SENSORY AND ANALYTICAL ASSESSMENT OF SPARKLING WINES

By

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To the Faculty of Washington State University:

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SENSORY AND ANALYTICAL ASSESSMENT OF SPARKLING WINES

Abstract

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Sparkling wine is a complex, alcoholic beverage in which carbonation provides its characteristic effervescence. The overall objective of this study was to investigate the role of certain processing decisions on final sparkling wine. In the first study, wines were made by adjusting the sugar concentration added to the liqueur de tirage to yield varying levels of carbonation (0–7.5 g CO₂/L). A consumer study (n=48) used a paired comparison test to compare sparkling wines of different carbonation levels (1.2, 2.0, 4.0, 5.8, or 7.5 g CO₂/L) to a control wine (0 g CO₂/L). Results indicated at least 2.0 g CO₂/L was needed for consumers to perceive the attributes of carbonation and “bite” (p≤0.001). A trained sensory panel evaluated these sparkling wines varying in carbonation using both static (Descriptive Analysis; DA) and dynamic (Temporal Check-All-That-Apply; TCATA) methodologies. Carbonation significantly influenced all mouthfeel attributes (p≤0.05). From the TCATA results, temporal curves separated attributes into early onset (proportion of citation peaked within 15 sec of evaluation) and delayed onset (proportion of citation peaked after 15 sec of evaluation). In the second set of studies, the dosage was adjusted at the finishing stages of sparkling wine production to vary residual sugar level (brut and demi sec) and sugar type (fructose, glucose, or sucrose). Trained sensory panel
evaluations revealed residual sugar level*sugar type interaction significantly influenced the flavor and taste attributes of sparkling wines (p<0.05). Likewise, residual sugar level*sugar type significantly influenced carbonation and overall acceptance (p<0.05). Consumers rated sweeter wines as significantly more “refreshing” as compared to a control wine with no added sugar (p<0.05). External preference mapping revealed two clusters of consumers, cluster 1 liking sweeter wines and cluster 2 liking drier wines, which suggests that consumer preference is segmented based upon sweetness affinity. The application of novel sensory methodologies (TCATA) for sparkling wine carbonation evaluation and characterization detailed the temporality and complexity of the perception of carbonation. Overall, this research has contributed to the previously understudied area of sparkling wine processing, demonstrating the influence of carbonation and residual sweetness as evaluated by analytical techniques and sensory analysis with consumers and trained panelists.
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CHAPTER I
INTRODUCTION

Since 2014, the global wine market has grown by 11.5%. Contributing to the growth of this market was the increased consumption of the whole sparkling wine category, including Champagne, Moscato, Prosecco, and other non-Champagne sparkling wines (Wine Institute, 2016; BNP Media, 2016). Industry experts forecast by 2019 that global consumption of sparkling wines will increase by an additional 7.4% (Vinexpo, 2016).

Sparkling wine is defined as a multicomponent hydroalcoholic solution supersaturated with CO₂-dissolved gas molecules (Liger-Belair et al., 2009). It is this dissolved CO₂ gas that creates the perception of carbonation characteristic of sparkling wines. Sparkling wines are produced using various methods including: the traditional method, the Charmat method, and the transfer method.

The traditional method is the more time and labor-intensive method. In this method, once the primary fermentation is complete, a second fermentation in bottle is necessary to produce CO₂. To induce this second fermentation, a liqueur de tirage is prepared. The tirage is composed of yeast, sugar (Gòdia, Casas, & Sola, 1991; Pérez-Magaiño et al., 2013) and a riddling aid. The second fermentation lasts about 6-8 weeks. Once complete, the wine ages and the yeast autolyze. As this process occurs, the bottle is riddled, or turned a fraction of a turn, which encourages the incorporation of yeast components into the wine. As aging nears completion, riddling eventually tilts the bottles until the neck is fully inverted, which forces yeast and wine sediment into the neck of the bottle. At this point, the bottles are prepared for disgorgement. Specifically, the neck is frozen in a glycol bath, the bottle is turned upright and the cap removed (Riu-Aumatell, Torrens, Buxaderas, & López-Tamames, 2013). Natural pressure behind the cap expels the yeast
and sediment. Some wine may be lost during this process. To make up for this loss, each bottle is topped up with wine, while some winemakers may add wine and/or a dosage liquor that can consist of sugar (0-50+ g/L), liquor (cognac or brandy), or other wines (Lubbers, Charpentier, Feuillat, & Voilley, 1994). Each bottle is sealed with a cork and wire hood to prevent the cork from being expelled due to the high carbonation pressure (Kemp, Alexandre, Robillard, & Marchal, 2015).

Research in the area sparkling wine carbonation is limited. Kemp et al. (2015) provide a review of the effect of processing on traditional sparkling wines. Studies have detailed sparkling wine foam (Martinez-Lapuente et al., 2013; Andrés-Lacueva, Lamuela-Raventós, Buxaderas, & de la Torre-Boronat, 1997; Pueyo, Martín-Alvarez, & Polo, 1995), bubble dynamics and the physicochemical nature of CO₂ (Liger-Belair, Lemaresquier, Robillard, Duteurtre, & Jeandet, 2001), and the influence of matrix components, such as foam active compounds (Brissonet & Maujean, 1991) and yeast cell wall compounds (Núñez, Carrascosa, Gonzalez, Polo, & Martínez-Rodríguez, 2006) that affect the final wine. Additionally, several studies have sought to describe the relationship between CO₂ and the perception of specific sensory properties through the development of lexicons for carbonation. Recently, a sparkling wine-specific lexicon was developed to further detail the complex perceptions related to this style of wine, with attributes including nasal pungency aroma, as well as the mouthfeel attributes of bubblepain, creamy, and foamy (Le Barbé, 2014).

In the studies mentioned above, the sparkling wines were profiled using static sensory methods, such as descriptive analysis. Static methods are based on the concept that a perception is an average of the entire sensory experience. However, researchers agree that a sensory perception is a dynamic process in which attribute perceptions change over time (Lawless &
Heymann, 2010; Cadena et al., 2014). As carbonation perception encompasses mouthfeel attributes that evolve over time, the application of temporal sensory evaluation methods would likely provide a more accurate depiction of the full sensory experience. Recently, a temporal method has been introduced, Temporal Check-All-That-Apply (TCATA), which allows for the simultaneous identification of both non-dominant and dominant attributes (Castura, Antúnez, Giménez, & Ares, 2016). Based on common CATA methodology, studies using this method instruct panelists to evaluate the product over time and constantly check and uncheck the attributes as they are perceived or not, respectively.

Beyond sensory methodologies to better detail sparkling wine profiles, no study has yet examined the effect of dosage on the final properties of the wine. A dosage liquid added at the final stage of sparkling wine processing serves to replace wine that was lost during disgorgement and possibly contribute sweetness. The composition of the dosage can consist of sugar (0-50+ g/L), liquor/spirits (brandy or cognac), older wines, wines aged in different vessels (i.e. stainless, oak, or concrete), preservatives (i.e. SO$_2$ or citric acid), and polyphenolic compounds (Kemp et al., 2015). The lack of specific information related to the dosage and its influence on sparkling wine sensory profiles and sweetness perception warrants further study.

The overall objective of this research was to assess the effects of sparkling wine processing, specifically the sugar composition of the *liqueur de tirage* and dosage, and the effects on the sensory and analytical profiles of the final sparkling wines. Specific objectives were:

1. To describe the sensory aspects of sparkling wines containing different concentrations of CO$_2$ using trained sensory evaluation panels (static and dynamic methods) and consumer panels. Based on a previous sparkling winemaking study (Cahill, Carroad, & Kunkee,
1980), we hypothesized that adding dextrose to the *liqueur de tirage* would yield an increase in CO₂ (g/L). We hypothesized that consumers would be able to detect carbonation differences in sparkling wines compared to a control wine with no added carbonation. We hypothesized the combination of two different sensory methods would complement one another in the information provided about the samples. Specifically, we hypothesized TCATA would be better able to detect subtle differences among the samples compared to descriptive analysis. Additionally, we hypothesized that TCATA would provide further detail about the complexity associated with carbonation.

2. To analyze the influence of *dosage* composition varying in residual sugar level (*brut* and *demi sec*) and sugar type (fructose, glucose, and sucrose) on the chemical and sensory profiles of sparkling wines. We hypothesized the residual sugar level would influence the flavors, tastes, and mouthfeels of sparkling wines. Specifically, increased sugar would influence the sweet aromatics of caramelized/vanilla/honey and fruity. Also, increased sugar would decrease the perception of sourness and bitterness and increase the perception of sweetness. Furthermore, we hypothesized the ratings of creamy mouthfeel would increase with increased sugar. Lastly, we hypothesized wines sweetened with fructose and sucrose would have greater sweetness ratings over those wines sweetened with glucose.

3. To identify the sensory attributes that drive consumer acceptance of sparkling wines. Based on previous results of beverage preferences (Blackman, Saliba, & Schmidtke, 2010; Lesschaeve, Bowen, & Bruwer, 2012), we hypothesized sparkling wine consumers would have increased liking for sweet sparkling wines.
This dissertation is comprised of six chapters. Following this initial chapter, Chapter II contains a detailed review of the literature concerning sparkling wine processing, sparkling wine composition, carbonation, sugar, and descriptive analysis. Chapter III contains the manuscript “The production and consumer perception of sparkling wines of different carbonation levels” under review in the *Journal of Wine Research* (McMahon, Culver, & Ross). Chapter IV contains the manuscript “Perception of sparkling wines of varying carbonation levels using descriptive analysis (DA) and temporal check-all-that-apply (TCATA).” Chapter V contains “Trained and consumer panel evaluation of sparkling wines sweetened to *brut* or *demi sec* residual sugar levels with three different sugars.” Finally, Chapter VI contains conclusions and recommendations for future research and direction.
CHAPTER II
LITERATURE REVIEW

Sparkling wine is a multicomponent hydroalcoholic system containing volatile and non-volatile compounds, and is supersaturated with carbon dioxide (CO$_2$) gas (Liger-Belair, 2004). Several types of sparkling wines are found within the global market, most notably Champagnes from the Champagne region of France. Sparkling wines made outside of Champagne, France cannot be labeled as Champagne, rather, only as sparkling wine. Some examples of such sparkling wines include Prosecco of Italy, Cava of Spain, and Sekt of Germany.

Although sparkling wine represents a small niche of the global wine market, it has a large global value, reaching $2.5 billion euros in 2005 (Pozo-Bayón, Santos, Martín-Álvarez, & Reineccius, 2009). In 2015, sparkling wine sales increased 11% and were valued at $857 million (IRI, 2015). Mariani, Pomarici, & Boatto (2012) attribute the rise in popularity of sparkling wine to geographical alternatives to Champagne, such as Prosecco and Cava, which tend to be value driven wines.

The sensory properties of sparkling wine are important and arise from a number of factors, including viticultural, mainly grape varietal, and enological, such as yeast strain, fining, tirage composition, and ageing on the lees. The sensory properties contribute to its increasing popularity. Bubble size is an important factor to consumers in evaluating quality of champagne (Martínez-Rodríguez & Polo, 2003; Barker, Jefferson, & Judd, 2002). In a rudimentary consumer (n=17) paired preference test, consumers preferred smaller bubbles over larger bubbles in sparkling waters (Barker et al., 2002). Furthermore, extended ageing on the yeast has a positive effect on wine quality (Gonzalez, Martínez-Rodríguez, & Carrascosa, 2003). Besides these factors, sparkling wine varies in the winemaking processing method used.
SPARKLING WINE PRODUCTION

Various processing methods exist to produce sparkling wines, such as bottle-fermentation, which includes traditional and transfer methods. Alternatively, tank fermentation, like Charmat or Asti, also produces sparkling wines. Lastly, natural fermentation of wine containing low concentrations of sugar or direct injection of pressurized CO₂ into the wine produces semi-sparkling or aerated semi-sparkling wines.

Traditional

The traditional method, also known as Methodé Champenoise, is used to produce sparkling wines associated with the highest prestige and value (Jackson, 2014; Jackson, 2009; Lichinés, 1985). The major steps in this process include an initial fermentation to create the base wine and a second fermentation to generate the CO₂ present in the final product.

The base wine composition is influenced by a number of factors including grape varietal, sugar content, yeast type, degree of press fractions, and blending. Varietals used in sparkling wine vary by geographical region, with more traditional varietals being Chardonnay, Pinot noir, and Pinot meunier (Chamkha, Cathala, Cheynier, & Douillard, 2003). Grapes are picked earlier for sparkling wines compared to table wines (Anderson, Smith, Williams, & Wolpert, 2008). Anderson et al. (2008) harvested grapes for sparkling wine at a target of 20 ºBrix. However, sugar levels of grapes at harvest should be such that fermentation of the juice will yield an alcohol content no greater than 10-10.5% (Tudela, Gallardo-Chacón, Rius, López-Tamames, & Buxaderas, 2012) since the second fermentation will increase the final alcohol content of the wine to around 11-12% (Hildalgo et al., 2004). Grapes are pressed and juice is fractionated to separate free run or gentle pressure fractions, which is used for higher quality sparkling wines,
from those fractions extracted using increased pressure (Buxaderas & López-Tamames 2003; Flanzy et al., 1999).

Alcoholic fermentation of the grape must is initiated with the addition of *Saccharomyces cerevisiae* (*S. cerevisiae*) (Spadari, Delamare, Cardozo, Vanderlinde, & Echeverriegaray, 2015). However, various yeast strains are commercially available. In one study, different industrial yeast strains were used in the primary fermentation during the production of Cava using the traditional method (Torrens et al. 2008). Higher fruity notes were produced using Fermol Arome Plus Nature (Pascal Biotech-AEB Group, Brescia, Italia), Anchor Stellevin NT 116 (DSM-Laffort, Heerlen, Netherlands), and a strain of *S. cerevisiae* isolated from the Spanish Freixenet winery (Sant Sadurni d’Anoia, Spain). These results aligned with the broad body of evidence indicating that yeast strain influences the ultimate sensory properties of wine (Rankine, 1972; Pretorius & Bauer, 2002; Jolly, Augustyn, & Pretorius, 2003).

Once primary fermentation is complete, the wine can be blended, known as *assemblage*, using two or more varieties or vintages. Since a majority of the fermentable sugars and nutrients are consumed by the yeast during the primary fermentation, additional sugar and nutrients must be added to this base wine, or cuvee, to allow for the re-fermentation that will give the final wine its characteristic effervescence. The processing step prior to re-fermentation in which these additional components are added is called the *tirage*. During *tirage*, a *liqueur de tirage* is formulated with yeast, a riddling aid, and sugar. Of the *liqueur de tirage* components, the yeast is the least variable and is generally *S. cerevisiae* or *S. bayanus* yeast due to their high alcohol tolerance (Jackson, 2014; Jackson, 2009). The yeast must begin fermentation in wine containing alcohol upwards of 10%. For example, Hildalgo et al. (2004) used a base wine containing 10.7% alcohol to initiate second fermentation in bottle. Additionally, the yeast must tolerate low
temperatures of 6-12°C (Coloretti, Zambonelli, & Tini, 2006) and a low nutrient environment as sugar and nutrients are diminished over the course of the second fermentation. Finally, autophagy is a catabolic process in which yeast components and macromolecules are released from the cell. Autolysis is essential to the quality of sparkling wines (Charpentier & Feuillat, 1992; Cebollero, Carrascosa, & Gonzalez, 2005; Cebollero & Gonzalez, 2007). Núñez, Carrascosa, Gonzalez, Polo, & Martínez-Rodríguez (2005) discovered a strain of *S. cerevisiae*, mutant strain IFI473I, possessed accelerated autolytic capacity compared to IFI473E, IFI473G, IFI473J and IFI473K. The researchers confirmed wines fermented with strain IFI473I had improved foamability as measured by foam height and foam height stability compared to wines fermented using a different yeast strain. Additionally, a trained panel (n=10) evaluated wines fermented with IFI473I revealing a positive effect on foam area and foam collar attributes, as well as having decreased bubble size.

Another component of the tirage, a riddling agent (*e.g.* bentonite), is added to encourage aggregation of sediment (*e.g.* yeast components and tartrate crystals) in the bottle (Poinsaut & Hardy, 1995; Pozo-Bayón, Hernández, Martín-Álvarez, & Polo, 2003; Martí & Polo, 2003). Bentonite has been shown to negatively influence sparkling wine bubble size and foam (Vanrell et al., 2007; Andrés-Lacueva et al., 1997). In fact, over-finishing with bentonite will create larger bubbles in the wine (Marchal & Jeandet, 2009). Similarly, Martínez-Rodríguez and Polo (2003) observed sparkling wines with added bentonite had medium sized bubbles, little foam, and only partial coverage of the surface with the foam compared to wines without added bentonite. Alternatives to bentonite have been employed to overcome the limitations associated with bentonite. For example, use of gelatin agents in the form of gelatin-tannin or gelatin-silica gels
increases foaming characteristics compared to wines not fined with these mixtures (Marchal et al., 1998).

The source of energy for yeast metabolism is sugar, a key component present in the tirage. Generally 22-23 g sugar is added to the base wine to yield ~11 g/L CO$_2$. The type and form of sugar varies and includes sucrose (Pueyo et al., 1995; Pozo-Bayón et al., 2003; Núñez et al., 2005; Malfeito-Ferreira, Loureiro, Wium, & St Aubyn, 1990), concentrate (e.g. rectified grape must concentrate (RGMC)) (Vine, 1981), and dextrose (Cahill, Carroad, & Kunkee, 1980). Use of each sugar has benefits and limitations. Usually, sucrose is used in sparkling wine tirage recipes (Gódia et al., 1991; Pozo-Bayón et al., 2009; Martí-Raga, Sancho, Guillamón, Mas, & Beltran, 2015). However, dextrose has been used in tirage preparation to facilitate a more rapid fermentation, since S. cerevisiae yeast is glucophilic (Fugelsang & Edwards, 2007; Wang, Xu, Hu, & Zhao, 2004). When glucose was the sole sugar in apple wine, yeast (S. cerevisiae) growth rate and maximum biomass concentration were higher than when the sole sugar was fructose or sucrose (Wang et al. 2004). However, Wang et al. (2004) showed high significance in the model describing the conversion of glucose ($r^2=0.990$), fructose ($r^2=0.989$), and sucrose ($r^2=0.985$) to ethanol, suggesting that this inefficiency of glucose conversion is not always the case.

Besides fermentability of the sugar type chosen, additional factors such as dissolvability and interactions with other wine components must be considered. Dextrose (also known as glucose) was found to be a better option compared to RGMC in tirage preparation as the RGMC contained high solids content and unstable tartrates (Vine, 1981) that could interfere with later processing steps. It is also important to note that some researchers (Coelho, Coimbra, Nogueria, & Rocha, 2009) don’t specify the type of sugar used in the tirage process or use a combination of sugar types, such as glucose in combination with fructose (Valade & Laurent, 2001).
The tirage allows for the completion of the second fermentation, also known as prise de mousse (“foam creation”) which finishes in a sealed bottle. This fermentation also generates CO₂, thus creating the characteristic effervescence in the final wine. The wine is sealed with a crown cap and bidule, which will capture the sediment from the liquor de tirage after the second fermentation is complete (Torresi, Frangipane, & Anelli, 2011; Serra-Cayuela, Aguilera-Curiel, Riu-Aumatell, Buxaderas, & López-Tamames, 2013). The second fermentation lasts about 6-8 weeks after which time the wine is undergoes ageing.

During the ageing process, the volatile profiles of the wines evolve. One study classified Spanish cavas using volatile age markers as young wines (<9 months ageing) or aged cavas (>20 months ageing) (Francioli, Torrens, Riu-Aumatell, López-Tamames, & Buxaderas, 2003). In young cavas, isoamyl acetate, hexyl acetate, ethyl decanoate, and 2-phenylethyl acetate served as the age markers, while in older cavas, 1,2-dihydro-1,1,6-trimethylnaphthalene (TDN) served as a marker (Francioli et al., 2003). Likewise, other work identified the specific volatile compounds, such as TDN, vitispirane, diethyl succinate, phenylethyl acetate, and β-damascenone, that were found in association with yeast autolysis and ageing (Riu-Aumatell, Bosch-Fusté, López-Tamames, & Buxaderas, 2006; Pozo-Bayón et al., 2003; Gallardo-Chacón, Vichi, López-Tamames, & Buxaderas, 2010). As certain volatile compounds (i.e. farnesol and nerolidol) are considered to improve the quality of the wine (Molnar, Oura, & Suomalainen, 1981; Loyaux, Roger, & Adda, 1981), some originating from yeast (Francioli et al., 2003), each bottle of wine is ‘riddled’ to facilitate the incorporation of yeast components into the wine.

Riddling is traditionally performed by hand or by machine using a gyropalette (Kemp et al., 2015). Both methods accomplish the same objective which is to slowly rotate the bottle and facilitate the incorporation of yeast components. This process also gradually inverts the wine
bottle neck down, which is important for the subsequent disgorgement process. Once all the sediment is in the neck of the bottle, the neck is frozen in a glycol bath (-27°C) (Riu-Aumatell et al., 2013; Breivik, Berlet, Krall, & Makeover, 2014) or calcium chloride solution (Kemp et al., 2015). The frozen bottle neck is then turned upright and the crown cap is removed. Since the wine is now naturally pressurized, the frozen material is expelled.

At this point, each sparkling wine bottle is topped up with a dosage liquor that may consist of sugar (0-50+ g/L), liquor (brandy or cognac), or wine only. The composition of the dosage is highly variable, with wineries hesitant to disclose its composition. A more complex dosage may contain a wide range of additional ingredients including sugar, older wines, wines aged in different containers (i.e. stainless, oak, or concrete), SO₂, citric acid, and tannins (Kemp et al., 2015). To date, no study has been conducted describing the influence of dosage composition on sparkling wine profiles (Kemp et al., 2015). Finally, after the dosage addition, each bottle is sealed with a cork and wire hood to prevent the cork from being pushed out due to the high carbonation pressure (Kemp et al., 2015).

The addition of the dosage creates the residual sweetness that places the final sparkling wine into one of six categories: brut nature (0 g sugar/L) (Martínez-Lapuente, Guadalupe, Ayestarán, Ortega-Heras, & Pérez-Magariño, 2013a; Martínez-Lapuente, L., Guadalupe, Z., Ayestarán, B., Ortega-Heras, M., & Pérez-Magariño, 2013b), brut (<12 g sugar/L) extra brut (12-17 g sugar/L), sec (17-32 g sugar/L), demi sec (32-50 g sugar/L), and doux (50+ g sugar/L) (Jackson, 2014; Jackson, 2009; Riu-Aumatell et al., 2013).
OTHER METHODS OF SPARKLING WINE PRODUCTION

Charmat

Another method to produce sparkling wines is the Charmat method, which is also known as the bulk method (Bordiga et al., 2013). The Charmat process was first introduced by Federico Marinotti in 1895, and later developed by Eugene Charmat in 1910. Using this method, the base wine is first produced, followed by the second fermentation in a pressure reinforced tank (Pueyo & Martínez-Rodríguez, 2009). The *liqueur de tirage* needed for the second fermentation to occur is added to this tank. Once pressures reaches 5-6 atm within the tank (Amerine & Joslyn, 1970), the wine is filtered and bottled under isobarometric conditions.

Transfer Method

Contrasting the Charmat method, the transfer method is more similar to *Methodé Champenoise* in that the second fermentation occurs in bottle. However, the commercial bottle is not the same bottle in which the second fermentation occurs. Using the transfer method, after the second fermentation, the bottles are aged >9 mo. and then opened into a Charmat tank under isobarometric conditions, filtered to remove yeast, and blended before being re-bottled (Jackson, 2014; Jackson, 2009; Berti, 1961). The advantages of the transfer method over the traditional method are the reduction of bottle-to-bottle variation, reduced time, and reduced labor required (Jackson, 2014; Jackson, 2009).

To simplify the process of riddling and collecting the yeast in the neck of the bottle, advances in sparkling wine biotechnology include new yeast preparations in which the yeast cells are immobilized inside gel beads. Commonly, wines made by the transfer method are not riddled, rather placed neck down (Buxaderas & López-Tamames, 2003). When the bottles are inverted, the immobilized yeast cells settle quickly and are collected in the neck, making the plug
easier to remove (Torresi et al., 2011). Additionally, no riddling agent is necessary when using immobilized yeasts (Fumi, Trioli, Colombi, & Colagrande, 1988; Yokotsuka, Yajima, & Matsudo, 1997).

### Semi-Sparkling Wines

Carbonation in semi-sparkling wines is liberated from fermenting low concentrations of sugar (endogenous) or from adding carbonation (exogenous) (Gaillard, Guyon, Salgoïty, & Médina, 2013). The benefits of exogenous carbonation over natural fermentation are that it expedites product to market capabilities and is controllable (Gaillard et al., 2013). Direct sparging is the least common method of sparkling wine production and one that produces lower quality, less expensive sparkling wines (Tudela et al., 2012). As a result, the European Union (EU) does not classify these wines as sparkling, rather these are considered “fizzy” (Tudela et al., 2012) or “aerated” sparkling wines (6.6.2008 Official Journal of the European Union L 148/47). Interestingly, even though the common perception of directly carbonated wines is the production of a wine of low quality and value, Culbert, Cozzolino, Ristic, & Wilkinson (2015) analyzed several sparkling wines and reported a carbonated wine within their sample set to have unexpectedly high quality and complex characteristics. Quality and complexity standards used in this study were in reference to Gawel and Godden (2008). This specific wine was created using an aged base wine prior to direct carbonation, suggesting that it was not the mode of direct carbonation that was the origin of the quality in the wines studied, rather it was the age and composition of the base wine.

### SPARKLING WINE COMPOSITION

The main distinguishing feature of sparkling wine from table wine is its effervescence or carbonation. Besides CO₂ (1-1.2%), sparkling wine is composed of ethanol (11.5-12.5%),
glycerol (~0.5%), organic acids (<0.8%), volatile organic compounds (VOCs, <0.07%),
polysaccharides (0.02%), polyphenols (0.01%), amino acids (<0.0002%), and proteins
(<0.0001%) (Dussaud, 1993; Stefenon et al., 2014; Pozo-Bayón et al., 2009). Sparkling wines
also contain several different minerals (~0.0003-0.0009%), which differ by region (Jos, Moreno,

**Sparkling Wine Composition**

The composition of sparkling wines is dependent upon numerous factors, many of which
relate to the processing method. These factors in turn influence final wine quality (Kemp et al.,
2015; Andrés-Lacueva, Gallart, López-Tamames, & Lamuela-Raventós, 1996). Caliari, Panceri,
Rosier, & Bordignon-Luiz (2015) produced Moscato sparkling wines using the traditional,
Charmat, and Asti (an extension of Charmat) methods. These wines were profiled using a trained
sensory evaluation panel. Wines made using the traditional method were higher in ethyl esters
(fruity), monoterpenes (linalool (floral) and α-terpineol (oil, anise)), and fatty acids (rancid)
compared to wines produced following the Charmat and Asti methods (p<0.05). Also compared
to wine produced using the Asti method, traditional and Charmat wines had significantly higher
concentrations of higher alcohols, the volatile compounds that originate during the second
fermentation (Perestrelo, Fernandes, Albuquerque, Marques, & Câmara, 2006; Francioli et al.,
2003). Other researchers found that Charmat wines tend to have higher fruity notes compared to
traditional sparkling wines due to ageing on the yeast lees during the second fermentation (Iland
& Gago, 1997).

In addition to the influence of processing method on the volatile profile of sparkling
wines, several studies have shown production method impact the non-volatile components in the
sparkling wine. This is noteworthy as sparkling wines contain phenolics which possess
antioxidant activity (Chamkha et al., 2003; Pozo-Bayón et al., 2003; Satué-Garcia, Andrés-Lacueva, Lamuela-Raventós, & Frankel, 1999). For example, brut and sec sparkling wines produced using the traditional method were found to have higher antioxidant activity compared to these same wines produced using the Charmat method (Stefenon et al., 2010). Specifically, the Charmat wines had lower total polyphenols, total flavonoids, and trans-resveratrol (Stefenon et al., 2010), which may be due to the fact that yeast can metabolize these compounds or the absorption of these antioxidants by yeast lees during ageing (Morata et al., 2003; Mazauric & Salmon, 2005). However, not all studies have found a significant impact of processing method on antioxidant potential. Caliarai et al. (2015) found no difference in antioxidant potential among wines produced using the traditional, Charmat, or Asti production methods.

Besides phenolic compounds, other differences in wine chemistry parameters as influenced by processing method have been reported. Alcohol and residual sugar (RS) have varied among wines produced using different processing methods, with wines produced using the Asti method having the lowest alcohol (9.2%) and highest RS (28.25 g/L) compared to wines produced using the traditional and Charmat methods (Caliari et al., 2015). These results are expected since Asti wine fermentations cease prematurely once the desired alcohol level is reached, resulting in higher residual sweetness. Caliari et al. (2015) found no significant differences among wines produced using the traditional, Charmat, or Asti methods for total acidity, volatile acidity, ash, or antioxidant potential. The different styles of sparkling wines vary in composition, but common to all sparkling wines is its carbonation.
Carbonation

Production of Carbon Dioxide

A diagnostic trait of sparkling wine is its effervescence, attributed to the dissolved CO₂ gas in the matrix. As mentioned above, the carbonation in the sparkling wine is produced by fermentation generation of CO₂. The fermentation process was first outlined in 1815 and is known as the Gay-Lussac equation (Eq. 1), in which one part sugar (monosaccharide) is converted to two parts ethanol and two parts CO₂; some energy is released as heat (Williams, 1982).

\[ \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2 \text{CO}_2 + 2 \text{C}_2\text{H}_5\text{OH} + \Delta \]  Eq.1

It was not until 1860 when Louis Pasteur discovered that yeast were responsible for the conversion of sugar to ethanol and CO₂. Pasteur documented that 100 grams (g) of cane sugar in the presence of yeast will yield 49.25 g CO₂ (24.9 vol CO₂/vol) (Howe, 2003). More recently, Howe (2003) demonstrated that 4 g sucrose was needed to produce 1 vol CO₂, which is equivalent to using 4.2 g glucose or fructose to yield the same vol CO₂. However, sucrose is found in low concentrations in grapes (Clarke & Bakkar, 2004).

Perception of Carbonation

Sensory receptors, such as chemesthetic and somesthetic, help humans perceive environmental stimuli. The sensory process begins with a stimulus, such as effervescence on the tongue, which is translated into a sensation, such as bursting bubbles or pain. This sensation is sent through the nerves to the central nervous system where it is perceived. Once the perception is interpreted, it is then translated into a response, such as a facial expression in response to the bubbles bursting in mouth. This process is dependent upon the stimulus, product, and individual.
The mechanism and concept of carbonation perception is multimodal (Calvert, Brammer, & Iversen, 1998). Carbonated matrices are dynamic and several aspects of the evaluation can influence the multi-modal response (Leksrisompong, Lopetcharat, Guthrie, & Drake, 2013). Carbonated matrices engender multimodal interactions among visual, olfactory, trigeminal, and gustatory stimuli (Hewson, 2008; Ross, 2009). Each of these responses will be described in more detail below.

*Visual Response*

The initial assessment of a carbonated product includes visual cues in the form of bubbles and effervescence. These visual signs are due to the sudden decrease in partial pressure above the air-liquid interface upon opening the bottle. Once a bottle of soda or champagne is opened, the dissolved CO$_2$ in the matrix is no longer in thermodynamic equilibrium and therefore, according to Henry’s law, the CO$_2$ in the system will strive to maintain equilibrium with the atmosphere. As a result, CO$_2$ outgasses from the matrix, resulting in the formation of bubbles (Liger-Belair, Polidori, & Jeandet, 2008).

Origination of bubbles occurs at nucleation sites, a point at which dissolved CO$_2$ can overcome the critical radius necessary to form a bubble (Liger-Belair et al., 2008; Liger-Belair, Marchal, & Jeandet, 2002; Liger-Belair, Vignes-Adler, Voisin, Robillard, & Jeandet, 2002). Hollow cellulose fibers, tartrate crystals (*e.g.* either in bottle or from hard water marks), or glass imperfections (*i.e.* scratches or etchings) serve as nucleation sites. If the surface is perfectly smooth and/or cleaned with detergents or surfactants, bubble formation will be prevented. Other factors that influence effervescence include surface tension, CO$_2$ solubility, viscosity, density, volume of liquid, CO$_2$ partial pressure, surface properties of vessel (*i.e.* etching and debris), and dimensions of vessel (Casey, 1988).
Modeling of the kinetics of bubble formation has been detailed in several studies and the pattern of bubble formation is not constant (Liger-Belair, Tufaile, Robillard, Jeandet, & Sartorelli, 2005; Liger-Belair, 2006). Results showed that bubbles have a number of different patterns, including trains of rhythmic frequency (Liger-Belair et al. 1999), flowers (Liger-Belair, Robillard, Vignes-Adler, & Jeandet, 2001), fliers (Liger-Belair, Beaumont, Jeandet, & Polidori, 2007), as well as bubble coalescing as they rise to the surface. Liger-Belair, Villaume, Cilindre, & Jeandet (2009) found differences in CO$_2$ flow and outgassing between two wine glasses, a coupe and a flute. The coupe had increased CO$_2$ losses due to its large surface area at the wine-air interface.

As the bubbles rise to the surface, the visual perception of carbonation further extends to the appearance of foam. Foam is another visual feature that consumers first notice about a carbonated product (Martínez-Lapuente, Guadalupe, Ayestarán, & Pérez-Magariño, 2015). A high quality foam is one that has a slow release of small bubbles of CO$_2$ rising through the liquid to form a ring or collar at the surface of the liquid (Blasco, Viñas, & Villa, 2011). Contributing to foam quality is its stability (Maujean, Poinsaut, Dantan, Brissonet, & Cossiez, 1990).

Foam stability has been directly correlated with several matrix constituents in wine, including proteins (Blasco et al., 2011), more specifically glycoproteins. There is a large fraction of proteins, especially mannoproteins (a glycoprotein), in sparkling wines due to yeast autolysis and ageing on the yeast (Gonçalves, Heyraud, de Pinho, & Rinaudo, 2002; Moss, 2014; Núñez et al. 2005; Rowe et al. 2010; Smith, Penner, Bennett, & Bakalinsky, 2011). These proteins and glycoproteins are surface active and impact the velocity of bubble ascension (Liger-Belair et al. 1999). In one study, thermally extracted mannoproteins were added to model sparkling wines, with a positive effect on foam stability (Núñez et al., 2006). Foam stability is also impacted by
polysaccharides (Ferreira, Jorge, Nogueira, Silva, & Trugo, 2005; Bartolomé, Moreno-Arribas, Pueyo, & Polo, 1997; Moreno-Arribas, Pueyo, Nieto, Martin-Alvarez, & Polo, 2000). Moreno-Arribas et al. (2000) observed significant correlations of neutral polysaccharides and nitrogen containing constituents on foam peak height \( (r^2=0.82) \) and foam plateau height \( (r^2=0.71) \) \( (p<0.05) \). Foam is an initial assessment of carbonation in sparkling wines and the bubbles that make up the foam cue other parameters associated with carbonation.

**Auditory Response**

The auditory stimulus of carbonation also contributes to the multimodal response. A carbonated product produces an auditory response associated with the sounds generated by bursting bubbles. Zampini and Spence (2005) found that the loudness of bubble bursting is correlated with perceived degree of carbonation. Specifically, consumers \( (n=24) \) listened through headphones to a recording of carbonated water, which varied in loudness and/or frequency. When the overall carbonation sound was louder, the consumers perceived the samples as being more carbonated even though carbonated waters had the same CO\(_2\) concentration. Additionally, researchers increased the sound frequency \( (2-20 \text{ kHz}) \) of the sound that caused consumers to rate the water samples as being more carbonated. In another study, Spence and Wang (2015) investigated a person’s ability to distinguish carbonation level during the act of pouring the beverage into a flute versus a water glass. Their findings revealed that consumers were able to discriminate between the sound of San Pellegrino sparkling water, Pisani Prosecco, and Tattinger non-vintage Champagne \( (p\leq0.05) \). Industry professionals mislabeled the Champagne as Prosecco but were able to discriminate sparkling water from sparkling wine. Arguably, Vickers (1991) suggested fine Champagnes having finer (smaller) bubbles would create a higher pitched noise
related to ‘fizziness.’ In effect, this would aid in a person’s discrimination ability. Clearly, the auditory stimulus of carbonation is capable of influencing sensory perceptions.

**Olfactory Response**

In addition to carbonation’s visual and audible stimuli, carbonation also interacts with the olfactory system. Le Barbé (2014) created and validated a sparkling wine wheel using trained panelists and included the olfactory response to CO$_2$ as ‘nasal pungency’. As CO$_2$ is odorless to humans, this pungency is a bimodal response in which the olfactory and trigeminal systems act together to produce a central neural interaction in response to stimulation by high concentrations of CO$_2$ (Cain & Murphy, 1980). Specifically, CO$_2$ activates an independent set of trigeminal nerves associated with chemesthesis (Chen, Belmonte, & Rang, 1997). Chemesthesis is a feeling stimulated by chemicals and is associated with several somatosensory modalities including irritation, pungency, cooling, burning, or tingling (Pelchat et al., 2014; Sdravou, Walshe, & Dagdilelis, 2012; Roper, 2014). Cain and Murphy (1980) confirmed that CO$_2$ stimulates the trigeminal nerve, and when CO$_2$ is presented to one nostril, the perception of an olfactory modal through the other nostril is impacted. However, some research has shown that irritant stimulation interferes with retronasal flavor perception, conflicting with the results of the interaction of oral chemesthetic stimulation and flavor perception (Hewson, Hollowood, Chandra, & Hort, 2009; Lawless, Rozin, & Shenker, 1985).

The aroma and flavor perception in a carbonated matrix is dynamic and complex. Specifically, a study conducted in beer with 7.11 g CO$_2$/L (~3.6 vol CO$_2$) evaluated the influence of carbonation on beer aroma and found a significant increase in release of ethyl acetate and isoamyl alcohol in carbonated beer compared to uncarbonated beer (p≤0.0001) (Clark, Linforth, Bealin-Kelly, & Hort, 2011). This study suggests that carbonation impacts volatilization of
certain compounds through the increase in surface area at the air-wine interface (Liger-Belair et al. 2009) or via mixing flow kinetics of the liquid (Liger-Belair et al. 2007; Liger-Belair et al. 2008; Tsachaki, Martin, Guichard, Issanchou, & Sulmont-Rossé, 2008). Several other studies have also shown that carbonation aids in the volatilization of aromatic compounds (Pozo-Bayón et al., 2009; Saint-Eve et al., 2009). A possible explanation for the interaction between carbonation and aroma compounds may be due to the Marangoni effect. The Marangoni effect helps to explain that when CO₂ diffuses through the interface, a surface tension gradient is created. In effect, the kinetic motion may drive and move underlying liquid and volatile compounds to the surface. In effect, this could cause increased aroma release by carbonation due to an increase in volatile concentration at the interface (Tsachaki et al., 2008). Liger-Belair et al. (2005) go on to suggest sparkling wine volatilization is dependent upon molecular structure and compound characteristics (including vapor pressure and molecular weight), which could impact the aromatic perception. Amphiphilic compounds orient at the interface and will volatilize during the bursting of bubbles. However, others have shown no effect of carbonation on olfactory perception (Prescott & Stevenson, 1995; Green, 1996; Frasnelli, Schuster, & Hummel, 2010), a function of the experimental design. As a whole, more research is warranted to help explain how the perceptions of aromas and aromas-in-mouth are dependent on the dynamics of carbonation.

**Oral Response**

In addition to the trigeminal response in the olfactory system, CO₂ has been described as triggering oral receptors in a similar manner. Specifically, studies have found that CO₂ stimulates the trigeminal system in the mouth in two ways: 1) activating the mechanoreceptors embedded within the oral mucosa and 2) triggering a chemogenic response as CO₂ is converted to carbonic acid that is detected by nociceptors (pain receptors) (Carstens et al., 2002; Dessirier, Simons,
Carstens, O’Mahony, & Carstens, 2000; Simons, Dessirier, Carstens, O’Mahony, & Carstens, 1999). Hewson et al. (2009) concluded overall fizziness originates from bursting bubbles stimulating the mechanoreceptors while tingling and irritancy in model beverages are the result of CO₂ acting on oral nociceptors. Wang, Chang, & Liman (2010) confirmed that CO₂ is activates transient receptor potential (TRP) channels. These TRP channels have been known to play a pivotal role in chemical sensations within the oral cavity (Silver, Clapp, Stone, & Kinnamon, 2006). In humans, increased tingling and pain perception was observed in the mouth as CO₂ increased from ~3 g CO₂/L to ~7.2 g CO₂/L in mineral water (Hewson, 2008).

Temperature has been shown to impact pain related perceptions associated with carbonation (Yau & McDaniel, 1991, Green 1992). In one study, Wise and Bryant (2014) had subjects submerge their tongues in CO₂ solutions (0, 2.0, 2.8, and 4.0 v/v) at five different temperatures (18.3, 24.5, 29.9, 34.5, and 39.6°C). Both CO₂ concentration and temperature had a significant impact on the perception of “bite” (p≤0.000001), with increasing concentration of CO₂, causing an increased intensity of bite. Also, intensity of carbonation bite was greater at temperatures below 30°C.

Interestingly, CO₂ bubbles are not necessary to perceive all carbonation attributes (McEvoy, 1998; Wise, Wolf, Thom, & Bryant, 2013). In one study, carbonated waters served under normal atmospheric conditions and in a closed chamber under 2 atm pressure, a level at which bubbles do not form (Wise et al. 2013). The ratings of oral pungency were identical under both atmospheric conditions suggesting that bubbles do not stimulate pungency. Furthermore, McEvoy (1998) observed subjects who were placed in a hyperbaric chamber perceived the attribute of tingle without the presence of CO₂ bubbles.
In light of the complex mechanisms by which \( \text{CO}_2 \) is perceived in the mouth, it is not surprising that there are several terms and definitions for sensory attributes to describe this complex oral perception. In soda beverages, the terms carbonation, bite, burn, and numbing described the mouthfeel perceptions related to \( \text{CO}_2 \) (Kappes, Schmidt, & Lee, 2006; Kappes, Schmidt, & Lee, 2007; Leksrisompong et al., 2013; Harper & McDaniel, 1993). In beer, mouthfeel attributes related to carbonation include sting, bubble size, foam volume, and total \( \text{CO}_2 \) (Langstaff, Guinard, & Lewis, 1991). Szczesiak (2002) further defines carbonation related terms as bubbly, tingly, and foamy. Mineral water foam related attributes include foam intensity and foam stability (Sipos et al., 2013). Most pertinent to this review, Le Barbé (2014) created and validated a sparkling wine wheel using trained panelists to define carbonation including foamy, bubble pain, and creamy.

The reference standards for carbonation mouthfeel attributes also vary. In the white wine mouthfeel wheel developed by Pickering and Demiglio (2008), mineral water was used as the reference to describe carbonation. Panelists were asked to swirl the sample when evaluating it for tingle, the sole attribute used to describe carbonation as either slight or had a tingle perception. Green (1992) used carbonated water to elicit the perception of bite. In soft drinks, other references for bite include cinnamon oil (Leksrisompong et al. 2013) or cinnamon chewing gum (Kappes et al., 2006). The difficulty in describing carbonation perceptions is that the references are also dynamic and relative to the matrix being studied.

Specifically, the term creaminess is primarily used when describing various food products, such as semi-solid puddings (Elmore, Heymann, Johnson, & Hewett, 1999), soup (Wood, 1974), cream based products (Daget, 1987; Daget & Joerg, 1991), and chocolate mousse (Kilcast & Clegg, 2002). However, Le Barbé (2014) included creamy in their lexicon to describe
the mouthfeel in sparkling wines as having a smooth sensation due to aging on yeast lees. Related to smoothness, silky mouthfeel in white wines is an impression of mouthcoating, softness and fullness (Pickering & Demiglio, 2008). Of specific relevance to the present findings, common to these definitions are softness and smooth sensations, which have been positively correlated with residual sugar content and sweet taste (Hjelmeland, King, Ebeler, & Heymann, 2013).

**Taste**

Physiological receptors, namely mechanoreceptors and nociceptors as detailed above, lie adjacent to taste receptors that are responsible for the perception of basic tastes in the oral cavity (Green, 2003). The major taste elicited by carbonation is sourness. The equilibrium of CO\(_2\) is the basis of its taste, as described by Eq. 2:

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^- \quad \text{Eq. 2}
\]

In fact, Chandrashekar et al. (2009) used genetic ablation (or removal) to confirm that the sour-sensing cells specifically responded to carbonation ions. More specifically, the carbonic anhydrase 4 functions as the principle CO\(_2\) taste sensor (Chandrashekar et al. 2009; Pelchat et al., 2014).

Besides sourness, carbonation impacts the perception of other tastes including sweetness, saltiness, and bitterness (Cometto-Muñiz, García-Medina, Calviño, & Noriega, 1987; Yau & McDaniel, 1992; Cowart, 1998). Due to limitations of previous studies, the study of Cowart (1998) better defines the effect of carbonation on basic tastes. In this study, a trained panel (n=15) analyzed carbonated aqueous solutions of sweet, salty, sour, and bitter. The concentration of CO\(_2\) (4.8 and 6.4 g CO\(_2\)/L) significantly suppressed sweetness and saltiness compared to their respective non-carbonated counterparts. Additionally, the carbonated solutions showed enhanced
sourness compared to the non-carbonated solutions. The findings in Cowart (1998) supports the hypothesis that carbonation suppresses basic tastes. More specifically, Passe, Horn, & Murray (1997) analyzed the effect of carbonation on sweetness perception in beverages. Their findings confirmed carbonation significantly suppressed sweetness perceptions (p≤0.05). Likewise, in model beers, CO₂ significantly suppressed sweetness (Clark et al., 2011). Furthermore, Symoneaux, Le Quéré, Baron, Bauduin, & Chollet (2015) analyzed the interaction between CO₂ and matrix components of model cider. Their findings revealed CO₂ (~5 g/L at 10°C) had no impact on bitterness, confirming those findings in previous studies (Clark et al., 2011; Cometto-Muñiz et al., 1987). Additionally, CO₂ suppressed sweetness in model ciders containing 60 g fructose/L compared to a non-carbonated cider with the same amount of fructose (p≤0.05). In light of these results, carbonation is dynamic and elicits multimodal and cross modal interactions among visual, auditory, olfactory, and basic taste modalities.

SWEETNESS IN SPARKLING WINE

Overview

In sparkling wine, the majority of residual sweetness originates from the sparkling wine processing step whereby a dosage liquid is added to the finished sparkling wine. The origin of sweetness perception is sugar. Sugars are a category of carbohydrates, found in certain foods and beverages. Different types of sugar include monosaccharides (one sugar unit), oligosaccharides (>1 sugar unit), and polysaccharides (>10 sugar units). Monosaccharides are the simplest in structure, since hydrolysis will not result in a smaller carbohydrate form and include fructose, glucose, arabinose, and xylose (BeMiller & Huber, 2008). Compared to the monosaccharides, sucrose is a disaccharide composed of one unit each of D-glucose and D-fructose. Other examples of disaccharides include lactose (consisting of D-glucose and D-galactose) and maltose.
(two glucose units). Of interest to this review are monosaccharides, particularly glucose and fructose, as well as disaccharides, specifically sucrose, since these sugars are likely to be found in the final sparkling wine.

**Sensory Perception of Sweetness**

The molecular basis of detecting sweetness associated with sugars is outlined in the Shallenberger-Acree model (Shallenberger & Acree, 1967). In their model, intermolecular hydrogen bonding is pivotal to the response between the AH-B unit of the sweet tasting compound and the complimentary AH-B unit of the taste receptor. The AH portion of the unit is the proton donor, and B is the proton acceptor. Due to the specific orientation of the taste receptors, enantiomers have different tastes, namely the D- and L-sugars in which the former are sweet, while the latter are not sweet (Boyd & Matsubara, 1962).

As may be inferred from the Shallenburger model, sugars differ in their sweetness based upon their structure. Relative sweetness is the ratio of concentration of substances matching in sweetness (Moskowitz, 1970). Tou, Fitch, and Bridges (2009) report a sweetness index, establishing sucrose at 1, fructose at 1.7, while glucose had a relative sweetness of 0.7-0.8. However, Hanover and White (1993) found that while fructose was still sweeter than sucrose, fructose had a lower sweetness level that originally published, at 117. Likewise, in another study, fructose had an index of 114, sucrose at 100, and glucose at 69 (Belitz, Grosch, & Schieberle, 2009).

The laws of psychophysics play an important role in the interaction between sugar concentration and sweetness perception. Several studies have analyzed the influence of stimulus concentration on the intensity of the response (Beebe-Center & Waddell, 1948; Stevens, 1960).
Later work by Moskowitz (1970) concluded that the relationship between concentration and sweetness was a power function, defined by Eq. 3 below:

\[ S = kI^n \]  

(Eq. 3)

where, \( S \), is the intensity of sweetness, and, \( I \), is the physical intensity. The equation for all sugars but mannose had the exponent of \( n=1.3 \). However, at high concentrations, sugar perceptions differed thus affecting the psychophysical relationship. Stephens (1969) observed a deviation from the power function for sucrose. As concentrations approached 24 and 32% (w/w), the magnitude estimation (where a person is instructed to label one stimulus from a sensation and use it for the basis of other sensations (Boring, 1942)) of sweetness appeared to plateau.

**Sugar Interactions in Wine**

Sugar influences the perception of several tastes, including sweet, sour, and bitter, as well as the mouthfeels of viscosity and astringency. Sugar is one of the major defining factors of white wine taste, with one of the criteria describing wine quality being the sweet/sour balance (Zamora, Goldner, & Galmarini, 2006). Using a trained panel, traditional Champagne wines were evaluated for sweetness, sourness, and total taste intensity (Martin, Minard, & Brun, 2002). As expected, the findings revealed increased perception of sweetness with increasing sucrose concentration \( (p<0.0001) \). More specifically, in these Champagnes, sweetness perception increased from 12.8 to 20.5 g sucrose/L. Furthermore, higher total taste intensity was observed in Champagnes containing 20.5 g sucrose/L and 4.22 g tartaric acid/L compared to wines with lower concentrations of sucrose and tartaric acid \( (p<0.05) \). In the Champagne wines, sucrose had a greater effect on suppressing sourness rather than the effect of tartaric acid suppressing sweetness. Contrastingly, Zamora et al. (2006) witnessed the opposite effect where suppression was greatest by tartaric acid on fructose sweetness rather than fructose suppressing the sourness.
of tartaric acid. Additionally, Schiffman, Booth, Losee, Pecore, & Warwick (1995) discovered that as sugar concentration increased, the bitterness associated with natural sugars decreased. In the same study, high potency sweeteners had the opposite effect. In model wines, sweetness, viscosity, and density perceptions are elicited by sugar. Sugar (0-300 g/L) had the greatest effect on mouthfeel parameters, including physical viscosity, physical density, perceived viscosity, and perceived density, as compared to ethanol and glycerol (Nurgel & Pickering, 2005). Likewise, fructose (20 and 60 g/L) significantly suppressed bitterness, astringency, and sourness (p≤0.05) (Symoneaux et al., 2015).

Besides tastes and mouthfeels, sugar concentration and type impacts the flavor profile of a wine. Robinson et al. (2009) analyzed a model wine matrix spiked with 20 volatile compounds. Results indicated that glucose (160-320 g/L) had a significant outgassing effect, represented in the increased relative peak area of all the volatile compounds. For fructose, Villamor, Evans, Mattinson, & Ross (2013) showed that fructose (0.2 and 2 g/L) concentrations in table wines deemed ‘dry’ interacted with tannin and ethanol to decrease the model wine headspace concentrations of volatile compounds (p<0.05). The effect was variable with ethanol concentration (8, 10, and 12%). The authors explained that the increased fructose concentrations influenced the polarity of the model wine such that the retention of certain volatile compounds was favored. This line of thought was supported by To, Westh, Trandum, Hvidt, & Koga (2000) who concluded fructose is more hydrophobic than sucrose, therefore it is likely that the former would further increase the partitioning coefficient of hydrophobic odorants, thus preventing the odorants from volatilizing.
SENSORY METHODS TO DESCRIBE SPARKLING WINES

Static

Sensory evaluation is the scientific discipline used to evoke, measure, analyze, and interpret reactions to the characteristics of food and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing, the five basic modalities of sensory physiology (Stone & Sidel, 1993; Schmidt, 1978). Descriptive analysis (DA) techniques enable the sensory scientist to profile products, identify underlying variables, and determine variables of acceptance (Lawless & Heymann, 2010). Several well-established static methods include the Flavor Profile Method (Kaene, 1992), Free-Choice Profiling, Texture Profile Method (Civille & Szczesniak, 1973), Spectrum™ method, Quantitative Flavor Profiling, and Quantitative Descriptive Analysis™ (QDA). These methods vary in their use of scale, number of panelists, reference standard development and usage, which all contribute to their advantages and disadvantages, especially related to panel data reliability and power. Of interest to this review is descriptive analysis.

DA is a popular static approach used to rate the intensities of all important attributes (Stone, Sidel, Oliver, Woolsey, & Singleton, 1974; Stone & Sidel, 1998; Lawless & Heymann, 2010); these evaluations result in single point evaluations of the product under study (Cliff & Heymann, 1993). Studies using DA methodology have spanned across numerous products including biscuits (Vázquez, Curia, & Hough, 2009), chestnuts (Warmund, Elmore, Adjikari, & McGraw, 2011), vinegar (Zeppa et al., 2013), beef (Song et al., 2010), and tea (Koch, Muller, Joubert, Van der Rijst, & Næs, 2012). Stone, Bleibaum, & Thomas (2012) outline the benefits of using DA as the ability to identify and measure all product attributes using language generated and agreed upon using panel consensus. One major advantages of DA is the ability to evaluate...
and validate panel performance. Methods to do so involve prolonged training (Civille & Szczesniak, 1973; Labbe, Rytz, & Hugi, 2004), evaluating a warm-up sample (Plemmons & Resurreccion, 1998), and measuring the panel’s discriminatory ability.

**Dynamic**

Several methods exist to capture the dynamic nature of a product evaluation, including Time-Intensity (TI), Temporal Dominance of Sensations (TDS), and Temporal Check-All-That-Apply (TCATA). New approaches to capturing the complexities of product evaluations has combined techniques (Sokolowsky, Rosenberger, & Fischer, 2015; Meillon, Urbano, & Schlich, 2009; Ng et al., 2012; Ares et al., 2015). Sokolowsky et al. (2015) used descriptive analysis and the temporal methods of TI and TDS to analyze the impact of skin contact on Riesling and Gewürztraminer wine properties. Using descriptive analysis, differences in flavors, aromas, and tastes were identified, specifically bitterness as a function of varietal. The dynamic methods, TI and TDS were also able to describe these differences. Specifically, Gewürztraminer wines differed in maximum intensity of bitterness and area under the curve (total area under the curve capturing moments of increasing and decreasing perceptions) for TI, while Riesling wines had no significant differences in TI parameters. TDS revealed the dominant sensation was astringency rather than bitterness which dominated in TI and DA.

In light of this discussion, as carbonation perception is a mouthfeel expected to change over time, the application of temporal methods would provide a more accurate assessment of how the perception is changing over time. In tracking the changing perception of carbonation, one previous study employed TI methodology for the determination of carbonation in water (Green, 1992). Results showed that increasing the level of CO₂ to 6.5 g/L caused an increased intensity of carbonation. The study also found a higher percentage of panelists reported
perceived pain at 6.5 g CO$_2$/L than at 3.2 g CO$_2$/L. Additionally, Frasnelli et al. (2010) evaluated the temporal nature of carbonated water and observed burning, stinging, and tingling attributes were weaker over the testing period of 30 min (p<0.026).

While TI provides valuable information regarding how an attribute changes over time, one challenge associated with this method is that the panelist is limited to the evaluation of one or two attributes at a time. This contributes to a halo-dumping effect (Clark & Lawless 1994). TDS was developed to alleviate this problem (Pineau et al., 2009). TDS methodology has been applied to several products including partially dealcoholized red wine (Meillon et al., 2009), fish sticks (Albert, Salvador, Schlich, & Fiszman, 2012), espresso coffee (Barron et al., 2012), semi-solid gels (de Lavergne, Van Delft, Van De Velde, Van Boekel, & Stieger, 2015), and yogurt (Bouteille et al., 2013). Using TDS, each panelist is asked to determine the dominant attribute from a list of up 10 attributes (Pineau et al., 2009). However, the limitation with TDS is that non-dominant attributes, still important to profiling, are not considered, since the panelist is asked to identify the most dominant attributes. A new temporal method has been proposed called TCATA.

TCATA was developed to allow for the identification of non-dominant attributes, with simultaneous identification of dominant attributes (Castura et al., 2016). For TCATA, panelists are instructed to continuously evaluate the product over time with constant checking and unchecking attributes as they perceive them or not, respectively. Recently, studies have applied TCATA to evaluate orange juice and yogurt (Castura et al., 2016), cosmetic creams (Boinbaser, Parente, Castura, & Ares, 2015), and chocolate milk (Oliveira et al., 2015). TCATA does not obtain intensities of attributes. However, new research has found a complimentary relationship between TDS and TCATA (Ares et al., 2015) by comparing TDS and TCATA of various food
products. The authors concluded TCATA was effective in capturing temporality and providing more details about the dynamic sensory perception of a food compared to TDS.

The methods of data analysis for TCATA data are still being optimized and several analytical approaches have been proposed. Castura et al. (2016) has pioneered the data analysis methods. Commonly, studies generate graph line plots that are derived from aggregated data similar to TDS curves (Pineau et al., 2009), smooth curves using lowess or cubic splines (both of which are localized regression analysis techniques), establish reference lines to highlight areas of the evaluation time of one product that are distinct among other samples, generate difference plots to compare two separate samples, and perform correspondence analysis (CA). CA enables the researcher to visualize the product trajectories over the course of evaluation time. However, it is still unclear how to most effectively analyze and display multiple comparisons among samples and further work into the visualization of products is needed. Regardless, TCATA is a sensitive temporal method that is able to profile a wide range of products and in dynamic matrices.

DISSERTATION OBJECTIVES

Considering the literature above, CO₂ and sugar are key components in the sparkling wine matrix. Thus, research to determine the influence of each of these components on the sparkling wine profile and resulting consumer preference would be beneficial to winemakers. Moreover, as these components are crucial to other carbonated beverages, other industries would also benefit from this knowledge.

The overall objective of this research was to assess the effects of sparkling wine processing, specifically the sugar composition of the liqueur de tirage and dosage, and the effects on the sensory and analytical profiles of the final sparkling wines. Specific sub-objectives were to:
1. To describe the sensory aspects of sparkling wines containing different concentrations of CO₂ using trained sensory evaluation panels (static and dynamic methods) and consumer panels.

2. To analyze the influence of dosage composition varying in residual sugar level (brut and demi sec) and sugar type (fructose, glucose, or sucrose) on the chemical and sensory profiles of sparkling wines.

3. To determine the sensory attributes that drive consumer acceptance of sparkling wines.
CHAPTER III

THE PRODUCTION AND CONSUMER PERCEPTION OF SPARKLING WINES OF DIFFERENT CARBONATION LEVELS

ABSTRACT

The objective of this study was to determine the influence of wine processing on the chemical and sensory properties of sparkling wines, and describe the influence of carbonation on consumer perception. Eleven sparkling wine treatments were produced through the addition of different concentrations of dextrose during wine processing to create sparkling wines varying in carbonation (CO₂) level. Final wines ranged in CO₂ concentration from 0 to 7.5 g CO₂/L (p≤0.05). A consumer sensory evaluation panel (n=48) evaluated the wines using a paired comparison test in which a sparkling wine at CO₂ concentrations of 1.2, 2.0, 4.0, 5.8, or 7.5 g CO₂/L, was compared to the control sparkling wine (0 g CO₂/L) for mouthfeel attributes (carbonation and bite) and sour taste. Results showed significant differences (p≤0.001) between the control and sparkling wines containing 2.0, 4.0, 5.8 and 7.5 CO₂/L for the mouthfeel attributes of carbonation and bite, suggesting that a minimum CO₂ concentration of >1.2 g CO₂/L was required for consumers to detect mouthfeel differences compared to the control. The results of this study provide sparkling winemakers and manufacturers of other carbonated products insight into the influence of CO₂ on consumer perception.
INTRODUCTION

Carbonation, defined as the tingling imparted by the presence of carbon dioxide (Szczesniak, 1979), is an important sensory property in the acceptance of many beverages. In soft drinks, carbonation produces an appealing mouthfeel that is often described as “tingling” (Dessirier, Simons, O’Mahoney, & Carstens, 2001). While carbonation is influential in the acceptance of these non-alcoholic beverages, it is also important in the identity of sparkling wine and contributes its characteristic effervescence (Liger-Belair et al., 1999).

Sparkling wine is defined as a multicomponent hydro-alcoholic solution that is supersaturated with CO2-dissolved gas molecules and ethanol, both formed during fermentation (Liger-Belair et al., 2009). By U.S. law, wines fall into the category of sparkling wines once the CO2 levels reach ≥3.92 g CO2/L (27 CFR 24.245). In sparkling wines, CO2 can reach concentrations up to 11.8 g/L, but on average, CO2 levels are near ~9 g/L (Descoins, Mathlouthi, Le Moual, & Hennequin, 2006; Liger-Belair et al., 2008). The level of carbonation in the sparkling wine differs by sparkling wine style and standard of identity. For example, Vinho Verde, a sparkling wine of Portugal, is carbonated by direct sparging (Gallart, Tomás, Suberbiola, López-Tamames, & Buxaderas, 2004) or naturally through the process of malolactic fermentation (MLF). Both methods produce wines with CO2 concentrations of 2-4 g/L. MLF is a decarboxylation reaction of L-Malate to L-Lactate (Bartowksy & Borneman, 2011) and occurs in Champagnes, but the MLF processing step is optional (Shimazu & Watanabe, 1979; Kemp et al., 2015). To place these CO2 concentrations in context, the carbonation level of a highly carbonated soft drink, such as tonic water, is in the range of 4-7 g CO2/L (Liger-Belair, Sternenberg, Brunner, Robillard, & Cilindre, 2015).
Different sensory properties are associated with increased concentrations of CO$_2$. In a model beverage, the influence of CO$_2$ concentration on perceived sensory pain showed that more panelists reported perceived pain at 6.5 g CO$_2$/L compared to 3.2 g CO$_2$/L (Green, 1992). Similarly, in mineral water, tingling and pain perception increased as CO$_2$ concentration increased from ~3 g CO$_2$/L to ~7.2 g CO$_2$/L (Hewson, 2008). In white table wine, at concentrations of 1 g CO$_2$/L, the wine was described as prickly while at concentrations of 0.5 – 1.8 g CO$_2$/L, the wines were described as spritzy (Peynaud, 1983).

The more time and labor-intensive traditional method is known as *Methodé Champenoise*. In this method, once primary fermentation is complete, refermentation is necessary as the natural grape sugars are completely metabolized during the first fermentation. The second fermentation in the *Methodé Champenoise*, is also known as *prise de mousse*, and finishes in the sealed bottle and produce the CO$_2$ that provides the finished wine its effervescence. To initiate this second fermentation, a *liqueur de tirage* is formulated composed of *S. cerevisiae* yeast, sugar (22-23 g) (Gòdia et al., 1991; Pérez-Magaiño, Ortega-Heras, Martinez-Lapuente, Guadalupe, & Ayestaran, 2013) and a riddling aid, such as bentonite (Poinsaut & Hardy, 1995; Martinez-Rodríguez & Polo, 2003). Several other winemaking studies also added diammonium phosphate (DAP) or thiamine to the tirage preparation (Monk & Storer, 1986; Fumi et al., 1988; Ganss, Kirsch, Winterhalter, Fischer, & Schmarr, 2011; Valade & Laurent, 2001). Ganss et al. (2011) supplemented Riesling and Chardonnay sparkling wine tirage recipes with DAP and thiamine. Additionally, Valade and Laurent (2001) mention DAP and/or thiamine are beneficial in *tirage* preparation as the additives prevent the formation of reductive attributes in the wine. The second fermentation lasts about 6-8 weeks after which time the wine ages. During aging, yeast cells autolyze. As the yeast autolyze, the bottle is riddled, or turned a
fraction of a turn, to facilitate the incorporation of yeast components into the wine. The riddling process forces yeast and wine sediment into the neck of the bottle as the wine is gradually inverted neck down; this inversion is critical for the disgorgement process. Once all the sediment is in the neck of the bottle, the neck is frozen in a glycol bath, the bottle is turned upright and the crown cap removed (Riu-Aumatell et al., 2013). Since the wine is now naturally pressurized, the frozen yeast is expelled. At this time, the wine is topped up with wine and/or a dosage liquor that can consist of sugar (0-50+ g/L), liquor (cognac or brandy), or wine (Lubbers et al., 1994). Each bottle is sealed to contain the carbonation pressure, most often with a cork and wire hood (Kemp et al., 2015).

To influence the CO₂ levels in the final sparkling wine, the concentration of sugar added in the *liqueur de tirage* can be manipulated as demonstrated by the Gay-Lussac equation:

\[
C_6H_{12}O_6 \text{(aq)} \rightarrow 2 \text{CH}_3\text{CH}_2\text{OH \text{(aq)}} + 2 \text{CO}_2 \text{(g)} + \text{heat} \quad \text{Eq. 1.}
\]

The influence of CO₂ on the sensory properties of the final wine, particularly mouthfeel, represent an area of great interest due to its anticipated influence on consumer acceptance, with the influence of carbonation on consumer acceptance being limited to studies in soft drinks (Dessirier et al., 2000; Kappes et al., 2007) and dairy products (Karagül-Yüceer, Coggins, Wilson, & White, 1999). In wine, previous studies in table wine have shown that consumers differ in their preference for wine attributes (Bruwer, Saliba, & Miller, 2011; Gil & Sánchez, 1997; King et al., 2010).

The overall objective of this study was to determine the influence of wine processing, specifically the composition of the *liqueur de tirage*, on the chemical and sensory properties of sparkling wines. This study also described the influence of these different carbonation levels on consumer perception. The present study focused on consumers as we were interested in
determining the difference in carbonation that untrained consumers were able to perceive, as opposed to trained panelists. Previous literature has stated that consumers can provide attribute information, provided the ballot is carefully structured, as it was in the present study with the use of the paired comparison test (Moskowitz, Munoz, & Gacula, 2003).

MATERIALS AND METHODS

Materials

Thiazote® (source of thiamine) and diammonium phosphate (DAP) (Laffort, Bordeaux, FRA), dextrose (Archer-Daniels-Midland Co., Chicago, IL, U.S.A.), purified water (Culligan, Rosemont, IL, U.S.A.), yeast (Lallemand Vitilevure Quartz, Scott Labs, Petaluma, CA, U.S.A.), as well as PhosphatesMazure and ClarifiantS (Scott Labs, Petaluma, CA, U.S.A.) were donated for this study. Analytical grade anhydrous D (+)-glucose and anhydrous D (-)-fructose were obtained from Sigma-Aldrich (Sigma, St. Louis, MO, U.S.A.).

Wine Treatments

The wine treatments were designed to vary in dextrose concentration added to the liqueur de tirage. Dextrose concentrations of 0 (control), 1.6, 3.2, 4.8, 6.4, 8.0, 9.7, 11.3, 12.9, 14.5, and 16.1 g dextrose/L were selected to yield sparkling wines of differing concentrations of CO₂. Dextrose was selected instead of other sugars to facilitate a rapid fermentation as Saccharomyces is glucophilic (Fugelsang & Edwards, 2007; Wang et al., 2004). Also, previous work has used dextrose in the preparation of the liqueur de tirage (Cahill, Carroad, & Kunkee, 1980). These concentrations of dextrose were calculated based on the molecular relationship between dextrose and CO₂ from the Gay-Lussac equation above (Eq. 1). Because an objective of the study was to determine the CO₂ concentration at which panelists could distinguish differences from a control wine, more wines were produced at low CO₂ concentrations to allow for this determination.
Grapes were harvested from the Columbia Valley American Viticulture Area (AVA) of Washington State. At a commercial winery, grapes were whole-cluster pressed and each press cut underwent primary fermentation that lasted ~2 weeks. Each press cut was maintained as separate until blending was performed. The final cuvee blend consisted of 63% Chardonnay, 19% Pinot noir, and 18% Pinot Gris.

To produce 11 wine treatments (30 L each), ~340 L of base cuvee was used. Separate tirage recipes were formulated for each treatment. To prepare the different treatments, a five gallon stainless steel vessel was used, into which four gallons of cuvee were added. Wine was heated to ~22-23°C and 0.08 g Thiazote®/L wine was added to provide a source of thiamine for the yeast and the respective weight of dextrose (g) per treatment (defined above) were dissolved (Ganss et al., 2011). Once heated, the wine was poured into the tirage mixing tank. Purified water (~200 mL) was heated to 35-40°C, at which point the dextrose, 0.3 g yeast/L wine and 0.0015 g DAP/L wine were added. The yeast was rehydrated for no longer than 4 hr. To the rehydrated yeast slurry, approximately 100 mL base wine (at ~10°C) was added to equilibrate the yeast to the wine temperature in the tirage tank (~22-23°C). Once acclimated, the yeast mixture was then poured into the tirage tank equipped with a motorized propeller. Commercial riddling aids, PhosphatesMazure and ClarifiantS, were shaken to homogenize the mixture of riddling aids. After shaking, 30 mL ClarifiantS and 7.5 mL Phosphate Mazure were mixed and added to the tirage tank. The tirage tank housed a motor unit equipped with a propeller which was used to stir the wine and other adjuncts for 15 min. Bottles (750 mL) were gravity filled and sealed with crown caps. Wines were stored in the winery cellar at ~12°C. For each of the treatments, 30 bottles were filled and sealed for second fermentation in-bottle. The fill heights of
each bottle within each treatment were measured to ensure the headspace remained the same for fermentation in the bottle.

Wine analyses (sugar, alcohol, and CO$_2$) confirmed that fermentation completed in bottle prior to further processing. Bottles were then riddled for the 16 weeks leading up to disgorgement. In total, the wines were aged for ~8 months. The wines were hand-disgorged, with care taken to remove all the lees from the bottle. The wine was not used if the frozen yeast mass (or ‘plug’) failed to expel from the bottle.

**Wine Chemistry**

Following disgorgement, the wine treatments were analyzed for standard wine chemistry measurements followed general procedures described by Iland, Bruer, Edwards, Weeks, & Wilkes (2004). Titratable acidity (TA) and pH were measured using a Metrohm® 855 Robotic Titrosampler (Metrohm USA, Riverview, FL, U.S.A.), the CO$_2$ content (g/L) was measured using an AntonPaar CarboQC (AntonPaar GmbH, Austria), ethanol (v/v) with an AntonPaar Alcoholyzer, and volatile acidity measured with a Horiba ABX Pentra 400 (Irvine, CA, U.S.A.).

Quantification analysis of glucose and fructose in the sparkling wine treatments was performed using high performance liquid chromatography (HPLC). The system was composed of an Agilent 1100 Series system (Agilent Technologies, Santa Clara, CA) with a quaternary pump, degasser, autosampler, and coupled with a RI detector. For each treatment, a 1:10 sparkling wine dilution was analyzed, with an injected sample volume of 10 µL. The concentrations of glucose and fructose in wines were quantified using standard addition. Standard addition was performed whereby 0, 0.5, 1.5, 2.5, and 3.5 g/L each of glucose and fructose were pipetted into wine matrix. These concentrations were selected based on ranges reported in white and sparkling wines (Moro, Majocchi, Ballabio, Molfino, & Restani, 2007).
Wine treatments and standards were filtered using a 0.45 µm syringe filter (EMD Millipore, Billerica, MA) attached to a glass syringe. The HPLC settings were as follows: an Aminex® fermentation monitoring column (150 x 7.8 mm, particle size 9 µm; Bio-Rad Laboratories, Hercules, CA, Cat# 125-0115) with Micro-Guard Cation H+ (30 x 4.6 µm) guard column (Bio-Rad Laboratories, Hercules, CA, Cat# 125-0129), mobile phase of 0.001 M H₂SO₄ in MilliQ water, flow rate of 0.6 mL/min at room temperature, run time of ~15 min, column temperature of 60ºC, and RI detector temperature of 40 ºC. Each compound was identified in the chromatogram based on its retention time. The areas of each peak were used in the calculation of the concentration of compounds in the wine using a standard curve generated for each compound. All samples were analyzed in triplicate.

**Sensory Analysis Facility**

Evaluation took place in individual tasting booths under white light at Washington State University Sensory Evaluation Facility. Panelists were recruited using electronic advertisements (e.g. listserv, emails, and school advertisements) and consisted of students, faculty/staff, and members of the community. All participants signed an informed consent form and the Washington State University Institutional Review Board (IRB) for use of human subjects approved the project. Panelists received a non-monetary incentive for their participation.

A paired comparison test was used, with pairs presented to each panelist for the identification of the sample with the higher intensity of a particular attribute (Stone et al., 2012). During day 1, six paired comparison tests in which each CO₂ concentration (0, 1.2, 2.0, 4.0, 5.8, and 7.5 g CO₂/L) was compared to the control sparkling wine (0 g CO₂/L). The experiment was repeated on a second day. Wine samples were served using a randomized block design for sample presentation.
Due to the influence of temperature on CO$_2$ perception, all wines were presented at 8-9°C. At least two bottles per treatment were opened so as to avoid significant CO$_2$ losses from the kinetics of pouring and wait time between panelists. The same employee poured the carbonated sample or control to standardize the pouring process and minimize variation in sample preparation (Gallart et al., 2004). Consumers were also provided with the definition of the mouthfeel attribute of “bite”, which was defined as the stinging experience in the oral cavity when exposed to carbonation (as adapted from Szczesniak, 1979). Consumers were also asked about their familiarity with the perception of carbonation. Each panelist was presented with six pairs of wines. For each pair, consumers were required to evaluate both samples and indicate on paper ballots (given with each presented pair) which sample of the pair had a greater intensity of the mouthfeel attributes of carbonation and “bite”, along with identifying which sample had a more sour taste. Comment boxes were provided for each comparison. The panelists rested at least 2 min in between pairs, with a 10 min break following the fourth set of wines.

**Statistical Analysis**

Wine chemistry parameters were analyzed by analysis of variance (ANOVA), with mean separation carried out by Fishers Least Significantly Difference (LSD) test at $p \leq 0.05$ (STATA IC 13, StataCorp, College Station, TX, U.S.A.). For the paired comparison data, criteria for the significant differences among panelists as a function of CO$_2$ level were based on binomial distribution tables for paired comparison (Roessler, Pangborn, Sidel, & Stone, 1978). Levels of significance were established at $p \leq 0.05$ and $p \leq 0.001$. 

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RESULTS AND DISCUSSION

**Wine Characterization**

Wine treatments were characterized prior to sensory evaluation (Table 1). Wine treatments significantly differed in their carbonation levels \((p \leq 0.05)\), which varied from 0 to 7.5 g CO\(_2\)/L \((p \leq 0.05)\), with a positive relationship identified between the concentration of dextrose added and the resulting CO\(_2\) concentration \((r^2 = 0.99)\). The highest CO\(_2\) concentration presented in the present study (7.5 g CO\(_2\)/L) was within the range reported by others in literature. Commonly, sparkling wines produced using the traditional method reach 11.5 g CO\(_2\)/L (Liger-Belair, 2012); however, one study reported CO\(_2\) concentrations in sparkling wines to range from 6.2 – 9.7 g CO\(_2\)/L (Autret et al., 2005).

For several of the wine treatments, the concentration of dextrose added in the *liqueur de tirage* influenced the final ethanol concentration \((p \leq 0.05)\). In the present study, ethanol concentrations ranged from 10.7% to 11.4%. However, in a study of Chardonnay, retronasal sensory difference threshold of ethanol was reported to range from 0.22 to 4.94%, with a reported group threshold of 1.2% in white wine (Yu & Pickering, 2008). In sparkling wines of different varietals, ethanol concentration was reported to range from 9.7 to 10.5% for the Macabeo varietal, 10.1 to 11.1% for the Xarel.lo varietal, and 9.6 to 10.2% for Parellada (Andrés-Lacueva et al., 1996). Results also showed that within each varietal, ethanol differences within these ranges did not influence foamability or foam collar persistence. In the present study, initial alcohol content was the same for all treatments and final alcohol ranged no more than 0.7%. Even though significant differences in ethanol were found among the treatments, these differences were below this reported threshold level, and hence not expected to play a significant role in the sensory differences among the wines. In addition, due to these small differences in
ethanol concentration among treatments, foamability was likely not influenced (Andrés-Lacueva, López-Tamames, Lamuela-Raventós, Buxaderas, & de la Torre-Boronat, 1996).

Additionally, differences among the wine treatments for TA were found (p≤0.05). However, the differences in the observed TA values (0.1 g/L) among the sparkling wine treatments were below the threshold identified for sensory difference detection, which have been published as 0.5 g/L (Amerine, Roessler, & Ough, 1965; Berg, Filipello, Hinreiner, & Webb, 1955). As a result, this parameter likely did not contribute to the differences observed in consumer sensory perceptions.

After second fermentation, residual glucose and fructose concentrations ranged from 1.2-2.1 g/L and 1.1-2.0 g/L, respectively, across treatments. Glucose and fructose differ in their recognition and detection thresholds. The recognition thresholds of aqueous fructose and glucose solutions are reported as 9.37 g/L and 16.21 g/L, respectively, with detection thresholds of 3.6 g/L and 11.71 g/L, respectively (Belitz et al., 2009). While the differences in glucose and fructose concentrations were significantly different across some of the treatments, these differences were sub-threshold and likely did not contribute to in-mouth attributes differences among the wines.

**Consumer Evaluation**

Of the 48 consumers, 83.4% consumed both table and sparkling wines a few times per month. The panel consisted of 46% males and 50% females (4% not reporting), between 21 and 60+ years of age. The highest consumed sparkling wine types included Champagne (58.3%), Prosecco (37.5%), mixed (e.g. mimosa, Bellini, etc.) (33.3%), *Blanc de blancs* (29.2%), and *Blanc de noirs* and non-vintage sparkling wine equally (25%).
Paired comparison testing was conducted to determine if consumers were able to
distinguish between a control wine (containing 0 g CO₂/L) and a sparkling wine treatment
containing 1.2, 2.0, 4.0, 5.8 or 7.5 g CO₂/L (Table 2). The mouthfeel attributes of carbonation
(“which wine is more carbonated?”) and bite (“which wine has more bite?”) were examined. For
both attributes, when the control wine (0 g CO₂/L) was compared to itself (blind control) or
compared to the sparkling wine containing 1.2 g CO₂/L, no significant differences in any
attributes were found. However, when the control wine was compared to 2.0 g CO₂/L, more
consumers (n=38) selected the treatment wine as being more “carbonated” and having more
“bite” (p≤0.001). As the CO₂ concentration increased to 4.0, 5.8 and 7.5 g CO₂/L., the number of
consumers selecting the treatment wine as being more “carbonated” and having more “bite”
plateaued (p≤0.001). These results suggest that the minimum concentration of CO₂ (g/L) required
for consumers to distinguish between sparkling wine treatments for the sensory attributes of
carbonation and “bite” was >1.2 g CO₂/L. These findings support a previous study in which
Harper and McDaniel (1993) reported that a trained panel reported a greater mouthfeel
perception of “bite” in carbonated water as CO₂ increased in concentration from 0 to 0.9 g
CO₂/L. The results also suggest that differences exist in panelist sensitivity to carbon dioxide.
Beyond the comparison of the base wine to 4.0 g CO₂/L, the number of consumers identifying
the treatment with higher CO₂ concentration did not appreciably change.

Carbonation provides mechanosensory and chemosthetic sensations that contribute to
mouthfeel (Chandrashekar et al., 2009; Karagül-Yüceer et al., 1999). The oral sensation elicited
by carbonated beverages is partly due to the conversion of CO₂ to carbonic acid, which
stimulates receptors embedded in the tongue. However, studies of carbonation content and its
relationship to consumer acceptance are limited. Leksrisompong et al. (2013) showed that
mouthfeel attributes associated with carbonation, specifically after-numbing, numbing, burn, and bite, were the main drivers for consumer liking for regular and diet soda beverages. The results highlight the differences among consumers in both perception and liking of carbonation.

Building on this present study, future work in this area would include the production of wines with higher carbonation levels, reflecting the higher CO$_2$ concentrations observed in commercial sparkling wines. Subsequent carbonation and consumer acceptance studies would then be conducted on these wines. Futures studies could also explore the idea that consumers differ in their sensitivity and acceptance of carbonation in sparkling wines. Further exploration of these differences among consumers with consumer segmentation studies would allow winemakers and marketers to gain more insight about differences in consumer preferences, along with their willingness to purchase sparkling wines (Thiene, Galletto, Scarpa, & Boatto, 2013a; Thiene, Scarpa, Galletto, & Boatto, 2013b; Onofri, Boatto, & Bianco, 2015) based on varying sensory properties.

CONCLUSIONS

Eleven sparkling wine treatments of varying carbonation level were created through the manipulation of dextrose concentration in the liqueur de tirage. Final sparkling wines ranged in CO$_2$ concentration from 0 to 7.5 g CO$_2$/L. In the sensory evaluation of these wines by consumers, results showed that at CO$_2$ concentrations >1.2 g CO$_2$/L, consumers identified the CO$_2$ wine was having more “bite” and carbonation than the control wine with no carbonation. The results of this study provide sparkling winemakers and manufacturers of other carbonated products, such as beer, soda, and water, the insight into the influence of CO$_2$ on consumer perception of carbonation and “bite.”
Table 1. Wine chemistry measurements of sparkling wine treatments. (n=11). Values are presented as the mean of replicate measurements. Different letters within a column represent a significant difference among wine matrix treatments for a given parameter as determined by Fisher’s least significant difference test (p≤0.05). The sparkling wine treatments evaluated by consumers are denoted with †.

<table>
<thead>
<tr>
<th>Final CO₂ (g/L) at 20°C</th>
<th>Final CO₂ (psi) at 20°C</th>
<th>% Ethanol</th>
<th>Dextrose added prior to second fermentation (g/L)</th>
<th>Titratable Acidity (g/L)</th>
<th>pH</th>
<th>Residual Glucose (g/L)</th>
<th>Residual Fructose (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0±0.0 a †</td>
<td>0.0± 0.0 a</td>
<td>10.7 a</td>
<td>0.0</td>
<td>5.3 a</td>
<td>3.4</td>
<td>2.11±0.45</td>
<td>1.35±0.08</td>
</tr>
<tr>
<td>1.2±0.2 b †</td>
<td>17.6± 2.9 b</td>
<td>10.7 a</td>
<td>1.6</td>
<td>5.3 a</td>
<td>3.4</td>
<td>1.20±0.26</td>
<td>1.96±0.58</td>
</tr>
<tr>
<td>2.0±0.4 c †</td>
<td>29.4± 5.9 c</td>
<td>10.8 c</td>
<td>3.2</td>
<td>5.3 a</td>
<td>3.4</td>
<td>2.08±0.66</td>
<td>1.36±0.13</td>
</tr>
<tr>
<td>2.8±0.4 d</td>
<td>41.6± 5.9 d</td>
<td>10.8 c</td>
<td>4.8</td>
<td>5.3 a</td>
<td>3.4</td>
<td>2.06±0.71</td>
<td>1.33±0.17</td>
</tr>
<tr>
<td>3.1±0.1 d</td>
<td>45.6± 1.5 d</td>
<td>10.9 d</td>
<td>6.4</td>
<td>5.3 a</td>
<td>3.4</td>
<td>1.99±0.75</td>
<td>1.30±0.15</td>
</tr>
<tr>
<td>4.0±0.3 e †</td>
<td>58.8± 4.4 e</td>
<td>11.0 e</td>
<td>8.0</td>
<td>5.3 a</td>
<td>3.4</td>
<td>2.05±0.70</td>
<td>1.33±0.12</td>
</tr>
<tr>
<td>4.6±0.3 ef</td>
<td>67.6± 4.4 ef</td>
<td>11.1 f</td>
<td>9.7</td>
<td>5.3 a</td>
<td>3.4</td>
<td>2.11±0.61</td>
<td>1.43±0.10</td>
</tr>
<tr>
<td>4.9±0.7 f</td>
<td>72.0±10.3 f</td>
<td>11.2 g</td>
<td>11.3</td>
<td>5.2 b</td>
<td>3.4</td>
<td>2.02±0.70</td>
<td>1.34±0.13</td>
</tr>
<tr>
<td>5.8±0.0 g †</td>
<td>85.3± 0.0 g</td>
<td>11.3 h</td>
<td>12.9</td>
<td>5.2 b</td>
<td>3.4</td>
<td>2.03±0.71</td>
<td>1.29±0.12</td>
</tr>
<tr>
<td>6.7±0.3 h</td>
<td>98.5± 4.4 h</td>
<td>11.3 h</td>
<td>14.5</td>
<td>5.2 b</td>
<td>3.4</td>
<td>2.07±0.71</td>
<td>1.29±0.13</td>
</tr>
<tr>
<td>7.5±0.0 i †</td>
<td>110.3± 0.0 i</td>
<td>11.4 i</td>
<td>16.1</td>
<td>5.2 b</td>
<td>3.4</td>
<td>1.92±0.69</td>
<td>1.14±0.11</td>
</tr>
</tbody>
</table>
Table 2. Number of agreeing consumer responses (n=48) for paired comparison tests of sparkling wine treatments of varying final CO₂ content (g/L) compared to the control base wine (BW) containing no carbonation. Under each paired comparison question, the value shown is the number of panelists who selected the treatment wine over the base wine. Significance was defined as 36 agreeing responses (p≤ 0.001**). For CO₂ concentrations, different letters within a column represent a significant difference among wine matrix treatments as determined by Fisher’s least significantly different test (p≤0.05).

<table>
<thead>
<tr>
<th>Final CO₂ (g/L)</th>
<th>Which wine is more carbonated?</th>
<th>Which wine has more “bite”?</th>
<th>Which wine tastes more sour?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 ± 0.00 a</td>
<td>26</td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td>1.2 ± 0.21 b</td>
<td>26</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>2.0 ± 0.35 c</td>
<td>38**</td>
<td>38**</td>
<td>23</td>
</tr>
<tr>
<td>4.0 ± 0.28 d</td>
<td>48**</td>
<td>44**</td>
<td>17</td>
</tr>
<tr>
<td>5.8 ± 0.03 e</td>
<td>48**</td>
<td>46**</td>
<td>18</td>
</tr>
<tr>
<td>7.5 ± 0.01 f</td>
<td>48**</td>
<td>45**</td>
<td>21</td>
</tr>
</tbody>
</table>
CHAPTER IV
PERCEPTION OF SPARKLING WINES OF VARYING CARBONATION LEVELS USING DESCRIPTIVE ANALYSIS (DA) AND TEMPORAL CHECK-ALL-THAT-APPLY (TCATA)

ABSTRACT

Carbonation is an important temporal sensory property of sparkling wine. In this study, 11 sparkling wines of different carbonation (CO₂) levels were prepared through the addition of varying concentrations of dextrose during the winemaking process. Sparkling wines, ranging in CO₂ concentration from 0.0 to 7.5 g CO₂/L (p<0.05), were evaluated by a trained panel (n=11) using Descriptive Analysis (DA) for mouthfeel attributes associated with carbonation, as well as taste, aroma, and flavor attributes. Canonical Variates Analysis (CVA) showed that the mouthfeel attributes explained the majority of variation among the wine treatments based on the DA data. Increased CO₂ concentrations in the wine treatments resulted in increased intensity of mouthfeel attributes, with the attributes burn, bite, carbonation/bubble pain, and foamy showing the greatest differences among treatments, and after-numbing and tingly showing the least. The sparkling wines were also evaluated by a trained panel (n=13) using Temporal Check-All-That-Apply (TCATA) methodology to describe temporal changes in mouthfeel perceptions. Smoothed TCATA curves suggested a relative grouping of attributes: attributes that were perceived earlier in the evaluation time (peak citation <15 s into evaluation), and attributes with a delayed onset of perception (>15 s into evaluation). Furthermore, average proportion of citations results indicated that attribute citation plateaued at ≥4.0 g CO₂/L for the attributes of bite/burn, prickly/pressure, and tingly. Principal Component Analysis (PCA) was used to obtain wine treatment trajectories,
which enabled the visualization of attribute perception over time. Additionally, multiple factor analysis (MFA) showed all the mouthfeel attributes evaluated by both TCATA and DA were highly correlated (RV= 0.98) suggesting that both methods were similar in their ability to distinguish between carbonated wine treatments. The results of this study highlight the application of TCATA methodology to describe CO$_2$ perception, which produces complex temporal sensations.
INTRODUCTION

In sparkling wine, the perception of effervescence is elicited by the presence of carbon dioxide (CO$_2$) bubbles. Sparkling wine has been defined as a multicomponent hydroalcoholic solution supersaturated with CO$_2$-dissolved gas molecules (Liger-Belair et al., 2009). In sparkling wine, according to the Gay-Lussac equation (Williams, 1982), CO$_2$ originates from the microbial fermentation of sugar to form alcohol and carbon dioxide. According to U.S. law, a wine is legally considered a sparkling wine if the CO$_2$ concentration exceeds 3.92 g/L (27 CFR 24.245).

Studies in the area of sparkling wine carbonation have been focused on such areas as the mousse or foaming properties (Andrés-Lacueva et al., 1997; Pueyo et al., 1995), bubble dynamics (Liger-Belair et al., 2001), and matrix components that influence various wine parameters, such as foam active compounds (Brissonet & Maujean, 1991) and yeast cell wall compounds (Núñez et al., 2006); however, few studies have profiled carbonation. One study on the perception of carbonation in sparkling wine was examined and reported that a minimum of 2.0 g CO$_2$/L is required for consumers to perceive the attributes of carbonation and bite (McMahon, Culver, & Ross, under review).

Studies describing the perception of carbonation in other matrices are more plentiful. Non-wine studies have revealed or confirmed that the perception of carbonation is auditory (Spence & Zampini, 2006), visual (Liger-Belair et al., 2007), with nociceptive (Wang et al., 2010), mechanosenory (Rofes, Cola, & Clavé, 2014), and chemosensory origins (Smith, Martinez-Velazquez, & Ringstad, 2013). Few studies have examined the influence of carbonation on product acceptance and are limited to products including carbonated pineapple juice (Baranowski & Park, 1984) and lemon-lime soda (Lekrisompong et al., 2013).
Leksrisompong et al. (2013) concluded that carbonation-related mouthfeel attributes of afternumbing, numbing, burn, and bite were drivers of consumer liking for carbonated beverages.

Additionally, several studies have sought to describe the relationship between CO\textsubscript{2} and the perception of specific sensory properties through the development of lexicons for the perception of carbonation. Recently, a sparkling wine-specific lexicon was developed to further detail the complex perceptions related to this style of wine, with attributes including nasal pungency aroma, as well as the mouthfeel attributes of bubble pain, creamy, and foamy (Le Barbé, 2014). Moreover, a mouthfeel wheel for white wine was developed and incorporated attributes related to carbonation, such as tingle and mousse dynamics (Pickering & Demiglio, 2008). Other profiling studies developed vocabulary to describe carbonation-related attributes for non-wine beverages including bite, burn, numbing, and carbonation for lemon-lime sodas (Kappes et al., 2006), carbonation level for carbonated apple juice (McLellan, Barnard, & Queale, 1984), and bubbly, bubble size, bubble sound, and gas expansion for carbonated water (Harper & McDaniel, 1993).

In the studies mentioned above, the carbonated beverages were profiled using static sensory methods. These static methods are based on the notion that perception is an average of the entire sensory experience. As carbonation perception encompasses mouthfeel attributes that change over time, the application of temporal sensory evaluation methods would provide a more accurate depiction of the full sensory experience. Such temporal methods, including Time-Intensity (TI), have been used in wine to study the changing perception of astringency (Guinard, Pangborn, & Lewis, 1986), bitterness (Robichaud & Noble, 1990; Sokolowsky & Fischer, 2012), and wine finish (Baker & Ross, 2014).
While TI provides valuable information regarding the temporality of an attribute, one challenge associated with this method is that the panelist is limited to the evaluation of only one or two attributes at a time, contributing to a halo-dumping effect (Clark & Lawless, 1994). Temporal Dominance of Sensations (TDS) allows each panelist to continually indicate the dominant attribute, usually from a list of up to ten attributes (Pineau et al., 2012). Several studies have applied TDS to study wine taste and flavor (Pessina, Boivin, Moio, & Schlich, 2005), to describe subtleties in dealcoholized red wine (Meillon et al., 2009), and to describe bitterness in white wine (Sokolowsky & Fischer, 2012). However, the challenge with TDS is that non-dominant attributes, which are still important to profiling, are not considered.

A more recent method, Temporal Check-All-That-Apply (TCATA), allows for the simultaneous identification of both non-dominant and dominant attributes (Castura et al., 2016). Using this method, panelists are instructed to evaluate the product over time and constantly check and uncheck the attributes as they are or are not perceived, respectively. Researchers have applied TCATA to evaluate a wide range of products, including orange juice and yogurt (Castura et al., 2016), cosmetic creams (Boinbaser, Parente, Castura, & Ares, 2015), chocolate milk (Oliveira et al., 2015), salami, cheese, French bread, and marinated mussels (Ares et al., 2015), and red wine finish (Baker, Castura, & Ross, in press).

Regarding carbonated beverages, published temporal method studies are scarce. One study used TI to evaluate the dynamic nature of aroma perception as influenced by carbonation in mint-flavored beverages (Saint-Eve et al., 2009). Results showed that compared to non-carbonated beverages, carbonated beverages (containing 5 g CO₂/L) possessed a higher aroma intensity for the volatile compounds of menthol (mint leaf), menthone (fresh and polar mint), and
(Z)-hex-3-en-1-ol (green) (p<0.05). This increased aroma intensity was attributed to CO₂ outgassing that transported volatiles up through the liquid to the interface.

The overall objective of the present study was to describe the sensory aspects of sparkling wines containing different concentrations of CO₂ (0.0–7.5 g CO₂/L). Specifically, we sought to describe the sensory properties of the finished wine using both static (DA) and dynamic (TCATA) methods. Ultimately, this study will provide further insight into the complexity of CO₂ perception over time and allow for the comparison of results collected using static and dynamic sensory methods.

MATERIALS AND METHODS

Wine Samples

Details about the production and final wine chemistry of the sparkling wines can be found in another publication (McMahon et al., under review). The CO₂/L concentrations of the sparkling wines were 0, 1.2, 2.0, 2.8, 3.1, 4.0, 4.6, 4.9, 5.8, 6.7, and 7.5 g CO₂/L. Wines were stored at 4.4 °C until analysis and moved to a 3 °C refrigerator for 24 h prior to sensory evaluation.

Sensory Analysis Facility

Evaluation took place in individual tasting booths under white lights at Washington State University’s (WSU) Sensory Evaluation Facility, a member of the Compusense Academic Consortium (Guelph, Canada). The use of human subjects for this study was approved by the Washington State University Institutional Review Board (IRB #13422-003).
Descriptive Analysis (DA)

Demographic Overview

Eleven volunteers were recruited from the Pullman, WA community using electronic advertisements (e.g. listserv, emails, and school advertisements). Past experience in wine, beer, or sensory evaluation was a requirement for participation in the trained panel. The panel consisted of 8 males and 3 females (mean age of 25.4 years) who all indicated they consumed sparkling wine at least several times per year. The lowest age allowed to participate on the panel was 21 years to comply with federal and state laws related to alcohol consumption. All panelists expressed interest in learning more about sparkling wine. Panelists received a small nonmonetary compensation for their participation at the end of each training session.

Training

Panelists were trained over eight, one-hour sessions. During the first session, demographic information was collected and the evaluation protocol was introduced. More detailed instructions included no swirling of the glass, holding the stem of the flute, and no gurgling or swishing the wine in-mouth. This protocol was based on preliminary bench trials to minimize the change in CO\textsubscript{2} during evaluation. Initial training of panelists identified and evaluated mouthfeel attributes. Subsequent training sessions expanded the attribute list to include aroma, flavor, and taste attributes.

Panelists were trained using commercial and experimental sparkling wines of different carbonation levels, varietal, and dosage level, including non-dosed, brut, Vinho Verde, Methodé Champenoise, and Charmat style sparkling wines. The definition and reference standard for each attribute are shown in Table 1. These attributes and definitions were developed in reference to published literature (Le Barbé, 2014; Pickering & Demiglio, 2008; Kappes et al., 2006;
McLellan et al., 1984; Harper & McDaniel, 1993), benchwork prior to training sessions, and panel consensus on attribute definitions. All attributes were evaluated using an unstructured 15-cm line scale, anchored with “low” at 1.5 cm and “high” at 13.5 cm. Panelist training and performance were monitored for discrimination and consistency among the panelists when presented with blind reference standards prepared in wines, as well as a range of treatment wines. During training sessions, repeatability was also assessed using replicate samples.

*Evaluation Sessions*

For profiling of the sparkling wine samples, four formal evaluation sessions were conducted over two days, allowing for replicate evaluations of each treatment by each panelist. Wine samples (~30 mL) were labeled with three-digit codes and served at 8-9°C in wine flute tasting glasses (SKU: 71086, Cardinal International, Inc., Pine Brook, NJ) covered with a Petri dish. Wines were presented using a randomized complete block design blocked by session (Castura et al., 2016; Boinbaser et al., 2015). For each CO₂ treatment, two randomly selected bottles were opened at each evaluation session. Each bottle served no more than eight panelists each so as to avoid significant CO₂ losses from the kinetics of pouring. Moreover, wines were poured beer-style into sparkling wine flutes to minimize CO₂ losses (Liger-Belair et al., 2010). Immediately after pouring, panelists were presented with flutes and instructed to start evaluations. Panelists were instructed to expectorate the wine sample after 10 s in mouth. The order in which attributes were evaluated for each sample were first the mouthfeels, aromas, tastes, and (lastly) flavors. Following the evaluation of each sample, panelists were instructed to wait at least 60 s and cleanse their palates with water and crackers. All data were collected using computerized sensory software (Compusense *at-hand*, Compusense Inc., Guelph, Ontario, Canada).
**Temporal Check-All-That-Apply (TCATA) Trained Panel**

**Demographic Overview**

Eleven panelists were recruited from the DA panel described above. Two additional panelists with previous wine sensory panel experience were also recruited. In total, the panel consisted of nine males and four females (mean age of 26.3 years). At the end of each session, panelists received a small nonmonetary compensation for their participation.

**Training**

For those panelists who did not participate in the DA panel (n=2), a preliminary training session was necessary to introduce the evaluation protocol and attributes, as well as to collect demographic information and to obtain signed consent forms. For all panelists, four in-booth training sessions were conducted, exceeding the number of training sessions stated by other researchers as sufficient to familiarize panelists with the procedure (e.g. Pineau et al., 2009). During these four in-booth sessions, panelists became familiarized with evaluation protocol (as described in the DA section) and the TCATA methodology. Panelists also became familiar with the list of attributes, which was adapted from the previous DA panel and modified through open discussion and panel consensus. Temporal characterization analyzed both gustatory and mouthfeel sensory attributes. As a result, eight attributes composed the TCATA list (Table 2), not exceeding the suggested 10 attribute maximum established in other temporal studies (Pineau et al., 2012). Positions of attributes on the TCATA list were randomized across panelists; however, the list order remained consistent for a given panelist across all sessions (Meyners & Castura, 2016).
Evaluation Sessions

For profiling of the sparkling wine treatments, six formal evaluation sessions were conducted over three days, allowing for replicate evaluations of each treatment by each panelist. Wines were presented using a randomized complete block design blocked by session (Castura et al., 2016; Boinbaser et al., 2015). For each CO$_2$ treatment, two randomly selected bottles were opened at each evaluation session. Wine samples (~30 mL) were labeled with three digit codes and served at 8-9°C in wine flute tasting glasses. Wines were served and poured in a similar manner as described in the DA panel above.

Instructions were presented to the panelists using Compusense at-hand. All of the attributes shown in Table 2 were presented to the panelists in a three-column format. Panelists pressed the “start” icon once the sample was in-mouth (t=0 s). The wine was held in-mouth for 10 s at which point the panelist was prompted by an onscreen instruction to expectorate the sample. The total duration of evaluation was established as a maximum of 125 s, which was selected through preliminary evaluations by an experienced panel to ensure that the entire duration of the perception would be captured. From the attributes presented, the panelist checked and unchecked attributes that described the sample during this 125 s period. If panelists ceased to perceive attribute(s) prior to 125 s, the evaluation session could be stopped. A forced 1-min break was set between samples whereby panelists were instructed to chew one cracker and rinse with deionized water. Collected data were exported in which the response for each wine treatment at each time slice (0.1 s) was either ‘1’ or ‘0’ to indicate the perception of a given attribute or no perception, respectively.
**Data Analysis**

**DA**

DA data were analyzed using the following linear mixed effects model,

$$ Y = Samp + Rep + Samp*Rep + Panelist + Panelist*Rep + Panelist*Samp + \text{error}, $$

where $Y$ refers to the attribute intensities, and where $Samp$ and $Rep$ (referring to samples and replicates) and the $Samp*Rep$ interaction are treated as fixed factors, whereas $Panelist$ and its interactions are treated as random effects. Analysis was conducted in the R 3.2.3 (R Code Team, 2015) using the package `lmerTest` (Kuznetsova, Brockhoff & Christensen, 2015; Kuznetsova, Christensen, Bavay, & Brockhoff, 2015). Sample differences were evaluated using differences in least squares means. The significance value for all analyses was established as $p<0.05$. Canonical Variates Analysis (CVA) was applied to separate wines based on their mouthfeel attributes (XLStat 10, Sensory Package, Addinsoft, Paris, France). Bartlett’s test was employed to determine the significance from the 95% confidence intervals.

**TCATA**

**TCATA Curves**

Following a similar procedure as described in Castura et al. (2016) and Boinbaser et al. (2015), proportions of citations were calculated as the percentage of panelists who perceived (or checked) an attribute at any given moment (0.1 s) during the evaluation period. For each attribute, reference lines were calculated per treatment at each time point (each 0.1 s during the evaluation period. For a given attribute, reference lines (represented in the figures as dotted lines) were presented only during periods of significant differences in proportion of citations for each treatment compared to the other ten treatments. These reference line segments were contrasted with highlighted sections of attribute curves to allow for ease of identification of time periods.
during which significant differences were observed. For visualization purposes, TCATA attribute
curves were also smoothed using the smooth.spline function in R. Specifically, a cubic
spline was applied to the data in order to reduce variation in the data.

**Multivariate Analysis of TCATA Attributes**

The relationships among sparkling wine treatments and the unscaled TCATA attributes
were investigated using principal component analysis (PCA) on unfolded data, as proposed by
Castura, Baker and Ross (under review). Each treatment was expected to form a trajectory, or
path, that would chart its change in sensory perception. PCA biplots were constructed to
visualize the treatments in relation to the attributes evaluated.

**Analysis of Duration**

The Duration of each TCATA evaluation was obtained by subtracting the Start time (the
time that the first attribute was checked) from the Stop time (the time that the last attribute was
unchecked, or, rarely, that the 125-s maximum time was reached). Duration data were analyzed
as the response variable Y in the linear mixed effects model presented in (1). Sample differences
were evaluated using differences in least squares means (p<0.05).

**Analysis of Average Proportions of Citations**

The average proportion of citations was obtained for each attribute in each TCATA
evaluation as the proportion of the 125 s evaluation time that the attribute was selected. For
example, if a panelist selected bitter for a duration of 25 s and Sour for a duration of 30 s, then
the proportion of citations for bitter would be 25.0/125.0 = 0.20 and the proportion of citations
for Sour would be 30.0/125.0=0.24. Proportion of citations, which can range from 0 to 1, and is
analogous to Area Under the Curve (AUC) in Time Intensity studies, which is often used as a
parameter of interest during analysis (see Lawless & Heymann, 2010, Ch. 8). Univariate linear
mixed effects models were then fitted using (1), but in which the response is proportion of citations as the response variable Y.

**Correlation Between DA and TCATA**

Multiple factor analysis was applied to extracted mouthfeel variables from both the DA and TCATA data. Prior to running MFA, TCATA was segmented into 15 s time intervals to better capture temporal evolution (Dinnella, Masi, Naes, & Monteleone, 2013). Specifically, time intervals included: 15 s (0 to 15.0 s), 30 s (15.1 to 30 s), 45 s (30.1 to 45 s), 60 s (45.1 to 60 s), and 75 s (60.1 to 75 s). TCATA variables were reduced to determine a significant sample effect on mouthfeel proportion of citations per time segment using a linear mixed model using the following model components: Sample, Replicate, and Sample*Replicate; Panelists were considered a random factor. Extracted parameters for DA included all eight DA mouthfeel variables. Extracted parameters for TCATA were as follows: 15 s (bite/burn, carbonation/bubble pain, foamy, numbing, prickly/pressure), 30 s (bite/burn, carbonation/bubble pain, foamy, numbing, prickly/pressure, tingly), 45 s (bite/burn, numbing, tingly), 60 s (numbing, tingly), and 75 s (numbing, tingly). The regression vector (RV; Robert & Escoufier, 1976) coefficient generalizes squared Pearson correlation coefficient. Possible RV values are between 0 (no similarity) to 1 (high similarity). The RV coefficient was calculated to determine the degree of similarity between the two methods. The significance value for all analyses was established as p<0.05.

**RESULTS AND DISCUSSION**

**Wine Characterization**

Wine composition of the sparkling wines is shown in Table 1 from Chapter III. As expected, the addition of dextrose prior to second fermentation in the bottle significantly
influenced the final CO₂ content (g/L), with increased added dextrose resulting in increased concentration of CO₂ in the wine (p<0.05). Some differences were observed among other wine chemistry parameters. However, these values were below the threshold for sensory perception as reported in previous studies of ethanol (Yu & Pickering, 2008; Pickering & Demiglio, 2008), pH (Amerine et al., 1965), titratable acidity (Berg et al., 1955), and residual glucose and fructose (Belitz et al., 2009). As a result, while statistical differences were observed for certain wine chemistry parameters, they were not expected to influence the descriptive and temporal sensory profiles of the sparkling wine.

**Descriptive Analysis**

**Mouthfeel Attributes**

Analysis of variance results for mouthfeel attributes are shown in Table 4. The sparkling wine sample, primarily defined by its CO₂ concentration, significantly influenced the perception of all mouthfeel attributes (p<0.001). Mean separation for the sparkling wine mouthfeel attributes are presented in Table 5. For the mouthfeel attributes of burn, carbonation/bubble pain, and tingly, the lowest concentration at which there was a significant difference from the control wine was 2.0 g CO₂/L. In contrast, for the mouthfeel attributes of bite, numbing, after-numbing, prickly, pressure, and foamy, the lowest concentration at which there was a significant difference from the control wine was 2.8 g CO₂/L. The separation of the wine treatments containing increasing concentrations of CO₂ was clear for these attributes, with increasing intensities as the CO₂ concentration increased.

The mid-level ranges in CO₂, particularly 2.8 and 3.1 g CO₂/L, were not different enough to elicit difference in the ratings of the mouthfeel attributes, suggesting differences in intensity begin to plateau. Likewise, for the mouthfeel attributes of bite, burn, numbing, after-numbing,
prickly, foamy, and tingly, no significant differences were observed between 4.0 and 4.6 g CO₂/L. Differences in intensity varied at the higher CO₂ concentrations.

The intensity of each mouthfeel plateaued varied with the wine treatment. For the perception of tingly, the panel could not distinguish a difference between 4.0 to 4.9 g CO₂/L. The panel could not distinguish a difference in after-numbing and prickly, above 4.6 g CO₂/L with no significant differences in intensity at concentrations above this level. For bite, numbing, carbonation/bubble pain, pressure, and foamy, intensity ratings plateaued at sparkling wine treatments containing 5.8 g CO₂/L, with no significant intensity differences noted at concentrations above this concentration.

Overall, increased CO₂ concentrations also resulted in increased detection or intensity of perception for carbonation related attributes, particularly bite, burn and carbonation/bubble pain. The present results were similar to those of a previous study on sparkling wines in which no significant difference were observed by consumers in the perception of carbonation and bite when comparing sparkling wines containing 0 or 1.2 g CO₂/L (McMahon et al., under review). However, compared to a control sample (0 g CO₂/L), consumers detected the attributes of carbonation and “bite” in sparkling wine treatments containing at least 2.0 g CO₂/L (p<0.05). The CO₂ concentration at which the trained panelists perceived bite as compared to the control was 2.8 g CO₂/L (p<0.05). Even when provided the definition of bite, the consumer understanding of the term may have been less defined in McMahon et al. (under review). Consumers are untrained assessors who potentially may be dumping other carbonation-related perceptions into their perception of bite. As seen in the DA results, the mouthfeel attributes of burn, carbonation/bubble pain, prickly, pressure, and tingly could have been mistaken for bite by the consumers in the previous work. Additionally, sparkling wines containing CO₂
concentrations above 2.0 g CO$_2$/L (4.0, 5.8, and 7.5 g CO$_2$/L) were all perceived to be more carbonated and to have more “bite” as compared to the control (p<0.001) (McMahon et al., under review).

The present results also align with a previous study in carbonated water in which the influence of CO$_2$ concentration on perceived pain was examined (Green, 1992). In this carbonated water study, 22.5% more panelists perceived pain from the water containing 6.5 g CO$_2$/L compared to water containing 3.2 g CO$_2$/L, with these concentrations representing similar concentrations as those reported in the present study. In another study in mineral water, increased tingling and pain perception (also defined as overall fizziness) was described by panelists as carbonation increased from ~2.96 to ~7.11 g CO$_2$/L (Hewson et al., 2009). Taken together with the present study, these results confirm that higher concentrations of CO$_2$ elicit more intense effervescence-related mouthfeel sensations.

The trained sensory panel mouthfeel data were analyzed using canonical variates analysis (CVA), a multivariate technique which for these data seeks to find linear combinations of attributes that maximize the ratio of between-product variation to between-panelist variation. The separation of the wine treatments based on their mouthfeel attributes are illustrated in Figure 1. Sparkling wine treatments were separated based on carbonation level across the F1 axis (accounting for 92.12% of the variation). The CVA analysis revealed a strong (nearly unidimensional) relationship between the CO$_2$ concentration in the sparkling wine and the intensity of the different mouthfeel attributes. Sparkling wine treatments containing 4.6, 4.9, 5.8, 6.7, and 7.5 g CO$_2$/L, were highly associated with all the mouthfeel attributes. The sparkling wines with lower carbonation concentrations, namely, 0, 1.2, 2.0, 2.8, and 3.1 g CO$_2$/L were lower in intensity of all of these mouthfeel attributes. Grouping of wines containing similar CO$_2$
concentration based upon the intensity of the mouthfeel attributes perceived by the trained panel was clear, with some overlapping ellipses between similar CO₂ concentrations. For example, the sparkling wines containing 0 and 1.2 g CO₂/L showed a high degree of overlap, indicating that these samples were very similar to each other in their perception of mouthfeel attributes. This analysis clearly visualized the influence of increasing carbonation on the mouthfeel attributes evaluated and the carbonation levels at which these mouthfeel differences were apparent.

*Tastes, Aromas, and Flavors*

Analysis of variance results for the sparkling wine tastes, aromas, and flavors are shown in Table 6. For the tastes, sweetness was significantly different among treatments (p<0.01). The treatment had a significant effect on vanilla aroma (p<0.01) and caramel flavor (p<0.05).

As shown in Table 7, although the panel detected differences between specific treatments, the sweetness intensity was not modulated systematically by carbonation level, suggesting that the difference in sweetness perception was likely not a function of carbonation level. Previous work in non-wine products is inconclusive regarding the influence of CO₂ concentration on perceived sweetness. Passe et al. (1997) analyzed the effect of carbonation (~0, 2.2, 4.5, and 5.9 g CO₂/L at 20°C) on sweetness perception in beverages and reported that a higher carbonation level significantly suppressed sweetness perception (p<0.05). Likewise, in model beers, CO₂ (~7.1 g CO₂/L at 20 °C) significantly suppressed perceived sweetness (Clark et al., 2011), while in carbonated milk beverages, carbonation significantly enhanced sweetness compared to non-carbonated milk beverages (p<0.05) (Yau, McDaniel, & Bodyfelt, 1989). However, in a study of an aqueous solution containing sucrose, no effect of carbonation on the sweetness perception was reported (Cometto-Muñiz et al., 1987).
Significant differences in intensity were also observed for vanilla aroma and caramel flavor (Table 7). There is some suggestion that CO$_2$ is influencing the outgassing and perception of volatiles. More vanilla aroma was perceived at 7.5 g CO$_2$/L compared to 0 to 2.8 g CO$_2$/L (p<0.05). Additionally, 7.5 g CO$_2$/L had more vanilla aroma than 4.6 g CO$_2$/L (p<0.05). No differences in vanilla aroma were observed between 2.8 to 5.8 g CO$_2$/L. In addition, the differences in caramel flavor were less distinct. Caramel flavor was significantly higher at 5.8 g CO$_2$/L compared to wines with lower carbonation (0 to 4.9 g CO$_2$/L) (p<0.05). No differences were found between 5.8 to 7.5 g CO$_2$/L.

Several previous studies have reported increased volatile partitioning into the headspace with increasing carbonation level (Saint-Eve et al. 2009; Pozo-Bayón et al., 2009; Clark et al., 2011). However, another study reported a significant negative correlation of the perception of caramel and vanilla aroma with carbonated-related attributes (Kappes et al., 2007). Taken together, the interactions between carbonation and wine volatile perception are complex, which may be summarized as being compound specific and other matrix interactions beyond CO$_2$, such as sugar and acid, should be considered.

**TCATA**

*Aggregated Evaluations With Reference Lines*

TCATA curves are shown for selected CO$_2$ sparkling wine treatments. The base wine (containing no CO$_2$) was generally lower in citation rates for all attributes compared to the other treatments (Figure 2A). Within the first ~10 s of evaluation, sourness was used more frequently to describe the base wine compared to the average frequency of sour citation for the other treatments during this period of time. Carbonation/bubble pain was cited less frequently during the first 17 s as compared to the average frequency of carbonation/bubble pain citation for the
other treatments during this time. Although the proportion of citation for these carbonated-related mouthfeel attributes was low, it was not zero as may have been expected as this treatment contained 0 g CO$_2$/L. However, as was seen in the DA panel, there was no significant difference in mouthfeel perceptions in wines containing 0, 1.2, and 2.0 g CO$_2$/L.

As the CO$_2$ concentration increased to 4.6 g/L CO$_2$ (Figure 2B), higher citation rates were observed for prickly/pressure within the first 23 s of evaluation. In addition, bite/burn was used more frequently within the first 11 s compared to the other wine treatments. Furthermore, greater citation for carbonation/bubble pain occurred between ~5 and 12 s compared to the other treatments. Between ~25 to 35 s, the wine was more characterized as tingly in relation to the other wine treatments.

As expected, the sparkling wine containing 7.5 g CO$_2$/L displayed higher citations for a number of the mouthfeel attributes (Figure 2C). Proportions for bite/burn (between 1 and 10 s, with a second burst of perception between 30 and 38 s), carbonation/bubble pain (between 2 to 30 s), and prickly/pressure (between 5 and 27 s) were all higher compared to the other treatments (p<0.05). Additionally, the sparkling wine containing 7.5 g CO$_2$/L had extended durations of numbing and tingly perception relative to the other wine treatments. Between ~45 and 60 s, the sparkling wine containing 7.5 g CO$_2$/L was described by significantly more panelists as sour compared to the other treatments. At the highest CO$_2$ level, the profile is clearly different from those at lower CO$_2$ concentrations. Compared to these lower concentrations of CO$_2$, evaluations of numbing and tingly continued beyond 1 min of evaluation signifying the continuous evolution of carbonation perception.

Overall, TCATA curves showed that the sensory profile for each mouthfeel attribute changed over time. The base wine (0 g CO$_2$/L) had a proportion of citations that was lower for
all mouthfeel attributes. As CO\textsubscript{2} concentration increased, proportion of citations for the mouthfeel attributes tended to increase (i.e. increased curve heights) whereas proportion of citations for bitterness and sourness tended to decrease slightly (i.e. decreased curve heights). Taken as a whole, these plots suggest that duration increases if CO\textsubscript{2} concentration is increased (i.e. increased curve lengths).

*Multivariate Analysis of TCATA Attributes*

Biplots from PCA were employed to plot the temporal evolution of wines over the course of evaluation (Figure 3). The first principal component (PC1) is defined by cumulative citation rate. PC2 contrasts the initial impact of carbonation on mouthfeel (e.g. carbonation/bubble pain, prickly/pressure, bite/burn, foamy) with attributes that emerge and then linger beyond the initial impression (e.g. numbing, tingly, and taste attributes bitter and sour). The clockwise proximity on the PCA map for such attributes, helps confirm the separation of attributes around the time in which they peaked (before or after 15 s) in the evaluation. The PC1 vs. PC2 plane accounts for 94.02% of the variation in citation frequency explained among the wine treatments.

Figure 3 provides visual confirmation that increasing carbonation levels have direct effect on the sensations elicited. The trajectory for each of the wines is shown, along with their labels, and markers to indicate a temporal progression. Each of the trajectories follows a clockwise loop. Each of the trajectories starts at the far left, where the citation rate for all attributes is 0, increases rapidly to its maximum between 10 s (where treatment labels are placed) and 15 s, and declines from 20 s, more slowly, until the end of the evaluation, when the maximum rate returns to 0. Sparkling wines containing 0 and 1.2 g CO\textsubscript{2}/L were very similar in their temporal profiles. Similar grouping patterns were also seen among the other wines. Specifically, wines containing 2.8 and 3.1 g CO\textsubscript{2}/L followed a similar temporal evolution, and were not significantly different
from each other for a number of attributes. Overall, increases in carbonation corresponded with
increases in maximum citation rate, evidenced by the positive change in PC1. Furthermore,
successive increases in carbonation correspond with greater relative disparity between the
citation rates, particularly for the attributes perceived early in the evaluation.

Analysis of Duration

As shown in Table 8, the sparkling wine sample had a significant effect on duration
(p<0.0001). A significant replicate effect was observed (p<0.01). This was not unexpected as a
previous temporal study on bitterness in beer found a significant replicate effect on duration
(p<0.01) (Pangborn, Lewis, & Yamashita, 1983). Mean separation results are presented in Table
9. One interesting observation among the durations is that an increase of 1.8 g CO₂/L from 3.1 to
4.9 g CO₂/L had a greater impact on discrimination. Furthermore, discrimination is not evident at
certain levels, such as between 0 and 2.0 g CO₂/L or also 1.2 and 3.1 g CO₂/L. However, at the
midlevel concentrations, such as 2.8 and 4.9 g CO₂/L, the discrimination is more apparent.
Overall, as CO₂ concentration increased, the duration of perception increased significantly.

These findings provide statistical evidence supporting the observation made when
reviewing TCATA curves that increased carbonation level seemed to be associated with
increased evaluation duration. Furthermore, it is noted that the systematic relationship between
carbonation level and duration would be lost if conducting time-standardization on these data in
a manner similar to the approach introduced for TDS data by Lenfant, Loret, Pineau, Hartmann
and Martin (2009). For this reason, all times are left on the original (raw) time scale. Temporal
studies associated with carbonation are limited. One time intensity study of gaseous CO₂ nasal
irritation noted that CO₂ (35.5%, 53%, and 70% purity) showed rapid increases to maximum
intensity of perception, which quickly diminished after ~10 s (Wise, Wysocki, & Radil, 2003).
While Wise et al. (2003) shed light on the dynamic nature of CO$_2$ irritation, the perception was limited to olfaction. No study has detailed the in-mouth duration of carbonation perception.

**Analyses of Temporal Data**

Results of the linear mixed effects model (1) used to investigate main effects (sample, replicate) and their interaction on proportion of citations are presented in Table 10. Significant sample effects were found for all mouthfeel attributes (p<0.001), but not for the taste attributes bitter and sour (p>0.05). A significant Sample*Replicate interaction was observed only for carbonation/bubble pain (p<0.05).

Mean separation for the sparkling wine attributes are presented in Table 11. The lowest concentration at which there was a significant difference in proportion of citations from the control wine was 2.8 g CO$_2$/L for bite/burn, carbonation/bubble pain, and prickly/pressure (p<0.05). For numbing, 3.1 g CO$_2$/L was required for there to be a difference from control, while 4.0 g CO$_2$/L was required for separation from the control using foamy and tingly (p<0.05).

Failure to discriminate between wines was considered to be a proportion of citations plateau. Citation rates for mouthfeel attributes plateaued at different CO$_2$ concentrations. Bite/burn, carbonation/bubble pain, prickly/pressure, and tingly showed plateaus below 2.8 g CO$_2$/L. Carbonation/bubble pain also had the plateau above 4.0 g CO$_2$/L ended at 5.8 g CO$_2$/L and a higher plateau between 4.9 and 7.5 g CO$_2$/L. Foamy was better discriminated at higher concentrations having plateaus below 4.0 g CO$_2$/L, as well as between 4.0 and 5.8 g CO$_2$/L, and between 5.8 and 7.5 g CO$_2$/L. Plateaus for numbing occurred below 3.1 g CO$_2$/L, between 3.1 and 4.9 g CO$_2$/L, and above 4.9 g CO$_2$/L. Plateaus for tingly occurred below 4.0 g CO$_2$/L, and between 4.0 and 6.7 g CO$_2$/L.
The differences in mean proportion of citations for bitter and sour showed no clear trend that would suggest an effect due to carbonation level. Several studies have found conflicting results about the interaction between certain tastes and CO₂. One study on model cider showed no influence of CO₂ on bitterness (Symoneaux, Le Quéré, Baron, Bauduin, & Chollet, 2015). Likewise, Cowart (1998) found no effect of CO₂ on bitterness in aqueous solutions of quinine sulfate. However, in peach flavored carbonated milk beverages, increased CO₂ (1.19, 1.46, and 2.81 g CO₂/L) was associated with a significant increase in bitterness (p<0.05) (Lederer, Bodyfelt, & McDaniel, 1991). For the strawberry, peach, and root beer flavored milk beverages, sourness increased with CO₂ concentration (<0.05). However, Hewson et al. (2009) reported that a trained panel found no significant differences in sourness of mineral waters between carbonated samples (~2.97 and 7.12 g CO₂/L), which are particularly relevant as these carbonation levels are in the range of the carbonation levels of samples in the present study. Therefore, the perception of bitterness and sourness is not dependent on CO₂, rather on matrix compounds that elicit these tastes. The present results add further details into the complexity associated with carbonation perception with distinct plateaus revealed as compared to the DA.

Correlations Between DA and TCATA

Using a multivariate technique to co-analyze DA and TCATA data would be advantageous in order to provide a more detailed profile of the carbonated wines, rather than using each descriptive technique alone. DA and TCATA were strongly similar (RV=0.98) in their characterization of differences in mouthfeel attribute perception among the wines (p<0.0001). Additionally, multiple factor analysis (MFA) allows for the analysis of different variables simultaneously to observe the correlation between the methods (Sokolowsky & Fischer, 2012). The variance in citation rate explained by TCATA citation data is quite different.
from the variance explained by DA static intensity data. Using MFA, the relationship of the two methods was separated based on increasing carbonation levels among the treatments. However, the limitation of using proportion of citations values calculated for TCATA integrated across the entire evaluation period is the loss of information on the temporal evolution to characterize carbonation perception and dynamics. In effect, the separation of early and later perceived attributes is weakly captured in an overall MFA. Therefore, segments of evaluation time (every 15 s) were analyzed and proportion of citations was calculated for the mouthfeel terms.

Results from the MFA analysis to relate DA and TCATA proportion of citations at 15 s time intervals of evaluation time are presented in Figure 4. Factor 1 of the MFA defined 90.9% of the variation among the treatments and separated the treatments based on increasing carbonation levels. Factor 2, which accounted for 3.9% of the variance, was generally defined by the attributes of DA (bite, burn, numbing, after-numbing, carbonation/bubble pain, prickly, pressure, foamy, tingly), 15 s (bite/burn, carbonation/bubble pain, numbing, prickly/pressure), and 30 s (numbing, tingly) vectors oriented in the positive direction. However, the vectors oriented in the negative direction of Factor 2 defined by the respective attribute were 15 s and 30 s (foamy), as well as 45 s, 60 s, and 75 s (numbing, tingly).

Two groups were observed in the map: a group with low carbonation, 0 to 3.1 g CO₂/L, which was located on the left part of the figure, and another group containing higher carbonation levels between 4.0 to 7.5 g CO₂/L. The orientation of the vectors indicated the degree to which each method differentiated the treatments in relation to carbonation and mouthfeel attributes. For the lower carbonated treatments (0 to 3.1 g CO₂/L), the methods are discriminated along Factor 2. Specifically, the vectors for DA, 15 s, and 30 s were oriented toward the negative direction, while the later time segments, 45 s, 60 s, and 75 s were oriented toward the positive direction of
Factor 2. When CO$_2$ increases to 4.0 and 4.6 g CO$_2$/L, vector rotation is evident whereby Factor 1 explained the variance where DA, 15 s, and 30 s vectors are oriented to the positive direction, while the 45 s, 60 s, and 75 s are oriented toward the negative direction. As compared to the lower CO$_2$ levels (0 to 3.1 g CO$_2$/L), at the higher CO$_2$ levels (4.9, 5.8, 6.7, and 7.5 g CO$_2$/L), the DA, 15 s, and 30 s vectors are oriented in the positive direction of Factor 2 and oppositely associated with the later time segments (45, 60, or 75 s). The opposite association further details the grouping of attributes into early and late perceptions over the evaluation period.

Additionally, the proximity of the DA vector to TCATA time segments helps to indicate how and when panelists are detailing their average intensity perception when using DA. Overall, DA is associated with TCATA variables within the first 30 s of evaluation. This indicates that panelists were basing their attribute intensity and overall perception of carbonation at the beginning of evaluation time. These results, in addition to the results described above for each method, confirm the ruggedness of both methods in their ability to distinguish mouthfeel attributes in sparkling wine, to obtain similar results, and to complement one another in analysis. Overall, both methods are effective in capturing carbonation perception.

Similarly, Dinnella et al. (2013) determined the criteria when selecting time segments in temporal data for sweetened coffee as analyzed by TDS to further detail attribute dominance over time. Specifically, Dinnella et al. (2013) compared 20 s and 30 s intervals while focusing on the first 60 s of evaluation time as no dominant attributes were observed after 60 s. Results showed that 20 s time intervals did not influence sample discrimination nor add new information on dynamics of product perceptions. Thus, evaluation intervals should be set based on data specific to the product and dynamics of attribute perceptions as was conducted in the present study.
In addition, several studies have demonstrated the benefit of using two different sensory methods to characterize a product. One study used static descriptive profiling and the temporal methods of TI and TDS to analyze the impact of skin contact on Riesling and Gewürztraminer wine properties (Sokolowsky et al., 2015). Using descriptive analysis, differences in flavors, aromas, and tastes, specifically bitterness, were found as a function of varietal. The dynamic methods, TI and TDS were able to describe these differences. Using TI, Gewürztraminer wines were found to differ in maximum bitterness intensity and the total perception of bitterness. However, TDS revealed the dominant sensation was an astringency mouthfeel, rather than a bitter taste, which predominated in TI and DA. Recently, Ares et al. (2015) compared TCATA and TDS in the evaluation of several different product categories, and reported that TCATA provided a more thorough sensory profile of the two methods, and that it is suitable for analyzing the temporal nature of product attributes. The authors reported that numerous instances where product profiles obtained from TCATA and TDS were similar, but also cases where products received high citation rates when evaluated by TCATA, yet relatively low dominance rates when evaluated by TDS. The two temporal methods were reported to be complimentary. Likewise, the two descriptive methods in the present study are complimentary.

CONCLUSIONS

Eleven sparkling wine treatments of varying carbonation level were created by varying the sparkling wine processing method. Using trained panelists, these sparkling wines of varying carbonation levels were evaluated by DA and TCATA, which generated a detailed profile of carbonation perception. Each method provided meaningful information on attribute perception. DA, a common descriptive analysis method, provided static intensity ratings for sparkling wine attributes. Results for DA data revealed mouthfeel attributes were the main driver for the
variation among wine treatments, separating treatments based on their CO₂ concentration.

TCATA provided the dynamic profile of carbonation of sparkling wines, revealing the complexity and temporality of effervescence. Differences among wine treatments in proportion of citations highlighted differences among the treatments at specific periods of the evaluation time. Mouthfeel attributes were separated into those that were perceived early in the sensory experience (peaked within the first 15 s of evaluation) and those with delayed onset (peaked after 15 s of evaluation). MFA showed a high correlation between the mouthfeel attributes and carbonation concentration using both sensory methods.

In light of these results, further studies on the influence of carbonation on the sensory and analytical profiles of sparkling wine are merited. Information on how the sensory profile of the final wine is impacted by specific sparkling wine processing decisions could be directly implemented by winemakers when processing their wines to ensure an optimum wine profile. The results of this study can provide sparkling winemakers and other carbonated product manufacturers practical knowledge of the temporal changes in CO₂ perception.
Table 1. Definitions, reference standards, and assigned intensities for attributes used in DA trained sensory panel (n=11). Standards were prepared in Carlo Rossi Chablis white wine where indicated.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Standard</th>
<th>Intensity&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mouthfeel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bite</td>
<td>Perception of stinging experienced in the oral cavity within the first 3 seconds after exposure to CO&lt;sub&gt;2&lt;/sub&gt;.</td>
<td>30 mL seltzer water served at 8-9ºC</td>
<td>8</td>
</tr>
<tr>
<td>Burn</td>
<td>Perception of increased trigeminal pain and irritation while the sample is in mouth resulting from exposure to CO&lt;sub&gt;2&lt;/sub&gt;; the sensation produced by chemical irritants.</td>
<td>½ piece of cinnamon gum (Dentyne Fire)</td>
<td>8</td>
</tr>
<tr>
<td>Numbing</td>
<td>Perception of a bodily extremity/limb going to ‘sleep’; loss of feeling within the oral cavity; dull sensation, not a lack of sensation.</td>
<td>30 g peroxide-baking soda toothpaste (Colgate placed on tongue and moved within oral cavity)</td>
<td>7</td>
</tr>
<tr>
<td>After-numbing</td>
<td>Perception of loss of feeling after the sample has been expectorated (modified from Koppel and Chambers 2010).</td>
<td>1 lemon-honey cough drop (Hall’s) dissolved in 300 mL boiling water</td>
<td>7</td>
</tr>
<tr>
<td>Carbonation / Bubble</td>
<td>Perception of pain related to bubbles bursting in mouth.</td>
<td>30 mL seltzer water served at 8-9ºC</td>
<td>9</td>
</tr>
<tr>
<td>Prickly</td>
<td>Sharp sensations similar to those of a pinprick; experience</td>
<td>0.5 g candy (PopRocks) with tongue pressed to roof</td>
<td>8.5</td>
</tr>
</tbody>
</table>
reminiscent of a bodily extremity/limb going to ‘sleep.’

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Sensation produced by bubbles touching the mucosa.</th>
<th>0.5 g candy (PopRocks) with tongue pressed to roof of mouth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foamy</td>
<td>Dynamic feeling of foam or bubble expansion; sensation perceived in mouth similar to egg white foam, froth on ice cream float, coffee, or beer.</td>
<td>30 mL soda (7-Up) served at 8-9°C</td>
</tr>
<tr>
<td>Tingly</td>
<td>Persistent irritation due to carbonation (Green 1992); “pins-and-needles” feeling (Hewson et al. 2009).</td>
<td>30 g peroxide-baking soda toothpaste (Colgate)</td>
</tr>
</tbody>
</table>

### Taste

<table>
<thead>
<tr>
<th>Taste</th>
<th>Sensation</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet</td>
<td>Taste stimulated by sucrose or other sugars.</td>
<td>70 g sucrose/L wine</td>
</tr>
<tr>
<td>Sour</td>
<td>Taste stimulated by acids.</td>
<td>2.5 g tartaric acid/L wine</td>
</tr>
<tr>
<td>Bitter</td>
<td>Taste stimulated by quinine salt and other bitter tasting substances.</td>
<td>1.5 mg quinine sulfate /L wine</td>
</tr>
</tbody>
</table>

### Aroma/Flavor

<table>
<thead>
<tr>
<th>Aroma/Flavor</th>
<th>Sensation</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus</td>
<td>Aromatics associated with lime and lemon.</td>
<td>0.03% lime juice and 0.5 cm² each of lime and lemon peel soaked for 30 sec in 30 mL wine</td>
</tr>
<tr>
<td>Tree fruit</td>
<td>Aromatics associated with apple, pear, or peach.</td>
<td>1 cm³ piece each of Granny Smith apple,</td>
</tr>
</tbody>
</table>
Intensity ratings were along a 15-cm line scale.

<table>
<thead>
<tr>
<th></th>
<th>Aromatic notes that may include honey, caramel, caramelized sugar, butterscotch, brown sugar, and molasses.</th>
<th>One hard caramel candy (Werther’s Original) crushed into 30 mL wine</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Caramel</td>
<td></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>Vanilla</td>
<td>Aromatics associated with vanilla.</td>
<td>450 μL vanilla extract in 30 mL wine</td>
<td>11</td>
</tr>
</tbody>
</table>

* Intensity ratings were along a 15-cm line scale.
Table 2. Definitions and reference standards for attributes used in TCATA trained sensory panel (n=13). Standards were prepared in Carlo Rossi Chablis white wine where indicated.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Reference Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mouthfeel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bite/Burn&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Perception of stinging experienced in the oral cavity within the first 3 seconds after exposure to CO₂; perception of increased trigeminal pain and irritation while the sample is in mouth resulting from exposure to CO₂; the sensation produced by chemical irritants.</td>
<td>Bite – 30 mL seltzer water served at 8-9ºC; Burn – ½ piece cinnamon gum (Dentyne Fire)</td>
</tr>
<tr>
<td>Numbing&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Perception of a bodily extremity/limb going to ‘sleep’; loss of feeling within the oral cavity; dull sensation, not a lack of sensation; perception of loss of feeling after the sample has been expectorated (modified from Koppel and Chambers 2010).</td>
<td>30 g peroxide-baking soda toothpaste (Colgate) placed on tongue and moved around within oral cavity</td>
</tr>
<tr>
<td>Carbonation/Bubble pain</td>
<td>Perception of pain related to bubbles bursting in mouth.</td>
<td>30 mL seltzer water served at 8-9ºC</td>
</tr>
<tr>
<td>Prickly/Pressure&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Sharp sensations similar to those of a pinprick; experience reminiscent of a bodily extremity/limb going to ‘sleep’; sensation produced by bubbles touching the mucosa.</td>
<td>0.5 g candy (PopRocks) with tongue pressed to roof of mouth</td>
</tr>
<tr>
<td>Foamy</td>
<td>Dynamic feeling of foam or bubble expansion; sensation perceived in mouth similar to egg white foam, froth on ice cream float, coffee, or beer.</td>
<td>30 mL soda (7-Up) served at 8-9ºC</td>
</tr>
<tr>
<td>Taste</td>
<td>Persistent irritation due to carbonation (Green 1992); “pins-and-needles” feeling (Hewson et al. 2009).</td>
<td>30 g peroxide-baking soda toothpaste (Colgate) placed on tongue and moved around within oral cavity</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Sour</td>
<td>Taste stimulated by acids.</td>
<td>2.5 g tartaric acid/L wine</td>
</tr>
<tr>
<td>Bitter</td>
<td>Taste stimulated by quinine salt and other bitter tasting substances.</td>
<td>1.5 mg quinine sulfate/L wine</td>
</tr>
</tbody>
</table>

a The mouthfeel attributes were combined to define one attribute based on panel discussion and consensus

b The mouthfeel attribute of after-numbing used in the trained DA panel was combined with numbing agreed upon by panelist discussion and consensus of perception and definition.
Table 3. F ratios from Analysis of Variance of DA sensory mouthfeel parameters for 11 sparkling wine treatments as evaluated by trained panel and analyzed by linear mixed model. Sample, Replicate, and the interaction Sample*Replicate were fixed factors, while Panelists were considered a random factor.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Bite</th>
<th>Burn</th>
<th>Numbing</th>
<th>After-numbing</th>
<th>Carbonation/ Bubble pain</th>
<th>Prickly</th>
<th>Pressure</th>
<th>Foamy</th>
<th>Tingly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample (S)</td>
<td>10</td>
<td>37.58***</td>
<td>46.34***</td>
<td>25.67***</td>
<td>19.23***</td>
<td>40.48***</td>
<td>21.78***</td>
<td>30.57***</td>
<td>36.08***</td>
<td>14.69***</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>1</td>
<td>1.37</td>
<td>2.02</td>
<td>0.90</td>
<td>0.09</td>
<td>0.58</td>
<td>1.98</td>
<td>0.25</td>
<td>0.01</td>
<td>0.92</td>
</tr>
<tr>
<td>S*R</td>
<td>10</td>
<td>0.86</td>
<td>1.22</td>
<td>0.81</td>
<td>0.57</td>
<td>1.25</td>
<td>1.16</td>
<td>0.82</td>
<td>1.09</td>
<td>0.92</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; ***p<0.0001
Table 4. Mean separation of mouthfeel attributes of 11 sparkling wine treatments as evaluated by trained DA panel. Different letters within a column represent a significant difference among treatments based on differences in least squares means (p<0.05).

<table>
<thead>
<tr>
<th>CO₂ concentration (g / L)</th>
<th>Bite</th>
<th>Burn</th>
<th>Numbing</th>
<th>After-numbing</th>
<th>Carbonation / Bubble pain</th>
<th>Prickly</th>
<th>Pressure</th>
<th>Foamy</th>
<th>Tingly</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.9 a</td>
<td>1.6 a</td>
<td>2.1 a</td>
<td>2.9 a</td>
<td>1.2 a</td>
<td>1.3 a</td>
<td>1.0 a</td>
<td>1.2 a</td>
<td>1.9 a</td>
</tr>
<tr>
<td>1.2</td>
<td>2.1 a</td>
<td>2.0 ab</td>
<td>2.4 a</td>
<td>3.0 a</td>
<td>1.3 a</td>
<td>1.6 a</td>
<td>1.3 a</td>
<td>1.2 a</td>
<td>2.2 ab</td>
</tr>
<tr>
<td>2.0</td>
<td>2.8 a</td>
<td>2.7 b</td>
<td>2.7 a</td>
<td>3.2 a</td>
<td>2.4 b</td>
<td>2.0 ab</td>
<td>1.7 ab</td>
<td>1.8 a</td>
<td>2.9 bc</td>
</tr>
<tr>
<td>2.8</td>
<td>4.2 b</td>
<td>4.5 c</td>
<td>3.8 b</td>
<td>4.7 b</td>
<td>3.4 c</td>
<td>3.0 bc</td>
<td>2.4 bc</td>
<td>2.8 b</td>
<td>3.9 de</td>
</tr>
<tr>
<td>3.1</td>
<td>4.7 b</td>
<td>4.7 cd</td>
<td>4.1 b</td>
<td>4.6 b</td>
<td>3.5 c</td>
<td>3.5 c</td>
<td>2.3 bc</td>
<td>2.8 b</td>
<td>3.4 cd</td>
</tr>
<tr>
<td>4.0</td>
<td>5.1 bc</td>
<td>5.6 de</td>
<td>4.4 bc</td>
<td>4.8 bc</td>
<td>4.1 c</td>
<td>3.8 cd</td>
<td>3.0 c</td>
<td>3.8 c</td>
<td>4.2 def</td>
</tr>
<tr>
<td>4.6</td>
<td>6.0 cd</td>
<td>6.5 ef</td>
<td>5.1 cd</td>
<td>5.6 cd</td>
<td>5.7 de</td>
<td>4.8 de</td>
<td>4.0 d</td>
<td>4.6 cd</td>
<td>5.2 fgh</td>
</tr>
<tr>
<td>4.9</td>
<td>6.9 de</td>
<td>7.0 f</td>
<td>5.2 cd</td>
<td>6.1 de</td>
<td>5.4 d</td>
<td>5.5 ef</td>
<td>4.2 de</td>
<td>5.1 de</td>
<td>4.7 efg</td>
</tr>
<tr>
<td>5.8</td>
<td>7.5 ef</td>
<td>7.4 fg</td>
<td>5.8 de</td>
<td>6.6 e</td>
<td>6.6 ef</td>
<td>6.1 f</td>
<td>5.2 f</td>
<td>5.8 ef</td>
<td>5.4 gh</td>
</tr>
<tr>
<td>6.7</td>
<td>7.9 f</td>
<td>8.4 h</td>
<td>5.9 de</td>
<td>6.3 de</td>
<td>6.7 f</td>
<td>5.6 ef</td>
<td>5.0 ef</td>
<td>6.1 f</td>
<td>5.0 fgh</td>
</tr>
<tr>
<td>7.5</td>
<td>8.1 f</td>
<td>8.3 gh</td>
<td>6.6 e</td>
<td>6.8 e</td>
<td>7.0 f</td>
<td>6.0 f</td>
<td>5.3 f</td>
<td>6.7 f</td>
<td>5.9 h</td>
</tr>
</tbody>
</table>
Figure 1. Canonical Variates Analysis (CVA) of the mouthfeel attributes of the 11 sparkling wines of variable CO$_2$ levels as evaluated by the DA trained panel. A confidence ellipse surrounds each the mean of each sparkling wine, determined as a function of the mouthfeel attributes. The value near the centroid of each ellipse (in **bold**) is the CO$_2$ concentration (g/L). Non-overlapping ellipses indicate significant differences among the wine samples ($p<0.05$).
Table 5. F ratios from Analysis of Variance of DA sensory tastes, aromas, and flavors attributes for 11 sparkling wine treatments as evaluated by trained panel and analyzed by a linear mixed model.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Taste Attributes</th>
<th>Aroma Attributes</th>
<th>Flavor Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sweet  Sour  Bitter</td>
<td>Citrus  Tree fruit  Caramel  Vanilla</td>
<td>Citrus  Tree fruit  Caramel  Vanilla</td>
</tr>
<tr>
<td>Sample (S)</td>
<td>10</td>
<td>2.15* 0.69 0.88</td>
<td>0.80 0.86 1.42</td>
<td>3.14***</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>1</td>
<td>0.81 0.70 0.60</td>
<td>0.53 4.44* 0.38</td>
<td>0.49</td>
</tr>
<tr>
<td>S*R</td>
<td>10</td>
<td>0.76 1.80 0.76</td>
<td>0.56 1.37 0.95</td>
<td>1.02</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; ***p<0.0001
Table 6. Mean separation of significant taste, aroma, and flavor attributes of 11 sparkling wine treatments as evaluated by trained DA panel and analyzed using differences in least squares means. Different letters within a column represent a significant difference among treatments based on differences in least squares means (p<0.05).

<table>
<thead>
<tr>
<th>CO₂ concentration (g/L)</th>
<th>Sweet taste</th>
<th>Vanilla aroma</th>
<th>Caramel flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 a</td>
<td>4.4 ab</td>
<td>3.3 abc</td>
<td>2.9 abc</td>
</tr>
<tr>
<td>1.2 b</td>
<td>4.0 a</td>
<td>2.5 a</td>
<td>2.5 ab</td>
</tr>
<tr>
<td>2.0 c</td>
<td>5.1 bc</td>
<td>2.5 a</td>
<td>2.2 a</td>
</tr>
<tr>
<td>2.8 d</td>
<td>4.5 ab</td>
<td>3.2 abc</td>
<td>2.6 abc</td>
</tr>
<tr>
<td>3.1 d</td>
<td>4.7 ab</td>
<td>3.5 bcd</td>
<td>3.1 abc</td>
</tr>
<tr>
<td>4.0 e</td>
<td>5.3 bc</td>
<td>3.6 bcd</td>
<td>3.0 abc</td>
</tr>
<tr>
<td>4.6 ef</td>
<td>4.5 ab</td>
<td>3.1 ab</td>
<td>2.9 abc</td>
</tr>
<tr>
<td>4.9 f</td>
<td>4.9 ab</td>
<td>3.7 bcd</td>
<td>2.8 abc</td>
</tr>
<tr>
<td>5.8 g</td>
<td>4.9 ab</td>
<td>4.0 bcd</td>
<td>3.5 d</td>
</tr>
<tr>
<td>6.7 h</td>
<td>5.9 c</td>
<td>4.1 cd</td>
<td>3.4 cd</td>
</tr>
<tr>
<td>7.5 i</td>
<td>5.2 bc</td>
<td>4.3 d</td>
<td>3.4 bcd</td>
</tr>
</tbody>
</table>
Figure 2. Smoothed TCATA curves for 0 (A), 4.6 (B), and 7.5 g CO₂/L (C) with various colors representing each attribute. Each attribute has its own smoothed curve and reference line (thin, non-continuous line of corresponding color). Reference lines (dotted) are non-continuous; only the periods of significant differences in proportion of citations for each treatment as compared to the other ten treatments are indicated. These non-continuous reference lines are contrasted by highlighted thick sections of attribute curves to allow for ease of identification of significant periods. Time is in seconds.
Figure 3. Principal component analysis is conducted on TCATA data for the mouthfeel attributes of the sparkling wine treatments. The first two components explain 93.02% of the variance. Wine treatment trajectories each move in a clockwise loop, and are indicated at the 10 s mark by labels indicating the carbonation level (g/L CO$_2$). Markers are placed along the remainder of each of the trajectories at 10 s intervals.
Table 7. F ratios from Analysis of Variance of TCATA duration of perception for 11 sparkling wine treatments as evaluated by trained panel and analyzed using a linear mixed effects model.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample (S)</td>
<td>10</td>
<td>14.79***</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>2</td>
<td>5.32**</td>
</tr>
<tr>
<td>R*S</td>
<td>20</td>
<td>1.07</td>
</tr>
</tbody>
</table>

*p≤0.05; **p≤0.01; ***p≤0.0001
**Table 8.** Mean separation of duration (sec) for sparkling wine treatments as evaluated by trained TCATA panel. Values represent mean duration across all evaluations. Different letters within a column represent a significant difference among treatments for a given parameter based differences in least squares means (p<0.05).

<table>
<thead>
<tr>
<th>CO₂ (g/L)</th>
<th>Duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 a</td>
<td>45.7 a</td>
</tr>
<tr>
<td>1.2 b</td>
<td>46.3 a</td>
</tr>
<tr>
<td>2.0 c</td>
<td>47.0 ab</td>
</tr>
<tr>
<td>2.8 d</td>
<td>49.9 ab</td>
</tr>
<tr>
<td>3.1 d</td>
<td>51.6 abc</td>
</tr>
<tr>
<td>4.0 e</td>
<td>55.8 bcd</td>
</tr>
<tr>
<td>4.6 ef</td>
<td>55.8 bcde</td>
</tr>
<tr>
<td>4.9 f</td>
<td>59.8 cde</td>
</tr>
<tr>
<td>5.8 g</td>
<td>62.9 de</td>
</tr>
<tr>
<td>6.7 h</td>
<td>62.5 de</td>
</tr>
<tr>
<td>7.5 i</td>
<td>64.4 e</td>
</tr>
</tbody>
</table>
Table 9. F ratios from Analysis of Variance of TCATA sensory attributes proportion of citations for 11 sparkling wine treatments as evaluated by trained panel and analyzed by linear mixed effects model.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Mouthfeel Attributes</th>
<th>Taste Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bite/Burn</td>
<td>Carbonation/Bubble pain</td>
</tr>
<tr>
<td>Sample (S)</td>
<td>10</td>
<td>13.69***</td>
<td>18.89***</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>2</td>
<td>1.29</td>
<td>0.76</td>
</tr>
<tr>
<td>S*R</td>
<td>20</td>
<td>1.58</td>
<td>1.86*</td>
</tr>
</tbody>
</table>

*p≤0.05; **p≤0.01; ***p≤0.0001
Table 10. Mean separation of mouthfeel attributes of 11 sparkling wine treatments as evaluated by trained TCATA panel. Values represent panel means for the average proportion of citations. Different letters within a column represent a significant difference among treatments based on differences in least squares means ($p<0.05$).

<table>
<thead>
<tr>
<th>CO$_2$ (g/L)</th>
<th>Bite/Burn</th>
<th>Carbonation/Bubble pain</th>
<th>Foamy</th>
<th>Numbing</th>
<th>Prickly/Pressure</th>
<th>Tingly</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 a</td>
<td>0.040 a</td>
<td>0.025 ab</td>
<td>0.016 a</td>
<td>0.105 a</td>
<td>0.030 a</td>
<td>0.099 ab</td>
</tr>
<tr>
<td>1.2 b</td>
<td>0.033 a</td>
<td>0.017 a</td>
<td>0.017 a</td>
<td>0.104 a</td>
<td>0.020 a</td>
<td>0.069 a</td>
</tr>
<tr>
<td>2.0 c</td>
<td>0.060 ab</td>
<td>0.048 bc</td>
<td>0.018 a</td>
<td>0.141 ab</td>
<td>0.040 ab</td>
<td>0.105 ab</td>
</tr>
<tr>
<td>2.8 d</td>
<td>0.078 bc</td>
<td>0.062 cd</td>
<td>0.028 a</td>
<td>0.157 ab</td>
<td>0.054 bc</td>
<td>0.129 bc</td>
</tr>
<tr>
<td>3.1 d</td>
<td>0.085 bcd</td>
<td>0.076 de</td>
<td>0.027 a</td>
<td>0.185 bc</td>
<td>0.075 cd</td>
<td>0.128 bc</td>
</tr>
<tr>
<td>4.0 e</td>
<td>0.113 efg</td>
<td>0.093 ef</td>
<td>0.051 bc</td>
<td>0.235 cd</td>
<td>0.099 ef</td>
<td>0.176 cd</td>
</tr>
<tr>
<td>4.6 ef</td>
<td>0.102 def</td>
<td>0.098 efg</td>
<td>0.046 b</td>
<td>0.245 cd</td>
<td>0.083 de</td>
<td>0.178 cde</td>
</tr>
<tr>
<td>4.9 f</td>
<td>0.131 efg</td>
<td>0.111 fgh</td>
<td>0.062 cd</td>
<td>0.292 de</td>
<td>0.094 def</td>
<td>0.199 de</td>
</tr>
<tr>
<td>5.8 g</td>
<td>0.146 g</td>
<td>0.111 fgh</td>
<td>0.068 d</td>
<td>0.322 e</td>
<td>0.106 ef</td>
<td>0.201 de</td>
</tr>
<tr>
<td>6.7 h</td>
<td>0.134 fg</td>
<td>0.123 h</td>
<td>0.088 e</td>
<td>0.326 e</td>
<td>0.092 def</td>
<td>0.214 de</td>
</tr>
<tr>
<td>7.5 i</td>
<td>0.149 g</td>
<td>0.122 gh</td>
<td>0.089 e</td>
<td>0.348 e</td>
<td>0.114 f</td>
<td>0.237 e</td>
</tr>
</tbody>
</table>
Figure 4. Multiple Factor Analysis (MFA) of sparkling wines (n=11) comparing DA and TCATA descriptive profiling techniques. CO₂ concentrations (g/L) of the sparkling wines are presented near the centroid (in **bold**) of each vector. DA vector is labelled with DA (dashed line). Intervals (15 s) of TCATA are presented at the end of each vector labelled as 15s (proportion of citations between 0 to 15.0 s), 30s (proportion of citations between 15.1 to 30.0 s), 45s (proportion of citations between 30.1 to 45.0 s), 60s (proportion of citations between 45.1 to 60.0 s), and 75s (proportion of citations between 60.1 to 75.0 s).
CHAPTER V

TRAINED AND CONSUMER PANEL EVALUATION OF SPARKLING WINES
SWEETENED TO BRUT OR DEMI SEC RESIDUAL SUGAR LEVELS
WITH THREE DIFFERENT SUGARS

ABSTRACT

The dosage liquid, added at the final stage of sparkling wine production, imparts residual sweetness to the wine. No study has yet analyzed the influence of dosage composition on the final wine’s sensory profile or consumer acceptance. In this study, dosage composition was altered through the addition of different sugar types (ST; fructose, glucose, or sucrose) to produce seven sparkling wines of varying residual sugar levels (RSL; no sugar added, brut (5.3-8.4 g/L) or demi sec (34.9-37.8 g/L)). Sparkling wine treatments were then evaluated by a trained panel (n=9). Results showed that the interaction between ST and RSL influenced the perception of caramelized/vanilla/honey (CVH) flavor, sweet taste, and sour taste attributes (p<0.05). RSL influenced the perception of aroma, flavors, tastes, and mouthfeels, while ST influenced green flavor (p<0.05). Demi sec wines displayed significantly lower intensities of green and yeasty flavors compared to the brut wine (p<0.05). Demi sec wines were higher in intensities of fruity and creamy mouthfeel while being lower in sourness (p<0.05). Consumers (n=126) also evaluated the sparkling wines and results indicated that ST, RSL, and their interaction influenced acceptance parameters, as well as the perception of the “refreshing” aspect of the wine (p<0.05). Overall consumer acceptance of sparkling wines was highly correlated to CVH (r^2=0.94), floral (r^2=0.88), and fruity (r^2=0.99) flavors, as well as sweet taste (r^2=0.92) and creamy mouthfeel.
(r²=0.93). External preference mapping revealed two clusters of consumers. Both consumer clusters liked wines sweetened with fructose, but Cluster 1 liked the demi sec sparkling wine sweetened with fructose (containing 32.8 g/L fructose) while Cluster 2 preferred the brut wine sweetened with fructose (containing 8.4 g/L fructose). Sucrose and glucose sweetened brut wines were the least preferred and were described as having high yeasty aroma and toasted flavor. These results suggest that consumer preference for sparkling wine was segmented based on sweetness preference. The results of this study offer winemakers knowledge about the influence of dosage composition on the sensory profile of sparkling wine.
INTRODUCTION

A sparkling wine is defined based upon its mode of processing, with processing methods including traditional, Charmat and transfer methods. Sparkling wines produced using the traditional method are more time and labor intensive compared to the other styles of sparkling wine production since wines ferment in the same bottle in which the primary fermentation occurs. The more famous wines and their associated regions that use the traditional method of sparkling wine production include Champagnes and Crémants from France, Cava from Spain, and Sekt from Germany. Alternatively, using the Charmat method, wines are produced by tank fermentation while in the transfer method, wines are fermented in a bottle similar to the traditional method. However, after fermentation, wines made by the transfer method are emptied into a blending tank before being re-bottled in a new bottle. This contrasts to the traditional method in which wines remain in the same bottle throughout processing.

A review of traditional sparkling wine processing is described by Kemp et al. (2015). Traditional sparkling wines are produced by a second fermentation in bottle whereby yeast ferment sugar to produce dissolved CO$_2$ gas. Once the second fermentation is complete, wines are aged on the yeast lees and bottles are riddled prior to disgorgement. Once the yeast is removed by the process of disgorgement, bottles are topped up with a dosage liquid; after the dosage is added, the bottles are sealed. The dosage serves to replace the wine that was lost during disgorgement while often contributing sweetness to the final wine. The composition of a given winery’s dosage is highly variable and often kept confidential (Bosch-Fusté et al., 2009). Typically, the composition of the dosage can consist of wines (i.e. base wine or aged wines), wines aged in different containers (i.e. stainless, oak, or concrete), liquor/spirits (brandy or cognac), SO$_2$, citric acid, tannins, and sugar (0-50+ g/L) (Kemp et al., 2015).
As described above, sugar is an important component to the dosage. Commonly, wineries will use cane sugar or sucrose (Grainger & Tattersall, 2005), beet sugar (Kemp et al., 2015), grape must, concentrated grape juice, rectified concentrated grape juice, or a mixture of these ingredients (Bosch-Fusté et al., 2009; Buxaderas & López-Tamames, 2003; Panda, 2011). The dosage composition contributes to wine complexity and residual sweetness, with the latter further defining the sparkling wine into one of six categories: brut nature (0-3 g sugar/L) (Martínez-Lapuente et al., 2013a; Martínez-Lapuente et al., 2013b), brut (<12 g sugar/L) extra brut (12-17 g sugar/L), sec (17-32 g sugar/L), demi sec (32-50 g sugar/L), and doux (50+ g sugar/L) (Jackson, 2014; Jackson, 2009; Serra-Cayuela et al., 2013).

Consumer acceptance of sweet white wines varies, with published studies being limited to table wines. In one study of white wines, German consumers (n=521) displayed different preferences for sweetness, with 28.9% of the consumers preferring semi sweet/sweet wines, 33.7% preferring semi-dry wines, and 36.0% of the consumers preferring dry white wines (Mueller & Szolnoki, 2010). In a previous study of German wine consumers (n=2919), 21.5% of the consumers preferred semi sweet/sweet, 31.4% preferred semi-dry, and 47.1% preferred dry white wines (Hoffman, Mueller, Szolnoki, Nöll, & Schanowski, 2006). Additionally, Mueller and Szolnoki (2010) identified three consumer classes of white wine, with younger consumers preferring sweet and semi-dry wines and older consumers preferring drier styles of wines. Likewise, Lesschaeve, Bowen, & Bruwer (2012) revealed two consumer clusters in the preference of Chardonnay, Riesling, and Sauvignon blanc wines: Cluster 1 preferred tropical fruit flavor, tree fruit flavor, and sweet taste and Cluster 2 preferred caramel, butterscotch and petroleum flavors and did not like sweet and fruity wines. However, no study has yet examined the influence of sweetness on the consumer acceptance of sparkling wines.
The overall objective of the present study was to determine the influence of sugar type (fructose, glucose, or sucrose) and residual sugar level (RSL) (brut or demi sec) on the sensory properties and consumer acceptance of sparkling wines. Specifically, the sensory properties of the finished wines using descriptive profiling and consumer evaluations is provided. Ultimately, this study will provide insight into the complexity of sparkling wine evaluation, specifically the interaction with sugar and wine components, as well as the added knowledge of consumer perceptions of sparkling wines.

MATERIALS AND METHODS

Materials

Bulk (50 lb.) glucose and fructose were obtained from Tate & Lyle (≥99%; Tate & Lyle Ingredients Americas, Decatur, IL, U.S.A.) and sucrose from C & H (ASR Group, Crockett, CA, U.S.A.). Diammonium phosphate (DAP) and thiazote was obtained from Laffort USA (Petaluma, CA, U.S.A.). Riddling aids, Clarifiant S and Phosphate Mazure, and potassium metabisulfite were obtained from Scott Labs (Petaluma, CA, U.S.A.). Ethanol (100%, v/v) was obtained from Decon Laboratories, Inc. (King of Prussia, PA, U.S.A.). For sensory evaluation, the food-grade flavor compound 2-phenylethanol (≥99%) was obtained from Sigma-Aldrich (St. Louis, MO, U.S.A.). Sodium chloride was obtained from JT Baker (Phillipsburg, NJ, U.S.A.). For the electronic tongue analysis, hydrochloric acid, sodium chloride and sodium-L-glutamate standards were obtained from Alpha-MOS (Tolouse, France). Materials for HPLC analysis included: glucose (≥99.9%; Clintose A, Archer Daniels Midland, Decatur, IL, U.S.A.), fructose (≥98-102%; Spectrum Chemical Manufacturing Corp., Gardena, CA, U.S.A.), sucrose (≥99.0%; Sigma-Aldrich), 2 mL amber screw-top glass vials (Waters Corporation, Milford, MA, U.S.A., Part#: WAT094220) and screw cap and PTFE/silicon septum (Waters Corporation, Part #WAT094172).
Wines

The wine treatments were designed to vary in sugar type and concentration present in the dosage. Sparkling wines were produced in a commercial winery using Methodé Champenoise style (Chateau Ste Michelle Wine Estates, Paterson, WA, USA). A tirage liquid (composed of yeast (Saccharomyces cerevisiae rf bayanus), sugar (~240 g/L sucrose), DAP (0.0012 g/L), thiazote (0.24 g/L), and riddling aids (Clarifiant S at 1.19 mL/L and Phosphate Mazure at 0.30 mL/L) was added to the base wine. Over ~12 weeks, the second fermentation occurred in bottle at 12°C. Wine chemistry analyses (sugar, alcohol, and CO$_2$) confirmed that fermentation was completed in bottle prior to further processing. Once the second fermentation was complete, the wines were aged on the lees for eight months at 12°C. After aging, bottles were riddled prior to disgorgement by rotating the wines using mechanical equipment.

Six separate dosage recipes were prepared. Specifically, one recipe was prepared for each sugar type (ST) (sucrose, glucose and fructose) and residual sugar level (RSL) (brut and demi sec). Each sugar was weighed to achieve ~12.8 g/L for the brut RSL treatment and ~37.8 g/L for the demi sec RSL treatment and dissolved in purified water (Culligan, Rosemont, IL, U.S.A.). Wine volumes were adjusted so that a set volume of dosage liquid (36 mL) was added to each bottle in order to standardize the dilution of the wine. The seventh treatment, a control, was processed at the same time as the other treatments except that the dosage added back was the same base wine (36 mL) and SO$_2$ (30 mg/L). To all treatments and the control, potassium metabisulfite (30 mg/L) was dissolved in the dosage liquid or wine, respectively, to prevent microbial contamination and/or oxidation. All treatments (84 bottles per treatment) were finished with a natural cork and wire hood. Wines were stored at 12.8°C until analysis. For all analyses, both sensory and analytical, wine treatments were measured in replicate.
**Wine Chemistry**

The wine treatments were analyzed at room temperature (~23°C) for standard wine chemistry measurements followed general procedures described by Ilard et al. (2004). Titratable acidity (TA) and pH were measured using a Metrohm® 855 Robotic Titrosampler (Metrohm USA, Riverview, FL, U.S.A.), the CO₂ content (mg/L and volume) was measured using an AntonPaar CarboQC (AntonPaar GmbH, Austria), and percent ethanol (v/v) with an AntonPaar Alcoholyzer (AntonPaar GmbH).

Quantification of fructose, glucose, and sucrose was performed by high performance liquid chromatography (HPLC). Sparkling wine treatments were decarbonated by transferring wine (~30 mL) between two 50 mL beakers for 2 min and then filtered through a 0.45 µm filter pad (EMD Milipore, Billerica, MA, U.S.A). The concentrations of fructose, glucose, and sucrose in wines were quantified using standard curves. For each standard curve, concentrations of 0, 1, 2, 5, 10, 15, 30, 40, and 50 g/L of either fructose, glucose, and sucrose were added to a 12% ethanol (v/v) solution. These concentrations were based on ranges reported in sparkling wines (Martínez-Lapuente et al., 2013a; Martínez-Lapuente et al., 2013b; Kemp et al., 2015; Jackson, 2014).

Wines (1.5 mL) or standards (1.5 mL) were filtered using a 0.45 µm syringe filter attached to a plastic syringe. About 1.5 mL of each solution was filled into amber vials. Each sample (10 µL) was injected into the HPLC. Each compound was identified in the chromatogram based on its retention time and its comparison with the elution of the standard. For each sugar, a standard curve was constructed using the peak area of each sugar concentration. The HPLC settings were as follows: an Agilent 1260 Series system (Agilent Technologies, Santa Clara, CA, U.S.A.) equipped with an Agilent 1200 RI detector set to 35°C. The HPLC settings were as
follows: mobile phase of ddH$_2$O (MilliQ®, EMD Millipore), Aminex® column (300 x 7.8 mm; HP-87N column; Bio-Rad Laboratories, Richmond, CA, U.S.A.) housed in an EchoTherm™ CO20 HPLC column heater (Torrey Pines Scientific, Inc., Carlsbad, CA, U.S.A.) set to ~82°C, an Aminex HP-87N guard column (Bio-Rad Laboratories), a flow rate of 0.8 mL/min, and a total run time of ~11 min (Ekvall, Stegmark, & Nyman, 2006; Knudsen & Li, 1991). The quantification of each sugar was performed using the previously constructed standards curves.

Due to sucrose hydrolysis over time at wine pH (Wilker, 1992), extra calculation steps were required to determine sucrose concentrations in the wine at the time of sensory analysis. To account for the baseline values the concentrations of fructose and glucose were determined. The lowest value was subtracted from the fructose and glucose concentrations that were found in the sucrose treatments. As sucrose hydrolyzes to equal proportions of glucose and fructose, the lowest value used above was added to the sucrose concentration to calculate the initial sucrose concentration prior to hydrolysis.

**Electronic Tongue Analysis**

Taste attributes of wine samples (saltiness, sourness, sweetness, umami, metallic, bitterness and spiciness) were analyzed using a potentiometric electronic tongue (Astree II electronic tongue unit, AlphaMOS, Tolouse, France) equipped with a liquid auto sampler (LS48) and seven set #5 sensors (sour, sweet, bitter, salty, umami, spicy and metallic). A pre-run system preparation comprising of conditioning, calibration and diagnostics were performed according to manufacturer’s instruction using 25 mL of 0.01 M standard solutions prepared from 0.1 M each of hydrochloric acid, sodium chloride and sodium-L-glutamate. This preparation was followed by an overnight hydration of the set #5 sensors (saltiness, sourness, sweetness, umami, metallic, bitterness and spiciness) in 25 mL reagent grade Milli-Q filtered water. A confirmatory
diagnostic run was performed prior to sample analysis. A programmed auto sampler method consisting of the following parameters was used: delay = 0 s; acquisition time = 120 s; stirring rate = 1 and acquisition period = 1. A six-looped sequence consisting of a 10 s sensor cleaning in 25 mL reagent grade Milli-Q filtered water between samples was used during data acquisition.

Prior to analysis, wine samples were equilibrated to room temperature and filtered through qualitative filter paper (Whatman, GE Healthcare Life Sciences, Pittsburgh, PA, U.S.A.) to degas and remove any sediment from the wine samples (~125 mL) according to the literature (Diako, McMahon, Mattinson, Evans, & Ross, under review; Cetó, Gutiérrez, Moreno-Barón, Alegret, & Del Valle, 2011; Cetó, Capdevila, Puig-Pujol, & Del Valle, 2014). Wines were analyzed in quadruplicate. As the sample carousel was limited in the number of samples per analysis, one of the control wine treatments (no added sugar) selected at random served as the reference in order to combine data from two separate electronic tongue runs.

**Descriptive Analysis**

Evaluations took place in individual tasting booths under white lights at the Washington State University (WSU) Sensory Evaluation Facility, a member of the Compusense Academic Consortium (Guelph, Canada), on the WSU campus in Pullman, WA. Bottles of wine were moved from cold storage (12.8°C) into a 3°C refrigerator 24 hr prior to analysis. Wine samples (~30 mL) were labelled with a three-digit random code and served at ~8-9°C in International Standards Organization (ISO)/Institut National d’Appelation d’Origine (INAO) tasting glasses covered with a Petri dish. Panelists were given unsalted saltine crackers, a cuspidor, and MilliQ water. Following the evaluation of each sample, panelists were instructed to cleanse their palates with water and crackers. All data were collected using Compusense Cloud.
Demographic Overview

Sensory panelists (n=9) were recruited from the Pullman community via electronic advertisements (i.e. listserv, emails, and school advertisements). The panel consisted of six males and three females, with a mean age of ~28 years. These panelists were selected to participate in the trained sensory panel based on their availability, previous trained panel experience, and experience in the evaluation of sparkling wines. The use of human subjects for this study was approved by the Washington State University Institutional Review Board (WSU IRB #13422-003). Prior to panel participation, panelists signed an Informed Consent Form. All panelists indicated that they consumed sparkling wine at least once a month and expressed interest in learning more about sparkling wine. Panelists received a small nonmonetary compensation for their participation at the end of each training session and a larger nonmonetary reward at the completion of the study.

Training

Panelists were trained over 12-one hr sessions over a four week period. Panelists were trained to evaluate the aroma, flavor, basic taste, and mouthfeel attributes of sparkling wines. The definition and reference standard for each attribute is shown in Table 1. These attributes and definitions were developed in reference to published literature (McMahon et al., under review; Le Barbé, 2014; Sokolowsky & Fischer, 2012; Nobel et al., 1987), trials prior to training sessions, and using panel consensus and discussion on attribute definitions.

Panelists evaluated these samples using a standard evaluation protocol in which aroma, flavor, and taste attributes were evaluated first, followed by mouthfeel attributes. Attributes and reference standards used for sensory training are presented in Table 1. Since carbonation outgasses over time (Liger-Belair et al. 2010), for the mouthfeel attributes, a second glass was
poured. Specific instructions for the mouthfeel evaluations included no swirling of the glass, holding the stem of the flute, and no gurgling or swishing the wine in mouth. This protocol was developed based on a previous study (McMahon et al., under review). Panelists were instructed to expectorate all samples and cleanse their palates between samples with water and unsalted saltine crackers.

Following initial training with standards, panelists were trained using commercial sparkling wines and other sparkling wines containing different sugar concentrations (brut, extra brut, and demi sec) to represent the full range of sensory properties. In this way, prior to formal evaluations, panelists became familiar with the attributes using a similar matrix. Instructions and 15-cm line scales were presented to the panelists using a computerized sensory software and data collection program (Compusense, Guelph, Canada). Panelists recorded their response along 15-cm unstructured line scales, anchored with “low” at 1.5 cm and “high” at 13.5 cm. Standards were revisited to confirm group consensus in intensity and identification of the attributes. The final three training sessions were used to familiarize the panelists with the sensory software. Panelist training and performance were assessed using SenPAQ statistical software (Qi statistics, Berkshire, UK) for repeatability, consistency, and discrimination to determine training validation, with extra training was provided as needed. Prior to formal evaluations, all panelists were found to be performing at an acceptable standard as analyzed using panel checking software.

**Experimental Design**

For sparkling wine profiling, three formal evaluation sessions were conducted over three days, allowing for replicate evaluations of each treatment by each panelist. Wines were presented using a William’s Latin Square design (Castura et al., 2016; Boinbaser, Parente, Casture, & Ares,
2015), with a random presentation order of samples across panelists. No two panelists received the same progression samples. Also, even though the William’s Latin Square design is not a complete blocking scheme given the number of panelists and treatments, it ensured the sample order was different and balanced across panelists. All sessions started with a warm-up sample to improve the reliability of panelist responses (Plemmons & Ressurreccion, 1998). For each session, wine treatments were presented one at a time and each panelist evaluated all seven wine treatments. In order to prevent panelist fatigue and carryover, a 60 s break was inserted between each sample, with a forced six min break after the fourth sample. Each session used two bottles of each treatment.

**Consumer Panel Evaluation**

**Demographic Overview**

Following the descriptive analysis study, consumers (n=126) also evaluated the sparkling wine samples to relate consumer acceptance to the trained panel data. Consumers were recruited from the WSU and Pullman communities using electronic advertisements (i.e. listserv, emails, and school advertisements). The consumer panel was composed of 68.3% women and 31.7% men, with a panel mean age of 29.6 years. Consumers were selected on the criteria of being of legal drinking age (21 years or older) and a sparkling wine consumer. Upon arriving at the facility, consumers were checked in to their 30 min session, checked that they had a valid photo ID showing proof of legal drinking age, and signed an Informed Consent Form. The project was approved by the WSU IRB for use of human subjects. Panelists received a nonmonetary incentive at the end of the evaluation.
Experimental Design

To reach the appropriate serving temperature of 8-9°C, sparkling wine samples were moved from cold storage (12.8°C) into a 3°C refrigerator 24 hr prior to analysis. During the panel, open bottles were sealed with a champagne bottle stopper and submerged in ice baths. One bottle was used to serve no more than 16 panelists to ensure similar carbonation level across samples. Samples (~25 mL) were served in International Standards Organization (ISO)/Institut National d’Appelation d’Origine (INAO) tasting glasses covered with a Petri dish. Glasses were labelled with a three-digit random code and were randomly presented one at a time to each consumer.

Prior to sample evaluation, consumers were asked a series of demographic questions. Consumers then evaluated all seven sparkling wine treatments using the 9-pt hedonic scale (1=dislike extremely, 9=like extremely) based on their acceptance of appearance, aroma, flavor, carbonation (a definition was provided on the computer screen stating, “the perception elicited by the presence of bubbles in the mouth”), foamy, sweetness, acidity, bitterness, and overall acceptance. Additionally, consumers were asked to rate their perception of the intensity of the “refreshing” aspect of the wine (1=not at all refreshing, 9=extremely refreshing). Following the evaluation, the consumer had the option to provide further information in a comment box. Between samples, a 45 s forced break was established, with a 4-min break after the fourth sample. Consumers were also instructed to expectorate the sample, and cleanse their palate with water and/or crackers.
**Statistical Analysis**

**Wine Chemistry**

Wine chemistry parameters were analyzed by Analysis of Variance (ANOVA) with treatment as the independent variable using XLSTAT (Version 10, Addinsoft, France). Mean separation by Fishers Least Significantly Difference (LSD) test was performed to determine differences among the treatments for wine chemistry parameters. The level of significance was established at p<0.05.

**Descriptive Analysis**

Data were analyzed using ANOVA, including Panelist, Replicate, Sugar type (ST), Residual Sugar Level (RSL), and the RSL*ST interaction. Fisher’s Least Significance Difference (LSD) test of multiple comparisons was performed using XLSTAT. The significance value for all analyses was established as p<0.05.

**Consumer Evaluation**

Consumer data were analyzed using ANOVA by XLSTAT (including Consumer, RSL, ST, and the RSL*ST interaction, which were fixed terms in the model) for differences in consumer acceptance of appearance, aroma, flavor, carbonation, foamy, sweetness, acidity, bitterness, and overall acceptance, as well as refreshing intensity. When ANOVA indicated significance (p<0.05), mean separations were performed using Fisher’s LSD test with a predetermined significance level of p<0.05.

**Electronic Tongue Discrimination and Correlation Analysis**

Principal Component Analysis (PCA) was performed on the sparkling wines in relation to the response by the electronic tongue sensors using the Astree Alpha Software (version 12)
(AlphaMOS). Correlations between descriptive data and electronic tongue data were also calculated.

*Preference Mapping*

Consumer hedonic data were correlated with trained panel data by Partial Least Squares Regression (PLSR) analysis using the PLS regression function in XLSTAT. The acceptance scores were the dependent variables (y-matrix) and the descriptive data were the independent variables (x-matrix). PLSR was used to identify the sensory attributes that were drivers for consumer acceptance.

PCA was conducted on the trained panel data and overall acceptance score from the consumer panel (standardized to the same scale as the trained panel data). Factor scores were used for the external preference mapping using the PREFMAP function in XLSTAT. Preference mapping was performed to segment the consumers’ overall acceptance for the sparkling wines. Agglomerated Hierarchical Cluster (AHC) analysis was performed on the consumer overall acceptance data. Mean cluster acceptance data per treatment was regressed against the factor scores of the PCA obtained from descriptive analysis. A contour map was generated using all the fitted models in which the consumer clusters, descriptive attributes, and overall acceptance vectors were displayed to further segment the consumer population.

**RESULTS AND DISCUSSION**

*Wine Chemistry*

Wine composition of the sparkling wines is shown in Table 2. No replicate effect was observed. As expected, significant differences in sugar concentrations were observed (p<0.05). Within the *brut* or *demi sec* sparkling wine treatments, sugar levels varied based on the sugar type (ST) that was added in the dosage. For example, when fructose was the sole sugar added to
the dosage, fructose was found to be present at the highest concentration compared to sucrose and glucose. Within each RSL, final brut sparkling wines ranged in sugar concentration from 5.3 (sucrose) to 8.4 g/L (fructose) and demi sec wines ranged in sugar from 32.8 (fructose) to 37.7 g/L (glucose). Although there were significant differences within either brut or demi sec class of wines by ST, these differences fell within the ranges reported in other studies for the respective RSL wine classifications (Martínez-Lapuente et al., 2013a; Martínez-Lapuente et al., 2013b; Jackson, 2014; Kemp et al., 2015).

Due to the low pH in the wines, the sucrose added at the dosage processing step was expected to hydrolyze over time. In table wines, the rate of sugar hydrolysis differs based on grape variety and presence of invertase (Wilker, 1992). Wilker (1992) suggested that the complete non-enzymatic hydrolysis of 10 g/L sucrose in Seyval blanc wines with a pH between 3-3.4 would occur over 2.5 to 5.5 months. Furthermore, bentonite fining (0.36, 0.72, and 1.08 g bentonite/L) slowed the rate of sucrose hydrolysis, since the riddling agent removed proteins and enzymes, most likely invertase (Wilker, 1992). Another study confirmed a significant decrease in invertase (17, 37, 55, and 73%) in sparkling wines fined with bentonite (0.1, 0.2, 0.4, and 0.5 g/L, respectively) (Dambrouck, Marchal, Cilindre, Parmentier, & Jeandet, 2005). The present study fined the sparkling wines using a higher rate of bentonite (1.13 g bentonite/L), which helped minimize sucrose hydrolysis. Invertase would likely have been removed from the wine during the disgorgement process when the yeast lees and other sediment collected by bentonite were expelled. In addition, the sensory evaluations of the sparkling wines in the present study (average pH=3.1) were conducted within 5 weeks after the dosage liquid was added to the wine, a shorter time frame than the minimum 2.5 months suggested by Wilker (1992).
The present wine treatments varied significantly in other wine chemistry parameters, including ethanol, CO₂, titratable acidity (TA), and malic acid. However, the ranges observed for ethanol (0.27%) and TA (0.20 g/L) were not likely to influence the sensory profile of the wines. The differences observed in the present study were below reported sensory difference thresholds for ethanol (1.2% in white wine) (Yu & Pickering, 2008) and TA (0.5 g/L in white wine and water) (Amerine et al., 1965; Berg et al., 1955). The difference in malic acid across the wine treatments was 0.047 g/L. Panelists were likely not perceiving differences in malic acid at the reported ranges as previous studies reported a difference threshold of 2.3 g/L in water (Berg et al., 1955). Finally, for CO₂, the range of values in the wines was 1.6 g/L. A previous study reported that the minimum concentration of CO₂ required to distinguish samples in the attributes of carbonation and bite was 2.0 g CO₂/L (McMahon et al., under review).

Descriptive Analysis

Analysis of variance results for aroma attributes are shown in Table 3. A replicate effect was observed for yeasty aroma (p<0.05). Even during training, panelists mentioned yeasty aroma was a difficult attribute to conceptualize. A significant panelist effect (p<0.0001) was observed for all aroma attributes. It is expected that panelists would be a significant source of variation in descriptive analysis as previous studies have reported such variation (Sham, Scaman, & Durance, 2001), and panelists tend to have differences in use of scale and differences in perception (Landon, Weller, Harbertson, & Ross, 2008). Differences among other attributes were also found based on sparkling wine sample. In the evaluation of sparkling wine flavors, the interaction between RSL*ST was significant for CVH flavor (p<0.01; Table 4). RSL significantly influenced the flavor perceptions of fruity, yeasty, and green (p<0.0001). A significant replicate
effect was observed for green flavor (p<0.05). Similar to yeasty aroma, panelists mentioned
green flavor was the other difficult attribute to conceptualize.

The results from the taste evaluations are shown in Table 5. The interaction between
RSL*ST was observed for sweet (p<0.0001) and bitter (p<0.05) taste perceptions. RSL
significantly influenced sour taste (p<0.0001). In the perception of mouthfeel attributes, RSL
significantly influenced the perceptions of creamy (p<0.0001) and foamy (p<0.05; Table 6).

RSL*ST Interaction

Mean separation results for the flavor attributes are presented in Table 7. In the
perception of CVH flavor, the demi sec wine sweetened with sucrose was rated the highest
(p<0.05). Demi sec sparkling wines sweetened with glucose or fructose were significantly higher
in CVH flavor compared to the control (p<0.05). The brut wines did not differ in CVH flavor
from the control wine. The findings for both green and CVH flavor suggest that the demi sec
sugar concentrations had the greatest impact on the perceptions of these flavors as compared to
the brut and control wines.

Treatments differences were also observed among sparkling wine treatments in the
perception of tastes. The demi sec wines sweetened with either fructose or sucrose were
perceived as significantly more sweet compare to the other treatments (p<0.05). The glucose
demi sec treatment was significantly higher in sweetness than the control, but not different from
the brut wines. Brut wines were also not significantly different in sweetness from the control.

As for bitterness, again the control was rated significantly more bitter than all of the demi
sec wines (p<0.05). Sucrose demi sec was significantly lower in bitterness compared to glucose
demi sec (p<0.05). Both fructose and sucrose demi sec were significantly lower in bitterness

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compared to the fructose brut wine (p<0.05). No differences were found in bitterness ratings between the control and fructose brut wines.

These taste differences among ST and RSL wines may be explained using the relative sweetness index ratings of the sugars used to sweeten the wines. Sugars have different relative sweetness levels (Moskowitz, 1970). Tou, Fitch, and Bridges (2009) report a sweetness index, establishing sucrose at 1, fructose at 1.7, while glucose had a relative sweetness of 0.7-0.8. However, Hanover and White (1993) found that fructose was less sweet at an index of 117 compared to the benchmark sweetness of 100 for sucrose. Likewise, in another study, fructose had an index of 114, sucrose at 100, and glucose at 69 (Belitz et al., 2009). The trend was always the same: fructose was the sweetest, followed by sucrose, and then glucose. However, the degree of difference reported by these studies varied. The relative difference in sweetness in the present study for the demi sec wines is most similar to the relative indices reported in Belitz et al. (2009) with sucrose and fructose being more similar in relative sweetness, while glucose was much less sweet. No trend in sweetness was observed in the brut wines, likely a function of the complex matrix as these reported studies were conducted in water.

**Influence of Residual Sugar Level (RSL)**

The influence of RSL on the intensity of specific sensory attributes was evaluated. Mean separation results for the effect of RSL on aroma and flavor attributes is presented in Table 8. In regards to aroma, the control wine was significantly higher in yeasty aroma compared to the brut and demi sec wines (p<0.05). No difference in yeasty aroma was observed between brut and demi sec wines.

Differences in flavor perception varied as sugar concentration increased. Fruitiness increased as sugar concentration increased with the control wine being rated significantly lower
as compared to brut and demisec wines (p<0.05). In contrast, the opposite trend was observed for yeasty flavor, whereby the intensity decreased significantly with increased sugar concentration (p<0.05). Additionally, green flavor was impacted by RSL. Demisec wines were considered to have significantly more green flavor over the other RSL wines (p<0.05). No significant differences in green flavor perception were observed between the control and brut wines.

These differences in aroma and flavor perception among wine treatments may be explained by differences in volatile partitioning. It is well known that small molecular weight compounds, such as sugar, influence volatile partitioning (Chandrasekaran et al., 1972). To et al. (2000) describe fructose as more hydrophobic compared to sucrose, therefore wines with increased residual fructose would have increased hydrophobicity and in turn, cause greater retention (resulting in less volatilization) of hydrophobic flavors. Furthermore, in a model carbonated beverage, researchers increased the concentration of sucrose (20 to 60% w/v or 200 to 600 g/L, respectively) and showed a significant increase in the volatilization of isopenethyl acetate, ethyl hexanoate, cis-3-hexenyl acetate, linalool, and L-menthone (p<0.05) (Hansson, Andersson, & Leufven, 2001). The authors attribute this finding to a salting-out effect whereby the sucrose is competing for water in the matrix (Voilley, Simatos, Loncin, 1977; Wientjes, 1968). Hansson et al. (2001) also sweetened the model soft drink with glucose syrup (60% w/v or 600 g/L), which significantly increased the release of ethyl hexanoate, L-menthone, and cis-3-hexenyl acetate (p<0.05). The concentrations used in these previous studies exceeded those used in the present study, suggesting that a salting-out effect may not be in effect.

For sourness, demisec wines were significantly less sour compared to the control and brut wines (p<0.05). No differences were observed between the control and brut wines for
sourness perception. These findings are supported by several studies which have demonstrated that sweet-tasting stimuli suppress sourness (Schifferstein & Frijters, 1991; Pangborn, 1961; Pangborn, 1963; Bonnans & Noble, 1993; Frank & Archambo, 1986).

In addition to differences in flavor and taste attributes, the sparkling wine treatments also varied in mouthfeel attributes. In the perception of foamy, *demi sec* wines were significantly less foamy compared to the control wine (*p*<0.05) (Table 8). No differences were observed between *brut* and *demi sec* wines. Likewise, no differences were found between *brut* and control wines for foaminess. As for creamy mouthfeel, as sugar concentration increased there was a significant increase in creaminess (*p*<0.05). The *demi sec* wines had the highest creamy mouthfeel, control had the lowest creamy mouthfeel and the *brut* wine was in between these two values (*p*<0.05).

Creamy has been used to describe the mouthfeel in sparkling wines (Le Barbé, 2014). In the development a sparkling wine lexicon, Le Barbé (2014) introduced “creamy” as a smooth sensation. Relevant to the present findings, common to these definitions are softness and smooth sensations, which have been positively correlated with sweet taste and residual sugar content in Cabernet sauvignon red wines (Hjelmeland et al., 2013).

*Influence of Sugar Type (ST)*

In Table 9, differences in ST revealed differences in green flavor perception. Sparkling wines that contained the glucose dosage were rated higher in green flavor compared to wines prepared with sucrose (*p*<0.05). Fructose containing wines were not significantly different from the other ST.

*Electronic Tongue Discrimination and Correlation Analysis*

The electronic tongue was able to differentiate among the sparkling wine treatments based on by RSL*ST as witnessed by the high discrimination index (DI = 85) (Figure 1). A total
of 85.7% of the variation in the electronic tongue data was explained by the first two principal components. The response from the sweet and sour vectors was loaded onto the first principal component, thus explaining the majority of the variation (73.6%). The e-tongue appeared to group the wines by RSL, with the *demi sec* wines clustered on the left side of the plot and the *brut* and control wines clustered on the right side of the plot.

The electronic tongue was developed to use non-specific and cross-sensitive sensors to detect matrix components within a liquid medium (Zeravik, Hlavacek, Lacina, & Skládal, 2009) and relate the analytical response to human sensory data. Therefore, electronic tongue data was correlated to descriptive data to further detail and explore the relationships among analytical and sensory data. Responses by the electronic tongue were highly correlated to trained sensory data for the attributes of sweetness ($r^2=0.927$), sourness ($r^2=0.960$), and creamy ($r^2=0.870$). The electronic tongue was weakly correlated to trained sensory data for the attributes of bitter ($r^2=0.744$), bubble pain ($r^2=0.795$), and foamy ($r^2=0.711$). The correlation to the bitterness sensor and trained sensory data could be a function of the specific bitter compounds used to calibrate the electronic tongue sensors. As such, the correlation could have been higher if the specific compounds related to bitterness in white and sparkling wines were used to calibrate the sensor. However, the identity of the specific compounds used to calibrate the sensor is confidential and not released by the manufacturing company. These correlation results revealed a strong relationship between some of the human and analytical assessment of sparkling wines for different attributes.

Previous developments using an electronic tongue have discriminated wine Merlot wines of different compositions (Diako et al., under review), Italian dry red wines (Buratti, Ballabio, Benedetti, & Cosio, 2007), Port wine (Rudnitskaya et al., 2007), and micro-oxygenated red
wines (Gay et al., 2010). Sparkling wines have also been discriminated using the e-tongue (Cetó et al., 2011; Cetó et al., 2014). Of specific relevance to the present study, Cetó et al. (2011) analyzed 21 various sparkling wine samples ranging from brut, brut nature, and medium dry (or extra brut) using a voltammetric electronic tongue. These sparkling wines were highly discriminated based on the wines’ residual sugar and region of production. Similar results were found in another study that analyzed rosé cavas (Spanish sparkling wines) using a voltammetric bio-electronic tongue. In this study, the electronic tongue showed high discrimination among the wines (98.4%) based on residual sugar and phenolic content (Cetó et al., 2014). The application of electronic tongues extends to mouthfeel discrimination among wines. A potentiometric electronic tongue was used to discriminate 61 Merlot red wines (Diako et al., under review). Diako et al. observed a high discrimination among wines based on wine chemometrics as evident by a high discrimination index (DI=95). These authors also showed a high correlation between overall electronic tongue responses and trained panel assessment of astringency ($r^2=0.998$). These results suggest that the ability to distinguish among wines samples extends beyond taste attributes and may include some mouthfeel attributes.

**Consumer Acceptance**

In addition to characterizing the sparkling wine samples by the trained panel, consumers (n=126) also evaluated these sparkling wine sample for acceptance of various sensory attributes and for the intensity of “refreshing” (Table 10). The interaction between RSL*ST significantly influenced the acceptance of carbonation and overall acceptance of the wine. A significant RSL effect was observed for the acceptance of aroma, flavor, foamy, sweetness, acidity, and bitterness (p<0.0001). Additionally, RSL had a significant influence on the intensity of “refreshing”
(p<0.0001). Furthermore, ST significantly influenced the acceptance of flavor and sweetness (p<0.05).

Mean separation results for consumer acceptance, as influenced by the interaction between RSL*ST, are presented in Table 11. When analyzing consumer acceptance for sparkling wine mouthfeel attributes, the wines with the lowest acceptance of carbonation were the control and fructose brut sparkling wines (p<0.05). For their levels of carbonation, glucose and sucrose brut wines were more acceptable over the fructose brut (p<0.05). For demi sec wines, fructose and sucrose sweetened wines were more acceptable over the glucose sweetened wine (p<0.05). No difference was observed in carbonation acceptance between glucose demi sec and the brut wines (p<0.05). Additionally, consumers showed no difference in carbonation acceptance between fructose demi sec and sucrose brut (p<0.05). The fructose demi sec wine showed higher acceptance for carbonation over its respective brut treatment (p<0.05). For overall acceptance, consumers had a higher acceptance for the fructose and sucrose demi sec wines over the other wine treatments (p<0.05). The control wine was least acceptable overall compared to the other wine treatments (p<0.05). No differences in acceptance were revealed between glucose demi sec and the brut wines.

Furthermore, the mean separation indicating differences in consumer acceptance for wines with varying RSL is presented in Figure 2. For aroma, demi sec wines had higher acceptance than brut and control wines (p<0.05). No differences in aroma acceptance were seen between control and brut wines. As RSL increased, flavor acceptance significantly increased among wines, with the demi sec wines being the most accepted and the control being the least accepted (p<0.05). The same trend was observed for acceptance of foamy, sweetness, acidity, and bitterness (p<0.05). Lastly, as RSL increased, the consumer perception of “refreshing”
intensity increased among the wines with *demi sec* being most “refreshing” (p<0.05). In summary, consumers preferred *demi sec* wines and thought the *demi sec* wines were most “refreshing.”

Additionally, mean separation results for the ST effect on consumer acceptance revealed that the sparkling wine treatments that were sweetened with sucrose had higher acceptance compared to the other treatments (p<0.05). Fructose-sweetened wines were not significantly different from glucose or sucrose wines for flavor acceptance. In the acceptance of sweetness, wines with added sucrose were liked more than the other ST (p<0.05). No differences in sweetness acceptance were observed between fructose and glucose-sweetened wines.

Partial Least Squares Regression (PLSR) analysis was used to predictively model specific attributes of the sparkling wine sample as evaluated by a trained panel with consumer acceptance. PLSR indicated the sensory attributes with the greatest influence on consumer acceptance of these sparkling wines (Figure 3). Results indicated that overall acceptance of sparkling wine was driven by fruity, floral, and CVH flavors, as well as sweet taste and creamy mouthfeel (r² > 0.80). Also, fruity (r² = 0.93), floral (r² = 0.86), and CVH (r² = 0.92) flavors, as well as sweet taste (r² = 0.82) and creamy mouthfeel (r² = 0.90) attributes were highly correlated with consumer perception of “refreshing.” Overall consumer acceptance was highly correlated with consumer acceptance of flavor (r² = 0.99), carbonation (r² = 0.95), foamy (r² = 0.94), sweetness (r² = 0.96), acidity (r² = 0.99), and bitterness (r² = 0.98). Overall acceptance of sparkling wines was negatively correlated with green flavor (r² = -0.90), yeasty flavor (r² = -0.88), sourness (r² = -0.93), and bitterness (r² = -0.99). Similarly, yeasty aroma (r² = -0.84), green flavor (r² = -0.82), yeasty flavor (r² = -0.85), sourness (r² = -0.82), and bitterness (r² = -0.97) were negatively correlated with consumer perceptions of “refreshing.”
In addition, an external preference map (Figure 4) revealed the direction and intensity of consumer preferences for sparkling wine attributes and allowed for the comparison of preference of each sparkling wine. Agglomerative Hierarchical Cluster (AHC) analysis revealed two clusters of consumers in their sparkling wine preference. Using Principal Components Analysis (PCA), the first dimension (54.4% variance explained) was mainly associated with fruity flavor, sweet taste, floral flavor, CVH flavor, and creamy mouthfeel, as well as overall consumer acceptance. These attributes were opposed by the sensory attributes of nasal pungency aroma, yeasty flavor, green flavor, sourness, and bitterness. The second dimension (19.9% variance explained) was mainly associated with foamy mouthfeel, toasted aroma, CVH aroma, and green aroma. These attributes were opposed by bubble pain mouthfeel and fruity aroma.

Cluster analysis revealed the presence of three clusters using the vector model. It should be noted that the higher order models were included in the analysis. However, no significance was observed when applying the elliptical or quadratic solutions. Since Clusters 1 and 3 were nearly identical in order of wine acceptance and also highly associated making them less interpretable; therefore, they were combined to form Cluster 1. Specifically, Cluster 1 (73.8% of consumers) was mainly loaded onto Factor 1, while Cluster 2 (26.2% of consumers) was mainly loaded onto Factor 2. Cluster 1 was defined by its preference for increased fruity, floral, and CVH flavors, sweet taste, and creamy mouthfeel and demi sec wines sweetened with fructose. Consumers in Cluster 2 preferred less sweet wines, specifically brut wines sweetened with fructose, and wines possessing a foamy mouthfeel and green aromas. Both Cluster 1 and 2 accepted the demi sec sparkling wines sweetened with glucose and sucrose. More broadly, fewer consumers (0-20%) liked the brut wines sweetened with sucrose or glucose. More consumers (40-60%) accepted the fructose-sweetened demi sec wine. Overall, these results suggest that
consumers prefer sparkling wines with fruity, floral, and CVH flavors, sweet taste, and creamy mouthfeel. Consumers also felt these attributes also contributed to the “refreshing” qualities of sparkling wines. Additionally, consumers want sparkling wines lacking in green aroma/flavor, yeasty aroma/flavor, sourness, and bitterness.

Consumer research in the area of sparkling wine is limited. One study used a mail survey approach to analyze the influence of consumer segmentation on wine acceptance (Pickering, Jain, & Bezawada, 2014). The researchers reported expertise and adventurousness were significant drivers for consumer acceptance of sparkling wines (p<0.001). Greater acceptance of sparkling wine was seen for consumers with high/very high/expert wine expertise and also for consumers with high adventurousness (p<0.001). Blackman, Saliba, and Schmidtke (2010) analyzed consumer preference of two sweetened Semillon wines compared to a control base wine (no added sugar) using novice consumers, experienced consumers, and winemakers. All three groups of participants had different preferences for wine sweetened with 32 g glucose/L compared to the control (p<0.05). Novice consumers preferred sweeter wines compared to experienced consumers (p<0.05). In a study of Chardonnay, Riesling, and Sauvignon blanc white wines, two white wine consumer segments have been identified: one segment which preferred drier and fruitier white wines and the other segment that preferred dry wines with burning and oaky attributes (Lesschaeve et al. 2012). These studies generally demonstrate how consumers of white wine can be segmented by sweetness preference; a similar result was found in the present study.

The concept of “refreshing” has been examined in other beverages, including beer (Guinard, Souchard, Picot, Rogeaux, & Siefferman, 1998), passion-fruit juice (Deliza, MacFie, & Hedderley, 2004), dairy products (Tournier, Martin, Guichard, Issanchou, & Sulmont-Rossé,
2007), soft drinks (McEwan & Colwill, 1996), and gels (Labbe, Gilbert, Antille, & Martin, 2009; Damasio, Costell, & Durán, 1997). However, the definition varied among these studies. Many of these studies report sweetness to have a negative impact on refreshing (McEwan & Colwill, 1996; Guinard et al., 1998; Labbe et al., 2009). In contrast in a carbonated beverage, acidity, or sourness has been found to contribute to the perception of “refreshing” and enhances its perception (McEwan & Colwill, 1996). Most likely, acidity adds to the thirst-quenching quality of the beverage (Labbe et al., 2009). No studies have yet examined the concept of “refreshing” in sparkling wines.

CONCLUSIONS

This is the first study that directly altered the dosage processing step to determine the effect of dosage composition, namely RSL and ST, on sparkling wine profiles and consumer acceptance. Six sparkling wine treatments of varying RSL (no sugar added, brut and demi sec) and ST (fructose, glucose, and sucrose) were created by varying the processing methods. A seventh sparkling wine treatment, the control, was created with no added sugar. Using trained panelists, these sparkling wines of varying sugar were evaluated by DA. Results for DA data revealed the influence of RSL on flavor perception, with an enhancement of fruity, but suppression of green and yeasty with increased RSL. Also, differences seen in sweetness were influenced by the relative sweetness indices of the sugar type. The electronic tongue discriminated among the sparkling wine treatments and showed high correlations with trained data for the basic tastes of sweetness and sourness, as well as creamy mouthfeel. Using consumers, demi sec wines were more acceptable overall compared to the other sparkling wines; greater acceptability was also found for sparkling wines sweetened with fructose and sucrose. Through cluster analysis, two consumer clusters were revealed. Cluster 1 preferred sparkling
wines having fruity, floral, and CVH flavors, sweet taste, and creamy mouthfeel, while Cluster 2 preferred a foamy mouthfeel, green aroma, and were more accepting of the non-drivers of acceptance.

In light of these results, further studies on the impact of dosage composition on the sensory and analytical profiles of sparkling wine are deserved. Information on how the dosage influences the aroma profiles could further detail the complexity associated with sparkling wines. Also, knowledge on how the balance of fructose and glucose sugars impacts the sensory profile of the final wine could be directly implemented by winemakers when processing their wines to produces wines of possessing specific sensory properties.
Table 1. Definitions, reference standards, and assigned intensities for attributes used in DA trained sensory panel (n=9). Standards were prepared in Carlo Rossi Chablis white wine where indicated.

<table>
<thead>
<tr>
<th>Attribute**</th>
<th>Definition</th>
<th>Standard</th>
<th>Intensity**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aroma/Flavor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nasal pungency</td>
<td>Perception of irritation, prickling, or burn in the nasal cavity.</td>
<td>0.25 g horseradish (Beaver Brand) in 25 mL wine.</td>
<td>10</td>
</tr>
<tr>
<td>Fruity</td>
<td>Aromatics associated with an overall rating of fruit including tree and stone fruits.</td>
<td>1 cm² each of fresh apple and canned peach soaked in wine with 5 g unsweetened apple sauce.</td>
<td>10</td>
</tr>
<tr>
<td>Floral</td>
<td>Aromatics associated with rose.</td>
<td>28 mg phenylethyl alcohol/L wine</td>
<td>9</td>
</tr>
<tr>
<td>Green</td>
<td>Aromatics associated with grass and/or unripe fruit.</td>
<td>30 mm piece of wheat grass ground in 25 mL wine</td>
<td>8</td>
</tr>
<tr>
<td>Yeasty</td>
<td>Aromatics associated with fresh yeast.</td>
<td>~280 g/L yeast (Lallemand Quartz) proofed in 25 mL wine with ~7 g sucrose. Diluted 1:12.5 in wine.</td>
<td>10</td>
</tr>
<tr>
<td>Toasted</td>
<td>Aromatics associated with toasted bread, fresh nuts or toasted/roasted nuts.</td>
<td>One crushed dry roasted and unsalted almond soaked in 25 mL wine for 30 min and diluted 1:3 in wine.</td>
<td>10</td>
</tr>
<tr>
<td><strong>Caramelized/Vanilla/Honey (CVH)</strong></td>
<td>Aromatic notes that include honey, caramel, vanilla, caramelized sugar, butterscotch, brown sugar, or molasses.</td>
<td>Vanilla extract (450 μL), 1/2 caramel, and honey (5-8 mL) combined in 25 mL wine. Diluted 1:12.5 in wine</td>
<td>10</td>
</tr>
<tr>
<td><strong>Basic tastes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet</td>
<td>Taste stimulated by sucrose and other sugars, such as fructose or glucose.</td>
<td>26.67 g sucrose/L wine</td>
<td>10</td>
</tr>
<tr>
<td>Sour</td>
<td>Taste stimulated by acids, such as citric or malic.</td>
<td>2.5 g tartaric acid/L wine</td>
<td>11</td>
</tr>
<tr>
<td>Bitter</td>
<td>Taste stimulated by bitter substances, such as quinine, caffeine, or hops.</td>
<td>1.5 mg quinine sulfate/L wine</td>
<td>8</td>
</tr>
<tr>
<td><strong>Mouthfeel</strong></td>
<td>Description</td>
<td>Sample</td>
<td>Intensity</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Bubble pain</td>
<td>Perception of the amount of pain from the bubbles bursting in the mouth.</td>
<td>25 mL club soda (Schweppes’s) served at 8-9ºC</td>
<td>13.5</td>
</tr>
<tr>
<td>Creamy</td>
<td>Sensation from small, dense bubbles with a feeling similar to mousse or whipped cream.</td>
<td>25 mL beer (Guinness) served at 8-9ºC</td>
<td>10</td>
</tr>
<tr>
<td>Foamy</td>
<td>Sensation that is similar to egg white foam or the froth on the top of an ice cream float. It may feel like the foam is expanding in the mouth.</td>
<td>25 mL soda (7-Up) served at 8-9ºC</td>
<td>10.5</td>
</tr>
</tbody>
</table>

\[a\] All attributes and definitions were in reference and adapted from McMahon et al., under review; Le Barbé, 2014; Sokolowsky & Fischer, 2012; Vidal et al. 2004; Noble et al. 1987

\[b\] Intensities were along a 15-cm line scale.
Table 2. Analytical characterization of seven sparkling wine treatments. Values are presented as the mean of replicate measurements. Different letters within a column represent a significant difference among wine matrix treatments for a given parameter as determined by Fisher’s LSD test (p<0.05).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% Ethanol (v/v)</th>
<th>CO₂ (g/L) at 20°C</th>
<th>CO₂ (psi) at 20°C</th>
<th>Titratable Acidity (g/L)</th>
<th>Malic acid (g/L)</th>
<th>pH</th>
<th>Glucose (g/L)</th>
<th>Fructose (g/L)</th>
<th>Sucrose (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No sugar added</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>12.03 abc</td>
<td>10.44 c</td>
<td>100.30 c</td>
<td>6.27 cd</td>
<td>1.03 c</td>
<td>3.1</td>
<td>&lt; 1.00</td>
<td>&lt; 1.00</td>
<td>&lt; 1.00</td>
</tr>
<tr>
<td>Brut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fructose</td>
<td>12.17 c</td>
<td>9.93 bc</td>
<td>95.40 bc</td>
<td>6.30 d</td>
<td>1.01 bc</td>
<td>3.1</td>
<td>&lt; 1.00</td>
<td>8.40</td>
<td>&lt; 1.00</td>
</tr>
<tr>
<td>Glucose</td>
<td>11.90 a</td>
<td>10.07 bc</td>
<td>96.77 bc</td>
<td>6.10 a</td>
<td>0.98 a</td>
<td>3.1</td>
<td>7.03</td>
<td>1.02</td>
<td>&lt; 1.00</td>
</tr>
<tr>
<td>Sucrose</td>
<td>11.97 ab</td>
<td>9.39 ab</td>
<td>90.21 ab</td>
<td>6.27 cd</td>
<td>1.01 bc</td>
<td>3.1</td>
<td>&lt; 1.00</td>
<td>&lt; 1.00</td>
<td>5.29</td>
</tr>
<tr>
<td>Demi sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fructose</td>
<td>11.93 ab</td>
<td>9.18 a</td>
<td>88.22 a</td>
<td>6.10 a</td>
<td>1.01 b</td>
<td>3.1</td>
<td>&lt; 1.00</td>
<td>32.79</td>
<td>&lt; 1.00</td>
</tr>
<tr>
<td>Glucose</td>
<td>12.00 ab</td>
<td>10.03 bc</td>
<td>96.32 bc</td>
<td>6.20 bc</td>
<td>0.98 a</td>
<td>3.1</td>
<td>37.70</td>
<td>&lt; 1.00</td>
<td>&lt; 1.00</td>
</tr>
<tr>
<td>Sucrose</td>
<td>12.07 bc</td>
<td>10.41 c</td>
<td>100.01 c</td>
<td>6.13 ab</td>
<td>1.01 bc</td>
<td>3.2</td>
<td>1.87</td>
<td>&lt; 1.00</td>
<td>34.90</td>
</tr>
</tbody>
</table>
### Table 3. F ratios from Analysis of Variance of DA sensory aroma parameters for seven sparkling wines as evaluated by trained panel and analyzed by ANOVA.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Nasal pungency</th>
<th>Fruity</th>
<th>Floral</th>
<th>Green</th>
<th>Yeasty</th>
<th>Toasted</th>
<th>CVH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panelist (P)</td>
<td>8</td>
<td>15.70***</td>
<td>22.01***</td>
<td>43.67***</td>
<td>28.33***</td>
<td>30.68***</td>
<td>39.78***</td>
<td>23.68***</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>2</td>
<td>0.45</td>
<td>0.29</td>
<td>1.23</td>
<td>0.58</td>
<td>4.62*</td>
<td>1.57</td>
<td>0.96</td>
</tr>
<tr>
<td>Residual Sugar Level (RSL)</td>
<td>2</td>
<td>0.60</td>
<td>1.15</td>
<td>1.22</td>
<td>3.00</td>
<td>8.98***</td>
<td>0.18</td>
<td>0.74</td>
</tr>
<tr>
<td>Sugar Type (ST)</td>
<td>2</td>
<td>0.64</td>
<td>0.41</td>
<td>0.31</td>
<td>0.15</td>
<td>0.01</td>
<td>0.30</td>
<td>0.17</td>
</tr>
<tr>
<td>RSL*ST</td>
<td>4</td>
<td>0.313</td>
<td>1.02</td>
<td>0.45</td>
<td>0.51</td>
<td>0.64</td>
<td>0.20</td>
<td>0.33</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; ***p<0.0001
Table 4. F ratios from Analysis of Variance of DA sensory flavor parameters for seven sparkling wines as evaluated by trained panel and analyzed by ANOVA.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Fruity</th>
<th>Floral</th>
<th>Green</th>
<th>Yeasty</th>
<th>Toasted</th>
<th>CVH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panelist (P)</td>
<td>8</td>
<td>33.46***</td>
<td>48.85***</td>
<td>47.48***</td>
<td>19.82***</td>
<td>20.66***</td>
<td>18.43***</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>2</td>
<td>0.24</td>
<td>0.40</td>
<td>3.90*</td>
<td>1.78</td>
<td>1.66</td>
<td>0.57</td>
</tr>
<tr>
<td>Residual Sugar Level (RSL)</td>
<td>2</td>
<td>55.57***</td>
<td>1.51</td>
<td>14.20***</td>
<td>17.23***</td>
<td>0.71</td>
<td>36.60***</td>
</tr>
<tr>
<td>Sugar Type (ST)</td>
<td>2</td>
<td>1.35</td>
<td>0.23</td>
<td>3.71*</td>
<td>0.27</td>
<td>0.34</td>
<td>4.37*</td>
</tr>
<tr>
<td>RSL*ST</td>
<td>4</td>
<td>2.14</td>
<td>0.09</td>
<td>2.30</td>
<td>0.53</td>
<td>0.54</td>
<td>4.07**</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; ***p<0.0001
Table 5. F ratios from Analysis of Variance of DA sensory taste parameters for seven sparkling wines as evaluated by trained panel and analyzed by ANOVA.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Sweet</th>
<th>Sour</th>
<th>Bitter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panelist (P)</td>
<td>8</td>
<td>34.15***</td>
<td>18.18***</td>
<td>28.50***</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>2</td>
<td>4.05*</td>
<td>1.25</td>
<td>2.44</td>
</tr>
<tr>
<td>Residual Sugar Level (RSL)</td>
<td>2</td>
<td>112.56***</td>
<td>41.88***</td>
<td>57.30***</td>
</tr>
<tr>
<td>Sugar Type (ST)</td>
<td>2</td>
<td>13.19***</td>
<td>2.25</td>
<td>2.26</td>
</tr>
<tr>
<td>RSL*ST</td>
<td>4</td>
<td>10.98***</td>
<td>1.83</td>
<td>2.55*</td>
</tr>
</tbody>
</table>

*p<0.05; p<0.01; *p<0.0001
Table 6. F ratios from Analysis of Variance of DA sensory mouthfeel parameters for seven sparkling wines as evaluated by trained panel and analyzed by ANOVA.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Bubble pain</th>
<th>Foamy</th>
<th>Creamy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panelist (P)</td>
<td>8</td>
<td>17.16***</td>
<td>44.89***</td>
<td>51.14***</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>2</td>
<td>0.97</td>
<td>1.30</td>
<td>1.63</td>
</tr>
<tr>
<td>Residual Sugar Level (RSL)</td>
<td>2</td>
<td>1.30</td>
<td>3.14*</td>
<td>15.98***</td>
</tr>
<tr>
<td>Sugar Type (ST)</td>
<td>2</td>
<td>0.37</td>
<td>0.97</td>
<td>1.47</td>
</tr>
<tr>
<td>RSL*ST</td>
<td>4</td>
<td>0.96</td>
<td>1.64</td>
<td>0.43</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; ***p<0.0001
Table 7. Mean separation of significant flavors and taste attributes of seven sparkling wines as evaluated by trained DA panel and analyzed using Fisher’s LSD test. Values are presented as the mean of replicate measurements. Different letters within a column represent a significant difference among wine matrix treatments for a given parameter (p<0.05).

<table>
<thead>
<tr>
<th>RSL*ST</th>
<th>Flavor</th>
<th>Tastes</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CVH</td>
<td>Sweet</td>
<td>Bitter</td>
<td></td>
</tr>
<tr>
<td>No sugar added</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>4.15 a</td>
<td>3.94 a</td>
<td>6.62 e</td>
<td></td>
</tr>
<tr>
<td>Brut</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fructose</td>
<td>4.99 b</td>
<td>4.53 ab</td>
<td>5.88 d</td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>4.82 ab</td>
<td>4.43 a</td>
<td>5.52 cd</td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td>4.88 ab</td>
<td>4.66 ab</td>
<td>5.62 cd</td>
<td></td>
</tr>
<tr>
<td>Demi sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fructose</td>
<td>5.93 c</td>
<td>7.82 c</td>
<td>4.83 b</td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>5.11 b</td>
<td>5.23 b</td>
<td>5.24 bc</td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td>7.00 d</td>
<td>8.16 c</td>
<td>4.15 a</td>
<td></td>
</tr>
</tbody>
</table>
Table 8. Mean separation of significant attributes of seven sparkling wines of different residual sugar levels as evaluated by trained DA panel and analyzed using Fisher’s LSD test. Values are presented as the mean of replicate measurements. Different letters within a column represent a significant difference among wine matrix treatments for a given parameter (p<0.05).

<table>
<thead>
<tr>
<th>Residual Sugar Level</th>
<th>Aroma</th>
<th>Flavors</th>
<th>Taste</th>
<th>Mouthfeels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yeasty</td>
<td>Fruity</td>
<td>Yeasty</td>
<td>Foamy</td>
</tr>
<tr>
<td>No Sugar Added</td>
<td>5.08 b</td>
<td>4.60 a</td>
<td>5.00 c</td>
<td>7.71 b</td>
</tr>
<tr>
<td>Brut</td>
<td>4.42 a</td>
<td>5.46 b</td>
<td>4.51 b</td>
<td>7.35 b</td>
</tr>
<tr>
<td>Demi sec</td>
<td>4.30 a</td>
<td>6.47 c</td>
<td>3.87 a</td>
<td>5.69 a</td>
</tr>
</tbody>
</table>
Table 9. Mean separation of a significant flavor attribute of seven sparkling wines as evaluated by trained DA panel and analyzed using Fisher’s LSD test. Values are presented as the mean of replicate measurements. Different letters within a column represent a significant difference among wine matrix treatments for a given parameter (p<0.05).

<table>
<thead>
<tr>
<th>Sugar Type</th>
<th>Flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green</td>
</tr>
<tr>
<td>Fructose</td>
<td>4.26 ab</td>
</tr>
<tr>
<td>Glucose</td>
<td>4.50 b</td>
</tr>
<tr>
<td>Sucrose</td>
<td>4.04 a</td>
</tr>
</tbody>
</table>
Figure 1. Electronic tongue discrimination of treatments used for sensory profiling (n=7) showing high discrimination of the wines based on the Astree set #5 sensors. The sensors are indicated by: UMS-1 (umami), SPS-1 (spicy), GPS-1 (metallic), BRS-1 (bitter), STS-1 (salty), SRS-1 (sour), and SWS-1 (sweet). The control wine is labelled as “Control”. Wine prepared using the dosage treatments (Frucbrut = Fructose brut; Frucsec = Fructose demi sec; Dexbrut = Glucose brut; Dexsec = Glucose demi sec; Sucbrut = Sucrose brut; Sucsec = Sucrose demi sec). Letters B, C, and D indicate replicate evaluations.
Table 10. Statistical significance of attribute acceptance and intensity of “refreshing” of seven sparkling wines as evaluated by a consumer panel (n=126) and analyzed by ANOVA.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Acceptance</th>
<th></th>
<th></th>
<th></th>
<th>Intensity</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Appearance</td>
<td>Aroma</td>
<td>Flavor</td>
<td>Carbonation</td>
<td>Foamy</td>
<td>Sweetness</td>
<td>Acidity</td>
<td>Bitterness</td>
<td>Overall</td>
<td>Refreshing</td>
</tr>
<tr>
<td>Consumer</td>
<td>125</td>
<td>7.40***</td>
<td>5.96***</td>
<td>4.65***</td>
<td>6.66***</td>
<td>7.07***</td>
<td>3.69***</td>
<td>5.15***</td>
<td>5.61***</td>
<td>3.72***</td>
<td>6.21***</td>
</tr>
<tr>
<td>RSL</td>
<td>2</td>
<td>2.90</td>
<td>7.75***</td>
<td>72.24***</td>
<td>35.28***</td>
<td>26.36***</td>
<td>60.04***</td>
<td>53.17***</td>
<td>67.12***</td>
<td>73.65***</td>
<td>59.27***</td>
</tr>
<tr>
<td>ST</td>
<td>2</td>
<td>2.58</td>
<td>0.30</td>
<td>3.10*</td>
<td>3.23*</td>
<td>0.28</td>
<td>4.21*</td>
<td>2.27</td>
<td>2.87</td>
<td>3.14*</td>
<td>2.04</td>
</tr>
<tr>
<td>RSL*ST</td>
<td>4</td>
<td>1.21</td>
<td>1.88</td>
<td>2.29</td>
<td>3.76**</td>
<td>1.94</td>
<td>2.15</td>
<td>1.98</td>
<td>2.13</td>
<td>2.38*</td>
<td>2.22</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; ***p<0.0001
Table 11. Mean separation of carbonation and overall acceptance of seven sparkling wines as evaluated by a consumer panel (n=126) and analyzed using Fisher’s LSD. Values are presented as the mean of replicate measurements. Different letters within a column represent a significant difference among wine matrix treatments for a given parameter (p<0.05). A 9-point hedonic scale was used where 1=dislike extremely and 9=like extremely.

<table>
<thead>
<tr>
<th>RSL*ST</th>
<th>Carbonation</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>No sugar added</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>6.01 a</td>
<td>5.17 a</td>
</tr>
<tr>
<td>Brut</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fructose</td>
<td>6.28 ab</td>
<td>5.78 b</td>
</tr>
<tr>
<td>Glucose</td>
<td>6.53 bc</td>
<td>5.91 b</td>
</tr>
<tr>
<td>Sucrose</td>
<td>6.63 cd</td>
<td>6.02 b</td>
</tr>
<tr>
<td>Demi sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fructose</td>
<td>6.87 de</td>
<td>6.62 c</td>
</tr>
<tr>
<td>Glucose</td>
<td>6.39 bc</td>
<td>6.16 b</td>
</tr>
<tr>
<td>Sucrose</td>
<td>6.95 e</td>
<td>6.90 c</td>
</tr>
</tbody>
</table>
Figure 2. Impact of sparkling wine RSL on consumer (n=126) acceptance of aroma, flavor, foamy, sweetness, acidity, and bitterness, as well as intensity of refreshing. For acceptance of attributes, a 9-point point hedonic scale was used (1=dislike extremely and 9=like extremely) while for the intensity of “refreshing”, a 9-point intensity scale was used (1=not at all refreshing and 9=very refreshing).
Figure 3. Partial Least Squares Regression (PLSR) biplot correlating aroma, flavor, taste, and mouthfeel attributes (red dots) evaluated by the trained panel (n=9) to the acceptance ratings of the consumer panel (n=126) for sparkling wine treatments made to vary in RSL and ST (denoted with green squares and labelled with the specific treatment). Consumer evaluations of acceptance are shown in blue italics.
Figure 4. Preference map of consumer (n=126) preferences for the sensory attributes of seven sparkling wine treatments. Sparkling wine treatments are labelled by a green circle outlined in black. Attribute vectors from trained data are in denoted in red. Clusters are labelled with dashed vectors. Overall liking is labelled by a blue vector. Shaded areas (percentages of consumers as labelled in the legend) of the contour plot signify which clusters have preferences above average in a given region of the preference map.
CHAPTER VI

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The influence of carbonation and sugar on the sensory and chemical profiles of sparkling wines was described in further detail in this dissertation. The significance of the study of sparkling wines was described in Chapter I, while an overview of the literature was presented in Chapter II. Results of the three separate studies were detailed in Chapters III, IV, and V.

In the first study, sparkling wines were produced by altering the sugar composition of the liqueur de tirage to yield sparkling wines of different levels of carbonation (0-7.5 g CO$_2$/L). Consumers used a paired comparison test to compare a control sparkling wine (no carbonation) to a subset of these carbonation levels (1.2, 2.0, 4.6, 5.8, and 7.5 g CO$_2$/L). Results showed ≥2.0 g CO$_2$/L was needed for the perception of the attributes of carbonation and “bite” in sparkling wine. The influence of carbonation on the specific sensory attributes of the sparkling wines was explored using a trained sensory evaluation panel. Sparkling wines of variable CO$_2$ concentration were evaluated by trained panels using descriptive analysis (DA) and Temporal Check-All-That-Apply (TCATA). Results from DA indicated that as CO$_2$ level increased, the mouthfeel attributes increased in their perceived intensity. Using TCATA, differences in attribute citation (percentage of panelists selecting a specific attribute at any given moment during the course of evaluation) were found over the duration of consumption. Mouthfeel attributes were separated into those that were perceived early in the sensory experience (peaked within the first 15 s of evaluation) and those with delayed onset (peaked after 15 s of evaluation).

Finally, the third study is the first to date to detail the impact of dosage composition, specifically residual sugar level (brut and demi sec) and sugar type (fructose, glucose, and sucrose) on the chemical and sensory profiles of sparkling wine. ST significantly influenced
flavors, tastes, and mouthfeel, while RSL significantly influenced the perception of yeasty aroma, as well as flavors, tastes, and mouthfeel attributes. No differences in fructose and sucrose were observed for CVH flavor, sweet and bitter tastes, and creamy mouthfeel. Glucose was considered to have the highest green flavor and bitter taste. As expected, increased residual sugar resulted increases sweetness perception and decreased the perceptions of sourness and bitterness. Lastly, as RSL increased, the perception of creamy mouthfeel significantly increased.

Considering the significant impact of carbonation and dosage composition on sparkling wine sensory profiles, future studies are warranted. Specifically, studies should include the following:

1. Evaluate the effect of higher carbonation levels (7.5-11 g CO₂/L) on temporal profiling and consumer perception of carbonation.
2. Detail consumer expectation of creaminess while looking at a video or photos of bubbles.
3. Use microscopy to analyze the bubble interface to determine the bubble affinity to matrix components and interfacial relationships.
4. Incorporate eye-tracking technology to determine the important parameters of the appearance of sparkling wines using consumer panel. Additionally, test in what order of appearance parameters consumers look at a glass of champagne.
5. Explore the correlation between the number of fungiform papillae and transient receptor protein (TRP) channels, which modulate chemesthetic tastes of bitter and chemical substances, respectively.
6. Future work on dosage composition should research other sweeteners, such as high fructose corn syrup, or the inclusion of distilled spirits, such as brandy or cognac, to determine the impact on sparkling wines and consumer acceptance.

7. Determine the effect of glass shape on sparkling wine evaluations.

8. Define sparkling wine quality and complexity.

It is clear more work on the sensory aspects of sparkling wine is needed to further detail these complex matrices and wines. More knowledge on these subjects will benefit sparkling wine makers and businesses to better understand the complexities associated with this style of wine and market preferences.
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