Influence of ethanol content on sweetness and bitterness perception in dry wines

Blandine N. Cretin[a,b] & Denis Dubourdieu[a,b] & Axel Marchal[a,b]

[a] Univ. de Bordeaux, ISVV, EA 4577, Unité de recherche Œnologie, 33882 Villenave d'Ornon, France
[a] INRA, ISVV, USC 1366 Oenologie, 33882 Villenave d'Ornon, France

Corresponding author:
Axel Marchal
axel.marchal@u-bordeaux.fr

Abstract:

Ethanol is the second major component of wine after water and exhibits important sensory properties. Previous studies suggested that its bittersweet taste varies according to the alcohol content and the matrix. However, the organoleptic impact of ethanol on wine remains largely ambiguous. Various sensory tests were carried out with a trained panel and the results were statistically analyzed. Tastings revealed that variations of ethanol content usually observed in dry wines have no direct effect on sweet taste of wine. The role of ethanol in white wine bitterness was also studied, revealing its ability to impart the perception of bitterness due to sensory interactions with other constituents. Moreover, a threshold effect was observed between 7 and 10% alc. vol.. These results underline the importance of sensory interactions in the perception of taste and illustrate the role of matrix effects.

Keywords: Wine, Ethanol, Bitterness, Sweetness, Sensory analysis

Highlights

Sweetness and bitterness intensity were evaluated in dry wine after panel training.

The panel was able to discriminate intensity modulations of sweet and bitter taste.

Sweetness of dry wines was not affected by usual variations of ethanol content.

Ethanol had an indirect effect on white wine taste by increasing the bitterness perception.

These results highlighted the importance of matrix on the perception of wine taste.

1. Introduction

Ethanol is a primary metabolite produced by yeasts during alcoholic fermentation of grape sugars present in must. Its content generally varies between 12 and 14% alc. vol. in most dry wines (Ribéreau-Gayon, Glories, Maujean, & Dubourdieu, 2006). The presence of ethanol entails the moderate intake of wine due to its psychophysiology (Allen et al., 2014, Lanier et al., 2005, Nolden and Hayes, 2015) and health (Baum-Baicker, 1985, Cao et al., 2015) effects. However, it also significantly contributes to the physico-chemical properties and to the microbiological stability of the wine. Moreover, ethanol is the most abundant volatile compound in wine and might therefore, depending on its concentration, modify the aromatic perception (Guth & Seis, 2002). For instance, some studies described that the intensity of wine fruitiness decreases with the amount of ethanol (Escudero et al., 2007, Goldner et al., 2009, Le Berre et al., 2007). In addition to ethanol impact on wine aromas, the effects of ethanol level on oral sensation have been investigated (DeMiglio et al., 2002, Nurgel and Pickering, 2005). Studies have shown the minimizing effect of ethanol on red wine astringency (Fontoin, Saucier, Teissedre, & Glories, 2008). This observation has been attributed to the interference of ethanol with hydrophobic interactions between proteins and tannins, leading to a reduction of tannin precipitation and a decreased astringent sensation (Gawel, 1998, McRae et al., 2015). Finally, ethanol is also a taste-active compound. Various authors have described the sweet taste of ethanol in aqueous solution containing low levels of ethanol (0–4% alc. vol.) (Blizard, 2007, Scinska et al., 2000, Wilson et al., 1973) as well as the bitter taste and the burning characteristics associated with higher levels of ethanol (10–22% alc. vol.) (Bartoshuk et al., 1993, Blizard, 2007, Mattes and DiMeglio, 2001, Scinska et al., 2000, Thorngate, 1997, Wilson et al., 1973). Neurophysiological and genetic studies have explained the link between sweet taste perception and ethanol consumption by a similar gustatory neural pathway response (Blednov et al., 2008, Lemon et al., 2004). Sour and salty attributes have also been cited to describe ethanol taste, but with much lower intensities than bitter or sweet taste (Fischer and Noble, 1994, Mattes and DiMeglio, 2001, Scinska et al., 2000).

Ethanol has been established as bittersweet, and it appears that its taste-properties vary according to its content. This raises the question of its real contribution to wine sweetness and bitterness. Concerning its sweet taste, ethanol has been described to enhance wine sweetness directly through its own sweet taste (Jackson, 1994). However, recent studies showed that ethanol does not influence sweet taste of model dry wines and Australian Riesling base wines

(Gawel et al., 2007, Jones et al., 2008). Thus, the impact of ethanol on red and white dry wine sweet taste was not clearly established. According to several authors, increasing ethanol content through the range of those encountered in wine results in an elevation of its bitter taste. Fischer and Noble described the enhancing role of ethanol between 8 and 14% alc. vol. in a model wine solution containing 100 mg/L of catechin (Fischer & Noble, 1994) while other studies demonstrated a similar enhancing effect by quinine (Martin & Pangborn, 1970), epicatechin and catechin (Noble, 1994, Thorngate, 1992) and grape seed tannin oligomers (Fontoin et al., 2008). A more recent study (Gawel, Van Sluyter, Smith, & Waters, 2013) has investigated the effects of a complex mixture of phenolics on white wine bitterness under various pH and alcohol levels. Its results have also supported a direct effect of ethanol on wine bitterness perception. The results of these studies suggest the influence of ethanol on wine taste. However, the question remains whether ethanol affects wine flavor directly or indirectly in the concentration range encountered in wine.

For this reason, this study was conducted in order to better understand the role of ethanol content on the sweet and bitter taste of wine. Despite the clearly stated bittersweet taste of ethanol, its overall contribution to dry wine taste is still unclear. The first part of this work was aimed at studying the influence of variations of ethanol content in quantities generally encountered in wines (12–14% alc. vol.) on the sweet taste of a red and a white wine. Then, the influence of ethanol content on bitter perception was comparatively studied in two wines of differing levels of bitterness (low and high). This approach sought to determine whether the impact of ethanol on wine bitterness was direct or indirect and to demonstrate the importance of matrix effects on taste perception.

2. Materials and methods

2.1. Chemicals

Quinine sulfate and tartaric acid were purchased from Sigma-Aldrich (Saint-Quentin-Fallavier, France). Neohesperidin dihydrochalcone (NHDC) was purchased from Extrasynthese (Genay, France). The water used for solution preparation was pure and demineralized (eau de source de Montagne, Laqueuille, France).

2.2. Wines

2.2.1. Study of ethanol effect on sweetness perception

One white wine (WW) and one red wine (RW) were chosen for their relatively low ethanolic content. The white wine was a Bordeaux 2008 (12% alc. vol.; pH 3.1; 7.2 g/L of titratable acidity; 0.5 g/L of glucose + fructose) and the red wine was a Bordeaux 2008 (12.5% alc. vol.; pH 3.6; 5.6 g/L of titratable acidity; 0.2 g/L of glucose + fructose).

2.2.2. Study of ethanol effect on bitterness perception

During a preliminary sensory analysis, two white wines were selected on the basis of their taste by five experts strongly experienced in wine tasting, The first white wine ("wine A"), chosen for its very low bitterness, was a white Bordeaux 2011 (12.2% alc. vol.; <2 g/L of glucose + fructose; pH 3.1). The second white wine ("wine B"), chosen for its strong bitterness, was a Pessac-Léognan 2011 (12.5% alc. vol.; <2 g/L of glucose + fructose; pH 3.1).

2.3. Sensory analysis

Tastings sessions took place in a specific room equipped with individual booths and air-conditioned at 20 °C (ISO 8589:2007). Normalized glasses were used (ISO 3591:1977). All panelists (15 men and 15 women aged from 25 to 65 years) were wine tasting specialists. They were informed of the nature and risks of the present study and were asked to give their consent to participate in the sensory analyses.

Due to saturation and persistence of the bitter taste as well as palate fatigue of the panel, training and test sessions were spread over one week. Panelists were asked to rinse mouth with water and wait one minute between each sample.

For all evaluations, samples were labeled with random three-digit codes and presented in counterbalanced order to avoid bias.

2.3.1. Panel training

Panelists attended four sessions to train in recognition and discrimination of taste perception.

During the first two sessions, different concentrations of reference standard solutions representative of taste were presented to the panel: NHDC (0–4 mg/L) for sweetness and quinine sulfate (1.5–12 mg/L) for bitterness. Also, different concentrations of quinine sulfate (1.5–12 mg/L) with 3 g/L of tartaric acid were presented to the panel to train them to perceive bitterness independent of acidity.

The last two sessions were used to improve the panel's ability to discriminate sweetness and bitterness. Three series were presented to the panel: quinine sulfate (1.5, 3, 6 and 12 mg/L) with and without 3 g/L tartaric acid and NHDC (0, 1, 2 and 4 mg/L) (Table 1). Panelists were asked to sort the samples by increasing order of bitterness and sweetness for each series.

2.3.2. Sensory experiments on sweetness

To study the effect of ethanol content on wine sweetness, distilled ethanol was added to the white Bordeaux 2008 (12% alc. vol.) to provide ethanol levels of 12.5, 13 and 13.5% alc. vol., and in the same manner, distilled ethanol was added to the red Bordeaux 2008 (12.5% alc. vol.) to provide ethanol levels of 13, 13.5 and 14% alc. vol. as presented in Table 2. The difference between the lower and higher alcohol percentage (1.5% alc. vol.) was based on the ethanol content range generally encountered in wine. The alcoholic strength by volume in wine was measured with a FOSS Winescan (Hillerød, Danmark) and by the O.I.V. official Gibertini method (O.I.V., 2015).

The addition of ethanol leads to a maximal dilution of 1.5%, which is considered as negligible. The four samples of each wine were presented to the panelists,who were first asked to rate the sweetness intensity on an eight-point scale (0 = "absence" to 7 = "very high"). This test was chosen based on the panel's familiarity with the intensity scale for profile description. In a second phase, panelists were asked to sort the wines by increasing order of sweetness.

2.3.3. Sensory experiments on bitterness

To study the effect of ethanol content on bitterness perception, two white wines were chosen. The first wine had an imperceptible bitterness ("wine A") while the second wine was representative of a bitter wine ("wine B").

Both wines were first dealcoholized by evaporation under vacuum to obtain a white wine concentrate of 5% alc. vol. Then, for each wine, addition of distilled ethanol and pure and demineralized water provided wine samples with ethanol levels of 4, 7, 10 and 12.5% alc. vol. as presented in Table 2 (the final volume was the same for all samples and similar to the initial volume of wine before dealcoholization). As described for sweetness experiments, the levels of alcohol were determined after sample preparation.

The panelists were asked to rate the bitterness intensity of these wines on an eight-point scale (0 = "absence" to 7 = "very high"). For this experiment, the panel was not asked to sort the wines by increasing order of bitterness, as the difficulty of this exercise increases with the number of samples (8 wines).

2.4. Statistical analysis

All statistical analyses were carried out using the software, R Statistical (Foundation for Statistical Computing, Vienna, Austria).

According to the international organization for standardization (ISO 8587:2007), results obtained from ranking tests are interpreted by Page's trend test, used to test the hypothesis of a predicted order of levels. Indeed, the order of samples for each wine is predetermined by the increasing concentrations of reference standard (Section 3.1. Panel Training) and ethanol (Section 3.2. Sensory Experiments on Sweetness). For each judge, a value between 1 and 4 was attributed to each sample (1 = "less intense sample" and 4 = "more intense sample"). The sums of the ranks Ri were obtained for each sample, then the parameters L and L' were calculated as described below and L' was compared to threshold values in order to determine whether the result of the test was significant or not for the factor concerned.

$$L = \sum_{i=1}^{p} i.Ri \qquad L' = \frac{12L - 3n.p.(p+1)^2}{p.(p+1).\sqrt{n.(p-1)}}$$

n, number of panelists ($n = 30$)

p, number of modalities ($p = 1$ to 4)

A one-way ANOVA (analysis of variance) with a 0.1% risk error was used to statistically interpret and discriminate wine samples on their sweetness or bitterness intensity. ANOVA was performed on normalized panel's rates. Levene's test for homogeneity of variance and Shapiro Wilk's test for normality were previously applied to prove, respectively, that variances were equal and that the population had a normal distribution as assumed by the ANOVA. When the ANOVA showed significant inequality of means ($P < 0.001$), the Tukey's "post-hoc" pairwise comparison was used to determine the groups of samples that were significantly different.

3. Results and discussion

3.1. Panel evaluation

To evaluate the panel's ability to recognize and discriminate taste perception, various levels of reference standard solutions were displayed as presented in Table 1. NHDC and quinine sulfate were used as they exhibit sweet and bitter taste, respectively. Panelists were asked to sort the samples following the increasing perception of the taste. Data presented in Table 3 showed that for both quinine sulfate series (with or without tartaric acid), panelists were able to classify the samples according to the intensity of the bitterness perception. Indeed, we observed that the sum of the ranks was increasing from *R1* to *R4* in coherence with the addition of quinine sulfate concentrations. Values of L' were distinctly higher to the critic value of 3.09 for a 0.1% risk error establishing the significance of the test.

In the same manner for the NHDC series, we observed that the sum of the ranks increased with the NHDC concentrations, meaning that the panel was able to significantly sort the samples according to the intensity of the sweetness perception, with a 0.1% risk error ($L' > 3.09$).

These results demonstrated the efficiency of the panel to detect sweetness and bitterness and to discriminate samples according to the intensity of these tastes.

3.2. Effect of ethanolic content on wine sweetness

The base wines used in these experiments displayed low concentrations of glucose + fructose (0.5 and 0.2 g/L for the white and red wine, respectively), far below their taste threshold (Amerine et al., 1965, Hladik and Simmen, 1996, Simmen and Hladik, 1998). Thus, these were actually dry wines.

To determine if varying ethanol levels in dry wines could affect their sweet perception, different quantities of distilled ethanol were added to these red and white wines as described in Table 2. The choice of using distilled ethanol from wine was made in order to avoid any taste bias from the addition of analytical grade ethanol in the samples. Panelists then rated the intensity of the perceived sweet taste of the four independent samples for the red wine as well as for the white wine on a linear eight point scale. The results were statistically interpreted by ANOVA. The Levene's test and Shapiro Wilk's test proved the homogeneity of variance (p-value RW = 0.3517; p-value WW = 0.2537) and the normal distribution (p-value RW = 0.6547; p-value WW = 0.6281) assumed by the ANOVA. Then, the ANOVA was performed on the sensory data (p-value RW = 0.487; p-value WW = 0.229) and revealed that the test was not significant, indicating that panelists did not perceive differences in sweetness of samples. Even if the panel proved to be efficient with discriminating variations of sweetness, the perception of a variation of 2% alc. vol. might be difficult to rate on an linear scale (Sauvageot, 2009b). In order to compel the panel to make a stand on samples' sweetness, they were asked in a second phase to sort the wines in ascending order of sweetness. Thus, a rank test was used here, which was a more intuitive test for the panel (Sauvageot, 2009a). As presented in Table 4, the results of the Page test were not significant for either wine. The progression of rank sums were not in agreement with the ethanol content for the red or the white wine. Also, the L' value was lower than the threshold value of 1.645 for a 5% risk error.

These results demonstrated that for both the red wine and white wine, the modality containing 1.5% alc. vol. more than the control wine was not perceived as sweeter. More generally, although the ethanol levels presented here covered a range of alcoholic strength characteristic of most French dry wines (12.5%–14% alc. vol. for RW and 12%–13.5% alc. vol. for WW), it appeared that variations of ethanol content did not result in increase of sweet taste of wine. These results were in accordance with previous works carried out on both white and red wines (Gawel et al., 2007, Jones et al., 2008, Marchal et al., 2011). However, some tasters have frequently pointed out a higher sweet sensation in wines containing high levels of alcohol. This phenomenon could be due to the release of grape or yeast compounds, increasing sweetness. For instance, the heat shock protein Hsp12p is responsible for a gain of sweetness of dry wines during yeast autolysis and it has been shown that the expression of the gene HSP12 increased with the progression of alcoholic fermentation (Marchal, Marullo, et al., 2015). Thus, the impact of ethanol on sweetness could be indirect through the release of taste-active compounds from yeast lees. Moreover, it is possible that matrix effects could occur, and that these results might be slightly different using alternative base wines. However, the small differences in ethanol concentration met in dry wines compared with a clear disparity of sweetness perceived suggest that the role of ethanol in the perception of sweetness of dry wines remains very limited. Compounds released from yeast lees autolysis and oak wood (Marchal et al., 2015, Marchal et al., 2011) have been recently proposed to give a molecular insight on the sweet taste of dry wines.

3.3. Effect of ethanol content on bitterness perception of a white wine

The wine with a very low bitterness ("wine A") and the bitter wine ("wine B") were both processed to display ethanol levels of 4, 7, 10 and 12% alc. vol. After dealcoholization of both wines under vacuum, different quantities of the distilled ethanol and demineralized water were added to obtain these ethanol levels.

Aromas of the four wine samples for both wines were judged by five experts as being consistent with the aroma of both selected wines. Also, the pH levels of these four samples were measured for both wines and remained consistent.

Panelists were then asked to rate the intensity of the perceived bitter taste on a linear eight point scale for these eight independent samples (Samples S1 to S4 for "wine A" and S1 to S4 for "wine B").

The Levene's test and Shapiro Wilk's test were applied and proved the homogeneity of variance (p-value = 0.5513) and the normal distribution (p-value = 0.7685) of the dataset. A one-way

ANOVA was performed and revealed significant differences (*p*-value = 5.7 × 10−13). This result established that at least one of the samples was perceived different from the others, with a 0.1% risk error.

The Tukey's “post-hoc” pairwise comparisons allowed for sorting of the samples in significantly different groups. This multiple means comparison showed that samples S1 to S4 of “wine A” and S1 to S2 of “wine B” were significantly different from sample S3 of “wine B”, with a 5% risk error, and moreover, highly significantly different from sample S4 of “wine B”, with a 0.1% risk error. In this way, the multiple means comparison highlighted the affiliation of the samples to two significantly different groups. The group « a » was characterized by its very low bitterness and the group « b » was significantly distinguished as more bitter (Fig. 1).

At 12.5% alc. vol., both wines were perceived as different regarding their bitterness, which confirms that the preliminary choice of these two wines was relevant: “wine B” actually exhibited a stronger bitter taste. For “wine A”, there was no distinction between the sample at 4% and 12.5% alc. vol. For “wine B”, the 4% alc. vol. sample was distinguished from the one at 12.5% alc. vol. and exhibited a much lower bitterness. This experiment highlighted the role of ethanol. At a 12.5% alc. vol., the “wine B” was distinguished from “wine A” by its higher bitterness, while there was no difference perceived between these two wines at 4% alc. vol. Moreover, increasing the ethanol level in “wine A” did not result in any gain of bitterness. Jointly, these results suggest that ethanol was not directly responsible for the perceived bitterness but allowed for its revelation.

Moreover, samples with 4, 7, 10 and 12.5% alc. vol. of “wine A” were not distinguished, and samples with 4 and 7% alc. vol. of “ wine B” were not distinguished from “wine A” samples, forming the group « a » (very low bitterness). Nevertheless, samples with 10 and 12.5% alc. vol. of “wine B” were judged to be significantly and highly significantly more bitter, respectively. In this way, a threshold effect for the “wine B” was observed. Indeed, this wine bitterness was not perceived at 4 and 7% alc. vol. while it appeared bitter at 10 and 12.5% alc. vol. Moreover, even if there was no significant difference between the 10 and 12.5% alc. vol. samples of “wine B”, we observed a slight increase of the bitterness. The value of this threshold might depend on the wine composition and more particularly the levels of phenolic or other taste active compounds.

These results were in agreement with Fontoin et al. (Fontoin et al., 2008). and Fischer and Noble (Fischer & Noble, 1994), who have reported the increasing effect of ethanol on the bitterness of some phenolic compounds, even if they did not use the same matrices and grade of ethanol. A more recent study (Gawel et al., 2013) has highlighted the complexity of ethanol influence on wine taste. They have established that higher amounts of ethanol and phenolics supplemented from various grape varieties are linked with a stronger bitterness in Riesling and Chardonnay base wines.

4. Conclusions

The present research focused on impact of ethanol level on wine sweetness and its role in wine bitterness. Sensory tests were carried out with a trained panel and the results were interpreted using statistical analysis.

First, ethanol was added into red and white wines to cover a range generally observed in dry wines (from 12 to 14% alc. vol.). The tasting revealed no modification of the perception of wine sweetness suggesting that ethanol has no direct effect on sweet taste of wine.

The results of the second part of this study showed that ethanol was not directly responsible for the perceived bitterness in white wine. Indeed, increasing the alcohol level did not provide more bitterness in a non-bitter wine contrary to a bitter wine. This supports the hypothesis that, in wine, ethanol allows for the perception of bitterness due to sensory interactions with other constituents. Moreover, a threshold effect was observed between 7 and 10% alc. vol. as well as a slight increase in bitterness between 10 and 12.5% alc. vol. These results clearly underline the importance of sensory interactions in the perception of taste and illustrate the role of matrix effects. For the past few years, some research studies have aimed at identifying molecular determinants of taste with an inductive approach. Such studies were based on a taste-guided approach and implied a tasting after each step of the purification protocol to select the relevant fractions (Glabasnia and Hofmann, 2006, Hufnagel and Hofmann, 2008, Marchal et al., 2011). The results of the present work demonstrated that the matrix used to taste the fraction has to be chosen very carefully to ensure the relevance of the approach, in particular if bitter compounds are targeted.

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References

Allen, A. L., McGeary, J. E., & Hayes, J. E. (2014). Polymorphisms in TRPV1 and TAS2Rs associate with sensations from sampled ethanol. Alcoholism : Clinical and Experimental Research, 38(10), 2550-2560.

Amerine, M. A., Pangborn, R. M., & Roessler, E. B. (1965). Principles of sensory evaluation of food. In A. Press (Ed.), Food science and technology : A series of monographs (p. 602). New York.

Bartoshuk, L. M., Conner, E., Karrer, T., Kochenbach, K., Palcso, M., Snow, D., ... Danowski, S. (1993). PROP supertasters and the perception of ethyl alcohol. Chemical Senses, 5, 526-527.

Baum-Baicker, C. (1985). The psychological benefits of moderate alcohol consumption: A review of the literature. Drug and Alcohol Dependence, 15(4), 305-322.

Blednov, Y. A., Walker, D., Martinez, M., Levine, M., Damak, S., & Margolskee, R. F. (2008). Perception of sweet taste is important for voluntary alcohol consumption in mice. Genes, Brain and Behavior, 7(1), 1-13.

Blizard, D. A. (2007). Sweet and bitter taste of ethanol in C57BL/6J and DBA2/J mouse strains. Behavior Genetics, 37(1), 146-159.

Cao, Y., Willett, W. C., Rimm, E. B., Stampfer, M. J., & Giovannucci, E. L. (2015). Light to moderate intake of alcohol, drinking patterns, and risk of cancer: Results from two prospective US cohort studies [10.1136/bmj.h4238] British Medical Journal, 351.

DeMiglio, P., Pickering, G. J., & Reynolds, A. G. (2002). Astringent sub-qualities eli- cited by red wine: The role of ethanol and pH. In C. W. Cullen, G. J. Pickering, & R. Phillips (Eds.), Proceedings of the international bacchus to the future conference. St Catharines Ontario, May 23rd - 25th, 2002.

Escudero, A., Campo, E., Fari~na, L., Cacho, J., & Ferreira, V. (2007). Analytical characterization of the aroma of five premium red wines. Insights into the role of odor families and the concept of fruitiness of wines. Journal of Agricultural and Food Chemistry, 55(11), 4501-4510.

Fischer, U., & Noble, A. C. (1994). The effect of ethanol, catechin concentration, and pH on sourness and bitterness of wine. American Journal of Enology and Viti- culture, 45(1), 6-10.

Fontoin, H., Saucier, C., Teissedre, P.-L., & Glories, Y. (2008). Effect of pH, ethanol and acidity on astringency and bitterness of grape seed tannin oligomers in model wine solution. Food Quality and Preference, 19(3), 286-291.

Gawel, R. (1998). Red wine astringency: A review. Australian Journal of Grape and Wine Research, 4(2), 74-95.

Gawel, R., Van Sluyter, S. C., Smith, P. A., & Waters, E. J. (2013). Effect of pH and alcohol on perception of phenolic character in white wine. American Journal of Enology and Viticulture, 64(4), 425-429.

Gawel, R., Van Sluyter, S. C., & Waters, E. J. (2007). The effects of ethanol and glycerol on the body and other sensory characteristics of Riesling wines. Australian Journal of Grape and Wine Research, 13(1), 38.

Glabasnia, A., & Hofmann, T. (2006). Sensory-directed identification of taste-active ellagitannins in american (Quercus alba L.) and european oak wood (*Quercus robur* L.) and quantitative analysis in bourbon whiskey and oak-matured red wines. Journal of Agricultural and Food Chemistry, 54(9), 3380-3390.

Goldner, M. C., Zamora, M. C., Di Leo Lira, P., Gianninoto, H., & Bandoni, A. (2009). Effect of ethanol level in the perception of aroma attributes and the detection of volatile compounds in red wine. Journal of Sensory Studies, 24(2), 243-257.

Guth, H., & Seis, A. (2002, 7-10 October 2001). Flavour of wines: Towards an understanding by reconstitution experiments and an analysis of ethanol's effect on odour activity of key compounds. In Paper presented at the eleventh Australian wine industry technical conference, Adelaide, SA Australian.

Hladik, C. M., & Simmen, B. (1996). Taste perception and feeding behavior in nonhuman primates and human populations. Evolutionary Anthropology, 5, 58-71.

Hufnagel, J. C., & Hofmann, T. (2008). Orosensory-directed identification of astringent mouthfeel and bitter-tasting compounds in red wine. Journal of Agricultural and Food Chemistry, 56(4), 1376-1386.

ISO 3591:1977. (2007a). Sensory analysis. Apparatus. Wine-tasting glass.

ISO 8587: 2007. (2007b). Sensory analysis. Methodology. Ranking.

ISO 8589:2007. (2007c). Sensory analysis. General guidance for the design of test rooms.

Jackson, R. S. (1994). Wine Science: Principles and applications.

Jones, P. R., Gawel, R., Francis, I. L., & Waters, E. J. (2008). The influence of interactions between major white wine components on the aroma, flavour and texture of model white wine. Food Quality and Preference, 19(6), 596-607.

Lanier, S. A., Hayes, J. E., & Duffy, V. B. (2005). Sweet and bitter tastes of alcoholic beverages mediate alcohol intake in of-age undergraduates. Physiology and Behavior, 83(5), 821-831.

Le Berre, E., Atanasova, B., Langlois, D., Etievant, P., & Thomas-Danguin, T. (2007).

Impact of ethanol on the perception of wine odorant mixtures. Food Quality and Preference, 18(6), 901-908.

Lemon, C. H., Brasser, S. M., & Smith, D. V. (2004). Alcohol activates a sucrose-responsive gustatory neural pathway. Journal of Neurophysiology, 92(1), 536-544.

Tables

Table 1. Samples used for the panel evaluation.

Compounds	Sample 1	Sample 2	Sample 3	Sample 4
Panel evaluation				
NHDC effect	0 mg/L	1 mg/L	2 mg/L	4 mg/L
Quinine sulfate effect	1.5 mg/L	3 mg/L	6 mg/L	12 mg/L
Quinine sulfate + Tartaric acid effect	1.5 mg/L + 3 g/L	3 mg/L + 3 g/L	6 mg/L + 3 g/L	12 mg/L + 3 g/L

Table 2. Samples used for sensory tests on sweetness and bitterness perception.

Factor studied	Test	Sample 1 S1	Sample 2 S2	Sample 3 S3	Sample 4 S4
Effect on sweetness					
Ethanol effect	Intensity notation *and* Ranking	RW (12.5% alc.vol.)	RW + 0.5% (13% alc. vol.)	RW + 1% (13.5% alc.vol.)	RW + 1.5% (14% alc.vol.)
		WW (12% alc.vol.)	WW + 0.5% (12.5% alc.vol.)	WW + 1% (13% alc.vol.)	WW + 1.5% (13.5% alc.vol.)
Effect on bitterness					
Ethanol effect	Intensity notation	Wine A 4% alc. vol.	Wine A 7% alc. vol.	Wine A 10% alc. vol.	Wine A 12.5% alc. vol.
		Wine B 4% alc. vol.	Wine B 7% alc. vol.	Wine B 10% alc. vol.	Wine B 12.5% alc. vol.

Table 3. Results of rank tests for panel evaluation.

Ranks sum	R_1	R_2	R_3	R_4	L	L'
NHDC	53	68	82	97	823	4.62***
Quinine sulfate effect	42	61	83	114	869	7.53***
Quinine sulfate + Tartaric acid effect	57	69	76	98	815	4.11***

(***) significant at 0.1%.

Table 4. Results of rank tests to study the effect of ethanolic content on wine sweetness.

Ranks sum	R_1	R_2	R_3	R_4	L	L'
Red wine	79	66	75	80	756	0.38 ns
White wine	63	80	77	80	774	1.52 ns

ns, not significant.

Figures

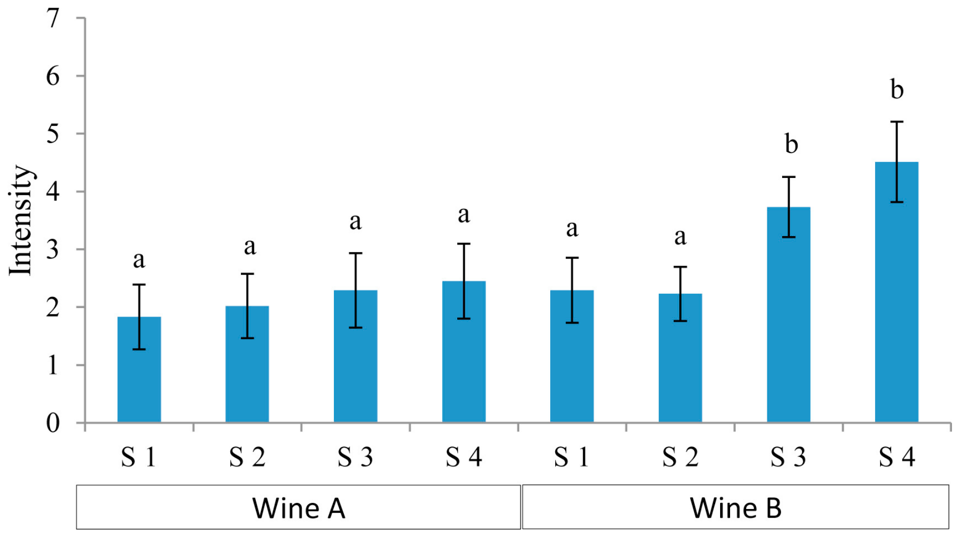

Fig. 1. Bitterness intensities of the samples and group affiliation.