International Journal of Food Science + Technology

Original article

Impact of chemical profile on sensory evaluation of tropical red wines

Caio Monteiro Veríssimo,[1,2] Rafael Lopes Alcântara,[2] Luciana Leite de Andrade Lima,[2] Giuliano Elias Pereira[3] & Maria Inês Sucupira Maciel[1,4*]

1 Food Science and Technology Graduate Program, Federal University of Paraíba, Cidade Universitária, Conjunto Presidente Castelo Branco III s/n, João Pessoa PB, CEP 58051-900, Brazil

2 Department of Rural Technology, Federal Rural University of Pernambuco, Rua Dom Manuel de Medeiros s/n, Dois Irmãos, Recife PE, CEP 52171-900, Brazil

3 Brazilian Agricultural Research Corporation, Embrapa Grape & Wine, Rua Livramento,n° 515, Bento Gonçalves RS, CEP 95701-008, Brazil

4 Consumer Science Department, Federal Rural University of Pernambuco, Rua Dom Manuel de Medeiros s/n, Dois Irmãos, Recife Pernambuco, CEP 52171-900, Brazil

(Received 8 September 2020; Accepted in revised form 22 January 2021)

Summary This study evaluated the correlation between the chemical composition of red wines and the sensory perception of the products. The visual, gustatory and flavour attributes of eight samples of tropical red wines were characterised by semi-trained panellists using the check-all-that-apply methodology. Titratable and volatile acidity, pH, contents of ethanol, total polyphenols and anthocyanins, and the chromatic parameters of the red wine samples were determined. The analysis of the correlations between visual attributes and sensory perception indicated that the evaluation of the wine colour attributes can predict other sensory characteristics related to aromas and flavours. This enabled the wine tasters to distinguish subtle variations in the visual attributes of the product. The results of this study indicated that panellists who underwent short-term training can sensorially perceive the influence of physicochemical variables on wine quality. Additionally, the correlation analysis enabled the identification of production adjustments and the understanding of the consumer perception of a complex product.

Keywords Check-all-that-apply, consumer analysis, correlation, São Francisco Valley, wine quality.

Introduction

The quality attributes, including the physicochemical, sensory and microbiological properties, of the product are important for consumer acceptance (Meilgaard *et al.*, 2015). Wine quality is dependent on a complex combination of factors, such as terroir, which can directly affect the physicochemical attributes and determine the sensory perception, product requirements and consumer acceptance of the product (Oliveira *et al.*, 2019a).

The physicochemical properties of the grapes, such as the sugar, acid and phenolic contents, and consequently those of the wines are determined based on a combination of intrinsic factors (such as grape variety clone and rootstock) and extrinsic factors (such as climatic conditions, soil type, irrigation management and pruning techniques) (Xu *et al.*, 2015). São Francisco Valley, which is located in northeast Brazil between the southern hemisphere parallels of 8–9° (altitude: 350 m), is characterised by a semiarid tropical climate with high average temperatures, high sunlight intensity (3000 h/year) and low annual rainfall (500 mm) (Padilha *et al.*, 2017). The use of water for irrigation and the absence of winter in this region can yield at least two crops in the same year. Compared with those produced using the traditional method globally, the wines produced in São Francisco Valley have characteristic chemical and sensory profiles (Lima *et al.*, 2015; Almeida *et al.*, 2016).

The unique climatic conditions and vineyard management in the São Francisco Valley enable the production of wines with unique chemical characteristics, especially those with a unique phenolic composition (Oliveira *et al.*, 2019b). Padilha *et al.* (2017) reported that phenolic compounds determine the expected sensory properties, such as colour, structure, astringency and bitterness, of red wines.

*Correspondent: E-mail: m.inesdcd@gmail.com

doi:10.1111/ijfs.14987

In addition to laboratory analysis, sensory analysis is essential for the development and quality control of products in the food and beverage industry (Meilgaard *et al*., 2015). The traditional characterisation of wines is performed using descriptive analysis with an intensively trained team to obtain a technical and precise result. However, this analysis is time-consuming and requires financial resources (Ares *et al*., 2015).

Various simple and effective techniques have been developed to rapidly determine the consumer perception of the sensory characteristics of the product (Ares & Varela, 2017). Check-all-that-apply (CATA) questionnaire, a descriptive test model, does not require specialised training and has been widely used to rapidly obtain the sensory profile of products from the consumers (Ares, 2015). However, the CATA model is associated with a low discriminant power when analysing complex matrices or products with subtle differences (Ares *et al*., 2015).

A short-term training has been considered in CATA application to reduce response instability, improve sample description and achieve assessments similar to those by trained panellists, making it possible to decrease the number of participants (Giacalone & Hedelund, 2016; Alexi *et al*., 2018).

Expert wine assessors tend to consciously correlate sensory attributes, such as visual, olfactory and flavour characteristics, with the overall quality of the product (Wang & Spence, 2019). However, consumers consider external aspects, such as label information, grape variety and wine production region, while determining wine quality (Danner *et al*., 2017; Kustos *et al*., 2019).

Spence (2019) and Heatherly *et al*. (2019) reported that factors determining the colour attributes of a food or drink can affect the multisensory perception of its aromas and flavours. For example, dark colours are perceived to be associated with strong aromas, while pink/red colour and red-coloured fruits are perceived to be associated with sweet taste (Heatherly *et al*., 2019; Spence, 2019). These data indicate the correlation between sensory perceptions and the importance of an accurate investigation of the effect of the sensory properties of a beverage on consumption behaviour.

Considering the economic relevance of wine for the São Francisco Valley region and the importance of monitoring wine characteristics, this study aimed to evaluate the effects of chemical parameters (such as pH, titratable and volatile acidities, and the contents of ethanol, total phenolics and anthocyanins) and chromatic attributes on the perception of sensory characteristics of tropical red wines. The effect of physicochemical characteristics on the perception of sensory properties of tropical red wines was examined by semi-trained assessors by analysing the correlation between these variables.

Materials and methods

Samples

The study was performed using eight samples of commercial red wine (*Vitis vinifera* L.) (Table 1) from a winery located in the municipality of Lagoa Grande (9°03′S, 40°11′W) in São Francisco Valley (Pernambuco State, Brazil). Wines, which were collected directly from the winery, were chosen based on their possibility to receive the indication of origin seal of the region.

Vocabulary development for sensory analysis

Sensory descriptors (Table 2) were instituted by trained panellists, who had undergone a minimum of 30 h of training and were chosen based on their ability to discriminate samples, repeat assessment and reach group consensus according to the ISO 8586 (ISO, 2012) guidelines. They used a modified Repertory Grid method (Damasio & Costell, 1991), obtaining twenty-four attributes (three visual, nine olfactory and twelve flavour attributes). The final list had a vocabulary that could be adapted to consumers, making it a simple list with accessible language, to avoid misunderstandings and to reflect consumers' perception and description of the products in real life (Fiszman *et al*., 2015; Ares & Varela, 2017).

Sensory analysis

Sensory evaluations were performed in standardised individual booths according to the ISO 8589:2007

Table 1 Characteristics of the commercial red wine samples (*Vitis vinifera* L.) from São Francisco Valley, Northeastern Brazil

Sample	Grape variety	Maturation	Vintage
CS	Cabernet Sauvignon	No maturation	2018
CS/SY	Cabernet Sauvignon, Syrah	No maturation	2018
SY	Syrah	No maturation	2018
TP	Tempranillo	No maturation	2018
RES	Cabernet Sauvignon, Syrah, Alicante Bouschet	6 months in French oak barrel	2018
AB	Alicante Bouschet	9 months in French oak barrel	2018
TN	Touriga Nacional	9 months in French oak barrel	2018
PR	Cabernet Sauvignon, Syrah, Alicante Bouschet, Touriga Nacional, Aragonês	12 months in French oak barrel	2017

Table 2 Attribute list and composition of physical references provided to semi-trained panel in CATA analysis

CATA Attributes	Product used	Concentration
1. Purplish colour	Violet dye solution in red wine	1.6% v/v
2. Reddish colour	Intense red dye solution in red wine	1.6% v/v
3. Clear	Corn starch solution in red wine	10% m/v
4. Fresh fruit aroma	Mix of strawberries, red grape and plum in hydroalcoholic solution[1]	70% m/v
5. Fruit Jam aroma	Mixed berry jam in hydroalcoholic solution[1]	50% m/v
6. Dried fruit aroma	Mix of raisins and prunes in hydroalcoholic solution[1]	50% m/v
7. Spice aroma	Mix of ground black pepper, cinnamon and clove in hydroalcoholic solution[1]	20% m/v
8. Vegetal aroma	Green pepper in hydroalcoholic solution[1]	45% m/v
9. Flower aroma	Artificial flower aroma in hydroalcoholic solution[1]	0.2% v/v
10. Smoked aroma	Artificial smoke aroma in hydroalcoholic solution[1]	1.5% v/v
11. Vinegary odour	Red wine vinegar in hydroalcoholic solution[1]	16% v/v
12. Alcoholic odour	Hydroalcoholic solution	20% v/v
13. Sweetish	Sucrose in hydroalcoholic solution[1]	4.5% m/v
14. Sour	Citric acid in hydroalcoholic solution[1]	0.45% m/v
15. Bitter	Caffeine in hydroalcoholic solution[1]	0.1% m/v
16. Astringent	Tannic acid in hydroalcoholic solution[1]	0.2% m/v
17. Alcoholic flavour	Hydroalcoholic solution	20% v/v
18. Fresh fruit flavour	Mix of strawberries, red grape and plum in hydroalcoholic solution[1]	70% m/v
19. Fruit jam flavour	Mixed berry jam in hydroalcoholic solution[1]	50% m/v
20. Dried fruit flavour	Mix of raisins and prunes in hydroalcoholic solution[1]	50% m/v
21. Pungent flavour	Ginger in hydroalcoholic solution[1]	10% m/v
22. Woody flavour	Wood chips in hydroalcoholic solution[1]	10% m/v
23. Full-bodied	Whole red grape juice	100%
24. Persistent flavour	20 seconds of perception	

[1]Hydroalcoholic solution in concentration of 6% v/v.

standard (ISO, 2007) guidelines. The assessors were served with 25 mL of sample in wine tasting glasses as recommended by ISO 3591:1977 standard (ISO, 1977) at 18.0 ± 0.5°C. Additionally, the assessors were provided with still water and a water cracker to remove residual taste between the analyses.

All samples were blind-labelled with a three-digit random code and presented in a monadic and balanced order to account for the first-order and carry-over effects (Williams design).

Semi-trained panel – CATA Questions

Thirty assessors were recruited based on an online survey that evaluated psychographics, consumption habits, and the ability to identify the quality and defect attributes of red wines. Only respondents who correctly listed the quality and defect characteristics of red wines and were regular wine consumers were accepted. Potential consumers were preferred over those with experience in wine tasting, such as wine researchers and experts, to obtain a response similar to that of the consumer market for this product.

The 2-h training was performed in three steps. Initially, the assessors attended a short class on the type of wine to be evaluated and its producing region. Next, a clear definition of sensory attributes was provided along with the presentation and evaluation of the different physical references (Table 2). Physical and written definitions were available to panellists during all sensory evaluations.

The trained assessors aged between 21 and 43 years performed sensory evaluation using the CATA questionnaire. This questionnaire enables the description of the product based on the perceived sensory attributes in a predefined list and simultaneously evaluates the overall liking using a hedonic scale (Ares, 2015). Additionally, the CATA model incorporated the wine tasting dynamics (visual, olfactory and flavour attributes) to reduce the cognitive effort of the assessors. The sample presentation order followed an incomplete block design that was balanced for carry-over and position effects.

Physicochemical characteristics of wines

Classical oenological parameters

The following oenological physicochemical analyses were performed according to official methods for wine analysis: pH, volatile acidity, titratable acidity and alcoholic content (OIV, 2019). Volatile acidity and titratable acidity were expressed as milliequivalents per litre (mEq L^{-1}) of acetic acid and tartaric acid, respectively, at 20 °C. Alcoholic content was expressed as the percentage of ethanol (v/v) at 20 °C.

Spectrophotometric parameters

Total polyphenols were measured using the Folin–Ciocalteu method at 725 nm. The samples were diluted to 0.1% (v/v) in water and incubated with the phenolic

Folin–Ciocalteu reagent stabilised with sodium carbonate. The total polyphenol content was expressed as milligram of gallic acid equivalents per litre (Giovanelli & Buratti, 2009).

The concentration of monomeric anthocyanins was determined using the differential pH method at 520 nm to eliminate the interference from other phenolic compounds, which do not exhibit chromatic variations due to pH changes (OIV, 2014). The monomeric anthocyanin contents were expressed as milligram equivalents of malvidin 3-glycoside per litre.

The colour intensity was determined by adding the absorbances at 420, 520 and 620 nm of the samples. The chromatic tone value was calculated using the ratio of the absorbance at 420 to that at 520 nm (Caillé *et al.*, 2010). The % Yellow, % Red and % Blue colorimetric indices were calculated by measuring the absorbances at wavelengths 420, 520 and 620 nm, respectively (Monagas *et al.*, 2006).

All analyses were performed using a Varian® 50 Bio UV-vis spectrophotometer with a 1-cm quartz cuvette.

Colorimetric parameters

The colour parameters (L^*, a^* and b^*) were analysed by directly reading the samples using the tristimulus (CIELAB system) colorimeter in the absence of light. The C^* and H^* values were calculated following the methods of Caillé *et al.* (2010) and Harbertson & Spayd (2006), respectively. The analyses were performed using a Chroma Meter® CR-400 colorimeter, which was calibrated with the D65 illuminant, at 10° observer angle with a white porcelain plate.

Statistical analysis

Physicochemical attributes

The data of the physicochemical analysis were obtained in triplicate and presented as global mean and standard deviation. Mean impact and percentage variation were calculated using Equations 1 and 2, respectively:

$$\text{Mean Impact} = \frac{\text{Attr.k mean}}{\text{Attr.k global mean}} \quad (1)$$

$$\text{Percentual variation}(\%) = \frac{\text{Max attr.k} - \text{Min attr.k}}{\text{Min attr.k}} \times 100 \quad (2)$$

where 'Attr.k mean' is the mean of a specific attribute, 'Attr.k global mean' is the mean of the entire sample set of a specific attribute, 'Max attr.k' is the maximum value for an attribute and 'Min attr.k' is the minimum value for an attribute.

The data were analysed using analysis of variance, followed by Duncan's test. The differences were considered significant at $P < 0.05$. All statistical analyses were performed using the XLSTAT software (Addinsoft, New York, NY).

Sensory analysis

For the CATA dataset, the frequency of citation of each sensory attribute was determined by counting the number of assessors that used a particular term to describe each sample. The significance between the samples and the attributes was analysed using Cochran's Q test (Manoukian, 1986; Meyners *et al.*, 2013). Additionally, the normalised total citation frequency of an attribute was calculated (Alexi *et al.*, 2018).

Correlation between sensory and physicochemical parameters

A bivariate correlation matrix was generated to analyse the correlation between sensory and physicochemical variables and display Pearson's correlation coefficient (r). For data analysis, the samples were allocated in rows, while the physicochemical and sensory variables were placed in columns. The differences were considered significant at $P < 0.05$.

Partial least squares (PLS1) regression was performed with all significant correlations to confirm the correlation between sensory and physicochemical variables and to predict the positions of samples on the correlation map.

All statistical analyses were performed using the XLSTAT software (Addinsoft, New York, NY).

Results

Effect of physicochemical characteristics on the samples

The physicochemical data are shown in Table 3. The variables 'Total polyphenols' (243.32%), 'Volatile acidity' (235.00%), 'Anthocyanins' (116.45%) and 'Colour intensity' (115.33%) exhibited a high degree of variation among the samples. In contrast, the attributes 'pH' (2.40%), 'h^*' (4.84%), '%Red' (5.97%), '%Blue' (6.26%) and '%Yellow' (7.18%) exhibited a small degree of variation among the samples.

Generally, young wine samples (CS, SY, CS/SY and TP) were affected by the following attributes: 'Tone', '%Yellow' and 'b^*'. This indicated a possible colour development, which is an undesirable attribute. Wine samples that have undergone ageing (AB, TN, RES and PR) were affected by the 'Anthocyanins', 'Total polyphenols', 'Colour intensity' and '%Red' attributes, which are characteristic attributes of this type of wine. The attributes related to possible defects, such as 'Titratable acidity' and 'Volatile acidity', also affected the characterisation of wines matured in oak.

Table 3 Global mean, mean impact with pairwise comparisons[1] and percentage variation of classical, spectrophotometric and colorimetric analyses in tropical red wines from São Francisco Valley

Physicochemical variables	Global mean	Mean impact[2]								Percentual variation[3]
		CS[4]	CS/SY[4]	SY[4]	TP[4]	AB[4]	TN[4]	RES[4]	PR[4]	
Classic										
pH	4.12 ± 0.05	1.01^{a}	1.01^{a}	1.01^{a}	1.01^{a}	0.99^{b}	0.99^{b}	0.99^{b}	0.99^{b}	2.40
Titratable acidity (mEq L^{4} of tartaric acid)	75.30 ± 7.26	0.96^{d}	0.89^{e}	0.99^{c}	0.88^{e}	0.98^{cd}	1.09^{b}	1.07^{c}	1.15^{a}	30.51
Volatile acidity (mEq L^{4} of acetic acid)	4.44 ± 1.55	0.46^{g}	0.69^{f}	0.92^{e}	1.38^{b}	0.92^{e}	1.54^{a}	1.15^{c}	0.96^{d}	235.00
Alcohol content (%v/v 20°C)	12.41 ± 0.87	0.97^{f}	0.98^{e}	0.86^{g}	1.03^{c}	1.06^{a}	1.06^{ab}	0.98^{d}	1.06^{b}	24.03
Spectrophotometric										
Total polyphenols (mg L^{4} of gallic acid equivalents)	3290.76 ± 969.76	0.95^{cd}	0.38^{e}	0.93^{cd}	0.92^{d}	1.32^{a}	1.20^{b}	1.01^{c}	1.27^{ab}	243.32
Anthocyanins (mg L^{4} of malvidin 3-glycoside)	394.54 ± 113.78	0.65^{f}	0.94^{c}	0.81^{de}	0.85^{d}	1.40^{a}	1.32^{b}	1.27^{b}	0.76^{e}	116.45
Colour intensity	9.58 ± 2.88	0.77^{e}	0.78^{d}	0.73^{f}	0.72^{g}	1.11^{c}	1.17^{b}	1.17^{b}	1.55^{a}	115.33
Tone	0.84 ± 0.04	1.07^{a}	1.00^{d}	1.03^{c}	1.06^{b}	0.96^{e}	0.95^{f}	0.95^{f}	0.97^{e}	13.58
%Yellow	40.35 ± 1.09	1.04^{a}	1.00^{d}	1.02^{c}	1.03^{b}	0.98^{e}	0.98^{f}	0.97^{g}	0.98^{f}	7.18
%Red	48.13 ± 1.13	0.97^{f}	0.99^{d}	0.99^{e}	0.97^{f}	1.02^{b}	1.03^{a}	1.03^{a}	1.01^{c}	5.97
%Blue	11.52 ± 0.27	0.98^{cd}	1.03^{a}	0.99^{c}	1.01^{b}	0.99^{cd}	0.97^{d}	0.99^{cd}	1.03^{a}	6.26
Colorimetric										
*L**	13.31 ± 1.22	0.94^{e}	0.93^{f}	0.97^{d}	0.92^{f}	0.92^{f}	1.14^{a}	1.09^{b}	1.08^{c}	24.18
*a**	3.43 ± 0.34	1.03^{c}	1.08^{b}	1.03^{c}	1.15^{a}	1.02^{c}	0.95^{d}	0.87^{e}	0.86^{e}	33.60
*b**	–3.56 ± 0.29	0.97^{c}	0.93^{b}	0.99^{c}	0.89^{a}	0.99^{c}	1.10^{d}	1.14^{e}	0.98^{c}	21.53
*C**	4.94 ± 0.16	1.00^{a}	1.01^{a}	1.01^{a}	1.03^{a}	1.00^{a}	1.03^{a}	0.99^{a}	0.93^{b}	11.69
*h** (°)	313.94 ± 4.83	1.01^{c}	1.01^{b}	1.00^{d}	1.02^{a}	1.00^{d}	0.99^{e}	0.98^{f}	0.99^{e}	4.84

[1]Means followed by different letters in the lines denote significant differences among the samples ($P \leq 0.05$) according to Duncan's test.
[2]Mean impact was calculated using Eq. (1).
[3]Percentual variation was calculated using Eq. (2).
[4]For samples: CS, Cabernet Sauvignon; CS/SY, Cabernet Sauvignon/Syrah; SY, Syrah; TP, Tempranillo; AB, Alicante Bouschet; TN, Touriga Nacional; RES, Cabernet Sauvignon/Syrah/Alicante Bouschet and PR, Cabernet Sauvignon/Syrah/Alicante Bouschet/Touriga Nacional/Aragonês.

Sensory characterisation of samples

Of the twenty-four attributes listed in the CATA questionnaire, the samples could be discriminated based on twelve attributes, which significantly varied among the samples (Table 4). Among these, the most frequently cited attributes were 'Clear' and 'Reddish Colour' (approximately 70% citation frequency). This fact may reveal a facility of the semi-trained public to evaluate the visual characteristics of the beverages. The least cited attributes were 'Purplish colour', 'Dried fruit flavour' and 'Smoked aroma'. This may indicate the absence of the first term and difficulty in the evaluation of other attributes.

Interestingly, the sample PR had the lowest citation frequency for the 'Clear' attribute and the highest citation frequency for the 'Purplish colour' attribute. However, the analysis of the colorimetric data (cf. Table 3) revealed that the samples had purple-red tones. The term 'Purplish colour' was probably attributed to colour intensity, which indicated confusion among the members of the semi-trained panel or a 'dumping effect' (Lawless & Heymann, 2010). This may be because the term 'intense colour' was not available on the CATA questionnaire. Similarly, the sample PR obtained the highest value for 'Colour intensity' (cf. Table 3), a spectrophotometric attribute that represents the colour saturation of the beverage.

Young samples (CS, CS/SY, SY and TP) were characterised by the following attributes: 'Clear', 'Reddish colour', 'Flower aroma', 'Fruit jam aroma', 'Alcoholic odour', 'Sour' and 'Astringent'. The aged samples (AB, TN, RES and PR) were characterised by the following attributes: 'Clear', 'Reddish colour', 'Fruit jam aroma' 'Spice aroma', 'Alcoholic odour', 'Sour' and 'Astringent'.

Correlation between sensory and physicochemical variables

Pearson correlation coefficients (r) calculated between sensory and classic oenological, spectrophotometric and colorimetric variables are presented in Tables 5, 6 and 7, respectively. All sensory data were subjected to correlation analysis. The analysis was performed not to distinguish the samples but to investigate the effect

Table 4 Frequency[1] and pairwise comparisons[2] for sensory terms which were significant for CATA questions with semi-trained assessors ($n = 30$)

Attributes	Simples								
	CS	CS/SY	SY	TP	AB	TN	RES	PR	Citation frequency (%)[4]
Clear	26^{ab}	23^{ab}	23^{ab}	28^{a}	24^{ab}	22^{ab}	20^{ab}	16^{b}	75.19
Purplish colour	2^{ab}	4^{ab}	2^{ab}	1^{ab}	0^{b}	2^{ab}	2^{ab}	8^{a}	8.89
Reddish colour	21^{abc}	15^{bc}	22^{ab}	20^{abc}	28^{a}	24^{ab}	25^{ab}	10^{c}	68.89
Flower aroma	9^{b}	15^{ab}	7^{b}	10^{ab}	6^{b}	4^{b}	8^{b}	21^{a}	31.45
Fruit jam aroma	9^{ab}	11^{ab}	13^{ab}	17^{a}	20^{a}	4^{b}	10^{ab}	13^{ab}	40.74
Spice aroma	14^{ab}	8^{ab}	12^{ab}	6^{ab}	4^{b}	11^{ab}	10^{ab}	17^{a}	34.07
Smoked aroma	9^{ab}	4^{ab}	2^{b}	2^{b}	6^{ab}	5^{ab}	2^{b}	13^{a}	19.26
Alcoholic odour	10^{b}	12^{ab}	23^{a}	11^{ab}	18^{ab}	17^{ab}	16^{ab}	10^{b}	49.63
Sweetish	9^{ab}	8^{ab}	3^{b}	10^{ab}	14^{a}	8^{ab}	3^{b}	12^{ab}	26.30
Sour	15^{abc}	26^{a}	20^{a}	7^{bc}	5^{bc}	15^{abc}	17^{ab}	3^{c}	41.85
Astringent	13^{abc}	23^{a}	23^{a}	9^{bc}	6^{c}	15^{abc}	20^{ab}	11^{abc}	50.00
Dried fruit flavour	10^{ab}	7^{ab}	11^{a}	3^{ab}	5^{ab}	2^{ab}	1^{b}	4^{ab}	17.41

[1]Frequency range from 0 to 30.
[2]Within an attribute, different letters denote significant differences among the samples ($P \leq 0.05$) according to Cochran's *Q* test.
[3]For samples: CS, Cabernet Sauvignon; CS/SY, Cabernet Sauvignon/Syrah; SY, Syrah; TP, Tempranillo; AB, Alicante Bouschet; TN, Touriga Nacional; RES, Cabernet Sauvignon/Syrah/Alicante Bouschet and PR, Cabernet Sauvignon/Syrah/Alicante Bouschet/Touriga Nacional/Aragonês.
[4]Calculated according to Alexi *et al.* (2018).

of physicochemical characteristics on the perception of the sensory attributes of wines. Additionally, the synergistic correlation among various parameters was considered.

In total, 108 significant correlations were obtained between physicochemical and sensory variables. The highest number of significant positive and negative correlations was observed among the following sensory attributes (11 correlation each): 'Clear', 'Bitter' and 'Dried fruit flavour'. The strongest correlations were observed between the following attribute pairs: 'Clear' and 'Titratable acidity' (−0.849); 'Clear' and 'Colour intensity' (−0.848); 'Clear' and 'a^*' (0.881); 'Reddish colour' and '%Blue' (−0.842); 'Flower aroma' and '% Blue' (0.876); and 'Pungent flavour' and '%Blue' (−0.806).

In contrast, the lowest number (approximately 19% of the possible correlations) of correlations was observed for olfactory attributes. Interestingly, no correlations were observed between the following attribute pairs: 'Vinegary odour' and 'pH', 'Titratable acidity' or 'Volatile acidity'; 'Sour' and 'Titratable acidity' or 'Volatile Acidity'; 'Alcoholic flavour' and 'Alcohol content'; and 'Bitter' and 'Total polyphenols'.

PLS1 regression (Fig. 1) was applied to corroborate the correlations and generate a Products × Sensory × Physicochemical map. The first PLS components accounted for 61% of the variance in the experimental data, and the plot t1 × t2 was chosen for improved discrimination of the two groups of samples (young and aged wines). The first PLS component could distinguish samples and correlated characteristics according to the type of maturation of the beverage. The young wine samples (TP, SY, CS/SY and CS) were characterised by positive t1 values with the sensory attributes 'Clear', 'Sour', 'Full-bodied', 'Dried fruit flavour' and 'Fruit jam flavour', as well as with the physicochemical variables 'C^*', 'a^*', 'h^*', 'pH', '% Yellow', 'Tone' and 'b^*'. The aged wines (TN, RES, AB and PR) were characterised by negative t1 values with the sensory attributes 'Bitter', 'Spice aroma', 'Smoked aroma' and 'Fruit jam flavour', as well as with the physicochemical variables '%Red', 'L^*', 'Total polyphenols', 'Titratable acidity', 'Colour intensity' and 'Alcoholic content'. The t2 axis complemented the characterisation of samples and contributed to the correlation between attributes related to the colour of the products. A correlation between 'Anthocyanins' and 'Reddish colour' was observed for the samples TN, RES, AB, TP and SY. Similarly, a correlation between '%Blue' and 'Purplish colour' was observed, especially for the PR sample. These findings corroborate the data with the highest impacts reported in Tables 3 and 4, as well as the effectiveness of the correlations obtained using the Pearson method.

Discussion

In addition to sensory characterisation and assessment of the effect of physicochemical composition on sensory perception, the discussion will focus on the correlations and the potential errors in the perception of sensory attributes.

Table 5 Pearson correlation coefficient[1] (r) calculated between sensory and classic oenological variables in tropical red wines from São Francisco Valley

	Classic enological variables			
Sensory variables	pH	Titratable acidity[2]	Volatile acidity[3]	Alcohol content[4]
Purplish colour	−0.216	**0.506***	−0.177	0.135
Reddish colour	−0.146	−0.121	0.244	−0.057
Clear	**0.665*****	**−0.849*****	−0.061	−0.168
Fresh fruit aroma	−0.069	−0.139	**0.776*****	**0.545****
Fruit jam aroma	0.101	−0.371	−0.129	0.092
Dried fruit aroma	0.255	0.049	−0.338	−0.347
Spice aroma	−0.095	**0.618*****	−0.235	−0.177
Vegetal aroma	−0.053	−0.141	**−0.483***	0.067
Flower aroma	−0.025	0.158	−0.323	0.162
Smoked aroma	−0.370	**0.483***	−0.370	**0.431***
Vinegary odour	−0.057	−0.098	0.328	−0.121
Alcoholic odour	−0.047	0.115	0.231	**−0.473***
Sweetish	−0.269	−0.047	−0.079	**0.754*****
Sour	**0.439***	−0.331	−0.272	**−0.666*****
Bitter	**−0.559****	**0.515****	0.190	−0.041
Astringent	0.319	−0.053	−0.172	**−0.740*****
Alcoholic flavour	0.192	−0.168	−0.228	−0.198
Fresh fruit flavour	0.112	−0.184	**0.544****	**0.520****
Fruit jam flavour	−0.188	**0.608****	0.145	0.075
Dried fruit flavour	**0.659*****	−0.397	**−0.752*****	**−0.724*****
Pungent flavour	−0.070	0.176	0.058	**−0.444***
Woody flavour	0.192	0.282	**−0.567****	**−0.727*****
Full-bodied	0.217	**−0.551****	−0.385	**0.422***
Persistent flavour	0.235	−0.013	**−0.658*****	**−0.537****

[1]Significant correlations are marked in bold (*$P \leq 0.05$, *** $P \leq 0.01$ and ***$P \leq 0.001$).
[2]mEq L^{-1} of tartaric acid.
[3]mEq L^{-1} of acetic acid.
[4]%v/v 20°C.

The first objective of the study was to evaluate the sensory perception of tropical red wine samples by semi-trained panellists. A satisfactory characterisation was achieved, and the samples were distinguished with 50% of the available attributes. Red wine is associated with a low level of difference in the sensory profile between the samples and a high degree of complexity. Similar results were obtained by Ares *et al.* (2015) who did a comparative analysis of the sensory description of white wines by trained panellists and consumers. Additionally, the results of this study were consistent with those of Alexi *et al.* (2018) who achieved approximately 50% reduction in the panel size through short-term training.

The isolated perception and distinction between the samples based on the attributes 'Sour' and 'Astringent' (Table 4) are important factors for the sensorial characterisation of wines. According to Sáenz-Navajas *et al.* (2020), oral sensations, such as 'astringency' and 'body', are generally the least understood attributes and tend to be associated with limited quantity in complex systems, including red wines.

The high citation frequency of the terms related to visual attributes, which were the most cited in this study, indicated that the assessors could easily identify this type of stimulus. Wang & Spence (2019) reported that a correct evaluation and the preliminary understanding of wine colour can be used to reduce the cognitive load to classify the wines. This is because there are several correlations between the colour of wines and related aromas and flavours that are stored in the semantic memory even in occasional wine consumers (Heatherly *et al.*, 2019).

However, there may be a lack of understanding of the terms 'Clear' and 'Purplish colour', especially for the sample PR, among the panellists in this study. The physicochemical variable '%Blue' (Table 3), which indicates a high bluish or purplish tone, had the highest impact on the sample PR. However, the low-citation frequency of the term 'Clear' may represent the need of the evaluators to indicate a high 'colour intensity', sensory attribute which was not available on the CATA questionnaire. This 'attribute dumping' (Lawless & Heymann, 2010) is corroborated by a marked impact of the physicochemical variable 'Colour intensity' (Table 3) in the sample.

The analysis of the impact of physicochemical variables and correlation with sensory perceptions revealed that the highest number of correlations was obtained for the visual attributes 'Clear', 'Purplish colour' and 'Reddish colour'. As the term 'Clear' may have been used to replace the terms 'Colour intensity' or 'Colour vivacity', a significant positive correlation was obtained for the physicochemical variable 'pH' (0.665***), and a significant negative correlation was obtained for the variables 'Titratable acidity' (−0.849***) and 'Colour intensity' (−0.848***). This can be directly attributed to the content of phenolic compounds, such as anthocyanins, in wines. Phenolic compounds provide a red-violet colour to wines under

Table 6 Pearson correlation coefficient[1] (*r*) calculated between sensory and spectrophotometric variables in tropical red wines from São Francisco Valley

	Spectrophotometric variables						
Sensory variables	**Total polyphenols[2]**	**Anthocyanins[3]**	**Colour intensity**	**Tone**	**%Yellow**	**%Red**	**%Blue**
Purplish colour	−0.032	**−0.442***	**0.565****	−0.202	−0.276	0.101	**0.684*****
Reddish colour	0.302	**0.666*****	−0.222	−0.153	−0.065	0.268	**−0.842*****
Clear	−0.309	−0.118	**−0.848*****	**0.720*****	**0.754*****	**−0.662*****	−0.273
Fresh fruit aroma	0.297	0.402	−0.052	−0.021	0.002	0.058	−0.247
Fruit Jam aroma	0.145	0.001	−0.103	0.168	0.139	−0.208	0.299
Dried fruit aroma	**−0.407***	−0.320	−0.181	0.139	0.151	−0.129	−0.071
Spice aroma	0.161	**−0.559****	0.388	0.030	0.014	−0.048	0.142
Vegetal aroma	−0.295	−0.102	−0.037	0.112	0.104	−0.106	0.020
Flower aroma	−0.206	**−0.543****	0.357	0.023	−0.070	−0.146	**0.876*****
Smoked aroma	**0.405***	−0.331	**0.601****	−0.076	−0.108	0.036	0.282
Vinegary odour	−0.011	**0.595****	−0.120	−0.393	−0.361	**0.410***	−0.248
Alcoholic odour	0.195	**0.457***	−0.116	−0.305	−0.246	0.362	**−0.511***
Sweetish	0.377	0.051	0.316	−0.011	−0.041	−0.025	0.264
Sour	**−0.782*****	−0.064	**−0.538****	0.107	0.122	−0.095	−0.095
Bitter	0.105	**0.463***	**0.467***	**−0.680*****	**−0.674*****	**0.682*****	−0.123
Astringent	**−0.655*****	−0.131	−0.309	−0.042	−0.042	0.030	0.043
Alcoholic flavour	−0.333	0.076	−0.330	0.070	0.116	−0.016	−0.396
Fresh fruit flavour	0.113	0.028	−0.133	0.253	0.262	−0.224	−0.119
Fruit jam flavour	0.281	**−0.476***	**0.545****	−0.070	−0.124	0.004	**0.474***
Dried fruit flavour	−0.346	**−0.612*****	**−0.577****	**0.630*****	**0.641*****	**−0.621*****	0.005
Pungent flavour	**0.406***	0.317	−0.131	−0.080	0.008	0.189	**−0.806*****
Woody flavour	−0.120	**−0.541****	−0.003	0.148	0.145	−0.159	0.074
Full-bodied	−0.201	−0.254	−0.178	0.395	0.347	**−0.450***	**0.469***
Persistent flavour	**−0.569****	−0.336	−0.192	0.093	0.093	−0.100	0.040

[1]Significant correlations are marked in bold (*$P \leq 0.05$, *** $P \leq 0.01$ and ***$P \leq 0.001$).
[2]mg L^{-1} of gallic acid equivalents.
[3]mg L^{-1} of malvidin 3-glycoside.

acidic conditions and directly affect the colour intensity (Nel, 2018). A strong positive correlation was also obtained with the attributes ‘Tone’ (0.720***) and ‘% Yellow’ (0.754***), which indicated a high sensory perception of the attribute ‘Clear’ in samples with yellowish tones or low levels of anthocyanins.

Among the visual attributes, a significant correlation between ‘Purplish colour’ and ‘%Blue’ (0.684***), as well as between ‘Reddish colour’ and ‘Anthocyanins’ (0.666***), indicated that these physicochemical features impacted the sensory characteristics and consequently were correctly perceived by consumers who underwent short-term training. According to Valentin *et al.* (2016), Spence (2018), and König & Renner (2018), the colour of a drink represents an important predictor of quality, which influences both the choice and the consumption quantity by consumers. Valentin *et al.* (2016) also highlighted the positive correlation between ‘global acceptance’, ‘appearance acceptance’ and physicochemical measures, such as ‘colour density’ and ‘total anthocyanin concentration’, in the sensory evaluation of red wines by consumers.

The least number of correlations was observed for the olfactory attributes. However, various significant correlations were observed, such as between ‘Fresh fruit aroma’ and ‘Volatile acidity’ (0.776***). Leoncini *et al.* (2018) indicated that wines with high residual sugar content, such as the wines examined in this study, have a high potential to generate acetic acid, which may lead to a perception of vinegar-like odour. However, the evaluators possibly related this acetic perception to the aroma of fresh fruits, such as red and blackberries, which exhibit acidic odour. A significant negative correlation was observed between ‘Fruit jam aroma’ and the colorimetric variable ‘L^*’ (−0.652***), which indicates that samples that exhibited decreased luminosity or an enhanced colour intensity, provided an increasingly perception of fruit jam aroma, which is typical of young or matured red wines. Similar results have been reported by Piqueras-Fiszman & Spence (2015), who reported that the extrinsic characteristics, such as colour tone of products, can lead to the creation of an expectation and the consequent effective perception of some aromas. In

Table 7 Pearson correlation coefficient[1] (r) calculated between sensory and colorimetric variables in tropical red wines from São Francisco Valley

Sensory variables	Colorimetric variables				
	L^*	a^*	b^*	C^*	h^* (°)
Purplish colour	0.364	**−0.486***	0.094	**−0.700*****	−0.260
Reddish colour	−0.033	0.082	**−0.455***	**0.534****	−0.153
Clear	**−0.702*****	**0.881*****	**0.468***	**0.675*****	**0.759*****
Fresh fruit aroma	0.096	0.356	0.032	**0.511***	0.230
Fruit Jam aroma	**−0.652*****	0.363	**0.565****	−0.128	**0.480***
Dried fruit aroma	0.182	−0.043	−0.102	0.095	−0.067
Spice aroma	0.182	−0.043	−0.102	0.095	−0.067
Vegetal aroma	−0.115	−0.113	−0.092	−0.149	−0.109
Flower aroma	−0.020	−0.185	**0.428***	**−0.671*****	0.077
Smoked aroma	0.189	**−0.424***	0.131	**−0.631*****	−0.203
Vinegary odour	−0.009	0.157	−0.161	**0.405***	0.027
Alcoholic odour	0.102	−0.095	**−0.408***	0.281	−0.242
Sweetish	−0.260	0.152	**0.464***	−0.205	0.304
Sour	−0.078	0.179	−0.156	0.350	0.046
Bitter	**0.562****	**−0.708*****	**−0.744*****	−0.265	**−0.777*****
Astringent	0.133	−0.084	−0.259	0.105	−0.166
Alcoholic flavour	0.030	0.163	−0.170	**0.431***	0.031
Fresh fruit flavour	0.078	0.404	0.178	**0.439***	0.326
Fruit jam flavour	**0.466***	**−0.511***	−0.008	**−0.641*****	−0.327
Dried fruit flavour	**−0.588****	0.376	**0.452***	0.036	**0.444***
Pungent flavour	0.112	−0.184	**−0.516****	0.251	−0.346
Woody flavour	0.067	−0.368	−0.100	**−0.420***	−0.270
Full-bodied	**−0.677*****	**0.547****	**0.780*****	−0.055	**0.694*****
Persistent flavour	0.020	−0.151	−0.124	−0.100	−0.143

[1]Significant correlations are marked in bold (*$P \le 0.05$, *** $P \le 0.01$ and ***$P \le 0.001$).

this study, this association may have occurred due to the similarity of colours between wine and red or blackberry jams.

The tertiary aromas, which are generated during the storage period in oak barrels and result in the loss of freshness and the generation of intense aromas, such as toasted and woody aromas, affect the perception of aged wines (Le Menn *et al.*, 2019). The correlation between 'Smoked aroma' and 'Colour intensity' (0.601**) demonstrated that the assessors tend to have a high perception of this class of aromas in aged wines, which exhibited a high colour intensity (cf. Table 3).

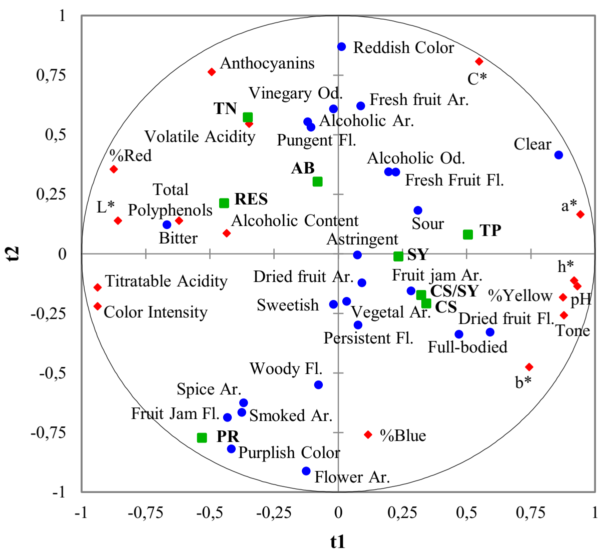

Figure 1 Partial least squares (PLS1) regression plot illustrating wine samples (■), physicochemical attributes (◆) and sensory variables (●). Abbreviations: AB, Alicante Bouschet; Ar, aroma; CS, Cabernet Sauvignon; CS/SY, Cabernet Sauvignon/Syrah; Fl, flavour; Od, odour; PR, Cabernet Sauvignon/Syrah/Alicante Bouschet/Touriga Nacional/Aragonês; RC, Ruby Cabernet; RES, Cabernet Sauvignon/Syrah/Alicante Bouschet; SY, Syrah; TP, Tempranillo; TN, Touriga Nacional.

The sensory attribute 'Alcoholic odour' can be interpreted as a defect in wine depending on the intensity. In this study, the 'Alcoholic odour' was weakly and negatively correlated with 'Alcohol content' (−0.473*). This demonstrated that the variation in the alcohol content of wines was not sufficient to increase the perception of the 'Alcoholic odour', as well as that of the 'Alcoholic flavour', which exhibited a non-significant correlation. According to Cretin *et al.* (2018), the presence of ethanol in red wines can have a multisensory role and affects both olfactory and gustatory profiles. Therefore, the effective perception of ethanol as a defect in the wine must occur if the ethanol concentrations are high or due to the presence of other physicochemical factors.

Among the taste sensory attributes, the term 'Sweetish' was positively correlated with 'Alcohol content' (0.754***), which indicated that alcoholic wines provide a high sweet perception to assessors. According to Brazilian legislation (BRASIL, 2014), the wines examined in this study are classified as 'dry' with a glucose content of $\leq$4 g L^{-1}. This sensory perception may be related to an enhanced intensity of flavours that are typical of aged wines. Similarly, the physicochemical variable 'Alcohol content' had a marked impact in this class of wines and was positively correlated with 'Full-bodied' (0.422*).

The perception of the taste attribute 'Sour' varied among different samples. The low variation in 'pH' values (Table 3) combined with the positive correlation between these attributes (0.439*) and the lack of direct interaction between the sensory attribute 'Sour' and the variables 'Titratable acidity' and 'Volatile acidity' indicated that these physicochemical variables are unlikely to interfere in isolation in the perception of wine acidity at the evaluated levels. Further, the interactions of intrinsic and extrinsic factors in the product are predominant in the perception of sensory characteristics of wines (Heatherly *et al*., 2019).

The positive correlation between 'Bitter' and 'Anthocyanins' (0.463*) indicated that bitter perception is high in aged wines, which are most impacted by this physicochemical variable (Nel, 2018). In this study, these data are corroborated by the positive correlation between 'Colour intensity' (0.467*) and '% Red' (0.682***). In contrast, the negative correlation between 'Astringent' and 'Total polyphenols' (−0.655***) and the lack of correlation with 'Anthocyanins' indicate that these factors alone may not trigger the perception of astringency for semi-trained panellists. Similarly, Canon *et al*. (2018) reported that in addition to the interaction of oral components (saliva and mucosa) with the phenolic compounds, the sensation of astringency can be influenced by cognitive processing through the interaction with flavours and aromas.

Among the fruity flavours, the 'Dried fruit flavour' attribute was associated with the highest number of correlations. This attribute was negatively correlated with 'Alcohol content' (−0.724***), 'Anthocyanins' (−0.612***) and positively correlated with 'Tone' (0.630***) and '%Yellow' (0.641***). This indicates that young wines, which were the most impacted by these correlations, provided an enhanced perception of this class of flavours. Additionally, these correlations are related to a small amount of sensory interference in the sample, such as ethanol (Cretin *et al*., 2018).

All correlations obtained with the Pearson method and discussed in this section were confirmed using PLS analysis (Fig. 1). The PLS analysis enables the increased prediction of the correlations. The plots reveal a correlation between sensory and physicochemical data. However, there is an increased dispersion of data. This is because data generated in assessments by semi-trained consumers vary markedly from those generated in assessments by trained or expert assessors.

These findings indicated that wine producers must be advised on the importance of correlating chemical and sensory data to determine the effect of chemical attributes on the sensory perception of a product with a high degree of complexity. This evaluation enables the identification of critical points in the composition and the introduction of potential adjustments during the winemaking process, which will lead to a product with increased acceptance in the consumer market.

Conclusion

This study enabled a comprehensive understanding of the sensory perception of consumers who underwent short-term training with physical references. This enabled the visualisation of the correlations with physicochemical attributes and the impact of these variables on the sensory evaluation of tropical red wines.

The sensory evaluation of red wine, which is a complex system, is dependent on its chemical constituents, as well as on the habits and culture of assessors. The sensory panel comprised members who were trained; however, these members still responding as consumers, in a simple and sometimes limited language. Hence, there is a need to accurately interpret the data to understand the public perception of the product.

The results of this study indicate that panellists who undergo short-term training can sensorially perceive the influence of physicochemical variables on wines. The correlations obtained from the analysis can aid in the identification of production adjustments and understanding the consumer perception of a complex product.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES) – Finance Code 001. The authors are thankful to the wineries of São Francisco Valley for providing the samples and the staff of the Gastronomy and Culinary Arts Laboratory (Universidade Federal Rural de Pernambuco) for help with the pilot work and data collection.

Ethical guidelines

This research was approved by the Brazilian Research Ethics Committee (CONEP/UPE) (registration number: 89884818.5.0000.5207).

Conflict of interest

All authors declare no conflict of interest.

Author contribution

Caio Verissimo: Conceptualization (equal); Data curation (lead); Methodology (equal); Validation (lead); Writing-original draft (lead). **Rafael Lopes Alcântara:** Formal analysis (equal); Validation (equal). **Luciana Leite de Andrade Lima:** Conceptualization (equal); Funding acquisition (equal); Methodology (equal); Writing-review & editing (equal). **Giuliano Elias Pereira:** Resources (lead); Supervision (equal). **Maria Inês Sucupira Maciel:** Methodology (equal); Supervision (equal); Writing-review & editing (lead).

Peer review

The peer review history for this article is available at https://publons.com/publon/10.1111/ijfs.14987.

Data availability statement

Research data are not shared.

References

Alexi, N., Nanou, E., Lazo, O., Guerrero, L., Grigorakis, K. & Byrne, D.V. (2018). Check-All-That-Apply (CATA) with semi-trained assessors: Sensory profiles closer to descriptive analysis or consumer elicited data? *Food Quality and Preference*, **64**, 11–20.

Almeida, C.M.S., Almeida, A.C., Godoy, M.L.D.P. & Saint'Pierre, T.D. & Godoy, J.M. (2016). Differentiation among Brazilian wine regions based on lead isotopic data. *Journal of the Brazilian Chemical Society*, **27**, 1026–1031.

Ares, G. (2015). Methodological challenges in sensory characterization. *Current Opinion in Food Science*, **3**, 1–5.

Ares, G., Antúnez, L., Bruzzone, F. *et al.* (2015). Comparison of sensory product profiles generated by trained assessors and consumers using CATA questions: Four case studies with complex and/or similar samples. *Food Quality and Preference*, **45**, 75–86.

Ares, G. & Varela, P. (2017). Trained vs. consumer panels for analytical testing: Fueling a long lasting debate in the field. *Food Quality and Preference*, **61**, 79–86.

BRASIL. (2014). *Decreto n. 8198, de 21 de fevereiro de 2014. Regulamenta a Lei n. 7.678, de 8 de novembro de 1988, que dispõe sobre a produção, circulação e comercialização do vinho e derivados da uva e do vinho*. [Internet document] URL http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2014/decreto/D8198.htm. Accessed 06/04/2020.

Caillé, S., Samson, A., Wirth, J., Diéval, J.B., Vidal, S. & Cheynier, V. (2010). Sensory characteristics changes of red Grenache wines submitted to different oxygen exposures pre and post bottling. *Analytica Chimica Acta*, **660**, 35–42.

Canon, F., Neiers, F. & Guichard, E. (2018). Saliva and flavor perception: perspectives. *Journal of Agricultural and Food Chemistry*, **66**, 7873–7879.

Cretin, B.N., Dubourdieu, D. & Marchal, A. (2018). Influence of ethanol content on sweetness and bitterness perception in dry wines. *LWT - Food Science and Technology*, **87**, 61–66.

Damasio, M.H. & Costell, E. (1991). Análisis Sensorial Descriptivo: Generación de Descriptores y Selección de Catadores. *Revista de Agroquímica y Tecnología de Alimentos*, **32**, 165–177.

Danner, L., Johnson, T.E., Ristic, R., Meiselman, H.L. & Bastian, S.E.P. (2017). "I like the sound of that!" Wine descriptions influence consumers' expectations, liking, emotions and willingness to pay for Australian white wines. *Food Research International*, **99**, 263–274.

Fiszman, S., Salgado, N., Orrego, C.E. & Ares, G. (2015). Comparison of methods for generating sensory vocabulary with consumers: A case study with two types of satiating foods. *Food Quality and Preference*, **44**, 111–118.

Giacalone, D. & Hedelund, P.I. (2016). Rate-all-that-apply (RATA) with semi-trained assessors: An investigation of the method reproducibility at assessor-, attribute- and panel-level. *Food Quality and Preference*, **51**, 65–71.

Giovanelli, G. & Buratti, S. (2009). Comparison of polyphenolic composition and antioxidant activity of wild Italian blueberries and some cultivated varieties. *Food Chemistry*, **112**, 903–908.

Harbertson, J.F. & Spayd, S. (2006). Measuring phenolics in the winery. *American Journal of Enology and Viticulture*, **3**, 280–288.

Heatherly, M., Dein, M., Munafo, J.P. & Luckett, C.R. (2019). Crossmodal correspondence between color, shapes, and wine odors. *Food Quality and Preference*, **71**, 395–405.

ISO. (1977). *Sensory analysis: Apparatus – Wine Tasting Glass. ISO Standard 3591:1977*. Geneva, Switzerland: International Organization for Standardization.

ISO. (2007). *Sensory analysis: General guidance for the design of test rooms. ISO Standard 8589:2007*. Geneva, Switzerland: International Organization for Standardization.

ISO. (2012). *Sensory analysis: General guidance for the selection, training, and monitoring of selected assessors and expert sensory assessors. ISO Standard 8586:2012*. Geneva, Switzerland: International Organization for Standardization.

König, L.M. & Renner, B. (2018). Colourful = healthy? Exploring meal colour variety and its relation to food consumption. *Food Quality and Preference*, **64**, 66–71.

Kustos, M., Goodman, S., Jeffery, D.W. & Bastian, S.E.P. (2019). Using consumer opinion to define New World fine wine: Insights for hospitality. *International Journal of Hospitality Management*, **83**, 180–189.

Lawless, H.T. & Heymann, H. (2010). *Sensory Evaluation of Foods: Principles and Practices*, 2nd ed. New York: Chapman & Hall.

Lencioni, L., Taccari, M., Ciani, M. & Domizio, P. (2018). Zygotorulaspora florentina and Starmerella bacillaris in multistarter fermentation with *Saccharomyces cerevisiae* to reduce volatile acidity of high sugar musts. *Australian Journal of Grape and Wine Research*, **24**, 368–372.

Lima, M.S., Leite, A.P.S., Sampaio, Y.C., Vianello, F. & Lima, G.P.P. (2015). Influences of the harvest season on analytical characteristics of syrah grapes and wines produced in the northeast region of Brazil. *International Journal of Agriculture and Forestry*, **5**, 151–159.

Manoukian, E.B. (1986). *Mathematical nonparametric statistics*. New York: CRC Press.

Meilgaard, M.C., Civille, G.V. & Carr, B.T. (2015). *Sensory Evaluation Techniques*, 5th ed. Florida: CRC Press.

Menn, N.Le, Leeuwen, C.Van, Picard, M., Riquier, L., Revel, G.De & Marchand, S. (2019). Effect of vine water and nitrogen status, as well as temperature, on some aroma compounds of aged red bordeaux wines. *Journal of Agricultural and Food Chemistry*, **67**, 7098–7109.

Meyners, M., Castura, J.C. & Carr, B.T. (2013). Existing and new approaches for the analysis of CATA data. *Food Quality and Preference*, **30**, 309–319.

Monagas, M., Martín-Álvarez, P.J., Gómez-Cordovés, C. & Bartolomé, B. (2006). Time course of the colour of young red wines from *Vitis vinifera* L. during ageing in bottle. *International Journal of Food Science and Technology*, **41**, 892–899.

Nel, A.P. (2018). Tannins and anthocyanins: From their origin to wine analysis - A review. *South African Journal of Enology and Viticulture*, **39**, 1–20.

OIV. (2014). *Recueil des méthodes internationales d'analyse des vins et des mouts*. Paris: Organisation Internationale de la Vigne et du Vin.

OIV. (2019). *Compendium of international methods of wine and must analysis* [Internet document] URL http://www.oiv.int/public/medias/6620/compendium-2019-en-vol2.pdf. Accessed 10/11/2019.

Oliveira, J.B., Egipto, R., Laureano, O., de Castro, R., Pereira, G.E. & Ricardo-da-Silva, J.M. (2019a). Chemical composition and sensory profile of Syrah wines from semiarid tropical Brazil – Rootstock and harvest season effects. *Lwt*, **114**, 1–9.

Oliveira, J.B., Egipto, R., Laureano, O., de Castro, R., Pereira, G.E. & Ricardo-da-Silva, J.M. (2019b). Chemical characteristics of grapes cv. Syrah (*Vitis vinifera* L.) grown in the tropical semiarid region of Brazil (Pernambuco state): influence of rootstock and harvest season. *Journal of the Science of Food and Agriculture*, **99**, 5050–5063.

Padilha, C.V. da .S., Biasoto, A.C.T., Corrêa, L.C., Lima, M. dos S. & Pereira, G.E. (2017). Phenolic compounds profile and antioxidant activity of commercial tropical red wines (*Vitis vinifera* L.) from São Francisco Valley, Brazil. *Journal of Food Biochemistry*, **41**, 1–9.

Piqueras-Fiszman, B. & Spence, C. (2015). Sensory expectations based on product-extrinsic food cues: An interdisciplinary review of the empirical evidence and theoretical accounts. *Food Quality and Preference*, **40**, 165–179.

Sáenz-Navajas, M.P., Ferrero-del-Teso, S., Jeffery, D.W., Ferreira, V. & Fernández-Zurbano, P. (2020). Effect of aroma perception on taste and mouthfeel dimensions of red wines: Correlation of sensory and chemical measurements. *Food Research International*, **131**, 1–9.

Spence, C. (2018). What is so unappealing about blue food and drink? *International Journal of Gastronomy and Food Science*, **14**, 1–8.

Spence, C. (2019). On the relationship (s) between color and taste/flavor. *Experimental Psychology*, **66**, 99–111.

Valentin, D., Parr, W.V., Peyron, D., Grose, C. & Ballester, J. (2016). Colour as a driver of Pinot noir wine quality judgments: An investigation involving French and New Zealand wine professionals. *Food Quality and Preference*, **48**, 251–261.

Wang, Q.J. & Spence, C. (2019). Drinking through rosé-coloured glasses: Influence of wine colour on the perception of aroma and flavour in wine experts and novices. *Food Research International*, **126**, 1–11.

Xu, X.Q., Cheng, G., Duan, L.L. *et al.* (2015). Effect of training systems on fatty acids and their derived volatiles in Cabernet Sauvignon grapes and wines of the north foot of Mt. Tianshan. *Food Chemistry*, **181**, 198–206.