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3 **Xylitol Addition Enhances Generation Z Liking of Red Wine: A CATA and Penalty Analysis Approach**

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9

10 **GRAPHICAL ABSTRACT**

11 Findings support using sugar substitutes to expand dry red wine markets and reveal unexplored  
12 Generation Z wine consumption patterns warranting further scientific investigation. The R scripts  
13 developed for CATA and penalty analyses are publicly available to sensory researchers.

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## 27 **ABSTRACT**

28 The wine industry is facing a global crisis with a significant decline in wine consumption. This decline  
29 is particularly marked for red wine and the industry is seeking innovations to increase the  
30 attractiveness of such wine. The addition of sugars is known to improve the palatability of red wine,  
31 but the risk of in-bottle fermentation necessitates the use of stabilizers. Xylitol is a non-fermentable  
32 sugar alcohol with a sweetening power similar to sucrose. To evaluate young adult perception of  
33 xylitol-sweetened products, we applied an innovative penalty analysis approach combining liking  
34 scores with CATA questions. The results obtained in this study show that its addition to red wine  
35 significantly increased liking among a panel of 119 young adults, with an average age of 22 years. The  
36 combination of CATA (Check-All-That-Apply), liking, and penalty analyses revealed that attributes  
37 such as sweet, soft, and fruity were enhanced by xylitol addition and positively impacted liking,  
38 whereas attributes such as acidic, bland, and bitter characterized the control red wines and  
39 negatively impacted liking.

## 40 **Practical applications**

- 41 • The R scripts used in this study are available from the publisher's website and should be a  
42 valuable resource for researchers and students in sensory analysis, willing to run CATA and  
43 liking analyses, then calculate penalties.
- 44 • The results should encourage industry research and development units to test sugar  
45 substitutes for improving market access of dry red wines.
- 46 • This study opens a field of research about Generation Z wine consumption habits that has  
47 not been investigated in scientific journals yet.

48

49 **Keywords:** wine, sweetener, sensory analysis, hedonic, young adults

50

## 51 **1 Introduction**

52 The wine industry is facing multiple crises, among which are climate change affecting production (van  
53 Leeuwen et al., 2024) and a strong economic crisis with decreasing wine consumption (Del Rey and  
54 Loose, 2023). Red wine has been particularly affected, with sales declining by 15% in the last fifteen  
55 years, representing a drop of 20 million hectoliters (OIV, 2023). The wine industry is looking at  
56 alternatives, particularly for young adults, who have been identified as dynamic but volatile

57 consumers of alcoholic drinks (Qenani-Petrela et al., 2007). This last study considered the  
58 generations “baby-boomers”, “X” and “Y”, born 1945-1964, 1965-1976, and 1977-2000, respectively.  
59 While this study was more focused on economic aspects - average bottle price each generation is  
60 ready to spend, or world geographical origin linked to quality - the trend for a wine that was easy to  
61 drink outside a meal was already standing out for younger generations. A limited number of recent  
62 papers in international peer-reviewed journal has yet targeted generation “Z”, born from the mid-  
63 1990s to mid-2010s (Collins, 2025), some of which are now reaching the status of young adulthood.  
64 For instance, Geffroy et al. (2025) recently demonstrated that French young adults exhibit a  
65 preference for white wines characterized by terpenic and floral aromas over those with thiolic notes,  
66 thereby challenging a widely held assumption within the wine industry. Although conducted on  
67 different wine or grape-derived matrices, previous studies have consistently identified sweetness as  
68 a major determinant of consumer liking, both in fully dealcoholized Chardonnay wines and in grape  
69 juices produced from hybrid varieties (Podworny et al., 2024; Lytra et al., 2025).

70 Other studies, not specifically targeting young adults, have suggested that “a sweeter taste” could  
71 improve liking of red wines (Francis & Williamson, 2015). These authors, reviewing several sensory  
72 studies, showed that sweetness is often listed as a positive attribute for red wines, among Australian  
73 and Chinese consumers, and also by recent drinkers, having consumed wine for less than 5 years.  
74 Sena-Esteves et al. (2018) showed that several categories of potential consumers preferred  
75 sweetened red wine, ranging from 5 to 20 g of sugars per liter of red wine (50% glucose, 50%  
76 fructose). The two categories preferring sweeter samples were females and the “novices” -  
77 individuals who had been wine consumers for fewer than 10 years, drinking less than three times a  
78 week, and who did not self-report as being “knowledgeable”.

79 Adding sugar is an admitted practice in the wine industry, with some regulations according to the  
80 producing country, but the major drawback of this practice is the need for “extra” stabilization to  
81 avoid in-bottle refermentation. This means higher levels of sulfites or addition of potassium sorbate  
82 to stabilize the wines (Sofos and Busta, 1981). Furthermore, growing concerns have been reported  
83 among younger consumers regarding the detrimental impact of sugar intake on body image,  
84 particularly in relation to weight control (Joo et al., 2017).

85 A solution could be non-fermentable sweeteners, which have the potential to improve red wine  
86 liking among young adults (Geffroy et al. 2024a). These authors showed that the addition of  
87 erythritol and Stevia glucoside was related to better liking scores, and to an increased “fruity”  
88 perception. To our knowledge, another sweetener, xylitol, has not yet been tested in red wine. Xylitol  
89 is a sugar alcohol that is commonly used as a sweetener (Gasmi Benahmed et al., 2020), it can be

90 found naturally in some fruits and can be manufactured from xylan-rich plant material - these  
91 authors list a series of health benefits for this polyol. Xylitol has a sweetening power similar to  
92 sucrose, and the energy provided by xylitol is approximately 10 kJ/g (2.4 kcal/g), which is about 40%  
93 less than sucrose (Winkelhausen et al., 2007).

94 For product development, penalty analyses are interesting approaches, conventionally employing  
95 just-about-right (JAR) sensory measurements with variable adjustment (e.g. acidity, sweetness) in  
96 combination with liking scores. In the context of wine, penalty analyses have been conducted to  
97 explore perceptual typicality associated with terroir (Cadot et al., 2010; Leriche et al., 2020). More  
98 recently, research has also focused on identifying negative drivers of liking in a peppery red wine  
99 produced during a cool and wet vintage (Geffroy et al., 2024b). Interestingly, Plaehn (2012) and Ares  
100 et al. (2014) have proposed an interesting combination of CATA and liking analyses to generate  
101 penalty analyses. These have been further extended with success to temporal penalty analyses  
102 (Harwood & Drake, 2021).

103 Here we will test the impact of xylitol on red wine, monitoring attributes by CATA and associating  
104 them with liking scores, using a panel of young adults. We will test each attribute by penalty analysis.  
105 The R scripts will be made available through the publisher's website for users willing to test them in  
106 teaching or product development.

107

## 108 **2 Material and Methods**

### 109 **2.1 Wine and chemicals**

110 The red wine was 100% Fer (also called Fer Servadou or Braucon), a cultivar of *Vitis vinifera*, vintage  
111 2024, obtained from a local winery, Fronton area, 20 km North of Toulouse, France. The wine  
112 analyses were performed as described previously (Lytra et al., 2025) and are shown in Supplemental  
113 Table S1, it is considered as a “dry” red wine with residual sugars below 2 g/L. The bulk volume of 16  
114 liters of wine was separated into 4 batches of 4 liters, one kept as control (named CONT), the other  
115 three being mixed with increasing amounts of xylitol, + 10g/L (named PLUS10), +20 g/L (named  
116 PLUS20) and + 30g/L (named PLUS30). Sulfites were adjusted to 30 mg free SO<sub>2</sub>/L, then the wines  
117 were kept 2 weeks at 15°C until further analysis. The pure xylitol (E 967) was obtained from Intenson  
118 Europe (Karcew, Poland).

119

### 120 **2.2 Panel and sensory method**

121 Panelists are characterized in Supplemental Table S2. Briefly, they were 119 young adults with an  
122 average age of  $21.9 \pm 3.7$  years, there were 56 % women, 43 % men, 1% other. They were recruited  
123 from Toulouse area, and participated voluntarily, after signing an informed consent, on a paper form,  
124 and were given a unique booth number when entering the tasting room. Ethical approval was  
125 obtained from the Institutional Review Board of AgroToulouse prior to commencement of  
126 the study.

127 They were presented the four wines monadically (20 ml of each wine at 16°C) in a random order with  
128 three-digit random numbers, and the serving order was balanced across participants. Then, they  
129 were asked to fill the CATA 9-attribute page before being presented the liking 1 to 9 score scale, as  
130 previously developed (Geffroy et al., 2024). The relatively short list of attributes was justified by two  
131 reasons: (i) Jaeger et al. (2023) showed that for rapid consumer analyses, a list of around 10  
132 attributes is well adapted, and (ii) we restricted the attributes to non-specialist terminology, as  
133 preliminary studies showed that key wine-related sensory dimensions (e.g., astringency, body,  
134 balance, aroma intensity) are not understood by consumers. The CATA list of attributes was similar  
135 to this previous study with sweeteners and the attributes were randomly presented to each panelist.  
136 The questionnaire was deployed through Google Forms, but panelists entered only the booth  
137 number in these forms to keep the enquiry anonymous. A typical questionnaire can be found in  
138 Supplemental Figure S1.

139

### 140 **2.3 Data and statistical analyses**

141 When uploading the data set from Google Forms a transformation was necessary to convert  
142 attributes listed in each line to "0" and "1" in a contingency table; this transformation was performed  
143 with the Excel formula available in Supplemental Table S3.

144 The data are formatted in .csv files with ";" as separators. The R scripts are available in Supplemental  
145 Data D1. The analyses were performed with R-Studio (Posit, Boston, MA, USA;  
146 <https://posit.co/downloads/>). The script for running ANOVA plus Tukey post-hoc tests for multiple  
147 comparisons (Script\_ANOVA+) was similar to the one published by Geffroy et al. (2024). It has been  
148 improved to automatically process all numeric attributes present in the dataset. Additionally, we  
149 added a simulation feature that generates graphs showing the distribution of p-values for the  
150 "Product" effect as a function of sample size (number of panelists), based on random resampling. The  
151 script can be applied to all variables measured on a Likert scale (or any numeric scale), provided they  
152 were included as columns in the data file (.csv), alongside the fixed columns "Product" and

153 "NumPanel". The Correspondence Analysis (CA) is performed using a dedicated script (Script\_CA+)  
154 similar to the one published by Geffroy et al. (2024). We added a series of commands (provided as  
155 commented code at the end of the script) to enable axis rotation when needed for comparison  
156 between multiple graphs. The script for running penalty analysis (Script\_Penalty) has been developed  
157 based on previous works by Plaehn (2012) and Ares et al. (2014). Briefly, the script compares mean  
158 liking scores when an attribute has been checked (mean\_checked) to mean scores when this  
159 attribute was not checked (mean\_not\_checked), with the penalty calculated as:  $\text{Penalty} =$   
160  $\text{mean\_not\_checked} - \text{mean\_checked}$ . A positive penalty indicates that the attribute is perceived as a  
161 defect (products without it score higher), while a negative penalty indicates the attribute is a quality  
162 (products with it score higher). T-tests are used to assess the statistical significance of the difference  
163 between mean liking scores when an attribute is checked versus not checked (e.g.,  
164  $\text{mean\_score\_sweet\_checked}$  vs  $\text{mean\_score\_sweet\_not\_checked}$ ). To account for multiple testing  
165 across all attributes, p-values from individual t-tests were adjusted using the Benjamini-Hochberg  
166 False Discovery Rate (FDR) procedure. Pedagogical explanations are detailed throughout the script.  
167 We recommend using three dedicated folders, one for ANOVA containing the ANOVA+ script and the  
168 DataForANOVA.csv file, one for CA containing the CA+ script and the DataForCA.csv file, and one for  
169 penalty containing the penalty script and both DataForANOVA.csv and DataForCA.csv files.

170

### 171 **3 Results and Discussion**

172 As shown in Figure 1A, the panelists associated logically the red wines with the high doses of xylitol  
173 (20 and 30 g/L, PLUS20 and PLUS30, respectively) to sweet and soft, and to fruity which seems less  
174 obvious, but enhancement of fruitiness by sweetener addition has been shown previously (Baldwin  
175 and Korschgen, 1979). Nevertheless, as no aroma or volatile analyses were performed, the observed  
176 effect is more plausibly explained by cross-modal sweetness–aroma interactions rather than actual  
177 changes in fruity compounds. In the same series of analyses, the controls (CONT) were associated  
178 with acidic, bitter and bland. It is therefore clear that the addition of xylitol attenuated perceptions  
179 of these latter attributes, with the confidence ellipses being particularly disjointed between PLUS30,  
180 PLUS20 and CONT. The Figure 1B shows that the analysis became robust with approximately 32  
181 panelists, with most p-values below 0.05, except for few outliers. This p-value tests the  
182 independence between products and attributes using a chi-square test. Thus, the lower the p-value,  
183 the stronger the evidence against independence (i.e., the stronger the evidence for dependence  
184 between products and attributes).

185 As shown in Figure 2A, the panelists preferred the red wines with high doses of xylitol, 20 and 30 g/L.  
186 This result was significant compared to the lower dose of 10 g/L, which was itself better scored than  
187 controls. To further analyze the impact of sweetener addition, a Just-About-Right (JAR) test  
188 would have been useful to assess whether the sweetness intensity was actually appropriate  
189 for consumers. The beginning of a plateau in liking (Fig. 2A) at approximately 20 to 30 g  
190 xylitol/L of wine provides a tentative indication that the JAR concentration could be around  
191 30 g/L, though a proper JAR test would be needed to confirm this. However, one major  
192 consideration is that the highest xylitol dose (30 g/L) may approach or exceed thresholds  
193 that could redefine product typicality or regulatory classification, which would require further  
194 investigation. Regarding the analysis in Figure 2A, note that the current script uses a two-way  
195 ANOVA treating both Product and NumPanel (consumers) as fixed effects. In future studies, it would  
196 be worthwhile to test a mixed-effects model with Product as a fixed effect and NumPanel as a  
197 random effect; these results might allow generalization beyond our specific panelists to a broader  
198 consumer population. In the present case, both two-way ANOVA and mixed-effects ANOVA gave  
199 similar results (data not shown). The Figure 2B shows that the analysis became robust with  
200 approximately 30 panelists, with most p-values below 0.05, except for a few outliers.

201 Thus, one can guess that sweeter taste was well correlated to better score, and this was driving us to  
202 run a penalty analysis on the bases published by Plaehn (2012) and Ares et al. (2014). One important  
203 thing to remind when looking at penalty values is that the highest values are obtained for the most  
204 negative attributes, this may be counter-intuitive. This is induced by the fact that “penalty” has a  
205 negative valence. The results shown in Figure 3A are nevertheless quite easy to understand as it is  
206 obvious that the most penalizing attributes are Bland, Bitter and Acidic, while the less penalizing  
207 attributes are Fruity, Soft and Sweet, these latter showing “negative penalty” values, which indicate  
208 that they positively contribute to liking. We also developed an approach combining penalty analysis  
209 with significance testing using t-test, and produced Figure 3B. This shows the attribute penalty as a  
210 function of the attribute usage percentage, an information that was not given in Figure 3A. Logically  
211 the attributes, Sweet, Fruity and Soft were more used than Bitter, Acidic, Bland, Strong, which were  
212 mainly perceived in one wine: CONT, when Sweet, Fruity and Soft were perceived in two or three  
213 wines: PLUS30, PLUS20, PLUS10. The additional information given in this bubble plot is the  
214 significance of the attribute impact on the liking score; e.g. “mean\_score\_fruity\_not\_checked” vs  
215 “mean\_score\_fruity\_checked”, revealing that fruity has a significant effect on the liking score.  
216 Significance levels in Figure 3 reflect FDR-adjusted p-values (adj.p values) with thresholds of  $\text{adj.p} <$   
217  $0.05$ ,  $\text{adj.p} < 0.01$ , and  $\text{adj.p} < 0.001$  (shown if applicable). Thus, by looking at Figure 3B we have the

218 confirmation that Soft, Fruity and Sweet had a significant positive impact on the liking score, whereas  
219 Bland, Bitter, Acidic and Strong had a negative impact on the liking score. Overall, these findings are  
220 in accordance with previous research particularly the one by Geffroy et al. (2024b) conducted on a  
221 Duras red wine showing that the lack of fruity notes, and the excessive sourness were the main  
222 penalizing sensory characteristics for this target of consumers. Obviously, the penalty analysis is  
223 limited to the available attributes and could be extended in future studies to attributes that are  
224 better understood by oenologists, such as several key wine-related sensory dimensions (e.g.,  
225 astringency, body, balance). Finally, because the various sweeteners available on the market vary in  
226 sweetness onset, intensity, temporal profile, and aftertaste, further studies are clearly necessary to  
227 help the industry choose adapted solutions and to better focus requests for product and dosage  
228 authorizations.

229

#### 230 **4 Conclusion**

231 This set of results shows that French young adults with limited wine experience, a small of part of  
232 Generation Z, would favor red wines with sweeter and fruitier tastes than the dry red wines that  
233 currently dominate the market. The use of xylitol as a non-fermentable sweetener may be of interest  
234 to the wine industry, confirming similar results (Geffroy et al., 2024a) previously obtained with a  
235 different red wine and different sweeteners (erythritol and stevia glycosides). Nevertheless, the wine  
236 industry may face restrictions on the use of such sweeteners depending on the country of  
237 production, however, it is worth noting that some sweeteners are permitted in beer-making. This  
238 study represents a clear step forward in innovation for the wine industry, and the demonstrated  
239 preference for sweetened wine is currently driving some European wine industries to push for the  
240 authorization of sugar substitutes in wines, as this practice is already permitted in certain countries  
241 (US Patent, 2008; FDA, 2003). Finally, we produced an R script that is freely available from the  
242 publisher's website and should be a valuable resource for researchers and students in sensory  
243 analysis willing to combine CATA, liking, and penalty analyses.

244

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247 developing the questionnaire and running this series of analyses, and to Dr Elie Maza for the earlier  
248 versions of the R scripts. Thanks to the editor and two anonymous reviewers for their time and  
249 comments.

250 **Author contributions**

251 Christian Chervin: conceptualization, running chemical analyses and organizing tasting panels,  
252 developing R scripts, writing the first draft, Julie Bornot: running chemical analyses and editing the  
253 manuscript, Olivier Geffroy: writing and editing the manuscript.

254 **Conflicts of interest**

255 The authors declare no conflict of interest.

256 **Data availability statement:**

257 All data including R scripts are available on the editor website and at  
258 <https://doi.org/10.57745/SYT7QU>

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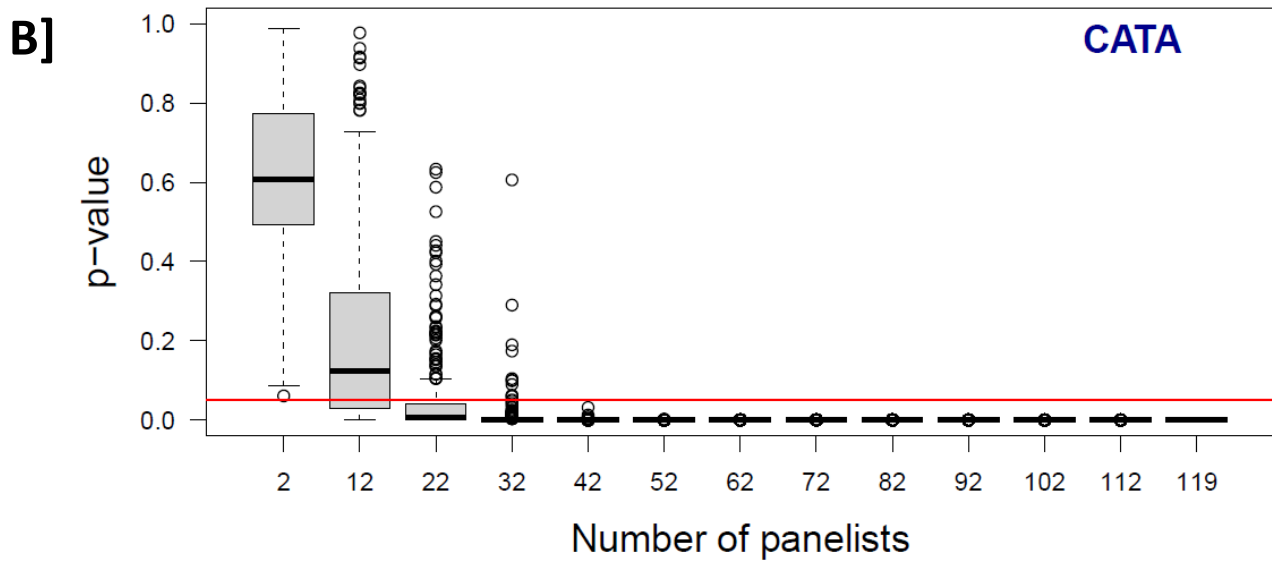
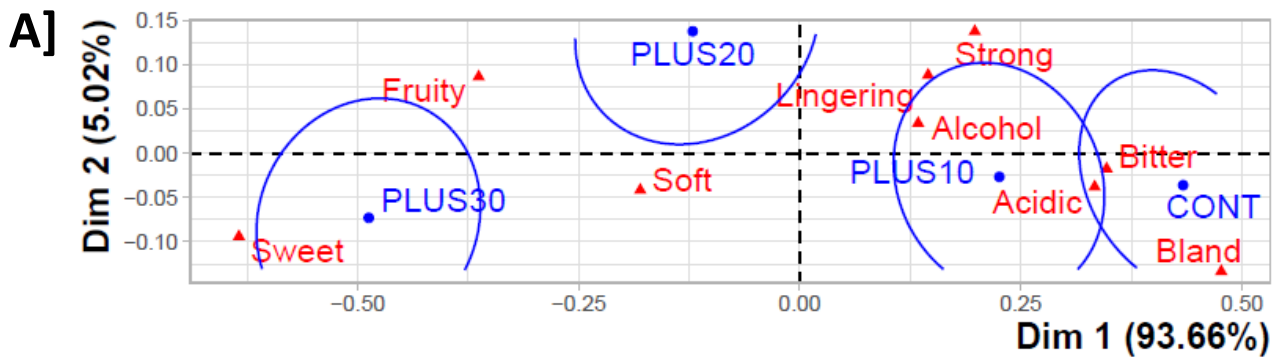
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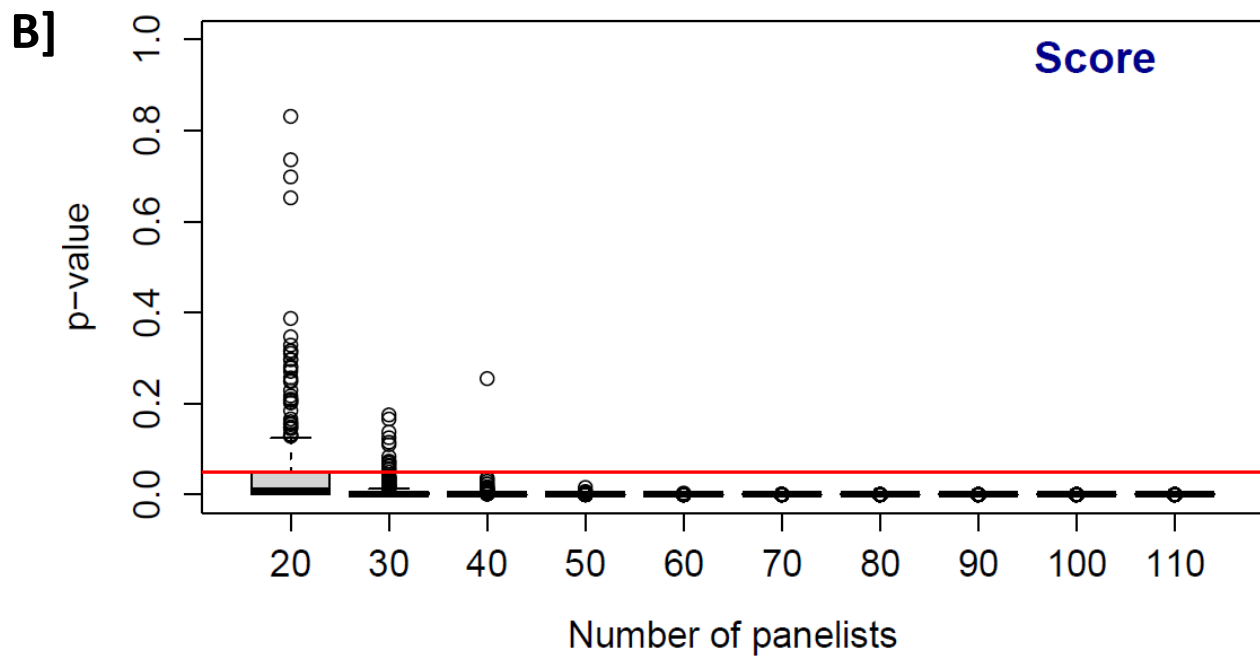
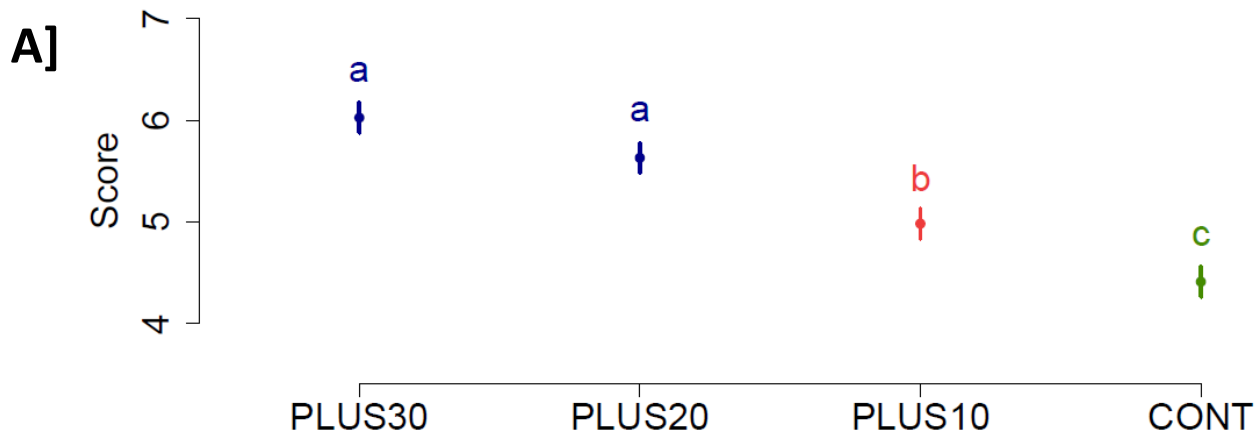
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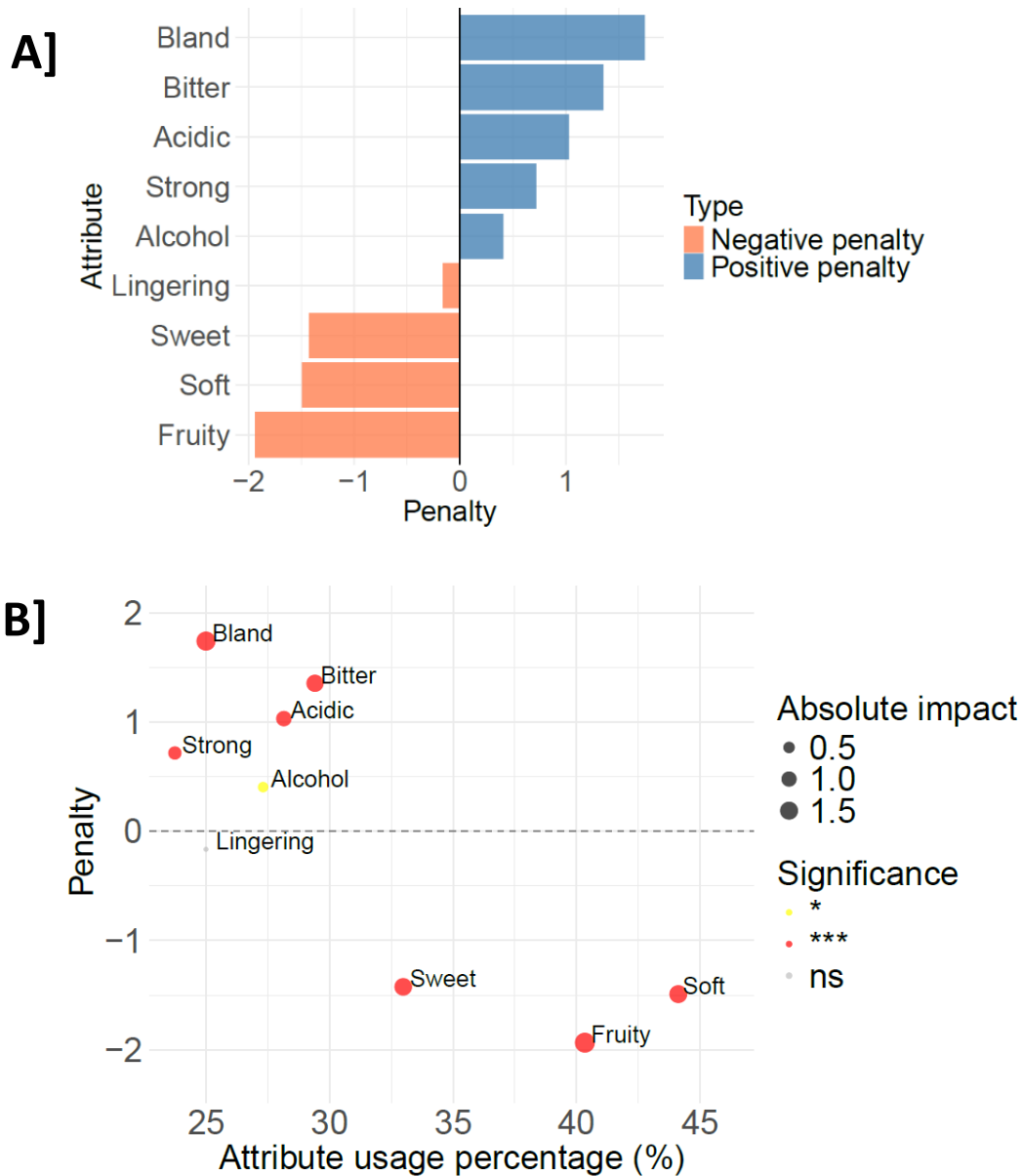
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**Figure 1:** Effects of xylitol addition in red wine on **(A)** young adults' association of attributes with the various products (xylitol at different doses), the 95 % confidence ellipses are drawn in blue around product acronyms, and **(B)** p-values of chi-square tests of independence between products and attributes, as a function of the number of randomly sampled panelists (300 simulations for each sample size); the xylitol doses were +10g/L (PLUS10), +20g/L (PLUS20), +30g/L (PLUS30), CONT stands for controls without addition; n=119 panelists, CATA stands for Check All That Apply.



**Figure 2:** Effects of xylitol addition in red wine on (A) young adults' liking score, the multiple comparison was performed with Tukey HSD (at 5% risk), different small letters indicate significant differences, error bars show SE and (B) distribution of p-values for the "Product" effect (xylitol addition) in ANOVA as a function of the number of randomly sampled panelists (300 simulated ANOVAs for each panelist number); the xylitol doses were +10g/L (PLUS10), +20g/L (PLUS20), +30g/L (PLUS30), CONT stands for controls without addition; n=119 panelists.



**Figure 3:** Penalty analysis after addition of xylitol in red wine, tested with 119 young adults; **(A)** bar plot representing the attributes with positive penalty on liking scores (blue bars) and the attributes having a negative penalty on liking (orange bars) as a function of the intensity of the penalty (X axis), and **(B)** bubble plot representing the intensity of the penalty, as a function of attribute usage percentage (X axis), with additional indications of significance shown by dot color and asterisks. Significance levels are based on FDR-adjusted p-values (Benjamini-Hochberg correction): \* adj. p < 0.05, \*\*\* adj. p < 0.001, ns stands for non-significant. The absolute impact, dot size, is a visual reinforcement strategy of the information already given by the value of the penalty.