine flavor: Chemistry in a glass. Critical review. *Chemical Society Reviews, 37*, 2478–2480.
Rapp, A. (1990). *Journal of Analytical Chemistry, 337*, 777–785.
Rapp, A., & Versini, G. (1991). Influence of nitrogen compounds in grapes on aroma compounds of wine. In Rantz (Ed.), *Proceedings of the international symposium on nitrogen in grapes and wines* (pp. 156–164). Davis, CA: American Society for Enology and Viticulture.
Rocha, S. M., Rodrigues, F., Coutinho, P., Delgadillo, I., & Coimbra, M. A. (2004). Volatile composition of Baga red wine assessment of the identification of the would-be impact odourants. *Analytica Chimica Acta, 513*, 257–262.
Romano, P., Suzzi, G., Domizio, P., & Fatichenti, F. (1997). Secondary products formation as a tool for discriminating non-*Saccharomyces* wine strains. *Antonie Van Leeuwenhoek International Journal of General and Molecular Microbiology, 71*, 239–242.
Saurina, J. (2010). Characterization of wines using compositional profiles and chemometrics. *Trends in Analytical Chemistry, 29*, 234–245.
Sauvageot, F. (1994). *Sciences des Aliments, 14*, 557.
Schneider, P. (1979). Flavor composition of wines. A review. *Critical Reviews in Food Science and Nutrition, 12*, 59–111.
Styger, G., Prior, B., & Bauer, F. F. (2011). Wine flavor and aroma. *Journal of Industrial Microbiology and Biotechnology, 38*, 1145–1159.
Sumby, K. M., Grbin, P. R., & Jiranek, V. (2010). Microbial modulation of aromatic esters in wine: Current knowledge and future prospects. *Food Chemistry, 121*, 1–16.
Swiegers, J. H., & Pretorius, I. S. (2005). Yeast modulation of wine flavor. Review article. *Advances in Applied Microbiology, 57*, 131–175.
Tufariello, M., Capone, S., & Siciliano, P. (2012). Volatile components of Negroamaro red wines produced in Apulian Salento area. *Food Chemistry, 132*, 2155–2164.
Ugliano, M., & Henschke, P. A. (2009). Yeasts and wine flavor en. In M. V. Moreno-Arribas & M. C. Polo (Eds.), *Wine chemistry and biochemistry* (pp. 313–392). New York: Springer Science+Business Media, LLC.
Vilanova, M., & Sieiro, C. (2006). Determination of free and bound terpene compounds in Albarino wine. *Journal of food composition and analysis, 19*, 694–697.