Glass and wine: a good example of the deep relationship between drinkware and beverage.

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Abstract

As the choice of the drinkware could deeply affect consumer perception during beverage consumption, an experimental research was carried out by expert testers to investigate the evolution of chemical-physical and sensory profiles of a typical rosé wine maintained in different types of glasses. The aim of this research was to select some parameters to well correlate beverage sensory properties with glass characteristics which can be used for drinkware design. The different sensorial profiles, obtained as a function of the geometric characteristics of glasses, were compared with one another. In order to find any significant parameter useful to represent the time evolution of the wine inside each vessel, the wine poured in all glasses was also characterized at different times from a chemical and physical point of view.

As the design parameters are now guided more by aesthetic reasons rather than functional ones, this new "integrated approach", deriving from the merging of chemical, physical and sensorial data, can be used to design the optimum vessel for the enjoyment of the consumer during assessing sessions.

This innovative procedure could be easily adapted for every beverage such as fruit juices, sparkling wines or beer.

Keywords: glass features; wine; physical-chemical characteristics; temperature profile; oxidation profile; evaporation rate; sensorial profile.

Introduction

In wine sensorial characterization, the glass represents an essential tool which makes the interaction between the liquid and the taster's senses possible (Schifferstein, 2009; Spence, 2011; Schifferstein, Fenko, Desmet, Labbe, & Martin, 2013; Spence, & Wang, 2015).

Regarding sparkling wines and other carbonated beverages, from the consumer's point of view the role of bubbling is essential so that wine elaborators as well as sommeliers progressively has become aware of trying to define an ideal way of keeping and serving them (Liger-Belair, Villaume, Cilindre, Polidori & Jeandet, 2009). In this context, during the past decades a large body of research was devoted to investigate the influence of the glass shape on the losses of dissolved CO_2 escaping from sparkling wines in the form of bubbles in tasting conditions (Liger-Belair, Villaume, Cilindre, Polidori & Jeandet, 2009; Liger-Belair, Parmentier & Cilindre, 2012; Liger-Belair, Bourget, Pron & Cilindre, 2012) when classical types of drinking vessels (i.e. Flute versus Coupe) or innovative ones (i.e. laser-etched champagne glasses) are utilized (Liger-Belair, Conreux, Villaume & Cilindre, 2012).

Since the choice of a particular type of vessel could affect consumer perception also during still wine consumption, in the last years researchers have investigated the effect of different materials, colour and shape of the glass on the perceived aroma, taste and flavour of still wines (Cliff, 2001; Delwiche, & Pelchat, 2002; Russell, Weiss, Zivanovic, & Morris, 2002; Hummel, Delwiche, Schmidt, & Huttenbrink, 2003; Venturi et al., 2009; Hirson et al., 2012; Venturi et al., 2014).

According to the most traditional physical/chemical interpretation, different glass shapes release different amounts of volatile organic compounds from the wine surface (Spence, Harrar, & Piqueras-Fiszman, 2012). Moreover, the type of glass may influence both the development of some occurring chemical and physical processes (i.e. chemical oxidations, evaporation) (Liger-Belair, Polidori, & Zéninari, 2012*;* Venturi et al., 2014*;* Vilanova, & Vidal, 2008) as well as the headspace volatile composition together with the aroma profile of the wine (Hirson et al., 2012).

Despite the significant effect of the glass shape on the sensorial expression of wine, the existence of correlations between type of glass and aroma sensory descriptors of intensity and quality have not been clearly evidenced yet (Hirson et al., 2012), and the results of the available research in this field are somewhat contradictory (Spence & Wan, 2015).

Generally speaking, wine is a complex mixture of a lot of compounds which exhibit biological activity and considerable influence on taste and other sensorial properties (Ribéreau-Gayon, Glories, Maujean, & Dubourdieu, 2000*;* Cetó, Céspedes, & del Valle, 2012; Cetó, Capdevila, Minguez, & del Valle, 2014). Except for sparkling rosés, which are generally made by blending a small amount of red wine with a base of white wine, still rosés are usually produced from red grapes after a short maceration time. Although short maceration limits anthocyanin uptake (achieving the desired colour), it even more markedly restricts tannin extraction (Jackson, 2009, p. 371). Thus, rosés tend to show poor colour stability (much of the colour being derived from unstable free anthocyanins, and not from the more stable tannin-anthocyanin polymers typical of red wines). Because the tannins can be perceived during wine tasting by the tactile drying sensation and sense of bitterness that they can leave in the mouth (Jackson, 2009, pp. 147-151), rosé wines are generally characterized by a smaller body and astringency than full-bodied red wines obtained from the same grapes (Wirth et al., 2012). Even if rosé wines have the stigma of lacking aging potential because of their reduced phenolic content, there has been a recent and marked upsurge in rosé popularity (Jackson, 2009, p. 372) as savvy wine lovers have discovered that many of these pink wines are not the sugary sweet wines of some decades ago.

As the choice of the best combination of "glass type" and "wine tasted" appears to be an important factor for the definition of the wine sensorial profile (see Spence & Wan, 2015 for a review), this experimental research aimed to investigate the impact of glass shape on the sensory perception of the attributes of a rosé wine obtained from a short maceration (12 h) with skins of '*Sangiovese'* grapes, to choose the best glass among six commercial different glasses (Glass Code: A÷F). The sensorial profiles obtained for the wine tasted in every glass (Glass Code: A÷E) were compared with one another, and to the sensorial profile expressed by the same wine when tasted in the "ISO" technical glass (Glass F). Moreover, in order to find significant parameters useful to represent its time evolution, the wines were also characterized from a chemical and physical point of view at different times.

In order to meet the needs of the winemakers producing high quality rosés, this research also aimed to find the combination of glass parameters which could better express the close relationship between drinkware and beverage. This innovative procedure has been developed for still wines because of their economic impact, but it can be also easily adapted to other beverages like sparkling wines, beer, cocktails or fruit juices.

The main problem concerns the knowledge of the way in which the physical and chemical status of the product evolves during time and inside the glass, and how it is correlated with the design parameters which are currently chosen more for aesthetic reasons rather than functional ones.

Materials and Methods

Wine and glasses

The Castello di Ama Rosato IGT wine was made following the saignée method from the lots of Castello di Ama DOCG wine, as described in a previous paper (Venturi et al., 2014) so that the resulting wine was closer to a red wine than to a white one. The grapes were harvested at Castello di Ama winery, in the Chianti Classico region (Italy). Six different wine glasses (Tab. 1), supplied by "Bormioli Rocco e figlio" (Parma, Italy), were used during the tasting sessions.

Table 1 reports the values of the main geometrical parameters utilized to describe the shape of each glass, and a label letter (from A to F) was assigned to each of them. For synthetic reasons, in the following part of the manuscript references to glasses were made using the specific labelling letters reported in Table 1.

Among all the glasses, the Glass F was adopted as "reference glass" because of its similarity with the "official-tasting glass" (ISO).

Glass capacity was determined by measuring the mass of distilled water (T=20ºC). Glass shape parameters were determined with a caliper or measuring the circumference (Hirson et al., 2012).

During tasting sessions, glasses were always filled with the same volume of wine (120 mL) in order to avoid the influence of this parameter on the wine evolution.

Physical and chemical characterization of wine

- *Evaporation rate*

Because of the importance of smell intensity in the definition of the overall quality of rosé wines, the evaporation rate of wines was determined as a measure of the tendency of the volatile compounds to escape from the liquid phase (Venturi, Zinnai, Fantoni, Gabelloni, & Razionale, 2013). As the evaporation process is quite slow, the evaporation experiments were prolonged up to 120 h in order to gather reliable measurements. The evaporation rate of 120 mL of wine was determined in all glasses measuring the weight loss after 24, 48, 72 and 120 h (T=18°C and RH=80%). All the measurements were repeated in triplicate.

As reported in a previous paper (Venturi et al., 2013), the slopes of the straight lines obtained by the linear regression of the experimental data can be considered as a rough measurement of the evaporation rate at 120'.

- *Temperature profile*

During tasting sessions, cool temperatures have usually been found to suppress the perception of sweetness (Jackson, 2009, p. 151; Green, & Frankmann, 1988), and to increase those of bitterness and astringency. As a consequence, red wines are served at 18-22°C while the selected temperatures for tasting both rosé and white wines are generally lower (14-16°C and 12-14°C for rosé and white wines, respectively). The thermal profiles of the wine were measured at intervals of 10 minutes, starting from a storage temperature of 12°C until room temperature (18°C) was reached. As previously reported for the evaporation profile, also in this case all the measurements were repeated in triplicate.

- *Oxidation profile*

In order to determine the rate of oxygenation of the wine, an ADI dO_2 sensor (Fig. 1), generally used for measuring the partial pressure of dissolved oxygen in liquid media, in combination with an ADI 1030 Bio Controller (Applikon) was used.

The polarografic ADI dO_2 sensor is based on the principle of the Clark-cell. It consists of a platinum working electrode (catode) and a silver counter (reference) electrode (anode); the permeable membrane separates the electrode from the liquid medium.

The oxygen saturation was measured (± 0,1%) by immersion of the probe into the wine in static conditions at room controlled temperature and constant RH (T=20°C, RH=80%). Each experimental run was repeated in duplicate starting soon after filling the glasses with a constant volume of wine (120 mL) until 100% air saturation was reached. Also the oxygenation experiments were prolonged for a time longer than that of a typical wine tasting in order to gather reliable measurements.

- *Chemical evolution of wine*

In order to better understand the time evolution of the wine as a function of each glass, some chemical characteristics of the product (titratable acidity, volatile acidity, total SO_2, total phenols, total and free anthocyanins, proanthocyanins) were determined according to AOAC methods (2000). Each determination was repeated in duplicate. Because chemical analysis could show a much lower sensitivity than sensorial analysis, to observe reliable variations in chemical composition it was necessary to collect the last sample of wine 5 h after filling in static conditions at room controlled temperature and constant RH (T=20°C, RH=80%).

Sensorial analysis

- *Sensorial characterization of wine*

The sensorial profiles of wine, as a function of the glass utilized for tasting, were carried on by a trained panel (10 assessors, 7 males and 3 females aged between 30 and 65 years). All the assessors were included in the “expert panel” of the Department of Agriculture, Food and Environment (DAFE) of the University of Pisa, and had a previous experience in sensory descriptive analysis, mainly in wine evaluation. According to the DAFE internal procedure for assessor selection and training, based on a normalized technical procedure reported in the literature (Pérez Elortondo et al., 2007), expert assessors have to repeat and pass re-qualification tests at least once a year to demonstrate that they are still capable of evaluating the samples satisfactorily. As tests and criteria for re-qualification are the same as those for qualification, both qualification for new assessors and periodic re-qualification for expert assessors can be carried out at the same time. If an expert assessor does not pass one or more of the tests she/he can repeat the non-passed tests twice. If tests are not passed, the assessor is removed from the panel.

Re-qualification tests, besides providing information about assessor suitability, help to keep the assessors alert, avoiding relaxation and undervaluation of training.

The assessors used a sensorial sheet specifically developed for this purpose (Tab. 2) consisting of a not structured, parametric, descriptive wine scoring chart. In Table 2 are reported the synthetic definition of each descriptor present in the sensorial sheet shown to the assessors before starting the sensorial evaluations, with the aim to clearly define the meaning of the terms proposed in the sensorial sheet.

The panellists ranked the wine on a scale of 0-10, commented the qualities and evaluated the intensity of each parameter, including visual, aroma and taste attributes, as well as a hedonic parameter such as the overall appreciation (Martin & Rasmussen, 2011**)**.

Tasting was carried out in the morning, in a well-ventilated quiet room and in a relaxed atmosphere.

The wine was served to all the assessors by a trained sommelier that was not included in the panel involved in experimental tasting sessions.

As the drinking vessel could have an impact on both sensory-discriminative and hedonic responses of consumers (or participants) , according to the conclusions reported by Spence and Wan (2015), sensory scientists and companies should really think much more carefully about optimizing the sensory and conceptual properties of the drinking vessel in order to enhance the experience of the consumer since it is such an intrinsic part of the overall multisensory experience of a drink. In this context, in order to propose well controlled laboratory conditions together with a situation that is near as much as possible to that currently observed during a general wine tasting experience, in our opinion during tasting it appears necessary to give the panellist the possibility of a direct interaction with the glass.

The timing of the tasting sessions was fixed at 120 h from the filling of the glasses, with three different assessments starting soon after the wine pouring (at t=0', 40', 120' after filling the glasses).

The wine was assessed by the panellists at the same time in all the glasses. In every tasting session each glass was labelled with a capital letter, and a randomized serving order was utilised. All the assessments were repeated in duplicate in two different days by the same group of panellists.

Statistical analysis of data

The reliability of the results obtained was evaluated by statistical analysis:

- Chemical and physical characterization: as reported in the Material and Methods section, all the measurements were repeated in triplicate, with the exception of the oxidation rate that was repeated in duplicate. The reliability of data sets was evaluated by One Way Completely Randomized ANOVA (program: Cohort 6) using Bartlett's X2 corrected test ($P < 0.05$). Tukey's HSD multiple mean comparison test ($P < 0.05$) was used to state the differences among variables.
- Sensorial analysis: sensory properties were submitted to 2-Way Completely Randomized ANOVA (program Cohort 6) by Bartlett's test ($P < 0.05$) with Glass and Panellist as main effects. Tukey's HSD multiple mean comparison test ($P < 0.05$) was used to state the differences among variables. The mean ratings of the wine poured in the six different glasses were then analysed by Principal Component Analysis (PCA) (program R, version 2.10.0).

- Matrix of correlation: Pearson's correlation coefficient test was also performed to measure the strength of the association among variables.

Results

Physical and chemical characterization of wine

- *Evaporation rate*

During a wine tasting session, the evaluation of the olfactory sensations is directly influenced by the tendency of the wine volatile compounds to pass into a gaseous phase at normal temperatures. The wine evaporation rate can be assumed as a valid measure of the tendency of the volatile compounds to escape from the liquid phase (Venturi et al., 2013). However, the effect of this parameter on the olfactory expression of the wine can be contradictory. A too low evaporation rate can be associated to a reduced wine smell intensity due to the small amount of olfactory compounds able to exceed the olfactory threshold, while a too high evaporation rate can induce a too fast loss of the wine smell attributes during the tasting experience.

The experimental data concerning the amounts of wine evaporated at various run times were different as a function of the glass in which the wine was poured. The decrease of weight of every glass content as a function of run time was well described by a sheaf of straight lines passing through the origin of axes whose related slopes can be assumed as a measure of the evaporation rates (Fig. 2). The suitability of the approach followed in the statistical elaboration of these experimental results is proved by the high values of the squares of correlation coefficients (r^2) obtained. The highest rate of evaporation was observed for Glass C, followed by Glass A, while the Glass F presented the lowest value for this parameter. Moreover, the wines maintained in Glass D as well as in Glass E were characterized by the most balanced degree of evaporation.

- *Temperature profile*

To allow an easier and immediate comparison among the experimental data on the increase in temperature showed by the wines during the equilibration time, a kinetic approach was utilized (Zinnai, Venturi, Quartacci, Andreotti, & Andrich, 2010).

According to this approach, the rate of wine temperature increase ($d[T]_{t=t}/dt$) was assumed to be proportional to the difference occurring between the room temperature, which could be potentially considered the asymptotic maximum value ($[T]_{t=\infty}$,), and that measured in each glass ($[T]_{t=t}$) at a generic time (t=t):

$$d[T]_{t=t}/dt = k_{Ti} ([T]_{t=\infty} - [T]_{t=t}) \quad (1)$$

where k_{Ti} represents the kinetic constant related to the increase in wine temperature in the glass (i= A, B,…, F). This differential equation could be integrated, and the following kinetic relation, describing the time evolution of temperature profiles inside the glass (Fig. 3), was obtained:

$$[T]_{t=t} = (([T]_{t=\infty} - [T]_{t=0}) (1 - e^{-k_{Ti}t})) + T_0 \quad (2)$$

The functional parameters k_{Ti} could be assumed to be a valid measure of the thermal resistance offered by each glass (Fig. 3). The high values assumed by the squares of the correlation coefficients calculated for the linearized form of the kinetic equation (Fig. 3) give an indication of both the suitability of the theoretical approach and the reliability of the kinetic equations. The comparison of the values of the kinetic constant k_{Ti} showed that the temperature increases of the wine maintained inside the Glass F, closely followed by Glass B, were lower than those measured in glasses A, C, D and, above all, E. The greatest thermal inertia of the glass Glass F, closely followed by Glass B, can be considered a very useful property, particularly for white and rosé wines, because temperatures lower than room temperatures ($T<20°C$) are able to improve the balance of the taste attributes of these kind of wines.

❖ *Oxidation profile*

Aeration can greatly increase the pleasure of drinking a full bodied red wine, but can even soften the tannins in rosé and young reds, making them more balanced and smoother (Wirth, 2012). At the same time, the oxygen dissolved in the liquid phase can decrease the sensory and compositional qualities of wine (in particular white and rosé wines) because it is responsible of the oxidized aromatic character of wines and of the browning associated with oxidation of the phenolic compounds (Morozova, 2013). As showed in figure 4, the concentration of oxygen dissolved into the wine increased with time until the reaching of an asymptotic value corresponding to the air saturation limit. The rate of increase in oxygen concentration into the wine inside the glasses during the equilibration time varied significantly as a function of the glass shape (Fig. 4): the oxygenation process was faster when Glass C was utilised, closely followed by Glass A, while the lowest oxygenation rate was measured when wine was maintained in Glass E. The most balanced degrees of oxygenation were observed when Glasses B and D were utilized, while the glasses allowing the quickest and the slowest oxygenation rate were Glasses C and E, respectively.

❖ *Chemical evolution of wine*

Several chemical data were collected to find the most suitable criterion able to follow the chemical evolution of wine (Tab. 3). The concentration of total SO_2 was the most sensitive parameter among those evaluated, so that the differences between the initial value of total SO_2 and those evaluated at the same time (t=5 h) can be assumed as a measure of the intensity of wine degradation (particularly from an olfactory point of view). As showed in Table 3, Glass F, closely followed by glasses B, D, and E, allowed preserving the greatest fraction of total SO_2, while the wine maintained in Glass A, as well as that in Glass C, showed the lowest amount of this compound after five hours. Furthermore, Glass B also better preserved the free fraction of anthocyanins, allowing the maintaining of the original colour of the wine poured in this glass for a longer time compared to the other glasses.

Sensorial characterization of wine

❖ *Sensorial analysis*

To verify if and how the sensory properties of wine changed qualitatively and quantitatively over the time of tasting (Hirson et al., 2012), the analysis of variance was carried out on the experimental data related to the sensory attributes at different tasting times (t= 0’, 40’, 120’ from glass filling). The results of ANOVA applied to the main attributes utilized to describe view, smell and taste as well as the overall appreciation are reported in table 4. The two-way ANOVA, with glass and panellist as main effects, indicated that the differences among the wines increased with tasting time. In particular, Glass C generally showed the lowest mean intensities for each descriptor. Furthermore, at each tasting time, the overall appreciation was the best descriptor able to discriminate the wine contained in the different types of glass, and the Glass A as well as the Glass E were the most preferred by the panellists, while the Glass C represented the worst glass to appreciate the characteristics of the rosé wine.

In order to illustrate graphically the correlations between the ratings given to the different descriptors during different tasting sessions (t=0’; t=120’; Figs. 5a,b; 6a,b) a Principal Component Analysis (PCA) for each sensory attribute across six different types of glass was performed. At both tasting times (t=0’ and t=120’), the first two principal components showed a percentage of the total variance greater than 80% (92.93% and 82.67%, respectively).

In all the analysed assessing sessions, the first principal component (PC1) was positively characterized by the odour intensity, fineness and volume, having them positive loadings.

Even if the variables of the factor map remained nearly the same within the equilibration time, a few others related to the taste were added step by step during tasting because of the interaction between the oxygen dissolved in the liquid phase and the wine.

For the second principal component (PC2), the distribution of the different attributes and related loadings varied with the equilibration time. The correlations circles (Figures 5b for t=0’ and 6b for t=120’) showed the weights of the sensory attributes for each component.

At the starting time of the tasting session (Fig. 5a), the sensorial analysis results indicated the existence of some sensory differences due to the glasses geometrical characteristics. In particular, the wine contained in the Glass C was characterized by a significantly worst sensorial expression, with the greatest aftertaste and reduced colour intensity.

After 120 h, the results of sensory determinations significantly changed as a function of the different glasses utilized during the panel test (Fig. 6a, b). The mean points of the confidence ellipses related to the glasses increased their distance one from another. At this time the best sensorial profile was showed by the wines maintained in Glasses E, B and D, closely followed by that proposed in Glass A.

In the experimental conditions adopted, the discrimination among the expression of wine poured in different glasses at t=0 was very low, while after 120’ the results of the sensory determinations changed significantly as a function of the different glasses utilized during the panel test. That said, as the influence of possible bias deriving from prejudice of the panellists about glasses could be considered the same during all the tasting session, it could be possible to deduce that the trained panellists involved in this research were able to judge and measure their sensations limiting at minimum level the bias of their previous knowledge and opinions.

Final ranking of glasses used for tasting a rosé wine

With the aim to synthesize the data collected during the sensorial, chemical and physical characterization of the wine, a score related to the values assumed by the experimental parameters which showed reliable differences in sensory, chemical and physical evaluations, was assigned to each glass. The ranking of the chemical evolution was defined as a function of the development of total SO_2 concentration which was the most sensitive parameter among those evaluated, while the physical-chemical evolution was expressed by evaporation, oxygenation and temperature profiles. The sensorial evolution was ranked according to the main sensory attributes useful in order to put in evidence the existence of reliable differences among the wine maintained inside the different glasses at t=120’ after filling the glasses (Tab. 4).

The final ranking (Tab. 5), which derives from the sum of each assigned partial score, can be considered a measure of the suitability of each vessel for the wine rosé tasting.

As the sum of the scores attributed to the sensory parameters showed in Table 5 can cover, at maximum, less than 50% of available total scores (18 potential points referable to sensory attributes on 42 total available points), this approach could further limit the possible bias deriving from previous knowledge and opinions of the panellists, and allows to obtain an integrated characterization of wine evolution as a function of glasses that could include different aspects related to wine tasting, including chemical, physical, sensorial, emotional, hedonic aspects.

On these basis, it has been possible to select the ideal glass among those investigated to characterize a certain style of wine (in this case a rosé wine): in particular, Glasses B, D and E were individuated as eligible glasses in order to improve the tasting experience of a rosé wine, while Glass C appeared to be clearly the worst in both the proposed rankings.

Discussion

In order to analyse if and how the specific geometrical characteristics of the different glasses can really influence the sensory expression of the wine, some geometrical indexes appear useful to discriminate the glasses one from another. In a preliminary stage, among all available indexes, three of them have been selected as the most useful to investigate the correlation between the glass morphology and the sensorial expression of the wine poured inside: (a) “Volume of Headspace (mL)/Total Capacity (mL)” ratio, useful to define the distribution of “full” and “empty” volumes inside the vessel; (b) “Surface of liquid/Volume of liquid” ratio, which influences the oxygenation rate of the liquid medium; (c) “Surface of liquid/Surface of mouth of vessel” ratio, which can be a good way to represent the “chimney effect of the vessel”. These three geometrical indexes were correlated for all glasses with the sensory attributes reported in Table 4, as well as with the concentration of total SO_2 (chemical index) and the evaporation rate (physical property) of wines. The correlation coefficients are reported in Table 6. According to Paula and Conti-Silva (2014) a correlation coefficient of about 0.70 indicates a fairly strong correlation. Thus, it was possible to evidence that the “Volume of Headspace (mL)/Total Capacity (mL)” ratio strongly influences all the attributes related to smell and taste of the wine, while the chemical-physical evolution of products appears more correlated to the “Surface of liquid/Volume of liquid” ratio, closely followed by the “Surface of liquid/Surface of mouth of vessel” ratio.

This preliminary analysis of correlation among the geometrical characteristics of glasses and the sensory, chemical and physical attributes of wine indicates that the wine evolution (sensorial, chemical and physical parameters) during tasting was greatly influenced by the glass shape. Furthermore, also the volume of the liquid poured inside the vessel could play a key role on the evolution of wine since it directly influences all the geometrical indexes ((a), (b), (c)) that characterize the system “wine+glass”.

Conclusions

The experimental results showed how the characteristics of a glass could affect wine's bouquet and flavour, and suggest that their rational optimization, based on experimental data, could enhance the consumer enjoyment of wines.

On the basis of the obtained experimental data, a new “integrated approach”, deriving from the merging of the chemical, physical and sensorial data, can be used to design (or to select among those already existing) the optimum vessel to increase the enjoyment of the consumer during wine assessing sessions.

The preliminary analysis of correlation among the geometrical characteristics of glasses and sensory, chemical and physical attributes of wine indicates that the wine evolution (sensorial, chemical and physical parameters) during tasting was greatly influenced by the glass shape. Furthermore, also the volume of liquid poured inside the vessel plays a key role on the evolution of wine since it directly influences all the geometrical indexes ((a), (b), (c)) that characterize the system “wine+glass”.

The selected parameters can represent the key features to act on in order to redesign “the ideal glass” as a function of the type of the tasted beverage.

As future trend of this research, it would be necessary to extend this approach to the tasting of different types of wine (i.e.: white, sweet, sparkling wines) as well as of other beverages (i.e. beer, cocktails, fruit juices) and to determine the values of the main parameters for each of them.

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Figures captions

Figure 1 – Determination of dissolved oxygen into the liquid phase.

Figure 2 – Evaporation profile in static conditions during 120 hours from the filling of the glasses.

Figure 3 – Profile of temperature increase as a function of equilibration time.

Figure 4 – Profile of dissolved oxygen into the liquid phase as a function of equilibration time.

Figure 5 - Sensorial profile of wine as a function of the different glasses (t=time of glass filling): a) Confidence ellipses by a mean points; b) Variables Factor Map.

Figure 6 - Sensorial profile of wine as a function of the different glasses (t=120' from the filling of the glasses): a) Confidence ellipses by a mean points; b) Variables Factor Map.

Table 1 – Glasses utilized in the experimental runs.

Experimental code	Glass A	Glass B	Glass C	Glass D	Glass E	Glass F
Bormioli's factory code	Premium Mod. 1	Premium Mod. 2	Premium Mod. 5	Premium Mod. 10	Premium Mod. 15	Premium Mod. 9
Glass capacity (L)	0.720	0.378	0.574	0.465	0.556	0.289
Maximum diameter (m)	0.107	0.081	0.108	0.086	0.093	0.075
Top diameter (m)	0.084	0.062	0.090	0.067	0.067	0.054
Diameter of wine surface	0.098	0.078	0.098	0.083	0.093	0.074
						

Table 2: First order descriptors utilized to define the not structured parametric descriptive scoring chart and their definitions.

View attributes	**Definitions** (Jackson , 2009)
Clarity	Degree of brilliance (absence of haze-causing colloids or particulate matter); can vary from clear to dull to cloudy.
Color Intensity	
Viscosity	The perception of the resistance of wine to flow; a smooth, velvety mouth-feel.
Smell attributes	**Definitions** (Jackson , 2009)
Fineness	Finely balanced character of whole smell attributes of the wine.
Odor Intensity	Quantity of odorants compounds as perceived by the assessor.
Frankness	Absence of any off-flavors in smell of wine.
Harmony	Pleasant combination of different odorant notes that characterize the smell of the wine.
Taste attributes	**Definitions** (Jackson , 2009)
Acidity	A sour perception derived as a complex response to organic acids, wine pH, and the sensory impact of other sapid substance, notably sugars, ethanol, and phenolic compounds; flat refers to the absence of sufficient acidity, the opposite of acidic; tart usually denotes an appropriate, pleasant acidic perception.
Softness	Complex response to compounds such as sugars, glycerol, and ethanol, as influenced by sensations to the acidic and phenolic compounds in the wine; cloying refers to an intense, unpleasant sensation of sweetness; the opposite is dry.
Astringency	A set of tactile sensations including dryness, puckeriness, and dust-in-the-mouth perceptions; provoked principally by the polyphenolic content of wine, but also induced by acids; smooth implies a positive response to astringency; rough refers to excessive astringency.
Bitter	A perception induced primarily by the presence of small molecular weight phenolic compounds that is influenced marginally by the presence of sugars, ethanol, and acids.
Body	The summary perception of weight or richness in the mouth; a tactile sensation induced primarily by the presence of alcohol, but clearly influenced by the presence of sugars, glycerol (in high concentration), and phenolics; full-bodied is a positive perception of weight in the mouth; watery is the negative perception of the absence of sufficient body.
Volume	Tactile sensation induced primarily by the presence of alcohol, but clearly influenced by the presence of sugars, glycerol (in high concentration), and phenolics; full-bodied is a positive perception of weight in the mouth; watery is the negative perception of the absence of sufficient body.
Aftertaste	The taste-mouth feel aspects of finish.
Balance	The perception of harmony, notably between the sweet, sour, bitter, and astringent sensation in the mouth, but clearly influenced by the intensity of the aromatic sensation of the wine; one of the most highly regarded of wine attributes.
Persistency	It indicates the duration of the perceptions that linger in the mouth after the wine has been swallowed or expectorated. The persistency is measured in seconds.
Overall appreciation	Recognition and enjoyment of the good qualities of the wine evaluated on the whole.

Table 3 – Chemical composition of wine at different equilibration times (t=0, t=5 hours after filling the glasses).

Parameter	Test (t=0)	Glass A (t=5h)	Glass B (t=5h)	Glass C (t=5h)	Glass D (t=5h)	Glass E (t=5h)	Glass F (t=5h)
Titratable Acidity (g/L of tartaric acid)	**5.45 a**	**5.51 a**	**5.51 a**	**5.52 a**	**5.54 a**	**5.53 a**	**5.52 a**
Volatile Acidity (g/L of acetic acid)	**0.43 a**	**0.42 a**	**0.42 a**	**0.44 a**	**0.45 a**	**0.44 a**	**0.46 a**
Total SO_2 (g/L)	**0.063 a**	**0.049 c**	**0.053 bc**	**0.049 c**	**0.052 bc**	**0.052 bc**	**0.054 b**
Total phenols (g/l of catechins)	**0.890 a**	**0.886 a**	**0.890 a**	**0.905 a**	**0.893 a**	**0.898 a**	**0.889 a**
Total anthocyanins (g/l of malvidin)	**0.068 a**	**0.066 a**	**0.067 a**	**0.067 a**	**0.068 a**	**0.065 a**	**0.068 a**
Free anthocyanins (g/l of malvidin)	**0.051 a**	**0.044 b**	**0.045 ab**	**0.043 b**	**0.042 b**	**0.043 b**	**0.043 b**

*In the same row, parameters not sharing the same letter have significantly different mean concentration ($\alpha = 0.05$).

Table 4 – Sensorial evolution of wine at different equilibration times (t=0’, 40’, 120’ after filling the glasses).

Equilibration time t = time of filling the glasses								
Glass	**Intensity of color**	**Intensity of odor**	**Harmony of odors**	**Frankness**	**Fineness**	**Structure**	**Equilibrium**	**Overall appreciation**
Glass A	5.81 ab	6.37 ab	6.94 a	7.87 a	7.06 a	5.19 a	6.37 a	6.87 a
Glass B	6.69 ab	5.75 ab	6.50 a	7.50 a	7.00 a	5.50 a	6.44 a	6.12 ab
Glass C	5.62 b	5.06 b	6.19 a	7.06 a	6.25 a	4.87 a	5.87 a	4.81 c
Glass D	6.87 ab	6.00 ab	6.06 a	7.37 a	7.00 a	5.37 a	6.00 a	6.19 ab
Glass E	5.87 ab	6.50 a	6.87 a	7.56 a	7.44 a	5.37 a	6.25 a	6.94 a
Glass F	7.44 a	5.81 ab	6.25 a	7.12 a	6.69 a	5.25 a	6.00 a	5.62 bc
Equilibration time t = 40’ after filling the glasses								
Glass	**Intensity of color**	**Intensity of odor**	**Harmony of odors**	**Frankness**	**Fineness**	**Structure**	**Equilibrium**	**Overall appreciation**
Glass A	5.83 ab	7.00 a	6.58 a	7.42 ab	7.91 a	5.67 a	6.00 ab	6.58 ab
Glass B	7.17 a	6.42 a	6.50 ab	7.25 ab	7.25 a	6.08 a	6.17 ab	6.42 ab
Glass C	5.25 b	4.50 b	5.25 b	6.33 b	5.75 b	5.08 a	5.33 b	4.17 c
Glass D	7.00 ab	6.00 ab	6.50 ab	7.08 ab	7.08 a	6.00 a	6.58 a	6.33 ab
Glass E	6.25 ab	6.92 a	7.00 a	7.83 a	7.92 a	6.08 a	6.42 a	6.92 a
Glass F	7.58 a	6.08 ab	5.92 ab	7.00 ab	7.08 a	5.58 a	5.83 ab	5.83 b
Equilibration time t = 120’ after filling the glasses								
Glass	**Intensity of color**	**Intensity of odor**	**Harmony of odors**	**Frankness**	**Fineness**	**Structure**	**Equilibrium**	**Overall appreciation**
Glass A	6.69 ab	6.50 a	6.50 a	7.87 a	7.31 ab	5.37 ab	6.06 a	5.56 b
Glass B	6.75 ab	6.19 a	6.19 a	7.50 ab	7.06 ab	5.94 a	6.06 a	6.12 ab
Glass C	5.12 b	4.31 b	4.31 b	6.37 c	5.81 c	4.37 b	4.94 b	3.37 c
Glass D	6.94 a	5.81 a	5.81 a	7.12 abc	6.94 ab	5.25 ab	6.12 a	6.25 ab
Glass E	6.06 ab	6.56 a	6.56 a	7.85 a	7.69 a	5.87 a	6.50 a	7.06 a
Glass F	7.31 a	5.31 ab	5.31 ab	6.62 bc	6.62 bc	5.00 ab	5.50 ab	5.06 b

*In the same column, parameters not sharing the same letter have significantly different mean concentration (α = 0.05).

Table 5 – **Final ranking of glasses for their utilization in a rosé wine tasting.**

	Ranking due to selected attributes					
Score	**6pt**	**5pt**	**4pt**	**3pt**	**2pt**	**1pt**
Evaporation profile	D/E	-	A/B	-	C/F	-
Oxygenation profile	B/D	-	A/F	-	C/E	-
Temperature profile	F	B	A/D/C	-	-	E
Chemical evolution	F	B/D/E	-	-	A/C	-
View attributes	D/F	A/B/E	C			
Smell attributes	E	A	B	D	F	C
Taste attributes	E/B	A/D	F	C		
Total ranking						
	I		**II**	**III**	**IV**	**V**
Total score	**B/D**		**E**	**F**	**A**	**C**

Table 6 – Correlation matrix among main geometrical indexes of glasses and wine attributes.

Parameter	Liquid Sup./Mouth Sup.	Sup./Vol.	Head space V. /Tot V.
Intensity of colors	0.504	-0.745	0.565
Intensity of odors	0.455	-0.045	0.798
Fineness	0.577	-0.042	0.842
Harmony of odors	0.455	-0.045	0.798
Frankness	0.273	0.206	0.687
Structure	0.552	-0.270	0.723
Equilibrium	0.531	-0.107	0.712
Overall appreciation	0.655	-0.278	0.728
Evaporation rate	-0.810	0.870	-0.633
Temperature rate	0.104	0.685	0.287
Total SO_2	0.799	-0.932	0.458

Figure 1 – Determination of dissolved oxygen into the liquid phase.

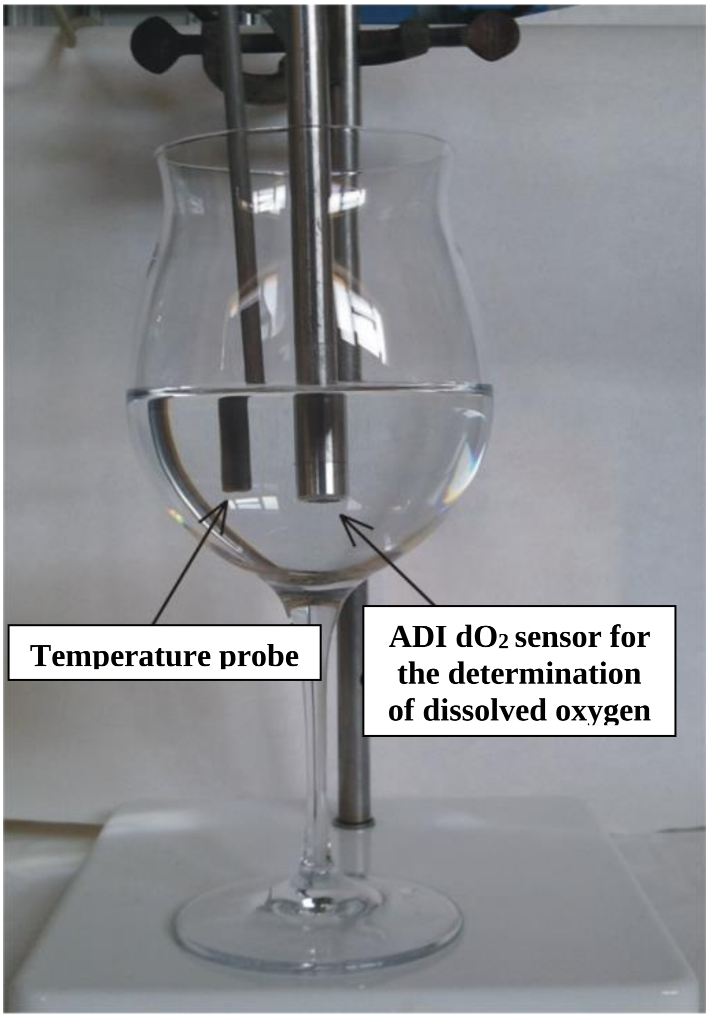
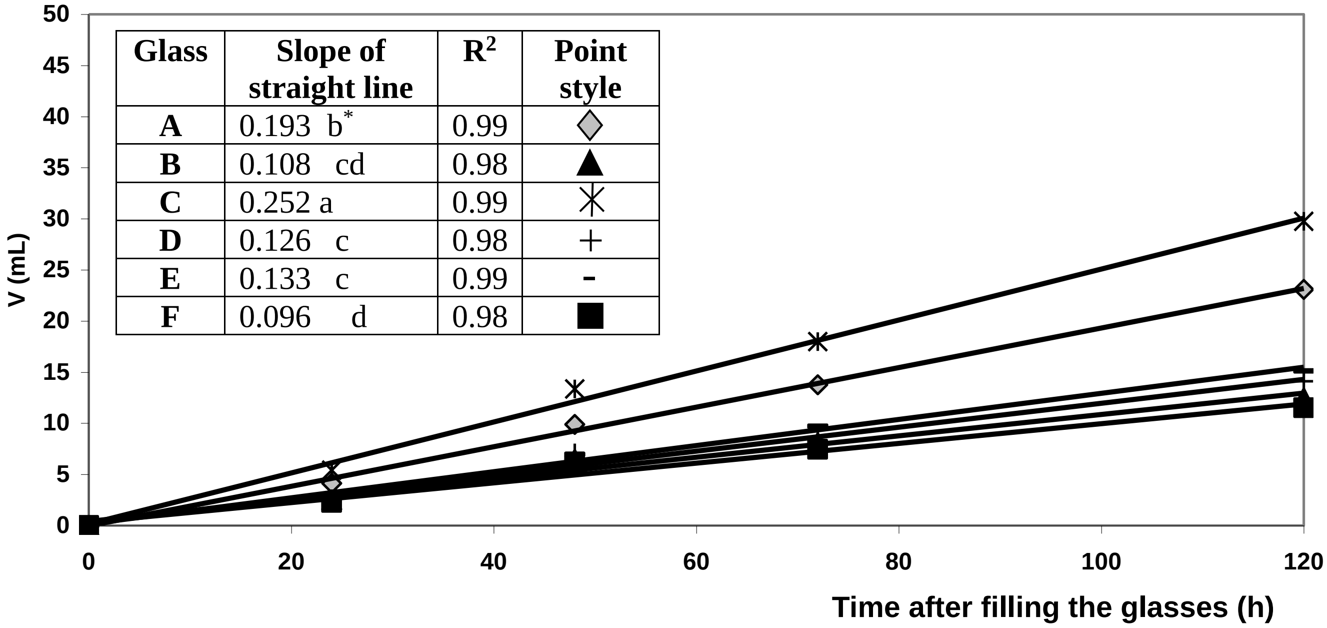


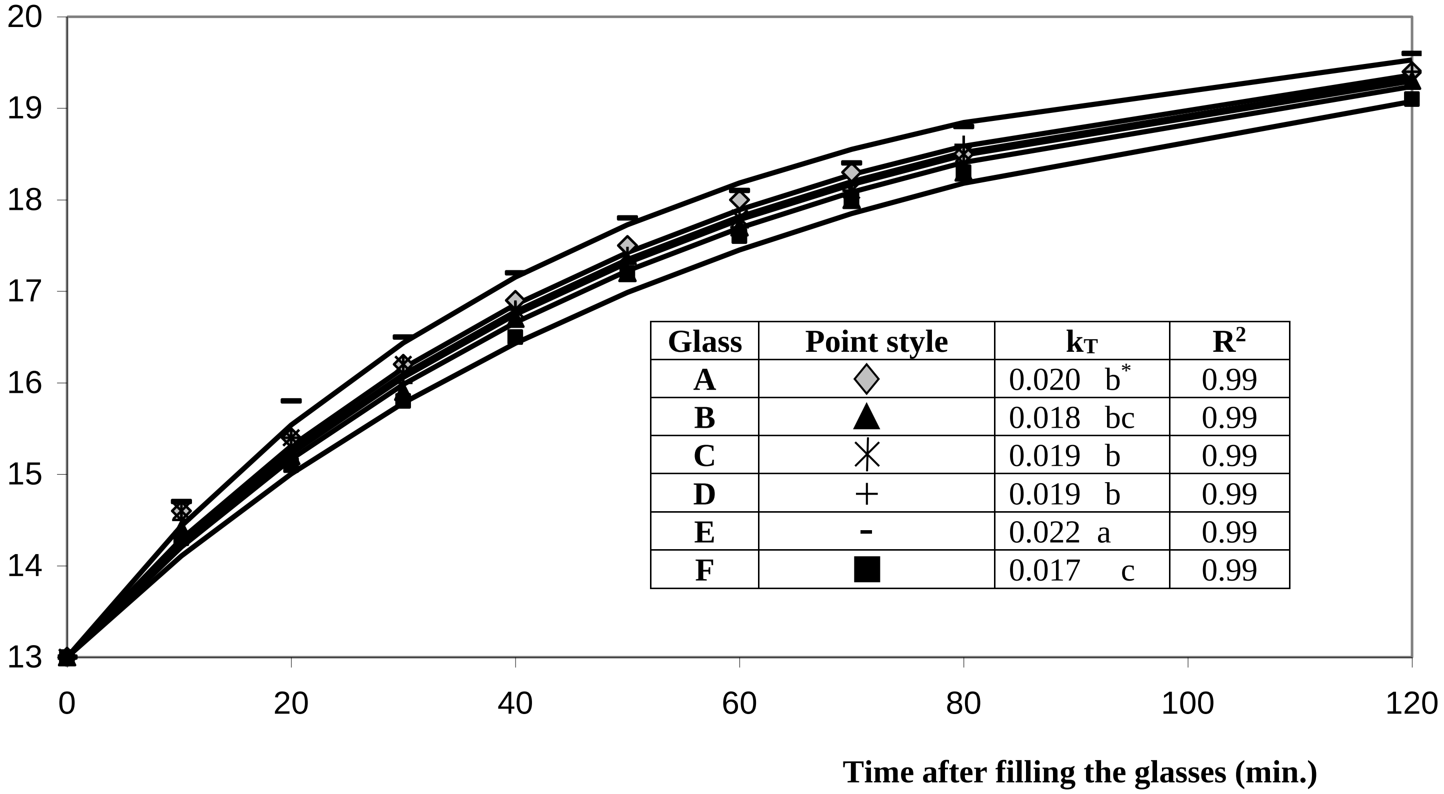
Figure 2 – Evaporation profile in static conditions during 120 hours from the filling of the glasses.



Glass	Slope of straight line	R^2	Point style
A	0.193 b*	0.99	◇
B	0.108 cd	0.98	▲
C	0.252 a	0.99	✳
D	0.126 c	0.98	+
E	0.133 c	0.99	-
F	0.096 d	0.98	■

*Parameters not sharing the same letter have significantly different mean values (α = 0.05).

Figure 3 – Profile of temperature increase as a function of equilibration time.



Glass	Point style	k_T	R^2
A	◇	0.020 b*	0.99
B	▲	0.018 bc	0.99
C	✳	0.019 b	0.99
D	+	0.019 b	0.99
E	-	0.022 a	0.99
F	■	0.017 c	0.99

*Parameters not sharing the same letter have significantly different mean concentration (α = 0.05).

Figure 4 – Profile of dissolved oxygen into the liquid phase as a function of equilibration time.

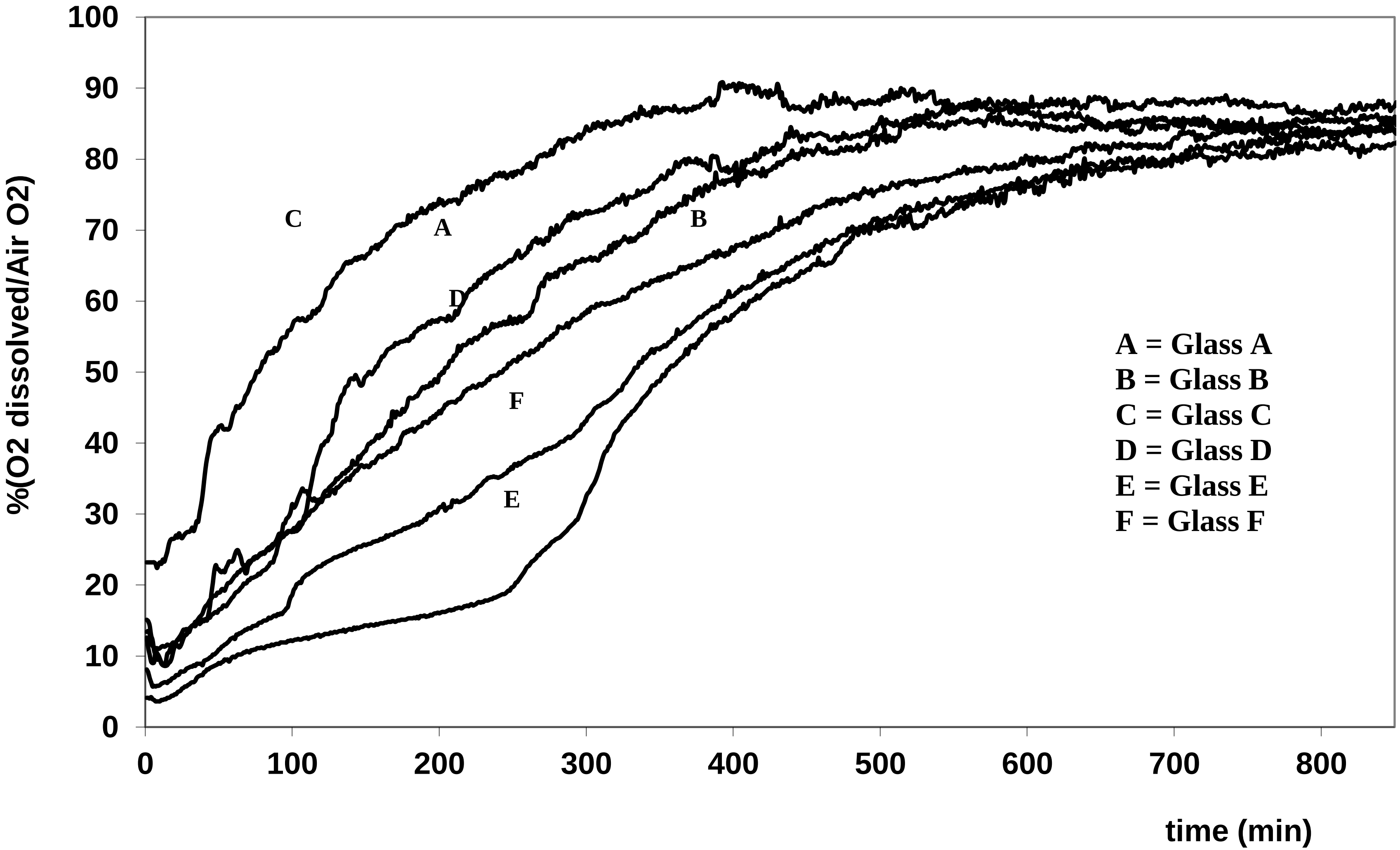
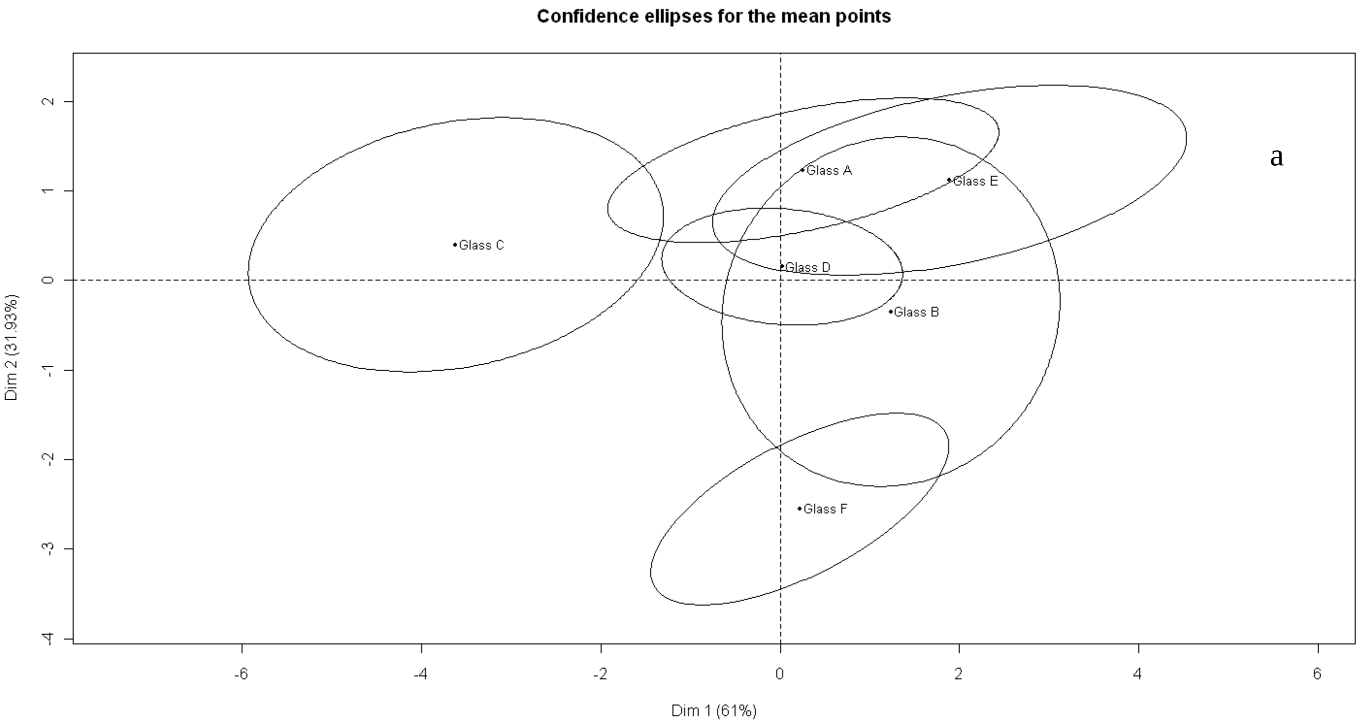


Figure 5 - Sensorial profile of wine as a function of the different glasses (t=time of glass filling): a) Confidence ellipses by a mean points; b) Variables Factor Map.



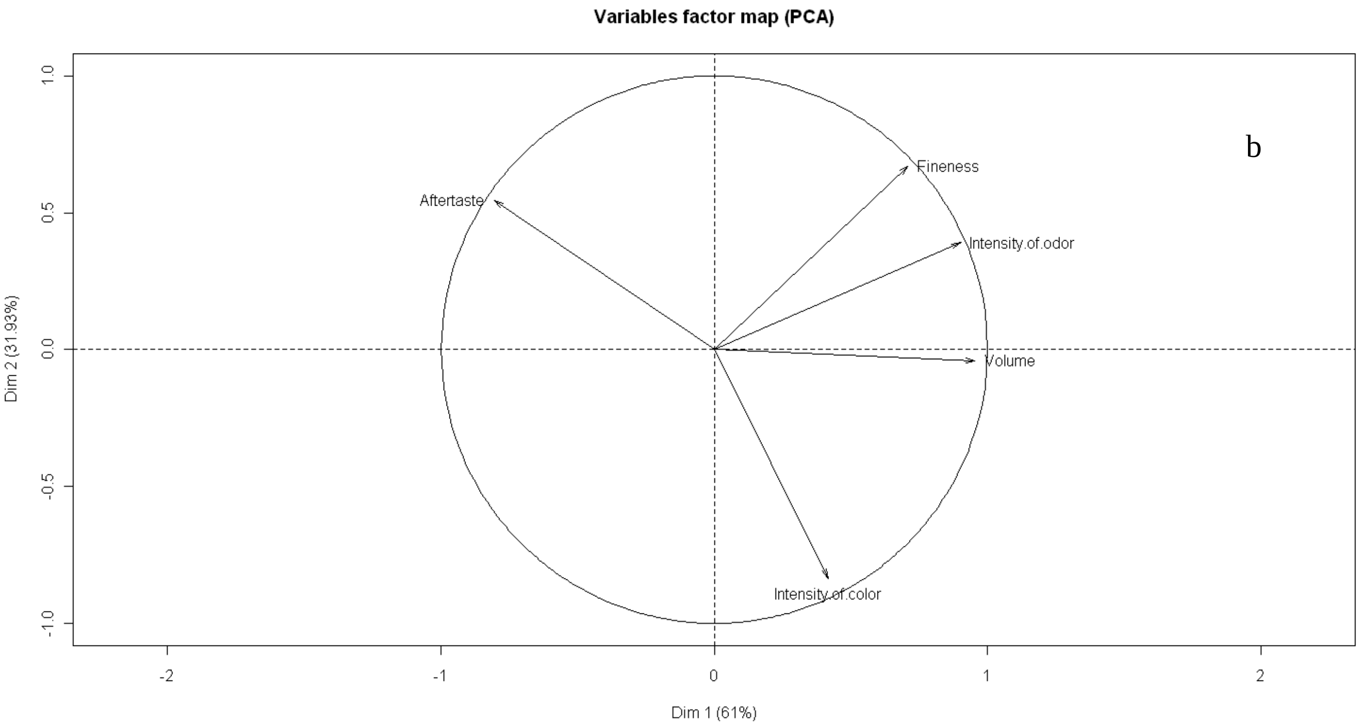


Figure 6 - Sensorial profile of wine as a function of the different glasses (t=120' from the filling of the glasses): a) Confidence ellipses by a mean points; b) Variables Factor Map.