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COMPREHENSIVE REVIEW

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Mouthfeel subqualities in wines: A current insight on sensory descriptors and physical–chemical markers

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Abstract

Astringency and more generally mouthfeel perception are relevant to the overall quality of the wine. However, their origin and description are still uncertain and are constantly updating. Additionally, the terminology related to mouthfeel properties is expansive and extremely diversified, characterized by common traditional terms as well as novel recently adopted descriptors. In this context, this review evaluated the mention frequency of astringent subqualities and other mouthfeel attributes in the scientific literature of the last decades (2000–August 17, 2022). One hundred and twenty-five scientific publications have been selected and classified based on wine typology, aim, and instrumental–sensorial methods adopted. *Dry* resulted as the most frequent astringent subquality (10% for red wines, 8.6% for white wines), while *body*—and related terms—is a common mouthfeel sensation for different wine types, although its concept is still vague. Alongside, promising analytical and instrumental techniques investigating and simulating the in-mouth properties are discussed in detail, such as rheology for the viscosity and tribology for the lubrication loss, as well as the different approaches for the quantitative and qualitative evaluation of the interaction between salivary proteins and astringency markers. A focus on the phenolic compounds involved in the tactile perception was conducted, with tannins being the compounds conventionally found responsible for astringency. Nevertheless, other non-tannic polyphenolic classes (i.e., flavonols, phenolic acids, anthocyanins, anthocyanin-derivative pigments) as well as chemical–physical factors and the wine matrix (i.e., polysaccharides, mannoproteins, ethanol, glycerol, and pH) can also contribute to the wine in-mouth sensory profile. An overview of mouthfeel perception, factors involved, and its vocabulary is useful for enologists and consumers.

Maria Alessandra Paissoni and Giulia Motta contributed equally to the study.

KEYWORDS
astringency subqualities, body concept, in-mouth perception, mouthfeel wheel, sensory analysis, tannin–protein interaction, tribology, wine

1 | INTRODUCTION

The wine properties defining mouthfeel are complex, heterogeneous, and often difficult to understand by sensory judges. For this reason, unlike fundamental tastes (i.e., sweetness, acidity, bitterness, saltiness, and umami), the tactile perceptions require a high and diversified number of reference standards and explicative definitions. These properties are drivers of quality, refinement, and typicality of different wine types. Concurrently, the origin of tactile perceptions and the astringent mechanisms are constantly updated. In this context, mouthfeel features, particularly astringency subqualities, are a current topic in the scientific research.

Sensory wheels are a useful tool for the categorization of different sensory terms and for the development of a common language among the wine tasters. Noble and colleagues (1984) were among the first to use them for wine aroma, and subsequently a modified version of the wheel was realized (Noble et al., 1987). Similarly, the mouthfeel wheel was a starting point for the formulation of a shared vocabulary in the scientific research, as well as in the winemaking industry, on mouthfeel characteristics of red wines (Gawel et al., 2000). Over the years, consumers became more demanding, and therefore, a greater comprehension and optimal classification of the different typologies of astringency influencing mouthfeel perception were necessary. Many definitions of mouthfeel have been presented, such as "*the group of sensations characterized by a tactile response in the mouth*" (Pickering & Demiglio, 2008) or, as reported by Gawel et al. (2018), "*mouthfeel encompasses the tactile, chemosensory and taste attributes of perceived viscosity, astringency, hotness and bitterness*." Nevertheless, a shared vocabulary of mouthfeel had not been agreed. In this context, the sensory mouthfeel wheel for red wines proposed by Gawel et al. (2000) was developed (Figure 1). It includes "Feel" and "Astringency" macro groups, alongside "Acidity," and "Flavor" grouping categories. In this graphical representation, the astringent-like descriptors (*Astringency* macro-group) have been classified in seven groupings, while feel sensations (*Feel* macro-group) have been grouped in four categories. Moreover, the descriptors were accompanied by physical standards, when possible, or by conceptual definitions to clarify the perceptible mouthfeel sensations.

Despite astringency being a complex oral perception combined in a large number of subqualities, they were conveniently classified according to Gawel et al. (2000) wheel in the following grouping terms: *particulate*, *surface smoothness*, *complex*, *drying*, *dynamic*, *harsh*, and *unripe* (Figure 1). In detail, *particulate* refers to the "*feelings of particulate matter brushing against the mouth's surfaces*," while *surface smoothness* concerns the "*textures felt on mouth surfaces when they come in contact with each other*." *Complex* is a positive hedonic grouping consisting of a mixture of pleasing astringent sensations; *drying* is the feelings of lack of lubrication or desiccation in mouth and *dynamic* is a sensation involving some form of mouth movement; *harsh* and *unripe* represent two negative hedonic groupings associated with an excessive roughness and with exaggerated green flavors, respectively (Gawel et al., 2000). The *feel* macro-group descriptors are often evaluated together with astringency since they are similarly involved in the tactile perception of the oral cavity. They could be classified into four groupings: *irritation*, *heat*, *texture*, and *weight* (Gawel et al., 2000). Particularly, *irritation* group includes strong and unpleasant sensations, like *spritz*, *prickle*, *tingle*, *pepper*, and *chilli*. Moreover, *heat* category is divided into *warm* and *hot* terms. *Creamy* and *syrup* soft-feel sensations take part of the *texture* grouping. In parallel, the mouthfeel sub-category of *weight* includes *viscous*, *full*, *thin*, and *watery* descriptors (Gawel et al., 2000). Additionally, mouthfeel has been evaluated in several publications in terms of purity, intensity, structure, harmony, persistence, and quality contribution (Duan et al., 2021; Gao et al., 2015; Sáenz-Navajas et al., 2016).

A sensory wheel on white wine's taste and mouthfeel characteristics has also been constructed on the basis of the hierarchical structure of the red wine wheel (Pickering & Demiglio, 2008). Differently from the latter, the white wine descriptors were categorized according to the number of sensory perceptions (i.e., single or multiple sensations) and the persistence over time. In particular, the *discrete* category concerned a clear individual sensation, whereas the *integrated* category gathered more than one sensation. In order to discriminate the perception of sensory stimuli over time (i.e., from ingestion to expectoration), *early* and *finish* categories were introduced. Moreover, no sections have been dedicated to flavor's descriptors, namely retro-nasal odors. Nonetheless, non-taste and texture sensations were still present in the white wine wheel, as in the categories of *pucker*, *mouthwater*, *fullness*, *surface texture*, *irritation*, *mouthcoat, overall drying*, and *length*.

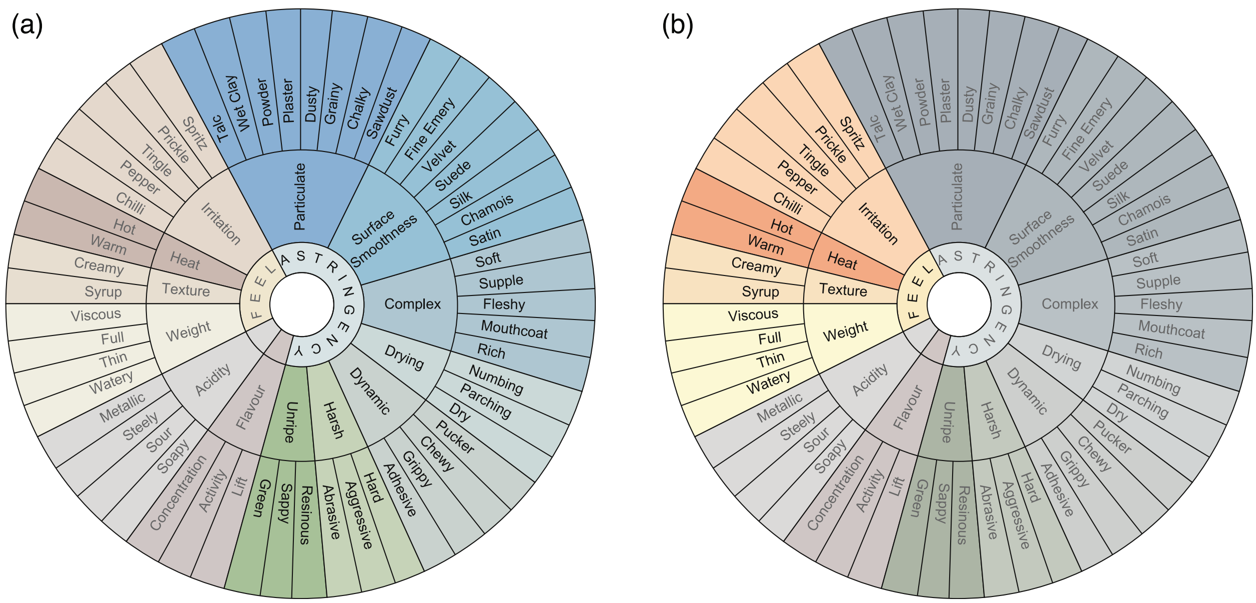

FIGURE 1 The Mouthfeel Wheel for red wine evaluation proposed by Gawel et al. (2000). Reproduced with modifications from Gawel et al. (2000), with permission by John Wiley & Sons, Inc.

Overall, the mouthfeel wheel's lexicon are frequently considered, adapted, and updated according to wine's typology, panel of tasters, and purpose of study in many publications (Harbertson et al., 2009; Oberholster et al., 2009; Piombino et al., 2020; Vidal et al., 2016; Watrelot et al., 2016). Therefore, the mouthfeel wheels remain a still valid approach for the study of wine tactile characteristics.

Alongside the sensory studies on mouthfeel perceptions of wine, the instrumental research has been for long focused on the related chemical compounds. Tannins have been the main and well-studied sources of astringent stimulation, but recently other phenolic classes and physical–chemical factors have shown their contribution on the oral mouthfeel. In this regard, phenolic acids, anthocyanins, flavonols, polysaccharides, and glycerol are only a part of the factors that influence the complex profile of a wine (Gonzalo-Diago et al., 2014; Laguna et al., 2019; Paissoni et al., 2018; Sáenz-Navajas et al., 2010; Sáenz-Navajas et al., 2017; Vidal et al., 2004a; Vidal et al., 2004b). Notably, the evolution of separation, identification, and quantification techniques by liquid chromatography coupled with mass spectrometry helped to achieve improved models relating chemical and sensory data when wines are under evaluation (Gonzalo-Diago et al., 2014; Sáenz-Navajas et al., 2010; Sáenz-Navajas et al., 2017). Additionally, the research of polyphenol–protein interactions by nuclear magnetic resonance (NMR) and the formed aggregates by dynamic light scattering (DLS) and microscopy approaches allowed to get closer to the in-mouth representation when tasting a wine (Brossard et al., 2016, 2021; Charlton et al., 2002; Ferrer-Gallego et al., 2014, 2015a, 2015b, 2017; Laguna et al., 2017; Soares et al., 2012). In this context, the use of tribological approaches is a promising field to mimic the friction caused by an astringent compound (Brossard et al., 2016, 2021; Edmonds et al., 2021; Laguna et al., 2017; Rudge et al., 2021; Wang et al., 2020, 2021; Watrelot et al., 2019). Simultaneously, the perception of the softness and roundness inducted by a viscous (or full-bodied) wine is often connected to its physical viscosity and therefore measurable by means of rheological methodology (Brossard et al., 2020; Danner et al., 2019; Runnebaum et al., 2011; Shehadeh et al., 2019; Yanniotis et al., 2007).

The aim of the present work is to elucidate the use and recent research that has led to update the terminology proposed by Gawel et al. (2000) in the wine scientific literature (period from January 1, 2000 to August 17, 2022). The red wine mouthfeel wheel remains a milestone and an inspiration for subsequent investigations; therefore, the selected literature (125 papers) was divided and grouped based on its terminology. A narrative synthesis of the papers applying the vocabulary proposed for sensory analysis, or investigating it instrumentally, was examined. Moreover, correlation with instrumental parameters (chemically and physically measured) is discussed in depth.

2 | METHODOLOGY

The present review used Scopus database (https://www.scopus.com/) as a research source for scientific publications containing "subquality/sub-quality" and "mouthfeel/mouth-feel" as main keywords. The time limit has been fixed from 2000, the year of the publication of the Gawel's red wine mouthfeel wheel. The following strings were used: Subqualit* AND (grape* OR wine*), Sub-qualit* AND (grape* OR wine*), Mouthfeel AND (grape* OR wine*), and Mouth-feel AND (grape* OR wine*). The resulting total number of papers was 389 (from January 1, 2000 to August 17, 2022). More precisely, 16, 27, 280, and 66 publications have been obtained from each string, respectively. Subsequently, the papers were examined by the authors of this review and selected according to (a) the consistency with the purpose of the research, (b) the explicit mention of one/more terms related to the mouthfeel, *feel*, and/or *astringency* subqualities, (c) the absence of articles in duplicate, and (d) the lack of recent reviews on specific topics. At the end of the screening, the results were merged and discussed. Finally, 125 publications were taken into account for frequency evaluation (criteria b) (Table S1) and for narrative synthesis of the results, whereas others without the specific mention of subqualities were selected for discussion purpose.

The 125 selected papers that mention at least one mouthfeel subquality term were divided on the basis of the aims of study (i.e., instrumental-sensory correlation, winemaking strategy, methodology, characterization, preference, agronomical practices) and further analyzed according to the descriptors used (i.e., *feel*/*astringency* mouthfeel wheel macro-groups) and the sensory methods adopted (e.g., descriptive analysis, sorting task, check-all-that-apply). The lists of *astringency* and *feel* subqualities for red/white/sparkling wines have been copied and their frequency rate studied after lemmatization (Table S2). The website Word Frequency Counter—WriteWords (http://www.writewords.org.uk) was used for frequency evaluation. The red wine mouthfeel wheel (Gawel et al., 2000) was used for categorization as a common denominator among 125 resulting papers.

3 | MAIN AIMS IN THE STUDY OF MOUTHFEEL SUBQUALITIES

The wine properties related to mouthfeel subqualities in the scientific publications have been studied for multiple reasons (Table 1), the most common being the correlation between instrumental techniques and sensory characteristics of wines. This requires a multidisciplinary approach that combines the study of wine chemical components or physical properties using instrumental methods with the in-mouth sensory and tactile properties. This is the most investigated purpose also because many different phenolic compounds contribute to oral-tactile and sensory elicitations. Concurrently, statistical predictive models are often built as good predictors of the oral sensory perception.

Also, the winemaking strategy impact on the mouthfeel has been extensively evaluated, as the influence of the pre-fermentative condition in terms of total soluble solids content (Casassa et al., 2013; Frost et al., 2021), maceration length, and different skin contact techniques (Casassa et al., 2013; Garrido-Bañuelos et al., 2021; González-Lázaro et al., 2019; Sokolowsky et al., 2015), as well as the use of native and commercial yeasts (Fanzone et al., 2020; Pickering & Nikfardjam, 2008). Furthermore, the post-fermentative influence of the tannin and mannoprotein addition (Li et al., 2017; Picariello et al., 2020; Rinaldi & Moio, 2018; Rinaldi et al., 2019; Rinaldi et al., 2021b), the oxygen-controlled exposure during aging (Gambuti et al., 2020a; Rinaldi et al., 2021c), and the combined impact of wine-packaging configurations and storage temperature (Hopfer & Heymann, 2013; Hopfer et al., 2012) were considered.

On the other hand, few scientific articles are aimed at evaluating the sensory or instrumental methodology, to ascertain their validity on mouthfeel evaluation. Among sensory analysis methods, descriptive analysis (DA) (Pickering & Robert, 2006; Pittari et al., 2020; White & Heymann, 2015), check-all-that-apply (CATA) (Vidal et al., 2018), and rate-all-that-apply (RATA) (Rinaldi et al., 2019) were found to be the most common. For the instrumental techniques, the main applications were about tribology, rheology, turbidity, and particle size measurement (Brossard et al., 2020, 2021; Danner et al., 2019; Edmonds et al., 2021; Rudge et al., 2021; Shehadeh et al., 2019; Wang et al., 2020, 2021; Watrelot et al., 2019; Yanniotis et al., 2007).

Oral sensory features have been used for the characterization of autochthonous and international varieties. Both red and white wines were taken into consideration, and the descriptive analysis was the most used sensory method for varietal characterization (Capitello et al., 2016; Carlucci & Monteleone, 2001; Etaio et al., 2008; King et al., 2003; King et al., 2014; Koussissi et al., 2003; Langlois et al., 2010; Mirarefi et al., 2004; Nel et al., 2015; Piombino et al., 2020; Sáenz-Navajas et al., 2016; Schlosser et al., 2005). As well, few papers wanted to understand preference evaluations, which is usually carried out by untrained consumers (Ivanova et al., 2022; Loureiro et al., 2016; Mezei et al., 2021; Niimi et al., 2017; Rinaldi et al., 2021a; Torrico et al., 2020). Only a small number of studies used the sensory for in-mouth properties evaluation of wine derived from grape subjected to different agronomical practices. For instance, the effect of deficit irrigation, leaf removal, and canopy exposure were studied (Duan et al., 2021; Minnaar et al., 2020; Ou et al., 2010).

TABLE 1 Counts of the selected scientific papers grouped by aim of the study (single and grouped into main categories)

Aims	Counts	Counts for the main aims grouped	Range of publication years
Correlation instrumental-sensory methods	34	**35**	**2001–2022**
Winemaking strategy	30	**33**	**2008–2021**
Methodology	20	**22**	**2002–2021**
Characterization	18	**22**	**2001–2021**
Preference	8	**13**	**2015–2022**
Agronomical practices	7	**8**	**2010–2021**
Winemaking strategy/Preference	2		2017
Characterization/Preference	2		2016–2021
Agronomical practices/Preference	1		2015
Methodology/Characterization	1		2003
Methodology/Correlation Instrumental-Sensory methods	1		2019
Winemaking strategy/Characterization	1		2011
Total selected papers	*125*		

TABLE 2 Counts of the most used sensory strategy in *astringency* and *feel* subqualities evaluation

Sensory strategy	Counts	Range of publication years
Descriptive analysis (DA)	82	2001–2022
Check-all-that-apply (CATA), Rate-all-that-apply (RATA)	28	2014–2022
Preference, Quality, Emotion	18	2013–2021
Sorting, Projective mapping (PM)	12	2003–2022
Temporal	9	2013–2019
Discriminative	7	2008–2020
Ultra-flash profiling (UFP)	4	2016–2021
Rate-*K*	3	2020–2022
Focus group, Free choice	2	2022

4 | SENSORY EVALUATION OF WINE MOUTHFEEL PROPERTIES

The main approach for the evaluation of mouthfeel subqualities is undoubtedly through sensory analysis (Table 2): In this sense, DA is by far the most widely adopted technique. This method presents a training phase of the assessors for the identification of attributes, the product familiarization, and the specific vocabulary development, supported by definitions and sensory standards. The training step is essential for the panel standardization and judgment alignment (Lawless & Heymann, 2010). DA is a trusted method, typically adopted for complex foodstuff description, which ensures precise, statistically robust, and high-quality results due to employment of trained assessors, sample replication, and intensity scales (Albert et al., 2011; Campo et al., 2010; Hopfer & Heymann, 2013). The training allows a limited number of assessors (8–20) to obtain discrimination of small differences in complex samples such as wine (Ares et al., 2015; Varela & Ares, 2012). In contrast, the drawbacks are attributable to the consumption of time for the training phase and to the possible loss of information when a relatively small vocabulary is used (Campo et al., 2010; Lawless & Heymann, 2010).

More recently, the so-called rapid sensory methods have been adopted as an alternative or in association with DA (Paissoni et al., 2020; Piombino et al., 2020). Briefly, the rapid sensory methodologies are traditionally divided into three categories: verbal-, similarity-, and reference-based methods (Valentin et al., 2012). Among the first, CATA and RATA are two rapid methods frequently used in mouthfeel characterization of wines. They are based on the sensory panel's ability to express the perception using descriptors—phrases or words—that could be provided by a pre-determined list or by the judges themselves (Valentin et al., 2012). The CATA methodology asks participants to tick as "apply" the perceived descriptors on the vocabulary list, regarding the focal sample (Adams et al., 2007). Hence, the contribution of sensory intensity is not evaluated, and only binary responses (i.e., 1/0 respectively for presence/absence) are collected for each descriptor. For this reason, CATA method could be a suitable technique for non-specific wine description or for products with a wide difference in terms of sensory properties (Ares et al., 2015; Varela & Ares, 2012). Nevertheless, this rapid technique has been frequently used for the evaluation of astringency and tactile subqualities. Its advantage is the possibility to assess the presence or absence of several attributes that may be difficult to be evaluated simultaneously with a scale—mouthfeel subqualities or aroma—in complex products—wine (Campo et al., 2010; Varela & Ares, 2012). For instance, four Italian red wine varieties (Rinaldi & Moio, 2018) and six commercial Uruguayan Tannat wines (Vidal et al., 2018) were characterized by CATA method adopting trained assessors ($n = 13$) and both trained ($n = 9$) and expert ($n = 43$) assessors, respectively. In addition, mouthfeel differences of South African Chenin blanc wines, obtained from different trellis systems, have been identified by two panels of trained ($n = 10$) and experienced ($n = 18$) judges using CATA sensory sessions (Panzeri et al., 2020).

An extension of CATA is represented by RATA method. This verbal-based technique integrates the sensory evaluation by rating the intensity of descriptors on a point line scale (Ares et al., 2014). For the mouthfeel subqualities, a 7-point scale (Mezei et al., 2021; Rinaldi et al., 2021a; Sáenz-Navajas et al., 2017) and a 9-point scale (Gambuti et al., 2020a; Picariello et al., 2020; Rinaldi & Moio, 2018; Rinaldi et al., 2019; Rinaldi et al., 2020a; 2020b) are the most frequently used. In this sense, there is no predetermined number of points to be used, but it is suggested to use the smallest scale as possible to maintain the method rapidity and easiness (Danner et al., 2018). A modification of these methods used in evaluating mouthfeel and taste perceptions in wines by experts is "Rate-*K* attributes," a variant of RATA, applicable also to CATA, as "Pick-*K* attributes" (Ferrero-del-Teso et al., 2020, 2022; Sáenz-Navajas et al., 2020; Valentin et al., 2012). In these variants, only the dominant attributes are selected or rated, highlighting the main characteristics of the product but reducing the complexity of the sensory information (Valentin et al., 2012).

RATA methodology is considered more suitable to overcome the limitation of CATA: with the intensity rating, it is possible to achieve higher statistical power by using parametric statistics, and even if the results are analyzed as binary data, the discriminating attributes were found to increase (Danner et al., 2018; Varela & Ares, 2012). Recently, RATA methodology used by untrained consumers ($n = 71$ and $n = 84$) for evaluating two sets of commercial wines showed a similar sample discrimination compared with the DA results of trained judges ($n = 11$) (Danner et al., 2018). Using RATA, also small differences in astringency subqualities obtained by the application of winemaking techniques, such as the effect of oxygenation with or without oenological tannins addition during ageing in different monovarietal wines, were evidenced by 13 trained assessors (Gambuti *et al.*, 2020; Picariello et al., 2020; Rinaldi et al., 2021c).

Some studies involving mouthfeel properties adopted naïve consumers for CATA and RATA techniques (Mezei et al., 2021; Torrico et al., 2020; Vidal et al., 2015). In this context, the debate for the recruitment between trained assessors, semi-trained, experts, and consumers in analytical tests is still open (Ares & Varela, 2017). For rapid methods, the training phase is not required; consequently, these techniques are faster, intuitive, and cost-effective, and also consumers are suitable in their application (Varela & Ares, 2012). Nevertheless, in many studies concerning the mouthfeel evaluation, the recruited assessors were wine usual consumers or wine professionals subjected to a minimum training even when rapid methods were used (Gambuti et al., 2020a; Picariello et al., 2020; Rinaldi & Moio, 2018; Vidal et al., 2018). This choice denotes the complexity of identifying and recognizing mouthfeel properties in wines, even for judges with a previous sensory or wine experience. For instance, five different types of Sauvignon blanc wines were similarly evaluated by trained panelists ($n = 10$) using DA method and consumers ($n = 134$) adopting a rapid method (in this case CATA questions) (Ares et al., 2015). However, trained judges perceived a greater difference for one wine sample from the rest of the samples, unlike untrained consumers, showing as expected higher discriminative power given by the training. In this study, not only mouthfeel attributes were considered, but the consensus on sample evaluation depended on both the degree of differences among the wines and the nature of the attributes: Complex mouthfeel attributes such as *smooth*, *tingly*, and *viscous* may have had different meaning for consumers (Ares et al., 2015). Therefore, the terminology adopted for wine evaluation by consumers should be easy and similarly understood by them, or an agreement on the definition should be obtained before the assessment. In this regard, Rinaldi and colleagues (2021a) reported that 134 consumers and the 13 trained assessors agreed on Sangiovese wine samples evaluated by CATA and RATA, respectively, but some difficulties for consumers emerged in recognizing complex attributes such as *hard* or the *wood* character. For consumers, the mouthfeel wheel terminology may be too technical and consumers' involvement as well as culture can influence the adopted terminology in describing astringency subqualities (Vidal et al., 2015). For instance, only 17 out of 31 descriptors from the mouthfeel wheel were used by more than 10% of the 125 consumers for describing Tannat astringency (Vidal et al., 2015). Besides the terminology, different assessors have been employed in verbal-based methodology depending on the aim of the study, and adapting the number depending on their experience and tasks, for example, trained (8–20), expert (14–43), or untrained consumers (30–443, average 149) (Table S3).

Even to a lesser extent, other methodologies have been applied in the studies of in-mouth properties. In particular, in order to estimate simultaneously the sensory perceptions—astringency above all—and their length over time, temporal strategies have been developed such as temporal-check-all-that-apply (TCATA) and temporal dominance of sensation (TDS) for evaluating qualitatively subqualities in wines (Frost et al., 2017; Kemp et al., 2019; McMahon et al., 2017a; Poveromo & Hopfer 2019; Vidal et al., 2016). In the former, multiple descriptors can be selected at each moment, whereas for the second only the dominant attribute is highlighted. A modification is progressive profile (PP) that enables to obtain multiple attributes' intensity at once (Kang et al., 2019). The advantage of these methodologies is the ability to decompose during time the different qualitative terms of mouthfeel. For example, Tannat wines with similar astringency intensity were found to have different TDS profile (Vidal et al., 2016), or Shiraz wines produced by different maceration techniques that were not discriminated in overall astringency by RATA (n = 61, untrained) showed different subqualities—*mouthcoat*, *adhesive*, and *graininess*—in the time-dependent evaluation (n = 8, trained). By contrast, only few (6–8) attributes can be evaluated during dynamic methods, assessors must be trained, and replications are required (Kang et al., 2019; Vidal et al., 2016, 2020).

Among the similarity-based methods, sorting and projective mapping (PM) have been applied to identify similarities (and dissimilarities) using sensory and mouthfeel descriptors for phenolic fractions and wine samples (Araujo et al., 2021; Barbe et al., 2021; Ferrero-del-Teso et al., 2020, 2022; Garrido-Bañuelos et al., 2021; Mafata et al., 2020; Piombino et al., 2020; Sáenz-Navajas et al., 2017; Sáenz-Navajas et al., 2020). The PM method takes advantage of a rectangular white paper sheet where samples are placed close/far to each other, based on their affinities/differences (Risvik et al., 1994). In association with PM, ultra-flash profiling (UFP) is frequently used afterward to describe the samples of interest with attributes on a list (Sereni et al., 2016, 2020; Hayward et al., 2020; Moss et al., 2021). Only a few studies used discriminative methods (e.g., Duo-trio tests) to highlight the macro differences between wine fractions and samples (Fanzone et al., 2020; Ferrer-Gallego et al., 2014).

Wine mouthfeel subqualities are important drivers of quality, preference, and emotional responses on consumers' perception, and in this regard, several studies deepened the liking and affective properties with consumers (Coste et al., 2018; King & Heymann, 2014; McMahon et al., 2017b; Mezei et al., 2021; Pagliarini et al., 2013; Torrico et al., 2020; Vidal et al., 2015). Sensory test with regular consumers can be good predictors of a product acceptability by the competitive market, but they require a considerable number of individuals for sensory tests (103–150) (Capitello et al., 2016; Coste et al., 2018; King & Heymann, 2014; Lawless & Heymann, 2010; McMahon et al., 2017b; Mezei et al., 2021; Niimi et al., 2017; Vidal et al., 2015). In order to obtain the liking profiles of wines, structured and unstructured line scales are usually used. A 7-point hedonic scale and a 9-point hedonic scale for preference, as well as a 10-cm unstructured line scale for quality have been extensively adopted (Capitello et al., 2016; McMahon et al., 2017b; Minnaar et al., 2020; Niimi et al., 2017; Pagliarini et al., 2013; Rinaldi et al., 2021a; Sáenz-Navajas et al., 2016). Astringency and its sub-terms related to wine quality were also evaluated by expert judges, such as winemakers (Minnaar et al., 2020; Sáenz-Navajas et al., 2016).

In conclusion, DA remains the most frequently applied method for the evaluation of mouthfeel and astringent-like wine characteristics in the scientific literature, followed by verbal-based strategies (e.g., CATA, RATA) and similarity-based techniques (e.g., sorting, PM) (Table 2). Undoubtedly, the task of illustrating the complex tactile properties of wines is still entrusted to the conventional DA sensory method due to its ability in discriminating small differences in complex products and the use of trained assessors on specific vocabulary. However, the most recent rapid methods are sensory tools of strong application and are useable even for the wine mouthfeel characterization, although a higher number of judges are required, in particular when they are consumers (Ares et al., 2015). In the last case, information on liking and preference can also be obtained without compromising the sensory profile characterization (Jaeger & Ares, 2015). Therefore, sensory tests should be selected according to a "fit-for-purpose" method, on the basis of matrix complexity, availability of judges and samples, and objectives of study.

5 | THE CHOICE OF DESCRIPTORS: THE TEN MOST USED ASTRINGENCY-RELATED SUBQUALITIES

5.1 | Red wine

Among the current publications regarding red wines' astringency subqualities, 56 different terms have been found with a total frequency of 440 (Table S4). The astringency subquality with the highest frequency among red

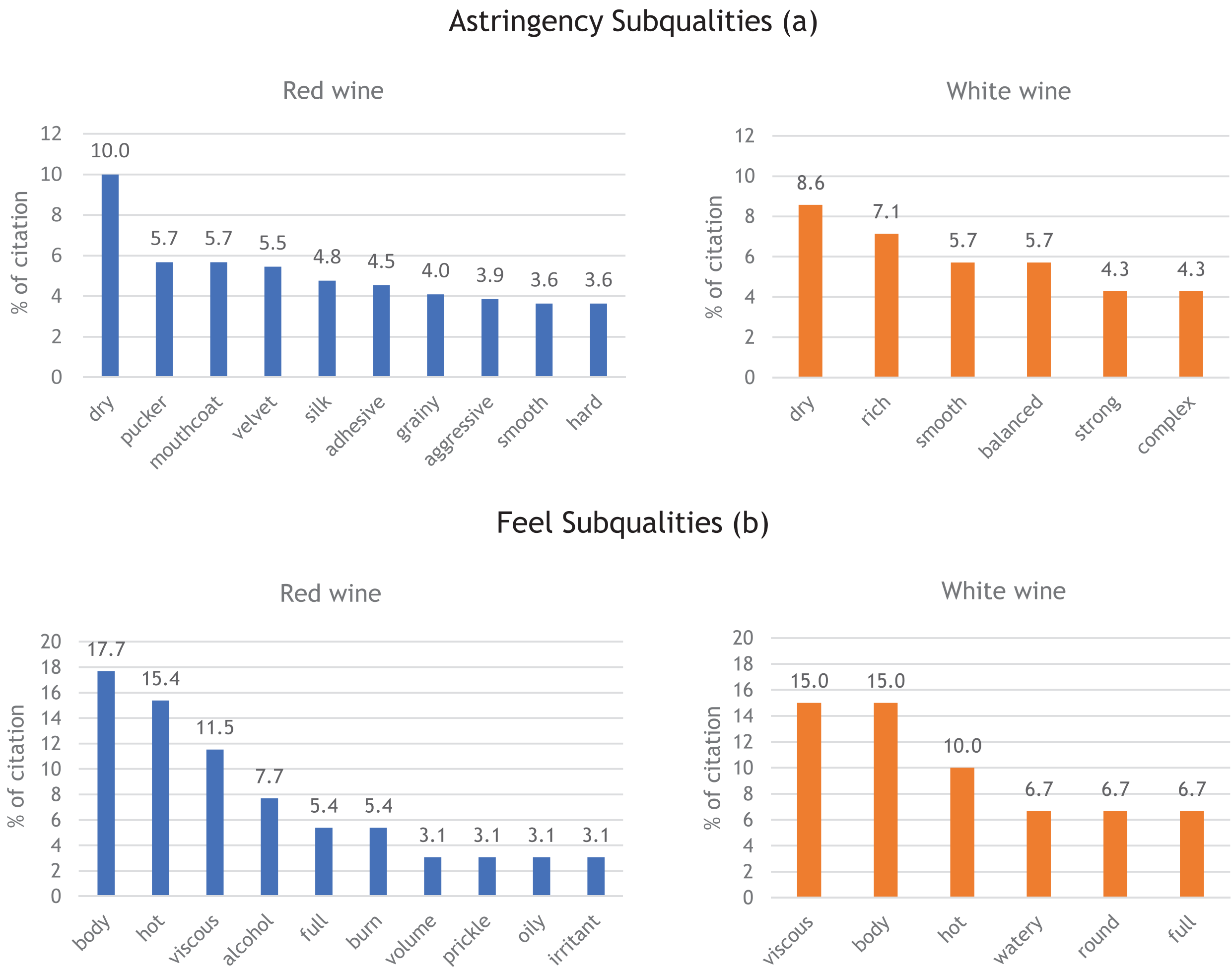

FIGURE 2 Citation frequency (%) of *astringency* subqualities (a) and *feel* terms (b) in red/white wine.

wines' literature is *dry* (10.0%) (Figure 2). It belongs to the *drying* category, together with *numbing* and *parching*. In this category, all the terms are united by the feelings of lack of lubrication or desiccation in the mouth (Gawel et al., 2000). The *dry* feeling could be perceived in all parts of the mouth (Gonzalo-Diago et al., 2014), on tongue side or on palate (Ferrero-del-Teso et al., 2020; Sáenz-Navajas et al., 2020). In order to simplify the assessors' understanding of *dry* subquality, potassium and aluminum sulfate, grape tannins, grape seed tannin extract, and green tea extract are employed as reference standards (Frost et al., 2017; Gonzalo-Diago et al., 2013; Sáenz-Navajas et al., 2011; Wang et al., 2020) (Table 3). Interestingly, terms related to dryness were the most frequently mentioned by consumers when they were asked to describe the astringency of red Tannat and Sangiovese wines (Rinaldi et al, 2021a; Vidal et al., 2015), confirming *dry* as a well-known and easily recognizable characteristic, even among untrained judges.

Pucker and *mouthcoat* are the most used terminologies (both 5.7%). The first is the result of a reflex action of mouth surfaces being brought together and released in an attempt to lubricate mouth surfaces (Gawel et al., 2000), and it was also previously described as "*the tightening or drawing sensation that can be felt in the cheeks and muscles of the face*" (Lawless & Corrigan, 1994). It could be perceived all over the tongue, including laterals and palate (Gonzalo-Diago et al., 2013). The *pucker* subquality is grouped in the *dynamic* category, which involves some form of mouth movement. The sensation of *pucker* could be explained by a conceptual definition, reference standards such as tannic acid or a solution of alum and tartaric acid (Gonzalo-Diago et al., 2013; Wang et al., 2020; Wang et al., 2021), and by burlap as touch standard (Rinaldi & Moio, 2018). Interestingly, *puckery* was among the astringency subqualities negatively correlated with Tannat wines quality when evaluated by experts (Vidal et al., 2018). With regards to *mouthcoat*, it is a *complex* group sensation that gives the impression of a coating film adhering to the mouth surfaces and falling with time (Gawel et al., 2000). In addition to this ordinary definition of *mouthcoat*, banana peel and suede were also used as touch standards (Kang et al., 2019; Rinaldi & Moio, 2018). It differs from

TABLE 3 Chemical/Touch reference standards of the most used *astringency* and *feel* subqualities

Term	Gawel's grouping	Chemical/Touch reference standard	Reference
	Astringency subqualities		
Dry	Drying	Potassium and aluminum sulfate (0–4 g/L);Grape tannins (5 g/L) Grape seed tannin extract (1–3 g/L)Green tea extract (1 g/L)	Frost et al., 2017; Gonzalo-Diago et al., 2013; Oberholster et al., 2009 ; Sáenz-Navajas et al., 2011; Wang et al., 2020
Velvet	Surface smoothness	Quercetin-3-*O*-galactoside (0–10 mg/L) Velvet cloth	Gawel et al., 2001; Paissoni et al., 2020; Scharbert et al., 2004; Pickering & Demiglio, 2008; Vidal et al., 2016
Pucker	Dynamic	Tannic acid (8 g/L) Alum (0.5–2 g/L) and tartaric acid (1–4 g/L) Burlap	Gonzalo-Diago et al., 2013; Rinaldi & Moio, 2018; Wang et al., 2020; Wang et al., 2021;
Mouthcoat	Complex	Banana peel Suede	Kang et al., 2019; Rinaldi & Moio, 2018
Silk	Surface smoothness	Silk cloth	Gawel et al., 2001; Oberholster et al., 2009; Pickering & Demiglio, 2008; Vidal et al., 2016
Adhesive	Dynamic	Grape seed extract (1.5 g/L) and tartaric acid (0.5 g/L) solution	Kang et al., 2019
Grainy	Particulate	Flour for fine grain,Semolina for medium grain Polenta for coarse grain Sand paper 1000 grade Silk cloth for fine grain Fine-grade emery paper for medium grain Coarser grade emery paper for coarse grain White sugar	Kang et al., 2019; Paissoni et al., 2020; Rinaldi & Moio, 2018
Aggressive	Harsh	Sand paper 600 grade	Rinaldi & Moio, 2018
	Feel subqualities		
Body	-	Solution of glycerol (6 mL) Gum arabic Xanthan gum (0.5 g/L in wine)Methylcellulose (4 g/L in water)Carboxymethylcellulose sodium salt (0.5–1.5 g/L in water)	Chong et al., 2019; Gawel et al., 2020; Hopfer & Heymann, 2013; Niimi et al., 2017; Pagliarini et al., 2013 ; Runnebaum et al., 2011; Wang et al., 2021
Viscous	Weight	Gum Arabic in red wine Carboxymethylcellulose sodium salt (0.5–1.5 g/L) in water	Gawel et al., 2020; Hopfer & Heymann, 2013; Rinaldi et al., 2021c
Hot	Heat	Water spiked with 8% (v/v) food grade alcohol Wine spiked to 23.5% (v/v) with 190 proof ethanol	Frost et al., 2017; Gawel et al., 2020
Burn	-	Water spiked with 12% and 20% ethanol Wine spiked with 20% 100-proof ethanol Wine spiked with grain neutral spirits	Chong et al., 2019 ; Diako et al., 2016; Wang et al., 2021
Tingle	Irritation	Soda water (15 mL)	Watrelot et al., 2016
Prickle	Irritation	Soda water (15 mL)	Watrelot et al., 2016
Metallic	Acidity	8 iron tablets (approximately 3.0 g) dissolved in 300 mL base wine and filtered	Diako et al., 2016

adhesive (4.5%), which is a *dynamic* subquality that concerns the sticky or adhering feelings of mouth surfaces to one other (Gawel et al., 2000) that could involve front lips and gums (Kang et al., 2019). In this case, no reference standards are usually adopted for this subquality, even if one study proposed a solution of grape seed extract and tartaric acid as chemical standard (Kang et al., 2019). Mouthcoating has been positively correlated to red wine liking in Tannat and Sangiovese wines (Rinaldi et al., 2021a; Vidal et al., 2018). Surface smoothness *velvet* and *silk* subqualities (5.5% and 4.8%, respectively) are used to describe the feeling when different mouth surfaces come in contact with each other. *Velvet* is described as finely textured kind of astringent sensation, notably perceived in the tip of the tongue and in front of superior teeth (Gonzalo-Diago et al., 2013; Gonzalo-Diago et al., 2014). Its reference standard is represented either by a quercetin-3-*O*-galactoside solution (Scharbert et al., 2004) or by touch standard using velvet cloth (Gawel et al., 2001; Pickering & Demiglio, 2008; Vidal et al., 2016). Like *velvet*, the *silk* astringent perception, instead of using a definition, is commonly described as the tactile sensation of silk itself (Rinaldi et al., 2021c) and coupled with a piece of silk fabric (Gawel et al., 2001; Pickering & Demiglio, 2008; Vidal et al., 2016). Notably, the term *smooth* is often reported (3.6%) in characterizing red wine sensory description. This descriptor is not present as a single term in the mouthfeel wheel but may be represented by the *surface smoothness* category. In fact, *smooth* is reported as a soft and delicate feeling often associated with *silky* and *velvety* astringent perception (Arajuo *et al.*, 2021), and in turn correlated to a lower astringency intensity (Vidal et al., 2016). *Smooth*, *velvety*, and *silky* have been reported by experts as markers of high-quality red wines in several studies (Ferrer-Gallego et al., 2014; Sáenz-Navajas et al., 2016; Vidal et al., 2018).

Grainy (4.0%) is the only subquality belonging to *particulate* group that is present in the ranking of the 10 most used astringent attributes for red wines. It is described as a sensation of microparticles in the mouth (Rinaldi et al., 2021c), and for this reason, *grainy* is better understood by judges with the help of particulate touch standards, which are sometimes used as scales of increasing *grainy* perception such as corn flour, semolina, polenta (Kang et al., 2019), or the touch standard sand paper 1000 grade (Rinaldi & Moio, 2018).

One of the unpleasant astringent terms in red wine description is *aggressive* (3.9%). It belongs to the category of *harsh*, together with *hard* and *abrasive*, and it consists of an excessive astringency of strong roughing nature (Rinaldi et al., 2021c), and the tactile sensation could be elicited by sandpaper of 600 grade (Rinaldi & Moio, 2018). This *aggressive/sandpaper* sensation has been correlated to low-quality or low-rated red wines by experts (Sáenz-Navajas et al., 2016; Vidal et al., 2018), and more precisely, *sandpaper* is considered relevant as the description of astringency for consumers, although not directly included in the mouthfeel wheel terminology (Vidal et al., 2015). Also, *hard* (3.6%) underlines aspects of excessive roughness and unbalanced astringency (Gawel et al., 2000) determined by the combined effect of bitterness and astringency (Gawel et al., 2000; Rinaldi et al., 2021c). Often used as a synonym of *harsh* in many scientific works (Piombino et al., 2020; Pittari et al., 2020), both terms are commonly used also by consumers in the description of red wines' astringency (Vidal et al., 2015). Interestingly, the term *aggressive* has been associated with the European red wine style, which was considered more "difficult" to understand than international style, and *harsh* is one of the subqualities utilized to describe "difficult" European white wines (Loureiro et al., 2016).

5.2 | White wine

For the white wine evaluation, only some astringent subqualities (i.e., 40 different terms) are adopted in the scientific literature on a total frequency of 70 (Table S4), which is in line with the lower interest in evaluating astringency in white wines, due to their minor content of polyphenols. Nevertheless, it is interesting to notice that *dry* remains the most frequently cited subquality for white wines (8.6%). *Rich* (7.1%), followed by *balanced/unbalanced* (5.7%), is the most cited astringent attribute for white wines. *Rich* attribute, which belong to the *complex* group, is often associated with white wine's tactile characterization and is defined as "*a high flavor concentration with balanced astringency*" (Gawel et al., 2000). Similarly, *balanced/unbalanced* terms are often used in white wine description, as in the evaluation of Chenin blanc old vine wines (Mafata et al., 2020), and are inclusively related to the aroma, acidic profile, and the astringent perception. Additionally, *complex* refers to the general category, which includes different qualities, like *soft, supple, fleshy, mouthcoat*, and *rich* (Gawel et al., 2000), and it is often present (4.3%) highlighting this category's importance in white wine's quality evaluation. The term *Strong* (4.3%) was identified with alcoholic, robust, intense in taste, and concentrated white wines' evaluation. As an example, *dry*, *smooth*, and *strong* attributes were present among the 10 most cited terms used to describe white wines produced in Nova Scotia by untrained participants in an on-line survey (Moss et al., 2021). In this study, *dry* was the term mentioned with the highest frequency, but some of the assessors used it to describe a still wine, with a low amount of sugar, while others adopted it with the meaning of *dry* mouth perception. *Smooth* descriptor (5.7%) was instead correctly associated with the astringent property, but also with the sensations of pleasant, round, easy to drink, low content of alcohol, and *velvety*. In addition, *dry, smooth, rich*, and *balanced/unbalanced* were evaluated in Chardonnay wines obtained at different timings and temperature conditions of malolactic fermentation by UFP and a restricted version of PM, namely Napping® (Sereni et al., 2020).

6 | THE CHOICE OF DESCRIPTORS: THE TEN MOST USED FEEL-RELATED SUBQUALITIES

6.1 | Red wine

In the current scientific literature, the mention frequency of the macro-category *feel* descriptors adopted is lower than that of astringency subqualities for the same wine category. For instance, a total mention frequency of 130 with 30 different terms has been highlighted for red wine (Table S5). Among *feel*-related descriptors, as shown by Figure 2, *body* is the most frequent mouthfeel descriptor (17.7%), followed immediately by *hot* (15.4%) and *viscous* (11.5%). These three terms together make up almost half (44.6%) of the total citation frequency for red wines. Subsequently, *alcohol* (7.7%), *full* (5.4%), and *burn* (5.4%) are the most used terms in this category, and only a few sources adopted *volume* (3.1%), *prickle* (3.1%), *oily* (3.1%), and *irritant* (3.1%).

Body presents different synonyms, like *full-body* and *full-bodiedness*, and is defined as a sensation of high viscosity (Rinaldi et al., 2021c). Traditionally, the term *body* was not included in the mouthfeel wheel, and its concept is adopted for the *weight* sensory evaluation of wines. Similarly, the *viscous* attribute is strictly related to the weight contribution of a wine and is defined as an apparent thickness resulting from pressure required to move the wine around the mouth (Gawel et al., 2000). When viscosity is low in intensity, it has been described as *watery* and *thin mouthfeel*, while for higher intensity it has been associated with *oily* and *thick mouthfeel* (Walker et al., 2019). *Hot* descriptor, which is higher in intensity than *warm*, together with the latter, belongs to the *heat* grouping of Gawel's wheel. Generally, *hot* is a thermal perception, characterized by heat sensation in the mouth and after expectoration (Li et al., 2017), stimulated by higher ethanol contents; indeed, its reference standard is water spiked with ethanol (8% v/v) or wine spiked to 23.5% v/v with ethanol (Frost et al., 2017; Gawel et al., 2020). Similarly, *burn* descriptor is represented by wine added with higher content of ethanol (12% and 20% v/v) as reference standard (Wang et al., 2021) or even grain neutral spirits (Chong et al., 2019). Besides, *hot* descriptor is commonly associated with *warm*, *tingling*, and *numbing* sensations (Li *et al.*, 2018). Interestingly, *tingle* and *prickle* sensations are often considered together, as they cause strong and disagreeable responses on consumers' perception. *Tingling* mouthfeel is defined as light, diffuse pins and needles sensation on the tongue. Conversely, *prickle* definition is associated with a deeper, more localized needle prick sensation on the tongue. Both descriptors are described with soda water as reference standard (Watrelot et al., 2016) (Table 3). Likewise, the term *irritant* is among the 10 most used in mouthfeel red wine description and refers to a generic unpleasant sensation, negatively influencing expert evaluation, which could be due to *prickle, tingle, spritz, pepper*, or *chilli* specific descriptors (Gawel et al., 2000, Vidal et al., 2018).

6.2 | White wine

In the white wine evaluation, the two most used mouthfeel attributes of the 20 terms found are represented by *viscous* (15.0%) and *body* (15.0%) (Figure 2). In particular, Chenin blanc wines obtained from grapes produced by different trellis systems showed differences in terms of light, medium, and full *body* (Panzeri et al., 2020). In addition, the wine *body* perception by consumers was studied, and it has been observed that wine with increased *body* did not influence wine liking and emotions, differently from an increased astringency perception (Niimi et al., 2017). Moreover, the tactile descriptor of *hot* (10.0%) was also frequently used. *Watery*, *round*, and *full* each accounted for 6.7% of the citation of descriptors employed in white wine sensory evaluation. Interestingly, *watery* was described by untrained judges with two different definitions. The first description was related to the lack of flavor in white wines and the stated *watery* descriptor was associated with bland or lacking wine. In the second definition, only some participants defined *watery* as a lack of body or a low viscous wine (Moss et al., 2021). Similarly, in another consumer study combining projective mapping (PM) and ultra-flash-profiling (UFP), *watery*, together with *light* and *pungent*, have been adopted in the red/white/rosé wine description (Hayward et al., 2020). Besides, the mouthfeel profile of Chardonnay white wines was partially influenced by malolactic fermentation conditions (i.e., different timing, temperature, strains), according to experts' judgment. Indeed, it has been noticed that there is no dominant factor, like temperature or malolactic fermentation timing, driving mouthfeel perception (Sereni et al., 2020). Moreover, in similar treatment conditions (i.e., Chardonnay wines obtained from different malolactic fermentation conditions), the retro-nasal aromatic perception was found to influence the mouthfeel perception (Sereni et al., 2016). Nevertheless, it is unclear if these differences are due to interactions between chemical groups, indirect effects of volatile fraction, or associative learning.

7 | THE PARTICULAR CASE OF SPARKLING WINE: MOUTHFEEL SUBQUALITIES

A further wine category has been researched: special wines. The results included sparkling wine, whereas no studies using mouthfeel subqualities concerning other

TABLE 4 Frequencies of *astringency* and *feel* subquality descriptors in sparkling wine

Term	Counts	Mention frequency (%)	Range of publication years
Carbonated	3	11.1	2017–2020
Foamy	2	7.4	2017
Bubble Pain	2	7.4	2015–2017
Bite	2	7.4	2017
Watery, viscous, tingly, strong, smooth, pungent, prickle, persistence, numbing, global perception, fresh, equilibrium, dry, crisp, creamy, burn, body, after numbing	1	3.7	2015–2020
Total mention frequency	27	100	
Number of terms	22		

special wines, such as *passito*, reinforced or orange wines, have been found. In sparkling wines' case, the sensory evaluation of foam, originated from carbon dioxide flow, is extremely important and the mouthfeel sensations considerably differ from still wines. Indeed, Pickering and Demiglio (2008) introduced separate categories (e.g., *mousse dynamics*, *tingle*, *fresh meringue*) for the mouthfeel properties elicited uniquely by sparkling wines. A total of 22 different astringent and mouthfeel related descriptors have been found in the scientific literature with a total mention frequency of 27 (Table 4). In the case of sparkling wines, the most frequently cited terms are *carbonated* (11.1%), *bubble pain* (7.4%), *foamy* (7.4%), and *bite* (7.4%). The other terminology found has only been mentioned once, as *watery*, *strong*, *viscous*, *smooth*, *creamy*, *fresh*, and *numbing*. As reference standards, 30 mL seltzer water for *carbonation/bubble pain*, 30 g peroxide-baking soda toothpaste for *numbing*, 1 lemon-honey cough drop dissolved in 300 mL boiling water for *after-numbing*, 0.5 g candy with tongue pressed to roof of mouth for *prickly*, 30 mL soda (7-Up) for *foamy*, 30 g peroxide-baking soda toothpaste for *tingly* were used (McMahon et al., 2017b). The bubbles of carbon dioxide could also be involved in irritating sensations, associated with *pungent*, *prickly*, and *tingly* descriptors. In addition, sparkling wine's weight is also considered with the terms of *watery*, *viscous*, and *body*. The only astringency subqualities mentioned in this category are *smooth*, *dry*, and *strong*.

8 | A FOCUS ON THE WINE *BODY* CONCEPT: SENSORY AND INSTRUMENTAL INVESTIGATIONS

Body is one of the most frequently cited descriptors in both red and white wines' mouthfeel sensory analysis, although this term does not fall explicitly into the vocabulary of the sensory wheels. This term is related to a wider concept, which unifies and includes a series of attributes employed to describe the same concept. First of all, the nearest words associated with body are *full-body*, *fullness* (Loureiro et al., 2016; Vidal et al., 2004b), *roundness* (Pineau et al., 2011), *volume* (Casassa et al., 2013; Diago et al., 2010; Hopfer & Heymann, 2013; King et al., 2014b), *weight* (Harbertson et al, 2009; Ou et al., 2010), *density* (Ivanova et al., 2022), and *viscous* (Gawel et al., 2016). All these terms commonly shared the concept of thickness resulting in pressure required to move the wine around the mouth (Gawel et al., 2000), the sensation of fullness and richness in the oral cavity (Coste et al., 2018), and the viscosity and overall intensity of wine (Li *et al.*, 2018).

The reference standards related to *body* are likewise numerous (Table 3): a solution of glycerol, carboxymethylcellulose sodium salt, methylcellulose, and xanthan gum (Chong et al., 2019; Gawel et al., 2020; Hopfer & Heymann, 2013; Niimi et al., 2017; Pagliarini et al., 2013; Runnebaum et al., 2011; Wang et al., 2021). In other words, the concept of *body* is wide and quite complicated, not only because of the several chemical reference compounds that could trigger it, but also because of the lack of lexical consensus. Among the various combinations of terminology, the necessity to clarify and unify many weight-related attributes under a unique wine body term has been highlighted by untrained judges. Namely, consumers associate this term with the wine flavor, fullness, and strength more rather than mouthfeel, and to a greater extent as their wine knowledge decreases (Niimi et al., 2017). In the cited study, Syrah, Cabernet sauvignon, and Port wines were associated with full-bodied wines in contrast with Sauvignon blanc, rosè, and sparkling wines that were associated with light-bodied ones (Niimi et al., 2017). The multi-modal dimension of wine (and beer) body by consumers was also recently studied by Ivanova and colleagues (2022), and it was confirmed how consumers associate this term with mouthfeel attributes (*velvety*, *smooth*, *creamy*) as well as with flavor, particularly with nuances of dark fruit (blackberry, cherry, plum), and derived from wood-aging (e.g., caramel, chocolate, and oak).

Body is often linked with the concept of *perceived viscosity*, which is in turn related with the thickness perceived in mouth and correlated with the *physical viscosity*. The latter is defined as the internal friction of a fluid and its presented resistance to the flow. It has been instrumentally measured in wine by rheological techniques, such as falling ball viscometer, capillary viscometer, or rotational rheometer (Brossard et al., 2020; Danner et al., 2019; Laguna et al., 2017; Runnebaum et al., 2011; Shehadeh et al., 2019; Yanniotis et al., 2007). Since Arrhenius' law is valid for wine, a decrease in viscosity is reported at increasing temperature, and usually the value at 20°C is measured analytically for comparison, although the wine serving temperature may vary with a consequent variation in perceived viscosity (Yanniotis et al., 2007). The viscosity of Australian Chardonnay wines was reported to range between 1.448 and 1.529 mPa·s at 20°C, whereas that of Californian Chardonnay wines was found between 1.232 and 1.313 mPa·s at 30°C, according to the higher measurement temperature, but values up to 1.93 mPa·s can be found at 20°C in Greek white wines (Danner et al., 2019; Runnebaum et al., 2011; Yanniotis et al., 2007). Interestingly, differences were found between Californian wine regions in terms of viscosity, allowing their discrimination (Runnebaum et al., 2011). Higher viscosity values were found in red wines, from 1.448 to 1.695 mPa·s for Australian Shiraz, and from 1.78 to 2.02 mPa·s for Greek red wines (Danner et al., 2019; Yanniotis et al., 2007). Indeed, the difference thresholds of perceived viscosity are reported at 0.141 mPa·s and, more recently, 0.138 mPa·s in the studies of Noble and Bursick (1984) and Danner and colleagues (2019), respectively.

Sugars are the main contributors to both physical and perceived viscosity in wine, which is well represented by the full-body sensation of sweet wines. Nevertheless, it has been reported that under 4 g/L of residual sugars, or as studied more recently 15 g/L of sucrose (Burns & Noble, 1985; Nurgel & Pickering, 2005; Runnebaum et al., 2011), their contribution is negligible in terms of viscosity. Other basic compositional makers are considered responsible for viscosity, such as ethanol, as well as glycerol, and other compounds present in the wine dry extract. The contribution of glycerol to wine viscosity and fullness is debated in several studies. Traditionally, the glycerol presence in white and model wines has been related to both perceived and physical viscosity (Jones et al., 2008; Laguna et al., 2019; Nurgel & Pickering, 2005; Runnebaum et al., 2011). Its production depends on yeast strain, fermentation parameters, and winemaking processes (Erasmus et al., 2004). In contrast, other scientific papers have not highlighted the relationship between glycerol and viscosity in white wines, suggesting that other chemical and physical factors may participate in wine body, such as pH or residual sugars (Gawel et al., 2014a; Runnebaum et al., 2011; 2018; Shehadeh et al., 2019). In few words, considering the above-mentioned difference thresholds, these perceived differences in viscosity correspond to an increase of 25 and 28 g/L of glycerol, respectively (Yannotis *et al.*, 2007; Danner et al., 2019), which is far from the content present in wines. Similar magnitudes are considered for alcohol content: With an increase of 0.047 mPa·s of viscosity for each alcohol degree (Yannotis *et al.*, 2007), a viscosity difference may be perceivable with more than 3% alcohol difference among wines. These results were confirmed also by Danner et al. (2019): Although a strong positive correlation was found between physical and perceived viscosity, an increase of 4.5% and 3.2% of alcohol was required in order to sense it in a white and a red wine, respectively. Additionally, the lubrication conditions of the oral cavity are modulated by the presence of solvents, like ethanol and glycerol. Both these compounds were found to be able to modulate the formation of salivary protein–polyphenol aggregates: in particular, glycerol was found to restore lubrication in the mouth, whereas ethanol was able to prevent them (Rudge et al., 2021). Therefore, other compounds involved in the wine dry extract (excluding glycerol) are presumably related to the body perception, such as the presence of organic acids, amino acids, yeast mannoproteins, and tannins. Metabolomic analyses by gas-chromatography coupled with time-of-flight mass spectrometry (GC-TOF-MS) and nuclear magnetic resonance (NMR) have been attempted to highlight the possible chemical markers correlated with perceived viscosity (Skorgerson *et al.*, 2009; Rochfort et al., 2010). The GC-TOF-MS determination allowed to discriminate between wines classified in three classes of perceived viscosity by 28 compounds, with the amino acid proline and some organic acids, such as lactic and succinic acids, as enhancers, in contrast to the presence of fatty acids (Skorgeson *et al.*, 2010). In addition, NMR was able to discriminate wines based on the different perceived "body" following different shading treatments of grapes in the vineyards (Rochfort et al., 2010), which could be correlated in turn by different secondary metabolites content and extraction, with tannins among others. Tannins are well known for their involvement in the mouthfeel and more specific in astringency. Considering the relationship between viscosity and tannins concentration in Shiraz wines, a positive trend has been observed, although non-significant (Danner et al., 2019). Interestingly, when an astringent compound is added to a model saliva (based on mucin salivary protein) or human saliva, the mixture showed a shear-thinning behavior (therefore as a non-Newtonian fluid) with increasing viscosity related to ascending tannin dose, although the tannin content necessary for this effect was dependent on the ratio's wine/saliva tested, and therefore of correspondent tannins/proteins content (Laguna et al., 2017; Brossard *et al.*, 2019). The change in viscosity was combined with the formation of tannin–salivary protein aggregates—analyzed by scanning electron microscopy or nephelometry—which suggested that those complexes were responsible for the increase in viscosity and the greater perceived thickness. In this case, the combination of rheology with the investigation of aggregate formations by microscopy and light-scattering techniques and the change of in-mouth lubrication by tribology is a promising approach.

9 | CORRELATION BETWEEN SENSORY MOUTHFEEL SUBQUALITIES AND INSTRUMENTAL MEASUREMENTS

As described previously, astringency is a complex tactile sensation perceived in the oral cavity, and it has been defined by the American Society for Testing and Materials as a group of sensations involving shrinking, drawing, or puckering of the epithelium (ASTM, 2004). According to the mechanism, the mouthfeel perception origins from the interaction between salivary proteins (i.e., PRPs or proline-rich proteins, histatins, α-amylase, lactoferrin, and mucins) (Condelli et al., 2006; de Freitas & Mateus, 2001; Gambuti et al., 2006; Lu & Bennick, 1998; Yan & Bennick, 1995) and polyphenolic compounds, like tannins. Additionally, other classes of compounds interact with salivary proteins, like organic and inorganic acids, dehydrating agents, and multivalent metallic cations (Bajec & Pickering, 2008).

Several phenomena influence the onset of in-mouth sensations, involving different oral tissues and constituents. Nevertheless, several mechanisms are mainly involved and widely accepted regarding the perception of astringent sensation, as recently reviewed by González-Muñoz et al. (2022). Briefly, the first one involves the interaction, aggregation, and precipitation of polyphenols with PRPs (Lu & Bennick 1998; Soares et al., 2012). In order to explain this mechanism, Charlton et al. (2002) proposed a three-step model, which has been confirmed and modified by other authors (Jöbstl et al., 2004). Initially, a polyphenol–PRP chemical bond is formed due to the development of hydrogen bonds (Hagerman & Butler, 1980) and hydrophobic forces (Bennick 2002; Simon et al., 2003). The first interaction triggers the subsequent aggregation with other polyphenols, like tannins, and the formation of a soluble complex. In the second stage, the complex forms cross-links with more polyphenols creating insoluble aggregates. Ultimately, polyphenol–protein large complexes precipitate, leading to dryness and puckering sensations on the oral surface.

The precipitation of polyphenol–PRP complexes determines a disruption of the lubricating salivary film, which covers all oral surfaces causing friction and mechanoreceptors activation, thus the astringent perception in the mouth (Gibbins & Carpenter 2013), as a second mechanism. This latter mechanism suggests the direct interaction of polyphenols alone or the polyphenol–protein complexes with oral mucosa surface (Gibbins & Carpenter, 2013). This process is allowed by the frictional force that decreases lubrication and leads to the exposure of inner epithelial layers. Even the tongue presents superficial slow-adapting and fast-adapting receptors which could respond to this mechanism (Breslin et al. 1993). Last, studies on the interaction of oral epithelial cells from buccal mucosa and tongue with the main oral components (human saliva, mucosal pellicle, epithelial cells membrane) and phenolic compounds showed their contribution to the astringent perception (Soares et al., 2017, 2020; Reis et al., 2020). It is still unknown if these mechanisms occur step-by-step or simultaneously in the oral cavity (González-Muñoz et al., 2022). Nevertheless, it has underlined their contribution to the mouthfeel and, in more detail, to the astringent perception in food and beverages, including wine.

9.1 | Tribology: Can lubrication loss determine the subqualities of astringency?

Recently, several studies on rheology, tribology, and turbidity investigated the mouthfeel and, more precisely, the astringent perception in wine, as summarized in Table 5. Although tribology measurements are widely diffused in food science (Shewan et al., 2020), and the correlation between the friction coefficient (μ) and sensory descriptors common in dairy foods—such as *smoothness*, *pastiness*, and *stickiness*—was deeply confirmed (Sarkar & Krop, 2019), the study of the relations between wine's perceived astringency and μ is relatively recent (Brossard et al., 2016). Using this approach, overall astringency can be discriminated in wines with different contents of tannins or produced from grapes picked at different levels of ripeness (Brossard et al., 2021; Watrelot et al., 2019). Previously, a tribological approach demonstrated the reduction in lubrication determined by galloylated flavan-3-ols standards, namely, epigallocatechin-gallate and epicatechin-gallate, whereas epicatechin was perceived as astringent but did not modify the measured lubricant properties (Rossetti

TABLE 5 Rheology, tribology, and alternative methods to investigate *astringency* and *feel* subqualities

Reference	Matrix	Chemical compounds	Sensory methods and adopted descriptors	Instrumental methods
Tribology-based studies				
Brossard et al., 2016	Model wines with standards and 4 red wines (Carménère, Merlot, 2 Cabernet sauvignon), human saliva	Tannic acid and catechin (both 1 g/L) in model wines	DA Astringency intensity	Purpose-built tribometer attached to a texture analyzer (PDMS surface and sliding probe consisting in three stainless steel half-ball).Morphological analysis of precipitate with a light microscopy (LM) and negative-stain scanning electronic microscopy (SEM) for visualizing the microstructure wine-saliva mixture.
Laguna et al, 2017	Model wines, human saliva	Presence/absence of ethanol, glycerol, commercial tannins (oak tannins), grape seed extract, commercial inactivated dry yeast, tartaric acid, L-glutathione	DA Mouth attributes: taste (bitterness, acidity, wood taste), mouthfeel (astringency, *dryness*, earthiness, *hot sensation*, *alcoholic feeling*), after feeling, (*overall persistency*, alcohol persistency, wood after taste), and color descriptors	Particle size measurement (Z-averaged diameter).Rheological measure of saliva-model wines mixture.Tribology (Mini-Traction Machine, both tribo-pairs and surface of PDMS) surfaces were lubricated and then model wine added.Negative-stain transmission electronic microscopy (TEM) for microstructure visualization of polyphenols and saliva aggregates.
Watrelot et al., 2019	Red wines (Cabernet sauvignon and Pinot noir), model saliva with mucins and human saliva			Tribology with surface force apparatus (SFA) evaluation of two surfaces: back-silvered hydrophilic mica (as it is) or coated with PDMS.
Wang et al., 2020	Model wines, whole human saliva	The model wines were added with different tannin extracts level and different pH	DA *Drying*, *pucker*, *rough*	Salivary precipitation index (SPI).Tribology (Mini Traction Machine, ball-on disk, both PDMS) with 3 protocols: dynamic with bulk saliva, Stribeck curve protocol, dynamic incorporating salivary pellicle.Quartz crystal microbalance with dissipation monitoring.
Brossard et al., 2021	Red wine Cabernet sauvignon (rough) and Carménère (soft/velvety), unstimulated whole human saliva	The wines were produced with different grape ripeness level	DA Astringency intensity (overall astringency), *drying*, volume (*full*)	Purpose-built tribometer attached to a texture analyzer.Particle size distribution of aggregates and Zeta potential.Morphological analysis with a light microscopy (LM) and scanning electronic microscopy (SEM).

(Continues)

TABLE 5 (Continued)

Reference	Matrix	Chemical compounds	Sensory methods and adopted descriptors	Instrumental methods
Edmond et al., 2021	Model wines, model saliva with poly-L-proline	Different concentration of grape tannins extract (0.2 g/L, low tannins and 1 g/L, high tannins)		Tribology with surface force apparatus (SFA) and PDMS coating.Turbidity.
Wang et al., 2021	Red wine (Malbec), whole human saliva	Different level of ethanol, pH, mannoprotein, grape seed extract	DA *Fullness*, *smoothness*, *drying*, *pucker*, *grippy*, *rough*, resalivation, *burning*, *hot*	Salivary precipitation index (SPI) and saliva turbidity.Viscosity (capillary viscometer).Tribology (Mini-Traction Machine, ball-on disk, both PDMS) with 3 protocols: dynamic with wine only, dynamic with wine + saliva mixture, dynamic incorporating salivary pellicle.Quartz crystal microbalance with dissipation monitoring.
Rudge et al., 2021	Model wine, human saliva, model saliva with porcine gastric mucin, isolated PRPs from human saliva	Epigallocatechin gallate, gallic acid, caffeic acid, tannic acid, aluminum salts		Ball (glass) on a three PDMS pins in a rheometer with incorporated lubricant pellicle.Particle size measurement by dynamic light scattering.
Rheology-based studies				
Yanniotis et al., 2007	White wines: Nemea, Naousa, Santorini, and Mantineia Greek PDO Model solutions	Model aqueous solutions were prepared with different level of ethanol and glycerol		Physical viscosity with a falling ball viscometer (20°C), correlation with dry extract, ethanol, and glycerol content.
Runnebaum et al., 2011	White wines: Chardonnay, Viognier, Pinot gris, Riesling, Sauvignon blanc. Covering thin to full body type of wines		DA *Viscous mouthfeel*, bitter, astringent, sour, sweet, *hot* (and aroma descriptors)	PLSR with physical viscosity with capillary viscometer (30°C), wine density, osmotic potential, and chemical compounds (glycerol, organic acids, total extract, reducing sugars, polyphenols, anions and cations.

(Continues)

TABLE 5 (Continued)

Reference	Matrix	Chemical compounds	Sensory methods and adopted descriptors	Instrumental methods
Shehadeh et al., 2019	Model solutions and white wine from Roditis *cv.*	Different levels of ethanol, tartaric acid, glucose, fructose, and glycerol		Viscosity by rotational-type viscometer (20°C).
Danner et al., 2019	Chardonnay, Syrah, and Semillon for addition	Xanthan gum (0.2–0.12 g/L) to alter perceived viscosity	2-AFC method for viscosity difference threshold	Viscosity by falling ball viscometer (20°C) and measurements of wine density, ethanol, residual sugars, titratable acidity, and tannin for correlation.
Brossard et al., 2020	Model wines, model saliva with porcine gastric mucin	Grape seed and skin tannin extract and gallic acid (0.05–1 g/L) in model wine solutions		Measurement of viscosity of wine and saliva mixture (in different proportion) at 28°C—simulating a tasting experience.Turbidity.
Other innovative instrumental techniques to study in-mouth sensation				
Skogerson et al., 2009	White wines: Chardonnay, Pinot gris, Riesling, Sauvignon blanc, and Viognier		DA Intensity of mouthfeel (*viscosity*)	Untargeted NMR and GC-TOF metabolomic.PLS correlation to wine body.
Rochfort et al., 2010	Red wines: Cabernet sauvignon, and Syrah with different bunch-shading treatment		DA Mouthfeel (tannin, astringency, *body*) and taste, aroma, flavor descriptors	Untargeted NMR metabolomic.
Umali et al., 2015	Red wine: Cabernet sauvignon made from grape at different ripeness levels		DA Mouthfeel (astringent, *hot*, *viscous*), Taste (sweet, sour, bitter)	Peptidic sensory array composed by pH indicator, divalent metals ions, short binding peptides Displacement of the indicators by wine tannin is monitored by UV–vis spectroscopy.PLSR with sensory analysis.

(Continues)

TABLE 5 (Continued)

Reference	Matrix	Chemical compounds	Sensory methods and adopted descriptors	Instrumental methods
Vera et al., 2010	Red wines: Garnacha, Cariñena, Cabernet Sauvignon, Merlot, and Syrah		DAIntensity of indicator "tannin amounts"	FT-MIR spectroscopy.
Diako et al., 2016	Red wine Merlot		DA Mouthfeel (astringent, *burning*, *metallic*) and taste, aroma, flavor descriptors	Wine composition and e-tongue.
McMahon et al., 2017a	Sparkling wines varying in sugar type and concentration in the *dosage*		DA Mouthfeel (*bubble pain*, *creamy*, *foamy*), and aroma/flavor descriptors, and basic taste (sweet, sour, bitter) preference	Wine composition and e-tongue.

Abbreviations: DA, descriptive analysis; 2-AFC, two-alternative forced choice; PDMS, polydimethylsiloxane; NMR spectroscopy, nuclear magnetic resonance spectroscopy; GC-TOF, gas chromatography/time of flight mass spectrometry; PLS, partial least square regression; FT-MIR, Fourier-transform mid infrared.

et al., 2009). Given that astringency is often related to a lack of lubrication in the mouth, the study of friction coefficient seemed the most suitable option to fill the gap between the molecular basis (protein–polyphenol interaction) and the perceived astringency (Brossard et al., 2016; Laguna & Sarkar, 2017; Upadhyay et al., 2016). The objective of this approach is to simulate the interaction between tongue/palate/gums and wine components. In particular, the difficulty of this purpose is to realize accurate experiments capable of measuring the different astringent perception mainly in term of instrumentation and of the surface mimicking the mouth properties (Shewan et al., 2020). In fact, the determination of the friction coefficient, unlike the viscosity, is based on a complex physical process involving both lubricant and surface characteristics (Laguna & Sarkar, 2017; Upadhyay et al., 2016). The typical representation of tribological results is the Stribeck curve, which plots the friction coefficient as a function of the entrainment speed. It is typically divided into three regimes: (i) the boundary regime, with low entrainment speed and mainly driven by the surface characteristics—which is considered the most related to the astringency of wine (Brossard et al., 2016)—, (ii) the mixed regime, where the surface properties are still determinant but it is influenced by the hydrodynamic regime, that is, the (iii) regime that happens at higher speed and the bulk lubricant rheological properties are predominant.

The lubricant under evaluation is saliva (human or artificial) or the mix of wine (or specific compounds) and saliva, which can be analyzed as bulk or by a thin layer formed by saliva on the surface (Wang et al., 2020, 2021). Despite wine being a Newtonian fluid, the saliva and the mentioned mix are proved to be not, showing a shear-thinning behavior (Brossard *et al.*, 2019). Moreover, human saliva showed higher lubricant capacity than artificial mucin-based saliva (Watrelot et al., 2019). Concerning the testing surface, it must mimic as much as possible the in-mouth characteristics. Watrelot and colleagues (2019) tested different material for tribological measurements of Pinot noir and Cabernet sauvignon wines, showing the different effects resulting from the use of hard-hydrophilic mica and soft-hydrophobic elastomer polydimethylsiloxane (PDMS) coated surface, with the latter considered preferable. Indeed, human tongue is characterized by soft, rough, and hydrophilic (due to the saliva) properties, and PDMS can be customized by different treatments to modify its elasticity, smoothness, hydrophobicity, and roughness (Rudge *et al.*, 2019). PDMS customization makes it the most used material for oral tribology studies, as reviewed recently by Shewan and colleagues (2020) and Sarkar and colleagues (2019). These studies highlighted the properties of elastomer PDMS in food studies compared to biological surface, such as pig tongue, and opened new frontiers in the use of hydrogels. In the future, this surface may be employed in reaching conditions as close as possible to mouth in the field of the soft-tribology (i.e., the measurement that involves at least one compliant surface).

Obviously, the frictional evaluation depends on the adopted instruments and experimental conditions, as well as on the lubricant and surface considered (Rudge *et al.*, 2019). In this regard, the application of PDMS soft-tribology in wine astringency studies showed potentialities to instrumentally investigate the astringency subqualities that were previously only investigable with sensory analysis. Wang and colleagues (2020) used three different tribological protocols and sensory results from a DA, performed by a trained panel, and found interesting instrumental–sensory correlations for the subqualities *drying* and *pucker*. The first term is mainly driven by the tannin content and instrumentally correlated with the increased friction studied in a bulk of model-wine and human saliva. The formation of salivary protein–tannin complex reduced the lubricant ability of saliva (Wang et al., 2020). *Pucker* was correlated with low pH and was instrumentally measurable using PDMS incorporated with human saliva: After model wine flushing, the wine with lower pH value caused a faster increasing in the friction coefficient. This approach was further used (Wang et al., 2021) adding a Malbec wine with various levels of ethanol, tannin, pH, and mannoprotein, evidencing that the descriptors *drying*, *grippy*, and *rough* were correlated with high tannin contents and increased boundary friction, whereas *burning* and *resalivation* were not-frictional correlated but linked, respectively, with an ethanol and acidity increase. On the contrary, the softening in astringency, *smoothness*, was correlated with a lower protein precipitation and higher viscoelasticity of salivary films as determined by quartz–crystal microbalance with dissipation monitoring (QCM-D). Briefly, high correlation with physical measurements was found for several investigated subqualities, except also for *fullness* that was more linked with the alcohol content. In another tribological approach, alcohol presence was proved to reduce the protein–polyphenol bonding between astringent standard and PRPs, which were found to be the main cause of lubrication loss. Glycerol showed increased viscous lubrication, restoring from astringency sensation (Rudge et al., 2021). Dynamic light scattering (DLS) confirmed the existence of smaller aggregates when ethanol and glycerol were present (Laguna et al., 2017).

Indeed, the study of particle size by DLS proved that larger polyphenols increased precipitation and therefore lubrication loss (Rudge et al., 2021), confirming that polyphenols' molecular mass together with their concentration are the drivers of lubrication loss, and that the interaction involves mainly PRPs differently from other salivary proteins, such as mucins (Edmonds et al., 2021; Rudge et al., 2021; Watrelot et al., 2019). In fact, even if the number of aggregates may influence the intensity of astringency, Brossard and colleagues (2021) showed that their characteristics in term of shape (such as roundness), size (as Feret diameter), and texture may drive the different astringency subqualities. In their evaluations, a Carménère wine resulting higher in astringency and *velvety* subquality than a Cabernet sauvignon showed lower aggregates formation, but with a compact globular form with respect to open and flat aggregates of Cabernet sauvignon.

Combined with tribological measurements, the amount and surface characteristics of salivary protein aggregates with wine polyphenols in different matrix may be a future improvement in the instrumental measurement of astringency subqualities, providing more knowledge. Moreover, the correlations among the results of sensory analysis, e-tongue, and peptide arrays have been recently investigated and applied successfully for taste and astringency discrimination among wines, whereas *feel*-subqualities are still a research topic (Diako et al., 2016; McMahon et al., 2017b; Umali et al., 2015; Vera et al., 2010).

9.2 | Polyphenol–protein interaction: Instrumental study of the chemical base of astringency

It is certain that polyphenols contribute to the complexity of color, flavor, and astringency (Ma et al., 2014; González-Muñoz *et al.*, 2021). Depending on their structural features, grape polyphenols can be divided into non-flavonoids and flavonoids. The former includes phenolic acids (i.e., hydroxybenzoic and hydroxycinnamic acids) and stilbenes. The latter consists of flavan-3-ols monomers, their polymeric structures proanthocyanidins (tannins), flavonols, flavones, and anthocyanins.

The importance of flavan-3-ols and tannins on astringency has been widely discussed in many works, and it is commonly accepted that the degree of polymerization and molecular weight of polyphenols increase the precipitation of proteins (Bate-Smith, 1973) and intensify the astringent perception (Arnold et al., 1980; Peleg *et al.*, 1999). In the investigated literature, wine often needs to be fractionated in order to determine the sensory influence of polyphenol compounds. In this sense, a number of analytical options are available as remarked in Table 6. Among the most common methodologies, liquid/liquid solvent extraction or counter-current chromatography, and solid/liquid extraction by solid phase extraction, preparative or semi-preparative liquid chromatography (LC) are often employed to achieve fractions from grape and

TABLE 6 Chemical markers of *feel* and *astringency* subqualities

Polyphenol class	Matrix	Chemical compounds		Sensory methods and elicited descriptors	Chemical and fractionation methods/Notes
Phenolic acids		Hydroxybenzoic acids and derivatives	Hydroxycinnamic acids and derivatives		
Hufnagel & Hofmann, 2008	Red wine fractions	Gallic acid, gallic acid ethyl ester, protocatechuic acid, protocatechuic acid ethyl ester, vanillic acid, vanillic acid ethyl ester, syringic acid, syringic acid ethyl ester	Caffeic acid, caffeic acid ethyl ester, *p*-coumaric acid, *p*-coumaric ethyl ester, ferulic acid ethyl ester, (*E*)-caftaric acid	DA, three-alternative forced-choice test, Half-tongue* test *Puckering* astringency, bitter	HPLC/TDA, LC-MS, NMR spectroscopy, sequential solvent extraction, HPLC/TDA, gel adsorption chromatography, ultrafiltration.
Sáenz-Navajas et al., 2010	Red premium wine fractions	Protocatechuic acid, gallic acid, protocatechuic acid ethyl ester	*Trans*-caffeic acid, *trans*-coumaric acid, *trans*-coutaric acid, *trans*-caftaric acid, ferulic acid	Sip and spit method, sorting task Sweetness, acidity, bitterness, astringency, global and aromatic intensity, and global persistence	HPLC-DAD, HPLC-ESI-MS, Size exclusion chromatography, Simple linear regression, PLSR.
Gonzalo-Diago et al., 2014	Red wine fractions	Gallic acid, protocatechuic acid, protocatechuic acid ethyl ester, syringic acid, vanillic acid	Coutaric acid, *trans*-caftaric acid, caffeic acid, caffeic acid ethyl ester, ferulic acid, *cis*-coumaric acid, *trans*-coumaric acid	DA Bitterness, *drying* and *velvety* astringency, persistence	UPLC-DAD-MS, Gel Permeation Chromatography, Solid phase extraction (SPE), PLSR for a bitter taste predictive model.
Ferrer-Gallego et al., 2014	Phenolic compounds in aqueous solutions	Gallic acid, protocatechuic acid	Caffeic acid, *p*-coumaric acid	DA—Labeled Magnitude Scale (LMS) *Drying*, *harsh*, *unripe*, *dynamic* and *velvety* (ripe) sensations, persistence, bitterness	Addition of pure chemical compounds in solutions.
Ferrer-Gallego et al., 2017	Complexes of phenolic acids and a model peptide	Gallic acid, protocatechuic acid	Caffeic acid, *p*-coumaric acid		Saturation-transfer difference (STD) NMR spectroscopy, molecular dynamics (MD) simulations, Salivary protein: Model peptide fragment $IB7_{12}$.

(Continues)

TABLE 6 (Continued)

Polyphenol class	Matrix	Chemical compounds	Sensory methods and elicited descriptors	Chemical and fractionation methods/Notes
Flavonols				
Hufnagel & Hofmann, 2008	Red wine fractions	Quercetin-3-*O*-β-D-galactopyranoside; dihydroquercetin-3-*O*-α-L-rhamnoside; dihydrokaempferol-3-*O*-α-L-rhamnoside; quercetin-3-*O*-β-D-glucuropyranoside; isorhamnetin-3-*O*-β-D-glucopyranoside; syringetin-3-*O*-β-D-glucopyranoside	DA, three-alternative forced-choice test, half-tongue* test *Velvety* and *puckering* astringency	HPLC/TDA, LC-MS, NMR spectroscopy, sequential solvent extraction, HPLC/TDA, gel adsorption chromatography, ultrafiltration.
Schwarz & Hofmann, 2008	Human and animal proteins + astringent compounds	Quercetin-3-*O*-β-D-glucopyranoside and quercetin-3-*O*-α-L-rhamnopyranosyl-(1→6)-β-D-glucopyranoside	Half-tongue* test Astringency	HPLC-UV/Vis, Incubation of mucin and human salivary protein with chemical compounds, Micro-centrifugation.
Gonzalo-Diago et al., 2014	Red wine fractions	Kaempferol, quercetin-3-*O*-rutinoside	DA Bitterness, d*rying* and *velvety* astringency, persistence	UPLC-DAD-MS, gel permeation chromatography, SPE, PLSR for a bitter taste predictive model.
Sáenz-Navajas et al., 2017	Red wine fractions	Flavonols in general	Sorting task, repertory grid, triangulation and RATA Bitterness, *burning*, *heat*	UPLC-DAD-MS, MALDI-TOF-MS, Semipreparative LC; solid phase extraction (SPE).
Ferrero-del-Teso et al., 2022	Grape polyphenolic fractions	Kaempferol, myricetin, and laricitrin	Sorting task, rate-k attributes In mouth: bitter	Solid phase extraction (SPE), UHPLC-MS/MS, PLSR for sensory variables predictive model.
Guerreiro et al., 2022	Yellow onion flavonols extract	Quercetin 4-glucoside, quercetin 3,4′-diglucoside, quercetin, quercetin 3-glucoside, isorhamnetin 4′-glucoside, isorhamnetin 3,4′-glucoside		Oral epithelia and cell-based models (buccal mucosa TR146, tongue HSC-3, human saliva, mucin).
Anthocyanins				
Vidal et al., 2004(a)	Purified grape anthocyanin fraction in a model wine	Anthocyanidin glucosides: malvidin, peonidin, petunidin, delphinidin, and cyanidin 3-*O*-glucosides. Anthocyanidin coumarates: malvidin 3-*O*-coumaroyl-glucoside, malvidin and peonidin 3-*O*-caffeoyl-glucoside.	DA in mouth and after expectoration: intensity rating, use of touch finger standards Overall astringency, bitter	HPLC-DAD, ESI–MS/MS, SPE, multilayer coil counter-current chromatography (MLCCC).

(Continues)

TABLE 6 (Continued)

Polyphenol class	Matrix	Chemical compounds	Sensory methods and elicited descriptors	Chemical and fractionation methods/Notes
Vidal et al., 2004 (b)	Purified grape anthocyanin fraction in a model wine	Anthocyanidin glucosides (mainly malvidin-3-*O*-glucoside), anthocyanidin acetylated and *p*-coumaroylated.	DA—intensity rating session, use of touch finger standards In mouth: *fullness*. After expectoration: astringency	HPLC-DAD, Extraction on Toyopearl TSK HW-50(F) gel in a semi-preparative column, purification on a divinyl benzene-polystyrene (DVB-PS) resin column.
Vidal et al., 2004 (c)	Purified grape anthocyanin fraction in a model wine	Anthocyanidin glucosides (mainly malvidin-3-*O*-glucoside), anthocyanidin acetylated, and *p*-coumaroylated.	DA—intensity rating, use of touch finger standards In mouth: *fullness*. In mouth and after expectoration: *coarse, chalky*	HPLC-DAD, Extraction on Toyopearl TSK HW-50(F) gel in a semi-preparative column, purification on a divinyl benzene-polystyrene (DVB-PS) resin column.
Gawel et al., 2007	Red wines and red wine fractions	Malvidin-3-*O*-glucoside, malvidin-3-*O*-glucoside acetate, and malvidin-3-*O*-glucoside *p*-coumarate	DA—labeled magnitude scale (LMS) with the word anchors, use of touch finger standards In-mouth *chalk-like* texture, *puckering* sensation	HPLC.
Oberholster et al., 2009	Isolated anthocyanins in white wine ferments	Glucoside, glucosyl-acetate, glucosyl-coumarate anthocyanins	DA in mouth and after expectoration: intensity rating *Fine grain*, *fine emery*, *dry*, *grippy*, overall astringency, viscosity	RP-HPLC Extraction with isoamyl alcohol.
Ferrer-Gallego et al., 2015(b)	Anthocyanins and human salivary proteins complexes	Anthocyanidin monoglucosides: malvidin 3-*O*-glucoside, cyanidin 3-*O*-glucoside, delphinidin 3-*O*-glucoside, and petunidin 3-*O*-glucoside	Labeled magnitude scale sensory test In-mouth: astringency intensity, *dryness*, *velvety*, *greenness*, *dynamic*, *persistence*	MALDI-TOF MS, FIA-ESI-MS, (STD) NMR spectroscopy aPRPs.
Paissoni et al., 2018	Grape anthocyanin fractions	Glucoside, acetylated and cinnamoylated anthocyanins	Triangular test, in-mouth detection threshold estimation	CPC, HPLC-DAD, BSA test, saliva test.

(Continues)

TABLE 6 (Continued)

Polyphenol class	Matrix	Chemical compounds	Sensory methods and elicited descriptors	Chemical and fractionation methods/Notes
Soares et al., 2019	Anthocyanins and human salivary proteins complexes	Malvidin-3-glucoside and epicatechin: malvidin-3-*O*-glucoside mixtures	-	(STD) NMR Spectroscopy, ITC, aPRPs, bPRPs.
Paissoni et al., 2020	Grape polyphenolic fractions	Glucoside, acetylglucoside, and *p*-coumaroylglucoside anthocyanins	DA, CATA, triangle test In mouth: *particulates.* After expectoration: *surface smoothness*	HPLC-DAD, Use of touch finger standards.
Soares et al., 2020	Red wine extract	Anthocyanidin glucosides: delphinidin-3-*O*-glucoside, peonidin-3-*O*-glucoside, petunidin-3-*O*-glucoside and malvidin-3-*O*-glucoside	-	Oral epithelia and cell-based models (buccal mucosa TR146, tongue HSC-3, human saliva, mucosal pellicle).
Pigments				
Sáenz-Navajas et al., 2010	Red premium wine fractions	Anthocyanin glucosides, derivatives and anthocyanin-flavanol dimers (e.g., malvidin-catechin dimer)	DA intensity rating, sorting task of wine quality Astringency, quality groups: exceptional, good/very good, right/approved, poor/disappointing, defective/rejectable	HPLC-DAD, HPLC-ESI-MS, Size exclusion chromatography.
Gonzalo-Diago et al., 2014	Red wine fractions	A type vitisin of malvidin-3-*O*-*p*-coumaroyl-glucoside (*p*-coumaroyl-vitisin A)	DA Bitterness, *Drying* astringency, persistence	UPLC-DAD-MS, Gel permeation chromatography, SPE, PLSR for a bitter taste predictive model.
García-Estévez et al., 2017		Pyranomalvidin-3-*O*-glucoside= vitisin B; pyranomalvidin-3-*O*-glucoside-catechol= pinotin A; pyranomalvidin-3-*O*-glucoside-epicatechin= epicatechin-vitisin B	-	STD-NMR, MALDI-TOF-MS, Salivary proteins: aPRPs (PRP1, PRP3).

(Continues)

TABLE 6 (Continued)

Polyphenol class	Matrix	Chemical compounds	Sensory methods and elicited descriptors	Chemical and fractionation methods/Notes
Sáenz-Navajas et al., 2017	Red wine fractions	Trimers of anthocyanins Anthocyanin-derivative pigments	Sorting task, repertory grid, triangulation, RATA *Dryness* Persistent, *sandy*, *dry*, *dry on palate*, bitter, sour, *burning*, *hot*, prickly	UPLC-DAD-MS, MALDI-TOF-MS, Semipreparative LC, SPE, Determination of monomeric, small polymeric and large polymeric pigments.
Sáenz-Navajas et al., 2018	Red wines and red wine fractions	Anthocyanin-derivative pigments (< tetramers)	DA - intensity rating, RATA, hedonistic test (preference of in-mouth properties) Stickiness, *dry* sensations	Preparative liquid chromatography, SPE, Determination of monomeric, small polymeric and large polymeric pigments.
Ferrero-del-Teso et al., 2022	Grape polyphenolic fractions	Anthocyanin polymeric pigments	Sorting task, rate-k attributes In mouth: *sticky*	SPE, UHPLC-MS/MS, PLSR for sensory variables predictive model.

*Half-tongue test, also called half-mouth test, is used to determine human threshold concentrations of the astringent compounds.

Abbreviations: DA, descriptive analysis; RATA, rate-all-that-apply; CPC, centrifugal partition chromatography; HPLC, high performance liquid chromatography; HPLC-DAD, high performance liquid chromatography diode-array detection; UHPLC, ultra-high performance liquid chromatography; TDA, taste dilution analysis; LC–MS, liquid chromatography–mass spectrometry; NMR spectroscopy, nuclear magnetic resonance spectroscopy; (STD) NMR spectroscopy, saturation-transfer difference nuclear magnetic resonance spectroscopy; UPLC-DAD-MS, ultraperformance liquid chromatography diode-array detection mass spectrometry; MALDI-TOF-MS, matrix-assisted laser desorption/ionization time of flight mass spectrometry; HPLC-ESI-MS, high-performance liquid chromatography electrospray ionization mass spectrometry; FIA-ESI-MS, flow injection electrospray ionization mass spectrometry; SPE, solid phase extraction; MLCCC, multilayer coil counter-current chromatography; ITC, isothermal titration calorimetry; aPRPs, acidic proline-rich proteins; bPRPs, basic proline-rich proteins; BSA, bovine serum albumin; PLSR, partial least square regression.

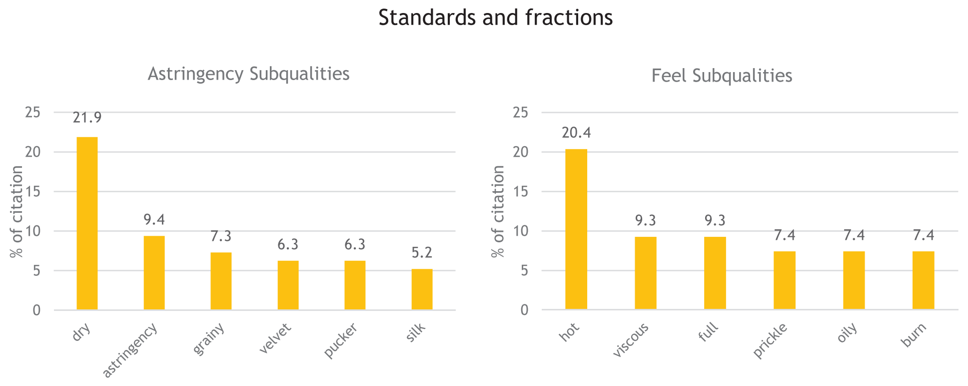

FIGURE 3 Citation frequency (%) of *astringency* subqualities and *feel* terms in standards and fractions.

wine (Ferrero-del-Teso et al., 2022; Gonzalo-Diago et al., 2014; Hufnagel & Hofmann, 2008; Paissoni et al., 2018; Sáenz-Navajas et al., 2017, 2018; Vidal et al., 2004a, 2004b, 2004c). In these studies, the identification and quantification analysis of the chemical compounds contained in the fractions is required by a mean of analytical LC coupled with spectrophotometer and mass spectrometer, as well as gel-permeation and size exclusion chromatography for tannins (Gonzalo-Diago et al., 2014; Hufnagel & Hofmann, 2008; Sáenz-Navajas et al., 2010). Last, by means of sensory analysis methods, the correlation between sensory attributes and single chemical molecules is achievable, with partial least square (PLS) regression as the most used statistical technique (Ferrero-del-Teso et al., 2022; Gonzalo-Diago et al., 2014; Sáenz-Navajas et al., 2010).

Remarkably, even in the study of grape/wine fractions, *dry* remains the most used astringent-investigated term (21.9%, Figure 3), and more precisely, wine fractions containing procyanidins and/or oligomerized flavan-3-ols have been associated with higher intensity of *dry* descriptor. In fact, the mean degree of polymerization and the tannin concentration are good predictors of *dryness* perception and *overall astringency* (9.4% of citation) (Vidal et al., 2003). In accordance with these results, tannin activity, tannin concentration, and the mean degree of polymerization (mDP) of tannins proved to be important factors for the *dryness* evaluation of phenolic fractions (Ferrero-del-Teso et al., 2022), as well as tannin concentration drives frictional forces of *dry* model wine (Wang et al., 2020). Besides, the intensity of all astringent attributes increased with tannin concentration and decreased with the addition of polysaccharides, such as rhamnogalacturonan II (Vidal et al., 2004c). Among astringency subqualities, *grainy* (7.3%), *velvet* (6.3%), *pucker* (6.3%), and *silk* (5.2%) also appeared. Besides, the subcategories of *fine/medium/coarse grain* rated in grape proanthocyanidin fractions have been related to the quantity of their extension flavanol units (Gonzalo-Diago et al., 2013; Vidal et al., 2003). It is well-known that the galloyl-substitution of flavan-3-ols increases both the hydrophobic interactions with PRP and the friction coefficient (Ma et al., 2014; Rossetti et al., 2009). Recently, their interaction with cell epithelial lipidic membranes has been also proven (Reis et al., 2020). Moreover, prodelphinidins (gallocatechin and epigallocatechin-based, B-ring trihydroxylated) are involved in smoother and velvety subqualities, with respect to di-hydroxylated B-ring procyanidins (catechin and epicatechin-based) that are reported more *dry, rough*, *unripe* (Ferrer-Gallego et al, 2015a). The former are present just in grape skins, whereas the latter are in both seeds and skins, and the galloylated-derivatives are exclusively in seeds (Ma et al., 2014). It is consolidated that the tannin content and sharing between grape tissues are varietal characteristics, although influenced by ripeness, climate, pedology, vintage, and agronomical practices. With regard to *feel* group descriptors for wine fractions' evaluation, *hot* is the most investigated (20.4%) (Ferrero-del-Teso et al., 2020, 2022; Gawel et al., 2014b).

Flavan-3-ols and tannins are the most studied classes for their contribution in astringency, and many studies confirm their essential role about mouthfeel perception. In fact, conventionally, tannins are the major class of polyphenolic compounds involved in the tannin-PRP complex formation (Arnold et al., 1980; Bate-Smith, 1954; Courregelongue et al., 1999; Joslyn & Goldstein, 1964), but also other compounds (Table 6) have been found to be implicated in the astringent stimuli, including monomers, dimers, and trimers (Naish et al., 1993; Peleg *et al.*, 1999).

Satisfactory results in the prediction of astringency by precipitation methods, such as the ones using salivary proteins or alternative proteins such as BSA, had been achieved in wine (Boulet et al., 2016; Rinaldi et al., 2012a; Schwarz & Hofmann, 2008), but soluble polyphenols may be able to activate astringency without precipitation, nonetheless. In particular, the improvement in the analysis of polyphenol–protein interactions has been achieved by the study of protein–ligand interaction by saturation transfer difference (STD)-NMR and molecular dynamic (MD) simulation or by isothermal titration calorimetry (ITC), as well as matrix-assisted laser desorption/ionization time of flight (MALDI-TOF) approaches that can be used for determination of soluble complexes (Ferrer-Gallego et al., 2014, 2015b, 2017, García-Estévez et al., 2017; Soares et al., 2019).

9.3 | Main wine metabolites influencing mouthfeel properties and their implication in winemaking

9.3.1 | Phenolic acids

The contribution of phenolic acids on mouthfeel sensory properties in wine, particularly astringency and bitter taste, has been highlighted in many studies (Ferrer-Gallego et al., 2014; Ferrer-Gallego et al., 2017; Gonzalo-Diago et al., 2014; Hufnagel & Hofmann, 2008; Sáenz-Navajas et al., 2010). Both hydroxycinnamic and hydroxybenzoic acids are key astringent compounds. Ferrer-Gallego and co-workers (2017) demonstrated for the first time the interaction between phenolic acids and salivary proteins by (STD)-NMR and molecular dynamic simulations. Notably, the affinity for the salivary peptide was higher in hydroxybenzoic acids than in hydroxycinnamic acids. Caffeic acid, *p*-coumaric acid, gallic acid, and protocatechuic acid were considered, and mixtures of these compounds rather than individual phenolic acid showed a higher affinity with PRPs, as confirmed by lower dissociation constant values (KD). In addition, when phenolic acids were tasted jointly, the perceived astringency and bitterness were higher than individual compound, indicating a synergistic effect (Ferrer-Gallego et al., 2014). Particularly, synergism was explained by the change in the secondary structure and in the receptor binding sites of salivary peptides (Ferrer-Gallego et al., 2017).

Concerning phenolic acids' sensory descriptors, they were mainly astringency, bitterness, and persistence (Ferrer-Gallego et al., 2014; Gonzalo-Diago et al., 2014; Hufnagel & Hofmann, 2008; Sáenz-Navajas, et al., 2010). *p*-Coumaric, caffeic, gallic, and protocatechuic acids induced astringency and slight bitterness, whereas as the complexity of the mixture increases, the trained panel's judgment moved to the *velvet* astringency subquality. Moreover, *trans*-caffeic and *trans*-coutaric acids had a strong significant correlation with the perceived astringency (Sáenz-Navajas et al., 2010). A few hydroxybenzoic and hydroxycinnamic acid ethyl esters were also described as bitter and *pucker* astringent in wine fractions (Hufnagel & Hofmann, 2008). Furthermore, a correlation between hydroxycinnamic acids (i.e., coutaric and *trans*-coumaric acids) and persistence attribute has been found (Gonzalo-Diago et al., 2014). In the cited study, wine fractions containing protocatechuic, *trans*-caftaric, and coutaric acids received higher scores by trained assessors for *dry* descriptor compared to those fractions in which a partial loss of phenolic acids occurred. Conversely, hydroxybenzoic and hydroxycinnamic fractions slightly contributed to *velvety* astringency. It is interesting to notice that the concentrations of coutaric and *trans*-caftaric acids were largely above their sensory thresholds of 10 and 5 mg/L, differently from *trans*-coumaric and protocatechuic acids with taste thresholds of 23 and 32 mg/L, respectively (Gonzalo-Diago et al., 2014).

Phenolic acids and their derivatives influence the sensory quality perception of wines. It has been observed that high-quality wines were associated with the presence of *trans*-coutaric and *trans*-caftaric acids, and higher concentrations of *trans*-caffeic acid (10 mg/L) were attributed to low-quality wines by experts (Sáenz-Navajas, et al., 2010). Phenolic acids, and in particular hydroxycinnamic acids, are a varietal-characteristic suggested for the discrimination of white winegrape varieties or even of natural versus artificial ice-wines (Ferrandino et al., 2012; Scalzini et. al., 2021). Nevertheless, their content is influenced by the winemaking process, in particular by oxygen management, due to their easiness to be oxidized. Winemaking techniques such as reductive winemaking of white winegrape varieties may conserve a high quantity of these compounds (Mattivi et al., 2012), and in absence of tannins extracted by grape solid maceration, their sensory implications may be relevant.

9.3.2 | Flavonols

Among the low-molecular-weight classes, flavonols play a remarkable role in the sensory qualities and complexity of wines. For instance, quercetin-3-*O*-galactoside (0–10 mg/L) is used as standard for *velvety* astringency during panel training phase (Gonzalo-Diago et al., 2014; Scharbert, et al., 2004). Flavonols are the polyphenolic class with the lowest astringency recognition threshold concentrations. Syringetin-3-*O*-β-D-glucopyranoside and quercetin-3-*O*-β-D-galactopyranoside present threshold values of 0.2 and 0.4 μmol/L, respectively

(Hufnagel & Hofmann, 2008). Similarly, quercetin-3-*O*-α-L-rhamnopyranosyl-(1→6)-β-D-glucopyranoside and quercetin-3-*O*-β-D-glucopyranoside exhibit 0.001 and 0.65 μmol/L (in water) as orosensory astringent thresholds, respectively. Nevertheless, some flavonol glycosides show no ability to form bonds with salivary proteins, suggesting the possibility of alternative mechanisms that explain astringent perception (Schwarz & Hoffman, 2008). Recently, the ability of a flavonol extract from yellow onion to interact with oral cell lines, particularly from the tongue, was demonstrated (Guerreiro et al., 2022), and this interaction (oral cell derived instead of salivary-related) may be the key to *velvety* descriptor. In fact, the astringency subqualities identified for flavonols were *velvet*, *dry*, and *pucker* (Gonzalo-Diago et al., 2014; Hufnagel & Hofmann, 2008). Particularly, quercetin and quercetin-3-*O*-rutinoside drive *dry* astringency, whereas kaempferol and quercetin-3-*O*-rutinoside have been found responsible for eliciting bitterness. Recently, red wine fractions containing flavonols have also been reported to be associated with bitter, *burn*, and *hot* sensations (Sáenz-Navajas et al., 2017), as well as main contributors of grape fractions' bitterness (Ferrero-del-Teso et al., 2022).

Flavonols are varietal markers of winegrape varieties, although they are strongly increased by UV-light exposure, thus being defined as indicators of winegrape sun exposure (Ferrandino et al., 2012; Martínez-Lüscher et al., 2019; Mattivi et al., 2006). Mainly found in grape skin as glycosides, their hydrolysis occurs in wines during aging, resulting in an increase of the free flavonols that may result in precipitation (Gambuti et al., 2020b; Makris et al., 2006). Clearly, a prolonged skin contact can increase their extraction, and the initial content may be relevant in determining in-mouth characteristics in the wine.

9.3.3 | Anthocyanins

Anthocyanins are a class of phenolic compounds primarily responsible for wine color, as well as the taste and mouthfeel properties of wines. Vidal and colleagues, 2004a, 2004b, 2004c) were among the first to observe the contribution of purified anthocyanins on the perception of astringency and its subqualities. Anthocyanidin glucosides and coumarates presented lower intensity values of astringency subterms, in comparison with proanthocyanidin- and tannin-like fractions. In particular, glucoside and coumarate anthocyanidin fractions did not significantly differ from the model wine regarding astringency subqualities, except for *dry* descriptor (Vidal et al., 2004a). Additionally, the anthocyanidin fraction evaluated in-mouth and after expectoration by a trained panel slightly increased the intensity of *fullness* and overall astringency when compared to the model wine (Vidal et al., 2004b). Anthocyanidin fraction also showed a contribution in *fullness* perception, coarseness, and chalkiness (Vidal et al., 2004c), but the presence of phenolic compounds other than the anthocyanin class could have occurred. Furthermore, Gawel et al. (2007), studying the correlation between phenolic composition and in-mouth textural characteristics of Shiraz red wines, found the *chalky* texture strongly and positively associated with anthocyanins, whereas a *puckery* sensation was attributed to low anthocyanin content wines.

Textural and sensory properties were also investigated in red juice fermented with skins and seeds, and white juice fermented with/without pomace and anthocyanin addition (Oberholster et al., 2009). The mouthfeel attributes and their intensity of white and red wines changed greatly. The presence of anthocyanins during the white juice fermentation determined an increase in the intensity of astringency-related attributes, mainly the *fine grain* astringency subquality, but also *dry*, *grippy*, and slightly viscosity and *fine emery*. Indeed, Soares et al. (2020) showed anthocyanin interaction with oral cells, which may link to different astringency subqualities, although no differences were observed among the five studied grape anthocyanidin glucosides. Previously, the ability of malvidin-3-*O*-glucoside to interact with salivary proteins forming soluble aggregates was reported (Ferrer-Gallego et al., 2015b), and when tasted at 400 mg/L concentration, anthocyanin glucosides were found to be slightly astringent (Ferrer-Gallego et al., 2015b; Paissoni et al, 2018), with *velvety* and *chalky* subqualities (Paissoni et al., 2020), whereas the substitution (acetyl- or coumaroyl-glucoside) can decrease their detection thresholds up to 68 mg/L for acetylated and 58 mg/L for cinnamoylated anthocyanins (Paissoni et al., 2018). A later study showed malvidin-3-*O*-glucoside as the driver of PRP interaction in mixtures with epicatechin, in a synergic effect that can explain why it is often difficult to correlate perceived astringency with the single compound concentration in the wine matrix (Soares et al., 2019). Particularly, the effect of anthocyanin perception may be different depending on the tannic composition (Paissoni et al., 2020).

Anthocyanins are among the most researched compounds in the wine field, and their extraction during maceration and preservation during aging are currently updated with new information. Surely, it is interesting to evaluate how their deriving structure during the winemaking process is involved also in sensory analysis.

9.3.4 | Pigments

Anthocyanin-derivative and anthocyanin-flavanol pigments showed a contribution to sensory properties (Ferrero-del-Teso et al., 2022; Sáenz-Navajas et al., 2010, 2017, 2018). More precisely, a red wine fraction containing a series of anthocyanin trimers was characterized by *dryness*, bitterness, and persistence. Monomeric and small polymeric anthocyanins were described as bitter, *burning*, and *hot*, whereas the fraction with large polymeric pigments presented many astringency subattributes, such as *sandy*, *dry*, *dry on palate*, bitter, sour, *burning*, *hot*, *prickly*, and persistent (Sáenz-Navajas et al., 2017). Low-polymerized anthocyanin derivative pigments, smaller than tetramers, also contributed to astringent perceptions and stickiness in red wine and grape fractions (Ferrero-del-Teso et al., 2022). Rinaldi et al. (2021b), studying the mannoprotein addition on free-run wines before aging, observed the formation of stable polymeric pigments: These compounds improved the wine quality and increased the perception of *silk*, *velvet*, and *mouthcoat* attributes. The interaction between isoamyl alcohol and anthocyanin derivative pigments in “green character” formation (Sáenz-Navajas, et al., 2018) has also been suggested. Interestingly, the “green character” was positively correlated with in-mouth astringency, green, *dry*, and negatively correlated with *oily* and sweet in-mouth descriptors. Red wines with a strong “green character” did not meet the preference of experts and consequently this sensory property could be a driver in the purchase choice of consumers. In addition, the correlation between the malvidin-catechin dimer and quality perception of premium red wines has been observed. In the same study, the anthocyanin content and astringency showed a significant correlation in the partial least squares regression (PLSR) model for astringency prediction (Sáenz-Navajas, et al., 2010). Gonzalo-Diago et al. (2014) studied the relation between low-molecular-weight compounds and their sensory properties in six red wines. Bitterness was positively correlated with several polyphenolic compounds, among others with pyranoanthocyanins. Interestingly, this study revealed for the first time the participation of anthocyanins and derived pigments to bitter taste, with A-type vitisin of malvidin-3-*O*-6-*p*-coumaroyl-glucoside (i.e., *p*-coumaroyl-vitisin A) being the major anthocyanin contributing to the bitterness prediction model. The *drying* astringency was also positively correlated with the presence of *p*-coumaroyl-vitisin A.

The interaction between pyranoanthocyanins and human salivary (acid) proline-rich proteins (aPRPs) was studied instrumentally for the first time by García-Estévez et al. (2017). Notably, the pigments considered in the study were pyranomalvidin-3-*O*-glucoside (i.e., vitisin B), pyranomalvidin-3-*O*-glucoside-catechol (i.e., pinotin A), and pyranomalvidin-3-*O*-glucoside-epicatechin (i.e., epicatechin-vitisin B). The molecular information by MALDI-TOF analysis showed that the anthocyanin-derived pigments, which formed the highest number of complexes with aPRPs, were in decreasing order: epicatechin-vitisin B, pinotin A, and vitisin B. Afterward, (STD)-NMR spectroscopy confirmed the binding affinity of the soluble aggregates by their dissociation constants. Vitisin B alone was associated with the highest value of KD, thus the lowest binding ability to aPRPs, while the presence of catechol or epicatechin into the pigment structure increased the interaction with aPRPs. Therefore, the presence of additional units to the pyranoanthocyanic structure greatly influences the number and the binding strength of pigment–protein complexes.

Pigment formation during wine aging and their reactivity toward flavan-3-ols are associated with the change of in-mouth properties during aging. Therefore, this topic of research remains of great scientific and practical value.

9.3.5 | Matrix effect: Ethanol, acidity, and pH

Wine is a hydroalcoholic solution in which different chemical and physical factors contribute to its complexity. Phenolic compounds present a fundamental role in the mouthfeel and more precisely in astringency of white and red wines, but they are not the only components that could influence such a complex and heterogeneous matrix. Notably, the contribution of polysaccharides, mannoproteins, ethanol, glycerol, and pH on oral sensory properties is of great interest and importance (Gawel *et al.*, 2008; Quijada-Morín et al., 2014; Rinaldi et al., 2021b; Shehadeh et al., 2019; Soares et al., 2017; Villamor et al., 2013). The presence of ethanol in wines is an additional factor which modulates taste and mouthfeel sensations and could present a suppression or enhancement effect on sensory and tactile attributes (Nurgel *et al.*, 2005; Demiglio & Pickering, 2008; Gawel et al., 2018; Laguna et al., 2017; Villamor et al., 2013). Its role in modulating the wine body was previously explained, but ethanol can also influence astringency subqualities, due to its good wetting behavior, as explained by its low friction coefficient of 0.15 at 1 mm/s (Rudge et al., 2021). In particular, ethanol addition may prevent hydrogen bond formation between saliva and tannic acid (Rinaldi et al., 2012b). However, the polyphenol–saliva aggregation dominates the frictional properties of ethanol, as the salivary lubrication layer is disorganized by phenolic compounds (Rudge et al., 2021). In addition, increasing contents of ethanol are frequently associated with bitter taste and *burning* perception (Wang et al., 2021), alongside a reduction in acidic intensity ratings (Vidal et al., 2004c). Ethanol levels were also associated with *fullness* (up to 15.9%), *lingering*, *pucker*, and *drying* (Wang et al., 2021). Nevertheless, the bitter taste could be modulated in the presence of proteoglycans, containing mannoproteins and arabinogalactan–proteins.

The masking effect of ethanol on sour taste was evident at a pH value of 3.2. In addition, flavors can be affected by an increase in ethanol concentration (Villamor et al., 2013). The increasing of bitterness sensation with ethanol content was similarly observed by Vidal et al. (2004c). Furthermore, as the ethanol content increased, the scores of *chalky*, *adhesive*, and *overall astringency* attributes were lower. In agreement with this consideration, Demiglio and Pickering (2008) observed higher scores for *pucker*, *grippy/adhesive*, and *unripe* mouthfeel properties in the dealcoholized red wines. Interestingly, in the same nonalcoholic model wine with pH 3.2, *overall astringency*, *acidity*, and *mouthcoating* intensities increased. Besides, greater intensities of *heat, viscosity*, and *velvet* attributes were correlated with higher pH values (3.4, 3.6). On the contrary, lower pH levels are commonly associated to the acidic perception, especially in white wines. Interestingly, perceived viscosity has been positively correlated to pH in white wines, rather than glycerol and polysaccharide content (Gawel et al., 2014a). Low pH value was associated with *pucker* astringency, and high acidity with *resalivation*, as sensory-tribological approaches highlighted (Wang et al., 2020, 2021). This involvement has been explained as an enhancement of salivary proteins' precipitation when the wine pH is lower than their isoelectric point (PRPs were reported to have an isoelectric point for pH values between 3.0 and 3.5), causing a loss of lubrication according to a speed up in the increase of the friction coefficient (Wang et al., 2020).

9.3.6 | Grape polysaccharides

Several families of polysaccharides are responsible for decreasing the intensity of astringent perception. As the ripening phase of grape proceeds, the release of soluble pectins from the cell walls increases and the subsequent loss of astringency occurs (Ozawa et al., 1987). The presence of pectin subunits prevents the possible formation of aggregates between tannins and salivary proteins; thus, the physiological disintegration of berry cell walls could deeply influence the oral perception of astringency in wines. In addition, in an alcoholic matrix, the loss of astringency due to the presence of carbohydrates could be explained by the competition mechanism of carbohydrates in tannin/protein interaction and by the ternary complex formation of protein/polyphenol/carbohydrates (Soares et al., 2017). Besides, ionic, hydrophilic, and hydrophobic interactions, as well as the size and structure of polysaccharides influence these astringent competitive mechanisms (Quijada-Morín et al., 2014; Soares et al., 2017). Among the main wine polysaccharides, rhamnogalacturonan-II shows a strong ability in decreasing the intensity of astringent perception, whereas neutral polysaccharides, as arabinogalactan proteins and mannoproteins, present a smaller contribution (Vidal et al., 2004a, 2004b). The decreasing effect of polysaccharides on astringency is modulated by the different polysaccharidic nature and salivary protein type (Carvalho et al., 2006a, 2006b). For instance, in the presence of α-amylase, the rhamnogalacturonan-II could prevent aggregate formation between the salivary protein and condensed tannins but does not show the same effect when IB8c (i.e., a PRP) is present (Carvalho et al., 2006a). In addition, the contribution of pectic polysaccharides in effectively reducing tannin/protein precipitation has been described by Soares et al., 2012. Nevertheless, it has been observed that oligosaccharides and their glycosyl residues are positively related to astringency perception (Boulet et al., 2016; Quijada-Morín et al., 2014).

9.3.7 | Mannoproteins from yeasts

In addition to polysaccharides from grape cell walls, the influence of mannoproteins on sensory characteristics of wines is a topic of recent in-depth study (Alcalde-Eon et al., 2019; Ramos-Pineda et al., 2018; Rinaldi et al., 2021b; Wang et al., 2021). Mannoproteins are highly glycosylated polysaccharides released in wines from yeast cell wall autolysis during alcoholic fermentation and aging (Del Barrio-Galán et al., 2012; Vidal et al., 2003). Besides, the addition of mannoproteins commercial formulations into wine is also common and widely practiced in the winemaking process. These compounds considerably improve the color and mouthfeel perception of wines, supporting a decrease in the astringent attributes (Rinaldi et al., 2021b). The modulation of mouthfeel differs according to mannoprotein structure and concentration, as well as phenolic compounds content. Particularly, mannoproteins with high molecular weight or high protein content present a greater number of binding sites, capable of interfering with the interaction between phenolics and salivary proteins. Consequently, the in-mouth astringent intensity and the negative astringency subqualities are strongly reduced. Moreover, it has been observed that the addition of commercial mannoproteins to phenolic fractions enhances the astringent attributes of roundness and softness on the palate. The inhibition effect of mannoproteins is shown at a concentration of 0.6 g/L (Wang et al., 2021). The polyphenolic content is a crucial factor in the modulation effect of mannoproteins. More precisely, the mouthfeel astringent perception of wines added with mannoproteins is influenced by the content of phenolics in wines. Rinaldi et al. (2021b) studied the influence of three different mannoproteins added before aging to wines obtained by different winemaking process (extended maceration, marc-pressed, free-run wines). In the presence of high phenolic content and tannins (extended maceration wines), a decrease in negative astringency subqualities (i.e., *dryness*, *hardness*, *unripeness*) and an increment of *mouthcoating*, *velvety*, *soft*, *satin*, and *persistent* attributes have been observed. Besides, the higher the decrease in tannins, the more positive astringent sub-terms like *velvet*, *full-body*, and *mouthcoating* are perceived. Furthermore, the same study showed that the addition of mannoproteins reduces the bitter taste in all treated wines. Finally, mannoproteins with a different chemical structure modulate perceived astringency differently. Concretely, those used to inhibit potassium bitartrate crystallization present the greatest positive mouthfeel improvement (Rinaldi et al., 2021b).

10 | CONCLUDING REMARKS AND NEW FRONTIERS FOR IN-MOUTH PROPERTIES STUDIES

Perceived wine astringency and mouthfeel properties are typically described according to different sensory methodologies, by using panels composed of consumers, trained assessors, and experts. As shown by many sensory studies, the alignment of the judges in the same sensory panel is a crucial factor. Likewise, the greater the lexical affinity among panelists of different research groups, the better comparable results obtained. Overall, the results of the present work underlined how a common thought in the definitions, reference standards, and use of the mouthfeel and astringent descriptors has not yet been achieved. In many cases, different words concern the same concept, such as *full*, *round*, and *viscous* for *body*. In other situations, the same descriptor refers to distant ideas, like *dry* for astringency wine descriptor and still wine, as well as *watery* for a wine without flavor and a wine with a weak viscosity. The scientific community should align on a common vocabulary in order to communicate the oral sensory perceptions between different experiments in the same manner. On one side, the terms traditionally related to the mouthfeel wheel could be inspiring, as well as the newest descriptors derived from the long-lasting experience of the sensory analysis. To summarize it with a sentence, "*When we judge a wine, we should all speak with the same sensory language*." Wine industries face several challenges, one of them is to establish the identity of their products and their recognizability by consumers, above all when they are not wine experts, and a common language can surely improve wine communication.

On the other hand, the study of physicochemical parameters for mouthfeel evaluation is twofold interesting to be investigated. First, knowing the mechanisms and the involved compounds allows wine technicians to modify and adapt the winemaking practices. Concerning astringency, tannin content and features are deeply involved. Additionally, climate change leads to separate technological and phenolic ripeness, which in turn could be responsible for the presence of unripe tannins, the excess of potential alcohol, or the pH increase, the latter both strongly related to the mouthfeel. Thus, a deeper understanding of the sensory implications can guide the winemaker's choices, providing a new evaluation tool. Instrumental analytical measurements sought to remove the variability of sensory analysis. Nevertheless, studying a complex matrix such as wine, fractionation is often required, and some variables risk to remain unexplored or hidden. As separation techniques and research progress, it will be possible to obtain extremely purified polyphenolic compounds' fractions, or even groups/individual salivary proteins, as well as testing mouth surface such as the use of oral cell, or new surfaces mimicking in-mouth features, such as hydrogel. The set of polyphenolic compounds and chemical–physical variables (e.g., polysaccharides, ethanol, and pH) cooperate for the overall perception of mouthfeel and astringency in wine. Several instrumental methods have been adopted to understand the different mechanisms and to contribute to a greater knowledge of in-mouth properties, as well as successful models have been adapted to describe analytically a wine in a more complete way. The new frontier of research turns to an integrated vision of in-mouth properties, and the most recent studies highlighted how the volatile fraction may also influence non-volatile compounds, particularly mouthfeel perceptions.

AUTHOR CONTRIBUTIONS

Maria Alessandra Paissoni: Writing - original draft; Conceptualization; Methodology; Formal analysis; Investigation. **Giulia Motta**: Writing - original draft; Data curation; Formal analysis; Investigation. **Simone Giacosa**: Visualization; Writing - review & editing; Methodology. **Luca Rolle**: Writing - review & editing; Supervision. **Vincenzo Gerbi**: Writing - review & editing; Funding acquisition. **Susana RÍo segade**: Writing - review & editing; Investigation; Supervision

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CONFLICT OF INTEREST STATEMENT

All authors declare no conflicts of interest.

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REFERENCES

Adams, J., Williams, A., Lancaster, B., & Foley, M. (2007). Advantages and uses of check-all-that-apply response compared to traditional scaling of attributes for salty snacks. In 7th Pangborn Sensory Science Symposium (Vol. *16*), Minneapolis, MN, USA.

Albert, A., Varela, P., Salvador, A., Hough, G., & Fiszman, S. (2011). Overcoming the issues in the sensory description of hot served food with a complex texture. Application of QDA®, flash profiling and projective mapping using panels with different degrees of training. *Food Quality and Preference*, *22*(5), 463–473. https://doi.org/10.1016/j.foodqual.2011.02.010

Alcalde-Eon, C., Ferreras-Charro, R., Ferrer-Gallego, R., Rivero, F. J., Heredia, F. J., & Escribano-Bailón, M. T. (2019). Monitoring the effects and side-effects on wine colour and flavonoid composition of the combined post-fermentative additions of seeds and mannoproteins. *Food Research International*, *126*, 108650. https://doi.org/10.1016/j.foodres.2019.108650

Araujo, L. D., Parr, W. V., Grose, C., Hedderley, D., Masters, O., Kilmartin, P. A., & Valentin, D. (2021). In-mouth attributes driving perceived quality of Pinot noir wines: Sensory and chemical characterisation. *Food Research International*, *149*, 110665. https://doi.org/10.1016/j.foodres.2021.110665

Ares, G., Bruzzone, F., Vidal, L., Cadena, R. S., Giménez, A., Pineau, B., Paisley, A. G., Denise, C. H., & Jaeger, S. R. (2014). Evaluation of a rating-based variant of check-all-that-apply questions: Rate-all-that-apply (RATA). *Food Quality and Preference*, *36*, 87–95. https://doi.org/10.1016/j.foodqual.2014.03.006

Ares, G., Antúnez, L., Bruzzone, F., Vidal, L., Giménez, A., Pineau, B., Beresford, M. K., Jin, D., Paisley, A. G., Chheang, S. L., Roigard, C. M., & Jaeger, S. R. (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. https://doi.org/10.1016/j.foodqual.2015.05.007

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. https://doi.org/10.1016/j.foodqual.2016.10.006

Arnold, R. A., Noble, A. C., & Singleton, V. L. (1980). Bitterness and astringency of phenolic fractions in wine. *Journal of Agricultural and Food Chemistry*, *28*, 675–678. https://doi.org/10.1021/jf60229a026

ASTM (2004). Standard definitions of terms relating to sensory evaluation of materials and products. In *Annual book of ASTM standards* (pp. 19–22). American Society for Testing and Materials.

Bajec, M. R., & Pickering, G. J. (2008). Astringency: Mechanisms and perception. *Critical Reviews in Food Science and Nutrition*, *48*(9), 858–875. https://doi.org/10.1080/10408390701724223

Barbe, J. C., Garbay, J., & Tempère, S. (2021). The sensory space of wines: From concept to evaluation and description. A review. *Foods*, *10*(6), 1424. https://doi.org/10.3390/foods10061424

Bate-Smith, E. C. (1954). Astringency in foods. *Food*, *23*, 124–127.

Bate-Smith, E. C. (1973). Haemanalysis of tannins: The concept of relative astringency. *Phytochemistry*, *12*, 907–912. https://doi.org/10.1016/0031-9422(73)80701-0

Bennick, A. (2002). Interaction of plant polyphenols with salivary proteins. *Critical Reviews in Oral Biology and Medicine*, *13*, 184–196. https://doi.org/10.1177/154411130201300208

Boulet, J. C., Trarieux, C., Souquet, J. M., Ducasse, M. A., Caillé, S., Samson, A., Williams, P., Doc, T., & Cheynier, V. (2016). Models based on ultraviolet spectroscopy, polyphenols, oligosaccharides and polysaccharides for prediction of wine astringency. *Food chemistry*, *190*, 357–363. https://doi.org/10.1016/j.foodchem.2015.05.062

Breslin, P. A. S., Gilmore, M. M., Beauchamp, G. K., & Green, B. G. (1993). Psychophysical evidence that oral astringency is a tactile sensation. *Chemical Senses*, *18*(4), 405–417. https://doi.org/10.1093/chemse/18.4.405

Brossard, N., Cai, H., Osorio, F., Bordeu, E., & Chen, J. (2016). "Oral" tribological study on the astringency sensation of red wines. *Journal of Texture Studies*, *47*(5), 392–402. https://doi.org/10.1111/jtxs.12184

Brossard, N., Bordeu, E., Ibáñez, R. A., Chen, J., & Osorio, F. (2020). Rheological study of tannin and protein interactions based on model systems. *Journal of Texture Studies*, *51*(4), 585–592. https://doi.org/10.1111/jtxs.12518

Brossard, N., Gonzalez-Muñoz, B., Pavez, C., Ricci, A., Wang, X., Osorio, F., Bordeu, E., Parpinello, G. P., & Chen, J. (2021). Astringency sub-qualities of red wines and the influence of wine–saliva aggregates. *International Journal of Food Science & Technology*, *56*(10), 5382–5394. https://doi.org/10.1111/ijfs.15065

Burns, D. J. W., & Noble, A. C. (1985). Evaluation of the separate contributions of viscosity and sweetness of sucrose to perceived viscosity, sweetness and bitterness of vermouth. *Journal of Texture Studies*, *16*(4), 365–380. https://doi.org/10.1111/j.1745-4603.1985.tb00703.x

Campo, E., Ballester, J., Langlois, J., Dacremont, C., & Valentin, D. (2010). Comparison of conventional descriptive analysis and a citation frequency-based descriptive method for odor profiling: An application to Burgundy Pinot noir wines. *Food Quality and Preference*, *21*(1), 44–55. https://doi.org/10.1016/j.foodqual.2009.08.001

Capitello, R., Agnoli, L., & Begalli, D. (2016). Drivers of high-involvement consumers' intention to buy PDO wines: Valpolicella PDO case study. *Journal of the Science of Food and Agriculture*, *96*(10), 3407–3417. https://doi.org/10.1002/jsfa.7521

Carlucci, A., & Monteleone, E. (2001). Statistical validation of sensory data: A study on wine. *Journal of the Science of Food and Agriculture*, *81*(8), 751–758. https://doi.org/10.1002/jsfa.879

Carvalho, E., Mateus, N., Plet, B., Pianet, I., Dufourc, E., & De Freitas, V. (2006a). Influence of wine pectic polysaccharides on the interactions between condensed tannins and salivary proteins. *Journal of Agricultural and Food Chemistry*, *54*(23), 8936–8944. https://doi.org/10.1021/jf061835h

Carvalho, E., Póvoas, M. J., Mateus, N., & De Freitas, V. (2006b). Application of flow nephelometry to the analysis of the influence of carbohydrates on protein–tannin interactions. *Journal of the*

Science of Food and Agriculture, *86*(6), 891–896. https://doi.org/10.1002/jsfa.2430

Casassa, L. F., Beaver, C. W., Mireles, M., Larsen, R. C., Hopfer, H., Heymann, H., & Harbertson, J. F. (2013). Influence of fruit maturity, maceration length, and ethanol amount on chemical and sensory properties of Merlot wines. *American Journal of Enology and Viticulture*, *64*(4), 437–449. https://doi.org/10.5344/ajev.2013.13059

Charlton, A. J., Baxter, N. J., Khan, M. L., Moir, A. J., Haslam, E., Davies, A. P., & Williamson, M. P. (2002). Polyphenol/peptide binding and precipitation. *Journal of Agricultural and Food Chemistry*, *50*, 1593–1601. https://doi.org/10.1021/jf010897z

Chong, H. H., Cleary, M. T., Dokoozlian, N., Ford, C. M., & Fincher, G. B. (2019). Soluble cell wall carbohydrates and their relationship with sensory attributes in Cabernet Sauvignon wine. *Food Chemistry*, *298*, 124745. https://doi.org/10.1016/j.foodchem.2019.05.020

Condelli, N., Dinnella, A., Cerone, A., Monteleone, E., & Bertuccioli, M. (2006). Prediction of perceived astringency induced by phenolic compounds II: Criteria for panel selection and preliminary application on wine samples. *Food Quality and Preference*, *17*, 96–107. https://doi.org/10.1016/j.foodqual.2005.04.009

Coste, A., Sousa, P., & Malfeito-Ferreira, M. (2018). Wine tasting based on emotional responses: An expedite approach to distinguish between warm and cool climate dry red wine styles. *Food Research International*, *106*, 11–21. https://doi.org/10.1016/j.foodres.2017.12.039

Courregelongue, S., Schlich, P., & Noble, A. C. (1999). Using repeated ingestion to determine the effect of sweetness, viscosity and oiliness on temporal perception of soymilk astringency. *Food Quality and Preference*, *10*, 273–279. https://doi.org/10.1016/S0950-3293(98)00055-X

Danner, L., Crump, A. M., Croker, A., Gambetta, J. M., Johnson, T. E., & Bastian, S. E. (2018). Comparison of rate-all-that-apply and descriptive analysis for the sensory profiling of wine. *American Journal of Enology and Viticulture*, *69*(1), 12–21. https://doi.org/10.5344/ajev.2017.17052

Danner, L., Niimi, J., Wang, Y., Kustos, M., Muhlack, R. A., & Bastian, S. E. (2019). Dynamic viscosity levels of dry red and white wines and determination of perceived viscosity difference thresholds. *American Journal of Enology and Viticulture*, *70*(2), 205–211. https://doi.org/10.5344/ajev.2018.18062

de Freitas, V., & Mateus, N. (2001). Nephelometric study of salivary protein-tannin aggregates. *Journal of the Science of Food and Agriculture*, *82*, 113–119. https://doi.org/10.1002/jsfa.1016

Del Barrio-Galán, R., Pérez-Magariño, S., Ortega-Heras, M., Guadalupe, Z., & Ayestarán, B. (2012). Polysaccharide characterization of commercial dry yeast preparations and their effect on white and red wine composition. *LWT-Food Science and Technology*, *48*(2), 215–223. https://doi.org/10.1016/j.lwt.2012.03.016

Demiglio, P., & Pickering, G. J. (2008). The influence of ethanol and pH on the taste and mouthfeel sensations elicited by red wine. *Journal of Food, Agriculture & Environment*, *6*(3-4), 143–150.

Diago, M. P., Vilanova, M., Blanco, J. A., & Tardáguila, J. (2010). Effects of mechanical thinning on fruit and wine composition and sensory attributes of Grenache and Tempranillo varieties (*Vitis vinifera* L.). *Australian Journal of Grape and Wine Research*, *16*(2), 314–326. https://doi.org/10.1111/j.1755-0238.2010.00094.x

Diako, C., McMahon, K., Mattinson, S., Evans, M., & Ross, C. (2016). Alcohol, tannins, and mannoprotein and their interactions influence the sensory properties of selected commercial Merlot wines: A preliminary study. *Journal of Food Science*, *81*(8), S2039–S2048. https://doi.org/10.1111/1750-3841.13389

Duan, B., Mei, Y., Chen, G., Su-Zhou, C., Li, Y., Merkeryan, H., Cui, P., Liu, W., & Liu, X. (2021). Deficit irrigation and leaf removal modulate anthocyanin and proanthocyanidin repartitioning of Cabernet Sauvignon (*Vitis vinifera* L.) grape and resulting wine profile. *Journal of the Science of Food and Agriculture*, *102*(7), 2937–2949. https://doi.org/10.1002/jsfa.11634

Edmonds, R. S., Finney, T. J., Bull, M. R., Watrelot, A. A., & Kuhl, T. L. (2021). Friction measurements of model saliva-wine solutions between polydimethylsiloxane surfaces. *Food Hydrocolloids*, *113*, 106522. https://doi.org/10.1016/j.foodhyd.2020.106522

Erasmus, D. J., Cliff, M., & Van Vuuren, H. J. (2004). Impact of yeast strain on the production of acetic acid, glycerol, and the sensory attributes of icewine. *American Journal of Enology and Viticulture*, *55*(4), 371–378.

Etaio, I., Pérez Elortondo, F. J., Albisu, M., Gaston, E., Ojeda, M., & Schlich, P. (2008). Development of a quantitative sensory method for the description of young red wines from Rioja Alavesa. *Journal of Sensory Studies*, *23*(5), 631–655. https://doi.org/10.1111/j.1745-459X.2008.00177.x

Fanzone, M. L., Sari, S. E., Mestre, M. V., Catania, A. A., Catelén, M. J., Jofré, V. P., González-Miret, M. L., Combina, M., Vazquez, F., Maturano, P., & Maturano, Y. P. (2020). Combination of pre-fermentative and fermentative strategies to produce Malbec wines of lower alcohol and pH, with high chemical and sensory quality. *OENO One*, *54*(4). https://doi.org/10.20870/oeno-one.2020.54.4.4018

Ferrandino, A., Carra, A., Rolle, L., Schneider, A., & Schubert, A. (2012). Profiling of hydroxycinnamoyl tartrates and acylated anthocyanins in the skin of 34 *Vitis vinifera* genotypes. *Journal of Agricultural and Food Chemistry*, *60*(19), 4931–4945. https://doi.org/10.1021/jf2045608

Ferrer-Gallego, R., Hernández-Hierro, J. M., Rivas-Gonzalo, J. C., & Escribano-Bailón, M. T. (2014). Sensory evaluation of bitterness and astringency sub-qualities of wine phenolic compounds: Synergistic effect and modulation by aromas. *Food Research International*, *62*, 1100–1107. https://doi.org/10.1016/j.foodres.2014.05.049

Ferrer-Gallego, R., Quijada-Morín, N., Brás, N. F., Gomes, P., de Freitas, V., Rivas-Gonzalo, J. C., & Escribano-Bailón, M. T. (2015a). Characterization of sensory properties of flavanols—a molecular dynamic approach. *Chemical Senses*, *40*(6), 381–390. https://doi.org/10.1093/chemse/bjv018

Ferrer-Gallego, R., Soares, S., Mateus, N., Rivas-Gonzalo, J., Escribano-Bailón, M. T., & Freitas, V. D. (2015b). New anthocyanin–human salivary protein complexes. *Langmuir*, *31*(30), 8392–8401. https://doi.org/10.1021/acs.langmuir.5b01122

Ferrer-Gallego, R., Hernández-Hierro, J. M., Brás, N. F., Vale, N., Gomes, P., Mateus, N., de Freitas, V., Heredia, F. J., & Escribano-Bailón, M. T. (2017). Interaction between wine phenolic acids and salivary proteins by saturation-transfer difference nuclear magnetic resonance spectroscopy (STD-NMR) and molecular dynamics simulations. *Journal of Agricultural and Food Chemistry*, *65*(31), 6434–6441. https://doi.org/10.1021/acs.jafc.6b05414

Ferrero-del-Teso, S., Suárez, A., Jeffery, D. W., Ferreira, V., Fernández-Zurbano, P., & Sáenz-Navajas, M. P. (2020). Sensory variability associated with anthocyanic and tannic fractions isolated from red wines. *Food Research International*, *136*, 109340. https://doi.org/10.1016/j.foodres.2020.109340

Ferrero-del-Teso, S., Suárez, A., Ferreira, C., Perenzoni, D., Arapitsas, P., Mattivi, F., Ferreira, V., Fernández-Zurbano, P., & Sáenz-Navajas, M. P. (2022). Modeling grape taste and mouthfeel from chemical composition. *Food Chemistry*, *371*, 131168. https://doi.org/10.1016/j.foodchem.2021.131168

Frost, S. C., Harbertson, J. F., & Heymann, H. (2017). A full factorial study on the effect of tannins, acidity, and ethanol on the temporal perception of taste and mouthfeel in red wine. *Food Quality and Preference*, *62*, 1–7. https://doi.org/10.1016/j.foodqual.2017.05.010

Frost, S. C., Sanchez, J. M., Merrell, C., Larsen, R., Heymann, H., & Harbertson, J. F. (2021). Sensory evaluation of Syrah and Cabernet Sauvignon wines: effects of harvest maturity and prefermentation soluble solids. *American Journal of Enology and Viticulture*, *72*(1), 36–45. https://doi.org/10.5344/ajev.2020.20035

Gambuti, A., Rinaldi, A., Pessina, R., & Moio, L. (2006). Evaluation of Aglianico grape skin and seed polyphenol astringency by SDS-PAGE electrophoresis of salivary proteins after the binding reaction. *Food Chemistry*, *97*, 614–620. https://doi.org/10.1016/j.foodchem.2005.05.038

Gambuti, A., Picariello, L., Rinaldi, A., Ugliano, M., & Moio, L. (2020a). Impact of 5-year bottle aging under controlled oxygen exposure on sulfur dioxide and phenolic composition of tannin-rich red wines. *OENO One*, *54*(3), 623–636. https://doi.org/10.20870/oeno-one.2020.54.3.3527

Gambuti, A., Picariello, L., Rinaldi, A., Forino, M., Blaiotta, G., Moine, V., & Moio, L. (2020b). New insights into the formation of precipitates of quercetin in Sangiovese wines. *Journal of Food Science and Technology*, *57*(7), 2602–2611. https://doi.org/10.1007/s13197-020-04296-7

Gao, Y., Tian, Y., Liu, D., Li, Z., Zhang, X. X., Li, J. M., Huang, J.-H., Wang, J., & Pan, Q. H. (2015). Evolution of phenolic compounds and sensory in bottled red wines and their co-development. *Food Chemistry*, *172*, 565–574. https://doi.org/10.1016/j.foodchem.2014.09.115

García-Estévez, I., Cruz, L., Oliveira, J., Mateus, N., de Freitas, V., & Soares, S. (2017). First evidences of interaction between pyranoanthocyanins and salivary proline-rich proteins. *Food Chemistry*, *228*, 574–581. https://doi.org/10.1016/j.foodchem.2017.02.030

Garrido-Bañuelos, G., Buica, A., Kuhlman, B., Schückel, J., Zietsman, A. J., Willats, W. G., Moore, J. P., & du Toit, W. J. (2021). Untangling the impact of red wine maceration times on wine ageing. A multidisciplinary approach focusing on extended maceration in Shiraz wines. *Food Research International*, *150*, 110697. https://doi.org/10.1016/j.foodres.2021.110697

Gawel, R., Oberholster, A., & Francis, I. L. (2000). A 'Mouth-feel Wheel': terminology for communicating the mouth-feel characteristics of red wine. *Australian Journal of Grape and Wine Research*, *6*(3), 203–207. https://doi.org/10.1111/j.1755-0238.2000.tb00180.x

Gawel, R., Iland, P. G., & Francis, I. L. (2001). Characterizing the astringency of red wine: a case study. *Food Quality and Preference*, *12*(1), 83–94. https://doi.org/10.1016/S0950-3293(00)00033-1

Gawel, R., Francis, L., & Waters, E. J. (2007). Statistical correlations between the in-mouth textural characteristics and the chemical composition of Shiraz wines. *Journal of Agricultural and Food Chemistry*, *55*(7), 2683–2687. https://doi.org/10.1021/jf0633950

Gawel, R., & Waters, E. J. (2008). The effect of glycerol on the perceived viscosity of dry white table wine. *Journal of Wine Research*, *19*(2), 109–114. https://doi.org/10.1080/09571260802622191

Gawel, R., Day, M., Van Sluyter, S. C., Holt, H., Waters, E. J., & Smith, P. A. (2014a). White wine taste and mouthfeel as affected by juice extraction and processing. *Journal of Agricultural and Food Chemistry*, *62*(41), 10008–10014. https://doi.org/10.1021/jf503082v

Gawel, R., Schulkin, A., Smith, P. A., & Waters, E. J. (2014b). Taste and textural characters of mixtures of caftaric acid and grape reaction product in model wine. *Australian Journal of Grape and Wine Research*, *20*(1), 25–30. https://doi.org/10.1111/ajgw.12056

Gawel, R., Smith, P. A., & Waters, E. J. (2016). Influence of polysaccharides on the taste and mouthfeel of white wine. *Australian Journal of Grape and Wine Research*, *22*(3), 350–357. https://doi.org/10.1111/ajgw.12222

Gawel, R., Smith, P. A., Cicerale, S., & Keast, R. (2018). The mouthfeel of white wine. *Critical Reviews in Food Science and Nutrition*, *58*(17), 2939–2956. https://doi.org/10.1080/10408398.2017.1346584

Gawel, R., Schulkin, A., Smith, P. A., Espinase, D., & McRae, J. M. (2020). Effect of dissolved carbon dioxide on the sensory properties of still white and red wines. *Australian Journal of Grape and Wine Research*, *26*(2), 172–179. https://doi.org/10.1111/ajgw.12429

Gibbins, H. L., & Carpenter, G. H. (2013). Alternative mechanisms of astringency–what is the role of saliva? *Journal of Texture Studies*, *44*(5), 364–375. https://doi.org/10.1111/jtxs.12022

González-Lázaro, M., Martínez-Lapuente, L., Palacios, A., Guadalupe, Z., Ayestarán, B., Bueno-Herrera, M., de la Cuesta, P. L., & Pérez-Magariño, S. (2019). Effects of different oenological techniques on the elaboration of adequate base wines for red sparkling wine production: phenolic composition, sensory properties and foam parameters. *Journal of the Science of Food and Agriculture*, *99*(10), 4580–4592. https://doi.org/10.1002/jsfa.9697

González-Muñoz, B., Garrido-Vargas, F., Pavez, C., Osorio, F., Chen, J., Bordeu, E., O'Brien, J. A., & Brossard, N. (2022). Wine astringency: more than just tannin–protein interactions. *Journal of the Science of Food and Agriculture*, *102*(5), 1771–1781. https://doi.org/10.1002/jsfa.11672

Gonzalo-Diago, A., Dizy, M., & Fernández-Zurbano, P. (2013). Taste and mouthfeel properties of red wines proanthocyanidins and their relation to the chemical composition. *Journal of Agricultural and Food Chemistry*, *61*(37), 8861–8870. https://doi.org/10.1021/jf401041q

Gonzalo-Diago, A., Dizy, M., & Fernández-Zurbano, P. (2014). Contribution of low molecular weight phenols to bitter taste and mouthfeel properties in red wines. *Food Chemistry*, *154*, 187–198. https://doi.org/10.1016/j.foodchem.2013.12.096

Guerreiro, C., Brandão, E., de Jesus, M., Gonçalves, L., Pérez-Gregório, R., Mateus, N., de Freitas, V., & Soares, S. (2022). New insights into the oral interactions of different families of phenolic compounds: Deepening the astringency mouthfeels. *Food Chemistry*, *375*, 131642. https://doi.org/10.1016/j.foodchem.2021.131642

Hagerman, A. E., & Butler, L. G. (1980). Determination of protein in tannin-protein participates. *Journal of Agricultural and Food Chemistry*, *28*, 944–947.

Harbertson, J. F., Mireles, M. S., Harwood, E. D., Weller, K. M., & Ross, C. F. (2009). Chemical and sensory effects of saignée, water addition, and extended maceration on high brix must. *American Journal of Enology and Viticulture*, *60*(4), 450–460.

Hayward, L., Jantzi, H., Smith, A., & McSweeney, M. B. (2020). How do consumers describe cool climate wines using projective mapping and ultra-flash profile? *Food Quality and Preference*, *86*, 104026. https://doi.org/10.1016/j.foodqual.2020.104026

Hopfer, H., Ebeler, S. E., & Heymann, H. (2012). The combined effects of storage temperature and packaging type on the sensory and chemical properties of Chardonnay. *Journal of Agricultural and Food Chemistry*, *60*(43), 10743–10754. https://doi.org/10.1021/jf302910f

Hopfer, H., & Heymann, H. (2013). A summary of projective mapping observations–The effect of replicates and shape, and individual performance measurements. *Food Quality and Preference*, *28*(1), 164–181. https://doi.org/10.1016/j.foodqual.2012.08.017

Hufnagel, J. C., & Hofmann, T. (2008). Orosensory-directed identification of astringent mouthfeel and bitter-tasting compounds in red wine. *Journal of Agricultural and Food Chemistry*, *56*(4), 1376–1386. https://doi.org/10.1021/jf073031n

Ivanova, N., Yang, Q., Bastian, S. E., Wilkinson, K. L., & Ford, R. (2022). Consumer understanding of beer and wine body: An exploratory study of an ill-defined concept. *Food Quality and Preference*, *98*, 104383. https://doi.org/10.1016/j.foodqual.2021.104383

Jaeger, S. R., & Ares, G. (2015). RATA questions are not likely to bias hedonic scores. *Food Quality and Preference*, *44*, 157–161. https://doi.org/10.1016/j.foodqual.2015.04.011

Jöbstl, E., O'Connell, J., Fairclough, J. P., & Williamson, M. P. (2004). Molecular model for astringency produced by polyphenol/protein interactions. *Biomacromolecules*, *52*, 942–949. https://doi.org/10.1021/bm0345110

Jones, P. R., Gawel, R., Francis, I. L., & Waters, E. J. (2008). The influence of interactions between major white wine components on the aroma, flavour and texture of model white wine. *Food Quality and Preference*, *19*(6), 596–607. https://doi.org/10.1016/j.foodqual.2008.03.005

Joslyn, M. A., & Goldstein, J. L. (1964). Astringency of fruits and fruit products in relation to phenolic content. *Advances in Food Research*, *13*, 179–217. https://doi.org/10.1016/S0065-2628(08)60101-9

Kang, W., Niimi, J., Muhlack, R. A., Smith, P. A., & Bastian, S. E. (2019). Dynamic characterization of wine astringency profiles using modified progressive profiling. *Food Research International*, *120*, 244–254. https://doi.org/10.1016/j.foodres.2019.02.041

Kemp, B., Trussler, S., Willwerth, J., & Inglis, D. (2019). Applying temporal check-all-that-apply (TCATA) to mouthfeel and texture properties of red wines. *Journal of Sensory Studies*, *34*(4), e12503. https://doi.org/10.1111/joss.12503

King, E. S., & Heymann, H. (2014). The effect of reduced alcohol on the sensory profiles and consumer preferences of white wine. *Journal of Sensory Studies*, *29*(1), 33–42. https://doi.org/10.1111/joss.12079

King, E. S., Stoumen, M., Buscema, F., Hjelmeland, A. K., Ebeler, S. E., Heymann, H., & Boulton, R. B. (2014). Regional sensory and chemical characteristics of Malbec wines from Mendoza and California. *Food Chemistry*, *143*, 256–267. https://doi.org/10.1016/j.foodchem.2013.07.085

King, M. C., Cliff, M. A., & Hall, J. (2003). Effectiveness of the 'Mouthfeel Wheel'for the evaluation of astringent subqualities in British Columbia red wines. *Journal of Wine Research*, *14*(2-3), 67–78. https://doi.org/10.1080/09571260410001677932

Koussissi, E., Paterson, A., & Piggott, J. R. (2003). Sensory flavour discrimination of Greek dry red wines. *Journal of the Science of Food and Agriculture*, *83*(8), 797–808. https://doi.org/10.1002/jsfa.1414

Laguna, L., & Sarkar, A. (2017). Oral tribology: update on the relevance to study astringency in wines. *Tribology-Materials, Surfaces & Interfaces*, *11*(2), 116–123. https://doi.org/10.1080/17515831.2017.1347736

Laguna, L., Sarkar, A., Bryant, M. G., Beadling, A. R., Bartolomé, B., & Moreno-Arribas, M. V. (2017). Exploring mouthfeel in model wines: Sensory-to-instrumental approaches. *Food Research International*, *102*, 478–486. https://doi.org/10.1016/j.foodres.2017.09.009

Laguna, L., Álvarez, M. D., Simone, E., Moreno-Arribas, M. V., & Bartolomé, B. (2019). Oral wine texture perception and its correlation with instrumental texture features of wine-saliva mixtures. *Foods*, *8*(6), 190. https://doi.org/10.3390/foods8060190

Langlois, J., Ballester, J., Campo, E., Dacremont, C., & Peyron, D. (2010). Combining olfactory and gustatory clues in the judgment of aging potential of red wine by wine professionals. *American Journal of Enology and Viticulture*, *61*(1), 15–22.

Lawless, H. T., & Corrigan, C. J. (1994). Semantics of astringency. In *Olfaction and taste XI* (pp. 288–292). Springer. https://doi.org/10.1007/978-4-431-68355-1_111

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices* (Vol. 2). Springer. https://doi.org/10.1007/978-1-4419-6488-5_2

Li, S., Bindon, K., Bastian, S. E., Jiranek, V., & Wilkinson, K. L. (2017). Use of winemaking supplements to modify the composition and sensory properties of Shiraz wine. *Journal of Agricultural and Food Chemistry*, *65*(7), 1353–1364. https://doi.org/10.1021/acs.jafc.6b04505

Loureiro, V., Brasil, R., & Malfeito-Ferreira, M. (2016). A new wine tasting approach based on emotional responses to rapidly recognize classic European wine styles. *Beverages*, *2*(1), 6. https://doi.org/10.3390/beverages2010006

Lu, Y., & Bennick, A. (1998). Interaction of tannin with human salivary proline-rich proteins. *Archives of Oral Biology*, *43*(9), 717–728. https://doi.org/10.1016/S0003-9969(98)00040-5

Ma, W., Guo, A., Zhang, Y., Wang, H., Liu, Y., & Li, H. (2014). A review on astringency and bitterness perception of tannins in wine. *Trends in Food Science & Technology*, *40*(1), 6–19. https://doi.org/10.1016/j.tifs.2014.08.001

Mafata, M., Brand, J., Panzeri, V., & Buica, A. (2020). Investigating the concept of South African old vine Chenin blanc. *South African Journal of Enology and Viticulture*, *41*(2), 168–182. https://doi.org/10.21548/41-2-4018

Makris, D. P., Kallithraka, S., & Kefalas, P. (2006). Flavonols in grapes, grape products and wines: Burden, profile and influential parameters. *Journal of Food Composition and Analysis*, *19*(5), 396–404. https://doi.org/10.1016/j.jfca.2005.10.003

Martínez-Lüscher, J., Brillante, L., & Kurtural, S. K. (2019). Flavonol profile is a reliable indicator to assess canopy architecture and the exposure of red wine grapes to solar radiation. *Frontiers in Plant Science*, *10*, 10. https://doi.org/10.3389/fpls.2019.00010

Mattivi, F., Guzzon, R., Vrhovsek, U., Stefanini, M., & Velasco, R. (2006). Metabolite profiling of grape: flavonols and anthocyanins.

Journal of Agricultural and Food Chemistry, *54*(20), 7692–7702. https://doi.org/10.1021/jf061538c

Mattivi, F., Fedrizzi, B., Zenato, A., Tiefenthaler, P., Tempesta, S., Perenzoni, D., Cantarella, P., Simeoni, F., & Vrhovsek, U. (2012). Development of reliable analytical tools for evaluating the influence of reductive winemaking on the quality of Lugana wines. *Analytica Chimica Acta*, *732*, 194–202. https://doi.org/10.1016/j.aca.2011.11.051

McMahon, K. M., Culver, C., Castura, J. C., & Ross, C. F. (2017a). Perception of carbonation in sparkling wines using descriptive analysis (DA) and temporal check-all-that-apply (TCATA). *Food Quality and Preference*, *59*, 14–26. https://doi.org/10.1016/j.foodqual.2017.01.017

McMahon, K. M., Diako, C., Aplin, J., Mattinson, D. S., Culver, C., & Ross, C. F. (2017b). Trained and consumer panel evaluation of sparkling wines sweetened to brut or demi sec residual sugar levels with three different sugars. *Food Research International*, *99*, 173–185. https://doi.org/10.1016/j.foodres.2017.05.020

Mezei, L. V., Johnson, T. E., Goodman, S., Collins, C., & Bastian, S. E. (2021). Meeting the demands of climate change: Australian consumer acceptance and sensory profiling of red wines produced from non-traditional red grape varieties. *OENO One*, *55*(2), 29–46. https://doi.org/10.20870/oeno-one.2021.55.2.4571

Minnaar, P. P., Jolly, N. P., & Ntushelo, N. S. (2020). Effect of grapevine canopy side on selected sensory attributes of Pinotage and Cabernet Sauvignon wines. *South African Journal of Enology and Viticulture*, *41*(1), 1–7. https://doi.org/10.21548/41-1-3619

Mirarefi, S., Menke, S. D., & Lee, S. Y. (2004). Sensory profiling of Chardonel wine by descriptive analysis. *Journal of Food Science*, *69*(6), S211–S217. https://doi.org/10.1111/j.1365-2621.2004.tb11007.x

Moss, R., Healey, K., Hayward, L., & McSweeney, M. B. (2021). Projective mapping and ultra-flash profile studies should include a list of descriptors and definitions: An investigation into descriptors used by untrained panelists. *Journal of Sensory Studies*, *36*(5), e12688. https://doi.org/10.1111/joss.12688

Naish, M., Clifford, M. N., & Birch, G. G. (1993). Sensory astringency of 5-O-caffeoylquinic acid, tannic acid and grape-seed tannin by a time-intensity procedure. *Journal of the Science of Food and Agriculture*, *61*, 57–64. https://doi.org/10.1002/jsfa.2740610110

Nel, A. P., Louw, L., Lambrechts, M. G., & Van Rensburg, P. (2015). The influences of different winemaking techniques on the mouthfeel of Shiraz grapes. *South African Journal of Enology and Viticulture*, *36*(1), 71–93. https://doi.org/10.21548/36-1-938

Niimi, J., Danner, L., Li, L., Bossan, H., & Bastian, S. E. (2017). Wine consumers' subjective responses to wine mouthfeel and understanding of wine body. *Food Research International*, *99*, 115–122. https://doi.org/10.1016/j.foodres.2017.05.015

Noble, A. C., & Bursick, G. F. (1984). The contribution of glycerol to perceived viscosity and sweetness in white wine. *American Journal of Enology and Viticulture*, *35*(2), 110–112.

Noble, A. C., Arnold, R. A., Masuda, B. M., Pecore, S. D., Schmidt, J. O., & Stern, P. M. (1984). Progress towards a standardized system of wine aroma terminology. *American Journal of Enology and Viticulture*, *35*(2), 107–109.

Noble, A. C., Arnold, R. A., Buechsenstein, J., Leach, E. J., Schmidt, J. O., & Stern, P. M. (1987). Modification of a standardized system of wine aroma terminology. *American Journal of Enology and Viticulture*, *38*(2), 143–146.

Nurgel, C., & Pickering, G. (2005). Contribution of glycerol, ethanol and sugar to the perception of viscosity and density elicited by model white wines. *Journal of Texture Studies*, *36*(3), 303–323. https://doi.org/10.1111/j.1745-4603.2005.00018.x

Oberholster, A., Francis, I. L., Iland, P. G., & Waters, E. J. (2009). Mouthfeel of white wines made with and without pomace contact and added anthocyanins. *Australian Journal of Grape and Wine Research*, *15*(1), 59–69. https://doi.org/10.1111/j.1755-0238.2008.00038.x

Ou, C., Du, X., Shellie, K., Ross, C., & Qian, M. C. (2010). Volatile compounds and sensory attributes of wine from cv. Merlot (*Vitis vinifera* L.) grown under differential levels of water deficit with or without a kaolin-based, foliar reflectant particle film. *Journal of Agricultural and Food Chemistry*, *58*(24), 12890–12898. https://doi.org/10.1021/jf102587x

Ozawa, T., Lilley, T. H., & Haslam, E. (1987). Polyphenol interactions: astringency and the loss of astringency in ripening fruit. *Phytochemistry*, *26*(11), 2937–2942. https://doi.org/10.1016/S0031-9422(00)84566-5

Pagliarini, E., Laureati, M., & Gaeta, D. (2013). Sensory descriptors, hedonic perception and consumer's attitudes to Sangiovese red wine deriving from organically and conventionally grown grapes. *Frontiers in Psychology*, *4*, 896. https://doi.org/10.3389/fpsyg.2013.00896

Paissoni, M. A., Waffo-Teguo, P., Ma, W., Jourdes, M., Rolle, L., & Teissedre, P. L. (2018). Chemical and sensorial investigation of in-mouth sensory properties of grape anthocyanins. *Scientific Reports*, *8*(1), 1–13. https://doi.org/10.1038/s41598-018-35355-x

Paissoni, M. A., Waffo-Teguo, P., Ma, W., Jourdes, M., Giacosa, S., Segade, S. R., Rolle, L., & Teissedre, P. L. (2020). Sensory assessment of grape polyphenolic fractions: an insight into the effects of anthocyanins on in-mouth perceptions. *OENO One*, *54*(4), 1059–1075. https://doi.org/10.20870/oeno-one.2020.54.4.4142

Panzeri, V., Ipinge, H. N., & Buica, A. (2020). Evaluation of South African chenin blanc wines made from six different trellising systems using a chemical and sensorial approach. *South African Journal of Enology and Viticulture*, *41*(2), 133–150. https://doi.org/10.21548/41-2-3889

Peleg, H., & Noble, A. C. (1999). Effect of viscosity, temperature and pH on astringency in cranberry juice. *Food Quality and Preference*, *100*, 343–347. https://doi.org/10.1016/S0950-3293(99)00009-9

Picariello, L., Rinaldi, A., Forino, M., Errichiello, F., Moio, L., & Gambuti, A. (2020). Effect of different enological tannins on oxygen consumption, phenolic compounds, color and astringency evolution of Aglianico wine. *Molecules*, *25*(20), 4607. https://doi.org/10.3390/molecules25204607

Pickering, G. J., & Robert, G. (2006). Perception of mouthfeel sensations elicited by red wine are associated with sensitivity to 6-n-propylthiouracil. *Journal of Sensory Studies*, *21*(3), 249–265. https://doi.org/10.1111/j.1745-459X.2006.00065.x

Pickering, G. J., & Demiglio, P. (2008). The white wine mouthfeel wheel: A lexicon for describing the oral sensations elicited by white wine. *Journal of Wine Research*, *19*(1), 51–67. https://doi.org/10.1080/09571260802164038

Pickering, G. J., & Nikfardjam, P. (2008). Influence of variety and commercial yeast preparation on red wine made from autochthonous Hungarian and Canadian grapes. Part II. Oral sensations and sensory: instrumental relationships. *European Food*

Research and Technology, *227*(3), 925–931. https://doi.org/10.1007/s00217-007-0807-5

Pineau, B., Trought, M. C., Stronge, K., Beresford, M. K., Wohlers, M. W., & Jaeger, S. R. (2011). Influence of fruit ripeness and juice chaptalisation on the sensory properties and degree of typicality expressed by Sauvignon Blanc wines from Marlborough, New Zealand. *Australian Journal of Grape and Wine Research*, *17*(3), 358–367. https://doi.org/10.1111/j.1755-0238.2011.00160.x

Piombino, P., Pittari, E., Gambuti, A., Curioni, A., Giacosa, S., Mattivi, F., Parpinello, G. P., Rolle, L., Ugliano, M., & Moio, L. (2020). Preliminary sensory characterisation of the diverse astringency of single cultivar Italian red wines and correlation of sub-qualities with chemical composition. *Australian Journal of Grape and Wine Research*, *26*(3), 233–246. https://doi.org/10.1111/ajgw.12431

Pittari, E., Moio, L., Arapitsas, P., Curioni, A., Gerbi, V., Parpinello, G. P., Ugliano, M., & Piombino, P. (2020). Exploring olfactory–oral cross-modal interactions through sensory and chemical characteristics of Italian red wines. *Foods*, *9*(11), 1530. https://doi.org/10.3390/foods9111530

Poveromo, A. R., & Hopfer, H. (2019). Temporal check-all-that-apply (TCATA) reveals matrix interaction effects on flavor perception in a model wine matrix. *Foods*, *8*(12), 641. https://doi.org/10.3390/foods8120641

Quijada-Morín, N., Williams, P., Rivas-Gonzalo, J. C., Doco, T., & Escribano-Bailón, M. T. (2014). Polyphenolic, polysaccharide and oligosaccharide composition of Tempranillo red wines and their relationship with the perceived astringency. *Food Chemistry*, *154*, 44–51. https://doi.org/10.1016/j.foodchem.2013.12.101

Ramos-Pineda, A. M., García-Estévez, I., Dueñas, M., & Escribano-Bailón, M. T. (2018). Effect of the addition of mannoproteins on the interaction between wine flavonols and salivary proteins. *Food Chemistry*, *264*, 226–232. https://doi.org/10.1016/j.foodchem.2018.04.119

Reis, A., Soares, S., Sousa, C. F., Dias, R., Gameiro, P., Soares, S., & de Freitas, V. (2020). Interaction of polyphenols with model membranes: Putative implications to mouthfeel perception. *Biochimica et Biophysica Acta (BBA)-Biomembranes*, *1862*(2), 183133. https://doi.org/10.1016/j.bbamem.2019.183133

Rinaldi, A., Gambuti, A., & Moio, L. (2012a). Application of the SPI (Saliva Precipitation Index) to the evaluation of red wine astringency. *Food Chemistry*, *135*(4), 2498–2504. https://doi.org/10.1016/j.foodchem.2012.07.031

Rinaldi, A., Gambuti, A., & Moio, L. (2012b). Precipitation of salivary proteins after the interaction with wine: The effect of ethanol, ph, fructose, and mannoproteins. *Journal of Food Science*, *77*(4), C485–C490. https://doi.org/10.1111/j.1750-3841.2012.02639.x

Rinaldi, A., & Moio, L. (2018). Effect of enological tannin addition on astringency subqualities and phenolic content of red wines. *Journal of Sensory Studies*, *33*(3), e12325. https://doi.org/10.1111/joss.12325

Rinaldi, A., Coppola, M., & Moio, L. (2019). Aging of Aglianico and Sangiovese wine on mannoproteins: Effect on astringency and colour. *LWT*, *105*, 233–241. https://doi.org/10.1016/j.lwt.2019.02.034

Rinaldi, A., Louazil, P., Iturmendi, N., Moine, V., & Moio, L. (2020a). Effect of marc pressing and geographical area on Sangiovese wine quality. *LWT*, *118*, 108728. https://doi.org/10.1016/j.lwt.2019.108728

Rinaldi, A., Moine, V., & Moio, L. (2020b). Astringency subqualities and sensory perception of Tuscan Sangiovese wines. *OENO One*, *54*(1), 75–85. https://doi.org/10.20870/oeno-one.2020.54.1.2523

Rinaldi, A., Vecchio, R., & Moio, L. (2021a). Differences in astringency subqualities evaluated by consumers and trained assessors on Sangiovese wine using check-all-that-apply (CATA). *Foods*, *10*(2), 218. https://doi.org/10.3390/foods10020218

Rinaldi, A., Gonzalez, A., Moio, L., & Gambuti, A. (2021b). Commercial Mannoproteins Improve the Mouthfeel and Colour of Wines Obtained by excessive tannin extraction. *Molecules*, *26*(14), 4133. https://doi.org/10.3390/molecules26144133

Rinaldi, A., Picariello, L., Soares, S., Brandão, E., de Freitas, V., Moio, L., & Gambuti, A. (2021c). Effect of oxidation on color parameters, tannins, and sensory characteristics of Sangiovese wines. *European Food Research and Technology*, *247*(12), 2977–2991. https://doi.org/10.1007/s00217-021-03851-6

Rinaldi, A., Errichiello, F., & Moio, L. (2021d). Alternative fining of Sangiovese wine: Effect on phenolic substances and sensory characteristics. *Australian Journal of Grape and Wine Research*, *27*(1), 128–137. https://doi.org/10.1111/ajgw.12466

Risvik, E., McEwan, J. A., Colwill, J. S., Rogers, R., & Lyon, D. H. (1994). Projective mapping: A tool for sensory analysis and consumer research. *Food Quality and Preference*, *5*(4), 263–269. https://doi.org/10.1016/0950-3293(94)90051-5

Rochfort, S., Ezernieks, V., Bastian, S. E., & Downey, M. O. (2010). Sensory attributes of wine influenced by variety and berry shading discriminated by NMR metabolomics. *Food Chemistry*, *121*(4), 1296–1304. https://doi.org/10.1016/j.foodchem.2010.01.067

Rossetti, D., Bongaerts, J. H. H., Wantling, E., Stokes, J. R., & Williamson, A. M. (2009). Astringency of tea catechins: More than an oral lubrication tactile percept. *Food Hydrocolloids*, *23*(7), 1984–1992. https://doi.org/10.1016/j.foodhyd.2009.03.001

Rudge, R. E. D., Fuhrmann, P. L., Scheermeijer, R., van der Zanden, E. M., Dijksman, J. A., & Scholten, E. (2021). A tribological approach to astringency perception and astringency prevention. *Food Hydrocolloids*, *121*, 106951. https://doi.org/10.1016/j.foodhyd.2021.106951

Runnebaum, R. C., Boulton, R. B., Powell, R. L., & Heymann, H. (2011). Key constituents affecting wine body–An exploratory study. *Journal of Sensory Studies*, *26*(1), 62–70. https://doi.org/10.1111/j.1745-459X.2010.00322.x

Sáenz-Navajas, M. P., Tao, Y. S., Dizy, M., Ferreira, V., & Fernández-Zurbano, P. (2010). Relationship between nonvolatile composition and sensory properties of premium Spanish red wines and their correlation to quality perception. *Journal of Agricultural and Food Chemistry*, *58*(23), 12407–12416. https://doi.org/10.1021/jf102546f

Sáenz-Navajas, M. P., Martín-López, C., Ferreira, V., & Fernandez-Zurbano, P. (2011). Sensory properties of premium Spanish red wines and their implication in wine quality perception. *Australian Journal of Grape and Wine Research*, *17*(1), 9–19. https://doi.org/10.1111/j.1755-0238.2010.00115.x

Sáenz-Navajas, M. P., Avizcuri, J. M., Echávarri, J. F., Ferreira, V., Fernández-Zurbano, P., & Valentin, D. (2016). Understanding quality judgements of red wines by experts: Effect of evaluation condition. *Food Quality and Preference*, *48*, 216–227. https://doi.org/10.1016/j.foodqual.2015.10.001

Sáenz-Navajas, M. P., Avizcuri, J. M., Ferrero-del-Teso, S., Valentin, D., Ferreira, V., & Fernández-Zurbano, P. (2017). Chemo-sensory characterization of fractions driving different mouthfeel properties in red wines. *Food Research International*, *94*, 54–64. https://doi.org/10.1016/j.foodres.2017.02.002

Sáenz-Navajas, M. P., Henschen, C., Cantu, A., Watrelot, A. A., & Waterhouse, A. L. (2018). Understanding microoxygenation: Effect of viable yeasts and sulfur dioxide levels on the sensory properties of a Merlot red wine. *Food Research International*, *108*, 505–515. https://doi.org/10.1016/j.foodres.2018.03.081

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*, 108945. https://doi.org/10.1016/j.foodres.2019.108945

Sarkar, A., & Krop, E. M. (2019). Marrying oral tribology to sensory perception: A systematic review. *Current Opinion in Food Science*, *27*, 64–73. https://doi.org/10.1016/j.cofs.2019.05.007

Scalzini, G., Giacosa, S., Río Segade, S., Paissoni, M. A., & Rolle, L. (2021). Effect of withering process on the evolution of phenolic acids in winegrapes: A systematic review. *Trends in Food Science & Technology*, *116*, 545–558. https://doi.org/10.1016/j.tifs.2021.08.004

Scharbert, S., Holzmann, N., & Hofmann, T. (2004). Identification of the astringent taste compounds in black tea infusions by combining instrumental analysis and human bioresponse. *Journal of Agricultural and Food Chemistry*, *52*(11), 3498–3508. https://doi.org/10.1021/jf049802u

Schlosser, J., Reynolds, A. G., King, M., & Cliff, M. (2005). Canadian terroir: sensory characterization of Chardonnay in the Niagara Peninsula. *Food Research International*, *38*(1), 11–18. https://doi.org/10.1016/j.foodres.2004.07.003

Schwarz, B., & Hofmann, T. (2008). Is there a direct relationship between oral astringency and human salivary protein binding? *European Food Research and Technology*, *227*(6), 1693–1698. https://doi.org/10.1007/s00217-008-0895-x

Sereni, A., Osborne, J., & Tomasino, E. (2016). Exploring retro-nasal aroma's influence on mouthfeel perception of Chardonnay wines. *Beverages*, *2*(1), 7. https://doi.org/10.3390/beverages2010007

Sereni, A., Phan, Q., Osborne, J., & Tomasino, E. (2020). Impact of the timing and temperature of malolactic fermentation on the aroma composition and mouthfeel properties of chardonnay wine. *Foods*, *9*(6), 802. https://doi.org/10.3390/foods9060802

Shehadeh, A., Kechagia, D., Evangelou, A., Tataridis, P., & Shehadeh, F. (2019). Effect of ethanol, glycerol, glucose and tartaric acid on the viscosity of model aqueous solutions and wine samples. *Food Chemistry*, *300*, 125191. https://doi.org/10.1016/j.foodchem.2019.125191

Shewan, H. M., Pradal, C., & Stokes, J. R. (2020). Tribology and its growing use toward the study of food oral processing and sensory perception. *Journal of Texture Studies*, *51*(1), 7–22. https://doi.org/10.1111/jtxs.12452

Simon, C., Barathieu, K., Laguerre, M., Schmitter, J., Fouquet, E., Pianet, I., & Dufourc, E. J. (2003). Three-dimensional structure and dynamics of wine tannin-saliva protein complexes. A multitechnique approach. *Biochemistry*, *42*(35), 10385–10395. https://doi.org/10.1021/bi034354p

Skogerson, K., Runnebaum, R. O. N., Wohlgemuth, G., De Ropp, J., Heymann, H., & Fiehn, O. (2009). Comparison of gas chromatography-coupled time-of-flight mass spectrometry and ^{1}H nuclear magnetic resonance spectroscopy metabolite identification in white wines from a sensory study investigating wine body. *Journal of Agricultural and Food Chemistry*, *57*(15), 6899–6907. https://doi.org/10.1021/jf9019322

Soares, S., Mateus, N., & de Freitas, V. (2012). Interaction of different classes of salivary proteins with food tannins. *Food Research International*, *49*(2), 807–813. https://doi.org/10.1016/j.foodres.2012.09.008

Soares, S., Brandão, E., Mateus, N., & de Freitas, V. (2017). Sensorial properties of red wine polyphenols: Astringency and bitterness. *Critical Reviews in Food Science and Nutrition*, *57*(5), 937–948. https://doi.org/10.1080/10408398.2014.946468

Soares, S., Silva, M. S., Garcia-Estevez, I., Brandão, E., Fonseca, F., Ferreira-da-Silva, F., Teresa Escribano-Bailón, M., Mateus, N., & de Freitas, V. (2019). Effect of malvidin-3-glucoside and epicatechin interaction on their ability to interact with salivary proline-rich proteins. *Food chemistry*, *276*, 33–42. https://doi.org/10.1016/j.foodchem.2018.09.167

Soares, S., Soares, S., Brandão, E., Guerreiro, C., Mateus, N., & de Freitas, V. (2020). Oral interactions between a green tea flavanol extract and red wine anthocyanin extract using a new cell-based model: Insights on the effect of different oral epithelia. *Scientific Reports*, *10*(1), 1–16. https://doi.org/10.1038/s41598-020-69531-9

Sokolowsky, M., Rosenberger, A., & Fischer, U. (2015). Sensory impact of skin contact on white wines characterized by descriptive analysis, time–intensity analysis and temporal dominance of sensations analysis. *Food Quality and Preference*, *39*, 285–297. https://doi.org/10.1016/j.foodqual.2014.07.002

Torrico, D. D., Han, Y., Sharma, C., Fuentes, S., Gonzalez Viejo, C., & Dunshea, F. R. (2020). Effects of context and virtual reality environments on the wine tasting experience, acceptability, and emotional responses of consumers. *Foods*, *9*(2), 191. https://doi.org/10.3390/foods9020191

Umali, A. P., Ghanem, E., Hopfer, H., Hussain, A., Kao, Y. T., Zabanal, L. G., Wilkins, B. J., Hobza, C., Quach, D. K., Fredell, M., Heymann, H., & Anslyn, E. V. (2015). Grape and wine sensory attributes correlate with pattern-based discrimination of Cabernet Sauvignon wines by a peptidic sensor array. *Tetrahedron*, *71*(20), 3095–3099. https://doi.org/10.1016/j.tet.2014.09.062

Upadhyay, R., Brossard, N., & Chen, J. (2016). Mechanisms underlying astringency: Introduction to an oral tribology approach. *Journal of Physics D: Applied Physics*, *49*(10), 104003. https://doi.org/10.1088/0022-3727/49/10/104003

Valentin, D., Chollet, S., Lelièvre, M., & Abdi, H. (2012). Quick and dirty but still pretty good: A review of new descriptive methods in food science. *International Journal of Food Science & Technology*, *47*(8), 1563–1578. https://doi.org/10.1111/j.1365-2621.2012.03022.x

Varela, P., & Ares, G. (2012). Sensory profiling, the blurred line between sensory and consumer science. A review of novel methods for product characterization. *Food Research International*, *48*(2), 893–908. https://doi.org/10.1016/j.foodres.2012.06.037

Vera, L., Aceña, L., Boqué, R., Guasch, J., Mestres, M., & Busto, O. (2010). Application of an electronic tongue based on FT-MIR to emulate the gustative mouthfeel "tannin amount" in red wines. *Analytical and Bioanalytical Chemistry*, *397*(7), 3043–3049. https://doi.org/10.1007/s00216-010-3852-z

Vidal, L., Giménez, A., Medina, K., Boido, E., & Ares, G. (2015). How do consumers describe wine astringency? *Food Research International*, *78*, 321–326. https://doi.org/10.1016/j.foodres.2015.09.025

Vidal, L., Antúnez, L., Giménez, A., Medina, K., Boido, E., & Ares, G. (2016). Dynamic characterization of red wine astringency: Case study with Uruguayan Tannat wines. *Food Research International*, *82*, 128–135. https://doi.org/10.1016/j.foodres.2016.02.002

Vidal, L., Antúnez, L., Giménez, A., Medina, K., Boido, E., & Ares, G. (2018). Astringency evaluation of Tannat wines: Comparison of assessments from trained assessors and experts. *Journal of Sensory Studies*, *33*(3), e12330. https://doi.org/10.1111/joss.12330

Vidal, S., Francis, L., Guyot, S., Marnet, N., Kwiatkowski, M., Gawel, R., Cheynier, V., & Waters, E. J. (2003). The mouth-feel properties of grape and apple proanthocyanidins in a wine-like medium. *Journal of the Science of Food and Agriculture*, *83*(6), 564–573. https://doi.org/10.1002/jsfa.1394

Vidal, S., Francis, L., Noble, A., Kwiatkowski, M., Cheynier, V., & Waters, E. (2004a). Taste and mouth-feel properties of different types of tannin-like polyphenolic compounds and anthocyanins in wine. *Analytica Chimica Acta*, *513*(1), 57–65. https://doi.org/10.1016/j.aca.2003.10.017

Vidal, S., Francis, L., Williams, P., Kwiatkowski, M., Gawel, R., Cheynier, V., & Waters, E. (2004b). The mouth-feel properties of polysaccharides and anthocyanins in a wine like medium. *Food Chemistry*, *85*(4), 519–525. https://doi.org/10.1016/S0308-8146(03)00084-0

Vidal, S., Courcoux, P., Francis, L., Kwiatkowski, M., Gawel, R., Williams, P., Waters, E., & Cheynier, V. (2004c). Use of an experimental design approach for evaluation of key wine components on mouth-feel perception. *Food Quality and Preference*, *15*(3), 209–217. https://doi.org/10.1016/S0950-3293(03)00059-4

Villamor, R. R., Evans, M. A., & Ross, C. F. (2013). Effects of ethanol, tannin, and fructose concentrations on sensory properties of model red wines. *American Journal of Enology and Viticulture*, *64*(3), 342–348. https://doi.org/10.5344/ajev.2013.12118

Walker, R. R., Blackmore, D. H., Clingeleffer, P. R., Holt, H., Pearson, W., & Francis, I. L. (2019). Effect of rootstock on yield, grape composition and wine sensory attributes of Shiraz grown in a moderately saline environment. *Australian Journal of Grape and Wine Research*, *25*(4), 414–429. https://doi.org/10.1111/ajgw.12409

Wang, S., Mantilla, S. M. O., Smith, P. A., Stokes, J. R., & Smyth, H. E. (2020). Astringency sub-qualities drying and pucker are driven by tannin and pH–Insights from sensory and tribology of a model wine system. *Food Hydrocolloids*, *109*, 106109. https://doi.org/10.1016/j.foodhyd.2020.106109

Wang, S., Mantilla, S. M. O., Smith, P. A., Stokes, J. R., & Smyth, H. E. (2021). Tribology and QCM-D approaches provide mechanistic insights into red wine mouthfeel, astringency sub-qualities and the role of saliva. *Food Hydrocolloids*, *120*, 106918. https://doi.org/10.1016/j.foodhyd.2021.106918

Watrelot, A. A., Byrnes, N. K., Heymann, H., & Kennedy, J. A. (2016). Understanding the relationship between red wine matrix, tannin activity, and sensory properties. *Journal of Agricultural and Food Chemistry*, *64*(47), 9116–9123. https://doi.org/10.1021/acs.jafc.6b03767

Watrelot, A. A., Kuhl, T. L., & Waterhouse, A. L. (2019). Friction forces of saliva and red wine on hydrophobic and hydrophilic surfaces. *Food Research International*, *116*, 1041–1046. https://doi.org/10.1016/j.foodres.2018.09.043

White, M. R. H., & Heymann, H. (2015). Assessing the sensory profiles of sparkling wine over time. *American Journal of Enology and Viticulture*, *66*(2), 156–163. https://doi.org/10.5344/ajev.2014.14091

Yan, Q., & Bennick, A. (1995). Identification of histatins as tannin-binding proteins in human saliva. *Biochemical Journal*, *311*, 341–347. https://doi.org/10.1042/bj3110341

Yanniotis, S., Kotseridis, G., Orfanidou, A., & Petraki, A. (2007). Effect of ethanol, dry extract and glycerol on the viscosity of wine. *Journal of Food Engineering*, *81*(2), 399–403. https://doi.org/10.1016/j.jfoodeng.2006.11.014

SUPPORTING INFORMATION

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