



SHORT COMMUNICATION

Are peppery notes the main negative driver of liking for young French consumers in a Duras red wine made from a cool and wet season?



*correspondence:
olivier.geffroy@purpan.fr

Associate editor:
David Jeffery



Received:
1 September 2023

Accepted:
17 November 2023

Published:
4 January 2024



This article is published under the **Creative Commons licence** (CC BY 4.0).

Use of all or part of the content of this article must mention the authors, the year of publication, the title, the name of the journal, the volume, the pages and the DOI in compliance with the information given above.

Olivier Geffroy*, Jeanne Laforge, Marie Denat, Léa Volmerange and Magali Peter

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

ABSTRACT

It has been shown that rotundone, the only identified aroma compound imparting peppery notes in red wine, was neutrally or positively perceived by consumers, except for young non-anosmic respondents who disliked it. This work aimed to explore the main negative driver of liking for this target of consumers in a peppery Duras red wine from a cool and wet season and for which other penalties might apply. A convenience panel of one-hundred and thirty-four young French consumers from Ecole d'Ingénieurs de Purpan in Toulouse (18–24 years) was recruited for the study. Panellists were asked to rate their overall liking on a 9-point hedonic scale of such wine and their perception of seven sensory attributes on a 5-point just-about-right (JAR) scale, with 3 corresponding to the central just-about-right word anchor. Results from penalty analysis demonstrated that a lack of fruity notes followed by an excessive sourness and an excessive intensity of peppery notes were the main penalising sensory characteristics. The findings, that are still preliminary and would deserve to be confirmed using a panel composed of young consumers with other social and cultural background, highlight that the intensity of peppery notes was not the main negative driver of young consumers' liking of Duras wine produced during a vintage year with unfavourable cool and rainy climate conditions. However, the results of this study encourage Duras producers targeting such consumers to propose a wine exhibiting a good balance between fruity and peppery notes and a moderate acidity level that could be achieved during such season through deacidification. This research is a good illustration of the fact that the penalty analysis method can be implemented on a single wine sample.

KEYWORDS: Just-about-right (JAR), penalty analysis, peppery notes, rotundone, Duras, young consumers

INTRODUCTION

Rotundone is the main aroma compound responsible for peppery notes in red wines (Wood *et al.*, 2008). It is a very potent molecule whose olfactory detection threshold (ODT) has been established at 8 ng/L in water and 16 ng/L in wine (Wood *et al.*, 2008). Specific anosmia to rotundone, representing 20 to 46 % of the panellists, has been previously reported (Geffroy *et al.*, 2020b; Wood *et al.*, 2008). Rotundone is a ubiquitous volatile found in a wide diversity of grape varieties including Syrah, Vespolina, Schioppettino, Grüner Veltliner, Gamay, and notably Duras, a cultivar only grown in the southwest of France within the Protected Designation of Origin (PDO) Gaillac (Caputi *et al.*, 2011; Geffroy *et al.*, 2016a; Geffroy *et al.*, 2014; Mattivi *et al.*, 2011; Siebert *et al.*, 2008; Wood *et al.*, 2008). However, for this latter variety, which is getting more and more popular to produce single-varietal wines, it has been shown that rotundone in wine was neutrally or positively perceived by consumers, except for non-anosmic young respondents who generally preferred the control wine without rotundone (Geffroy *et al.*, 2018).

This peppery character is enhanced in grapes and wines by the cool and wet conditions of the climate during the growing season (Caputi *et al.*, 2011). Climate change, which usually takes the form of higher temperatures and low precipitation during summer and maturation, is not favourable to obtaining wines with high rotundone levels. However, it also induces a large variability between seasons, with two or three seasons per decade still exhibiting some particularly rainy and cool climatic conditions associated with delayed harvest and poor grape maturity status (van Leeuwen and Darriet, 2016). Good examples of such seasons in southwest France are 2013 and 2021. According to the data provided by Météo France (Toulouse, France) for the Gaillac vineyard (Milhavet weather station), these vintages were characterised during the growing season, from April 1 to September 30, by cumulative rainfall of 446 mm and 401 mm, and growing degree days (GDD) of 1301 and 1290 for 2021 and 2013, respectively, while average data from 2011 to 2022 were $360 \text{ mm} \pm 72$ and 1509 ± 156 for cumulative rainfall and GDD, respectively. As a consequence, such wines generally have a lower overall quality and are frequently characterised by a weak colour intensity and alcohol content, a significant level of acidity, poor quality tannins (Biss and Ellis, 2021; Davis *et al.*, 2019), and intense peppery notes if the genotype allows it (Geffroy *et al.*, 2020a).

In such circumstances, it remains unclear if peppery notes remain the main negative driver of liking for young consumers, an interesting segment to target to revitalise red wine consumption (Castellini and Samoggia, 2018). Penalty analysis is a popular method used in the food industry that enables the identification of drivers to improve products (Pagès *et al.*, 2014). It relies on the assessment by consumers of a set of variables called just-about-right (JAR) variables and the rating of overall product liking. The JAR variable is a sensory characteristic rated using a hedonic scale ranging

from *not enough* to *too much*, while the anchored midpoint is *just about right* (Rothman and Parker, 2009).

Penalty analysis has been previously used to optimise the sugar concentration of protein beverages (Harwood and Drake, 2021), to determine the acceptance of commercial orange juice (Iserliyska *et al.*, 2017), or to identify the drivers of liking for Korean traditional rice wine (Lee *et al.*, 2021). A limited number of studies have also been performed on wine to investigate the sensory-perceptual typicality related to a terroir (Cadot *et al.*, 2010; Leriche *et al.*, 2020) or to a phenolic composition (Cadot *et al.*, 2012).

The work aimed to identify the main negative drivers of liking for young French consumers, notably their perception of peppery notes in a Duras red wine produced during a season with cool and wet climatic conditions, using penalty analysis.

MATERIAL AND METHODS

1. Duras wine

One commercially available, unwooded 100 % Duras red wine from the Gaillac PDO produced by a private cellar during the 2021 rainy and cool season, was selected by a small group composed of four experts as being representative of Duras red wines produced during this season. A total of eight bottles were used and stored at 12 °C throughout the duration of the study. The experts, who all had the French National Enology Diploma (DNO), described the wine as having a low colour intensity, fruity character and viscosity, and exhibiting significant sourness and intensity of peppery notes.

The rotundone analysis in the base wine was determined by Nyséos (Montpellier, France) with SPE-SPME-GC-MS using deuterated rotundone and previously described parameters (Mattivi *et al.*, 2011).

Classical analyses of the bottled wine were performed in duplicate using a Winescan FT-120 (Foss France SAS, Nanterre, France) and a Mi455 titrator (Milwaukee Instruments, Rocky Mount, USA) for free and total sulfur dioxide, showed the following: alcohol concentration $11.9 \text{ % v/v} \pm 0.1$, pH 3.61 ± 0.05 , titratable acidity $5.3 \text{ g/L} \pm 0.1$ as tartaric acid, malic acid $0.0 \text{ g/L} \pm 0.3$, tartaric acid $2.4 \text{ g/L} \pm 0.3$, lactic acid $2.1 \text{ g/L} \pm 0.3$, glucose + fructose $1.2 \text{ g/L} \pm 0.5$, volatile acidity 0.45 g/L acetic acid ± 0.05 , carbon dioxide $378 \text{ mg/L} \pm 45$, modified colour intensity 6.1 ± 0.2 calculated as the sum of absorbance at 420 nm, 520 nm, and 620 nm, total phenolic index 32 ± 5 , SO_2 (free) $20 \text{ mg/L} \pm 10$, SO_2 (total) $52 \text{ mg/L} \pm 10$.

2. Data acquisition

A convenience panel composed of one hundred and thirty-four young French consumers with a mean age of $20.5 \text{ years} \pm 0.7$ was recruited from the Ecole d'Ingénieurs de Purpan in Toulouse, France, based on consuming red wine several times a year. No ethics approval for this study was obtained, but all participants provided written informed consent prior

to performing the sensory task. The only information about the sample provided to the participants was that they were evaluating one red wine. The panel consisting of 71 females and 63 males was asked to provide information regarding their red wine consumption frequency.

The panellists were familiarised during a preliminary session with most of the sensory attributes except for the colour intensity and the ethanol content. The following aqueous solutions were prepared and used as references: three separate 10 % v/v solutions of natural food grade aroma of raspberry, cherry, and blackcurrant (Expressions Aromatiques, Mouans-Sartoux, France) for fruity aroma, 10 % w/v solution of black pepper (Ducros, Avignon, France) for peppery notes, citric acid 0.5 g/L for sourness, tannic acid 1 g/L for astringency, and caffeine 0.2 mg/L for bitterness. For the taste and trigeminal sensations, the concentrations chosen were close to the recognition values provided by the International Standard ISO 3972.

The tasting session took place in a neutral room, and the spacing between the panellists ensured that no communication could occur. The wine was coded with a three-digit code, and a constant volume of 40 mL was poured at 18 °C in clear wine-tasting glasses.

Consumers were asked to indicate their overall liking on a 9-point hedonic scale from 1, *I extremely dislike*, to 9, *I extremely like*. The attributes of colour intensity, fruity aroma, peppery aroma, sourness, alcohol, astringency, and

bitterness were assessed on a 5-point scale, with category 3 as the scale anchor denoting just-about-right.

3. Data treatment

The 5-point JAR scale was reduced to a 3-point scale consisting of 3 levels: *not enough* (by grouping the levels 1 and 2 responses), JAR, and *too much* (by grouping the levels 4 and 5 responses). The means of liking score for the three groups were calculated and compared to identify any significant differences. The penalty was calculated and evaluated for its significance at $\alpha = 0.05$. The data treatment was conducted using the penalty analysis module in XLSTAT version 2022.4.1 (Addinsoft, Paris, France).

RESULTS AND DISCUSSION

The rotundone analysis revealed a concentration of 101 ± 6 ng/L, suggesting that perceived peppery notes at tasting might be due to this molecule given its ODT in wine of 16 ng/L (Wood *et al.*, 2008).

The panellists claimed to consume red wine several times a week (13.4 %), once a week (36.6 %), twice a month (30.6 %), once a month (9.7 %) and less than once a month (9.7 %).

The mean liking score provided for the studied wine on the 9-point scale was 4.78 ± 1.59 , which is below the threshold acceptance of six proposed by Moskowitz *et al.* (2012). This indicates that the wine was not well-accepted by young

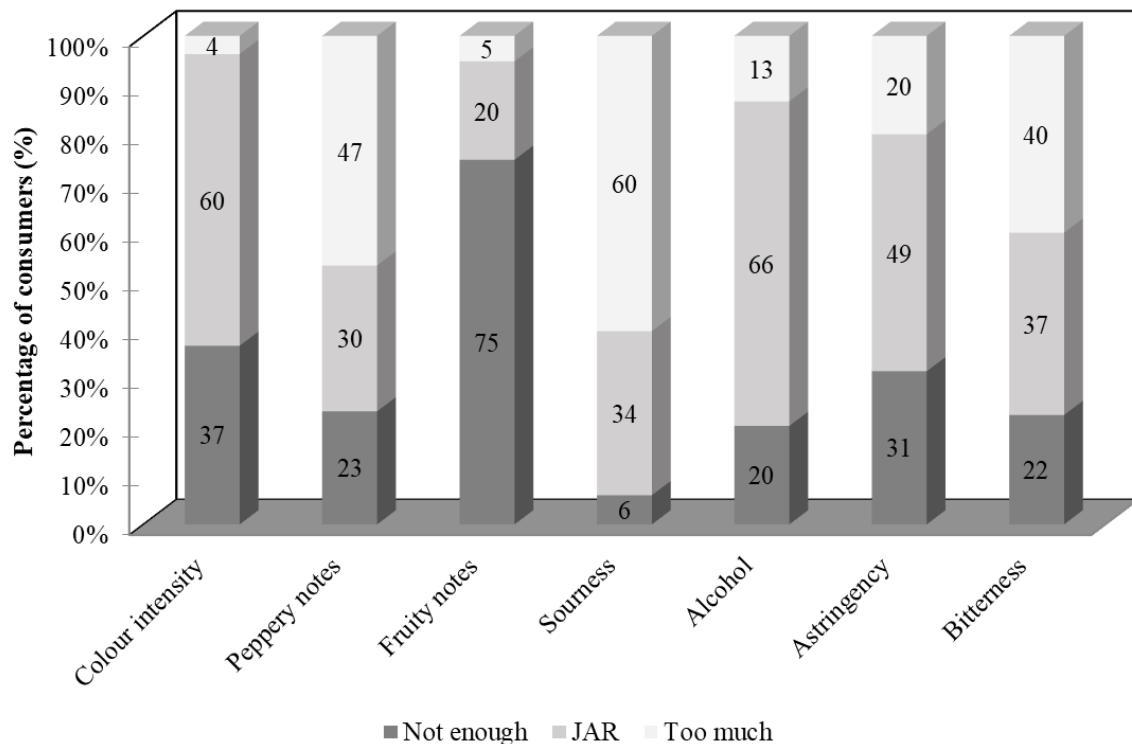


FIGURE 1. Percentage of panellists (n = 134) giving consumer ratings for selected attributes of a Duras red wine from a cool and wet season based on the collapsed JAR levels.

French consumers in accordance with previous findings (Geffroy *et al.*, 2018) and the initial hypothesis driving this work.

The distribution of the JAR scores merged to a three-level scale, and the results of the penalty analysis are shown in Figure 1 and Table 1.

These results highlighted that the greatest significant penalty ($P = 0.001$) with a value of 1.16 was due to the intensity of fruity notes, which were perceived as insufficient by almost 75 % of the young panellists. It can be mentioned that Spearman's correlation coefficient (r_s) of 0.325 with a $P < 0.05$ was observed between the score obtained for this JAR variable and the liking score. If studies investigating the appreciation of fruity notes by young consumers are scarce notably in red wine, these findings are somehow consistent with previous research conducted in France, Canada, New Zealand and Spain showing that young consumers particularly enjoyed fruity white wines (Beaulieu *et al.*, 2022; Lesschaeve *et al.*, 2012; Lund *et al.*, 2009), considered flavour and aroma as the most important aspects in red wines, with floral aromas eliciting positive emotions and liking (Mora *et al.*, 2021).

The second strongest penalty concerned the *sourness* attribute, which was perceived as being *too much* for 60 % of the participants. This observation is consistent with previous work emphasising that acidic wines are less well accepted by

newer wine consumers and, therefore, in most cases, by young consumers with less experience (Francis and Williamson, 2015).

The third and last significant penalty was related to the intensity of peppery notes. Surprisingly, no significant relationship was identified ($P = 0.206$) between the JAR scores for fruity and peppery notes ($r_s = -0.134$). Indeed, rotundone has been previously described as an impact aroma compound that can break the aroma buffer caused by ethanol and other major volatiles (Ferreira, 2012). Consequently, a stronger and more significant negative correlation would have been expected through a perceptual interaction mechanism (Atanasova *et al.*, 2004), with rotundone and peppery notes exhibiting a masking effect on the fruity character. Given the significant rotundone concentration in the studied wine, the proportion of subjects who perceived such character as *too much* did not exceed 50 %, which suggests that such aromatic components can be positive for some young consumers.

It cannot be excluded that some anosmic participants to rotundone, who were not able to smell peppery notes in the studied wine and were likely to perceive it as fruity as previously demonstrated (Geffroy *et al.*, 2020b), induced a bias in the dataset. Indeed, such subjects might have contributed to underestimating the percentage of consumers who rated the *peppery notes* as *too much* while overestimating

TABLE 1. Penalty analysis results for a Duras red wine from a cool and wet season.

Variable	Level	%	Sum (liking)	Mean (liking)	Mean drop	Penalty	<i>P</i> -value
Colour intensity	Not enough	36.6 %	228	4.65	0.22	0.25	0.385
	JAR	59.7 %	390	4.88			
	Too much	3.7 %	22	4.40	0.48		
Peppery notes	Not enough	23.1 %	149	4.81	0.54	0.82	0.006
	JAR	29.9 %	214	5.35			
	Too much	47.0 %	277	4.40	0.95		
Fruity notes	Not enough	74.6 %	454	4.54	1.16	1.16	0.001
	JAR	20.1 %	154	5.70			
	Too much	5.2 %	32	4.57	1.13		
Sourness	Not enough	6.0 %	31	3.88	1.50	0.91	0.002
	JAR	33.6 %	242	5.38			
	Too much	60.4 %	367	4.53	0.85		
Alcohol	Not enough	20.1 %	114	4.22	0.74	0.57	0.052
	JAR	66.4 %	442	4.97			
	Too much	13.4 %	84	4.67	0.30		
Astringency	Not enough	31.3 %	196	4.67	0.35	0.46	0.092
	JAR	48.5 %	326	5.02			
	Too much	20.1 %	118	4.37	0.65		
Bitterness	Not enough	22.4 %	143	4.77	0.31	0.48	0.089
	JAR	37.3 %	254	5.08			
	Too much	40.3 %	243	4.50	0.58		

the percentages of *JAR* or/and *too much* for the *fruity notes*. However, such impact that would deserve to be investigated through the determination of individual ODT for each consumer is likely to be minor as the percentage of anosmic respondents to rotundone among young consumers was estimated in a previous study at 10 % (Geffroy *et al.*, 2023), a much lower rate in comparison with the general population.

Although *astringency* has been previously described as a negative driver of acceptance by inexperienced wine consumers (Francis and Williamson, 2015), the fact that none of the other studied *JAR* variables induced a significant penalty despite *P*-values close to the $\alpha = 0.05$ threshold ($P = 0.092$ for astringency, $P = 0.089$ for bitterness) might be related to the wine characteristics that did not show any pronounced bitterness or astringency, some features not underlined by the expert panel. Although close to the significance threshold, the ethanol content was not identified as having a significant negative impact, which is consistent with recent research highlighting that ethanol concentration does not necessarily drive consumer preferences (Geffroy *et al.*, 2022). Given the importance of colour in overall wine liking (Dooley *et al.*, 2012), surprisingly, this characteristic was not identified as a significant penalty. The absence of familiarisation towards this *JAR* variable during the preliminary session and the relatively low amount of wine provided for the test (40 mL) might have played a role.

More generally, the fact that consumers were familiarised with most of the *JAR* variables prior to the experiment, using solutions with low concentrations close to the recognition threshold of the given attributes for trigeminal and taste sensations, might have contributed to these being over-perceived in wine, and to rating the product based on cognitive processing. Nevertheless, this hypothesis is unlikely as some variables for which familiarisation was undertaken, such as astringency, are still considered insufficient by many consumers. This latter attribute could also be explained by the total phenolic compound of the studied wine, namely 32 ± 5 , which was lower in comparison with other Duras wines produced during warmer and dryer seasons that exhibited values up to 74 ± 12 (Geffroy *et al.*, 2016b).

It can be pointed out that the panel used for this study was a convenience sample composed of French students in agriculture sciences with similar social and cultural backgrounds. It cannot be excluded that other results might have been obtained with French consumers exhibiting other and more diversified characteristics.

It should also be noted that these results may not apply to consumers from other French wine regions, particularly the places where young consumers are less familiar with wines containing great concentrations of rotundone. Indeed, the panel used for this study is likely to be familiar with rotundone, which has been reported apart from Duras, in other cultivars grown in the Toulouse area, such as Fer, Malbec, Duras or Prunelard (Geffroy *et al.*, 2020a). As familiarity is known to positively affect consumers' appreciation of a given aroma (Saliba *et al.*, 2009), it is possible that lower liking scores

and other penalty values would have been observed in other French cities.

The fact that a significant proportion of respondents (9.7 %) were infrequent consumers, drinking red wine less than once a month might have induced a bias, notably by lowering the panel liking score. However, when performing another data treatment after removing the 13 panellists concerned, no changes were observed in the panel liking score (4.70 ± 1.59), the significance and amplitude of penalties applied to the studied product (lack of fruity notes, 1.25; excessive sourness, 0.97 and excessive peppery notes, 0.81).

Although the studied wine was selected as being representative of a Duras wine produced during a cool and wet season, these results are only valid for a specific wine produced by a single estate. It cannot be excluded that other outcomes might have been obtained using another sample. However, it should be pointed out that though *Vitis vinifera* L. cv. Duras represents 800 ha under vines; the number of 100 % pure varietal commercial references available for this variety is still limited during a normal season, even if in strong increase, as it is mainly used for blending or less frequently to make rosé wines. In 2021, which was characterised by a low crop as a consequence of severe spring frost events, most of the winegrowers producing such pure varietal wines decided to blend it with at least 20 % of other varieties (e.g., Fer or Syrah), reducing drastically the number of samples available for this research.

Although penalty analysis can be conducted with one single product, and the present study illustrates this feasibility, it could have been relevant to include other wines and, notably, a control sample in the experimental design. This control could have been the same 2021 Duras red wine with similar taste and mouthfeel characteristics but without rotundone. This sample could have been obtained by using the procedure previously described by Geffroy *et al.* (2020b). In this work, wines were dearomatised using supercritical CO₂ before performing aroma reconstitution by mixing aroma compounds with Odour Activity Value (OAV) above five. The test sample would have been the full reconstitution, and the control sample the reconstitution without rotundone.

The results can also be useful for Fer, Malbec, Tardif, and Prunelard producers, some cultivars in which rotundone has been previously identified (Geffroy *et al.*, 2020a), even though the mouthfeel and aroma characteristics of the wines made from these latter varieties might differ in comparison with Duras. Indeed, they are likely to exhibit a more marked astringency, which could become a strong penalty for such a target consumer segment (Francis and Williamson, 2015).

CONCLUSION

This work, which is a good illustration of the fact that the penalty analysis method can be implemented on one single wine sample, enabled the identification of the main penalties impacting young consumers' liking of a Duras red wine made from a cool and wet season. In decreasing order of

importance, these penalties were an insufficient intensity of fruity notes, an excessive sourness, and an excessive intensity of peppery notes. This indicates that rotundone and related peppery notes are not the main negative drivers of liking for young consumers. When targeting such consumers, these results, which are still preliminary and would deserve to be confirmed on a similar age cohort with other social and cultural backgrounds, encourage Duras producers to propose a wine exhibiting a good balance between fruity and peppery notes. This could be achieved by blending up to 15 % with another fruity cultivar if the producer wants to maintain the name Duras on the label or by implementing viticultural or oenological strategies such as leaf removal or the use of *Saccharomyces uvarum* to lower rotundone in wine (Geffroy *et al.*, 2020a). The results of this study also suggest that reducing acidity through deacidification using calcium carbonate (CaCO₃) or potassium bicarbonate (KHCO₃) is a key aspect to consider to enhance liking for this segment of consumers.

ACKNOWLEDGEMENTS

The authors are grateful to the students from Ecole d'Ingénieurs de Purpan who participated in the study and to Jean-Noël Barrau, Vinovalie, for performing the wine classical analyses.

REFERENCES

- Atanasova, B., Thomas-Danguin, T., Langlois, D., Nicklaus, S., & Etievant, P. (2004). Perceptual interactions between fruity and woody notes of wine. *Flavour and Fragrance Journal*, 19(6), 476-482. <https://doi.org/10.1002/ffj.1474>
- Beaulieu, A., Giraud, V., Magro, P., Nougarede, S., Maza, E., Samson, A., Geffroy, O., & Chervin, C. (2022). Development of the Adapted Pivot Test method for descriptive sensory analyses with young untrained students. *Journal of Sensory Studies*, 37(5), e12779. <https://doi.org/10.1111/joss.12779>
- Biss, A., & Ellis, R. (2021). Modelling Chablis vintage quality in response to inter-annual variation in weather. *OENO One*, 55(3), 209-228. <https://doi.org/10.20870/oeno-one.2021.55.3.4709>
- Cadot, Y., Caillé, S., Samson, A., Barbeau, G., & Cheynier, V. (2010). Sensory dimension of wine typicality related to a terroir by Quantitative Descriptive Analysis, Just About Right analysis and typicality assessment. *Analytica Chimica Acta*, 660(1-2), 53-62. <https://doi.org/10.1016/j.aca.2009.10.006>
- Cadot, Y., Caillé, S., Samson, A., Barbeau, G., & Cheynier, V. (2012). Sensory representation of typicality of Cabernet franc wines related to phenolic composition: Impact of ripening stage and maceration time. *Analytica Chimica Acta*, 732, 91-99. <https://doi.org/10.1016/j.aca.2012.02.013>
- Caputi, L., Carlin, S., Ghiglieno, I., Stefanini, M., Valenti, L., Vrhovsek, U., & Mattivi, F. (2011). Relationship of changes in rotundone content during grape ripening and winemaking to manipulation of the 'peppery' character of wine. *Journal of Agricultural and Food Chemistry*, 59(10), 5565-5571. <https://doi.org/10.1021/jf200786u>
- Castellini, A., & Samoggia, A. (2018). Millennial consumers' wine consumption and purchasing habits and attitude towards wine innovation. *Wine Economics and Policy*, 7(2), 128-139. <https://doi.org/10.1016/j.wep.2018.11.001>
- Davis, R. E., Dimon, R. A., Jones, G. V., & Bois, B. (2019). The effect of climate on Burgundy vintage quality rankings. *OENO One*, 53(1). <https://doi.org/10.20870/oeno-one.2019.53.1.2359>
- Dooley, L. M., Threlfall, R. T., Meullenet, J. F., & Howard, L. R. (2012). Compositional and sensory impacts from blending red wine varieties. *American Journal of Enology and Viticulture*, 63(2), 241-250. <https://doi.org/10.5344/ajev.2012.11086>
- Ferreira, V. (2012). Bases moléculaires de l'arôme du vin. Proceedings of the international symposium on wine aroma (VINAROMAS project),
- Francis, I. L., & Williamson, P. O. (2015). Application of consumer sensory science in wine research. *Australian Journal of Grape and Wine Research*, 21, 554-567. <https://doi.org/10.1111/ajgw.12169>
- Geffroy, O., Buissonnière, C., Lempereur, V., & Chatelet, B. (2016a). A sensory, chemical and consumer study of the peppery typicality of French Gamay wines from cool-climate vineyards. *Journal International des Sciences de la Vigne et du Vin*, 50(1), 35-47. <https://doi.org/10.20870/oeno-one.2016.50.1.53>
- Geffroy, O., Dufourcq, T., Carcenac, D., Siebert, T., Herderich, M., & Serrano, E. (2014). Effect of ripeness and viticultural techniques on the rotundone concentration in red wine made from *Vitis vinifera* L. cv. Duras. *Australian Journal of Grape and Wine Research*, 20(3), 401-408. <https://doi.org/10.1111/ajgw.12084>
- Geffroy, O., Siebert, T., Herderich, M., Mille, B., & Serrano, E. (2016b). On-vine grape drying combined with irrigation allows to produce red wines with enhanced phenolic and rotundone concentrations. *Scientia horticultrae*, 207, 208-217. <https://doi.org/10.1016/j.scienta.2016.05.031>
- Geffroy, O., Descôtes, J., Serrano, E., Li Calzi, M., Dagan, L., & Schneider, R. (2018). Can a certain concentration of rotundone be undesirable in Duras red wine? A study to estimate a consumer rejection threshold for the pepper aroma compound. *Australian Journal of Grape and Wine Research*, 24(1), 88-95. <https://doi.org/10.1111/ajgw.12299>
- Geffroy, O., Kleiber, D., & Jacques, A. (2020a). May peppery wines be the spice of life? A review of research on the 'pepper' aroma and the sesquiterpenoid rotundone. *OENO One*, 54(2). <https://doi.org/10.20870/oeno-one.2020.54.2.2947>
- Geffroy, O., Morère, M., Lopez, R., Pasquier, G., & Condoret, J.-S. (2020b). Investigating the aroma of Syrah wines from the northern Rhone valley using supercritical CO₂ dearomatized wine as a matrix for reconstitution studies. *Journal of Agricultural and Food Chemistry*. <https://doi.org/10.1021/acs.jafc.0c04328>
- Geffroy, O., Pasquier, G., Pagès, M., & Violleau, F. (2022). Exploring the response to a new range of ethanol reductions in Chardonnay and Syrah wines using a Consumer Rejection Threshold approach. *OENO One*, 56(4), 147-155. <https://doi.org/10.20870/oeno-one.2022.56.4.7112>
- Geffroy, O., Aymard, F., Cuif, C., Baerenzung dit Baron, T., Denat, M., & Jacques, A. (2023). The olfactory threshold of rotundone in brandy is 10-fold higher than in wine and does not increase with the complexity of the matrix. *South African Journal of Viticulture and Enology*, In press
- Harwood, W. S., & Drake, M. (2021). Application of temporal penalty analysis for the optimization of sugar reduction in protein beverages. *Journal of Sensory Studies*, 36(3), e12644. <https://doi.org/10.1111/joss.12644>

- Iserliyska, D., Dzhivoderova, M., & Nikovska, K. (2017). Application of penalty analysis to interpret jar data—A case study on orange juices. *Current Trends in Natural Sciences*, 6(11), 6-12.
- Lee, S., Kwak, H. S., Jung, J. y., Kim, S. S., & Lee, Y. (2021). Identifying drivers of liking for Korean traditional rice wine (Yakju) across different age groups by penalty analysis based on the CATA method. *Journal of the Institute of Brewing*, 127(3), 286-295. <https://doi.org/10.1002/jib.649>
- Leriche, C., Molinier, C., Caillé, S., Razungles, A., Symoneaux, R., & Coulon-Leroy, C. (2020). Development of a methodology to study typicity of PDO wines with professionals of the wine sector. *Journal of the Science of Food and Agriculture*, 100(10), 3866-3877. <https://doi.org/10.1002/jsfa.10428>
- Lesschaeve, I., Bowen, A., & Bruwer, J. (2012). Determining the impact of consumer characteristics to project sensory preferences in commercial white wines. *American Journal of Enology and Viticulture*, 63(4), 487-493. <https://doi.org/10.5344/ajev.2012.11085>
- Lund, C. M., Thompson, M. K., Benkwitz, F., Wohler, M. W., Triggs, C. M., Gardner, R., Heymann, H., & Nicolau, L. (2009). New Zealand Sauvignon blanc Distinct Flavor Characteristics: Sensory, Chemical, and Consumer Aspects. *American Journal of Enology and Viticulture*, 60(1), 1-12. <https://doi.org/10.5344/ajev.2009.60.1.1>
- Mattivi, F., Caputi, L., Carlin, S., Lanza, T., Minozzi, M., Nanni, D., Valenti, L., & Vrhovsek, U. (2011). Effective analysis of rotundone at below-threshold levels in red and white wines using solid-phase microextraction gas chromatography/tandem mass spectrometry. *Rapid Communication in Mass Spectrometry*, 25(4), 483-488. <https://doi.org/10.1002/rcm.4881>
- Mora, M., de Matos, A. D., Vázquez-Araújo, L., Puente, V., Hernando, J., & Chaya, C. (2021). Exploring young consumers' attitudes and emotions to sensory and physicochemical properties of different red wines. *Food Research International*, 143, 110303. <https://doi.org/10.5344/ajev.2009.60.1.1>
- Moskowitz, H. R., Beckley, J. H., & Resurreccion, A. V. (2012). *Sensory and Consumer Research in Food Product Design and Development*. John Wiley & Sons.
- Pagès, J., Berthelo, S., Brossier, M., & Gourret, D. (2014). Statistical penalty analysis. *Food Quality and Preference*, 32, 16-23. <https://doi.org/10.1016/j.foodqual.2013.07.008>
- Rothman, L., & Parker, M. J. (2009). *Just about right (JAR) scales: Design, usage, benefits, and risks*. ASTM International West Conshohocken.
- Saliba, A.J., Bullock, J., & W.J, Hardie (2009). Consumer rejection threshold for 1,8-cineole (eucalyptol) in Australian red wine. *Food Quality and Preference*, 20, 500-504. <https://doi.org/10.1016/j.foodqual.2009.04.009>
- Siebert, T. E., Wood, C., Elsey, G. M., & Pollnitz, A. P. (2008). Determination of rotundone, the pepper aroma impact compound, in grapes and wine. *Journal of Agricultural and Food Chemistry*, 56(10), 3745-3748. <https://doi.org/10.1021/jf800184t>
- van Leeuwen, C., & Darriet, P. (2016). The impact of climate change on viticulture and wine quality. *Journal of Wine Economics*, 11(1), 150-167. <https://doi.org/10.1017/jwe.2015.21>
- Wood, C., Siebert, T. E., Parker, M., Capone, D. L., Elsey, G. M., Pollnitz, A. P., Eggers, M., Meier, M., Vossing, T., Widder, S., Krammer, G., Sefton, M. A., & Herderich, M. J. (2008). From wine to pepper: rotundone, an obscure sesquiterpene, is a potent spicy aroma compound. *Journal of Agricultural and Food Chemistry*, 56(10), 3738-3744. <https://doi.org/10.1021/jf800183k>