South African de-alcoholised sparkling wines: A study focused on sensory and chemical profiles

by

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), and that reproduction and publication thereof by Stellenbosch University will not infringe third party rights and that I have not previously, in its entirety or in part, submitted it for obtaining any qualification.

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Summary

De-alcoholised sparkling wines contain a maximum of 0.5% v/v ethanol and a minimum carbon dioxide (CO_2) pressure of 300 kPa. The wines are produced through yeast-mediated alcoholic fermentation to full ethanol-strength of table wines (*circa* 12 to 14% v/v), followed by the physical removal of the volatile aroma fraction and reduction of the ethanol concentration. De-alcoholised base wines are reconstituted by re-introducing the volatile fraction, adding permitted chemical compounds, and sparging with external CO_2. Although South Africa (SA) only recently joined the global trend of producing de-alcoholised sparkling wines in response to consumer preference for the products, no published information was available on their sensory quality and chemical composition when this study was undertaken.

This study used a quantitative and qualitative approach to investigate the sensory quality of nine commercially available South African de-alcoholised white and rosé sparkling wines. A panel of 51 South African wine industry professionals tasted the wines and evaluated their quality using a 20-point scoring system with maximum points for each sensory modality: appearance 3, aroma 7, and palate 10. Qualitative wine sensory profiles were generated using the free listing method, whereby the professionals described their perceptions of the different modalities. Text data mining included standardisation of raw text, lemmatisation to form sensory groups, and categorising of the groups as positive, neutral, or negative wine attributes. Correspondence analysis identified the sensory categories that best described the wine profiles.

The wines' average total quality scores ranged between 11 and 14 points out of 20, with palate quality scoring, on average, from 4.9 to 6.0 out of 10 points. The free listing method produced an information-rich dataset with 2414, 2110, and 3321 word counts for appearance, aroma, and palate, respectively. The lemmatised text data resulted in 10 appearance, 29 aroma and 61 palate sensory categories. Examples of neutral sensory categories included 'muscat', 'citrus', and 'fruit' aroma, whie positive sensory categories included 'wine-like' aroma and 'nose-palate follow-through' of wine flavours. Negative palate categories (22 in total) included 'watery', 'short finish', 'unbalanced' and 'acidic'.

The volatile aroma profile and basic wine oenological parameters were generated and compared to published data on full-ethanol strength sparkling wines, in the absence of published data on de-alcoholised sparkling wines. Glycerol concentrations were markedly higher in the de-alcoholised wines, ranging from 14.30 to 20.20 g/L. Volatile compounds' concentration showed lower ranges than in full-strength sparkling wines. For example, ethyl acetate and isoamyl alcohol ranged from 0.427 to 4.677 mg/L and 0.373 to 5.636 mg/L in this study, respectively, versus 8.000 to 45.200 mg/L and 16.317 to 167.080 mg/L in full-strength wines. The results showed that de-alcoholised sparkling wines are unique products with distinct sensory and chemical profiles. Future research topics to be pursued on best de-alcoholisation and re-constitution practices were pointed out. As a

first exploratory study into this technically challenging product category, the results generated meaningful and informative feedback for the South African wine industry.

Opsomming

Ge-dealkoholiseerde vonkelwyn bevat 'n maksimum van 0.5% v/v etanol en 'n minimum koolstofdioksied (CO_2) druk van 300 kPa. Die wyne word geproduseer deur gis-gemedieerde alkoholiese fermentasie tot volle etanol-sterkte van tafelwyne (ongeveer 12 tot 14% v/v), gevolg deur die fisiese verwydering van die vlugtige aromafraksie en vermindering van die etanolkonsentrasie. Ge-dealkoholiseerde basiswyne word hersaamgestel deur die vlugtige fraksie weer terug te plaas, toegelate chemiese verbindings by te voeg en eksterne CO_2 bygevoeg. Alhoewel Suid-Afrika (SA) eers onlangs by die wêreldwye neiging aangesluit het om ge-dealkoholiseerde vonkelwyne te produseer in reaksie op verbruikersvoorkeure vir die produkte, was geen gepubliseerde inligting oor die sensoriese kwaliteit en chemiese samestelling van die wyne beskikbaar toe hierdie studie onderneem.

Hierdie studie het 'n kwantitatiewe en kwalitatiewe benadering gebruik om die sensoriese kwaliteit van nege kommersieel-beskikbare Suid-Afrikaanse ge-dealkoholiseerde wit en rosé vonkelwyne te ondersoek. 'n Paneel van 51 wynindustriedeskundiges het die wyne geproe en die kwaliteit geëvalueer deur gebruik te maak van 'n 20-punt puntestelsel, met maksimum punte vir elke sensoriese modaliteit: voorkoms 3, aroma 7 en smaak 10. Kwalitatiewe wyn sensoriese profiele is gegenereer deur gebruik te maak van die vrye notering (Engels Free Listing) metode, waardeur die wynindustriedeskundiges hul persepsies van die verskillende modaliteite beskryf het. Teksdata-ontginning het standaardisering van rou teks, die vorming van sensoriese groepterme (Engels Lemmatisation) en kategorisering van die groepe as positief, neutraal of negatief behels. Die sensoriese kategorieë wat die wynprofiele die beste beskryf het, is met ooreenkomsanalise geïdentifiseer.

Die wyne se gemiddelde totale gehaltetellings het tussen 11 en 14 punte uit 20 gewissel, met smaakgehaltepunte gemiddeld 4.9 tot 6.0 uit 10 punte. Die vrye noteringmetode het 'n inligtingryke datastel met 2414, 2110 en 3321 woorde vir onderskeidelik voorkoms, aroma en smaak opgelewer. Die vrye notering teksdata het gelei tot 10 voorkoms-, 29 aroma- en 61 smaak- sensoriese kategorieë. Voorbeelde van neutrale sensoriese kategorieë positiewe en neutrale sensoriese kategorieë was 'muskaat', 'sitrus', 'vrugte'-aroma, terwyl positiewe kategorieë 'wynagtige' aroma, en 'aroma-smaak-integrasie' van wyngeure ingesluit het. Negatiewe smaakkategorieë (22 in totaal) het 'waterig', 'kort nasmaak', 'ongebalanseerd' en 'suur' ingesluit.

Die vlugtige aromaprofiel en basiese wynkundige parameters is gemeet en in die afwesigheid van gepubliseerde data oor gedealkoholiseerde vonkelwyne, vergelyk met gepubliseerde data oor vol-etanolsterkte vonkelwyne. Gliserolkonsentrasies was merkbaar hoër in die ge-dealkoholiseerde wyne en het gewissel het van 14.30 tot 20.20 g/L. Vlugtige aromaverbindings het laer konsentrasies getoon as in volsterkte vonkelwyne. Byvoorbeeld, etielasetaat en isoamielalkohol het onderskeidelik gewissel van 0.427 tot 4.677 mg/L en 0.373 tot 5.636 mg/L in hierdie studie, teenoor 8.000 tot 45.200

mg/L en 16.317 tot 167.080 mg/L in volsterkte wyn. Die resultate het getoon dat ge-dealkoholiseerde vonkelwyne unieke produkte is met duidelike sensoriese en chemiese profiele. Toekomstige navorsingsonderwerpe wat ondersoek moet word oor die beste de-alkoholiserings- en herkonstitueringspraktyke is uitgewys. As 'n eerste verkennende studie in hierdie tegnies uitdagende produkkategorie, het die resultate betekenisvolle en insiggewende terugvoer vir die Suid-Afrikaanse wynbedryf gegenereer.

The thesis is dedicated to my family, every person with dreams and aspirations. It is a written confirmation that everything is possible if you put in the work.

I can do all things through Christ who strengthens me- **Philippians 4:13**

If you put your mind to it, you can accomplish anything- **Unknown**

Biographical sketch

Lethabo Mologadi Maesela was born at Mohlaletse, Ga-Sekhukhune, Limpopo province on the 28th of September 1997. She attended Lerajane Primary until Grade 6, then moved to Middelburg, Mpumalanga, where she matriculated from L.D. Moetanalo Secondary School in 2015. She furthered her studies at the University of Limpopo, where she obtained her bachelor’s degree (in Life Sciences) and honours degree (in Microbiology) in 2018 and 2019, respectively. In 2020 she enrolled for her Master of Science (in Wine Biotechnology) at the Department of Viticulture and Oenology, Stellenbosch University, South Africa.

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Preface

This thesis is presented as a compilation of five chapters. Each chapter is introduced separately and is written according to the style of the South African Journal of Enology and Viticulture (SAJEV). However, the rule of writing numbers below 10 in words was not followed when reporting scores.

Chapter 1 General Introduction and project aims

Chapter 2 **Literature review**

The production of de-alcoholised beverages and the effect of de-alcoholisation on sensory and chemical profiles

Chapter 3 **Research results**

South African de-alcoholised sparkling wines' quality and sensory profiles: Insights gained through wine tasting using wine professionals

Chapter 4 **Research results**

Chemical profiling of a set of South African de-alcoholised sparkling wines: Focus on volatile aroma compounds

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Glossary of terms

Producing cellars: Refer to cellars that were producing commercially available de-alcoholised sparkling wines at the time of the study. Their products were thus included in the sample set analysed.

Non-producing cellars: Refer to cellars that were not producing commercially available de-alcoholised sparkling wines at the time of the study. Moreover, this category also included cellars producing de-alcoholised still wines, and a cellar producing only full-strength wines. The research institute was also classified as a non-producing cellar.

Full-strength wine: A wine with no ethanol removed.

De-alcoholisation: The process of physically removing ethanol from a fermented wine to a concentration of ≤0.5% v/v. However, the term partial de-alcoholisation may be used when a portion of ethanol (2 to 5% v/v) was removed from wine instead of reducing the ethanol to a final concentration of ≤0.5% v/v.

Chapter 1: General introduction and project aims

1.1. Introduction

South Africa (SA) is a new world wine-producing country that began producing still wines in 1659. In 1971, sparkling wines were introduced to the South African market by Simonsig Wine Estate outside Stellenbosch (Burger, 2011). Since then, sparkling wine has been a prominent product enjoyed by South African consumers.

Although sparkling wines can be produced by using several different methods (Jeandet *et al*., 2011), SA commonly uses two methods: *Méthode Traditionnelle* (traditional method) and the carbonation method (Newton, 2010; Zhang, 2022). The traditional method has two fermentation stages: alcoholic fermentation followed by secondary fermentation, which occurs in the wine bottles to obtain elevated ethanol strength and tertiary flavours, while simultaneously capturing yeast-produced carbon dioxide (CO_2). Alcoholic fermentation occurs when yeasts, commonly *Saccharomyces cerevisiae*, convert glucose and fructose found in grape must into ethanol and CO_2 (Torresi *et al*., 2011). When using the carbonation method, alcoholic fermentation occurs to produce the base wine and thereafter, it is sparged with additional CO_2 from an external source to make the wine effervescent.

The products from these two methods are referred to as *Méthode Cap Classique* (MCC) when produced by the traditional method and carbonated sparkling wine or just sparkling wine when produced by the carbonation method. The South African Wine Industry Information and Systems (SAWIS) reports that South African wine consumption is increasing, indicating increased consumer consumption habits, especially of sparkling wines (SAWIS, 2021).

Many consumers have expressed an interest to reduce their alcohol intake and have started to consider alcoholic beverages with no or low alcohol (so-called NOLO drinks) (Saliba *et al*., 2013; Whittaker, 2021). Worldwide, wine producers have taken this opportunity to produce and introduce de-alcoholised wines (including sparkling wines) into the market to address the needs and preferences of consumers better. De-alcoholised wines are produced through yeast-mediated alcoholic fermentation, followed by the physical reduction of ethanol to a maximum concentration of ≤0.5% v/v (SAWIS, 2020). As a result of fermentation, the wines develop aroma and flavour attributes of fermentative origin. Therefore, the products have flavour profiles resembling that of full-strength wines, but with ≤0.5% v/v ethanol.

Removing ethanol has been reported to disrupt the balance and structure of the palate, thereby rendering the taste of the wines unappealing (Liguori *et al*., 2019). As such, it is understandable why consumers have indicated the need to improve the taste of de-alcoholised wines (Bucher *et al*., 2019). Additionally, the volatile compounds are reduced (Liguori *et al*., 2019), thereby affecting the overall aroma and flavour of the wines. For example, it was found that the perception of red fruits, spices, bitterness, sweetness, and overall acceptability of red wine was reduced with increased removal of ethanol (Corona *et al*., 2019). It can be concluded that the overall chemical profiles of wines are affected by de-alcoholisation; however, the scope of the change is dependent on various factors. These include the hydrophobic characters of the volatile aroma compounds (Diban *et al*., 2008), the methods used for ethanol reduction, the concentration of ethanol removed, and the wine's physicochemical properties (Longo *et al*., 2017). As such, each wine produced by different strategies may be distinct from the other, and as a result also the wine's quality and sensory profile.

Liguori *et al*. (2019) showed over 90% loss of volatile compounds quantified in de-alcoholised wines with final ethanol strength of 0.3% v/v, in comparison to the original non-de-alcoholised wines that served as controls. Diban *et al*. (2008) reported that 0.9 to 5.6% of 2-phenylethanol was reduced whilst ethyl octanoate was reduced by 57.5 to 98.1% during partial de-alcoholisation. The volatile compounds were possibly reduced at different concentrations because of the factors highlighted by Longo *et al.* (2017) and Diban *et al.* (2008). Quantifying the compounds helps determine the change in concentration and understanding the effects of de-alcoholisation on wine. Changes in non-volatile compounds, including phenolic compounds, tannins and glycerol, may also occur and affect mouthfeel and taste. However, the focus of this study was on volatile aroma compounds.

Although studies on de-alcoholised wines have been conducted and published, to date, no studies have focused on de-alcoholised sparkling wines. As mentioned before, de-alcoholisation is an emerging concept in SA, and de-alcoholised sparkling wines that are locally produced have not officially been profiled or evaluated. Therefore, the current exploratory study set out to specifically investigate the sensory and chemical profiles of South African de-alcoholised sparkling wines.

Sensory evaluation has been used to evaluate the quality of sparkling wines (Culbert *et al*., 2017). It can aid in identifying aroma and palate attributes associated with wines, as well as rating the sensory quality. Additionally, this process can assist in identifying wine faults, thereby adding to quality improvement. Trained judges, consumers and wine professionals have been employed as assessors in the sensory evaluation of wines (Barton *et al*., 2020). In this study, wine professionals, including winemakers, wine researchers and marketers, have been used to assess the sensory quality of wines, because of their familiarity with and general knowledge of wines.

Several methodologies can be employed to assess the sensory profile and quality of the wine. The method selected, however, depend on the objectives. Free listing (FL), also known as a free comment method, is one of the methods used to profile wine products. This method requires judges to list or comment on all attributes associated with the wines without rules put in place on how the wines are supposed to be described (Lawrence *et al*., 2013). Spontaneity is an important aspect of this method, since judges are not influenced by pre-determined attributes on what should be perceived during evaluation. Therefore, for a new product category, such as de-alcoholised sparkling wine, this method was suited to explore the sensory profile with no reservations.

In determining the sensory quality of wines, however, quality scoring is widely used. It allows judges to rate the quality of wine either out of 10, 20 or 100 points (Parr *et al*., 2006; Cicchetti and Cicchetti, 2009). This method can be used to evaluate wine quality in research and in competitions, although there have been debates on which scoring system is best. Parr *et al*. (2006) showed that there is no difference between the 20- and 100-point scoring system and concluded that any of the latter two scoring methods produce reliable results. In some South African wine competitions, the 20-point scoring method is the common system used (Veritas, 2022). Since wine professionals were used as judges in the study, the 20-point quality scoring system was deemed appropriate for quality evaluation. Three modalities were rated, appearance out of 3, aroma out of 7, and palate out of 10 points.

1.2. Problem statement and project aims

Although studies have been conducted focusing on the quality and profiles of de-alcoholised still wines, none have been published on de-alcoholised sparkling wines. There was a knowledge gap on the quality of sparkling wines produced through de-alcoholisation. Furthermore, their sensory and chemical profiles were not reported. Considering that global studies have reported the change in sensory profiles and volatile compounds in de-alcoholised still wines, the South African wine industry was yet to acquire feedback on its products. This study addresses the knowledge gap and provides much-needed information to role players in the industry on their products. Furthermore, consumers desire to limit alcohol consumption and switch to alternatives that offer quality and good flavours, but with no or less ethanol. The de-alcoholised sparkling wines may offer that, therefore, studying their profiles in depth may help producers meet the consumers' preferences, and spark their interest in purchasing the wines.

This study was conducted to evaluate the sensory quality and chemical profile of de-alcoholised sparkling wines produced in SA. Furthermore, to evaluate the effect of de-alcoholisation on the volatile compounds of the wines in comparison to full-strength sparkling wines on published research. Additionally, the sensory profiles and wine quality were evaluated to explore the quality of the de-alcoholised sparkling wines for benchmarking purposes.

In summary, the primary focus of this study was the sensory and chemical profiling of a selection of South African de-alcoholised sparkling wines. The specific objectives of the study were to:

a. Evaluate the quality of the de-alcoholised sparkling wines using quality scoring;
b. Generate sensory profiles of a set of de-alcoholised sparkling wines using free listing;
c. Measure the basic oenological wine parameters through their respective methodology and volatile compounds through GCMS-MS;

d. Quantify the volatile aroma compounds and to compare the volatile aroma compounds concentrations to published research.

The study was conducted in two main phases: **phase 1**- wine quality evaluation coupled with sensory profiling, and **phase 2**- chemical profiling. **Figure 1.1** provides an overview of the steps that were followed:

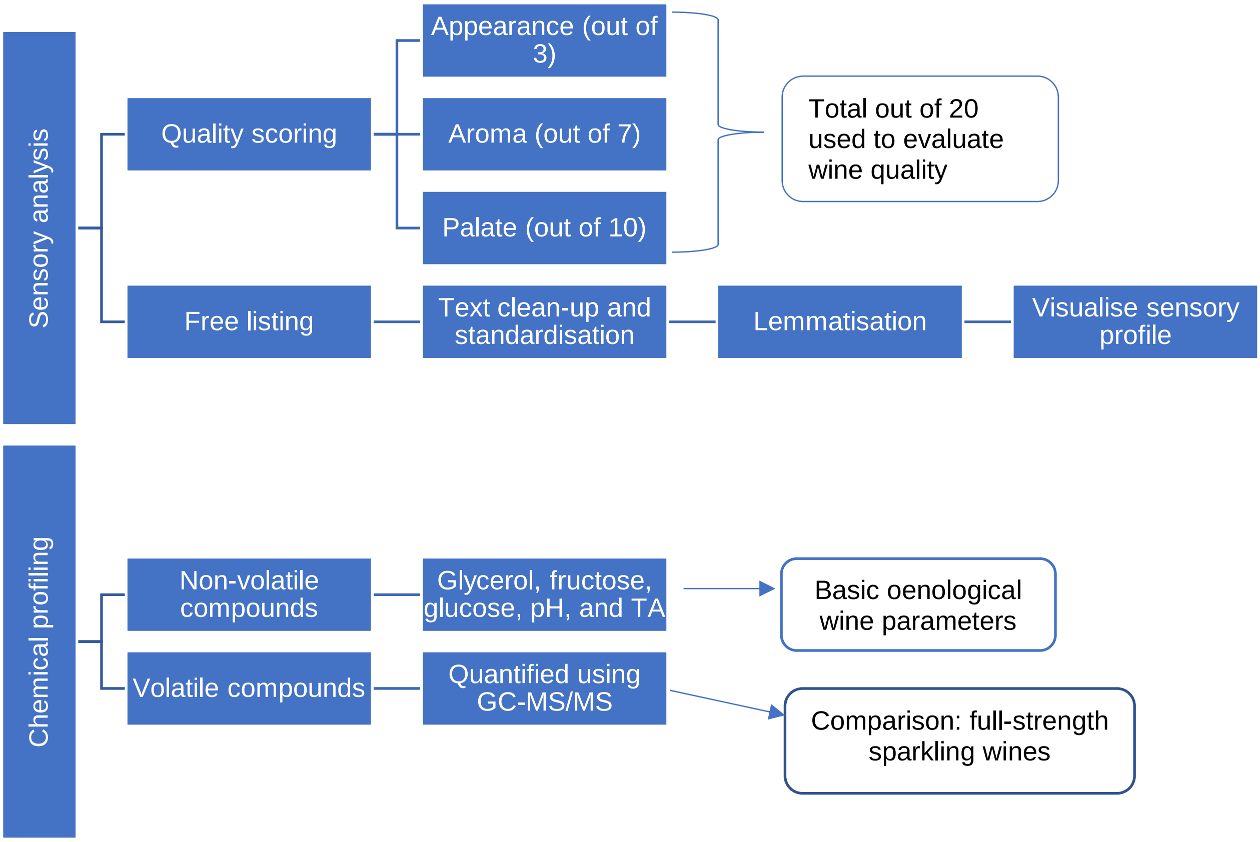

Figure 1.1 The study overview for analysing the de-alcoholised sparkling wines' sensory and chemical profiles.

A literature review on the concept of de-alcoholisation and its reported effect on products was conducted and reported in **Chapter 2,** to give an overview of what the process entails. The results for phase 1 and phase 2 (**Figure 1.1**) were separately discussed in **Chapter 3** and **Chapter 4**, respectively. Following that, the impact of the research on the wine industry and conclusions on the quality and profiles of the wines were discussed in **Chapter 5**.

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Chapter 2: The production of de-alcoholised beverages and the effect of de-alcoholisation on sensory and chemical profiles

2.1. Background

In simple terms, wine can be described as an alcoholic beverage that results from the fermentation of grape sugars, mostly glucose and fructose, by yeasts (Kemp *et al*., 2015). Wine falls into three major style categories, namely still, dessert and sparkling wines. These categories differ in terms of their production method, amount of residual sugar (RS) and the pressure of carbon dioxide (CO_2) in the final product.

Still wines are produced through alcoholic fermentation of grape must, and contain less than 100 kPa pressure of CO_2, because the CO_2 is naturally set free after fermentation (Easton, 2009). Dessert wines are also produced through alcoholic fermentation but have at least 20 g/L of residual sugar or 50 g/L, if a noble-late harvest product (Wines of South Africa (WOSA), 2020a). Sparkling wines are produced either by alcoholic fermentation only or by both alcoholic and secondary fermentation. When produced by alcoholic fermentation only, CO_2 from an external source is added to the base wine through a process known as carbonation (Jackson, 2008; Newton, 2010). However, when produced by both alcoholic and secondary fermentation, CO_2 as a by-product of fermentation accumulates and is trapped in the wine, resulting in the presence of bubbles (Jeandet *et al*., 2011).

Sparkling wines were globally identified as celebration drinks and only consumed on special celebratory occasions (Burger, 2011; Karlsson and Karlsson, 2020). However, since the year 2002, the production and consumption of these wines have increased in response to increased consumer demand (Organisation Internationale de la Vigne et du Vin (OIV), 2020a). The change in demand is mostly associated with consumers' evolution in their sparkling wine drinking patterns. For example, consumers have moved from drinking sparkling wines during celebratory events only to drinking sparkling wines daily (Karlsson and Karlsson, 2020).

Taking into consideration that consumer preferences have a major role in the wine market, winemakers pay attention to meeting consumer demands. Winemakers are aware of the demand for beverages with lower ethanol content and have recently introduced a range of de-alcoholised wines (≤0.5% v/v). The removal of ethanol in these wines can be achieved through physical strategies (Akyereko *et al*., 2021; Sam *et al*., 2021), this aspect is discussed in detail in the subsequent sections.

Countries such as Australia and the United Kingdom have been at the forefront of de-alcoholised wine research. Studies have been conducted to understand consumers' views and responses toward these products (Saliba *et al*., 2013; Bucher *et al*., 2019). In those studies, the wines' taste and flavour were of concern because of the change in quality because of the de-alcoholisation process. However, none of these studies focused on de-alcoholised sparkling wines' sensory and chemical characteristics. Furthermore, to date, no studies in South Africa focusing on de-alcoholised sparkling wines have been published. Therefore, this literature review will address the concept of de-alcoholisation. Focusing on the following aspects: 1) The production of de-alcoholised sparkling wine, 2) the chemical and sensory profile of de-alcoholised wine, 3) strategies to remove ethanol in the base wine when producing de-alcoholised sparkling wines and 4) potential sensory analysis methods that are ideal to determine the sensory profile of this emerging wine category

2.2. Historical perspectives on sparkling wine

Winemaking has been practised for over 7 500 years (Jackson, 2008), although the production of sparkling wine only started in the 17th century (LaVilla, 2010). It has been suggested that the production of Champagne first occurred by mistake in the Champagne region of France when wine was bottled before the completion of the alcoholic fermentation process during the cold winter months. However, with the onset of spring and higher ambient temperatures, fermentation resumed naturally in the bottles trapping CO_2, resulting in sparkling instead of the intended still wines. The now-known Champagne wine region in northeast France was since recognised for the first sparkling white wine production. Bearing the name of its origin, the alcoholic beverage was officially named Champagne in the 18th century (Burger, 2011).

Dom Pérignon, a French Benedictine monk, is regarded as the Champagne pioneer. He paved the way in 1693 for the improvement of the production methods (LaVilla, 2010). Hence, the Champagne region, France is regarded as a region for quality sparkling wines with its high-quality production procedures. Originally Champagne could only be produced from Pinot Noir, Pinot Meunier and Chardonnay hand-picked grapes; however, processes have since been adapted and mechanised by sparkling wine producers worldwide (LaVilla, 2010). Furthermore, in addition to the three grape cultivars, others including Pinot Blanc, Chenin Blanc, Semillon may be used for sparkling wine production (Jones *et al.,* 2014).

To preserve and protect the label Champagne and the conditions of its production, the wines are covered by the European Union’s Protected Designation of Origin (PDO) and the label is reserved for wines produced in the Champagne region only (European Union, 2013). Arguably, Champagne has become a generic term most widely recognised in modern times for sparkling wine. However, Champagne is not the only sparkling wine-producing region in the world. Germany, Italy, Spain, and South Africa (SA) are globally recognised for their sparkling wines (Kemp *et al*., 2019).

According to Wines of South Africa (2020b), the first production of still wines in SA commenced in 1659. This information was extracted from Jan van Riebeeck’s journal, a Dutch Commander of the Cape at that time (Burger, 2011). In his journal, Jan van Riebeeck reportedly noted, “Today praise be to God, wine was pressed for the first time from Cape grapes”. Since then, winemaking officially began in SA. However, challenges, including selecting suitable soil and microclimate conditions for vine farming, were experienced by farmers in those days, primarily because of the lack of farming knowledge (Burger, 2011).

Improvements in wine production and vine farming began in 1679 when Simon van der Stel became the new Commander of the Cape. Using his viticulture and winemaking knowledge, Van der Stel paved the way for the successful production of still wines in the Cape (Burger, 2011; WOSA, 2020b). Consequently, the South African wine industry started to flourish; however, at that time only still wines were produced in SA.

In 1971, winemaker Frans Malan, from Simonsig Wine Estate outside Stellenbosch, Western Cape, SA, was inspired to produce the first South African sparkling wine. Malan's inspiration came from a visit to France where he was introduced to Champagne. He subsequently set out to produce a South African sparkling wine according to the traditional French method. Although the production and marketing of sparkling wine in the 1970s was a challenge in SA, the product was unknown and there was no specialised equipment for sparkling wine production, Frans Malan persisted. His innovation led to the introduction of a new wine style, sparkling wine, into the South African market (Newton, 2010).

2.3. The production methods for sparkling wines

Sparkling wines are characterised by the presence of CO_2 at a pressure exceeding 300 kPa at 20°C, resulting in a product with effervescence (SAWIS, 2021). Effervescence is the foaming or fizzing of the wine due to CO_2. The CO_2, together with ethanol, is a by-product of fermentation resulting from the conversion of glucose. Wine containing less than 300 kPa of CO_2 pressure at 20°C is not considered a sparkling wine but may either be classified as a still wine (<100 kPa) or as a semi-sparkling wine (100 to 250 kPa) (Easton, 2009).

The production of sparkling wine via secondary fermentation occurs through various methods, namely: *Méthode Traditionnelle* (traditional method), ancestral, transfer and Charmat (Jeandet *et al.,* 2011). The choice of method depends on the region of production and winemakers' preference. Secondary fermentation takes place in bottles in these methods, except for the Charmat method where it occurs in tanks. However, the focus of this review will be on the traditional and carbonation method since they are the common methods of sparkling wine production in SA (Newton, 2010; Zhang, 2022).

The traditional method has been adopted globally to produce bottle fermented sparkling wines, but outside Champagne, these wines are given different names because of the Champagne PDO regulations. Some of the globally known bottle fermented sparkling wines include Cava of Spain, Crémant from regions other than Champagne in France, and *Méthode Cap Classique* (MCC) of SA (Jones *et al.,* 2014; Kemp *et al.,* 2015; Kemp *et al.,* 2019). Apart from the traditional method, South African sparkling wines may be produced using the carbonation method. Wines from this method do not have any PDO-protected names whatsoever; they are simply referred to as just sparkling wines.

2.3.1. Traditional method of sparkling wine production

The production of sparkling wines begins with harvesting wine grapes from the vineyard at the desired grape maturity, usually 17 to 20°Brix (Wolf, 2008). The production of MCC occurs in two fermentation steps. Firstly, during the alcoholic fermentation of still wine – this is known as a base wine - glucose found in the grape must is converted into ethanol and CO_2 (Kemp *et al*., 2015). Secondly, the base wine undergoes secondary fermentation ageing on lees in a bottle (Jeandet *et al.*, 2011). To initiate the secondary fermentation, a tirage, a mixture of sugar (approximately 24 g/L) and yeast (Liger-Belair *et al*., 2012), is added to the base wine. After secondary fermentation, the lees are removed (disgorged) from the bottle, and the wine volume lost is adjusted by adding a dosage containing sugar and wine. The final product has a high pressure of CO_2, which produces an effervescence when poured into a glass, and increased ethanol concentration and tertiary flavours (Jackson, 2008).

2.3.2. Carbonation method of sparkling wine production

Carbonated sparkling wines are produced by injecting CO_2, from an external source, into the base wine to form the sparkling sensation, also known as effervescence (Jackson, 2008; Newton, 2010). The base wine is produced by following steps one to four in **Figure 2.1** (Newton, 2010), and no secondary fermentation occurs. Filtration and stabilisation of the base wine, to clear the wine of any unwanted by-products or lees (Jeandet *et al*., 2011), occurs after alcoholic fermentation, instead of riddling and disgorging that takes place in the traditional method.

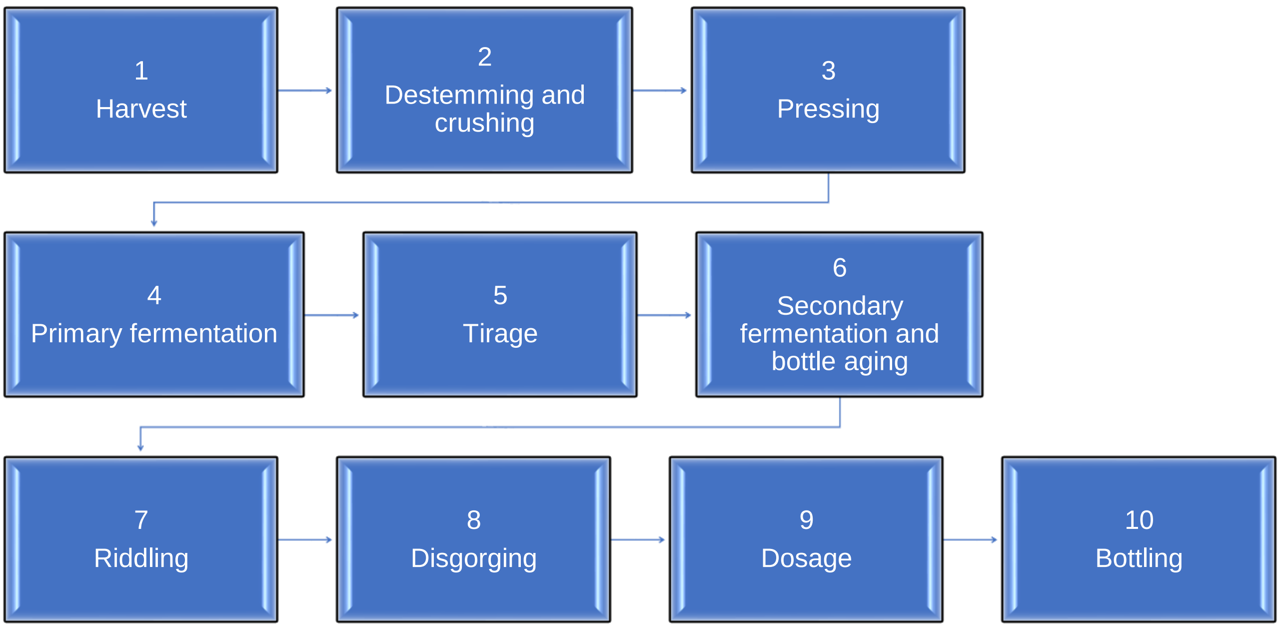

Figure 2.1 Diagrammatic representation of the traditional method for sparkling wine production.

The South African wine market introduced a relatively new category, de-alcoholised sparkling wines. For this category, the ethanol content has been reduced to less than 0.5% v/v (SAWIS, 2020). There is limited information available on the production of de-alcoholised sparkling wines within the public domain. Only a few South African producers have mentioned how they produce de-alcoholised sparkling wines. For example, Lautus sparkling wines are produced in a brut style, with the ageing of Chardonnay base wine on lees for four months before racking and de-alcoholisation (Lautus, 2019). Thereafter, CO_2 is introduced into the wine to give sparkle to the finished product. As such steps one to four (**Figure 2.1**) are followed before de-alcoholisation and carbonation.

After fermentation, there is always unfermented sugar, known as residual sugar (RS), left in the wine contributing to the sweetness of the wine. The amount of RS in the wine may be used to categorise sparkling wines. For example, sparkling wines containing <3 g/L are referred to as brut nature; extra brut for <6 g/L; brut for <12 g/L; extra dry for 12-17 g/L; dry/sec for 17-32 g/L; demi-sec/semi-sweet for 32-50 g/L; sweet/doux for >50 g/L (SAWIS, 2019).

2.4. The sparkling wine markets

The sparkling wine global market has been on the rise since 2002, with global production at 12 million hectolitres from 2002 (OIV, 2020a) to 20 million hectolitres in 2018. Representing 7% of global sparkling wine production as opposed to 5% observed in 2002 (OIV, 2020a). Similarly, in terms of consumption, a global increase from 5% in 2002 to 8% in 2018 was observed (OIV, 2020a; OIV, 2020b), indicating increased consumer demand. The increased demand was suggested to be a consequence of increased consumer willingness to purchase sparkling wines for everyday dinner, celebratory events or just as a relaxation drink (Karlsson and Karlsson, 2020; OIV, 2020a).

The South African wine market has experienced a similar pattern as the global market with sparkling wine consumption increasing from 5.86 million litres in the year 2000 to 11.6 million litres in 2019 (SAWIS, 2014; SAWIS, 2021). However, in 2020 there was a decline to 8.5 million litres, which picked up to 11.4 million litres in 2021 (SAWIS, 2021). The decline could have been due to the local bans on alcohol sales amid the COVID-19 pandemic (Swindells, 2021). Despite the decline, the consumption of sparkling wines in SA is increasing, and so is its market (SAWIS, 2021).

Amidst the COVID-19 pandemic when there was a decline in sparkling wine consumption, retail stores and de-alcoholised wine producers observed an increase in the sales of de-alcoholised wines. The increase in sales has been suggested to be influenced by the sales prohibition of alcoholic wines (Pretorius, 2020), but also the consumer's increased health consciousness, and customers' eagerness to try a new product (Whittaker, 2021).

Producers of de-alcoholised wine have distinct advantages in the wine market. The avoidance of tax associated with the sale and export of alcoholic beverages, and not requiring liquor licences to sell de-alcoholised beverages, are part of the advantages (Whittaker, 2021). Although the market for de-alcoholised sparkling wine in SA is still young and emerging, wine-producing companies have leveraged the market by producing de-alcoholised sparkling wines.

2.5. Strategies used to remove or lower the concentration of ethanol in base wines

Previous studies have indicated that sugar accumulation in wine grapes increased in the past years mainly due to climate change, which speeds up the formation of sugar, consequently limiting the period for aromatic and phenolic content maturity in those grapes (Jones *et al*., 2005; Palliotti *et al*., 2014). As such, winemakers sometimes prolong grape harvest periods to acquire the desired acidity, aromatic maturity, and phenolic content in grapes, which in turn increases grape sugar accumulation (De Orduña, 2010; Alston *et al*., 2015). The increased sugar concentration in grapes then leads to elevated ethanol in wine, to over 13.5% (Goold *et al*., 2017). Above this level, wines are hot on the palate with the ethanol masking the aroma and flavour perception of the wine, and below that level the wines are balanced. Moreover, high sugar concentration may affect the production of quality wines by leading to microbiological instability and stuck fermentations (Coulter *et al.,* 2008), or changing the style of the wine from being fresh and light to being highly alcoholic (Santos *et al*., 2020).

For these reasons, methods used to reduce sugar accumulation in grapes and reduce ethanol in wine have been introduced. Lowering ethanol from over 13.5% v/v to a level that allows a balance between palate and aroma perception produces wines of good quality. Moreover, to keep up with consumers being health-conscious, opting for low-kilojoule drinks or teetotalism (Bucher *et al*., 2019), producers have introduced de-alcoholised wines (≤0.5% v/v) as possible alternatives to alcoholic wines. Several methods have been used to reduce the ethanol content in wines, both physical methods and membrane-based methods. The choice of method to use depends on the targeted wine production stage and the final ethanol content desired.

There are four wine production stages at which ethanol may be reduced. The first is in the vineyard before grapes are harvested; secondly, pre-fermentation whereby the concentration of sugar in the grape must is reduced; thirdly, manipulating or diverting the production of ethanol during fermentation; lastly, removing ethanol in the wine after fermentation (Ozturk and Anli, 2014; Bucher *et al.,* 2019). The potential ethanol reduction level differs for all these stages, and it is only possible to physically reduce ethanol to <0.5% v/v after fermentation.

Reduction of the sugar level in the vineyard utilises viticultural strategies that help minimise the increase in sugar formation. This may occur pre-véraison, the beginning of grape ripening, post-véraison or just before harvest (Novello and De Palma, 2013). In the cellar, the use of glucose oxidase to convert glucose into gluconic acid or blending high sugar musts with low sugar musts may be used as strategies to reduce sugar concentration before fermentation (Schmidtke *et al*., 2012; Bucher *et al.,* 2019). In cases whereby ethanol has already formed, physical strategies must be used to remove the alcohol. With these strategies, special attention is paid to preserving the flavour and aroma compounds, thereby minimising the production of low-quality wine. The strategies are either membrane or thermal based, and they physically remove ethanol from wine under controlled pressure and thermal conditions.

2.5.1. Viticultural strategies used to limit sugar accumulation in grapes and grapes must

The correct use of viticultural strategies to lower the sugar accumulation in grapes during grape maturity in the vineyard is required (Novello and De Palma, 2013). Ozturk and Anli (2014) and Olego *et al*. (2016) noted that different viticultural strategies may be used, including choosing cooler vineyard locations, increasing grape yield and double harvesting.

Temperature plays a large role in sugar accumulation in grapes. Higher temperatures in the vineyard increase the sugar accumulation rate. This does not allow sufficient time for grapes to ripen, and for the development of phenolic compounds, which also contribute to wine quality (Gil *et al*., 2013). It has been suggested that cooler vineyard locations can help to reduce the rate of sugar accumulation in the grapes, giving the grapes enough time to ripen and develop the necessary phenolic compounds. Although phenolic maturity is essential, Gil *et al*. (2013) indicated that complete grape maturity may lead to higher sugar content and lower acidity. For this method, winemakers must find a balance between phenolic maturity and sugar accumulation to achieve the lower ethanol wine of preferred quality.

In the case where the vineyard location undergoes climate change, from being cool to warm, or is naturally warm, methods such as increasing grape yield and double harvesting may be used. Grape yield refers to the number of grape bunches produced per grapevine (Komm and Moyer, 2015), and has an impact on sugar accumulation. Increasing grape yield lowers the sugar accumulating in each grape by evenly distributing the sugar to all grapes on the vine. According to Novello and De Palma (2013), increasing the yield may be achieved by reducing cluster thinning and increasing bud load. However, increasing yield should not reduce wine quality hence the yield increase must be controlled.

Another viticulture method used for reducing sugar levels in the grape must is double harvesting, which entails harvesting grapes at two different maturity levels to produce the same wine (Ozturk and Anli, 2013). In a study by Martínez de Toda and Balda (2013) the first batch of low maturity grapes was harvested at 15.2 and 13.4 °Brix, in the 2009 and 2010 harvest years, respectively. The second batch is harvested at high phenolic maturity with high sugar content (>24 °Brix) (Gil *et al*., 2013; Martínez de Toda and Balda, 2013). Novello and De Palma (2013) indicates that while the first batch is less mature with herbaceous characteristics, the second batch is matured with ripe grape flavours. The different musts are blended to produce a wine of lower ethanol and pH (Schmidtke *et al*., 2012; Gil *et al*., 2013), and a higher titratable acidity (Novello and De Palma, 2013).

2.5.2. Biotechnological strategies to reduce ethanol concentration in wine

Biotechnological strategies are those used in the cellar to lower the resultant ethanol in wine, either by manipulating the pathway that produces ethanol or by reducing sugar in the grape musts. The strategies include the use of low ethanol-producing yeasts (Mangindaan *et al*., 2018; Schmitt and Christmann, 2019), the use of glucose oxidase (GOX) to produce gluconic acid and hydrogen peroxide (H_2O_2) instead of ethanol and CO_2 (Bucher *et al*., 2019; Schmitt and Christmann, 2019), the removal of a predetermined concentration of sugar from the grape must (Varela and Varela, 2019) or blending high sugar grape must with low sugar grape must (Bucher *et al*., 2019).

Low ethanol-producing yeasts are manipulated to produce carbon metabolites other than ethanol such as glycerol (Goold *et al*., 2017). The yeasts are exposed to conditions that favour the production of glycerol instead of ethanol. Researchers found glycerol as a suitable replacement for ethanol because it gives the wine body and richness (Schmitt *et al*., 2019), and helps keep yeast cells hydrated during fermentation (Schmidtke *et al*., 2012). However, diversion of the glycolytic pathway or genetic modification of yeasts may produce acetaldehyde, acetic acid, and acetoin (Goold *et al*., 2017); after diversion these compounds may be in high concentrations and deemed unacceptable to wine quality.

The use of GOX to produce gluconic acid and H_2O_2 is a pre-fermentative strategy aimed at lowering grape must sugar concentrations (Bucher *et al*., 2019). This approach requires a pH range of 3.5 to 6.5 (Ozturk and Anli, 2014), an aerobic environment (Goold *et al*., 2017), and a catalase enzyme to remove the resultant H_2O_2 (Schmidtke *et al*., 2012). If the required conditions are provided at optimal levels, then GOX efficiently converts the glucose. However, it should be noted that the conversion does not work on fructose, which also contributes to the total fermentable sugar content in grape must (Schmidtke *et al*., 2012). GOX was used by Pickering *et al*. (1999a, b) to reduce the ethanol produced from Riesling grape must. The resultant wine had 6.5% v/v alcohol, which was reduced by between 3.7 and 4.1% v/v in comparison with the control wine. The aroma of this wine was not significantly affected but the period of flavour persistence was lowered, and titratable acidity (TA) was higher in the GOX-treated wine. This showed that although the method may reduce the ethanol content, the sensorial and chemical profile may be affected.

Although all these strategies, both viticultural and biotechnological, may be applicable in lowering ethanol in wine, they are impractical in the case of de-alcoholising wines to <0.5% v/v, because they may reduce ethanol up to 2% v/v at most (Pickering *et al*., 1999b; Varela *et al*., 2012; Ozturk and Anli, 2014; Tilloy *et al*., 2014; Bucher *et al*., 2019; Sam *et al*., 2021). However, they are still effective when winemakers want to reduce ethanol in wine to make it more balanced and palatable. Due to the ineffectiveness of the above-mentioned strategies in producing de-alcoholised wines, physical strategies are used.

2.5.3. Physical strategies to remove or reduce the level of ethanol in wine

Physical strategies are used to remove ethanol in the wine after fermentation, and this is known as de-alcoholisation. De-alcoholisation of wines may either occur through membrane-based or thermal processes to potentially ≤0.5% v/v (Sam *et al*., 2021). These processes function at different pressures and temperatures to effectively lower ethanol while, to a certain extent, preserving flavour and aroma (Brányik *et al*., 2012; Schmidtke *et al*., 2012).

Membrane-based strategies have been widely used in industrial productions due to their energy efficiency, high molecule separation and low costs (Mangindaan *et al*., 2018). Membrane-based methods include reverse osmosis (RO) and osmotic distillation (OD) (Saha *et al*., 2013; Muller *et al*., 2020), with RO identified as the most used in SA (BevZero South Africa, 2022). RO uses a semi-permeable membrane that allows the permeation of water and ethanol from a highly concentrated solution, in this case, a base wine, to a low concentrated solution (Brányik *et al*., 2012; Schmitt and Christmann, 2019). The permeation of ethanol and water from the wine occurs under pressure that is greater than the osmotic pressure, 2 to 8 MPa (Brányik *et al*., 2012), and temperatures around 20 to 22°C (Schmidtke *et al*., 2012).

The semi-permeable membranes used may be made from ceramic, synthetic polymers, or cellulosic material (Schmidtke *et al*., 2012), but the most common are asymmetric polymers, which have been shown to have good flux, durability and are cleanable. This makes it possible to reduce ethanol to <0.5% v/v under pressure, and in multiple cycles without having to use new membranes. Moreover, RO has been indicated to lower ethanol to <0.5% v/v without significantly altering the aroma and flavour of the wine (Bui *et al*., 1986). However, this method still has its limitations, such as high energy consumption and high capital use (**Table 2.1)**.

OD sometimes referred to as pervaporation or isothermal distillation, is another membrane-based strategy that uses microporous and non-wettable membranes under atmospheric pressure to separate volatile compounds from a solution (Schmitt and Christmann, 2019). The strategy is sometimes used in conjunction with RO, to retain the volatile compounds removed with the ethanol when de-alcoholising the wine, which is later returned to the de-alcoholised wine.

Membrane-based strategies use membranes to separate the ethanol from wine, but thermal strategies use high temperatures to evaporate ethanol from the wine. A process that has the potential of degrading volatile compounds (Muller *et al*., 2020). Examples include spinning cone column (SCC), vacuum evaporation and vacuum distillation (Schmitt and Christmann, 2019; Muller *et al*., 2020). All these methods remove aroma or flavour compounds in wine under vacuum using vapour and reduce ethanol to <0.05% v/v (Muller *et al*., 2020). Out of all these methods, SCC is commonly used in the wine industry to reduce ethanol or de-alcoholise wine (BevZero South Africa, 2022).

Worldwide, SCC is used based on its efficiency in removing ethanol and preserving flavour, to a certain degree (Belisario-Sánchez *et al*., 2011). This method works in two steps to both preserve flavour compounds and removes ethanol from the wine, as mentioned by various authors (Brányik *et al*., 2012; Ozturk and Anli, 2014; El Rayess and Mietton-Peuchot, 2016; Muller *et al*., 2020). The steps include, firstly the removal of aroma compounds at a low temperature of approximately 28°C and vacuum pressure of 4 kPa (Ozturk and Anli, 2014). Secondly, the dearomatised wine is de-alcoholised at approximately 38°C through multiple cycles to obtain <0.5% v/v (Saha *et al*., 2013; Ozturk and Anli, 2014). SCC contains spinning cones and stationary cones, each inverted spinning cone on top of the stationary cone (**Figure 2.2)**. The wine is fed to the column on top of the spinning cone, which thins the wine as it rotates, and the thinning wine flows onto the stationary cone. This process repeats until the wine reaches the bottom stationary cone and is let out of the column. When the wines become thinner with each spin, the gas introduced through the gas inlet simultaneously vaporises volatile compounds and pushes them out of the gas outlet chamber, whereby the compounds are collected.

SCC has been used to de-alcoholise wine and can reduce ethanol up to <0.5% v/v. However, 100% flavour is not preserved, and a loss in flavour has been observed (Gómez-Plaza *et al*., 1999; Belisario-Sánchez *et al*., 2011; García *et al*., 2021). Nonetheless, SCC retains most of the volatile compounds and de-alcoholise high volumes of wine at a fast rate. Hence it is mostly used to de-alcoholise wines in industrial-scale wine-producing companies.

To summarise all the above strategies and their advantages and disadvantages to consider when reducing ethanol or de-alcoholising wines, see **Table 2.1**. In general, all the strategies have advantages and disadvantages, and wine producers select the best strategy to use based on their desired ethanol reduction concentration, wine volume and at times, the cost. The South African wine industry commonly uses SCC and RO to de-alcoholise wines (Logichem, 2017; BevZero South Africa, 2022). However, the effect of removing ethanol from wine on the chemical and sensory profile remains a topic of concern and interest.

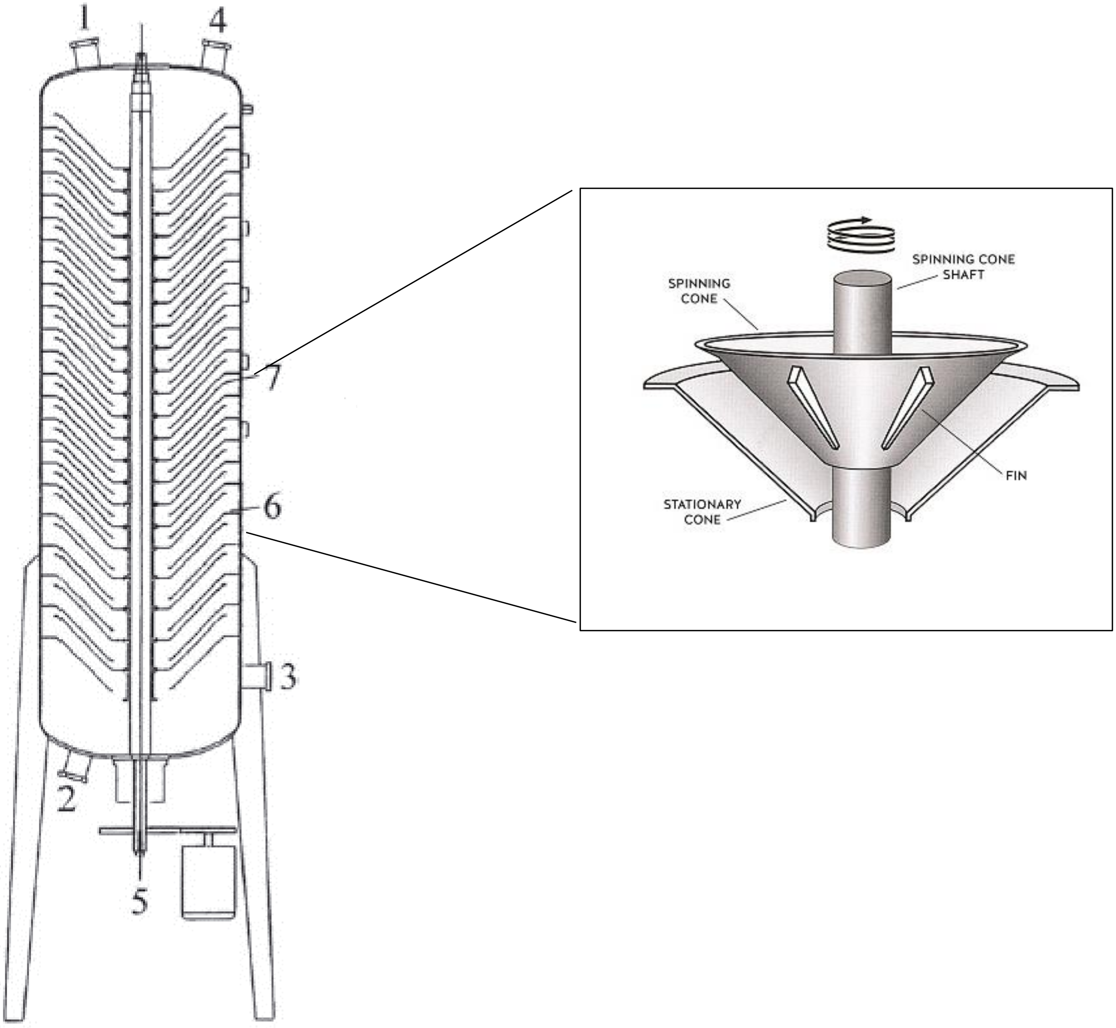

Figure 2.2 The compartments of the spinning cone column (SCC) used to de-alcoholise wines. ***1****-Base wine inlet;* ***2****-De-alcoholised base wine outlet;* ***3****-Gas/vapour inlet;* ***4****-Gas outlet;* ***5****-Spinning cone shaft;* ***6****-Stationary cone;* ***7****-Spinning cone* (adapted from Schimdtke *et al*., 2012; Flavourtech, 2021).

Table 2.1 The ethanol reduction potential, advantages, and disadvantages of the different ethanol reduction strategies.

Approaches	Strategies	Percentage of ethanol reduction	Advantages	Disadvantages	References
Viticultural approaches	Lowering sugar content by increasing grape yield	Not indicated	It allows phenolic and full grape maturation without the fast accumulation of sugar	May produce wines of unacceptable quality if sugar reduction is not balanced with phenolic maturation	Novelo and De Palma, 2013; Ozturk and Anli, 2014
	Colder vineyard location				Ozturk and Anli, 2014
	Double harvest	By 3% v/v	Wine produced has reduced pH and higher acidity, with no detected difference in organoleptic characters	The wine may have undesirable unripe 'green' characters	Novelo and De Palma, 2013; Ozturk and Anli, 2014;
Biotechnological approaches	Low ethanol-producing yeasts	By *circa* 3% v/v	Low production costs Ethanol production is diverted to that of glycerol	An increase in acetaldehyde and acetoin, which negatively affects wine quality	Varela *et al.,* 2012
	Glucose oxidase (GOX)	By *circa* 4.3% v/v	The process is fast, 87% of glucose was converted to gluconic acid in six hours; Organoleptic characters were not significantly affected	Requires high energy input; Leads to excessive acidity; Wine requires clarification- limited to use in white wine production	Pickering, 1997; Pickering *et al*., 1999b; Schmidtke *et al*., 2012; Ozturk and Anli, 2014; Bucher *et al*., 2019; Sam *et al*., 2021
	Physical removal of sugar	Up to 5% v/v	Helps prevent stuck fermentations; Reduces sugar before fermentation	Lowers the intensity of the wine colour; Reduces the concentration of volatile compounds such as higher alcohols, ethyl esters, acids	García-Martín *et al*., 2010; Sam *et al*., 2021
Physical approaches	Reverse Osmosis (RO)	Up to <0.5% v/v	Retains aroma and flavour better than the other mentioned strategies; Low	Constant addition of low sugar grape must is required to keep wine volume constant; Traps or retains some of the aromatic compounds in the membrane;	Mangindaan *et al.,* 2018; Schmidtke *et al*.,2012

		operational costs; Requires less labour	High capital cost; Consumes high energy	
Osmotic distillation (OD)	Up to <0.5% v/v	Low cost of operation; degradation of aroma compounds by heat is limited; Operates at low temperatures (10-20°C); reduced energy use	CO_2 is lost; Some volatile compounds are lost if the wine is de-alcoholised by high concentrations (5 to 10% v/v)	Becca, 2013; Liguori *et al*., 2013; El Rayess and Mietton-Peuchot, 2016; Mangindaan *et al.,* 2018
Spinning cone column (SCC)	Up to <0.05% v/v	Ability to preserve some flavours of the original wine; Operates at low temperatures; De-alcoholise at a fast rate	High energy costs as the process need a high amount of energy; Multiple cycles are required to reduce ethanol to the desired concentration; Reduces sensory quality	Brányik *et al*., 2012; El Rayess and Mietton-Peuchot, 2016; Mangindaan *et al.,* 2018; Muller *et al.,* 2020;

2.6. Wine quality and the methods used to assess it

As mentioned, the topic of de-alcoholised wine quality is of concern, as such, it is important to investigate. Wine quality has been intensively discussed in the literature, with no common definition used by authors due to the complexity and varying interpretation of the concept (Charters and Pettigrew, 2003, 2007; Hopfer and Heymann, 2014; Brand *et al*., 2020). Although no common definition for wine quality exists, several researchers have agreed on the factors that influence perceived wine quality, such as intrinsic and extrinsic factors (Charters and Pettigrew 2007; Hopfer and Heymann, 2014).

Intrinsic factors are those perceived when the wine is tasted, sometimes referred to as the experience factors because it requires drinking the wine to perceive them. The intrinsic factors include the basic sensory attributes (appearance, aroma, flavour, taste, and mouthfeel), but also complex aspects such as wine complexity, balance, length, finish (Charters and Pettigrew, 2003), typicity, varietal and origin characters, which are usually picked up by the more experienced wine consumers (Hopfer and Heymann, 2014).

Extrinsic factors include aspects such as wine origin (appellation), brand and price. Charters and Pettigrew (2003, 2007) discovered that these extrinsic factors sometimes influence consumers' wine purchasing choices, especially when the wine has not been tasted before. Both intrinsic and extrinsic factors play a major role in product development, quality control, benchmarking and meeting the requirements of the target market. Hence, each wine producer strives to produce quality wine, making the intrinsic factors the main focal point of the product.

Wine experts have judged the wines in settings such as competitions, academic research, wine production and development, to evaluate wine quality. Even so, when assessing wine quality, particularly the sensory profile thereof, consumers may be used (Charters and Pettigrew, 2003; Masson *et al*., 2007; Varela and Ares, 2012; De Mets *et al*., 2017). Generally, the sensory quality of wine is evaluated by wine experts using a specific method, predetermined by the researcher whilst keeping the aim of the research in mind. However, in some instances, consumers have been used to evaluate wine quality.

Sensory analysis methodologies may be qualitatively or quantitatively used to determine wine quality. As with any method, the choice of either qualitative or quantitative evaluation depends on the aim of the study. Common methods used in sensory science for profiling purposes are descriptive analysis (DA), free choice profiling (FCP), flash profiling (FP), sorting, projective mapping (PM), check-all-that-apply (CATA), rate-all-that-apply (RATA), and free listing (free comments) (Esti *et al*., 2010; Hough and Ferraris, 2010; Torrens *et al*., 2010; Valentin *et al*., 2012, Varela and Ares, 2012; Lawrence *et al*., 2013; Dos Santos *et al*., 2015; White and Heymann, 2015; Liu *et al*., 2018a; Mapheleba, 2018; Brand, 2019; Brand *et al*., 2020). These methods can be used individually or in combination with quality scoring, which gives a quantitative measure (score) of the wine quality instead of words.

2.6.1. Descriptive analysis (DA) as a sensory method

Descriptive analysis (DA) is the traditional, comprehensive profiling method that requires the training of a panel consisting of eight to twelve judges to obtain qualitative (sensory attributes) and quantitative data (Lawless and Heymann, 2010). As outlined by Valentin *et al*. (2012), DA is conducted in three steps; product familiarisation and identification of sensory descriptors, training of the panel of assessors and reaching consensus on standard sensory descriptors to use in sensory analysis, and the actual sensory analysis. This method has been used to analyse sparkling wines (Gallart *et al*., 2004; White and Heymann, 2015) and various food products (Yang and Lee, 2019), as well as a reference to analyse the reliability of rapid sensory methods such as sorting, PM, and FP (Dehlholm *et al*., 2012; Liu *et al*., 2018a; Brand, 2019).

The DA method is reliable in analysing the sensory characteristics of food and beverages and determining sensory quality. The reliability and accuracy of the results can be attributed to the fact that the panel of assessors is intensively trained. This training enables panellists to provide detailed and clear word descriptions (qualitative), and intensity ratings (quantitative) that may be essential for product development (Lawless and Heymann, 2010) and benchmarking. However, long training sessions can be required to familiarise judges with the product in question, and to determine standard sensory descriptors, making this process time-consuming and expensive.

The data obtained, using the DA method, are usually analysed using Principal Component Analysis (PCA) and Analysis of Variance (ANOVA). PCA is a multivariate tool that allows the analysis of multiple variables, depicting the relationship between samples and attributes on a scores-and-loadings PCA bi-plot. ANOVA is used to determine the significant differences between treatments per sensory attribute (Lawless and Heymann, 2010). In ANOVA, the variables are independent of each other.

2.6.2. Rapid sensory methods

Rapid sensory methods which give quick and reliable results were introduced, and used as alternatives to DA, to reduce training periods and high costs associated with the method. Examples of the rapid sensory methods include CATA (Valentin *et al*., 2012; Dos Santos *et al*., 2015; Alencar *et al*., 2019; Brand *et al*., 2020), RATA (Ares *et al*., 2014a), FCP (Lawless and Heymann, 2010; Varela and Ares, 2012; Yang and Lee, 2019), FP (Delarue and Sieffermann, 2000; Blancher *et al*., 2007; Liu *et al*., 2018a), sorting (Valentin *et al*., 2012; Fleming *et al*., 2015; Brand *et al*., 2018), PM (Pagès, 2005; Perrin *et al*., 2008; Dehlholm *et al*., 2012) and free listing (Hough and Ferraris, 2010; Lawrence *et al*., 2013). These rapid methodologies have been extensively used in research to evaluate the sensory profiles and quality of products.

Free choice profiling (FCP)

Free choice profiling (FCP) is one of the first rapid sensory methods developed (Williams and Langron, 1984). For FCP, the panel requires no training. Judges, which may be consumers or wine experts, are asked to give spontaneous word descriptors (attributes) of either the appearance, aroma, or palate of the wines and thereafter rate the intensity of each attribute given (Lawless and Heymann, 2010; Varela and Ares, 2012; Yang and Lee, 2019). The data obtained are analysed using Generalised Procrustes Analysis (GPA), a statistical tool suggested by Williams and Langron (1984) due to its ability to analyse a varying number of attributes.

The use of FCP by Williams and Langron (1984) showed that DA is not the only method that can identify the different and similar attributes in wine. Additionally, saving time and costs as no panel training is required. However, analysis of FCP data can be challenging as each judge uses his/her vocabulary, making the data diverse in terms of the language used. Therefore, the researcher needs to standardise the data using common definitions per attribute. Some authors have discovered that judges are sometimes inconsistent in their use of terms, making data analysis even more challenging (Heymann, 1994; Narain *et al*., 2003). Moreover, coming up with an individual vocabulary to describe wines, and rating intensities may be difficult for consumers.

Flash profiling (FP)

In 2002, Dairou and Siefferman (2002) suggested the use of Flash Profiling (FP), a method developed from FCP. This method, like FCP, allows the spontaneous use of attributes by the panel but instead of rating, the intensity of each attribute is ranked. Meaning that the wines are ranked on a scale from ‘low’ to ‘high’ on the intensity of each attribute. As reviewed by Varela and Ares (2012), FP is an easy method and can be used with consumers, trained panels, or semi-trained panels to analyse wines. In contrast, a study by Liu *et al*. (2018a) outlined that the assessors found FP more difficult in comparison with FCP. Kim and O’Mahony (1998) explained that FP is strenuous because judges sometimes may have to re-evaluate wines to recall the intensity of attributes before ranking. Like FCP, the statistical analysis of FP data may be complicated since each judge uses his/her own vocabulary. However, identifying the attributes that best describe the product in question is much easier in FP (Delarue and Sieffermann, 2000; Blancher *et al*., 2007; Moussaoui and Varela, 2010).

In a recent study, the comparison of sensory analysis of wines by DA, FP and FCP reported that FP efficiently differentiated between wines (Liu *et al*., 2018a). Although FP has been successful in describing the wines in question, it does not replace DA. Lawless and Heymann (2010) suggested that the FP method may be used for screening in new product development studies, whereas DA is most useful when the aim is to score the full range of attributes associated with a specific product in terms of intensity.

Sorting

Sorting is a rapid sensory method that requires judges to group wines based on similarities and differences and thereafter gives word descriptions to illustrate product differences and similarities.

Practically, the judges evaluate the wines and group wines that have similar sensory attributes in one group, and those with different attributes in separate groups (Valentin *et al*., 2012; Varela and Ares, 2012). Thereafter, the attributes which make the wines similar or different are noted - this is known as the verbalisation task. As an example, this method is visually represented in **Figure 2.3**.

The sorting method has variations, as reviewed by Valentin *et al*. (2012), and in these, researchers give instructions on how the judges should sort the wines. For example, in directed sorting, judges may be requested to sort the wines based on colour (or any other attribute) or limit the number of attributes used to describe a group of wines. This method has been used in a study by Brand *et al*. (2018) whereby no more than five attributes could be used to describe a group of wines. Additionally, the use of phrases, intensities and negative descriptions was prohibited. The second variation is the hierarchal sorting task in which, after the first sorting tasking outlined in **Figure 2.3**, judges are requested to further organise the groups that are most similar together. The process continues until all groups that were initially identified form one group, making a hierarchal arrangement (Valentin *et al*., 2012; Varela and Ares, 2012).

Step 1: Wine evaluation

Step 2: Wine grouping

Group	Wines
1	987; 243
2	744
3	990; 123; 764

Step 3: Verbalisation

Group1: Sweet, Fruity
Group2: Off-dry, Oak flavours, Wooded
Group3: Citrus, Peach, Orange, Fresh

Figure 2.3 An example outline of the sorting method.

Sorting data can be analysed using multidimensional scaling (MDS), a tool that presents the data on a plot showing similar and different groupings of samples (Lawless *et al*., 1995). In order to achieve this plot, a similarity matrix is generated by calculating the number of times a pair of wines are grouped by different judges (Valentin *et al*., 2012; Varela and Ares, 2012; Fleming *et al*., 2015). When it is important to consider the data of each judge, DISTATIS is used. This statistical tool was developed to analyse data in detail, with the ability to analyse the judging patterns of the panel. Furthermore, DISTATIS may be used as the sole tool to analyse sorting data (Abdi *et al*., 2007).

Projective mapping (PM)

Projective mapping (PM) is similar to sorting because each judge uses his/her criteria to identify the differences and similarities between wines. The variation between the methods is that in PM the wines are arranged on a piece of paper instead of being grouped. Wines are arranged far apart if they are different, and much closer to each other, if they are similar (Perrin *et al*., 2008; Dehlholm *et al*., 2012; Varela and Ares, 2012). PM is often referred to as Napping because an A2 or A3 piece of paper (or tablecloth, *nappe* in French) is used. The data are configured in two dimensions (X and Y) as represented on the two-dimensional paper surface. Following the arrangement of the wines on paper, descriptions are noted down next to the wines to indicate what the similarities or differences are. This additional task is referred to as Ultra Flash Profiling (UFP) (Perrin *et al*., 2008).

Overall PM is an easy method that requires no panel training. Multiple studies have used this method to analyse the sensory characteristics of food and beverages (Valentin *et al.,* 2012; Varela and Ares, 2012). PM has, however, been indicated to be a complementary method that must be coupled with a descriptive task to obtain detailed product attributes (Pagès, 2005). As suggested by Moussaoui and Varela (2010), verbalisation may serve as a good coupling method to describe product attributes. However, the data obtained from this method is much richer than that of sorting because sensory distances between the attributes are obtained instead of just a similarity matrix (Lawless and Heymann, 2010).

Initially, principal component analysis (PCA) was used to analyse PM data, but Pagès (2005) introduced the use of Multiple Factor Analysis (MFA). This statistical method collects the Euclidian configuration of each assessor with simultaneous processing of all maps. MFA produces a configuration in which two products are near each other if perceived to be similar by the whole panel, with each panel member using his own weighted set of criteria. When product descriptors are added using UFP, the qualitative data are added as a separate data table. Therefore, the supplementary variables, descriptors, do not interfere with the construction of the product map (Lawless and Heymann, 2010).

Check-all-that-apply (CATA) and rate-all-that-apply (RATA)

One of the regularly used rapid sensory methods is check-all-that-apply (CATA). This method, as the name suggests, entails marking all attributes that apply to the evaluated product. A pre-determined list of attributes is given to judges before the sensory evaluation begins. In this method, multiple attributes may be selected per product. The attributes in the pre-determined list may be obtained from available literature on the product (Alencar *et al*., 2019; Brand *et al.,* 2020), through DA used in the same study (Dos Santos *et al.*, 2015), informal focus groups (Valentin *et al*., 2012) and published wine technical sheets.

For wine studies, most CATA studies make use of consumers to analyse the wines because the method is easy and assessors require no training (Dos Santos *et al.*, 2015; Jaeger *et al*., 2015), but wine experts have been used as well (Brand *et al*., 2020).

Just like with any method there are limitations to the CATA method. If the list of attributes is very long, consumers tend to only select attributes listed at the top of the attribute list, or when the attribute list does not include the actual perceived attribute, an attribute closely associated with the perceived one is selected. Additionally, when long lists are used, judges may be fatigued when scanning through the long list and may select any attribute without giving it much thought (Krosnick, 1999). Moreover, the intensities of the attributes that are 'checked' are not ranked or rated (Dooley *et al*., 2010), thus limiting the detailed analysis of wines. These limitations have been studied and solutions were proposed. For example, the positioning of attributes in a list may be randomised to eliminate biased selections. The randomisation of attributes in a list may be for each wine or for each judge. Randomised for each wine means that for each wine, a judge will receive a list of attributes randomised differently from the previous wine. Whereas randomisation for each judge means that each judge receives a list randomised differently from another judge, and therefore, the order of attributes does not change between wines (Meyners and Castura, 2016). Ares *et al.* (2014b) recommended randomisation by wine as superior to that of judge, however, Meyners and Castura (2016) concluded that both randomisation methods offer valid results. Therefore, a researcher may select any of the two alternatives, and the results should not be negatively affected. Secondly, an attribute that is not on the predetermined list may be added. The use of short lists (about 14 attributes) is recommended for effective judge performance in comparison to long lists (150 attributes) (Hughson and Boakes, 2002).

The method has been modified to overcome the lack of intensity rating in CATA. Rate-all-that-apply (RATA) follows the same principles as CATA but additionally, the judges must rate the selected attributes (Ares *et al*., 2014a). To start the process of data analysis the citation frequency of each attribute is determined by counting the number of times each attribute has been selected by the panel of judges for a specific wine (Ares *et al*., 2014a). Moreover, for RATA the intensity rates are summed up before analysis by Correspondence Analysis (CA).

Free listing (free comments)

Free listing, in some studies referred to as Free comments, is a method that allows a panel of judges to describe the modalities of wine without the intervention of the researcher into what attributes should be perceived. In other words, the panel describes their perception of a given wine without pre-set expectations. The method has been initially used in anthropological studies (Henley, 1969; Trotter, 1981; Rusell-Bernard, 2005) and gained attention in food and beverage research through a study by Hough and Ferraris (2010). In the latter study, school students were asked to list all fruits that came to mind. The citation frequency of each fruit, also the order in which the fruits follow each other on the list, was of importance in the data analysis. It was concluded that fruits were listed next to each other because they followed each other in the thinking process of the participant. The same principle has been applied in sensory science, when attributes are listed after each other it was suggested that the attributes may have been perceived in that order, and the attribute listed first may have been perceived first in the nose or mouth (Libertino *et al*., 2012). Similarly, the citation frequency determines the relevance of the attribute to the study (Dos Santos *et al*., 2015).

In the light of sensory science, this method has been used to describe the modalities (appearance, aroma, flavour, and texture) of dry sausages (Dos Santos *et al*., 2015), orthonasal perceptions of Cabernet Franc wines (Lawrence *et al*., 2013), the palate descriptions of South African Chenin Blanc (Mapheleba, 2018) and more recently, the modalities (visual, orthonasal, gustatory sense) of wines in a home setting (Mahieu *et al*., 2020). The panel in all the mentioned studies consisted of either consumers or product professionals, and the results obtained suggest that both panel groups may be used. Additionally, in the study by Mahieu *et al*. (2020), free listing gave a richer and sample-specific data set highlighting dominant attributes.

It should be noted that the analysis of free listing data is tedious. As each judge uses their vocabulary sometimes making spelling or grammar errors, the data needs cleaning up before it may be analysed (Lawrence *et al*., 2013; Mahieu *et al*., 2020). This involves removing errors and grouping terms that describe the same attributes to reduce word overcrowding in analysis. The process may be biased on the terms grouped because the researchers make the decisions. The data may be statistically analysed by CA to plot the relationship between the wines and the attributes listed. Although the statistical analysis of free listing data may be tedious, the data obtained from this method is diverse and allows a broad-based sensory analysis of wines, without the limitation of using a predetermined list of attributes. In simple terms, this method allows spontaneity and honest opinions of wines, and broad analysis of new product categories (Lawrence *et al*., 2013).

Quality scoring

The use of quality scoring has been a way of evaluating wine quality in wine competitions (Brand *et al*., 2020; Parr *et al*., 2006). In competitions, scores may be allocated in the form of numerical values, stars or awards (e.g., silver, gold). For years, this method was used as a marketing strategy and as a way of quality control by wine-producing companies. The overall ratings given may be out of 10, 21 or 100, as suggested by Cicchetti and Cicchetti (2009), and 20 points (Brand *et al*, 2020; Parr *et al*., 2006). These rating scales are used by different wine critics and judges, each with their perspective of which is most suitable. However, in most wine tasting sessions or wine competitions, the 20-point and 100-point rating scales are used, even though the comparability of the two methods was initially questioned.

Parr *et al*. (2006) studied the comparability of the two scoring systems. The 20-point scale was deemed similar in scoring capability to the 100-point when wine professionals were used as judges. The 20-point scale functions by scoring appearance out of 3, aroma out of 7, and palate out of 10, thereafter, the total is added up out of 20 points (Parr *et al*., 2006). It is also worth noting that the 20-point scale is frequently used in the South African wine industry to judge wine quality (Veritas, 2022), and therefore, wine experts used in this study are familiar with the method. Additionally, the method is easy to use and even without training a panel of judges can use it to score the sensory quality of the wine. Researchers can determine the modality that drives the quality, by looking at the scores given for the different modalities.

2.7. Chemistry and sensory profile of sparkling wines

The sensory profile (appearance, aroma, and palate) of sparkling wine is determined by its chemistry, in other words, chemical compounds originating from the grape variety, fermentation and post-fermentation treatments (Lawrence, 2012; Zhu *et al.,* 2016; Ubeda *et al.,* 2019). These compounds are either volatile or non-volatile (Callejón *et al.,* 2012) with different sensory detection thresholds, and all contribute to wine aroma and flavour perception in one way or another (Sáenz-Navajas *et al*., 2012; Zhu *et al.,* 2016). Wine aroma, because of volatile aroma compounds, can be ortho-nasally perceived by sniffing the wine (Diaz, 2004). Conversely, wine flavour is retro-nasally perceived and is a result of the interaction of both volatile and non-volatile compounds (Zhu *et al.,* 2016). In wine tasting, both the wine aroma and flavour are perceived, together with mouthfeel attributes such as astringency, wine body and warmth (Gawel *et al*., 2000). Moreover, the presence of bubbles in sparkling wines, formed from high pressure CO_2, is an essential part of the visual aesthetics, aroma and mouthfeel perception appreciated in the products.

Volatile compounds include higher alcohols, esters, acids (Zhu *et al.,* 2016; Petrozziello *et al*., 2019), terpenes, aldehydes (Lawrence, 2012; Ubeda *et al.,* 2019), phenols (Lisanti *et al.*, 2013) and ethanol, and a change in their concentration may affect the overall wine aroma (Longo *et al*., 2017, 2018a, b; Liguori *et al.*, 2019). In a study by Torrens *et al.* (2010) a change in aroma perception was observed when Cava base wines were aged for 14 months. Before ageing, the base wines were dominantly fruity (tropical, ripe fruit, tree fruit, citrus fruit) whereas after ageing, the Cava sparkling wines had fruity, toasty, floral, yeasty, and lactic attributes. Accompanying this sensory change, reduction of acetate esters and an increase in 2-phenylethanol, linalool, vitispiranes, ethyl lactate and diethyl succinate was observed. The latter two compounds are considered as age markers in wine, and their increased concentrations from base to sparkling wines is expected. Ubeda *et al*. (2019) also observed an 85% loss of acetate esters and 50% loss of ethyl esters in secondary fermentation. The difference observed between the base wines and final sparkling wines showcases the change in sparkling wine sensory and chemical profiles as a result of secondary fermentation and ageing as mentioned by Pozo-Bayón *et al.* (2009). Furthermore, this emphasises that base wines and carbonated sparkling wines are dominantly fruity, in comparison to secondary fermented and aged sparkling wines.

In addition to the above discussion, the perception of wine aroma and flavour may be affected by the concentration of ethanol in that wine. Ethanol has been reported to reduce the perception of fruitiness in wines, especially at concentrations above 14.5% v/v (Goldner *et al*., 2009). Moreover, may give a burning hot mouthfeel if present in these high concentrations (Gawel *et al*., 2007), which is unappreciated by most consumers. However, ethanol also positively contributes towards wine body (Gawel *et al.,* 2007), aroma volatility and modifying mouthfeel and taste attributes at concentrations less than 10% v/v (Cretin *et al*., 2018). Despite the positive role of ethanol in wine flavour and body, there has been a recent production of de-alcoholised sparkling wines, fuelled by consumer interests. The following section discusses the effect of de-alcoholisation on wine profiles.

2.7.1. Effect of de-alcoholisation on the chemical and sensory profiles

The sensory and chemical profiles of de-alcoholised sparkling wines have not been studied thus far, and no peer reviewed publications were found. Therefore, the results of de-alcoholised still wines were discussed in this section. In the case of de-alcoholisation, either partially or to <0.5% v/v, some volatile compounds' concentrations are reduced (Liguori *et al*., 2013; 2019). Several literature reviews (Schmidtke *et al.,* 2012; Longo *et al.,* 2017) and studies (Lisanti *et al.*, 2013; Longo *et al.,* 2018a; Liguori *et al.*, 2019; Petrozziello *et al*., 2019) have outlined the effect of de-alcoholisation on volatile composition. Additionally, the effect of de-alcoholisation on volatile compound loss, and consequently, the overall sensory quality of the wine.

For instance, a study by Liguori *et al.* (2019) showed a high loss of esters (73%) and higher alcohols (>50%) in Falanghina white wines after de-alcoholisation using OD. The wines were de-alcoholised in eight consecutive cycles from an initial concentration of 12.5 to 0.3% v/v. A major loss of esters (71.5%) occurred in the 1st cycle (12.5 to 9.8% v/v) due to the hydrophobic nature of esters, while higher alcohols were progressively reduced from the 2nd cycle (6.9% v/v) to the last cycle (0.3% v/v). However, some higher alcohols were stable throughout the de-alcoholisation process, including cis-3-hexen-1-ol, 3-ethoxy-1-propanol and trans-3-hexen-1-ol, suggesting that not all compounds may be reduced in this process, at the same rate even.

Similarly, the loss of volatile compounds during de-alcoholisation was reviewed by Longo *et al*. (2017) and Sam *et al*. (2021), and it was reported that the removal or reduction of ethanol from wine affects the volatile compound composition (see **Table 2.2.**). Irrespective of the method used to de-alcoholise wines, volatile compounds are reduced (García *et al*., 2021; Gómez-Plaza *et al*., 1999; Liguori *et al*., 2019). However, the volatile compound fraction reduced is highly dependable on the method of de-alcoholisation used, the level of ethanol removed, the physicochemical properties of the aroma compounds, and non-volatile compounds in the wine (Longo *et al.,* 2017; Corona *et al*., 2019;). This altogether influences the overall aroma and flavour perception of the final de-alcoholised wine.

The perceived flavour of sparkling wine is a product of both volatile and non-volatile compounds (Sáenz-Navajas *et al*., 2012). Volatile compounds play a major role in the wine aroma. In any case, their sensory perception of wine is impacted by non-volatile compounds, and the perception of non-volatile compounds is impacted by volatile compounds. Although non-volatile compounds are commonly known to affect the taste, flavour and mouthfeel properties of wine, they work beside volatiles to impact the wine quality (Sáenz-Navajas *et al.,* 2012). Non-volatile compounds include sugars, glycerol, salts, phenolic compounds, or non-volatile organic compounds, and can result in taste and mouthfeel characteristics such as sweetness, astringency, saltiness, sourness, and bitterness (Sáenz-Navajas *et al.,* 2012).

As already mentioned, de-alcoholisation changes the volatile composition of wines. As such, a change in overall sensory perception of de-alcoholised sparkling wines can also be expected. Moreover, it is not only the volatile composition of wine that could be affected by the process of de-alcoholisation but also the non-volatile fraction. Meillon *et al*. (2010) reported a decrease in sweetness and wine body with the lowering of ethanol, and an increase in astringency was observed by Lisanti *et al.* (2013). Therefore, changes in the volatile and non-volatile fractions of base wines may occur, in turn affecting the overall sensory quality of sparkling wines. This sensory quality change may lead to reduced consumer acceptance (Bucher *et al*., 2018). It is, therefore, important for producers to balance the overall flavour of the base wine to have sparkling wine with a sensory quality that is acceptable to the consumer.

Jackson (2008) mentioned that ethanol helps enhance sweetness and wine body, at the same time balancing the sensory perception of wine characters and stabilising the hydrophobic nature of esters. Therefore, the removal of ethanol may affect the balance. In another review (Jordão *et al*., 2015) ethanol was indicated to have a multidimensional role in wine, including influencing the perception of volatile compounds. Therefore, sensory change perceived after de-alcoholisation is not much of a surprise but gives producers an extra task of ensuring efficient flavour retention.

Table 2.2 Effect of de-alcoholisation on the volatile compounds of still wines.

Volatile compound	Type of wine	Concentration (mg/L)	Change in volatile compound (%)	Ethanol reduction (% v/v)	% of ethanol removed	References
Ethyl lactate	White	4.02 to 2.30	-57.21	10.6 to 0.3	-97.17	Gómez-Plaza *et al*., 1999
	Falaghina white	2.12 to <0.08	-96.23	12.5 to 0.3	-97.60	Liguori *et al*., 2019
	Aglianico red	0.11 to <0.01	> (-90.91)	13.0 to 0.19	-98.54	Liguori *et al*., 2013
Diethyl succinate	White	7.13 to 6.03	-15.43	10.6 to 0.3	-97.17	Gómez-Plaza *et al*., 1999
	Falaghina white	1.29 to <0.03	> (-97.67)	12.5 to 0.3	-97.60	Liguori *et al*., 2019
	Aglianico red	12.17 to 1.45	-88.09	13.0 to 0.19	-98.54	Liguori *et al*., 2013
Ethyl acetate	Aglianico red	0.02 to n.d.	Unknown	13.0 to 0.19	-98.54	Liguori *et al*., 2013
Ethyl butyrate	Falaghina white	0.15 to 0.00	-100	12.5 to 0.3	-97.60	Liguori *et al*., 2019
2-Phenylethanol	White	58.20 to 57.60	-1.03	10.6 to 0.3	-97.17	Gómez-Plaza *et al*., 1999
	Falaghina white	52.71 to 1.86	-96.47	12.5 to 0.3	-97.60	Liguori *et al*., 2019
	Aglianico red	58.15 to 60.49	+4.02	15.46 to 10.84	-29.88	Lisanti *et al*., 2013
Butyric acid	White	0.48 to 0.53	+9.43	10.6 to 0.3	-97.17	Gómez-Plaza *et al*., 1999
	Aglianico red	0.03 to n.d.	Unknown	13.0 to 0.19	-98.54	Liguori *et al*., 2013
Octanoic acid	White	0.82 to 0.19	-76.82	10.6 to 0.3	-97.17	Gómez-Plaza *et al*., 1999
	Falaghina white	6.27 to 0.19	-96.97	12.5 to 0.3	-97.60	Liguori *et al*., 2019
	Aglianico red	0.90 to 0.15	-83.33	13.0 to 0.19	-98.54	Liguori *et al*., 2013
	Aglianico red	2.66 to 2.40	-9.77	15.46 to 10.84	-29.88	Lisanti *et al*., 2013
Decanoic acid	White	0.11 to n.d.	Unknown	10.6 to 0.3	-97.17	Gómez-Plaza *et al*., 1999
	Falaghina white	8.95 to 0.44	-95.08	12.5 to 0.3	-97.60	Liguori *et al*., 2019
	Aglianico red	0.19 to 0.02	-89.47	13.0 to 0.19	-98.54	Liguori *et al*., 2013
	Aglianico red	1.25 to 0.59	-52.80	15.46 to 10.84	-29.88	Lisanti *et al*., 2013
Isobutyric acid	Falaghina white	0.04 to 0.00	-100	12.5 to 0.3	-97.60	Liguori *et al*., 2019

Acetic acid	Falaghina white	0.04 to <0.003	> (-92.50)	12.5 to 0.3	-97.60	Liguori *et al*., 2019
	Aglianico red	0.43 to <0.10	> (-76.74)	13.0 to 0.19	-98.54	Liguori *et al*., 2013
Isobutanol	Aglianico red	2.28 to <0.07	> (-96.93)	13.0 to 0.19	-98.54	Liguori *et al*., 2013
	Falaghina white	1.02 to <0.05	> ()-95.10	12.5 to 0.3	-97.60	Liguori *et al*., 2019
Butanol	Falaghina white	0.12 to 0.00	-100	12.5 to 0.3	-97.60	Liguori *et al*., 2019
	Aglianico red	0.025 to 0.014	-44.00	15.46 to 10.84	-29.88	Lisanti *et al*., 2013
Isoamyl alcohol	Falaghina white	59.78 to <0.01	> (-99.98)	12.5 to 0.3	-97.60	Liguori *et al*., 2019

n.d. – not detected

2.7.2. The role of carbon dioxide in sparkling wines

The effervescent quality of sparkling wines, as a result of the presence of CO_2, is the signature characteristic of this wine product. It not only adds positively to the visual appearance of the product but also to the mouthfeel and aroma perception. Furthermore, it is regarded as one of the major quality characteristics that drive the consumer acceptability of sparkling wines (Culbert *et al*., 2017). Several studies have been conducted to better understand the compounds that influence this parameter (Martínez-Lapuente *et al.,* 2015; Liu *et al*., 2018b; Martínez-Lapuente *et al.,* 2018), and its effect on aroma and mouthfeel characters (Bryner, 2009; Saint-Eve *et al.*, 2009; Adams, 2018).

Some compounds identified to influence foam quality included proteins (Culbert *et al.,* 2017; Liu *et al*., 2018b). Liu *et al*. (2018b) suggested that the degradation of proteins reduces foam ability. Additionally, polysaccharides, peptides, organic acids, polyphenols, and lipids influence foaming (Martínez-Lapuente *et al*., 2018). Overall, the quality of foam in sparkling wines is sometimes influenced by the production method as most of the above-mentioned compounds are released during yeast autolysis (Martínez-Lapuente *et al.,* 2018). Carbonated sparkling wines may not be affected similarly because the CO_2 is externally added, but to date no study suggesting that has been published.

Furthermore, as studied by Liger-Belair *et al*. (2010), the release of CO_2, which influences the visual aspect of bubbles and resultant foam, may be affected by factors such as the way of pouring and serving temperature of sparkling wine. As detailed by the aforementioned authors, there are two ways of pouring sparkling wine, beer-like and champagne-like way. Simply put, the beer-like method involves pouring champagne down the side of a tilted glass, whereas the champagne-like method involves pouring champagne straight down the middle of a vertically oriented glass.

The former preserves the effervescence quality of sparkling wine better, meaning that CO_2 is lost much slower than when sparkling wine is poured using the champagne-like method. CO_2, other than being an aesthetic feature, carries concentrated volatile compounds in bubbles from the wine to the wine glass headspace making a consumer perceive aroma more easily (Bryner, 2009; Polidori *et al*., 2009). Additionally, in the mouth CO_2 adds a tingly tactile sensation. CO_2 is an essential part of sparkling wines contributing to the product being mostly appreciated, as a mouthfeel characteristic, volatilisation mechanism of aroma compounds to the nose and an appearance aesthetic feature.

2.8. Conclusions

De-alcoholised wine, and more specifically sparkling wine, have emerged in the South African market. Currently, the ethanol content of de-alcoholised sparkling wines is globally quite a grey area, as each country has its own regulations pertaining the concentrations. However, de-alcoholised sparkling wines refer to wines with <0.5% v/v as per the definition of the current South African wine regulations. As indicated in this review, the de-alcoholised sparkling wines currently produced in SA are non-MCC. Due to this tendency, each of the de-alcoholised sparkling wines selected for the current study was non-MCC sparkling wines; thus, no secondary fermentation occurred in the production of the selected sparkling wines. Although, de-alcoholised wines are emerging in the South African market, their production has been occurring in the global market. Moreover, change in sensory quality and volatile composition has been noted in various studies, which in turn led to reduced taste acceptability. For de-alcoholised sparkling wines, however, no profile and quality evaluation has been conducted, especially in SA. As such, information on their quality is unavailable to both the consumers and producers. Therefore, to address the knowledge gap, this study focused on profiling the sensory and volatile composition of South African de-alcoholised sparkling wines, as well as to evaluate their quality.

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Chapter 3: South African de-alcoholised sparkling wine quality and sensory profiles: Insights gained through wine tasting using wine professionals

Abstract

Assessing wine quality is an essential step in product development and benchmarking of wines and capturing sensory profiles is an essential part of this step. In this study, the sensory quality of nine South African de-alcoholised sparkling wines was rated out of 20 points (scored 3 points for appearance, 7 points for aroma and 10 points for palate), and the sensory profiles of the wines were generated through free-listing by 51 wine industry professionals. All the wines scored between 11 and 14 points out of 20. Palate quality scores had a significant effect ($p < 0.05$) on each wine's overall quality scores, as each wine was rated less than 6 out of 10. In terms of aroma profile, sensory categories such as, 'fruity' (25%), 'off-odours' (13%), 'lacks' aroma (7%), 'floral' (5%) and 'muscat' (5%) were cited. The presence of 'off-odours' negatively affected the aroma quality and profile of the wines, examples included 'slightly charred character on the nose initially', 'reductive and rubbery slight stink', and 'chemical'. Furthermore, the palate profiles were characterised by 22 negative palate categories (out of a total of 61 categories), including 'lacks' flavour, 'short finish', 'acidic', 'watery', and 'unbalanced' palate. These palate categories negatively affected the quality of the wines, as shown by the low scores for this modality. Nonetheless, the citation of 'fresh', 'floral', 'balanced', 'good mouthfeel', 'fruit' and 'good bubbles' on the palate added complexity to the profiles and highlighted good wine attributes that positively contributed to wine quality. Essentially, the results obtained could be used as a basis for future optimisation of de-alcoholised sparkling wine and wine style benchmarking.

Keywords: Wine quality; sensory profile; wine professionals; de-alcoholised sparkling wines, South Africa; 20-point quality scoring; free listing

3.1. Introduction

South Africa (SA) is regarded as a new world wine region, paving its way in the global wine market, and keeping in line with international market changes, particularly in terms of consumer preferences. One of the recent wine preferences is the desire for products with no or low alcohol (NOLO beverages). As a result, wine producers have introduced low-alcohol and de-alcoholised wines into the wine market. These wines have their ethanol content lowered to <4.5% v/v or ≤0.5% v/v when compared to their full-strength counterparts, according to the South African Wine Industry Information and Systems (SAWIS, 2020), respectively.

The legislative ethanol levels for classifying wines differ from country to country. In Australia, a wine with an ethanol content <0.5% v/v is classified as de-alcoholised, whereas low-alcohol wines have 0.5 to 1.2% v/v of ethanol (Saliba *et al*., 2013a; Bucher *et al*., 2019), making the low alcohol category different from that of SA. In the United Kingdom (UK), wines with <0.5% v/v ethanol are categorised as non-alcoholic wines, and in China, low-alcohol wines contain 1 to 7% v/v and non-alcoholic wines 0.5 to 1% v/v ethanol (Sam *et al*., 2021). The categories of wines with reduced ethanol levels are thus not the same in the global market, and this may be confusing.

Even though there has been confusion on the identity of de-alcoholised and low-alcohol wines, for producers and consumers, an agreement on the effect of ethanol reduction on the sensory quality of these wines has been noted (Saliba *et al*., 2013b; Longo *et al*., 2017; Liguori *et al*., 2019; García *et al*., 2021). Longo *et al*. (2017) highlighted that through the de-alcoholisation process, a certain percentage of volatile compounds is reduced, and as a result, the aroma and flavour profiles of the wines change.

Interestingly, with all the studies conducted on de-alcoholised wines, no research results have been published on de-alcoholised sparkling wines, especially within the South African market. Globally the market for sparkling wines has been growing with an observed 3% global consumption increase between the years 2002 and 2018 (Organisation Internationale de la Vigne et du Vin (OIV), 2020). Similarly, SA observed an increase in sparkling wine consumption from 8.6 million litres in 2006 to 11.4 million litres in 2021 (SAWIS, 2009; SAWIS, 2021). The latter tendency could be caused by a rise in sparkling wine purchases made on a regular basis, as opposed to simply on special occasions (Karlsson and Karlsson, 2020). This shift in sparkling wine purchasing behaviour and alcohol consumption could trigger investment in the production of quality de-alcoholised sparkling wines.

The current study focused on the sensory profiling of a set of South African sparkling wines selected in 2020 and evaluating their quality. In that period though, due to the COVID-19 pandemic, there was a decline in sparkling wine consumption in SA (SAWIS, 2021), primarily because of the alcoholic beverage ban imposed by the government. Conversely, the sales of de-alcoholised wines increased in retail stores and de-alcoholised wine-producing cellars (Pretorius, 2020). Even with this change in the sparkling wine market, no studies have focused on the sensory profile and quality of de-alcoholised sparkling wines. Therefore, this research serves as an introductory case study on the subject. South African wine professionals (winemakers, wine researchers and marketing personnel) were used to evaluate the sensory profile and quality of the wines because of their expertise in wine profiling and quality evaluation, especially since this category was relatively new in SA.

In this study, the 20-point quality scoring and free listing (FL) method were determined as effective for data collection. The 20-point quality scoring system was a relevant method to obtain the quantitative measure of wine quality. Additionally, the judges evaluating the wines were familiar with the method. FL was selected because it allowed spontaneity in profiling the wines, especially in the study of a relatively new product category, with no published studies. In comparison with the rapid methods, FL was determined to be the most effective method in allowing judges the freedom to describe the wines, avoid long training periods and limit the use of complicated rules which may affect their thinking and evaluation capacity.

3.2. Materials and methods

3.2.1. Wine selection

De-alcoholised sparkling wines available in retail stores were searched online from January to March 2020 using the following keywords: 'new de-alcoholised sparkling wines in South Africa', 'de-alcoholised sparkling wines', 'non-alcoholic sparkling wines', and 'alcohol-free sparkling wines in South Africa'. From this search, 10 wines were identified, one of which was not available for purchase and was thus excluded from the study.

The selection criteria for wines included: ethanol content of ≤0.5% v/v and ethanol removed through de-alcoholisation, additionally, the wines had to be available for purchase in retail stores or at cellars. The selected wines were of different styles and produced using varying grape varieties representing a diverse sample set (**Table 3.1)**. Retail stores at which the wines were purchased were Woolworths, Checkers, Makro, Tops Spar, and Pick n Pay. Between the day of purchase and the wine-tasting session, the wines were stored in the vinotique (temperature-controlled at 13 to 15ºC), at the Department of Viticulture and Oenology, Stellenbosch University, SA.

Table 3.1 The technical details of the South African de-alcoholised sparkling wines (n=9) profiled in this study.

Wine code	Grape Variety*	Wine style	Ethanol (% v/v) **	pH **	TA (g/L) **	Glycerol (g/L) **	Fructose (g/L) **	Glucose (g/L) **
W004	Chardonnay	Dry white	0.5	3.45	6.20	15.81	14.00 ± 0.10	12.24 ± 0.23
W111	Blend***	Dry white	0.5	3.52	5.80	5.01	21.30 ± 1.05	3.26 ± 0.02
W017	100% Sauvignon Blanc	Dry white	0.2	3.42	6.60	16.09	9.35 ± 0.10	9.74 ± 0.16
W214	Blend: 76% Pinot Noir and 24% Chardonnay	Dry white	0.5	3.15	7.40	14.30	12.83 ± 0.09	11.29 ± 0.04
W429	Blend: Sauvignon Blanc and White Muscadel	Sweet white	0.5	3.34	6.03	19.36	31.16 ± 0.90	27.35 ± 0.79
W818	100% Sauvignon Blanc	Sweet white	0.3	3.40	6.69	15.84	30.40 ± 0.04	31.13 ± 0.85
W566	Blend***	Dry rosé	0.5	3.53	5.87	4.89	11.98 ± 0.04	13.48 ± 0.04
W736	Blend***	Semi-sweet rosé	0.5	3.38	5.70	15.17	21.69 ± 0.58	19.72 ± 0.01
W916	Blend: 100% selection of red and white grapes	Sweet rosé	0.3	3.27	5.74	20.20	29.93 ± 0.64	26.43 0.04

* Grape variety obtained from published wine technical data ** The analyses of ethanol, pH, TA, glycerol, fructose, and glucose are detailed under **Chapter 4**, **Section 4.2**.*** The grape varieties used for the wine blends were not specified.

3.2.2. Judge recruitment

Before recruiting judges and evaluating wines, ethical clearance was obtained from the Research Ethics Committee: Social, Behavioural and Education Research (FESCAGRI-2020-14835), Stellenbosch University. Thereafter, wine professionals from cellars that produce either de-alcoholised still or sparkling wines and a research institute specialising in wine production in the Western Cape Province, SA, were invited to participate in the study. Emails were sent to these cellars as participation invites, and the purpose of the study and the procedures to be used in the wine evaluation were explained. Additionally, the email invited each cellar to propose judges familiar with the sensory evaluation of wines using the 20-point quality scoring system. In the process of judge recruitment, one cellar producing neither de-alcoholised still nor sparkling wines requested to participate in the study and was invited to join the judging panel. In total 51 judges participated, consisting of 23 females (aged 23 to 61 years) and 28 males (aged 26 to 64 years). All the judges agreed to participate in the study by signing a consent form (**Addendum A**).

The judges had the following formal vocations in the wine industry: brand managers, winemakers, sales and export managers, quality assurance managers, tasting room ambassadors, researchers, technicians, and marketing directors. The different vocations were grouped into the following categories: winemaking, research, marketing, and quality control (**Table 3.2**) to simplify data analysis and determine the possible influence of vocation on wine quality evaluation. Additionally, the participating cellars were grouped into producing cellars and non-producing cellars. Producing cellars were those producing de-alcoholised sparkling wines, and non-producing cellars were those not producing de-alcoholised sparkling wines at the time of the study. In total, 23 judges were from producing cellars and 28 from non-producing cellars.

Table 3.2 Wine professionals participating in sensory evaluation of nine South African de-alcoholised sparkling wines.

Vocational category	Vocation	Number of judges	Producing cellar*	Non-producing cellar**
Winemaking	Winemaker, Junior winemaker, Assistant winemaker, Cellarmaster, Head of winemaking and viticulture	19	14	5
Research	Researcher, Junior researcher, Senior researcher, Senior research technician, Technician	9	0	9
Marketing	Brand manager, Consultant, Sales/export manager, Marketing Director, Marketing Manager, Regional sales manager	10	3	7
Quality control	Tasting assistant, Intrinsic manager, Sensory manager, Quality assurance manager, Quality manager, Tasting room ambassador	13	6	7
Total		**51**	**23**	**28**

* Cellars producing de-alcoholised sparkling wines; **Cellars not producing de-alcoholised sparkling wines

3.2.3. Designing the tasting sheet

A tasting sheet (**Addendum B**) was designed detailing the two major wine evaluation tasks: quality scoring and free listing (FL). At the top of the sheet, each judge had to note their judge number, given by the researcher, and the date and venue at which the wines were evaluated. Additionally, the instructions to be followed for wine evaluation were detailed. For example, judges had to score the appearance, aroma, and palate modalities in terms of quality and thereafter, spontaneously describe the visual aesthetics of the same three modalities. The tasks were completed on a paper version of the tasting sheet to allow the judges to compare the sensory quality of the wines throughout the wine evaluation session.

3.2.4. Wine evaluation procedures

On each wine evaluation day, the wines were transported from the storage facility to the tasting venue. A hard copy of the tasting sheet (**Addendum B)** was given to judges to fill out.

In total, the wines were tasted in a single flight at seven different tasting venues of the participating cellars in the Stellenbosch, Robertson and Franschhoek areas in Western Cape, SA. The purpose of the study and procedures of the tasting, mentioned in emails, were re-emphasised before tasting sessions; however, no wine-tasting training was provided to judges. All COVID-19 regulations were also adhered to, as stipulated by the South African Government (2020) for gatherings at the time when preparing and tasting of the wines were done.

The wines were served in clear wine-tasting glasses provided by the cellars, coded with random three-digit codes using the Williams Latin square design, and covered with clear Petri dishes to avoid loss of aroma (Wang *et al.,* 2009). A bottle of still water and crackers were served for palate cleansing. Each judge was assigned a judge number (provided on the tasting sheet) and was asked to complete the respective tasks in English. They were not allowed to communicate with fellow judges until all tasks were completed. Additionally, the wines were tasted blind, meaning that the brand name and producer were not disclosed until all judges completed wine evaluation.

Quality scoring

Each wine was subjected to quality scoring using the 20-point quality scorecard in a blind tasting. Per wine sample, judges were instructed to allocate scores for each modality as follows: 3 points for appearance, 7 points for aroma, and 10 points for the palate. Overall quality was calculated as a total out of 20 points (the sum of appearance, aroma, and palate scores). The quality scores obtained from judges' scorecards were exported to Microsoft Excel® for Microsoft 365 MSO (Version 2201 Build 16.0.14827.20180) for processing and statistical analysis.

Free listing (FL) methodology and text data processing

The FL method was used to determine sensory profiles in this study. Judges were instructed to describe the appearance, aroma, and palate attributes they perceived for each wine on a paper version of the FL questionnaire (**Addendum B)**.

The text data were exported from paper to Microsoft Excel® for Microsoft 365 MSO (Version 2201 Build 16.0.14827.20180) for data processing. 'No comment' was used to indicate when no description was noted for a modality. Additionally, the data was cleaned-up by translating Afrikaans texts to English and correcting spelling and grammar errors. The use of wine descriptors was also standardised by using a common descriptor for descriptors written in different forms by different judges, as shown in **Table 3.3**.

Table 3.3 Example of standardised data from the original free listing (FL) text data.

Original data	**Standardised data**
Lychee, litchi	Litchi
Pawpaw, papaya	Papaya
Kakiebos, khakhibos	Khaki bush
Tropical fruit, tropical	Tropical fruit

Grouping of the cleaned-up and standardised data into sensory categories followed, a process is termed 'lemmatisation'. Lemmatisation refers to the grouping of sensory descriptors into categories that best describe each descriptor under that category (Rodrigues *et al*., 2015). This method also reduces the number of words used to describe a wine and simplifies data analysis. Sensory categories were formed to categorise the descriptions given for the wines and classify their nature in wine quality. Examples of sensory categories used, and classifications are outlined in **Table 3.4**, and the complete list is in **Addendum C (Tables C1** to **C3)**, representing all three modalities.

Table 3.4 Lemmatisation of the standardised text data and sensory categories used to group the text data.

Modality	Sensory category	Classification	Standardised data
Appearance	Good colour	Positive	Colour good; Colour is decent; Good intense colour; Colour nice vibrant colour; Pale gold with beautiful green tinges; Proper MCC or champagne colour;
Appearance	Brown tint	Negative	Hints of browning; Browning colour; Hints of brown; Slightly brown
Appearance	Appealing effervescence	Positive	Lots of bubbles; Extremely integrated bubble/perlage; Nice texture; Elegant bubbles; Finely streamed bubbles; Subtle bubbles; Substantial layer of bubbles on top; Lots of small bubbles; Thick circle of bubbles at the top; Fine perlage;
Appearance	Unappealing effervescence	Negative	Low bubble on appearance; Has a "beer-like" foam not fitting for a wine; Fine inconsistent bubbles; Fine mousse-not very active; Foam disappears quicker but does not add to visual appearance; No bubbles visible;
Aroma	Fruit aromas	Neutral	Apricots; Mixed fruit; Nectarine; Stone fruit; Tropical fruit; Summer fruit; Granny smith apple; Watermelon;
Aroma	Off-odours	Negative	Slightly charred character on the nose initially; Initially burnt/rubber-like; Almost soapy; Medicinal nose; Initially a bit reductive; Overwhelmed by sulphury off-odour (H_2S?); Turpentine smell;
Palate	Good flavour	Positive	Lively with nice red fruit flavours on the mid-palate; Pure fruitiness; Nice fruit; Pleasantly fruity
Palate	Balanced palate	Positive	Well structured; Acid/sweetness more in balance; Acidity and mouthfeel well balanced; Elegant and balanced; Good balance of wine; balanced acidity/sweetness/mouthfeel; Palate is well balanced (helped by RS); Balanced;
Palate	Not wine-like flavours	Negative	Grape juice character; Reminds me of sparkling grape juice; Buchu; Appletiser-like; Rooibos feel; Iced tea; Red grape juice; No wine character; Juice flavour; Green grape juice; Concentrated peach/apricot; Beer-like; Malty; Rosewater;
Palate	Bad bubbles	Negative	Bubbles dissipate quickly; Bubbles falls flat on the palate; Coarse bubbles; Minimal bubble; No bubble;

Not all data were lemmatised. Examples of data omitted in lemmatisation and statistical analysis, with a reason for the omission, are as follows, and for these data the term 'discarded' was used:

- Colour descriptions because a single sensory category could not be identified for all colours since each wine had a specific colour. Examples include 'pink', 'yellow', 'pale ruby red colour', 'garnet', 'greenish', 'straw yellow', 'salmon pink', 'pale straw with green tinges', 'deeper straw colour'
- Colour intensities without colour descriptions, such as, 'more depth in colour', 'more intense colour'

- Profile comparisons between wines in any modality, such as, 'not as pronounced as W017 but similar', 'most balanced so far', 'better freshness', 'sweeter compared to rest of flight'
- Comments that did not give context on the sensory profile of the wine, such as 'some acid; aftertaste; soft'

3.2.5. Data analysis

Both the quality scores and free listing data were statistically analysed on Microsoft Excel® for Microsoft 365 MSO (Version 2201) and TIBCO Statistica™ Software Incorporated (Version 14.0.0.15). Overall quality scores (out of 20 points) were subjected to box-and-whisker plot analysis to determine score distribution for the whole dataset and for the individual wines. Furthermore, the influence of factors other than wine quality on quality scoring was investigated. Examples included the judges' familiarity with wine style, either by producing the style or producing a similar product, unfamiliarity with the wine style and individual judge's vocation. A least significant difference (LSD) test, under a mixed model analysis of variance (ANOVA), was done using least square (LS) means to determine significant differences in the scores. Similarly, the mean scores and statistical differences in scores for all the wines under the different modalities were done using a mixed model ANOVA, and the results were used to determine the influence of each modality on the overall quality.

The processed free listing data were exported to the TIBCO Statistica™ Software Incorporated (Version 14.0.0.15) for statistical analysis of data. Citation frequencies, the number of times a specific sensory category was cited, were manually calculated for each different modality, and used to construct citation frequency plots. These citations were thereafter used to construct a visual representation of the wine profiles, using word clouds. Additionally, correspondence analysis (CA) on the sensory categories cited at least 10 times was used to determine which category best described a specific wine.

3.3. Results and discussion

The quality and sensory profiles of the selected South African de-alcoholised sparkling wines used in this study were obtained through quality scoring and the FL method, as mentioned in **Section 3.2.4.1** and **Section 3.2.4.2**. Quality scores were given by the judges; out of 3 points for appearance, 7 points for aroma, and 10 points for the palate. Thereafter, the overall quality score was calculated as a sum of the three modalities, making a total of 20 points. The judges also had to profile the wines by identifying the sensory attributes associated with the wines using FL. From this process, results were obtained, depicting the quality and sensory profiles associated with the wines. Additionally, possible factors influencing wine scoring were investigated, including familiarity with de-alcoholised sparkling wines and the judges' vocations.

3.3.1. Quantitative wine quality

Table 3.5 shows the average quality and the minimum-maximum score for each wine. All wines scored, on average, below 14 points out of 20. The highest overall score observed was for W818, with an average score of 13.6, and the lowest was 11.4 for W566. The appearance modality did not have much influence on the overall quality scores because all wines scored above 2.5 out of 3 points. However, the aroma and palate modalities had a higher impact on the low overall quality scores observed for the wines. For example, the aroma and palate scores were, on average, not above 5 and 7, out of 7 and 10 points, respectively.

Looking closely at the different wines, **Figure 3.1** shows that the overall quality was significantly different ($p<0.05$), and, on average, wines were scored between 11 and 14 points out of 20. W566 and W214 were scored significantly lower than the other wines, except for W017, which also had average score of less than 12. Additionally, W818 scored significantly higher than most wines, except W429, W916, and W736, with an average score of 13.6. As observed in **Table 3.5** and **Figure 3.1**, W429 and W916 had maximum scores of 18 from the individual judges, 15 as a maximum score for W214, and the rest of the wines with maximum scores of 16 points. Minimum scores of 3 out of 20 points were also observed, indicating that there were instances where judges perceived that the wine's quality was poor. The variation in overall scores observed (**Table 3.5**) showed the difference in the wines' quality perceived by judges, especially with the minimum scores being as low as 3 and the maximum up to 18 points. Furthermore, the aroma and palate scores played a major role in reducing the overall scores. Essentially, indicating that the wines' aroma and palate were not of good quality for some judges.

Table 3.5 Summary of the quality scores for de-alcoholised sparkling wines (n=9) for each modality.

Wine	Overall score [average (minimum to maximum)]	Appearance score [average (minimum to maximum)]	Aroma score [average (minimum to maximum)]	Palate score [average (minimum to maximum)]
W429	13.1 (8 to 18)	2.7 (2 to 3)	4.4 (2 to 7)	6.0 (3 to 9)
W916	12.6 (7 to 18)	2.5 (0 to 3)	4.2 (2 to 7)	5.9 (3 to 9)
W111	12.6 (4 to 17)	2.7 (2 to 3)	4.4 (1 to 6)	5.5 (1 to 8)
W566	11.4 (4 to 17)	2.7 (1 to 3)	3.8 (1 to 6)	4.9 (1 to 8)
W017	11.9 (4 to 17)	2.8 (2 to 3)	4.1 (1 to 7)	5.1 (1 to 8)
W818	13.6 (3 to 17)	2.8 (1 to 3)	4.6 (1 to 7)	6.1 (1 to 8)
W004	12.5 (5 to 17)	2.7 (1 to 3)	4.2 (1 to 6)	5.6 (1 to 8)
W736	13.2 (7 to 17)	2.8 (1 to 3)	4.4 (2 to 7)	6.0 (3 to 9)
W214	11.6 (3 to 16)	2.6 (1 to 3)	4.1 (1 to 6)	4.9 (1 to 7)

According to Jancis Robinson (no date), a British wine critic, when evaluating the quality of wine using the 20-point scaling system, the points indicate whether the wine is of good quality or not. The scores distinguish the wines in the following manner: 20-points, truly exceptional; 19-points, outstanding; 18-points, cut above superior; 17-points, superior; 16-points, distinguished; 15-points, average; 14-points, deadly dull; 13-points, borderline faulty or unbalanced; 12-points, faulty or unbalanced. In the national South African wine competition (Veritas, 2022) wines are given awards based on the following scores out of 20 points: double gold for 18 points and above; gold for 17 points; silver for 16 points; bronze for 15 points. For an Australian competition also using a 20-point system, wine awards are allocated as follows: gold for 18.5 or more; silver for 17.0 to 18.4; bronze for 15.5 to 16.9 (Rankine, 1990; Lattey *et al*., 2010).

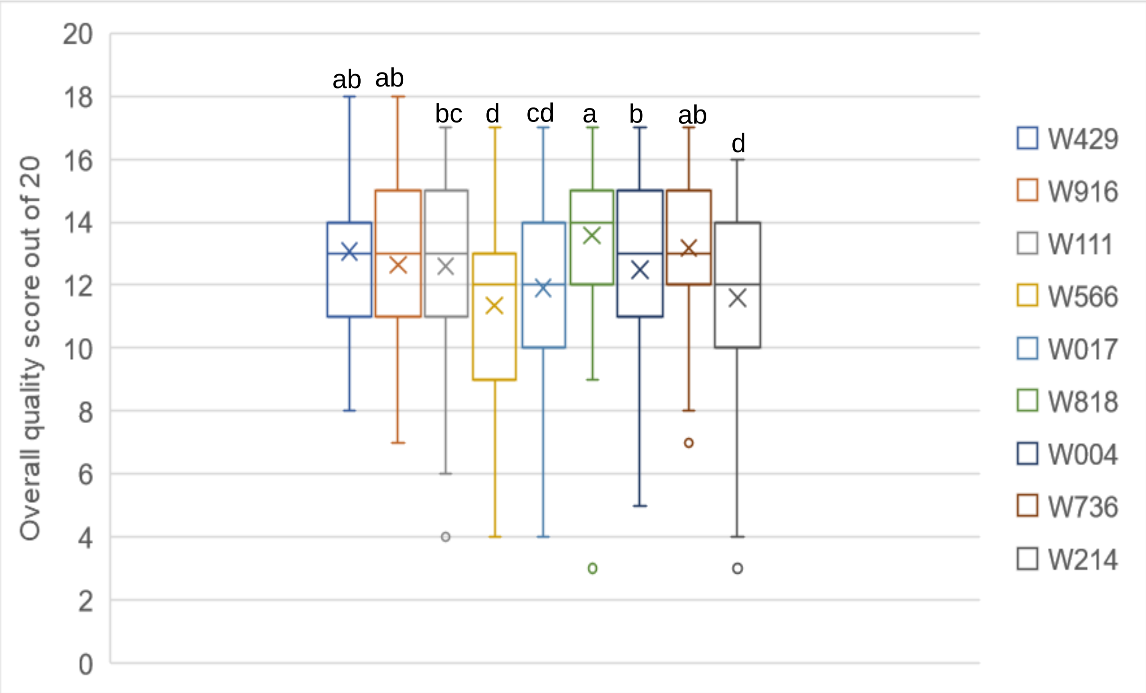


Figure 3.1 The quality of nine de-alcoholised sparkling wines evaluated out of 20 points. Letters indicate significant differences ($p<0.05$). Markings in the plots represent the following information: Average by X, outliers by O, the bottom-end of the whisker marks the minimum score, top-end of the whisker marks the maximum score out of 20 points. The distance between the bottom-end of the whisker and the bottom-end of the box represents 25% distribution of all scores, the middle line marks 50% and the top line marks 75%.

Looking at these scoring standards, the wines in this study would be described as borderline unbalanced, or unbalanced and faulty, particularly in terms of aroma and palate characteristics. Furthermore, there would be no award given to any of the wines in the set at a Veritas competition. This narrative could indicate that the wines were, in general, not of good sensory quality. Therefore, it was important to identify the possible factors influencing the quality associated with the set of wines and to investigate if each judge scored wines similarly. Ballester *et al.* (2008) and Barton *et al*. (2020) have reported that expertise plays a role in how wines are evaluated, as such the effect of the factor was studied in the current study. Although wine industry professionals evaluated the de-alcoholised sparkling wines in the current study, not all of them were familiar with the wine style. Therefore, familiarity or unfamiliarity with de-alcoholised sparkling wines and the de-alcoholised beverage category were studied as possible factors of quality scoring influence.

Distribution of quality scores and possible factors affecting scoring

The distribution of scores shows that overall, the wines were scored from 7 to 18 points out of 20, with a few outliers (3 to 6 points) (**Figure 3.2**). On average, the overall score of all wines was <13 points, but in distribution statistics, 50% of the scores were from 13 to 18 points, with the other 50% being less than 13 points. Furthermore, only 25% of the judges scored wines from 14 to 18, and none scored 19 or 20 points (**Figure 3.2**). Seventy-five per cent of the judges (representing 38 judges) perceived the wines to deserve less than 13 points and outliers, below 6 points, were observed. These results prompted further investigation into the causes of the low scores.

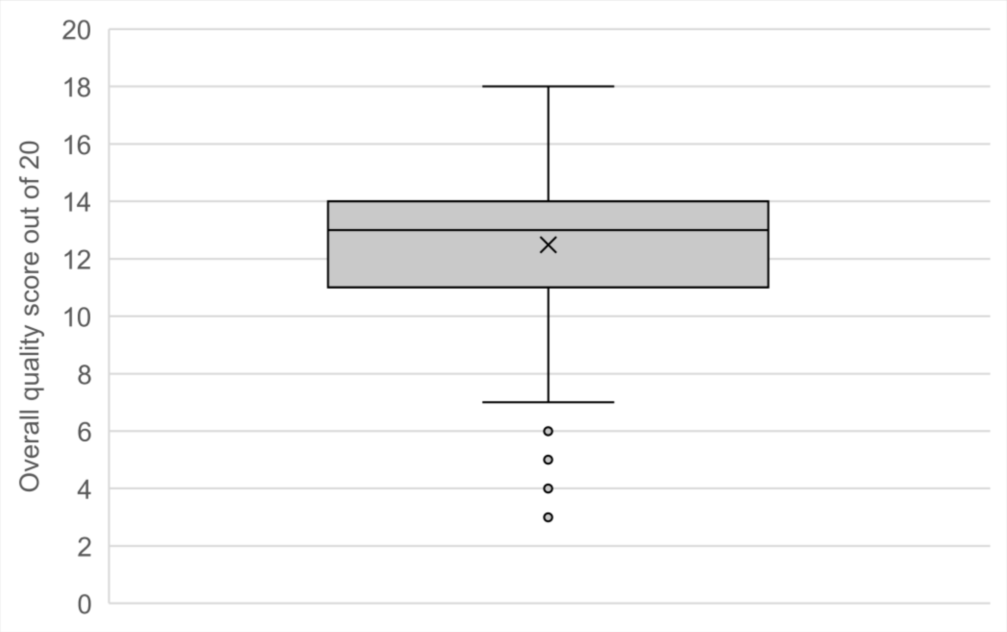


Figure 3.2 Distribution of overall quality scores for all de-alcoholised sparkling wines. Markings in the plots represent the following information: Average by X, outliers by O, the bottom-end of the whisker marks the minimum score, top-end of the whisker marks the maximum score out of 20 points. The distance between the bottom-end of the whisker and the bottom-end of the box represents 25% distribution of all scores, the middle line marks 50% and the top line marks 75%.

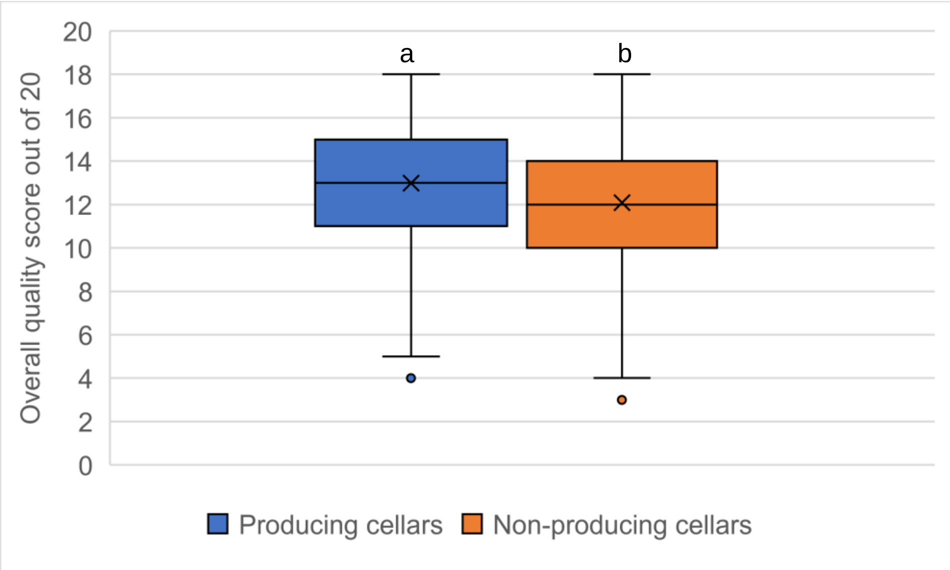
Factors such as judges' familiarity with wine style, vocation, and intrinsic wine quality, were investigated. **Figure 3.3a** shows that, on average, the cellars producing de-alcoholised sparkling wines and those not producing scored the wines 13 and 12 points, respectively. Both categories of cellars had maximum scores of 18, and the minimum score for non-producing cellars was 1 point below that of the producing cellars. These results suggested that the effect of cellars producing or not producing de-alcoholised sparkling wines was not major but was statistically significant. However, in the 'de-alcoholised sparkling wine non-producing cellars' dataset, there were judges from cellars producing de-alcoholised still wines, who were arguably more familiar with the de-alcoholised product category, and others who were not familiar with this category. In view of this, the effect of product familiarity and unfamiliarity on quality evaluation was investigated.

The non-producing cellars dataset was separated based on familiarity with de-alcoholised wines, producing only de-alcoholised still wines and producing neither still nor sparkling de-alcoholised wines. The wine research institute and the cellar producing only full-strength wines formed part of the cellars not producing de-alcoholised products, but their datasets were separated to investigate further if each category scored the wines differently (**Figure 3.3b**). The producing cellars dataset from **Figure 3.3a** was repeated and compared to the other categories. As shown in **Figure 3.3b,** the judges from the cellar producing full-strength wines scored the wines the lowest, with an average of 11 and a maximum score of 16. The research institute judges gave an average of 12 and a maximum of 18 points. Despite the research institute and full-strength wine cellars both producing neither de-alcoholised sparkling nor still wines, **Figure 3.3b** shows that they scored differently. This suggested that the full-strength wine-producing cellar perceived quality to be of the lowest standard, possibly due to their unfamiliarity with the wine style, unconscious comparison with full-strength wines, or perhaps the wine quality standard of the sample set was not satisfactory. The research institute judges were more accepting of the wine quality even though one judge perceived the wines to be of poor quality, with outlier scores of 3 and 4 points.

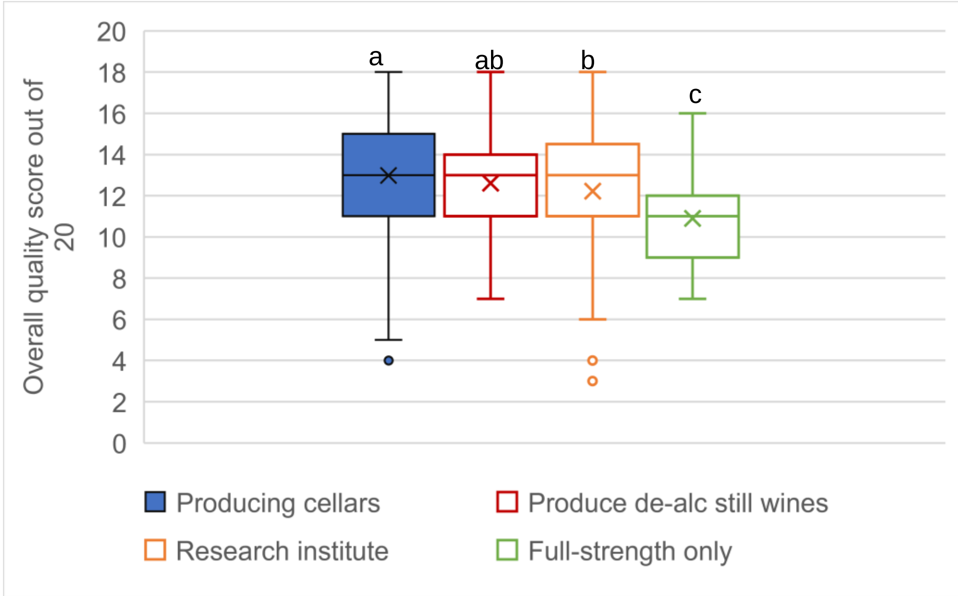
Judges from cellars producing de-alcoholised sparkling wines (producing cellar on **Figure 3.3b**) scored the wines significantly different from the cellar producing only full-strength wines. and the research institute, but not significantly different from the cellars producing de-alcoholised still wines (produce de-alc. still wines on **Figure 3.3b**). Some judges from the producing cellars did perceive the wines to be of poor quality (outlier of 4 points). Despite the different groups scoring the wines differently, on average, all groups perceived the wines to be borderline faulty or unbalanced as per the standard described by Jancis Robinson (no date). Interestingly, the producing cellars gave the lowest minimum score of 5 points, in comparison to 6 points by the research institute, and 7 points by de-alcoholised still wine and full-strength wine-producing cellar. These results suggested that the producing cellars could have been stricter in evaluating the wines' quality, but the difference in scoring between cellars could not be ascertained except when compared to the full-strength wine-producing cellar. Therefore, the influence of familiarity with the de-alcoholised wine style on quality scoring was inconclusive.

Another point of interest when considering wine quality scoring could be vocation (**Figure 3.3c)**. The judges were divided into four vocational categories: marketing, winemaking, quality control, and research, using the judges' vocation as references (**Table 3.2**). All vocational categories had maximum scores of 18, except marketing which had a maximum score of 17. Looking at the distribution of the scores, 75% of the quality control judges scored wines below 15 points and 25% from 15 to 18, making the average <13. Similarly, the average scores for winemaking, marketing, and research were <13 (**Figure 3.3c**) and thus, no significant difference ($p=0.97$) was observed between the vocational categories.

A



B



C

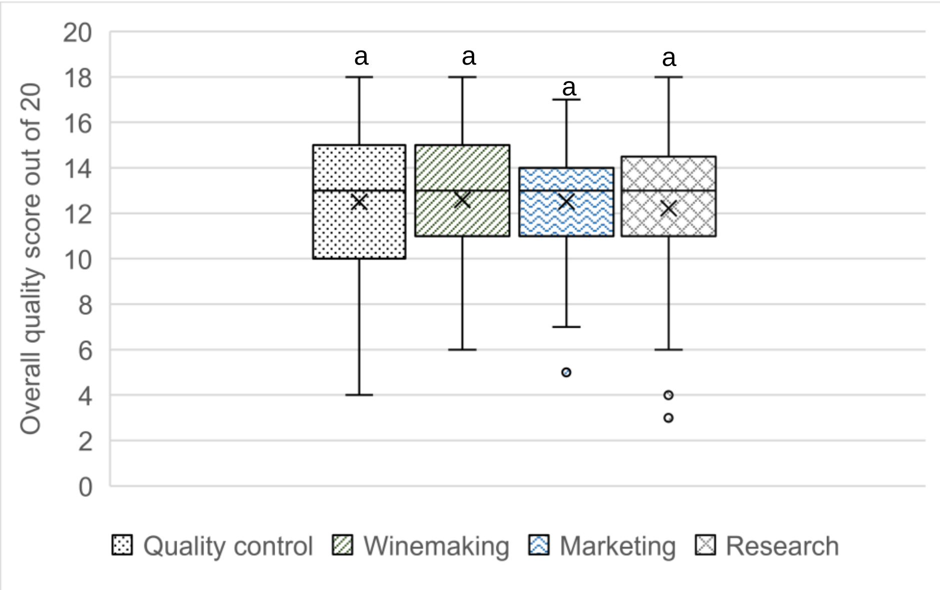


Figure 3.3 Influence of factors on quality scoring of de-alcoholised sparkling wines: **A**) familiarity with de-alcoholised sparkling wine production **B**) judges' familiarity with wine style **C**) the influence of vocational categories on overall quality scoring. Markings in the plots represent the following information: Average by X, outliers by O, the bottom-end of the whisker marks the minimum score, top-end of the whisker marks the maximum score out of 20 points. The distance between the bottom-end of the whisker and the bottom-end of the box represents 25% distribution of all scores, the middle line marks 50% and the top line marks 75%. *De-alc* refers to de-alcoholised on **Figure 3.3b**.

In summary, the overall quality of the wines was, on average, scored between 11 and 14 points, with the highest scored wine (W818) having 13.6 points and W566 with the lowest 11.4 points (**Table 3.5** and **Figure 3.1**). Distribution of the scores was done to investigate the factors that may have had a possible influence on quality scoring. **Figure 3.3a** shows that the de-alcoholised sparkling wine-producing cellars scored the wines significantly different from the non-producing cellars, although the difference, on average, was 1 point between the two categories. **Figure 3.3b** shows that the cellar producing only full-strength wines scored the wines the lowest, possibly due to product unfamiliarity. Interestingly the de-alcoholised still wine producing cellars scored the wines, on average, in a similar way as the producing cellars (**Figure 3.3b**), and the research institute scored significantly different from those producing sparkling wines. In observation, for the first two production groups, product familiarity may have played a role in how the wines' quality was scored. In terms of the vocational category (**Figure 3.3.c**), no significant difference was observed between the different categories in wine scoring, clearly outlining that an individual's occupation did not affect scores. Overall, the quality scores and therefore perceived quality, to a larger extent, may have been influenced by the different sensory modalities, especially aroma and palate.

Influence of the different sensory modalities on overall wine quality

Figure 3.4 shows that, on average, all de-alcoholised sparkling wines scored above 2 out of 3 points for appearance. Furthermore, no significant difference ($p \geq 0.05$) in appearance scores between the wines was observed. Similar results were reported by Brand *et al*. (2018) whereby the appearance of wines was scored, on average, above 2.5 out of 3 points, although in this instance the wines were not de-alcoholised. Liguori *et al*. (2019) reported that the de-alcoholisation of Falaghina white wines from 12.5 to 0.3% v/v had no significant effect on colour. However, there was a significant difference in Aglianico red wine colour intensity when it was de-alcoholised to 0.19% v/v (Liguori *et al*., 2013). Furthermore, Bogianchini *et al.* (2011) reported a 20% increase in colour intensity of a red wine blend (Cabernet Sauvignon–Merlot–Tempranillo) de-alcoholised to 2% v/v. These studies highlighted that the de-alcoholisation process might affect the colour intensity of the final wine product, although in Falaghina white wines the difference observed was not significant. In the current study, an investigation into the direct effects of de-alcoholisation on colour and its intensity, were outside the scope of the research, and no conclusions can be made in the absence of controlled experiments.

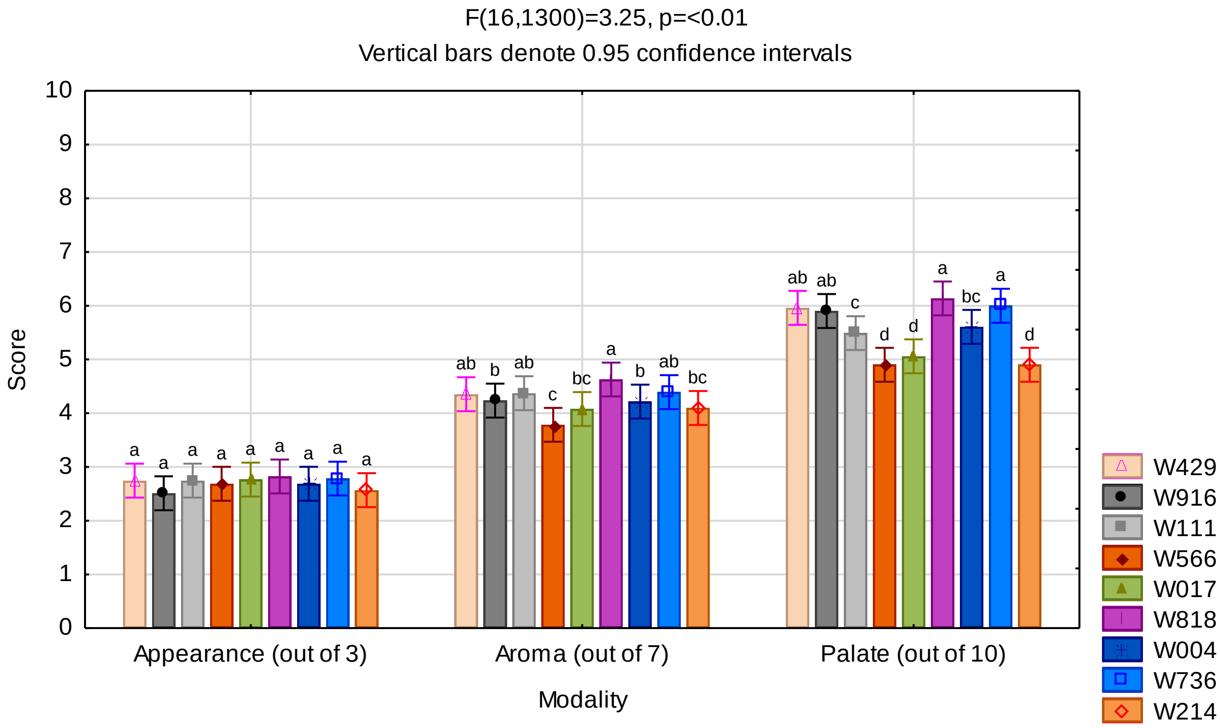


Figure 3.4 The quality scores of nine de-alcoholised sparkling wines measured through the different sensory modalities. Significant letters can only be compared within modality.

In terms of aroma quality, the wines were scored, on average, from 3.8 to 4.6 out of 7 points (**Figure 3.4**). Significant differences in aroma quality scores were observed, W566 had a lower score (<4 points) than the whole wine set, followed by W214 and W017. W818 scored higher than all the wines, with 4.6 points, although the difference was not significant in comparison with scores for W429, W111, and W736. None of the wines scored over 5 out of 7 points, suggesting that none of the wines had an outstanding aroma quality. In turn, this affected the overall quality of the wines since none of the wines scored over 14 points overall.

The overall palate quality of the wines was scored, on average, not more than 6 out of 10 points but, the wines differed significantly in palate quality. The highest scoring wines were W818, W736, W429, and W916 with an average score of *circa* 6, and the lowest scoring wines were W566, W017, and W214 with an average score of *circa* 5. These low-quality scores raise questions on whether the overall palate quality of the wines was satisfactory or not, and even more importantly, which of the sensory attributes influenced the quality the most. All in all, the results show that aroma and palate quality had the most effect on the overall quality of the wines. W566, W017, and W214 were of the lowest aroma and palate quality (**Figure 3.4**), even though all wines were not of satisfactory quality (**Figure 3.1**). Therefore, it was important to determine the wine profiles and identify the sensory factors which may have lowered the wine quality.

3.3.2. Wine profiles and qualitative wine quality

Qualitative wine quality was obtained by freely listing all sensory attributes associated with a wine that the judges could perceive. This was done for all the modalities, and the data were cleaned, standardised, and lemmatised into sensory categories (**Section 3.2.4.2.**). The sensory categories used to generate the wine profiles below, were groups that best summarise the original text data in a way that simplifies statistical data analysis. **Table 3.6** shows the categories formed from the original FL text data.

Table 3.6 Output from standardisation and lemmatisation of free listing (FL) text data.

Modality	Responses	No comments	Original data (in words)	Sensory categories	Classification of categories		
					Positive	Neutral	Negative
Appearance	453	6	2414	10	5	0	5
Aroma	455	4	2110	29	3	23	3
Palate	457	2	3321	61	17	22	22
Total	**1365**	**12**	**7845**	**100**	**25**	**45**	**30**

As indicated in **Table 3.6**, the appearance dataset was reduced from 2414 words to being represented by 10 sensory categories, and **Figure 3.5** shows the citation frequency of the categories. The wines were best described as 'clear', 'appealing' effervescence, 'unappealing' effervescence and 'bright', whereas 'watery' and 'not wine-like' appearance were cited less frequently. 'Clear', 'appealing' effervescence, 'bright', 'good' colour and 'good' appearance were identified as positive appearance categories. These positive categories, cited more than the negative categories, indicated that visually the wines were perceived to be appealing and reasonably good in terms of overall appearance quality. However, in some instances, the wines' effervescence was found to be unpleasant, depicted by the high citation of 'unappealing' effervescence (**Figure 3.5**). Examples of descriptions from the original data for this category included: 'low bubble on appearance', 'has a beer-like foam not fitting for a wine', 'fine inconsistent bubbles', 'fine mousse- not very active', 'foam disappears quicker but does not add to visual appearance', 'no bubbles visible', 'very thin ring (<1 mm) of bubbles', 'very little mousse' (**Addendum C, Table C1**). Inconsistent aesthetics of the bubbles and foam were seemingly the most identifiable factors reducing appearance quality. However, the method of pouring the sparkling wines into glasses and the time between pouring wine and tasting could have reduced the consistency (Liger-Belair, 2015; Scollary, 2020).

From the original data, wine colours were discarded during data processing, including 'yellow', 'straw yellow', and 'salmon pink'. This was done because each wine had a specific colour, and a single common category could not be used for all wines (as mentioned in **Section 3.2.4.2.**). Therefore, to avoid using all the wine colours and thereby cluttering the plots with colour descriptors cited only a few times, such terms were discarded. Even without the colour descriptions, the analysed data gave clear profiles of the wine's appearance, considering that not many faults were identified, elucidated by the scores in **Figure 3.4**.

For the aroma modality, a total of 29 sensory categories were formed, three of which were positive ('good', 'fresh' and 'wine-like' aroma), three negatives ('off-odours', 'not wine-like' and 'lacks' aroma), and 23 wine aroma categories were neutral, generally used to describe wine sensory profiles. A citation frequency plot (**Figure 3.6**) was constructed to depict how many times each category descriptor was cited. The wines were mostly described with a 'fruit' aroma category, cited 204 times (representing 25% of aroma citations), followed by the negative category 'off-odours' cited 105 times (13% of aroma citations) for the full sample set. The other aroma categories were cited much less (≤60 times), including 'sweet associated', 'not wine-like', 'good' and 'lacks' aroma.

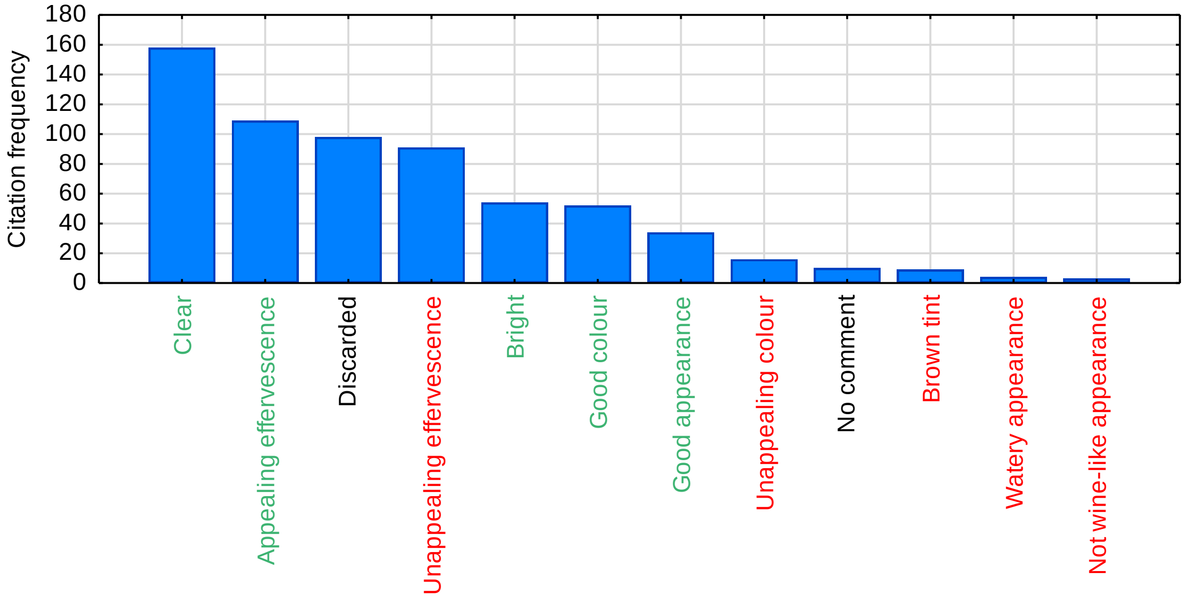


Figure 3.5 Citation frequency for sensory categories used to describe the appearance profiles of nine de-alcoholised sparkling wines. Green labels represent positive categories, red negative categories, and black no comments and discarded information.

Wine palate constitutes taste (sweet, bitter, salty, and sour), mouthfeel (astringency, finish, and body) and flavour (wine aroma perceived through the mouth) attributes. During wine sensory profiling, all these attributes were cited by judges and the palate data was illustrated by 61 sensory categories because of the palate complexity perceived amongst wines. As outlined in **Table 3.6,** there were more negative categories in the palate modality than in any other modality. As shown in **Figure 3.7,** the list of palate categories was much more diverse than the list for appearance (**Figure 3.5**) and aroma (**Figure 3.6**). The three major palate categories were 'fruit' on palate, 'lacks' flavour and 'balanced' palate, with the category 'fruit' receiving 132 citations and the latter two categories receiving less than 70 citations. The remainder of the palate-related categories were all cited less than 60 times.

All these categories (**Figure 3.5**, **Figure 3.6**, **Figure 3.7**) were important for the wine profiles, and in determining the contributing factors to the low-quality scores. As such, the overall profile of each wine was done to give an overview of how each wine was perceived. The sensory profiles were created by merging all appearance, aroma, and palate sensory categories associated with each wine. Each wine was perceived to have a 'clear' appearance and 'fruit' aroma by judges (represented by big font sizes in **Figure 3.8**). Additionally, W429 was also associated with a 'sweet associated' aroma, 'sweet' palate, 'fruit' on palate, 'balanced' palate, 'not wine-like' aroma and 'not wine-like' flavours; W916 with 'fruit' on palate, 'unappealing' effervescence, 'sweet' palate; W111 with 'appealing' effervescence, 'good' aroma, 'fruit' on palate, 'lacks' flavour, whereas W566 had a high citation of 'off-odours', 'lacks' flavour, 'acidic' palate, 'unappealing' effervescence; W017 also associated with 'off-odours', 'fruit' on palate; W818 with 'appealing' effervescence, 'fruit' on palate, 'balanced' palate; W004 with 'lacks' flavour, 'off-odours', 'appealing' effervescence, 'acidic' palate; W736 with 'fruit' on palate, 'appealing' effervescence, 'balanced' palate; W214 with 'appealing' effervescence, 'off-odours', 'acidic' palate.

Each wine had a distinct profile but with a similar highly cited 'fruit' aroma and 'clear' appearance. On aroma and palate, most wines were associated with positive sensory categories, but W566 had a high citation of 'off-odours' and 'lacks' flavour, W017 had 'off-odours', and W004 'lacks' flavour. The high citation of these categories may have had a significant effect on the overall quality of the wines. For example, W566 and W017 scored significantly lower than the other wines, and this could have been because the 'off-odours' in these wines were more pronounced than in other wines. Interestingly, W004 was lacking in flavours even though it had one of the highest scores, but this could have played a part in the wine not having an average of more than 13 points (**Figure 3.1**). Suggesting that even though most wines had positive categories cited higher than the negative ones, the presence of negative categories affected the overall wine quality scores.

However, a general observation is that the wines with the lowest scores shown in **Table 3.5** and **Figure 3.1**, were associated the most with the negative categories. Furthermore, W818 and W736, which had the highest scores, showed a high citation of positive and neutral wine categories than most wines (**Figure 3.8**). Therefore, the negative categories associated with each wine played a role in reducing the overall quality and may need to be further studied to establish their origin from the original text data.

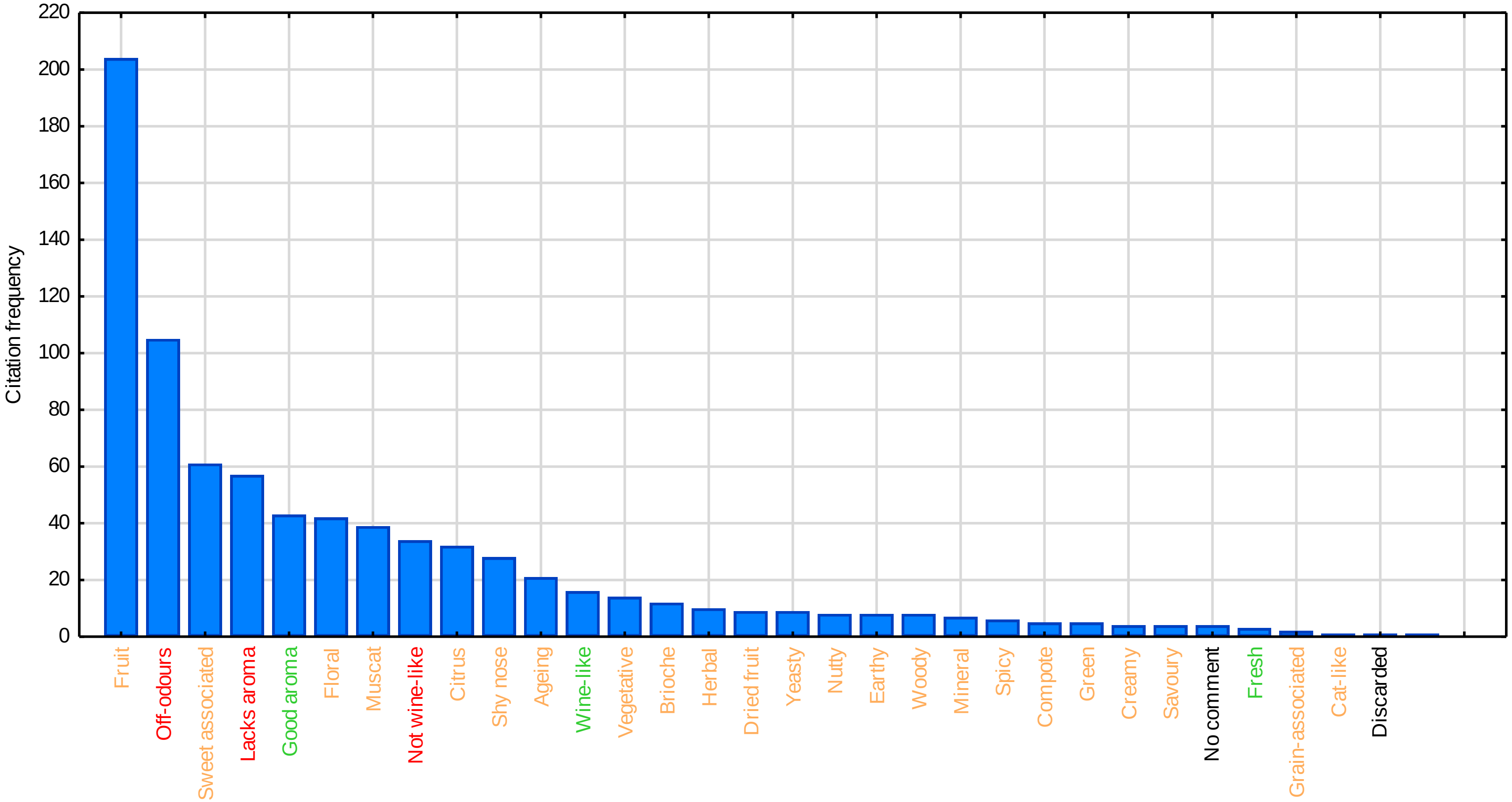


Figure 3.6 Citation frequency for sensory categories used to describe the aroma profiles of nine de-alcoholised sparkling wines. Green labels represent positive categories, red negative categories, orange neutral categories, and black no comments and discarded information.

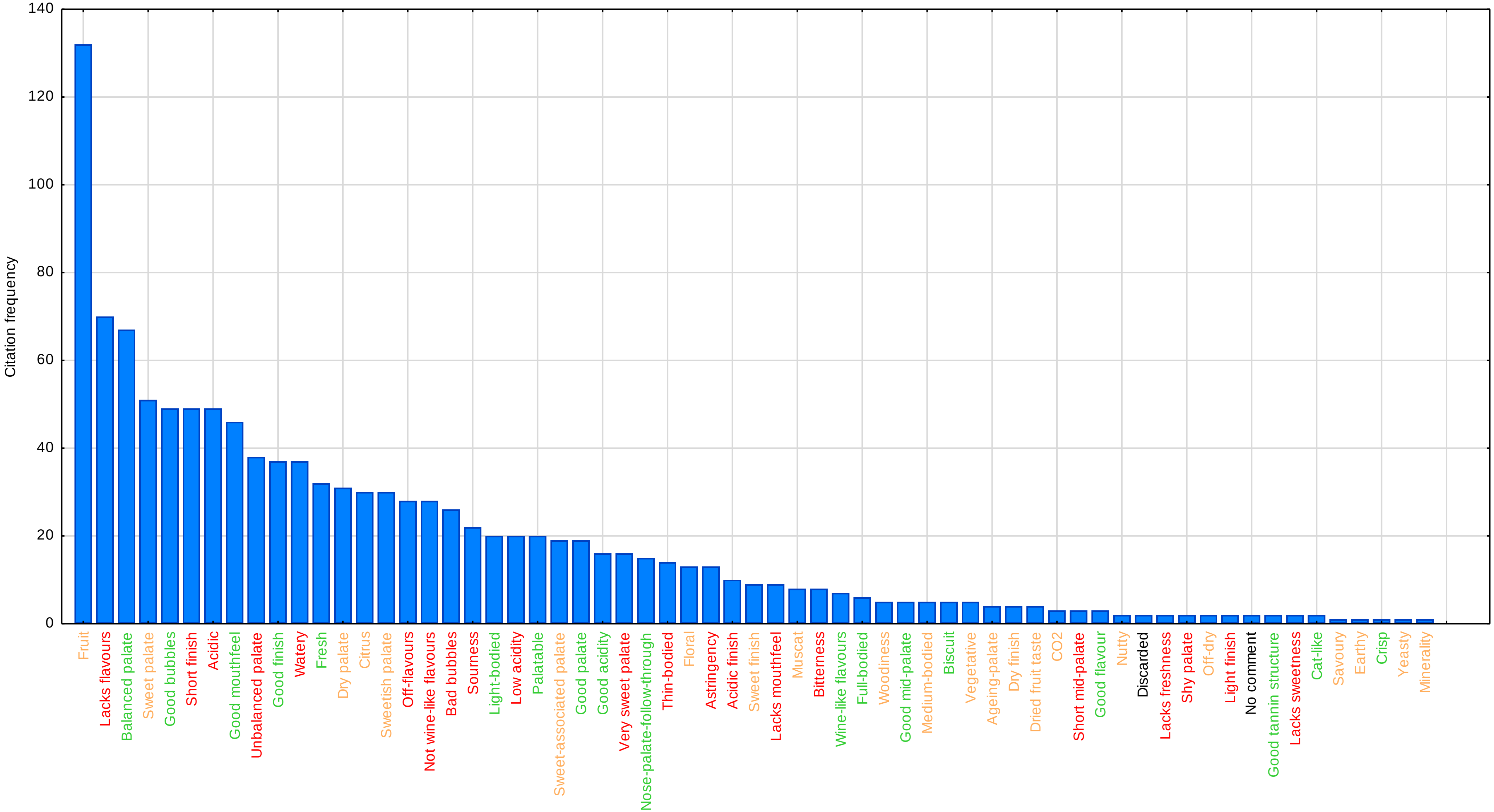
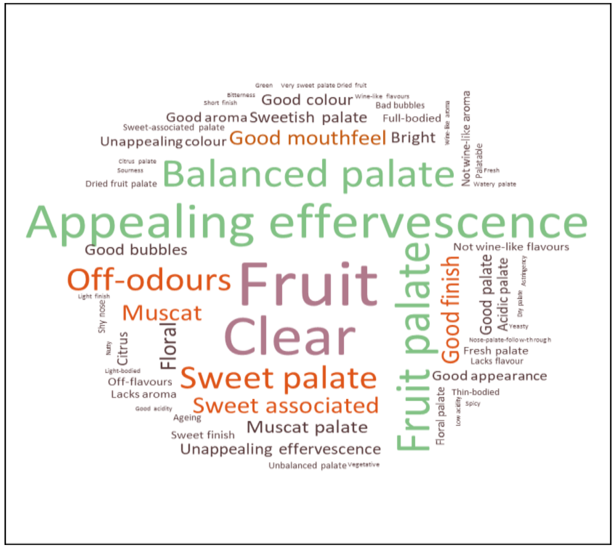
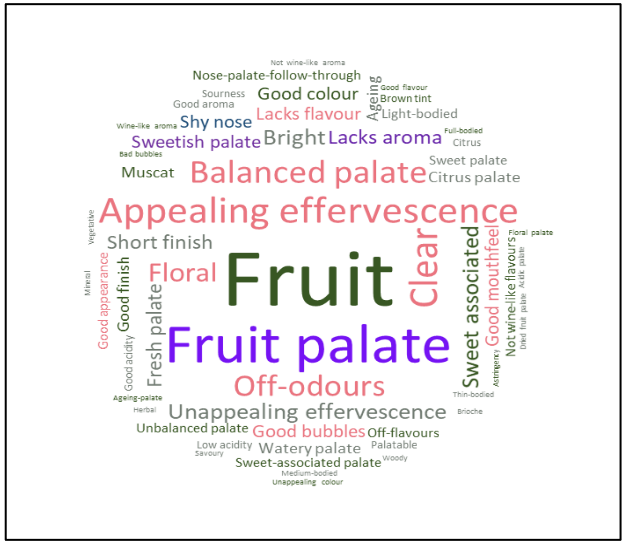


Figure 3.7 Citation frequency for sensory categories used to describe the palate profiles of nine de-alcoholised sparkling wines. Green labels represent positive categories, red negative categories, orange neutral categories, and black no comments and discarded information.

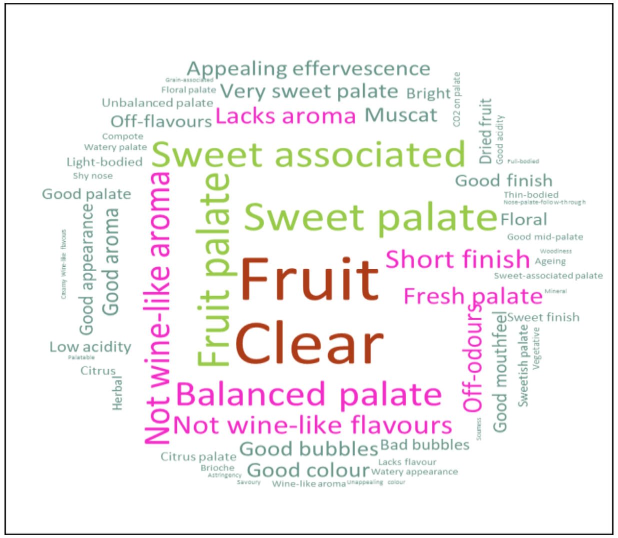
W818 (Quality **score=13.6)**



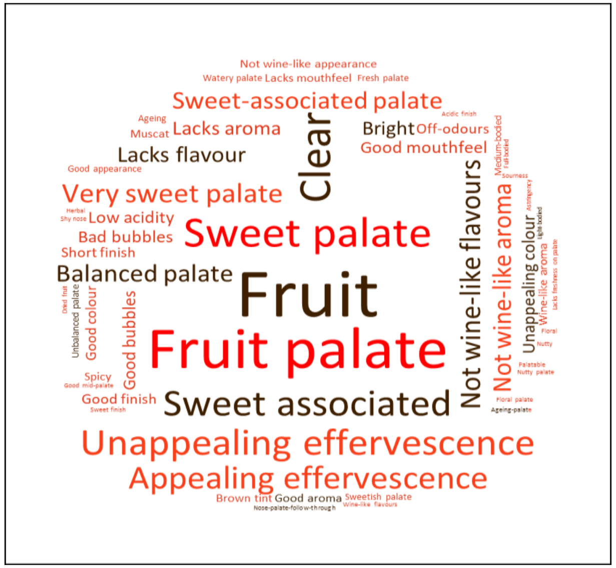
W736 (Quality score=13.2)



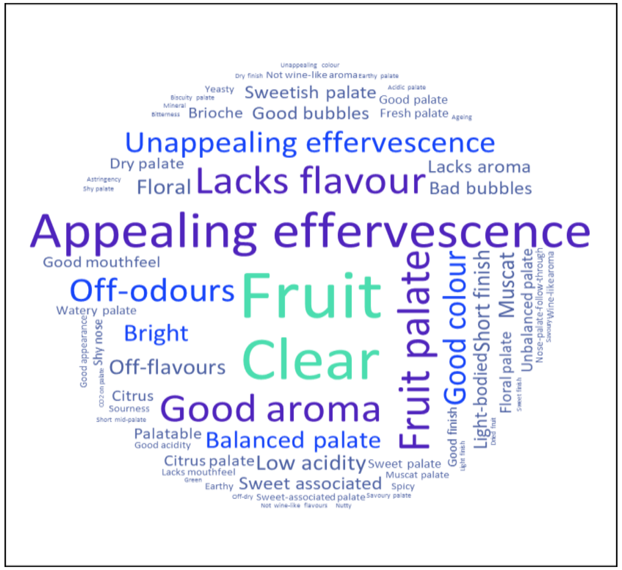
W429(Quality score=13.1)



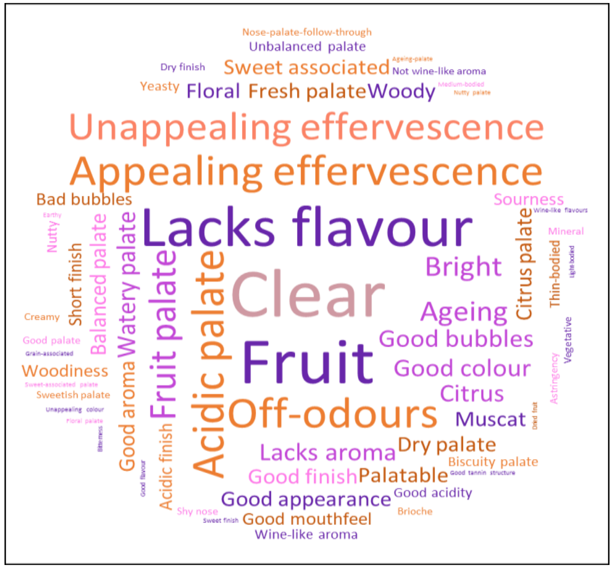
W916(Quality score=12.6)



W111(Quality score=12.6)



W004 (Quality score=12.5)



W017 (Quality score=11.9) **W214 (Quality score=11.6)** **W566 (Quality score=11.4)**

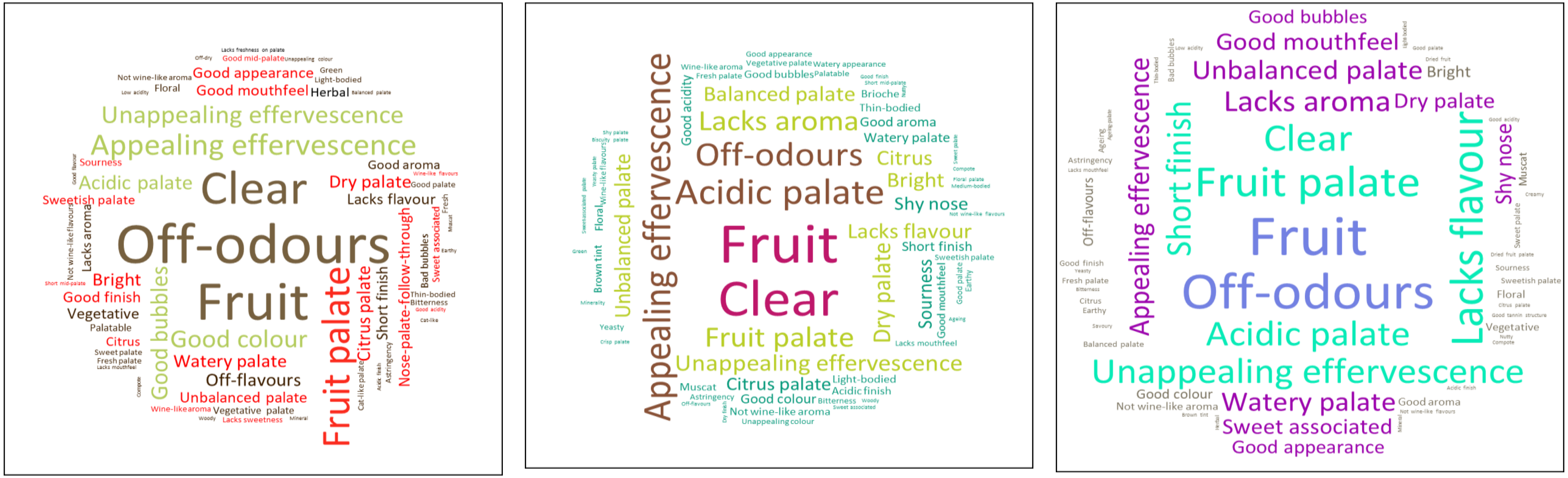


Figure 3.8 Overall profiles of the individual de-alcoholised sparkling wines. The font size represents citation frequency, larger font means the category was cited more than the small fonts. The colour, however, has no specific meaning in data analysis.

3.3.3. Origin of the negative sensory categories

The negative sensory categories identified in these wines seemingly contributed to the low quality of the wines. These included ‘unappealing’ effervescence, ‘acidic’ palate, ‘off-odours’, ‘unbalanced’ palate, ‘lacks’ flavour, ‘short finish’, ‘not wine-like’ aroma, ‘not wine-like’ flavour, ‘lacks’ aroma, in no particular order. For visual wine aesthetics the ‘unappealing’ effervescence was one of the categories which reduced the appearance quality score, although the reduction was not significant. Examples of the original data for this category included ‘low bubble on appearance’, ‘fine inconsistent bubbles’ and ‘fine mousse-not very active’, of which at times reduced the appearance score.

In terms of ‘off-odours’, there was a long list identified (**Addendum C2**). Examples included ‘faulty’, ‘chemical’, ‘overwhelmed by sulphury off-odour (H_2S?)’, ‘slightly charred character on the nose initially’, ‘initially burnt/rubber-like’, ‘slight SO_2 aroma’, ‘slight corky upon initial smell’, ‘volatile acidity overwhelms’. The presence of off-odours in a wine reduced the aroma quality, especially in W566, which observed the lowest aroma score in **Figure 3.4**. Additionally, in **Figure 3.9**, W566 was most correlated with off-odours, followed by W017, indicating that these wines had the most pronounced off-odours. In summary, off-odours were mostly from oxidative, reductive, sulphury (H_2S or SO_2), chemical, burnt attributes and volatile acidity origin.

The palate profiles were represented by 22 negative sensory categories (**Table 3.6**), and of these categories, ‘lacks’ flavour, ‘short finish’, ‘watery’, and ‘unbalanced’ were cited more than 30 times. As shown in **Figure 3.10**, W566, W214 and W004 were correlated with these categories, and the results highlighted detrimental effect on wine quality. The original text data included comments such as, ‘first appearance promising then the wine falls away totally’, ‘flavour disappears quickly’, ‘watered down palate’, ‘lacks finesse’; ‘taste a bit flabby’, and ‘lacks complexity’ for these categories (**Addendum C**, **Table C3**). These comments seemed to be the major detrimental effects on quality and, therefore, should be addressed to elevate palate quality. In addition to flavour and mouthfeel attributes, wine body was highlighted to be of low quality, specifically with comments such as ‘no structure to it’, ‘stripped’, ‘thin’, ‘lean’, and ‘lacks body’. All in all, the results showed that de-alcoholisation had an effect on the sensory profile. However, the level to which de-alcoholisation affected the quality of wines is inconclusive since the original non-de-alcoholised base wines were not studied. Other studies have, however, identified that de-alcoholisation does affect the quality of wine, especially on aroma and palate. For example, acidity perception increased (Lisanti *et al*., 2013; Corona *et al.*, 2019); a reduction in aroma, body, sweetness, and aftertaste was observed (Liguori *et al*., 2019). Similar results were obtained in the current study and may have highlighted a similar de-alcoholisation effect on the sparkling wines as observed in the aforementioned studies.

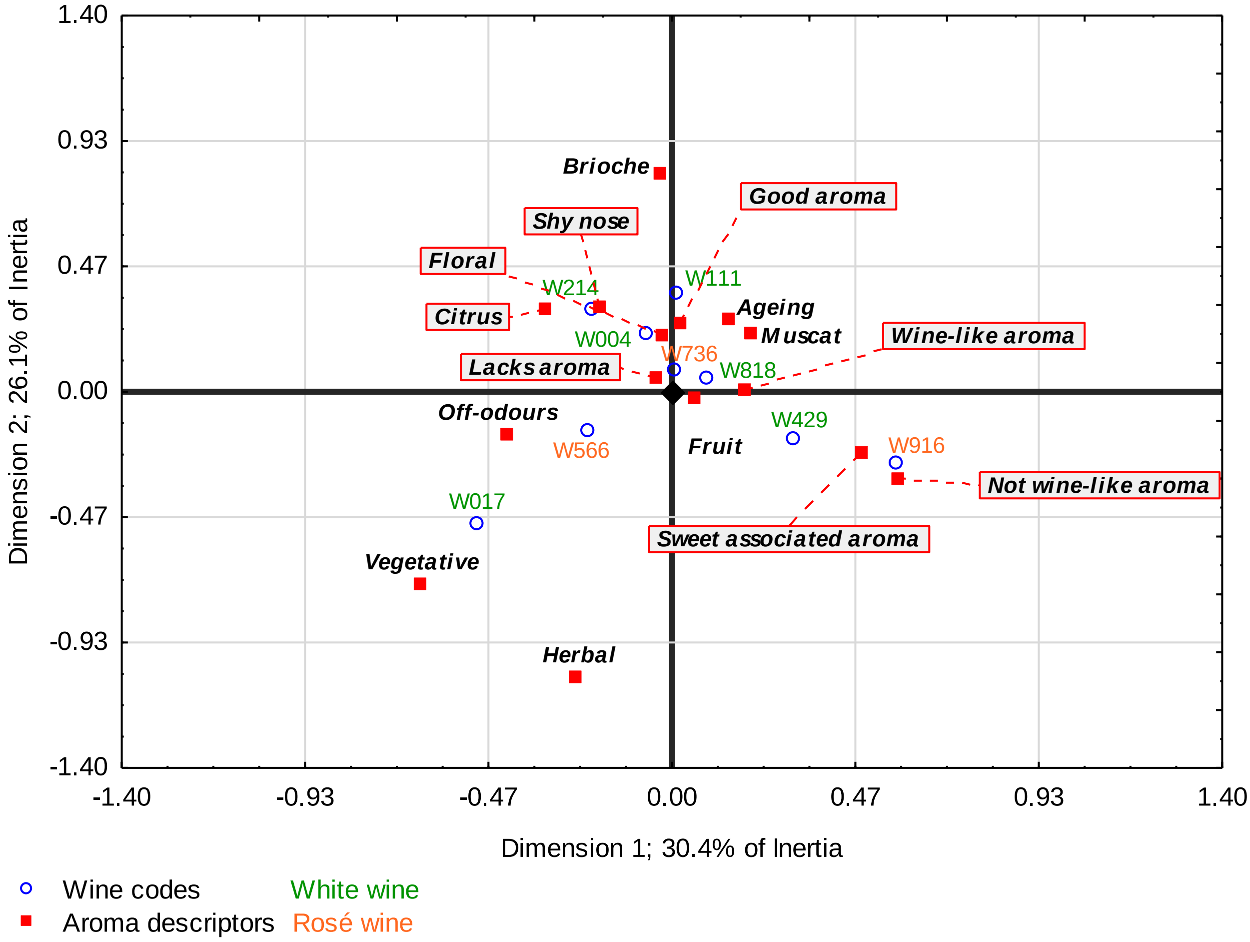


Figure 3.9 Correspondence analysis plot for aroma sensory categories cited ≥10 times across the sample set (n=9).

3.3.4. Summary of results

In summary, all wines were scored between 11 and 14 points out of 20, and the wine profiles showed that wines had fruity attributes on aroma and on the palate. However, in W566 and W017 'off-odours' were more pronounced, and consequently, the quality scores were less than 12 points indicating the detrimental effect on quality. However, the 'off-odours' in these two wines were not the only quality detrimental issues *per se* because none of the wines had over 15 points for quality and few 'off-odours' were cited in those wines. Other issues were listed in the profiles of all wines, including 'lacks' flavour, 'acidic' palate, 'short finish', 'unbalanced' palate, 'watery' palate, which could have been effects of de-alcoholisation. To a certain extent, de-alcoholisation changed the profiles of the wines, especially palate quality, whereby balance and flavour were reduced. However, at the same time, positive contributions to wine quality were observed with 'wine-like', 'floral' and 'fruit' aroma reported. Furthermore, on the palate, 'good bubbles' (contributed by 'fine mousse on palate', 'refreshing bubble', and 'delicate fizziness'), 'good mouthfeel', 'fresh' and 'dry' palate were reported, and these were appreciated by judges.

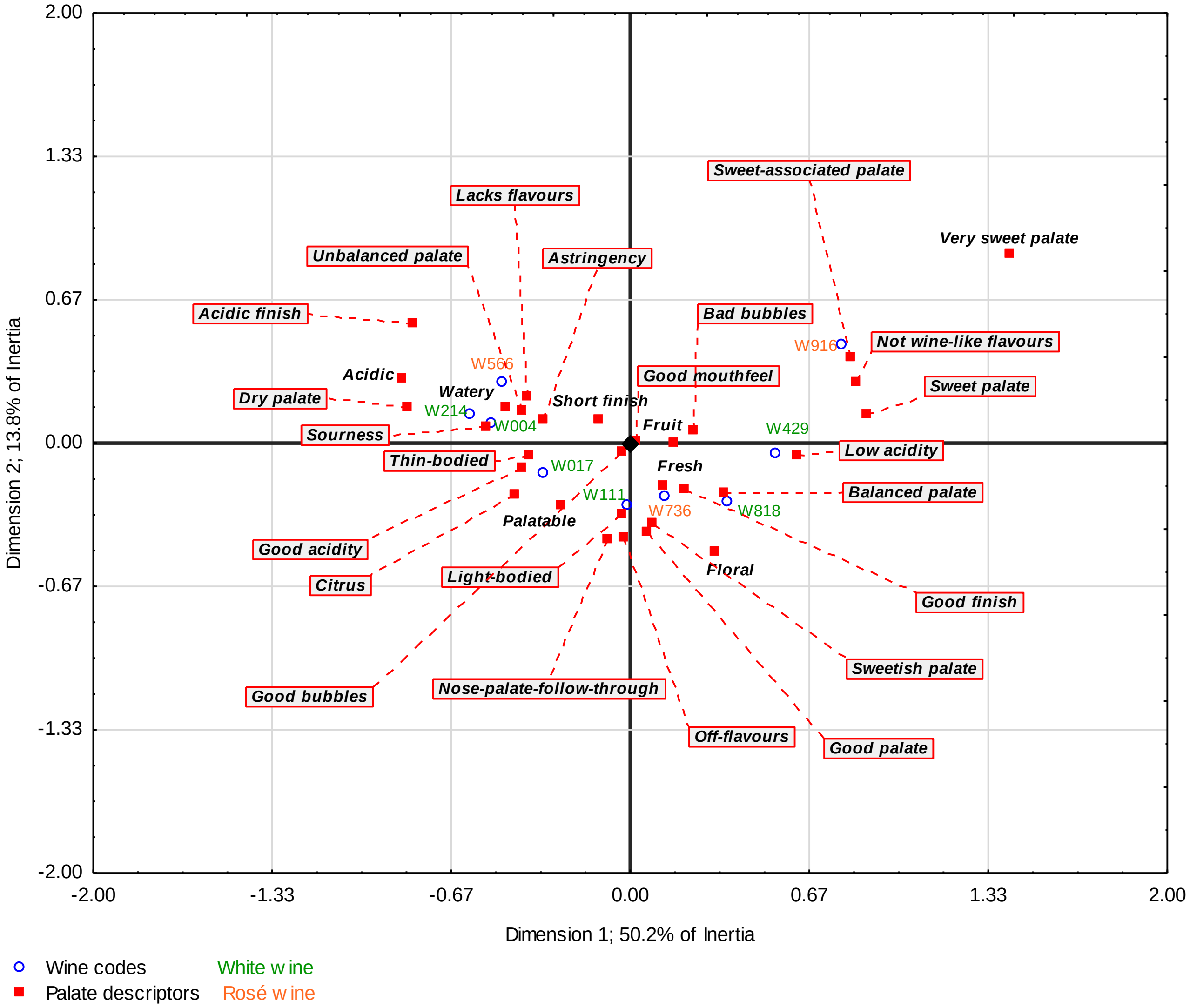


Figure 3.10 Correspondence analysis plot for palate sensory categories cited ≥10 times across the sample set (n=9).

3.4. Conclusions

The focus of this case study was to obtain the sensory profiles of the de-alcoholised sparkling wines, evaluate the quality and identify the drivers of wine quality associated with each wine. The results showed that each wine had few negative attributes in terms of appearance, hence the appearance quality was not significantly affected. In contrast, the aroma and palate had a high citation of off-odours and off-flavours, which negatively affected the quality scores; hence the wines were of low quality (11 to 14 points, on average). The palate quality showed the most detrimental effect, with scores less than 6 out of 10, lowering the overall quality scores. De-alcoholisation disrupted the wine body and flavour profile because comments such as the wines 'lacked' flavour, 'had a short finish', and 'were watery and unbalanced', were made. These comments highlighted a negative effect on flavour, mouthfeel and wine body. Similarly, for wine aroma, the presence of 'charred attributes', 'sulphury', and 'burnt/rubber-like' notes were highlighted. These characteristics need to be eliminated as they may be detrimental to quality and unpleasant to consumers. The results obtained in this study revealed components that were detrimental to wine quality (off-odours and low-quality mouthfeel), as such reducing the appreciation of the wine products. All wines were highlighted by the presence of ‘off-odours’, ‘watery’ and ‘unbalanced’ palate. As the latter result was a problem for the entire set of de-alcoholised sparkling wines, producers of de-alcoholised sparkling wines should take a step back and review the production process. The results reported may provide a basis from which the production process can be optimised so that best practises for retaining a balance between flavour and mouthfeel attributes are developed for the different cultivars and styles.

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Chapter 4: Chemical profiling of a set of South African de-alcoholised sparkling wines: Focus on volatile aroma compounds

Abstract

Wine chemistry plays an important role in quality perception and in determining the aroma, flavour, and mouthfeel attributes of wine. The South African wine industry has introduced a relatively new product category, de-alcoholised sparkling wines, into the wine market. The chemical profiles of these South African de-alcoholised sparkling wines have not been previously studied, and therefore their quality was not determined. In this context, information on the non-volatile and volatile composition of these wines was publicly scarce. Therefore, this study focused on quantifying the basic wine oenological parameters and volatile aroma compounds of these wines. Furthermore, compare the profile to published full-strength sparkling wines. Basic wine oenological parameters (ethanol, pH, titratable acidity (TA), glucose, fructose, and glycerol) were measured, and volatile compounds were quantified using gas chromatography-tandem mass spectrometry (GCMS-MS). The glycerol concentration ranged from 14.30 to 20.20 g/L and this range was higher than 5.21 to 9.36 g/L reported in research for full-strength wines. However, pH and TA ranges were comparable to those published for sparkling wines with full ethanol strength. No clear trend was observed for volatile composition compared to full-strength sparkling wines, as concentrations differed between wines. However, in this study, compounds such as 2-phenylethanol (3.513 to 9.515 mg/L), isoamyl alcohol (0.373 to 5.636 mg/L), ethyl butyrate (0.373 to 5.636 mg/L), and ethyl acetate (0.427 to 4.677 mg/L) were reported at lower concentrations than those in full-strength sparkling wines. Overall, a profile for de-alcoholised sparkling wines was obtained and the data obtained could be used for product benchmarking or as a basis for research focused on establishing a protocol for reduced loss of volatile compounds during de-alcoholisation.

Keywords: Volatile aroma compounds; de-alcoholised sparkling wines; South Africa; glycerol; full-strength sparkling wines

4.1. Introduction

The chemical profile of wine determines its overall sensory characteristics and hence its perceived quality. Volatile and non-volatile compounds constitute this profile and determine wine aroma, flavour, and mouthfeel attributes. More than a thousand volatile aroma compounds are found in wine, including esters, volatile acids, higher alcohols, aldehydes, volatile phenols, and ethanol (Francis and Newton, 2005; Tao and Li, 2009; Han *et al.*, 2022). Ethanol is a major volatile component in full-strength sparkling wines with concentrations of 10 to 13% v/v (Culbert *et al*., 2017; Cotea *et al*., 2021), and it enhances but at times suppresses the volatility of aroma compounds (Ferreira *et al*., 2007). Furthermore, it has been reported to enhance wine body, but may also impart a burning mouthfeel character in wine (Gawel *et al*., 2007). Each volatile compound has its unique physicochemical properties, such as hydrophobicity and volatility, determining its behaviour in a wine matrix. Non-volatile compounds include a wide range of phenolic compounds, organic acids, sugars, and glycerol. These compounds are correlated to mouthfeel and taste attributes such as body, length, texture, finish, sweetness, astringency, bitterness, and sourness (Sáenz-Navajas *et al*., 2012), but simultaneously correlate with volatile aroma compounds for wine aroma and flavour.

Recently, research has focused on the production and profiling of de-alcoholised beverages to understand the effect of ethanol reduction on the wine matrix and resulting wine quality. De-alcoholisation refers to the removal of ethanol from an alcoholic beverage, sparkling wine included, to a final concentration of ≤0.5% v/v (SAWIS, 2020). Methods such as spinning cone column (SCC) and reverse osmosis are used to de-alcoholise wines (Sam *et al*., 2021a). When using SCC, aroma compounds are extracted from the wine at 28°C and ethanol is removed from the de-aromatised wine at 38°C. The aroma fraction is then returned to the de-alcoholised base wine. Reverse osmosis uses semi-permeable membranes to remove ethanol from the wine at temperatures between 20 and 22°C. Both methods are used in the South African wine industry to de-alcoholise wines (BevZero, 2022).

Longo *et al.* (2017) has reviewed that during de-alcoholisation, volatile aroma compounds are inevitably reduced; the magnitude of reduction depended on the type of physical method used, the amount of ethanol removed and the physicochemical properties of the volatile compounds. In addition, Kopjar *et al*. (2010) and Rodríguez-Bencomo *et al*. (2011) highlighted that the hydrophobic character of each compound plays a role in its retention and salting effects. In a study by Rodríguez-Bencomo *et al*. (2011), ethyl decanoate and 2-phenylethanol, the most hydrophobic compounds, had the highest retention effects of all esters and higher alcohols, respectively. The results showed that the most hydrophobic aroma compounds are better retained during de-alcoholisation, while less hydrophobic can be lost at high concentrations. Therefore, de-alcoholisation can have different effects on the different volatile compounds present in wines.

The effects of de-alcoholisation on the chemical profiles of still wines and the resulting quality have been investigated (Petrozziello *et al.*, 2019; García *et al*., 2021). Although none of the studies focused on sparkling wines, it was reported that the removal of ethanol was accompanied by a reduction in the concentrations of volatile compounds. Sam *et al.* (2021b) reported more than 81% loss of esters, and it was concluded that the loss was due to the hydrophobicity of the compounds. This high loss of volatile compounds had a major impact on the sensory profile and quality because the compounds determine the aroma and flavour appreciated in wine, and their loss can therefore lead to poor quality wines.

All the above-mentioned studies were not on South African de-alcoholised sparkling wines. Moreover, the profiles of de-alcoholised sparkling wines have not been compared to those of full-strength sparkling wines to investigate the possible differences in volatile composition between the two product categories. Therefore, to bridge the gap in information available for these products, nine commercially available South African de-alcoholised sparkling wines were profiled, including white and rosé sparkling wines of dry, sweet, and semi-sweet styles. The focus was on obtaining the volatile profiles, but the non-volatile composition of the wines was also profiled.

4.2. Chemical profiling research methodology

4.2.1. Basic oenological wine parameter analysis

Ethanol

A single analysis of ethanol was done using the ALPHA II FTIR spectrometer (Bruker Optics, Ettlingen, Germany), at 4 cm^{-1} resolution scans with a 10 kHz scanner velocity. An attenuated total reflection (ATR) technique was used, using a ZnSe diamond ATR crystal fitted with a stainless-steel cap. A wine sample was loaded into the diamond platform, heated to 40°C, and the platform was cleaned with distilled water after each analysis. Thereafter, the spectra were processed through the OPUS software (OPUS version 7.0 software, Bruker Optics) at a wavenumber range of 4000 to 12500 cm^{-1} (Arendse *et al*., 2021). Ethanol content was quantified, in % v/v, using an in-house partial least squared (PLS) calibration build on the Alpha II FTIR instrument at the Department of Viticulture and Oenology, Stellenbosch University.

pH and titratable acidity (TA)

Single pH reading, for each wine, was measured using the Mettler DL 22 & Metrohm 702 pH meter and Merck buffer with pH 4 was used for electrode calibration. For TA analysis, 50 mL of a degassed wine sample was titrated using a Mettler & Metrohm auto-titrator. The sample was titrated to pH 7 using 0.3333 N of sodium hydroxide (NaOH) as a titration standard. Subsequently, the volume of NaOH used to titrate the wine was used to calculate TA.

Glucose and Fructose

Glucose and fructose concentrations were quantified by the enzyme analysis method using the Thermo Scientific™ Arena™ 20XT analyser (Thermo Fisher Scientific, Massachusetts, United

States of America). The samples were prepared as follows: 50 mL of wine, from a freshly opened bottle, was degassed for 40 seconds under vacuum, and 2 mL of the sample was transferred into two microtubes, for repeats, and centrifuged at 10000 g for three minutes for glucose analysis. The same procedure was followed for fructose analysis samples. After centrifugation, the supernatants were transferred into cuvettes containing the first reagent for glucose and fructose, respectively (see **Table 4.1**). Both glucose and fructose used standards from Merck (Johannesburg, SA) and Enzytec™ fluid sugar standard for automation (AEC-Amersham SOC Ltd., Halfway House, SA) as calibrators. Thermo Scientific™ fructose system kit (Anatech Instruments Ltd., Gauteng, SA) was used for fructose enzymatic analysis, whilst the Enzytec™ liquid glucose kit (AEC-Amersham SOC Ltd., SA) was used for glucose enzymatic analysis. For glucose reaction and analysis, 8 µL of the sample was incubated with 160 µL reagent one for a minute before a blank reading was measured at 340 nm. Thereafter, 40 µL of reagent two was added to the mixture and incubated for 10 minutes before measuring the glucose concentration (quantified in g/L) at 340 nm. The analysis of fructose differed in that 5 µL of fructose was added to 100 µL reagent one, and 25 µL of reagent two was added to the mixture before incubating for five minutes. After the incubation period, a blank reading was taken then 25 µL of reagent three was added. The mixture was incubated for seven minutes before measuring the amount of fructose in the sample, also quantified in g/L.

Table 4.1 Components of the reagents used for glucose and fructose analysis.

	Glucose analysis*	**Fructose analysis****
Reagent one	Buffer, NAD	Buffer, ATP, NAD
Reagent two	Hexokinase (HK), glucose-6-phosphate dehydrogenase (G6P-DH)	HK, G6P-DH
Reagent three	-	Buffer, phosphoglucose isomerase (PGI)

Supplied by * R-Biopharm, Darmstadt, Germany ** Thermo Scientific™, South Africa

Glycerol

A method developed by Eyéghé-Bickong *et al.* (2012) was used for glycerol analysis using high-performance liquid chromatography (HPLC). Samples were prepared by vortexing 1 mL of wine for one minute and then centrifuging the samples at 12000 g for two minutes. Eight hundred microlitres of the aliquot were collected and transferred into vials. A single sample was prepared per wine and was analysed. The analysis was performed on a 1260 Infinity liquid system (Agilent, California, United States of America) equipped with a micro-degasser (G1379B), 1260 binary pump (G1312B), 1260 standard auto-sampler (G1329B), 1260 thermostated column compartment (G1316A), 1260 diode array and multiple wavelength detector (G4212C) and a Hi-Plex H column (300 mm x 7.7 mm). A 10 mM sulphuric acid (H_2SO_4) was used as an isocratic mobile phase during analysis. Ten microlitres of each sample were injected into the Hi-Plex H column at 45°C with detection by the diode array detector at 210 nm and the reflective index detector at 45°C. The separation was performed at a flow rate of 0.6 mL/minute.

4.2.2. Volatile compounds analysis

Sample preparation

A sample from a bottle of each de-alcoholised sparkling wine was degassed under vacuum for 40 seconds to remove carbon dioxide (CO_2) in preparation for volatile compound analysis. Liquid-liquid extraction (LLE) was used to isolate volatile compounds from the wine into an extraction solvent, as described (Louw, 2007; Louw *et al*., 2009). Five mL of the degassed wine was mixed with 3 mL of 20 % sodium chloride (NaCl), 150 µL of 4-methyl-2-pentanol internal standard, and 2 mL of diethyl ether, in duplicates. The samples were vortexed and sonicated in a water bath at room temperature for 30 minutes to agitate the volatile compounds. After sonication, the samples were centrifuged at 2576 g for three minutes and were separated into two layers: aqueous and organic layer. The organic layers, containing the volatile compounds, were drawn out and transferred into vials containing sodium sulphate (Na_2SO_4) and were dried.

GCMS-MS conditions

The samples in vials were loaded onto a Trace 1300 gas chromatograph coupled with a Thermo Scientific™ TSQ™ 8000 triple quadrupole (GCMS-MS) as a detector for analysis, with a TriPlus RSH autosampler and was operated in a selected reaction monitoring (SRM) mode. The initial oven ramp was at a temperature of 40°C and was held at that temperature for five minutes before increasing to 200°C at a 5°C/minute rate with no holding time. Lastly, the temperature was increased to 250°C at a 25°C/minute rate, with a holding time of 11 minutes. One microliter of the sample was injected into the GCMS-MS through the Zebron™ ZB-WAX capillary GC column with dimensions of 60 m length x 0.25 mm internal diameter x 0.50 µm film thickness. The injection temperature was at 240°C in a split mode with a split flow rate of 5 mL/minute and split ratio of 5:1 for analysis. Each sample, prepared using the LLE method, was analysed in duplicate and data acquired in an SRM function for quantification.

4.2.3. Statistical analyses

Quantified data were exported to Microsoft Excel® for Microsoft 365 MSO (Version 2201 Build 16.0.14827.20180) for statistical analysis. The average and standard deviation for compounds measured in duplicate from one sample, such as glucose, fructose, and volatile aroma compounds, were calculated. A coefficient of variation was calculated to measure the distribution of the standard deviation relative to the average. The odour active value (OAV) for each volatile aroma compound was calculated by dividing the compound's concentration with its odour detection threshold (ODT).

4.3. Results and discussion

4.3.1. Basic oenological profiles of de-alcoholised sparkling wines

The ethanol concentration for all wines was ≤0.5% v/v (**Table 4.2**), achieved through the physical reduction of ethanol that was used to produce the wines, as permitted by SAWIS (2020). The pH levels ranged from 3.15 to 3.53 and fell within the range of 2.94 to 4.24 reported by Darias-Martín *et al*. (2003) for white wines and those reported for full-strength sparkling wines (Dos Santos *et al*., 2017; Rizzolo *et al*., 2018; Korenika *et al*., 2020). It was concluded that pH did not drastically change because of de-alcoholisation, as also observed in other de-alcoholisation studies (Corona *et al*., 2019; Liguori *et al*., 2019). The TA in the current study ranged from 5.70 to 7.40 g/L (**Table 4.2**). Darias-Martín *et al*. (2003) reported a TA range from 3.27 to 6.91 g/L in white wines and Louw (2007) reported a range from 4.33 to 7.55 g/L in young South African white wines. The TA range in the de-alcoholised sparkling wines in this study were of similar range, indicating that the TA values were normal in wines. The fructose and glucose concentrations predominately constitute residual sugar (RS), the total unfermented sugar in the wine, and winemakers determine wine style by this RS, hence the wine styles in **Table 4.2**. In this study, fructose ranged from 9.35 to 31.16 g/L and glucose from 3.26 to 31.13 g/L. Both these sugars contributed to the RS of each wine and the class to which the wines belong; dry (17 to 32 g/L), semi-sweet (32 to 50 g/L), and sweet (>50 g/L) (SAWIS, 2019).

Glycerol concentrations in the wines ranged from 4.89 to 20.20 g/L. W566 and W111 had the lowest concentrations of 4.89 and 5.01 g/L, respectively, and the rest had concentrations above 14.00 g/L. The concentrations above 14.00 g/L were unusual for sparkling wines, and as indicated by Ribereau-Gayon *et al*. (1998) wine rarely has above 12.00 g/L unless it is a noble late-harvest product. In South African wines, the glycerol range has been reported to be 5.21 to 9.36 g/L (Nieuwoudt *et al*., 2002) and 4.55 to 11.68 g/L (Louw, 2007), which is still below the 12.00 g/L rarely observed. Although the ranges in the above studies do not include those in sparkling wines, either full-strength or de-alcoholised, they serve as an indication of glycerol typically quantified in wines. An Italian sparkling wine study reported glycerol in sparkling wines below 10.00 g/L (Restani *et al*., 2007). This supports the notion by Ribereau-Gayon *et al*. (1998) that glycerol concentrations in wine are rarely higher than 12.00 g/L. Even in de-alcoholised still wines the concentration range was not found above 12.00 g/L, in fact, Corona *et al.* (2019) reported a reduction in glycerol from 8.75 to 4.49 g/L when the wine was de-alcoholised from 13.2 to 2.7% v/v, suggesting that when a wine is de-alcoholised, glycerol may be reduced. Therefore, the results obtained in this study are a rare occurrence and the reason may be that glycerol was physically added after fermentation, as permitted by SAWIS (2020).

4.3.2. Volatile profiles of de-alcoholised sparkling wines and comparison with full-strength sparkling wines

The volatile compounds were quantified through GCMS-MS and expressed in mg/L (**Table 4.3**), and out of all compounds quantified, acetic acid had the highest concentrations. The range for this compound was 49.957 to 103.867 mg/L. Published full-strength sparkling wine research has reported concentrations ranged from 90 to 230 mg/L (Ubeda *et al*., 2019) and 300 to 350 mg/L (Cotea *et al*., 2021). Furthermore, Capozzi *et al*. (2022) reported that the acetic acid concentration in wine (expressed as volatile acidity) may range up to 600 and 900 mg/L. Therefore, the values reported in the de-alcoholised sparkling wines were lower than all these ranges, except in W004, W111, W017 and W818, which had concentrations more than 90 mg/L (see **Table 4.3**).

Table 4.2 Basic oenological wine parameters for the de-alcoholised sparkling wines (n=9).

Wine code	**Cellar**	**Grape Variety**	**Wine style****	**Ethanol (% v/v)**	**pH**	**TA (g/L)**	**Glycerol (g/L)**	**Fructose (g/L)**		**Glucose (g/L)**	
								average ± SD	**%CV*****	**average ± SD**	**%CV**
W004	A	Chardonnay	Dry white	0.5	3.45	6.20	15.81	14.00 ± 0.10	0.714	12.24 ± 0.23	1.879
W111	B	Blend*	Dry white	0.5	3.52	5.80	5.01	21.30 ± 1.05	4.930	3.26 ± 0.02	0.613
W017	C	100% Sauvignon Blanc	Dry white	0.2	3.42	6.60	16.09	9.35 ± 0.10	1.070	9.74 ± 0.16	1.643
W214	D	Blend: 76% Pinot Noir and 24% Chardonnay	Dry white	0.5	3.15	7.40	14.30	12.83 ± 0.09	0.701	11.29 ± 0.04	0.354
W429	E	Blend: Sauvignon Blanc and White Muscadel	Sweet white	0.5	3.34	6.03	19.36	31.16 ± 0.90	2.888	27.35 ± 0.79	2.888
W818	C	100% Sauvignon Blanc	Sweet white	0.3	3.40	6.69	15.84	30.40 ± 0.04	0.132	31.13 ± 0.85	2.730
W566	B	Blend*	Dry rosé	0.5	3.53	5.87	4.89	11.98 ± 0.04	0.334	13.48 ± 0.04	0.297
W736	F	Blend*	Semi-sweet rosé	0.5	3.38	5.70	15.17	21.69 ± 0.58	2.674	19.72 ± 0.01	0.051
W916	E	Blend: 100% selection of red and white grapes	Sweet rosé	0.3	3.27	5.74	20.20	29.93 ± 0.64	2.138	26.43 ± 0.04	0.151

* The grape varieties used for the wine blend were not specified. **Style determined as per SAWIS regulations (2019). ***%CV – coefficient of variation (in %). One sample was measured in duplicate for both glucose and fructose, represented by average ± standard deviation. Standard deviation was determined as the difference between duplicate measurements.

Table 4.3 The concentrations (mg/L) of volatile compounds (average ± standard deviation) in South African de-alcoholised sparkling wines (n=9) quantified by GCMS- MS.

	Wine codes								
Compound	W004	W736	W566	W111	W017	W818	W214	W429	W916
Volatile acids									
Acetic acid	90.233 ± 0.789	69.847 ± 2.610	49.957 ± 2.483	103.867 ± 5.796	94.884 ± 5.699	92.347 ± 3.117	56.020 ± 1.159	84.532 ± 3.277	75.555 ± 9.511
Isobutyric acid	0.476 ± 0.019	0.427 ± 0.021	0.261 ± 0.011	0.667 ± 0.036	0.509 ± 0.030	0.476 ± 0.035	0.485 ± 0.008	0.310 ± 0.006	0.489 ± 0.004
Butyric acid	0.940 ± 0.047	0.916 ± 0.064	0.900 ± 0.046	0.837 ± 0.052	0.834 ± 0.049	0.706 ± 0.068	1.290 ± 0.024	0.510 ± 0.014	0.787 ± 0.001
Isovaleric acid	0.282 ± 0.000	0.260 ± 0.008	0.197 ± 0.009	0.297 ± 0.016	0.293 ± 0.013	0.271 ± 0.017	0.296 ± 0.001	0.186 ± 0.001	0.289 ± 0.011
Valeric acid	0.107 ± 0.000	0.109 ± 0.001	0.108 ± 0.002	0.109 ± 0.000	0.110 ± 0.001	0.108 ± 0.000	0.115 ± 0.011	0.112 ± 0.001	0.121 ± 0.000
Octanoic acid	1.780 ± 0.034	1.585 ± 0.024	2.316 ± 0.000	2.575 ± 0.113	1.627 ± 0.139	0.645 ± 0.010	2.920 ± 0.005	1.901 ± 0.056	1.742 ± 0.081
Decanoic acid	0.444 ± 0.024	0.255 ± 0.006	0.582 ± 0.004	0.822 ± 0.010	0.257 ± 0.020	0.170 ± 0.013	0.644 ± 0.034	0.223 ± 0.002	0.535 ± 0.016
Minimum to Maximum	**0.107 - 90.233**	**0.109 to 69.847**	**0.108 to 49.957**	**0.109 to 103.867**	**0.110 to 94.884**	**0.108 to 92.347**	**0.115 to 56.020**	**0.112 to 84.532**	**0.121 to 75.555**
Total volatile acids	**94.262**	**73.399**	**54.321**	**109.174**	**98.514**	**94.723**	**61.770**	**87.774**	**79.518**
Higher alcohols									
2-Phenylethanol	7.540 ± 0.345	7.753 ± 0.287	5.925 ± 0.038	5.873 ± 0.279	9.515 ± 0.987	7.458 ± 0.374	6.189 ± 0.268	3.513 ± 0.195	6.670 ± 0.989
1-Butanol	0.077 ± 0.003	0.069 ± 0.009	0.089 ± 0.009	0.085 ± 0.008	0.077 ± 0.008	0.079 ± 0.009	0.088 ± 0.007	0.093 ± 0.007	0.078 ± 0.009

2-Methyl-1-butanol	3.491 ± 0.389	2.952 ± 0.325	3.536 ± 0.457	4.729 ± 0.672	5.695 ± 0.647	0.470 ± 0.043	5.011 ± 0.487	1.484 ± 0.113	0.658 ± 0.006
Isoamyl alcohol	1.858 ± 0.117	1.587 ± 0.102	1.921 ± 0.160	2.406 ± 0.244	5.636 ± 0.622	0.373 ± 0.022	2.798 ± 0.194	0.857 ± 0.039	0.410 ± 0.002
Isobutanol	0.184 ± 0.001	0.428 ± 0.337	0.599 ± 0.043	0.192 ± 0.001	0.403 ± 0.314	0.222 ± 0.006	0.196 ± 0.007	0.295 ± 0.165	0.278 ± 0.018
Minimum to Maximum	**0.077 to 7.540**	**0.069 to 7.753**	**0.089 to 5.925**	**0.085 to 5.873**	**0.077 to 9.515**	**0.079 to 7.458**	**0.088 to 6.189**	**0.093 to 3.513**	**0.078 to 6.670**
Total higher alcohols	**13.150**	**12.789**	**12.070**	**13.285**	**21.326**	**8.602**	**14.282**	**6.242**	**8.094**
					Esters				
Ethyl acetate	1.944 ± 0.325	3.698 ± 0.182	3.942 ± 0.062	4.677 ± 0.994	2.926 ± 0.572	2.543 ± 0.159	2.929 ± 0.725	1.365 ± 0.222	0.427 ± 0.385
Isobutyl acetate	0.080 ± 0.001	0.077 ± 0.004	0.082 ± 0.004	0.090 ± 0.003	0.080 ± 0.002	0.080 ± 0.005	0.085 ± 0.004	0.083 ± 0.003	0.085 ± 0.005
Ethyl butyrate	0.037 ± 0.002	0.073 ± 0.006	0.041 ± 0.004	0.045 ± 0.005	0.057 ± 0.005	0.027 ± 0.000	0.055 ± 0.003	0.028 ± 0.000	0.034 ± 0.003
2-Methylbutyl acetate	0.050 ± 0.004	0.062 ± 0.003	0.112 ± 0.009	0.246 ± 0.022	0.097 ± 0.006	0.024 ± 0.001	0.144 ± 0.006	0.019 ± 0.000	0.018 ± 0.000
Ethyl lactate	7.579 ± 0.026	6.582 ± 0.100	4.694 ± 0.048	2.094 ± 0.120	1.770 ± 0.031	1.574 ± 0.032	2.328 ± 0.127	4.762 ± 0.393	1.384 ± 0.193
Diethyl succinate	0.551 ± 0.024	0.561 ± 0.049	0.162 ± 0.010	0.134 ± 0.008	0.111 ± 0.006	0.114 ± 0.006	0.204 ± 0.004	0.117 ± 0.003	0.149 ± 0.001
Minimum to Maximum	**0.037 to 7.579**	**0.062 to 6.582**	**0.041 to 4.694**	**0.045 to 4.677**	**0.057 to 2.926**	**0.024 to 2.543**	**0.055 to 2.929**	**0.019 to 4.762**	**0.018 to 1.384**
Total esters	**10.241**	**11.053**	**9.033**	**7.286**	**5.041**	**4.362**	**5.745**	**6.374**	**2.097**
					Aldehyde				
Trans-2-hexenal	0.058 ± 0.003	0.054 ± 0.002	0.050 ± 0.000	0.049 ± 0.002	0.049 ± 0.004	0.048 ± 0.000	0.049 ± 0.001	0.047 ± 0.002	0.047 ± 0.001

Standard deviation was determined as the difference between duplicate measurements of samples from one bottle.

Higher alcohols ranged from 6.242 mg/L in W429 to 21.326 mg/L in W017, and 2-phenylethanol had the highest concentration in all wines, ranged from 3.513 to 9.515 mg/L. The values reported for 2-phenylethanol were, however, not in range of 12.221 to 20.578 mg/L reported by Torrens *et al*. (2010) and 10.600 to 12.700 mg/L reported by Ubeda *et al*. (2019). In contrast, Korenika *et al*. (2020) reported a range from 2.950 to 26.107 mg/L in Croatian wines produced from vine of the Plešivica, Krašić and Zelina regions, which the results of this current study fall under. Isoamyl alcohol was observed at concentrations ranging from 0.373 to 5.636 mg/L in the de-alcoholised sparkling wines and was lower than 86.8 to 101.0 mg/L and 150.08 to 171.09 mg/L ranges reported by Ubeda *et al*. (2019) and Torrens *et al*. (2010), respectively. Contrarily, Cotea *et al*. (2021) reported an isoamyl alcohol range (0.486 to 1.019 mg/L) in Muscat Ottonel sparkling wines, which was inclusive of the values obtained for W818, W429 and W916, which were all sweet wines. However, the Muscat Ottonel sparkling wines were brut style with RS <3.0 g/L.

The total ester concentrations ranged from 2.097 to 11.053 mg/L (**Table 4.3**) in these de-alcoholised sparkling wines, and the highest values for esters were observed for ethyl lactate and ethyl acetate. The concentration ranges were 1.384 to 7.579 mg/L and 0.427 to 4.677 mg/L for ethyl lactate and ethyl acetate, respectively. In comparison to published sparkling wine research, Ubeda *et al.* (2019) reported a total ester concentration of 31.3 mg/L in base wine used for sparkling wine production, which changed to 7.21 mg/L after 12 months of ageing. Pozo-Bayón *et al.* (2009) pointed out that a reduction in ester concentration was observed from alcoholic fermentation to secondary fermentation, which was confirmed by Ubeda *et al.* (2019).

However, the values in the base wine of the study (Ubeda *et al.,* 2019) were notably different from those in the de-alcoholised sparkling wines currently profiled, although no secondary fermentation occurred in both these wines. In Cava base wines, ethyl lactate ranged from 6.44 to 8.62 mg/L, which although different from those reported in the current study, was more relatable since the concentration in aged Cava increased and ranged from 49.98 to 87.45 mg/L (Torrens *et al*., 2010). Dos Santos *et al*. (2017) reported 8.0 to 45.2 mg/L for ethyl acetate and these concentrations were above the ranges reported in the current study.

Volatile compound concentrations quantified in this study were compared with those of full-strength sparkling wines to determine the profile relative to similar wine styles, especially in the absence of published information on other de-alcoholised sparkling wines. The concentrations of most of the compounds were below those published for full-strength sparkling wines, examples included 2-phenylethanol, diethyl succinate, isoamyl alcohol, ethyl lactate, ethyl acetate and octanoic acid (**Table 4.4**). Only butyric acid, isovaleric acid and isobutyl acetate were exceeded the ranges reported in full-strength sparkling wines. Isobutyl acetate ranged from 0.077 to 0.090 mg/L in wines W736 and W111, respectively. While Korenika *et al*. (2020) reported concentrations of 0.010 to 0.078 mg/L, and W736 was within this range. However, the other wines exceeded these concentrations.

Volatile compounds such as trans-2-hexenal, ethyl butyrate, 2-methyl-1-butanol, isoamyl alcohol, and isobutanol were quantified at concentrations less than those in published research (**Table 4.4**).

Essentially, in comparison to published research, no clear trend was observed when investigating the profile of de-alcoholised sparkling wines. The comparison of profiles may not be straightforward because compound concentrations differ from wine to wine. As a result, when interpreting the volatile compound profile reported in this study, relative to the cited studies, it is important to keep in mind that the full-strength sparkling wines compared to were not the base wines from which the de-alcoholised wines were produced. Therefore, the profile comparison only serves as a guide in identifying the difference between the profiles of de-alcoholised and full-strength sparkling wines.

In cases whereby no data on the concentrations of specific volatile compounds in full-strength sparkling wines were available, full-strength still wines were used as comparison. For example, concentrations of valeric acid, isobutyric acid, 2-methylbutyl acetate and trans-2-hexenal were not mentioned in sparkling wine studies; therefore, results from still wines were used. Isobutyric acid concentrations ranged from 0.261 to 0.667 mg/L and Louw (2007) and Weldegergis *et al.* (2011) reported a range of 0.130 to 1.830 mg/L in South African full-strength still wines of which the values in de-alcoholised sparkling wines were in line with.

Valeric acid ranged from 0.107 to 0.121 mg/L in the current study, but Weldegergis *et al*. (2011) reported ranges from 1.41 to 1.68 mg/L in full-strength white wines produced from six South African regions. 2-Methylbutyl acetate ranged from 0.018 to 246 mg/L in the current study and a range of 0.100 to 0.399 mg/L was reported in full-strength still wines (Molina *et al*., 2007; Swiegers *et al*., 2009). Only W566, W111, and W214 were reported in the same range for 2-methylbutyl acetate in the de-alcoholised sparkling wines. Trans-2-hexenal ranges were also compared to those in still wines, a range of 0.047 to 0.058 mg/L was reported in the de-alcoholised sparkling wines, however, De Revel and Bertrand (1994) reported concentrations of 0.02 to 1.60 µg/L. Similar trends between de-alcoholised sparkling wines and full-strength still wines were observed when compared to full-strength sparkling wines. Some compounds were in the ranges reported for full-strength still wines whilst others were above and below these ranges, and as a result, no clear trend was observed.

In terms of perception threshold, most volatile compounds had concentrations below their ODT with an OAV less than one (**Table 4.5**), except for ethyl butyrate, isovaleric acid, butyric acid, trans-2-hexenal, and octanoic acid in all wines, and 2-methylbutyl acetate in only W111. Above the ODT, each volatile compound could potentially exert the aroma characteristics in wine listed **Table 4.4**, although other volatile compounds may possibly have suppressive aroma effects. However, compounds quantified below their ODT could still affect wine aroma because ODT does not guarantee that the attribute associated with compound will be perceived in aroma and flavour.

Volatile compounds, even below their ODT, may interact in synergy with other volatile compounds to exert flavour (Dalton *et al*., 2000; Ishii *et al*., 2008). Although most volatile compounds in this study were present below their ODT, they may have contributed to the wine profile. However, not enough information was generated in the current study to make a direct correlation between chemical and sensory profiles and determine the role of each aroma compound on the profiles reported in **Chapter 3**.

Table 4.4 The aroma descriptions and odour detection thresholds (ODT) of volatile compounds and their ranges in full-strength wines.

Volatile compounds	Aroma description	Odour detection threshold (mg/L)	Range in de-alcoholised sparkling wines	Range in full-strength sparkling wines (mg/L)
		Volatile acids		
Acetic acid	Sour, pungent, vinegar[a]	200.00[a]	49.957 to 103.867	90.000 to 350.000[bc]
Isobutyric acid	Acidic[d]	2.30[d]	0.261 to 0.667	0.130 to 1.830[ef] *
Butyric acid	Rancid, cheese, sweat[d]	0.17[d]	0.510 to 1.290	0.001 to 0.002[g]
Isovaleric acid	Sweat, rancid[g]	0.03[g]	0.510 to 1.290	0.003 to 0.044[g]
Valeric acid	n.f	n.f	0.107 to 0.121	1.41 to 1.68[f] *
Octanoic acid	Sweat, cheese[a]	0.50[a]	0.645 to 2.920	6.730 to 9.085[bh]
Decanoic acid	Rancid, fat[dg]	1.00[dg]	0.170 to 0.822	0.700 to 1.470[bi]
		Higher alcohols		
2-Phenylethanol	Floral, rose, honey[g]	14.00[dg]	3.513 to 9.515	10.600 to 20.578[bh]
1-Butanol	Medicinal, fusel odour[d]	150.00[dg]	0.069 to 0.093	0.028 to 0.186[g]
2-Methyl-1-butanol	whiskey, burnt, nail polish[g]	30.00[g]	0.470 to 5.695	6.898 to 38.100[gj]
Isoamyl alcohol	Alcohol, nail polish[g]	40.00[g]	0.373 to 5.636	16.317 to 167.080[bghj]
Isobutanol	Alcohol, nail polish[g]	30.00[g]	0.184 to 0.599	5.273 to 23.922[bghij]
		Esters		
Ethyl acetate	Varnish, fruity, solvent[d]	12.26[d]	0.427 to 4.677	8.000 to 45.200[j]
Isobutyl acetate	Apple, banana[g]	6.14[g]	0.077 to 0.090	0.010 to 0.078[gh]
Ethyl butyrate	Apple[a]	0.02[d]	0.027 to 0.073	0.385 to 1.900[hi]

2-Methylbutyl acetate	Banana, fruity[kl]	0.16[kl]	0.018 to 0.246	0.100 to 0.399[kl] *
Ethyl lactate	Butter, lactic, fruity[dg]	154.60[d]	1.384 to 7.579	2.131 to 14.871[ghi]
Diethyl succinate	Overripe, aged, fruity, melon[dg]	200.00[dg]	0.111 to 0.561	0.055 to 11.498[bgi]
		Aldehyde		
Trans-2-hexenal	Green[m]	0.004[m]	0.047 to 0.058	0.02 to 1.60 µg/L[m] *

[a]Francis and Newton (2005) [b]Ubeda *et al*. (2019) [c]Cotea *et al*. (2021) [d]Louw *et al*. (2010) [e]Louw (2007) [f] Weldegergis *et al*. (2011) [g]Korenika *et al*. (2020) [h]Torrens *et al*. (2010) [i]Hildago *et al*. (2004) [j]Dos Santos *et al*. (2017) [k]Molina *et al*. (2007) [l]Swiegers *et al*. (2009) [m]De Revel and Bertrand (1994). n.f– information not found. * In full-strength still wines.

Table 4.5 The odour activity value (OAV) of volatile compounds in South African de-alcoholised sparkling wines (n=9).

					Wine codes				
Compound	**W004**	**W736**	**W566**	**W111**	**W017**	**W818**	**W214**	**W429**	**W916**
Ethyl acetate	0.159	0.302	0.322	0.382	0.239	0.207	0.239	0.111	0.035
Isobutyl acetate	0.013	0.013	0.013	0.015	0.013	0.013	0.014	0.014	0.014
Ethyl butyrate	**1.837**	**3.631**	**2.074**	**2.268**	**2.844**	**1.341**	**2.747**	**1.377**	**1.710**
2-Methylbutyl acetate	0.314	0.389	0.700	**1.537**	0.607	0.148	0.900	0.116	0.111
Ethyl lactate	0.049	0.043	0.030	0.014	0.011	0.010	0.015	0.031	0.009
Diethyl succinate	0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2-phenylethanol	0.539	0.554	0.423	0.419	0.680	0.533	0.442	0.251	0.476
1-Butanol	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2-Methyl-1-butanol	0.116	0.098	0.118	0.158	0.190	0.016	0.167	0.049	0.022
Isoamyl alcohol	0.046	0.040	0.048	0.060	0.141	0.009	0.070	0.021	0.010
Isobutanol	0.006	0.014	0.020	0.006	0.013	0.007	0.007	0.010	0.009
Acetic acid	0.451	0.349	0.250	0.519	0.474	0.462	0.280	0.423	0.378
Isobutyric acid	0.207	0.186	0.113	0.290	0.221	0.207	0.211	0.135	0.212

Butyric acid	**5.431**	**5.296**	**5.200**	**4.840**	**4.821**	**4.080**	**7.459**	**2.950**	**4.549**
Isovaleric acid	**8.558**	**7.890**	**5.961**	**9.013**	**8.870**	**8.201**	**8.980**	**5.642**	**8.756**
Valeric acid	*	*	*	*	*	*	*	*	*
Octanoic acid	**3.559**	**3.170**	**4.631**	**5.151**	**3.253**	**1.290**	**5.841**	**3.802**	**3.484**
Decanoic acid	0.444	0.255	0.582	0.822	0.257	0.170	0.644	0.223	0.535
Trans-2-hexenal	**14.53**	**13.582**	**12.558**	**12.241**	**12.129**	**11.889**	**12.134**	**11.65**	**11.764**

*No odour detection threshold for valeric acid was found in published studies so OAV was not calculated. The values in bold highlight the OAVs above one.

4.3.3. Profile comparison between de-alcoholised sparkling and still wines

Acetic acid was one of the volatile compounds found at higher concentration in this study, with a range of 49.957 to 103.867 mg/L (**Table 4.4**), whereas in reported de-alcoholisation studies it was less than 0.100 mg/L (Liguori *et al*., 2013, 2019). However, this could be an invalid comparison, because the initial concentrations before de-alcoholisation, in both studies, were less than 0.450 mg/L. Butyric acid (0.510 to 1.290 mg/L) and isobutyric acid (0.261 to 0.667 mg/L) were also observed at concentrations above those reported for de-alcoholised still wine studies. Gómez-Plaza *et al*. (1999) reported a butyric acid concentration of 0.53 mg/L, while Liguori *et al.* (2013) reported that it was undetected after de-alcoholisation.

In terms of higher alcohols, butanol, isoamyl alcohol, and isobutanol were found at higher concentrations. For example, isobutanol ranged from 0.184 to 0.599 mg/L in this study, and Liguori *et al*. (2019) reported that its concentration was reduced from 2.28 to <0.07 mg/L. 2-Phenylethanol was at lower concentrations (3.513 to 9.515 mg/L) in this study than the concentrations, 56.60 and 60.49 mg/L, reported by Gómez-Plaza *et al*. (1999) and Lisanti *et al*. (2013) respectively. Diban *et al*., (2008) and Rodríguez-Bencomo *et al*. (2011) indicated that 2-phenylethanol was not easily reduced during de-alcoholisation, hence the retention observed by Gómez-Plaza *et al*. (1999) and Lisanti *et al*. (2013). However, Liguori *et al*. (2019) reported more than 96.47% loss in 2-phenylethanol from 52.71 to 1.86 mg/L. A similar high reduction trend could have been observed for the de-alcoholised sparkling wines, or perhaps the concentrations in the base wines used for de-alcoholised sparkling wine production were at ranges of 10.600 to 20.578 mg/L (**Table 4.4**).

Ethyl butyrate in this study ranged from 0.027 to 0.073 mg/L, while Liguori *et al*. (2019) reported 100% decrease of this compound from 0.15 to 0.00 mg/L. Ethyl lactate in wines W004, W736, W566 and W429 showed higher concentrations than the 2.30 mg/L reported by Gómez-Plaza *et al*. (1999) in white wine de-alcoholised from 10.6 to 0.3% v/v ethanol. In both these esters, de-alcoholisation could have reduced the concentrations to varying degrees due to the hydrophobicity of each compound (Diban *et al*., 2008). Therefore, ethyl lactate could have either been retained within the full-strength sparkling wine range due to the wine matrix, or it was in higher concentration in the original base wines and resulted in the final concentration observed. Other compounds, including 2-methyl-1-butanol, trans-2-hexenal, isovaleric acid, ethyl butyrate, valeric acid, and 2-methylbutyl acetate were not quantified in de-alcoholised still wines and therefore no profile comparison was done.

4.3.4. General discussion and recommendations

In summary, the profile comparison showed that volatile compounds may differ in concentrations from study to study. As indicated by Longo *et al*. (2017) factors such as, grape variety, the yeast used, fermentation and post-fermentation treatment have an influence on the concentrations and type of volatile compounds found in wine. De-alcoholisation and the method used to de-alcoholise the wines also have an impact on the concentrations reported in a wine. The spinning cone column (SCC) was used to de-alcoholise W214 and W004, while the de-alcoholisation method used for the other seven wines was not disclosed by the producing cellars. It has been reported that different methods affect the volatile compounds differently (García *et al*., 2021; Sam *et al*., 2021a, b). To obtain the dynamics of change in volatile concentrations a controlled experiment should be conducted. For example, a stepwise ethanol reduction and reconstitution of the wine after de-alcoholisation should be done to have a controlled study of the change in volatile compounds during de-alcoholisation. From this, an effective method for de-alcoholising South African wine cultivars could be identified and ultimately, a correlation between sensory quality and chemical composition could be found.

4.4. Conclusions

The focus of the study was to obtain the chemical profile of de-alcoholised sparkling wines and to provide a point of reference for the wine style by comparison with published research. pH and TA of the wines were of the typical wine range, but higher glycerol concentrations (14.30 to 20.20 g/L) were observed, as opposed to 5.21 to 9.36 g/L in other studies. However, the South African wine regulations for de-alcoholised products permit the addition of glycerol, and the concentrations could be the result of external addition. The main findings in volatile composition showed no clear trend in volatile profile between the de-alcoholised and full-strength sparkling wines. However, 2-phenylethanol, isoamyl alcohol, isobutanol, 2-methyl-1-butanol, ethyl butyrate, and ethyl acetate were at considerably lower concentrations in de-alcoholised sparkling wines than full-strength wines. Hence the total concentrations of esters and higher alcohol were lower than those in published research. This is comparable to observations of de-alcoholised wine research and highlights similar effects, loss of volatile compounds, on the chemical profile as reported by researchers before. Although the sample set was small (nine wines), the profiles obtained will aid in establishing a basis for future cultivar and wine style specific research. Furthermore, the profiles highlight the difference in volatile composition between the de-alcoholised wine category and full-strength wines. Future research should focus on optimising physical methods which can optimally preserve the volatile fraction during de-alcoholisation, and effectively reconstituting the base wines after de-alcoholisation for quality products.

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Chapter 5: General discussion and conclusions

5.1. Introduction

De-alcoholised sparkling wines are a relatively new category in the South African wine industry. Thus, no research has been published on the quality and profiles of these wines. However, there seems to be an increased global demand for de-alcoholised wines, mainly for the health and social benefits associated with these products (Bucher *et al*., 2019). This trend was also noted in South Africa (SA), where consumers are increasingly consuming de-alcoholised still and sparkling wines (Pretorius, 2020). De-alcoholised sparkling wines contain a maximum of 0.5% v/v ethanol and a minimum CO_2 pressure of 300 kPa (SAWIS, 2020). The wines are produced through yeast-mediated alcoholic fermentation to the full ethanol strength of table wines (*circa* 12 to 14% v/v) and, thereafter, subjected to the successive physical separation and removal of the volatile fermentative flavour fraction from the base wines, followed by the physical reduction of the ethanol content. The resulting de-alcoholised base wines are reconstituted by re-introducing volatile fractions, adding permitted chemical compounds, and sparging with external CO_2 to form the final product. Previous studies have, however, found that the de-alcoholisation process leads to reduced concentrations of volatile compounds and that it affects the sensory quality (Liguori *et al*., 2019; García *et al*., 2021; Sam *et al*., 2021). Therefore, since the production of de-alcoholised sparkling wines is relatively new in the market and their profiles have not been well studied, the focus of this study was to investigate the quality, sensory and chemical profiles of a selection of South African de-alcoholised sparkling wines.

5.2. Main research findings and general discussion

The research was conducted in two research phases, and nine commercially available South African de-alcoholised sparkling wines were profiled. Firstly, using a 20-point quality scoring system, wine quality was evaluated by 51 wine industry professionals. The professionals included winemakers, marketing directors, quality assurance managers, marketing managers, wine researchers and tasting room ambassadors. The three modalities evaluated were appearance, aroma and palate, and the points were distributed in this manner: 3 points for appearance, 7 for aroma and 10 for palate quality. Furthermore, sensory profiles, using the free listing method, were determined to investigate the main sensory categories associated with the wines (see **Chapter 3**). The main findings were:

a) All wines were scored, on average, between 11 and 14 points out of 20.
b) Palate quality had the most negative effect on the overall score, with average scores lower than 6 points out of 10 and, therefore, 4 points lost for palate quality.
c) Aroma and palate profiles mostly had fruity attributes but were accompanied by the presence of faults, especially on the palate. Examples of the faults included ‘something chemical on the nose’, ‘filter paper’, ‘vinegar’, ‘oxidative character’, ‘dirty on the palate’, ‘off-taste’, ‘taste of old sweat overpowers’, ‘slight reductive note’, ‘a watery mess’, ‘lacks finesse’, ‘acid is high and stands apart’.

The results of this study outlined the perceived quality and the drawbacks detected in de-alcoholised sparkling wines. However, the origin of the drawbacks is unknown but could be hypothesised to be acquired from de-alcoholisation. As such, a thorough investigation during production, needs to be conducted so that detailed protocols may be put in place for quality de-alcoholised sparkling wine production. Longo *et al.* (2017) concluded that all de-alcoholisation methods change wine composition. Therefore, change in wine aroma and mouthfeel characters is inevitable, especially when reducing the ethanol to 0.5% v/v. Lisanti *et al.* (2013) reported an increased presence of cooked off-flavour, which was also detected in this study, when 3 and 5% v/v ethanol was removed. It was concluded that this was a result of distillations (Lisanti *et al.*, 2013), and this suggests that other off-odours and flavours may accompany the process as observed in this study. However, understanding what conditions negatively affect the wine, which part of the process introduces faults, which method best produces the wines and how to optimise the production of faultless wines using that method, is essential for quality de-alcoholised products.

Considering that this study was the first that focused on the de-alcoholised sparkling category in the South African wine industry, it unpacked valuable attributes, such as ‘wine-like’ and ‘ageing’ attributes, in the sensory profiles of the set evaluated, which may be important for benchmarking the products. Although the sample set was small, with only nine wines, all wines had similar scores and only one wine scored significantly higher at 13.6 points. It might be that the de-alcoholised sparkling wines investigated were of a similar quality level and affected by similar faults, probably because they were de-alcoholised in a similar way. On the other hand, the results reported here may be inclusive of most commercially available de-alcoholised sparkling wines, suggesting that most South African de-alcoholised sparkling wines are of low quality and have faults. Producers have points of major concern to deliberate on, so that quality is improved.

On the positive side, complexity on aroma and palate was observed with citations such as ‘attractive red fruit on the nose’, ‘the nose is quite complex’, ‘very aromatic’, ‘good nose’, ‘matured’, ‘Chardonnay-like aroma with oak’, ‘TA brings nice freshness’, ‘age perceived on the palate’, ‘longevity’, ‘good foamy mouthfeel, and smooth entry’ (see **Addendum C** for more*)*. The positive wine attributes helped elevate the quality of certain wines and were appreciated by judges. Consumers may also appreciate these attributes and may be used as benchmarking characters to differentiate the wines from, for example, sparkling grape juice. These attributes were introduced by fermentation, and highlight the wine-like aroma, ageing, citrus, wine-like flavours, and floral characters, which sparkling grape juice may lack. Therefore, this category gives consumers beverage alternatives containing fermentative and wine flavours, without the effect of ethanol.

The second phase of the research focused on obtaining the chemical profiles of the de-alcoholised sparkling wines, specifically the volatile aroma compounds. A follow-up objective was to compare concentrations obtained in this study with those of full-strength sparkling wines in published research, and to investigate the relative extent to how de-alcoholisation changed the concentrations of the compounds. Concomitantly, the basic oenological wine parameters were obtained. The main findings of the investigation were:

a) Glycerol concentrations (14.30 to 20.20 g/L) were higher than those in reported research, 5.21 to 9.36 g/L (Nieuwoudt *et al*., 2002).
b) Relative to full-strength wines, volatile compounds were present at low concentrations in this study.

Although the magnitude of change in volatile compounds could not be determined, the concentrations of volatile compounds were reduced in comparison to published wine research. Out of 19 volatile aroma compounds, only ethyl acetate, diethyl succinate, 2-phenylethanol, 1-butanol, octanoic acid, and decanoic acid were quantified within the ranges observed in full-strength sparkling wines, whilst butyric acid, isovaleric acid, and isobutyl acetate were above the ranges found in full-strength sparkling wines. The volatile profile research reported similar results as those in de-alcoholised still wines, esters and higher alcohols presenting the lowest concentrations (Lisanti *et al*., 2013; Longo *et al*., 2017; Liguori *et al*., 2019). The aforementioned information consequently reflects the need for better volatile compounds retention, to avoid the production of overly affected aroma and flavour. The argument of whether the compounds were reduced at the same magnitude or not, may not be significant since all observations point to lowered volatile compound concentrations. As already mentioned, it should be a priority to take a step back when evaluating the production process and identify key points of improvement or better volatile compound retention.

5.3. Recommendations and limitations

In 2022, a concomitant study on SA consumers outlined consumers' liking of de-alcoholised wines, especially red wine (Filter, 2022). In the same study, consumers, through the best-worst scaling technique, specified that they mostly select the de-alcoholised wines to buy based on taste, followed by price and familiarity with the product. Even though that study was focused on de-alcoholised still wines, one can assume that the taste of de-alcoholised sparkling wines will also be of utmost importance for South African consumers and therefore, palate quality should be a major focus during de-alcoholised sparkling wine production. Additionally, this highlights the value of marketing the wines diligently and opening doors for de-alcoholised wine tasting, bringing about product familiarity amongst consumers. This, however, can only apply after the palate quality is improved, and faults in the wines are removed, to ensure taste acceptability. Familiarising consumers with de-alcoholised sparkling wines could be an important step toward opening the market for the products. Furthermore, prompting consumers to buy more of the wines. Even more intriguing to consumers would be to highlight the benefits of the wines, either during a wine tasting or next to the product in stores.

Another reason, except palate quality, which consumers have indicated to affect purchase patterns was product unavailability in stores (Filter, 2022). For example, only selected supermarkets, wine stores and restaurants offer de-alcoholised sparkling wines in SA, and it is at these locations where most consumers who do not consume alcohol could be targeted. Hence, if all stores and restaurants had the products, producers could experience increased purchasing patterns. Blackwell *et al*. (2020) concluded that the increased availability of non-alcoholic products increases their selection over alcoholic ones. Even though the study was not focused on de-alcoholised sparkling wines, perhaps, the presence of de-alcoholised sparkling wines in stores may prompt consumers to purchase more frequently.

Wine quality, availability and familiarity of de-alcoholised sparkling wines could even be more pivotal to South African alcohol consumption patterns. The per capita consumption of alcoholic beverages in SA was reported to be 11 litres in 2019 and was the highest in Africa (Department of Social Development, 2019). Considering that high alcohol consumption patterns have been linked to domestic violence and car accidents (Setlalentoa *et al*., 2010; Department of Social Development, 2019), the reduction of alcohol consumption could help control these. As such having campaigns driving the sales of de-alcoholised products as alternatives may help reduce the domestic violence associated with alcohol consumption.

The suggestions do not, in any way, excuse the improvement of taste quality as consumers have pointed out the need (Whittaker, 2021). Not only do consumers point out the need for product improvement, but wine professionals as well, as this study showed. Nevertheless, de-alcoholised sparkling wines are good substitutes for alcoholic beverages, either for celebratory or non-celebratory events, because of the health benefits associated with the products and the distinct sensory aesthetics elevated by the presence of bubbles. The focus of this exploratory study was to obtain sensory and chemical profiles of a sample of South African de-alcoholised sparkling wines. However, the change in volatile compounds and the effect of de-alcoholisation on taste were identified as the main problem and require depth investigation. The change in volatile compounds leads to reduced intensity of aroma and flavour, reducing the fermentative attributes appreciated in the wines. Similarly, the lack of balance between acidity and sweetness, and the watery mouthfeel perceived also reduce acceptability. In order to elevate the wine acceptability in these mentioned areas, perhaps winemakers should consider adding volatile compounds (flavourants) and grape musts to reconstitute the initial wine profile. This was done in a study by Liguori *et al.* (2019), and subsequently, the perception of aroma, sweetness, body, and overall wine acceptability was higher than that of the de-alcoholised counterpart. Perhaps, this may be an option for the South African de-alcoholised sparkling wines; although no wine regulation has yet permitted this volatile compound reconstitution, it could work for de-alcoholised sparkling wines as reported by Liguori *et al.* (2019).

A major limitation when profiling the wines was the absence of original base wines before the wines were de-alcoholised. These would have been used as experimental controls in determining the actual concentration of volatile compounds lost during de-alcoholisation. For sensory analysis, the change caused by de-alcoholisation could have been identified and therefore, the type of compounds to optimally preserve for palatable products highlighted to producers. Furthermore, to understand the role of each compound on the perceived aroma, a correlation between the observed volatile compounds' concentration and sensory quality could have been studied. Since the scope of this study did not cover that, future research on these products could investigate how the concentration of each compound is changed and the effect it has on a specific attribute. Additionally, the concentration thresholds that should be retained for each compound to ensure good flavour could be identified and serve as a guide for de-alcoholised wine producers in producing quality de-alcoholised products that are appealing to consumers.

5.4. Conclusions

The main research focus was to evaluate the quality and obtain the sensory and volatile aroma compound profiles of the South African de-alcoholised sparkling wines. In total, nine wines were evaluated, and their quality was rated between 11 and 14 points, which according to wine scoring standards, indicates that the wines were faulty or unbalanced. In context, the sensory profiles highlighted the presence of 'reductive', 'oxidative', 'chemical', and 'sulphury' off-odours in the wines, whilst the palate was at times 'unbalanced', 'watery' and had a 'short finish'. These faults were detrimental to the wines, but the presence of 'fruity', 'wine-like', and 'ageing' characters positively contributed to the wine quality. The in-depth study of the wine profiles, both sensorially and chemically, assisted in bridging the knowledge gap for the de-alcoholised sparkling wines in the South African wine market when no published data was available for these products. Secondly, the faults highlighted in the profiles have outlined the factors that negatively affected the quality of the wines, and this may negatively impact consumer acceptability of the products. Hence, it is important for de-alcoholised sparkling wine producers to find methods suitable for producing quality wines.

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Addenda

Addendum A: Participant consent form

Dear prospective participant

You have been invited to participate in research project on the sensory quality of de-alcoholised wines.

This is Winetech DSI-funded project conducted by a group of researchers and MSc students at Stellenbosch University. Project leader and main supervisor of MSc students: Dr HH Nieuwoudt, South African Grape and Wine Research Institute (SAGWRI), Department of Viticulture and Oenology (DVO)

Collaborators and co-supervisors:

Dr Jeanne brand, DVO; Nina Muller, Food Science; Dr Chris Pentz, Department of Business Management

Lethabo Maesela MSc student working on sparkling wines and Sinazo Qwebani, MSc student working on still wines.

PARTICIPATION

Your participation is entirely voluntary, and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

BENEFITS

You will not receive direct benefits from participating in this research study. The results of the study will be made public by Winetech, since the aim is to support, through scientific investigation the development and quality of the production of de-alcoholised wines by the South African Wine industry. The research team plans to publish results in scientific and popular papers, and present the results at technical meetings and in popular papers in Wineland Magazine.

RISKS

There are no foreseeable risks involved in participating in this study other than those encountered in day-to-day life.

CONFIDENTIALITY

Your responses on the sensory evaluation will be sent to a link at Compusense where data will be stored in a password protected electronic format. All paper copies will be destroyed after electronic capturing. Compusense does not collect identifying information such as your name, email address, or IP address. The verbatim transcript of your interview will be sent to you for your verification before submitted to data analysis. Your interview responses will be coded according to themes. Therefore, your responses will remain anonymous. No one will be able to identify you or your answers, and no one will know whether you participated in the study.

CONTACT

If you have questions at any time about the study or the procedures, you may contact my research supervisor, Dr Hélène Nieuwoudt, phone at +27-21-8082748, mobile 082 786 2644, or via email at hhn@sun.ac.za.

RIGHTS OF RESEARCH PARTICIPANTS:

You have the right to decline answering any questions and you can exit the survey at any time without giving a reason. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Mrs Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

To obtain a copy of this text, please send an e-mail request to hhn@sun.ac.za.

DECLARATION BY PARTICIPANT

By signing below, I …………………………………..………………. agree to take part in a research study entitled sensory quality of de-alcoholised wines conducted by Dr HH Nieuwoudt.

I declare that:

- I have read the attached information leaflet and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is voluntary and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.
- All issues related to privacy and the confidentiality and use of the information I provide have been explained to my satisfaction.

Signed on ………….....

…………………………

Signature of participant

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to ___________________ [name of the participant] [He/she] was encouraged and given ample time to ask me any questions. This conversation was conducted in [Afrikaans/*English/*Xhosa/*Other] and [no translator was used/this conversation was translated into ____________ by ________________________].

____ _______________

Signature of Investigator Date

Addendum B: Tasting sheet

Welcome to the DE-ALCOHOLISED sparkling wine sensory evaluation session!

Please provide us with your details, you do not have to provide your name. We need this information for scientific publication reasons. Your data will not be shared with a third party.

Judge number……………………….. Date……………………………… Venue………………………….

You will be asked to perform 2 TASKS.

1. Sensory profile description of each wine. (Please use your own terms).
2. Quality scoring of each wine using the 20-point scale.

You will be asked to taste one flight containing 9 wines.

Please taste the wines presented from left to right.

Take sufficient breaks between wines by rinsing you mouth with water and eating a cracker.

Remember to **write down EACH wine code** on your tasting sheet in the space provided.

Flight 1 Judge number ………… Age………….. Venue ………………… Date …………………………

Wine code	Sensory description			Quality scoring out of 20			
	Visual / Appearance Colours; intensity; clarity; bubbles: size, texture, amount	Nose Smell	Palate Taste and mouthfeel	Visual Max 3	Nose Max 7	Palate Max 10	**Total**

Thank you very much for participating!

Addendum C: Sensory free listing data

Table C1 Appearance sensory categories.

Sensory category	Classification	Examples taken from original data
Good colour	Positive	Colour good; Colour is decent; Good intense colour; Colour nice vibrant colour; Pale gold with beautiful green tinges; Proper MCC or Champagne colour; Slight orange tint typical of pinot noir; White/yellow Sparkle; Light gold reminiscent of Cap Classique; Colour clear and vibrant; The rosé colour is pleasant; Lovely green tinge; Fresh tint; Colour and clarity good; Pleasant light red; Vibrant; Good fresh colour; Very good colour; Fresh slight green hue
Good appearance	Positive	Good; Very good; Nice light foamy appearance; Looks like wooded Chardonnay Eye-catching; Opulent; Sparkly; Nice rosé; Crisp; Brilliantly clear; Looks pleasant; Colour and clarity good; Great visual; Good bubbles and colour; Clear colour with bubble to see; Not very clear/almost looks like Chardonnay
Clear	Positive	Clear; Good clarity; Clean; Brilliantly clear; Colour and clarity good; Translucent
Bright colour	Positive	Bright; Good brightness
Brown tint	Negative	Hints of browning; Browning colour; Hints of brown; Slightly brown
Unappealing colour	Negative	Colour is a bit light; Lean; Colour not good Too light for rosé; Pale watery colour; Bit confusing for this category **-**Too dark to be a white wine but too light to be a rosé; Slightly light in colour; Appearance of concentrate? Hazy; Brown/oxidised white colour; Colour a bit too light; Red colour to dark rosé; Looks flat; Too much colour; Not good colour for sparkly; Very dark; Not very clear; Not rosé colour
Watery appearance	Negative	Light in colour (like water); Watery lean colour
Appealing effervescence	Positive	Lots of bubbles; Extremely integrated bubble/perlage Nice texture; Elegant bubbles; Finely streamed bubbles; Subtle bubbles; Substantial layer of bubbles on top; Lots of small bubbles; Thick circle of bubbles at the top; Fine perlage; Foam covers top of glass; Small rim of bubbles on top; Some fine bubbles; Increased bubbles; Layer of bubbles and fine bubbles rising; Small bubbles; Bubbles to see; Subtle bubbles; Bubbles are present; Bubbles fine; Small bubbles; Ring of bubbles (5mm); Clear bubbles; Very bubbly small bubbles; Small foam collar; Foam covers top of wine; Fizzy; Foaminess on the surface; Lots of sparkle
Unappealing effervescence	Negative	Low bubble on appearance; Has a "beer like" foam not fitting for a wine; Fine inconsistent bubbles; Fine mousse-not very active; Foam disappears quicker but does not add to visual appearance; No bubbles visible; Very thin ring (<1mm) of bubbles; Very little mousse; Very few bubbles; No bubbles; No circle of bubbles around the top; Little bit of sparkle; Not much bubbles; Few bubbles - small Thick circle of bubbles at the top; No foam collar; Hardly any bubbles; Very fine bubbles can hardly see them; No apparent mousse; No bubbles visible; Thick circle of bubbles at the top; Too much foam; Big bubbles; Minimal bubbles present; Flat on bubbles; No bubbles at first sight; Big bubbles; Very little bubbles; Bubbles few; Very little mousse; Not much bubbles; Very few bubbles; No bubbles; Small bubbles No circle of bubbles around the top; Little bit of sparkle; Small bubbles rising no layer on top; No foam collar hardly any bubbles; No ring of bubbles; Medium bubbles; Minimal bubbles; Perhaps few fine bubbles; No visible bubbles; Not a lot of bubbles; Little bubble present; Slight bubbles on appearance; Little to no bubbles; Some bubbles-small ring
Not wine-like appearance	Negative	Strawberry-coloured juice!?; Foam creates an impression that sunlight liquid was added; Red grapetiser

Table C2 Aroma sensory categories.

	Classification	Sensory category	Examples taken from original data
Intensity	Negative	Lacks aroma	Still nose; Very little nose; No aroma on nose; Bit subdued; Lacks fruit; Initial fruity- dried mango but fades away quickly; Fruit flavours not too forthcoming but present; Very little aroma; Nose mostly paper/cardboard Not much fruit; Slight hints of dried fruit but disappears quickly; Flat; Nose one dimensional; Not very prominent; Fruity with hints of Muscat but disappears quickly; Sweet sweetness!! Nothing else; Not much on the nose; Bland; Not much on the nose; No fruit; Dull nose; Hardly any smell on the nose; Neutral; Hardly any smell on the nose
Intensity	Positive	Good aroma	Soft aromas; Lovely nose; Great nose-textured; Good upfront fruit on nose; Beautiful fruity nose with hints of floral; Beautiful nose Medium fruit intensity; Complex; Attractive; Grapey muscat-like nose fresh and enticing; Upfront fruit flavours; Inviting fresh lime and citrus notes; Nice combination of tropical fruit and green notes; Zesty; Shows developed characters on the nose; Pure; Subtle sweet Floral tones; Pleasant nose; Nice fruit intensity; Good fruit on the nose with some biscuit; Elegant; Delicate fruitiness; Fruit but not too much; No off aromas; Clean open; Aromatic; Attractive red fruit on nose; Nose is quite complex; Very aromatic ; Good nose; No faults; Matured; Fruity aromatic nose (Muscat); Inviting; Nice fruity
Intensity	Neutral	Shy nose	Takes a while to open up; Shy nose; Very shy nose
Freshness	Positive	Fresh aroma	Fresh; Fresh and crispy; Crisp; Clean
Off-odours	Negative	Off-odours	Slightly charred character on the nose initially; Initially burnt/rubber-like; Almost soapy; Medicinal nose; Initially a bit reductive; Overwhelmed by sulphury off-odour (H_2S?); Turpentine smell; Green bean (stewed) character; Not very fresh and clean; Sulphury; Slight SO_2 aroma; Wet wool; Cork?; Unattractive; Mousy/yeasty nose; Brett characters; Reductive and rubbery slight stink!; Not clean; Dirty water; Bad smell; Burnt character; Off; Unsavoury nose; Stuffy nose; Artificial herbaceous turns "stinky herby"; Slight corky upon initial smell; Faulty; Heavily oxidised aroma; Old "tawny port" aroma; Hessian sack; 'Catly' intense but unpleasant; Burnt caramel notes; Damp; Closed nose; Chemical; Musty; Slight H_2S notes; Dusty; Sour aromas; Damp/Old smell on the nose; Mustiness; Cardboard; Paper; Carton; Volatile acidity overwhelms; Rotten peaches; Lacks freshness; Something chemical on the nose; Filter paper; Vinegar; Oxidative character; Metallic; Oily; Burnt/tobacco; Cigarette ash; Dull nose; Sweaty; Polish character; Dusty; Oxidative notes; Reductive nose; Slight off flavour; Red onion oxidative
Ageing	Neutral	Ageing aromas	Almost bottle maturation; Age on the nose
Ageing	Negative	Ageing aromas	Waxy nose; Aged character; Cooked notes; Slight hints of cooked flavour
Aroma flavours	Neutral	Sweet associated aromas	Chocolate; Candy floss; Pink sherbet; Marshmallow; Musk sweets; Confectionery store aromas; Canned peaches; Caramel; Lemon cream; Marzipan; Ripe yellow fruit; Tutty fruity; Sweet undertone; Butterscotch; Marmelade; Red fruit sweetness; Cherry liqueur; Ripe fruit; Jammy; Sweet aroma; Processed fruit; Sherbet; Sweet fruit; Sweet nose; Nectar; Honey notes; Humbug character; Light honeyed aromas; Sweet associated; Toffee; Subtle sweet; Candy Floss; Honey notes; Vanilla; Turkish delight
Aroma flavours	Neutral	Fruit aromas	Apricots; Mixed fruit; Nectarine; Stone fruit; Tropical fruit; Summer fruit; Granny Smith apple; Watermelon; Apple skin; Fresh fruit salad; Golden delicious apple; Sour fig; Sour fruit; Passion fruit; Guava; White fruit; Fruit flavours;

			Pomegranate; Red fruit; Red berries; Redcurrant; Berries; Cranberries; Plum; Pink Lady apple; Quite fruity; pears; Ripe pear; Red apple; Ripe apples; Ripe peaches; Grapes; Papaya; Litchi; Melons; Quince; persimmon; Slight fruity note (quince); Fruity; Kiwi; Overripe fruit; Strawberry; Raspberry; Sweet melon; White peaches; Yellow fruit; Banana; Peach; Cherries; Tropical fruit; Apple; Green apple; Figs; Blackcurrant; Fresh pineapple; Green gage; Cherry; Granadilla
Aroma flavours	Neutral	Muscat aroma	A bit of muscat; Older Muscat character; Terpene; Muscat-like aromas
Aroma flavours	Neutral	Floral aromas	Honeysuckle; Elder flower; Roses; Jasmine; Blossom; Floral; Perfumery notes; Flowery
Aroma flavours	Neutral	Earthy aromas	Earthy; Damp soil; Straw; Wheat; Stalky
Aroma flavours	Neutral	Spicy aromas	Cloves; Spice
Aroma flavours	Neutral	Vegetative aromas (positive)	Tomato paste; Stalky; Rhubarb; Vegetative (dry); Vegetal; Onions; Red onion; Tinned peas; Canned peas; Asparagus; Khaki bush; Green pepper; Green tea
Aroma flavours	Neutral	Green aromas	Leafy; Green aroma; Grassy
Aroma flavours	Neutral	Creamy aromas	Butter; Buttery
Aroma flavours	Neutral	Mineral aromas	Mineral; Oyster shell; Flinty
Aroma flavours	Neutral	Yeasty aroma	Yeasty nose; Subtle yeast smell
Aroma flavours	Neutral	Dried fruit aromas	Raisins; Raisin/Sultana; Hints of dried fruit; Prune; Dried apricots/peaches; Dried mango; Dried fruit
Aroma flavours	Neutral	Woody aromas	Smoke; Wood character; Woody; Oaky notes; Wooded
Aroma flavours	Neutral	Savoury aromas	Meaty biltong!?; Bacon kips (savoury); Soysauce-like aroma
Aroma flavours	Neutral	Citrus	Citrus; Citrus peel; (orange; naartjie); Grapefruit; Orange; Ripe citrus; Citrus undertones; Lime; Lemon
Aroma flavours	Neutral	Herbal aromas	Herbaceous; Herbaceousness; Lemongrass
Aroma flavours	Neutral	Nutty aromas	Nuttiness; Nutty; Almonds
Aroma flavours	Neutral	Compote aromas	Stewed fruit; Pears- poached; Baked quince; Cooked dried fruit; Boiled fruit

Aroma flavours	Neutral	Grain-associated aromas	Muesli (breakfast); Wheat; Barley; Bread
Aroma flavours	Neutral	Brioche	Biscuit on the nose; Bread; Biscotti; Subtle brioche
Aroma flavours	Neutral	Cat-like	‘Catly'; Cat-pee;
Wine-like aroma	Positive	Wine-like aroma	Wine-like; Vinous (winey); Sweet rosé aroma; Chardonnay like aroma with oak; Grape-like/muscat notes; Like MCC (toasty); Wild /spontaneous fermentation nose; Fermentative character; Tropical and pyrazine; Grape aroma; Bit like MCC; Primary flavours; Fermentative character; Red grapes; Primary grape aromas; Wine red/blend aroma; Smells like bubbly
Wine-like aroma	Negative	Not wine-like aroma	Artificial; Artificial herbaceous; Seedless green grapes; Table grape to the nose; Nose comes across a bit synthetic; Synthetic resin nose; Some kind of carbonated cooldrink; Buchu; Lovely intense aromatics (added?); Grape juice on nose; Synthetic strawberry; Very unnatural nose; Smells like grape juice; Green grape juice; Red grapetiser; Artificial (cane sugar) sweetness on nose; Red cooldrink type of smell dominates; Grapetiser; Strange; Dried tea; Green tea; No sparkling wine character; Tea-like; Artificial nose; Tea

Table C3 Palate sensory categories.

	Classification	Sensory category	Examples taken from original data
Acidity	Negative	Acidic	Too tart; Increased acidity; Acid prominent; Strong acidity; Acid is high and stands apart; High acid; Acidity slightly pronounced; Bit acidic; Slightly acidic
Acidity	Positive	Good acidity	Integrated acid; Wine-like acid; Good acidity; Good acid; Not too acidic; Good acid balance; TA brings nice freshness
Acidity	Negative	Low acidity	No acidity; Needs more TA; Needs more acid; No acid; Low acid; Lack acidity; Low acidity; Medium acidity
Astringent	Negative	Astringency	Medium astringent; Low astringency; Astringent (high); Slightly astringent; Astringent
Ageing	Neutral	Ageing-palate	Age perceived on palate; Palate showing some age
Ageing	Negative	Ageing-palate	Cooked flavour
Bitterness	Negative	Bitterness	Bitter
Body	Positive	Full-bodied	Full bodied; Fuller on taste; Fuller style
Body	Positive	Light-bodied	Light; Light body; Very light taste; Light on the palate
Body	Neutral	Medium-bodied	Medium palate; Has some body (medium body)
Body	Negative	Thin-bodied	No structure to it; Stripped; Thin; Lean; Lacks body

Dryness	Neutral	Dry palate	Dry style; Dry; Pleasant dry; Not as dry; Dry mouthfeel; Dry-ish
Dryness	Neutral	Dry finish	Nice dry finish; Dryish finish
Dryness	Neutral	Off-dry	Off-dry
Bubbles	Positive	Good bubbles	Soft foam; Good bubble structure; Bubbly on mid palate; Fine mousse on palate; Lots of bubbles; A bit of foam in the mouth; Good soft bubble on palate; Refreshing bubble; Lots of foam in the mouth; Delicate fizziness; Frothy mid-palate; Good bubbles; Pleasant fine bodied bubble texture; Small bubbles; Best bubble; Fine bubble; Medium to large bubble texture
Bubbles	Negative	Bad bubbles	Bubbles dissipate quickly; Bubbles falls flat on palate; Coarse bubbles; Minimal bubble; No bubble; Bubbles disappear very fast; Harsh bubbles (large explosive); No bubbles in mouth; Almost no bubbles; Lacks fizz; No bubbles on the finish; Soft almost imperceivable bubble; Big bubbles; Low sparkle
Bubbles	Neutral	CO_2	High CO_2 levels; Fizzy palate; CO_2 too much; CO_2 results in a good freshness
Finish	Negative	Acidic finish	Flavour disappears quickly; Lacks longevity; No lingering; Falls away on palate; Short finishing; Doesn't linger for long; Short persistence; No long aftertaste; Short; Short finish; First appearance promising then the wine falls away totally
Finish	Negative	Light finish	Very light finish; Light finish
Finish	Positive	Good finish	Longevity; Lovely floral finish; Keep taste; Medium to long finish; Pleasant aftertaste; Pleasant finish; Lingering freshness on the finish; Nice aftertaste; Sweet lingering aftertaste; Nice finish; Good length; Good aftertaste; With a stonefruit finish
Finish	Negative	Short finish	Flavour disappears quickly; Lacks longevity; No lingering; Falls away on palate; Short finishing; Doesn't linger for long; Short persistence; No long aftertaste; Short; Short finish; First appearance promising then the wine falls away totally
Finish	Neutral	Sweet finish	Dull to sweet on finish; Sweet aftertaste; Ends with sweet sensation; Lingering sweetness on the finish; Sugar at the end; Sweet lingering aftertaste; Slight sweet aftertaste
Palate flavours and tastes	Negative	Lacks flavour	No real taste; Palate too simple; No depth in taste; No aroma on palate; Tasteless; Bland; Not a lot of aroma on the palate; Totally flat; One dimensional; Flat; Dull; Not much flavour; Stripped; Sweet No other flavours besides sugar on palate
Palate flavours and tastes	Positive	Good flavour	Lively with nice red fruit flavours on the mid palate; Pure fruitiness; Nice fruit; Pleasantly fruity
Palate flavours and tastes	Neutral	Fruit	White pears; Kiwi; Fruit salad; Ripe yellow fruit; Papaya; Litchi; Sour peach; Red apple; Cherry; Granny Smith apple; Grapey; Canned fruit; Off-ripe plum; Red berry entry; Cranberry; Raspberries; Ripe red fruit; Red cherry; Cranberry; Strawberry; Wild berry; Stonefruit; Tropical fruit; Pure fruitiness; Quince/guava; Lots of pear; Ripe apple; White peaches; Apple; Peaches; Apricots; Pineapple; Some banana skin; Tropical palate; Plenty of apple flavours; Fig; Berries; Melon
Palate flavours and tastes	Neutral	Muscat	Muscat flavour; Muscat taste; Hint of muscat

Palate flavours and tastes	Neutral	Floral	Floral; Flowery; Jasmine
Palate flavours and tastes	Neutral	Vegetative	Green character; Herbaceous finish; Greenery flavours; Onions in taste; Slight vegetativeness; Green
Palate flavours and tastes	Neutral	Savoury	Savoury
Palate flavours and tastes	Neutral	Citrus	Citrus; Lemon; Orange; Lime; Lime peel; Orange peel
Palate flavours and tastes	Neutral	Minerality	Touch of salinity (salty)
Palate flavours and tastes	Neutral	Nutty	Nutty; Hints of nuttiness
Palate flavours and tastes	Neutral	Yeasty	Yeasty
Palate flavours and tastes	Neutral	Dried fruit taste	Raisin; Dried fruit
Palate flavours and tastes	Neutral	Woodiness	Some wood; Oaked; Lots of oak on palate; Slight wood; Vanilla
Palate flavours and tastes	Neutral	Earthy	Earthy character
Palate flavours and tastes	Negative	Shy palate	Shy on taste
Palate flavours and tastes	Positive	Biscuit	Short bread flavours; Biscuit
Palate flavours and tastes	Positive	Cat-like	Catly; Cat pee

Fresh	Positive	Fresh	TA brings nice freshness; A crinchy crunch finish; Fresh; Crisp; Clean palate; Lingering freshness on the finish; Good freshness; CO_2 results in a good freshness
Fresh	Negative	Lacks freshness	Lacks freshness
Mouthfeel	Positive	Good mouthfeel	Attractive mouthfeel; Balanced "polished" mouthfeel; Smooth buttery mouthfeel; Good foamy mouthfeel; Smooth entry; Nice mouthfeel; Good smooth mouthfeel; Nice smooth; Good mouthfeel; Full mouthfeel; Fuller mouthfeel; Round mouthfeel
Mouthfeel	Negative	Lacks mouthfeel	Very light finish/mouthfeel; Not much mouthfeel; Light/short mouthfeel; Lacks mouthfeel; Short mouthfeel
Nose-palate follow-through	Positive	Nose-palate follow-through	That synthetic perception follows through on palate; Buchu notes pulls through to the palate; Lovely follow through of fruit on palate; Paw paw and mix fruit carry on palate; Same dried fruit/raisin on palate; Tropical fruit carries through on palate; Citrus character detected on nose; Same elements on nose came through on palate; Same nose characters on smell; "Polish" character of nose follows through; Very fruity follows through from nose; Red fruit character on nose follows through
Off flavours	Negative	Off-flavours	Slightly off-putting; Shoe-polish notes; Burnt characteristics; Synthetic feel; Taste corked; Pick up some SO2; Dirty on palate; Off-taste; Taste of old sweat overpowers; Slight reductive notes; Off smell; More cardboard than fruit; Soapy aftertaste; Soapy character; "Polish" character of nose follows through; VA on palate; Papery taste; Oxidised notes; Burnt/tobacco; Oxidative; With hints of nuttiness (acetaldehyde) which could be due to oxidation; Chemical nose; Baking soda; Musty; Artificial
Palate	Negative	Watery	Watered down appletiser; Watery mess; Watered down palate; Watery; Watery palate; Very watery
Palate	Positive	Balanced palate	Well structured; Acid/sweetness more in balance; Acidity and mouthfeel well balanced; Elegant and balanced; Good balance of wine; Balanced acidity/sweetness/mouthfeel; Palate is well balanced (helped by RS); Balanced; Good balance; Well balanced; Finish is better balanced
Palate	Positive	Good palate	Medium fruit complexity; Palate better than the nose; Sweetness helps to make flavours seem more full; Buttery flavour; Sweetness gives more weight; Butter; Good palate; Elegant; Fullish palate
Palate	Positive	Good mid-palate	Pleasant aromas that linger on the mid-palate; Lively with nice red fruit flavours on the mid palate; Reasonable mid palate; Beautiful mid palate
Palate	Negative	Short mid-palate	No mid palate; Grapetiser dies on mid-palate
Palate	Negative	Unbalanced palate	Tiny bit of balance between acidity and sweetness; Lacks finesse; Taste a bit flabby; Lacks complexity; Not a well-rounded taste; Needs more TA to balance the sweetness; Loose acid; TA loose; Acid is high and stands apart; Acid slightly separate; Sugar masks flavours; Loose components; Sugar unbalanced
Palate	Positive	Palatable	Very easy drinking; Pleasant taste; Nice smooth; Zesty; Refreshing; Very appealing palate
Sour taste	Negative	Sourness	More sour than thought; Sour; Slight bit of sourness at the end; Bit sour
Sweetness	Negative	Lacks sweetness	Lacks sweetness
Sweetness	Neutral	Sweetish palate	Not too much sugar; Hint of sweetness on entry and mid palate; Less sugary; Medium sweetness; Slightly sweet; A bit of sweetness coming through; Not too sweet; Sweetish; Sweetish entry lingering on mid-palate
Sweetness	Neutral	Sweet palate	Sweet; Pick up sweetness on palate; Sweet entry;

Sweetness	Neutral	Sweet associated palate	Candied apple; Nectar; Sweet sherbet; Candyfloss; Red lollipop; Strawberry jam; Honey; Sherbet; Vanilla; Lollipop flavour; Lemon cream; Candy
Sweetness	Negative	Very sweet palate	Strong residual sugar; Syrup-like mouthfeel too sweet; Too sweet upon entry; Too sweet; Sweetened too much; Very sweet and clawy; Very sweet
Tannins	Positive	Good tannin structure	Tannins and grippiness on palate; Slight tannins on mid-palate
Wine-like tastes	Positive	Wine-like flavours	Vibrant fruity character of a well-made bubbly; Lots of primary grape fruit; Very primary/grape flavour; Cooler climate flavours; Very dry- MCC base wine character; Chardonnay like; 'Noble' late harvest type flavour
Wine-like tastes	Negative	Not wine-like flavours	Beer-like; Malty; Rosewater; Reminds me of sparkling grape juice; Buchu; Very carbonated taste; Appletiser-like; Rooibos feel; Iced tea; Red grape juice; No wine character; Juice flavour; Green grape juice; Concentrated peach/apricot; Grape juice character; Grape juice; Closest to grape juice

Addendum D: Additional data

Table D1 Standard deviation (SD) in mg/L and coefficient of variation (%CV) of volatile compounds quantified in South African de-alcoholised sparkling wines

	Wine codes																	
Compound	W004		W736		W566		W111		W017		W818		W214		W429		W916	
	SD	**%CV**	**SD**	**%CV**	**SD**	**%CV**	**SD**	**%CV**	**SD**	**%CV**	**SD**	**%CV**	**SD**	**%CV**	**SD**	**%CV**	**SD**	**%CV**
Ethyl acetate	0.325	**16.731**	0.182	**4.930**	0.062	**1.577**	0.994	**21.244**	0.572	**19.536**	0.159	**6.264**	0.725	**24.736**	0.222	**16.236**	0.385	**90.091**
Isobutyl acetate	0.001	**1.158**	0.004	**4.603**	0.004	**4.837**	0.003	**2.908**	0.002	**3.052**	0.005	**6.799**	0.004	**4.499**	0.003	**3.040**	0.005	**6.235**
Ethyl butyrate	0.002	**6.663**	0.006	**7.947**	0.004	**9.788**	0.005	**10.797**	0.005	**7.920**	0.000	**1.401**	0.003	**5.668**	0.000	**1.356**	0.003	**9.199**
2-Methylbutyl acetate	0.004	**7.342**	0.003	**5.103**	0.009	**7.854**	0.022	**9.080**	0.006	**6.227**	0.001	**4.489**	0.006	**4.297**	0.000	**2.413**	0.000	**1.909**
Ethyl acetate	0.026	**0.349**	0.100	**1.515**	0.048	**1.032**	0.120	**5.716**	0.031	**1.767**	0.032	**2.022**	0.127	**5.467**	0.393	**8.263**	0.193	**13.909**
Diethyl succinate	0.024	**4.275**	0.049	**8.803**	0.010	**6.237**	0.008	**5.707**	0.006	**5.429**	0.006	**4.985**	0.004	**2.081**	0.003	**2.760**	0.001	**0.963**
2-Phenylethanol	0.345	**4.570**	0.287	**3.704**	0.038	**0.640**	0.279	**4.759**	0.987	**10.376**	0.374	**5.018**	0.268	**4.336**	0.195	**5.558**	0.989	**14.827**
1-Butanol	0.003	**3.580**	0.009	**12.944**	0.009	**10.249**	0.008	**9.710**	0.008	**9.873**	0.009	**11.441**	0.007	**7.703**	0.007	**6.991**	0.009	**11.530**
2-Methyl-1-butanol	0.389	**11.130**	0.325	**10.993**	0.457	**12.929**	0.672	**14.211**	0.647	**11.359**	0.043	**9.250**	0.487	**9.719**	0.113	**7.640**	0.006	**0.947**
Isoamyl alcohol	0.117	**6.298**	0.102	**6.424**	0.160	**8.349**	0.244	**10.160**	0.622	**11.038**	0.022	**5.873**	0.194	**6.930**	0.039	**4.524**	0.002	**0.543**
Isobutanol	0.001	**0.558**	0.337	**78.775**	0.043	**7.219**	0.001	**0.276**	0.314	**77.990**	0.006	**2.614**	0.007	**3.585**	0.165	**55.777**	0.018	**6.406**
Acetic acid	0.789	**0.874**	2.610	**3.736**	2.483	**4.971**	5.796	**5.581**	5.699	**6.007**	3.117	**3.375**	1.159	**2.069**	3.277	**3.876**	9.511	**12.589**
Isobutyric acid	0.019	**4.079**	0.021	**4.991**	0.011	**4.057**	0.036	**5.357**	0.030	**5.891**	0.035	**7.343**	0.008	**1.709**	0.006	**2.073**	0.004	**0.779**
Butyric acid	0.047	**5.047**	0.064	**6.950**	0.046	**5.066**	0.052	**6.189**	0.049	**5.922**	0.068	**9.621**	0.024	**1.846**	0.014	**2.646**	0.001	**0.097**

Isovaleric acid	0.000	**0.152**	0.008	**3.185**	0.009	**4.490**	0.016	**5.365**	0.013	**4.301**	0.017	**6.227**	0.001	**0.357**	0.001	**0.395**	0.011	**3.954**
Valeric acid	0.000	**0.386**	0.001	**1.059**	0.002	**1.398**	0.000	**0.158**	0.001	**1.109**	0.000	**0.283**	0.011	**9.297**	0.001	**0.636**	0.000	**0.359**
Octanoic acid	0.034	**1.901**	0.024	**1.499**	0.000	**0.016**	0.113	**4.369**	0.139	**8.572**	0.010	**1.502**	0.005	**0.177**	0.056	**2.945**	0.081	**4.659**
Decanoic acid	0.024	**5.334**	0.006	**2.188**	0.004	**0.675**	0.010	**1.165**	0.020	**7.950**	0.013	**7.865**	0.034	**5.263**	0.002	**1.089**	0.016	**2.901**
Trans-2-hexenal	0.003	**5.423**	0.002	**3.079**	0.000	**0.898**	0.002	**3.901**	0.004	**8.636**	0.000	**0.836**	0.001	**1.725**	0.002	**4.131**	0.001	**1.144**