



ORIGINAL RESEARCH ARTICLE

Exploring the response to a new range of ethanol reductions in Chardonnay and Syrah wines using a Consumer Rejection Threshold approach

Olivier Geffroy*, Grégory Pasquier, Marielle Pagès and Frédéric Violleau

Université de Toulouse, INP-Purpan, 75 voie du TOEC, BP57611, 31076 Toulouse Cedex 3, France



*correspondence:
olivier.geffroy@purpan.fr

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ABSTRACT

Ethanol is one of the major components of wine, which has a substantial impact on its sensory characteristics. However, data concerning consumer response to ethanol or changes in ethanol remains limited. The aim of this study was to determine the threshold ethanol concentrations beyond which ethanol lowering becomes undesirable in Chardonnay and Syrah wines using the consumer rejection threshold (CRT) methodology. Base wines from these two cultivars were first dearomatised and fully dealcoholised using spinning cone column technology. Then, control wines with a similar ethanol content to the base wines (13.8 and 13.5 % v/v for Chardonnay and Syrah respectively) and wines with lower ethanol contents were reconstituted by mixing the final beverage, the aroma fraction, food grade ethanol and distilled water. CRT values were determined as 2.8 % v/v for Chardonnay and at 7.0 % v/v for Syrah. These particularly low and unexpected concentrations indicate that consumer sensory liking might not be necessarily driven by ethanol concentration, especially for white wines. However, the post-evaluation questionnaire showed that consumers were expecting a high minimal ethanol content for quality wines (10.9 % v/v \pm 1.2 and 11.7 % v/v \pm 1.5 for white and red wines respectively) and had a limited experience with low and dealcoholised wines. Overall, our data, which are still preliminary and deserve to be validated using different base wines with a larger number of consumers, show that consumers would not necessarily be refractory from a sensory standpoint to the consumption of low ethanol beverages made from wine. Our findings strongly encourage professionals from the wine industry and public authorities to raise awareness about the increase in quality of such products and their benefits for human health.

KEYWORDS: Ethanol perception, difference threshold, consumer rejection threshold, Chardonnay wine, Syrah wine, spinning cone column

INTRODUCTION

After water, ethanol is the second major component of wine. According to the official definition of wine proposed by the Organisation Internationale de la Vigne et du Vin (OIV) in 1973, its “actual alcohol content shall not be less than 8.5 % v/v” but might be reduced to 7.0 % v/v in specific cases. Even if no upper limit has been defined, the maximal ethanol content is mainly driven by the yeast’s fermentation ability, which typically does not exceed 15 to 16 % v/v, as well as often by financial penalties that can apply in some markets for high ethanol wines (Österberg, 2011).

Since the second part of the 20th century, many concerns have been raised about ethanol and there has been a convergence in policies across the European Union (Babor *et al.*, 2010). Such policies - for example, the requirement to display the alcohol content along with health warnings on the label - are imposed as a result of its harmful effects on human health.

Over the same period of time, and as shown in a recent study conducted in Bordeaux and Napa (Gambetta and Kurtural, 2021), there has been an increase in grape sugar concentration and therefore in the final ethanol content of wine as a consequence of climate change, which has led to an increased cumulated annual growing degree days (GDD). For other wine regions that were traditionally dedicated to the mass production of entry level wines, such an increase in ethanol might have been amplified by the shift towards quality wines whose production involves better yield monitoring (Jackson and Lombard, 1993; Smart *et al.*, 1990).

As global consumer demand has moved towards fruitier, lighter wines, and to match demand and supply that might be considered out of balance (Bucher *et al.*, 2018), European regulations have evolved by authorising since 2009 the dealcoholisation of wines within the limit of -2 % v/v (EU Regulation N° 606/2009). For dealcoholisation over this limit, beverages must be named in accordance with the OIV International Code of Oenological Practices as “wines with alcohol content modified by dealcoholisation” for ethanol content above 8.5 % v/v; “beverages obtained by the partial dealcoholisation of wine” for ethanol content between 0.5 % and 8.5 % v/v; and “beverages obtained by the dealcoholisation of wine” for ethanol content less than 0.5 % v/v.

This dealcoholisation is generally achieved through physical processes based on membrane separation (i.e., nanofiltration, reverse osmosis) or thermal distillation (i.e., distillation, vacuum distillation, spinning cone column) (Pickering, 2000; Sam *et al.*, 2021).

The impact of ethanol on the sensory profile of wine is well known and has been the subject of much research. High ethanol content generally decreases acid perception (Fischer and Noble, 1994) and aroma volatility, which makes wines particularly rich in ethanol seem less fruity (Conner *et al.*, 1998; Escudero *et al.*, 2007). The impact of ethanol on sweetness is still under debate, with some authors reporting an increase in sweet taste with an increase in ethanol

(Martin and Pangborn, 1970; Scinska *et al.*, 2000). More recent work found that the sweetness of dry wines was not affected by the usual variations in ethanol, but it was mainly involved in wine bitterness as a consequence of sensory interactions with other compounds (Cretin *et al.*, 2018). The removal of ethanol leads to a loss of viscosity, body and fullness, and reinforces the aggressiveness of tannins (Jordão *et al.*, 2015; Longo *et al.*, 2017; Schmitt and Christmann, 2022). The complete elimination of ethanol, which can represent more than 20 % of the initial wine volume depending on the technology and the ethanol concentration of the distillate (Belisario-Sanchez *et al.*, 2009), can also indirectly contribute by concentrating non-volatile molecules, such as organic acids or polyphenols.

Data on consumer assessment of ethanol or ethanol lowering in wine, including in partially dealcoholised wines, remains scarce. In an early review article, Pickering (2000) suggested that expected limitations in sensory quality, intrinsic tastes and an attitude of “snobbishness” towards such beverages might constitute barriers to consumer uptake. Experimental studies have shown that for consumers the appeal of wine and its expected quality usually decreased with lower ethanol content on the wine label (Masson and Aurier, 2008; Vasiljevic *et al.*, 2018). While still preliminary, these findings were not consistent with the results of the tasting session, as wine with an ethanol content of 9 % v/v was not perceived differently to standard wine by consumers (Masson and Aurier, 2008). The same trend was also observed by Meillon *et al.* (2010) in the 10-14 % v/v ethanol range, even though consumer liking was less evident, suggesting strong segmentation.

The aim of this research work was to explore a wider range of ethanol lowering and to formally evaluate consumer response to ethanol in white and red wines using the consumer rejection threshold (CRT) method (Prescott *et al.*, 2005). The CRT approach, which is based on the repetition of paired preference tests, has been previously applied to compounds responsible for wine faults, such as cork taint (Prescott *et al.*, 2005) or 3-isobutyl-2-methoxypyrazine (Geffroy *et al.*, 2020), and more generally to determine a level of concentration beyond which a given molecule becomes undesirable (Francis and Williamson, 2015; Geffroy *et al.*, 2018). In both base wines, difference thresholds for ethanol were also defined during a preliminary experiment to determine the difference in ethanol concentration that can be perceived by consumers.

MATERIALS AND METHODS

1. Base wines and production of wines with different levels of ethanol

The two base wines used for the study were made from Chardonnay and Syrah, the most planted varieties in the Occitanie region in Southern France according to FranceAgriMer in 2018 (www.franceagrimer.com). They were sourced from a local cooperative cellar and were selected by a small group of tasters composed of four experts - all

holders of the French National Oenology Diploma (DNO) - as being representative and typical of the wines made from these cultivars within the Protected Geographical Indication (PGI) Pays d'Oc. Overall, both wines were well-balanced and did not exhibit any significant burning sensations in the palate. The Chardonnay wine was characterised by floral notes and a slight bitterness, while the Syrah wine was marked by red and black fruit aroma and smooth tannins.

Classical analyses were conducted on both wines using a Winescan™ SO₂ (Foss France SAS, Nanterre, France); ethanol was determined by ebulliometry (Dujardin-Salleron, Noizay, France). These wines comprised: 13.8 and 13.5 % v/v alcohol, 5.3 and 4.6 g/L titratable acidity (expressed as tartaric acid), pH 3.39 and 3.82, 0.23 and 0.49 g/L volatile acidity, 28 and 22 mg/L free SO₂, and 89 and 65 mg/L total SO₂ for Chardonnay and Syrah respectively.

To produce wines with different levels of ethanol, 200 L of the two base wines were dearomatised and fully dealcoholised through spinning cone column (SCC) technology using a pilot plant model SCC1,000 (Flavourtech, Reading, United Kingdom). The dearomatisation phase was conducted at a feed flow rate of 300 L/h at 33 and 36 °C, while the dealcoholisation phase was conducted at 100 L/h at 42 and 43 °C for Chardonnay and Syrah respectively. For the first pass and for both wines, the external stripping rate (ESR), which represents the percentage of the initial volume removed after the treatment, was estimated at 1.3 %. For the second pass, ESR was 33 and 37 % for Chardonnay and Syrah respectively. The ethanol content of the aroma fraction, determined using the same method as for the base wines, was 47.2 and 48.4 % v/v. After dearomatisation and dealcoholisation, the concentration in ethanol of the retentate was below 0.1 % v/v and considered as null. ESRs were used to reconstitute wines with distinct ethanol contents by mixing the final beverage, the aroma fraction, food grade ethanol 96 % v/v (Union des Distilleries de la Méditerranée, Olonzac, France) and distilled water in the proportion shown in Supplementary Tables 1 and 2. In order to avoid any concentration effect and to produce wines that only differ in level of ethanol, the choice was made to compensate for the loss in volume of the sample with reduced ethanol content by adding distilled water. An informal tasting session organised by the same group of four experts who had carried out the initial selection of the base wines confirmed that, after reconstitution, the Chardonnay at 13.8 % v/v and the Syrah at 13.5 % v/v which were to be the controls had similar sensory characteristics and typicality to the two base wines. All the samples produced were analysed for their ethanol content, confirming that the reconstitution was appropriate.

2. Determination of ethanol difference thresholds

Difference threshold concentrations for ethanol in Chardonnay and Syrah wines were determined according to the American Society of Testing and Materials (ASTM) methods E 679 (ASTM, 2004) and E 1432 (ASTM, 1997). ASTM E 679, a rapid method that makes it possible to obtain individual thresholds values in a single session, was

used to investigate the impact of the matrix on the ethanol difference threshold. The ASTM E 1432 method was used, because it generally provides a better estimation of group thresholds. The panelists (n = 19), who had little experience with discrimination testing and wine sensory evaluation, were staff and students from Ecole d'Ingénieurs de Purpan; they comprised 12 females and 7 males aged between 21 and 50 years old. The choice of concentrations to be tested was based on previously described difference thresholds for ethanol (Yu and Pickering, 2008).

Chardonnay wines were reconstituted to reach final ethanol contents of 13.8 % v/v for the control, and 13.55, 13.3, 12.8, 11.8 and 9.8 % v/v for the test samples. For Syrah, the ethanol content of the control sample was 13.5 % v/v, and 13.25, 13.0, 12.5, 11.5 and 9.5 % v/v for the test samples. For both varieties, the test samples corresponded to an ethanol decrease of 0.25, 0.50, 1.00, 2.00 and 4.00 % v/v in comparison with the control.

The 3-alternative forced choice (3AFC) tests, including the control samples, were served in descending order of ethanol content, as described in the two methods.

In accordance with the ASTM E 679 method, it was assumed that a panelist who missed at the highest concentration, would have been correct at twice this level, and who succeeded at the lowest concentration, would have been incorrect at half this level.

3. Determination of Consumer Rejection Thresholds

The panel was composed of 42 wine consumers recruited during a wine event held at the Ecole d'Ingénieurs de Purpan. The panelists, all of whom were self-declared regular consumers of wine (at least once per month), did not receive any remuneration for participating. They were not informed about the samples they were about to taste. After the tasting, they had to provide demographic information and to respond to questions regarding their wine knowledge and purchase behaviour for wine and low ethanol (9-10 % v/v) or dealcoholised wines (< 0.5 % v/v). They were also asked to state the minimal and maximal ethanol contents they expected for a quality wine, and at which frequency they consulted the label for ethanol content at purchase. The panel consisted of 19 women and 23 men, who were between 18 and 30 (28.6 %), 31 and 40 (14.3 %), 41 and 50 (14.3 %), 51 and 60 (14.3 %), 61 and 70 (14.3 %) and over 70 (14.3 %) years old. The panelists claimed to have consumed wine for a mean of 24.5 years ± 19.5, every day (9.5 %), 3 to 4 times a week (40.5 %), once a week (28.5 %), twice a month (16.5 %) and once a month (5.0 %), and to spend between 3 and 5 euros (9.5 %), between 5 and 10 euros (54.8 %) and over 10 euros (35.7 %) per bottle of wine.

The procedure for CRT determination relied on replicate series of paired comparison tests, one for each modified ethanol concentration (Prescott *et al.*, 2005). Each pair of samples was composed of a control sample at 13.8 or 13.5 % v/v for Chardonnay and Syrah respectively, and a sample with a modified ethanol content. The presentation

order was randomised, and each pair was presented in order of decreasing ethanol concentration. For both cultivars, the ethanol contents were chosen based on the difference threshold experiment, with the first levels of concentration evaluated being close to the obtained threshold values. The panelists were asked to indicate for each pair the sample they preferred. The questionnaire also contained a space for free comments for which the panelists were encouraged to detail the reason for their preference.

4. Procedure common to both sensory sessions

For both tasting sessions, the samples were coded with three-digit random numbers, and a constant volume of 15 mL of white and red wines was poured at 15 °C and 20 °C respectively. The participants were asked to conduct an olfactory assessment at room temperature (22 °C), to place the whole sample in their mouth, to swill it around for five seconds and to spit it back out. Black and clear ISO wine-tasting glasses were used for the difference threshold and CRT studies respectively. Black glasses were preferred for the threshold study to prevent discrimination based on visual aspects and especially tears of wine, a phenomenon impacted by the ethanol content and well-known by panelists with some wine knowledge. The two tasting sessions took place in a neutral room with white walls and the distance between the panelists ensured that no communication could occur. Thresholds were first assessed for Chardonnay, followed by Syrah after a 10 min rest. The panelists took a minimum break of 3 min between each set of samples. Both studies were conducted at the beginning of March 2022 over the same week in Toulouse, in the south-west of France.

5. Data treatment

For the ASTM E 679 method, the individual difference thresholds were determined for each panelist as the geometric mean of the differences in ethanol between the control and the sample at which the last failure occurred, and between the control and the following lower concentration. The panel difference threshold was calculated as the geometric mean of the individual thresholds, as proposed in the E 679 method (ASTM, 2004). A Mann-Whitney test was performed on the individual data to detect eventual differences in threshold according to cultivar. This test was preferred to a Student test, as a Shapiro-Wilk test revealed that the data did not follow a normal distribution.

For the ASTM E 1432 method, the panel difference thresholds were determined by converting the percentage correct (% correct) for each difference in ethanol between the control and the test samples to percent correct above chance (% correct above chance) using the equation (1) below and by plotting the percentage correct above chance against differences in ethanol.

$$(1) \% \text{ correct above chance} = 100 \times \frac{(\% \text{ correct} - \% \text{ correct by chance})}{(100 - \% \text{ correct by chance})}$$

Logarithmic trend lines resulted in equations that were used for the determination of thresholds at 50 % correct response above chance.

The CRT concentrations were determined as the concentration at which the sample with a modified ethanol concentration was significantly rejected using the binomial distribution for the paired comparison test (Roessler *et al.*, 1978). As proposed by Saliba *et al.* (2009), the Kolmogorov-Smirnov (two-tailed) test was performed to identify any preferences for ethanol concentration according to gender. For the other criteria, the Kruskal-Wallis test was used. The Kolmogorov and Kruskal-Wallis tests were performed for each cultivar and for each level of ethanol investigated on a matrix in which the quantitative variable was the ethanol concentration of the preferred sample.

The free comments generated by the participants to explain their preference were analysed for the two levels of ethanol concentration that framed the CRT values. One corpus was obtained for each cultivar. The terms were first lemmatised and then the synonyms were regrouped following a triangulation procedure (Abric, 2005). Three experimenters were asked to group the terms belonging to similar categories. These categories were discussed until a consensus was reached. The citation frequencies were calculated, and the terms used by at least 10 % of the consumers for one of the cultivars and for one of the two last levels of ethanol concentration were retained. The effect of the cultivar and ethanol content on the frequency of citation was assessed using a Chi-square (χ^2) test and a Marascuilo post-hoc procedure (95 %).

All the statistical treatments were performed using XLSTATS software (Addinsoft, Paris, France).

RESULTS AND DISCUSSION

The distribution of the individual difference threshold concentrations according to the E 679 method is shown in Figure 1. The panel difference threshold was estimated at 1.31 and 1.36 % v/v for Chardonnay and Syrah respectively. For both wines, one participant succeeded at the lowest tested concentration, while one and three participants missed at the highest concentration for Chardonnay and Syrah respectively. While difference thresholds of up to 4 % v/v have been previously reported for ethanol (Hinreiner *et al.*, 1955), our findings have the same range of concentrations as those found in a recent research based on ASTM E 679, which highlighted retronasal values ranging from 1.03 and 1.32 % v/v (Yu and Pickering, 2008). Our panel had little experience in wine assessment and was composed of Caucasian subjects. We can assume that our slightly higher thresholds might be related to panel differences in terms of experience, consumption frequency and ethnicity as proposed by Yu and Pickering (2008).

For the ASTM E 1432 procedure, thresholds of 1.55 and 1.82 % v/v were established for Chardonnay and Syrah respectively (Figure 2). The fact that lower difference thresholds were obtained for the ASTM E 679 is in accordance with previous work aiming at comparing the two methods (Cliff *et al.*, 2011).

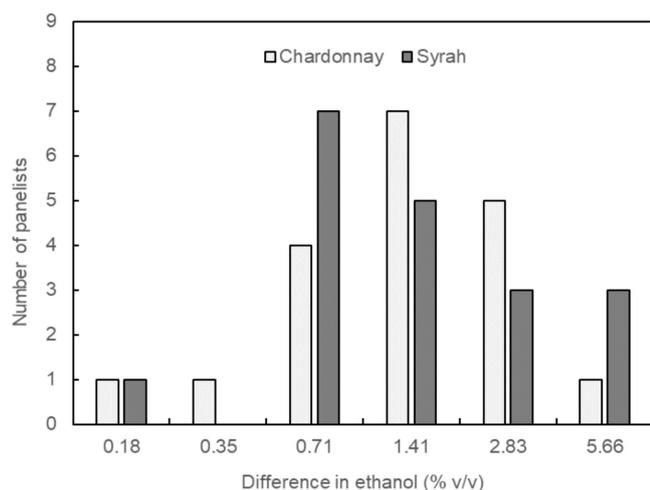


FIGURE 1. Distribution of difference thresholds for ethanol in Chardonnay and Syrah wines according to the ASTM E 679 method (n = 19 panelists). The panel threshold was estimated at 1.31 v/v and 1.36 % v/v for Chardonnay and Syrah respectively.

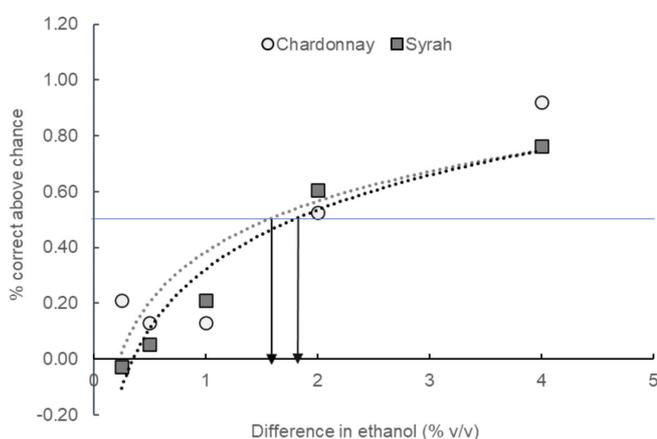


FIGURE 2. Difference threshold determinations for ethanol in Chardonnay and Syrah wines according to the ASTM E 1432 method using a log-linear model at 50 % correct response above chance (n = 19 panelists). Model gave $y = 0.2619 \ln(x) + 0.3842$, $r^2 = 0.71$ for Chardonnay; $y = 0.3075 \ln(x) + 0.321$, $r^2 = 0.94$ for Syrah. The panel threshold was estimated at 1.55 % v/v and 1.82 % v/v for Chardonnay and Syrah respectively.

Even though in agreement with previous observations (Yu and Pickering, 2008), the reason why a higher panel threshold - albeit non-significant according to ASTM E 679 and Mann-Whitney test ($P = 0.404$) - was observed for the red wine remains unclear. It can be hypothesised that its composition, in particular its tannin concentration, played a key role. It is well known that such macromolecules reduce the headspace concentration of volatile aroma compounds and their associated odour threshold values (Robinson *et al.*, 2009; Villamor *et al.*, 2013). We can assume that these phenolic compounds played a higher buffer role than

in Chardonnay, and mitigated the perception of ethanol modification during the olfactory evaluation.

The ethanol concentrations to be assessed were chosen on the basis that ethanol lowering should start at detectable levels, corresponding to around 1.5 % v/v for both wines according to the previously described results. For both cultivars, the ethanol in the test samples was lowered by 1.5, 3.0, 6.0 and 12.0 % v/v; the Chardonnay test samples thus had a final ethanol content of 12.3, 10.8, 7.8 and 1.8 % v/v, while Syrah had 12.0, 10.5, 7.5 and 1.5 % v/v.

CRTs were calculated as being 2.8 and 7.0 % v/v for Chardonnay and Syrah respectively (Figure 3). These particularly low threshold values were somewhat unexpected, as they support the hypothesis that consumer sensory preferences are little driven by ethanol content, particularly in the case of white wine. However, the post-evaluation questionnaire revealed that panelists expected minimal and maximal ethanol contents for a quality wine of $10.9\% \text{ v/v} \pm 1.2$ and $13.7\% \text{ v/v} \pm 1.2$, and $11.7\% \text{ v/v} \pm 1.5$ and $14.7\% \text{ v/v} \pm 1.0$ for white and red wines respectively. Moreover, they claimed to: drink low ethanol wines very often (2.4 %), often (21.4 %), rarely (54.8 %) and never (21.4 %); drink dealcoholised wines often (2.5 %), rarely (2.5 %) and never (95.0 %); and consult the label for ethanol content at purchase always (9.5 %), often (38.1 %), rarely (28.6 %) and never (23.8 %).

These observations indicate that consumers have high ethanol expectations for quality wines, but have little experience with low ethanol or dealcoholised wines. However, they would not necessarily be refractory to the consumption of such beverages from a sensory standpoint. Therefore, professionals from the wine industry and public authorities should be strongly encouraged to raise awareness about the increase in quality of such products and their benefits for human health.

The non-parametric tests showed that the frequency of wine and dealcoholised wine consumption, together with the frequency of that the label was consulted for ethanol content at purchase, had a significant impact on consumer preferences (Table 1). The results of these statistical treatments must be considered with caution as subgroups might not always be representative samples. Those who claimed to rarely consult the label for ethanol content significantly preferred the test samples at 7.8 % v/v for Chardonnay and at 12.0 % v/v for Syrah, in comparison to those who often checked for ethanol content and preferred the control. This highlights that the latter participants have a certain amount of knowledge and a greater awareness of ethanol, and a better ability to perceive it in wine. For Chardonnay, consumers who drink wine every day significantly preferred the control samples at 11.8 and 7.8 % v/v. This could be explained by such subjects being likely familiar with usual ethanol contents, such as those found in the control samples. Consequently, their unfamiliarity with modified ethanol concentrations, which is in most cases negatively correlated with liking (Saliba *et al.*, 2009), might have affected their assessment of the test samples. Unexpectedly, and contrary to what

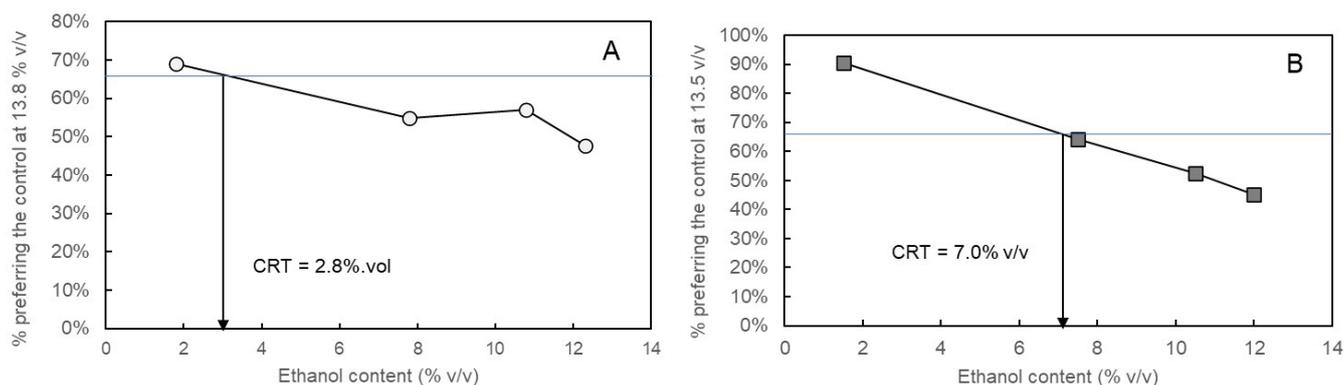


FIGURE 3. Proportion of panelists preferring the control sample in A) Chardonnay and B) Syrah wines. Horizontal lines show that the “control is significantly preferred” at 5 % risk using paired comparison tests (n = 42 consumers). The consumer rejection threshold (CRT) was estimated at 2.8 % v/v and 7.0 % v/v for Chardonnay and Syrah respectively

TABLE 1. Comparison of preference (*P*) for each ethanol concentration, and for gender, age, level of wine knowledge, average price spent per bottle, frequencies of wine, low ethanol wine and dealcoholised wine consumption, and frequency that the label was consulted for ethanol content at purchase (n = 42 consumers). The Kruskal-Wallis test was performed, except for gender, which was treated using the Kolmogorov-Smirnoff (two-tailed) test.

	Ethanol content (% v/v)	Gender	Age	Level of wine knowledge	Average amount spent per bottle	Frequency of wine consumption	Frequency of low ethanol wine consumption	Frequency of dealcoholised wine consumption	Frequency that label was consulted for ethanol content at purchase
Chardonnay	12.3	1.000	0.328	0.934	0.459	0.477	0.442	0.375	0.388
	11.8	1.000	0.579	0.704	0.935	0.037	0.730	0.464	0.435
	7.8	0.991	0.431	0.489	0.698	0.017	0.335	0.370	0.034
	1.8	1.000	0.390	0.259	0.948	0.167	0.483	0.268	0.743
Syrah	12.0	0.991	0.860	0.101	0.073	0.867	0.763	0.429	0.034
	10.5	1.000	0.778	0.418	0.992	0.066	0.597	0.394	0.680
	7.5	0.999	0.062	0.539	0.612	0.093	0.471	0.315	0.239
	1.5	0.114	0.220	0.135	0.537	0.228	0.345	0.008	0.180

would have been expected based on a previous study (Meillon *et al.*, 2010), the level of wine knowledge did not impact preferences. The fact that the preferences were not affected by age likely proves that no bias was introduced into our data by the larger proportion of young consumers included in our panel (28.6 %). Recalculations of CRT after randomly removing 6 consumers aged between 18 and 30 to obtain a perfect age balance within our panel, only lowered the concentrations to 2.6 and 6.9 % v/v for Chardonnay and Syrah respectively.

The difference in CRT concentrations between the two matrices indicates that the contribution of ethanol to the overall balance of red wine is higher. According to the terms used by consumers to describe the test samples (Table 2), the red samples reduced in ethanol to 7.5 and 1.5 % v/v were both significantly characterised by a higher aggressivity in comparison with Chardonnay samples;

this is likely due to tannins, which is in accordance with previous findings (Jordão *et al.*, 2015; Longo *et al.*, 2017; Schmitt and Christmann, 2022). Similar to other studies, these wines were also perceived as being more diluted, less sweet and sourer (Fischer and Noble, 1994; Martin and Pangborn, 1970; Scinska *et al.*, 2000). The fact that they were perceived as less intense in terms of aroma when a higher intensity would have been expected (Conner *et al.*, 1998; Escudero *et al.*, 2007) could be the consequence of the overall negative perception in the palate, which affects how aroma is perceived, and/or consumers being unable to describe their sensation. As expected, the Chardonnay wines at 7.8 and 1.8 % v/v were perceived as being more intense in terms of aroma, tasteless, more diluted and lighter in alcohol; however, the citation frequencies for these terms did not enable them to be discriminated from the Syrah samples.

TABLE 2. Citation frequencies (expressed in %) for the terms used by consumers in the space available for free comments to describe the two samples with the lowest ethanol content in comparison with the control for Chardonnay and Syrah, and significance (*P*) calculated from chi-square test. Only the terms showing a citation frequency above 10 % for one of the cultivars and for one of the two levels of ethanol concentration that framed the CRT values were retained. Different letters for a given term indicate significant differences based on the post-hoc Marascuilo test.

Term	Chardonnay		Syrah		<i>P</i>
	7.8 % v/v	1.8 % v/v	7.5 % v/v	1.5 % v/v	
Less intense aroma	7.1	7.1	7.1	16.7	0.554
More intense aroma	11.9	4.8	4.8	0.0	0.102
Tasteless	19.0	16.7	4.8	4.8	0.060
More diluted	7.1	19.0	4.8	14.3	0.192
Lighter in alcohol	19.0	14.3	9.5	7.1	0.316
Less sweet	9.5	7.1	2.4	11.9	0.602
More sour	4.8	7.1	11.9	11.9	0.470
More aggressive	0a	0a	19.0b	21.4b	< 0.001

It should be noted that our results are only valid for balanced wines made from Chardonnay and Syrah. The choice of unbalanced base wines could have led to distinct CRT concentrations notably lower CRT values for base wines characterised by excessive ethanol contents that cause intense burning sensations in the palate. On the other hand, it cannot be discarded that the use of base wines characterised by higher intensities of bitterness for Chardonnay and astringency for Syrah would have amplified the impact of ethanol reduction and led to higher CRTs. Our study is still preliminary, and more work would be needed to investigate the impact of the matrix more deeply by testing several wines made from the same grape variety.

In our study, we made the methodological choice of compensating for the loss in volume due to ethanol elimination by adding water. If permitted by the regulations, this could be of interest to wine producers, as it enables an economic valuation of ethanol without a reduction in volume of the alcoholic beverages. However, as reflected in the terms used to describe the Chardonnay test samples at 7.8 and 1.8 % v/v (Table 2), the addition of water might have enhanced the perception of dilution and lack of taste. It might also have contributed to obtaining lower CRT values by reducing the sensory perception of non-volatile compounds, such as organic acids and tannins that can enhance aggressiveness in reduced ethanol beverages (Jordão *et al.*, 2015; Longo *et al.*, 2017; Schmitt and Christmann, 2022).

Even if the SCC process, which limits aroma loss, has become the reference method for qualitative wine dealcoholisation (Pickering, 2000; Sam *et al.*, 2021), and the sensory properties of the two control wines after reconstitution were similar to those of the base wines, the use of the two native wines without treatment as control samples might have led to different results. In a similar way, it cannot be excluded that the implementation of alternative techniques to SCC, such as reverse osmosis that has recently proved its sensory superiority (García *et al.*, 2021), would have possibly affected CRT concentrations.

CONCLUSION

In accordance with previous findings, ethanol difference thresholds were estimated in this study to be around 1.5 % v/v in both matrices. The threshold ethanol concentrations at which ethanol becomes undesirable were determined to be 2.8 % v/v for Chardonnay and 7.0 % v/v for Syrah using the consumer rejection threshold approach (CRT).

These particularly low and somewhat unexpected concentrations indicate that ethanol content might not drive consumer sensory liking, especially in white wine. However, the post-evaluation questionnaire showed that consumers expected a high minimal ethanol content for quality wines, had limited experience with low and dealcoholised wines, and rarely or never consulted the wine label for ethanol content at purchase.

From a sensory standpoint, our data show that consumers might not necessarily be refractory to the consumption of beverages made from wine with a modified ethanol content; on this basis, wine industry professionals and public authorities can be strongly encouraged to raise awareness about the increase in quality of such products and their benefits for human health. Our findings are still preliminary, and more work would be necessary to validate them by studying a larger number of consumers. The impact of the matrix resulting from testing several wines made from the same grape variety should also be more deeply investigated.

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