

The sensory characterisation of old- vine Chenin blanc wine: an exploratory study of the dimensions of quality

by

Renée Crous



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Supervisor: Dr Hélène Nieuwoudt

Co-supervisor: Mrs Valeria Panzeri

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Declaration

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Date: December 2016

Summary

Recently, there has been a lot of mention of the term ‘old-vine’ in the media, the quality of the grapes they produce and the type of sensory profile they exude. Chenin blanc in South Africa is, historically, one of the first wine grape varieties cultivated in South Africa and is not only the most widely planted variety, but many of these vineyards are far over 20 years old. The aim of this research was to characterise a representative set of old-vine Chenin blanc wines and determine what could define it as a product style category, using descriptive sensory analysis (DA). There is no formally defined age for an old-vine, therefore, for the purpose of this study all old-vine wines evaluated were 40-years and older.

In this study the focus was shifted from mainly concentrating on the aroma characteristics of the wines, as had been the case in previous Chenin blanc research, to include other aspects that are also associated with the intrinsic quality of wine. These aspects were referred to as ‘in-mouth sensations’ and were selected by a focus group of industry professionals and expert panellists. The in-mouth sensations included body, heat, acidity, balance, complexity, concentration, integration and length. This was the first time the DA panel had to evaluate these concepts in wine, therefore, extensive panel training was needed and a framework was created to aid in the analysis of these concepts. Due to the difficulty of the analysis, and the limitations of DA, the wines were analysed in two smaller sets, with a maximum of 10 wines per set.

In general, information on the vines and the production practices of the wines investigated in this study, is fragmented and scarce. Qualitative research was, therefore, used by means of a questionnaire to give context on how the vineyards of the wines investigated in this study are managed and the winemaking techniques used to produce these wines.

The old-vine Chenin blanc wines were not all characterised by distinctive aroma attributes, but elicited a subtle array of aromas. The aroma profile of these wines was, therefore, described as complex. The wines had prominent, but different in-mouth properties within the set. The sensory data also showed that body, balance, concentration, complexity and integration were all positively correlated and that acidity was negatively correlated to those concepts. The correlation between the in-mouth sensations and physicochemical parameters was investigated as a secondary objective. Body had a strong positive correlation to ethanol, dry extract and reducing sugars. The results showed that the physicochemical parameters correlated with body, were also positively correlated to balance, concentration, complexity and integration. Therefore, the physicochemical composition of the old-vine Chenin blanc wines had a large impact on the perception of in-mouth sensations.

The results obtained on in-mouth sensations with DA, for the second set which included 10 wines, were compared to a reference based rapid method, polarised sensory positioning (PSP). PSP allowed for the analysis of a larger sample set (15 wines) and the results were similar compared to that of DA. This was the first application of this rapid method to wine.

Therefore, this study provided insight into the sensory profile of the old-vines wines of South Africa's most important cultivar, Chenin blanc, and developed a framework for analysing in-mouth sensations in wines, that could be applied in future research. The study also proved that PSP could successfully be applied to wine, which would allow for the analysis of more comprehensive sample sets. Lastly, the qualitative information gathered helped to identify opportunities for prospective research. Overall, research on the old-vine Chenin blanc wines helps aid in the awareness of the quality and importance of these vineyards.

Opsomming

Onlangs is daar baie melding gemaak van die term "ou-wingerdstok" in die media, die gehalte van die druiwe wat dit produseer en die sensoriese profiel van die wyne wat van hierdie ou-wingerde gemaak word. Chenin blanc in Suid-Afrika is, histories, een van die eerste wyn kultivars wat in Suid-Afrika verbou is en nie net die mees geplante kultivar nie, maar baie van hierdie wingerde is ver meer as 20 jaar oud. Die doel van hierdie navorsing was om 'n verteenwoordigende versameling van ou-wingerdstok Chenin blanc-wyne te karakteriseer en te bepaal wat hierdie wyne as 'n produk kategorie kan definieer, deur gebruik te maak van beskrywende sensoriese analise (DA). Daar is geen formeel gedefinieerde ouderdom vir 'n ou-wingerdstok nie, daarom, vir die doel van hierdie studie was die oud-wingerdstok wyne beoordeel almal van wingerde wat 40-jaar en ouer is.

In hierdie studie is die fokus verskuif van hoofsaaklik konsentreer op die aroma eienskappe van die wyne, soos die geval is in vorige Chenin Blanc navorsing, om ander aspekte wat ook verband hou met die intrinsieke gehalte van wyn, in te sluit. Hierdie aspekte is na verwys as 'binne-mondse sensasies' in hierdie studie en is gekies deur 'n fokusgroep met gesiene persone in die industrie en kundige paneellede. Die binne-mondse sensasies het volheid, hitte, suur, balans, kompleksiteit, konsentrasie, integrasie en lengte ingesluit. Dit was die eerste keer dat die DA paneel hierdie konsepte in wyn moes evalueer, dus, is breedvoerige paneel opleiding nodig gewees en 'n raamwerk is geskep om te help met die ontleding van hierdie konsepte. As gevolg van die moeilikheidsgraad van die ontleding van hierdie konsepte, en die beperkinge van DA, is die wyne ontleed in twee kleiner stelle, met 'n maksimum van 10 wyne per stel.

Inligting oor die wingerde en die produksie praktyke van die wyne in hierdie studie ondersoek, is oor die algemeen gefragmenteerd en skaars. Kwalitatiewe navorsing is dus gebruik, deur middel van 'n vraelys, om konteks te gee oor hoe die wingerde van die wyne wat in hierdie studie ondersoek is, bestuur word en die wynmaaktegnieke wat gebruik is om hierdie wyne te produseer.

Die ou-wingerd Chenin blanc-wyne is nie gekenmerk deur prominente aroma eienskappe nie, maar het 'n subtiële verskeidenheid van aromatiese geure ontlok. Die aroma profiel van hierdie wyne is dus beskryf as kompleks. Die wyne het prominente, maar verskillende binne-mondse profiele gehad. Die sensoriese data het ook getoon dat die volheid, balans, konsentrasie, kompleksiteit en integrasie almal positief gekorreleer is en dat suur negatief gekorreleer is met al die konsepte. Die korrelasie tussen die binne-mondse sensasies en fisiese-chemiese eienskappe is as 'n sekondêre doelwit ondersoek. Volheid is sterk gekorreleer met etanol, droë ekstrak en reduserende suikers. Die resultate het getoon dat die fisiese-chemiese eienskappe wat gekorreleer is met volheid, ook sterk gekorreleer is met balans, konsentrasie, kompleksiteit en integrasie. Daarom het die fisiese-chemiese samestelling

van die ou-wingerdstok Chenin blanc-wyne 'n groot impak op die persepsie van binne-mondse sensasies.

Die resultate verkry op binne-mondse sensasies met DA vir die tweede stel wyne, is vergelyk met 'n verwysing gebaseerde vinnige metode, gepolariseerde sensoriese posisionering (PSP). PSP het toegelaat vir die ontleding van 'n groter monster stel en die resultate was soortgelyk in vergelyking met dié van DA. Dit was die eerste toepassing van hierdie vinnige metode op wyn.

Hierdie studie verskaf insig tot die sensoriese profiel van die ou-wingerde wyne van Suid-Afrika se belangrikste kultivar, Chenin Blanc, en het 'n raamwerk ontwikkel vir die ontleding binne-mondse sensasies in wyn, wat in toekomstige navorsing toegepas kan word. Die studie het ook bewys dat PSP suksesvol toegepas kan word op wyn, wat sal toelaat vir die ontleding van 'n meer omvattende monster stel. Laastens, die kwalitatiewe inligting wat versamel is het gehelp om geleenthede te identifiseer vir toekomstige navorsing. Navorsing oor die ou-wingerdstok Chenin blanc-wyne dra by tot die bewustheid van die gehalte en belangrikheid van hierdie wingerde.

Dedication

This thesis is dedicated to

My family, friends and the best dog in the world, for their endless love and support. Thank you for reminding me to live a balanced life and offering me some much needed distraction at times. Most of all, thank you to God Almighty for His patience and guidance and showing me that I can achieve anything through His grace and strength.

“I have hated the words and I have loved them, and I hope that I have made them right” – The Book Thief by Markus Zusak

Biographical sketch

Renée Crous was born in Johannesburg, South Africa on 17 September 1992. She attended Jan Cilliers Primary School and matriculated at Helpmekaar Kollege in 2010. Renée then left the city life behind and obtained a 4-year BSc-degree in Food Science in 2014 at Stellenbosch University in the Western Cape. In 2015 Renée enrolled for an MSc in Wine Biotechnology at the Institute for Wine Biotechnology, Stellenbosch University.

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Preface

This thesis is presented as a compilation of 6 chapters. Each chapter is introduced separately and is written according to the style of the International Journal of Food Science and Technology.

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Chapter 1

General introduction and project aims

General introduction and project aims

1.1. Introduction

Sensory evaluation has an important role in both wine research, as well as the wine industry. In research, it is commonly used to evaluate the effect of different viticultural treatments or winemaking practices on the sensory characteristics of wine. In industry, it is often used for product development, comparing wine in a competitive market segment or quality evaluation. Research, has proven, though, that the evaluation of wine quality is a complex procedure (Jover *et al.*, 2004) and wine quality was found to consist of different dimensions (Charters and Pettigrew, 2007). Those dimensions include external and internal factors: external factors that influence the final product, but cannot be consumed, and are referred to as extrinsic quality cues; internal factors that are only perceived once the bottle has been opened for drinking, referred to as intrinsic quality attributes. In this study, the focus was on sensory characterisation, which forms an integral part of the intrinsic quality attributes of wine. The secondary objective, however, was also to provide context on the extrinsic elements used to manage the vineyards and produce the wines evaluated.

South Africa's most cultivated varietal, Chenin blanc (SAWIS, 2015), had recently been described as 'world class' after over a hundred wines had been judged for the Standard Bank Top 10 Chenin blanc competition (Du Preez, 2016). This cultivar is regarded as a neutral grape varietal as it lacks in primary aroma compounds that normally give wines distinctive sensory characteristics (Marais, 2006). With the establishment of the Chenin Blanc Association in 2000 (CBA, 2016), however, the potential and versatility of this grape was recognised and the focus shifted from only using the grapes for bulk production and brandy distilling, to producing bottled Chenin blanc table wines of quality that could compete on international level. This development sparked the formulation of several research projects that investigated the chemical and sensory profile of different category styles of commercial Chenin blanc wines (Bester, 2011; Hanekom, 2012; Lawrence, 2012; van Antwerpen, 2013). All of these studies mainly focused on the aroma profile of the wines, but taste and mouthfeel attributes were not investigated.

Although some vineyards have been around for a long time, the term 'old-vine' is said to be a relatively new concept in South Africa. The term was introduced by renowned wine writer Michael Fridjhon (2016a). Furthermore, recently, there has been a lot of mention of this term in the media (Fridjhon, 2016a) with accompanying questions of the age of such a vine (Beavers, 2016) and the quality of the wine its fruit produces (Meuse, 2015; Easton, 2016). Very little scientific research, however, has been published on old-vines. Some of publications include Zufferey *et al.* (2007, 2008) that firstly, compared

the physiology and secondly, the influence of age on grape and wine quality between young vines (7-year old vines) and old vines (31-36 years). Another study investigated the fungal colonies on the wood of 42 and 58 year-old vines (Bruez *et al.*, 2016), however, this study did not include any sensory analysis. The research on old-vines is few and rather disconnected. There is also no agreement on what the exact age of an old-vine is. Most specialised popular press stated that vines older than 30 – 35 years would be described as ‘old’, therefore, to ensure that the wines evaluated were from old vineyards, the old-vine wines investigated in this study were produced from vines aged 40-years and older.

A new trend that has taken shape in wine production over the past few years, involves producing wines that are more palate driven (Fridjhon, 2016b). The term ‘palate driven’ refers to more prominent and perceivable palate characteristics, for example taste and mouthfeel. This highlights the fact that aroma cannot be the only main focus in the sensory evaluation of wine, which had often previously been the case with Chenin blanc research. For the evaluation of palate attributes, mouthfeel wheels were designed for both red wine (Gawel *et al.*, 2000) and white wine (Pickering and Demiglio, 2008). These wheels included various cultivars and styles, including sweet wines and sparkling wines, which resulted in a very complex spectrum. It was, therefore, recommended that, when considering a specific product category, fewer attributes should be selected for evaluation (King *et al.*, 2003). For this study, the expertise of wine professionals with comprehensive domain knowledge on old-vine Chenin blanc wines as well as a panel with extensive experience in the sensory evaluation of wine, generated the terminology that described the palate attributes that these wines elicited. The terms included tactile sensations such as body, heat, acidity as well as concepts such as balance, concentration, complexity, integration and length. For the purpose of this study, all of these terms were referred to as in-mouth sensations. Furthermore, as one of the secondary objectives, this study also investigated the relationship between certain physicochemical parameters, normally associated with wine body, and all of the selected in-mouth sensations.

The most used sensory method for qualitative and quantitative product profiling is Descriptive Analysis (DA) (Murray *et al.*, 2001; Heymann *et al.*, 2014). Since the majority of the in-mouth sensations were mostly concepts, the main obstacle would be to train the panel to reach consensus on the evaluation of these difficult concepts in wine. DA allowed for extensive panel training and evaluation of each concept individually, but the analysis was, however, limited to a small sample set. This research, therefore, also explored the use of a rapid method, polarised sensory positioning, that would allow for the analysis of the in-mouth sensations of a larger sample set. This method is one of the most recently developed referenced based rapid methods that has successfully been used on products such as the water (Teillet *et al.*, 2010), cosmetic products (Navarro *et al.*, 2011), chocolate

flavoured milk (Antunez *et al.*, 2015), powdered orange drinks (de Saldamando *et al.*, 2013), functional yogurt (Cadena *et al.*, 2014) and astringent stimuli (Fleming *et al.*, 2015). This study would, however, be the first to apply it to wine.

The investigation of extrinsic factors, which included the vineyard management of the selected old-vine wines and the winemaking techniques used to produce them, as mentioned, was not part of the main objectives of the study. It has been highlighted, however, that it is important to understand the influence on extrinsic factors on the intrinsic quality of wine (Mueller *et al.*, 2010). Therefore, this study provided information on these external factors to provide context on the wines analysed.

This research was the first to specifically focus on the category of commercial old-vine (≥ 40 years) Chenin blanc wines. The sensory characterisation of this category of Chenin blanc, did not only include evaluating the aroma profile of these wines, but also specifically focused on selected in-mouth sensations. Some of these attributes, although associated with the intrinsic quality of wine, had never before been evaluated in wine. This study would also be the first to investigate the relationship between physicochemical parameters in wine and some of the selected in-mouth sensations in an effort to provide insight into what influences the intensity of these in-mouth sensations. This research is part of a series of projects focused on studying Chenin blanc in collaboration with the Chenin Blanc Association (CBA) at the Institute of Wine Biotechnology (IWBT) and the department of Viticulture and Oenology (IWBT-DVO), University of Stellenbosch. This specific study aimed at establishing a framework on how to analyse complex quality attributes, referred to as in-mouth sensations in, ultimately, any wine style category. With the application of the rapid method, PSP, to wine, this research created the opportunity for the analysis of larger sample sets, which is a limitation of DA as well as other rapid sensory methods. By providing context on the vineyard management and winemaking practices used to produce these wines, this study also creates more awareness of some of South Africa's oldest vineyards, believed to be capable of producing quality wines that are unique to the country's soil.

1.2. Project Aims

Primary objectives

1. Train a panel to evaluate selected in-mouth sensations of old-vine Chenin blanc wines and characterise the aroma and in-mouth sensory profile of the selected set, to ultimately determine the characteristics of Chenin blanc wines as a product style category.
2. Evaluate a rapid method, polarised sensory positioning, in the analysis of in-mouth sensations, which would allow for the analysis of a larger and more comprehensive sample set.

Secondary objectives

1. Investigate the correlation between physicochemical wine parameters and the in-mouth sensations selected for evaluation in old-vine Chenin blanc wines.
2. Provide context on the vineyard management and winemaking practices used to produce the old-vine Chenin blanc wines evaluated in this study.

1.2.2. Outcomes of study

Dissemination of information to industry

In order to portray the findings and information obtained with this research, popular articles are currently under construction and will be submitted to WineLand magazine. As a contribution to the scientific community, an article is under preparation for peer review in a scientific journal.

1.2.3. Conference presentations

The information presented at conferences was aimed at showcasing new developments and findings in sensory methodology as well as communicating important information that could be of great value to industry.

1. Crous, R., Panzeri, V., Nieuwoudt, H.H. **2015**. Framework for Training a Descriptive Analysis Sensory Panel to Evaluate Mouth-Feel Attributes in Wine: Special focus on a Product Category Unfamiliar to panellists. AfroSense 2015 International Conference, STIAS Conference Center, Stellenbosch, South Africa. FLASH PRESENTATION. (23 – 25 November 2015)
2. Crous, R., Brand, J., Panzeri, V., Nieuwoudt, H.H. **2016**. Traditional Descriptive Analysis versus an alternative rapid method for the analysis of in-mouth sensations in wine. 38th SASEV Congress, Lord Charles Hotel, Somerset West, South Arfrica. PRESENTATION. (23 – 25 August 2016) Theme: *Traditional vs Alternative Methods in the Production of Wine*
3. Crous, R., Panzeri, V., Nieuwoudt, H.H. **2016**. Crafting old vine Chenin blanc wine: feedback on vineyard management and cellar practices. 38th SASEV Congress, Lord Charles Hotel, Somerset West, South Africa. POSTER. (23 – 25 August 2016) Theme: *Traditional vs Alternative Methods in the Production of Wine*
4. Crous, R., Panzeri, V., Nieuwoudt, H.H. **2016**. The Evaluation of Mouthfeel Attributes in Chenin blanc Wine made from Old Vineyards: A comparison of Descriptive Analysis and Polarised Sensory Positioning. EuroSense: 7th European Conference on Sensory and Consumer Science, Dijon, France. POSTER. (11 – 14 September 2016) Theme: *A Sense of Time*

1.2.4. Experimental design

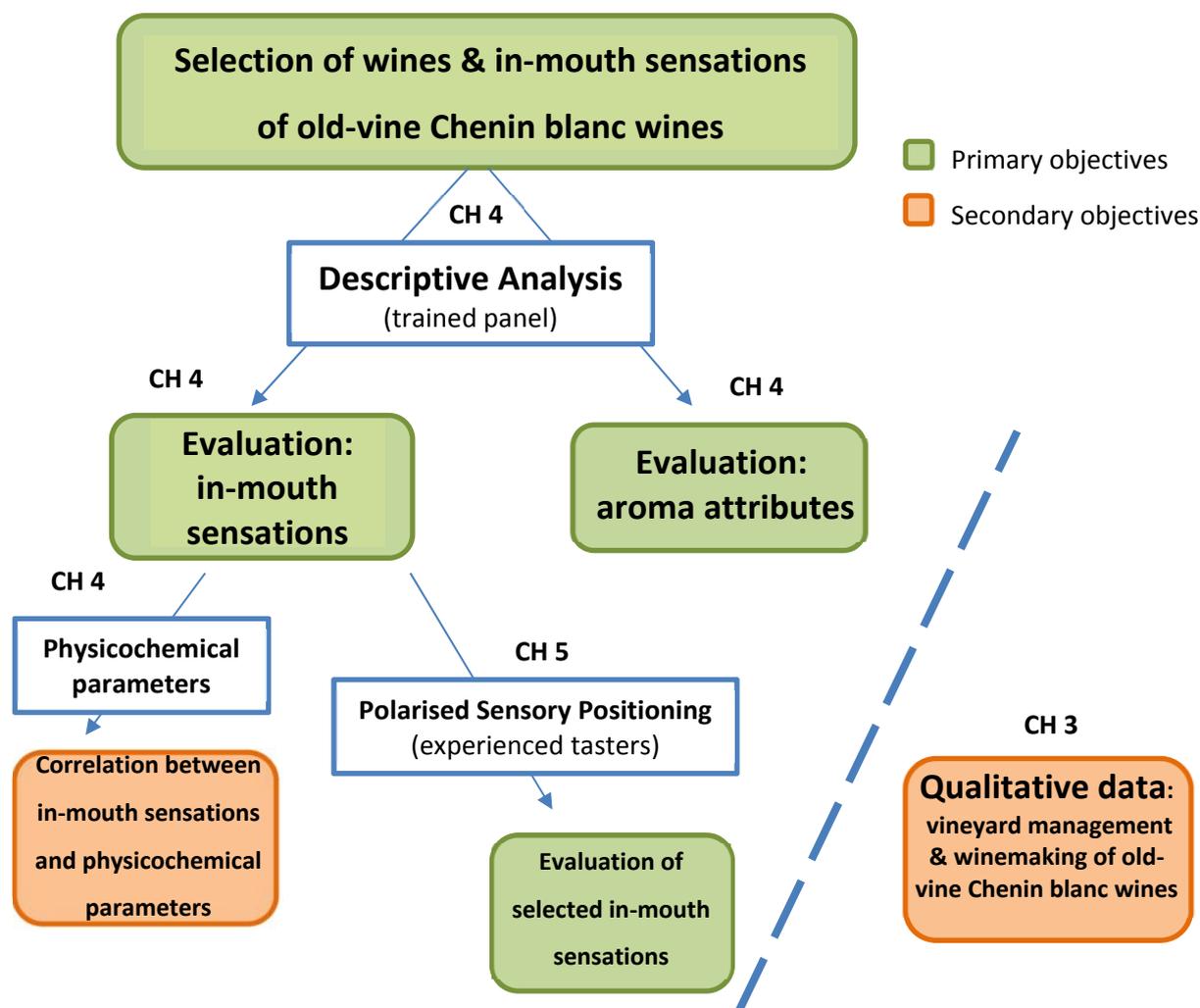


Figure 1.1 Summary of experimental layout and the aim of each research chapter (chapter 3 – chapter 5). The dotted line indicates that the qualitative data was used to provide context on the wines investigated in this study and were not part of the main aim of this study.

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Chapter 2

Literature review

Wine quality and the influence of in-mouth sensations

Wine quality and the influence of in-mouth sensations

2.1. The quality of wine

Determining the quality of any food or beverage product has proven to be a difficult task and this is especially true for a multi-dimensional product such as wine (Parr *et al.*, 2011). Quality cannot be linked to only one facet of the product, but is a combination of all of the different components that make up the final product (Peri, 2006). In an effort to assess product quality, the product is often split up into its different properties and characteristics and the quality of each is investigated individually. Quality within the food and beverage industry can be seen as the proverbial 'elephant' with wine being the Matriarch, and, how does one eat an elephant? One bite at a time.

In general, the first assessment of quality consisted of measuring a number of objective parameters that only had to meet the requirements of the producers and scientists creating the product (Cardello, 1995). This would include the chemical, microbiological and even textural quality of the food. If the product matched all set parameters, it was considered as high quality. There was, however, no guarantee that the product would meet consumer expectations. The first article to point out this issue was by H. Clarke in 1870, as referenced by Cardello (1995), but the first article to actually address this issue for the first time was published in 1995 (Cardello, 1995). It suggested that quality assessment should be based on consumer acceptance. Since then, there has been a large shift in focus towards consumers' expectations and how they perceive quality.

The first model designed to include the quality elements that consumers experience when purchasing a product, was created by Grunert *et al.* (1996) and was called the Total Food Quality Model (Grunert, 1997). What emerged from this were various models such as the one in Figure 2.1. This model (Figure 2.1) was designed based on the different dimensions of consumer requirements for quality (Peri, 2006) or what is referred to as 'perceived quality' (Oude Ophuis and Van Trijp, 1995). It incorporates what consumers expect when making their purchase decision (*homo oeconomicus*) as well as when consuming the product after purchase (*homo edens*).

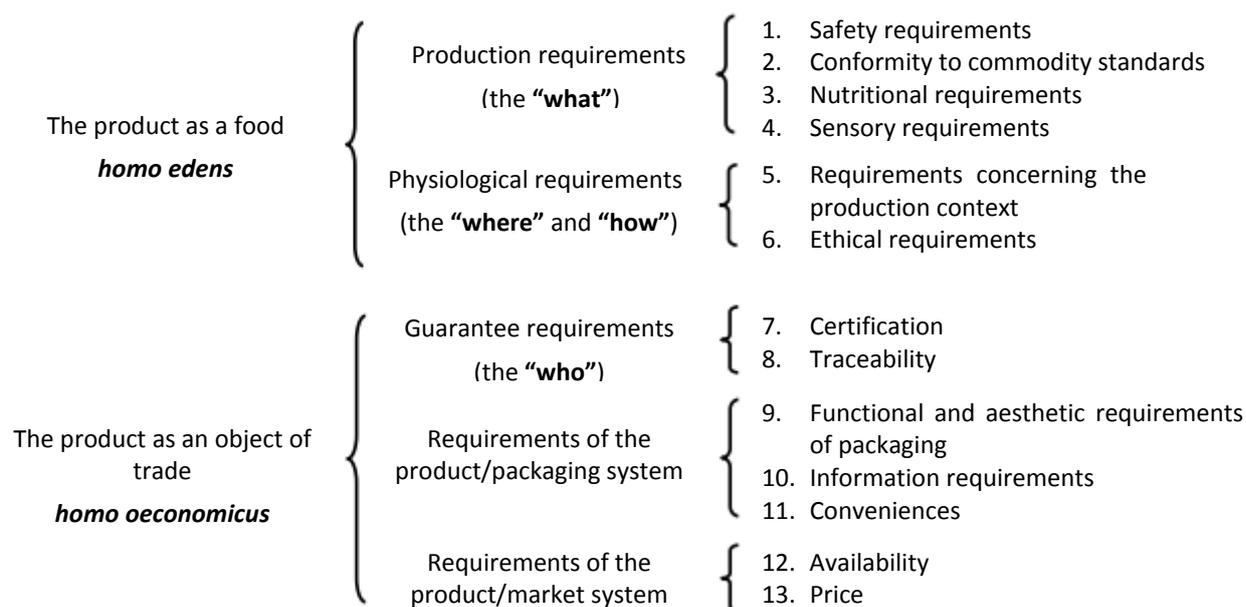


Figure 2.1 An analytical model of the quality factors of food product as determined by consumer requirement (Peri, 2006).

Figure 2.1 is a good illustration of how the perceived quality of a product unfolds into various dimensions. The model would also be applicable to wine, as wine was proven to have a multi-dimensional structure by Jover *et al.* (2004). The quality of wine is, however, not solely linked to consumer expectation and experience, as was highlighted in their study on red wine (Jover *et al.*, 2004). Certainly, wine production is consumer driven, but as a result of the influence of the winemakers, it is also driven by the producers’ requirements, and this, in turn, influences the consumer’s perception (Stuen *et al.*, 2015).

Due to the complex nature of wine, the quality of wine has been divided into two different dimensions – extrinsic factors and intrinsic attributes (Jover *et al.*, 2004). The extrinsic factors have been described as cues that are related to the product, but that are not part of the physical product that is consumed (Olson and Jacoby, 1972). The intrinsic quality attributes of wine are described as the chemical and physical constituents of the product that are perceived only once the product is consumed (Jover *et al.*, 2004). In Figure 2.1, the *homo edens* would be referred to as the intrinsic factors and the *homo oeconomicus* would refer to the extrinsic elements of the product. However, considering the influence of both consumers and experts on perceived wine quality as well as the fact that the type of aspects linked to wine quality might differ from that of other products, the model for wine quality, could look slightly different to Figure 2.1. The following section will briefly discuss the different types of wine consumers and other expert individuals that evaluate wine quality and determine quality dimensions.

The section will then also address what has been determined to make up the extrinsic cues and intrinsic quality attributes of wine.

2.1.1. Consumers' perceptions of wine quality

One of the factors that adds to the complexity of analysing wine quality, is the fact that there are different types of consumers who have different perceptions of quality (Lattey *et al.*, 2010). Wine consumers can be divided into four broad categories based on their knowledge of wine, namely: novice consumers (having little to no knowledge of wine), consumers with moderate knowledge, consumers with above average knowledge and connoisseurs (expert consumers). These different levels of involvement have been proven to influence the consumer's perception of quality. From the studies done on consumers with different levels of involvement, it was also apparent that knowledge of the product influenced how quality was conceptualised (Johnson and Bruwer, 2007; Ballester *et al.*, 2008). It was found that the level of involvement did not necessarily exclude certain quality cues, but, that the importance and complexity of specific cues increased with an increase in the consumer's level of involvement (Rahman and Reynolds, 2015). Quality cues and attributes are less complex for low-involvement consumers who focus more on sensory aspects, compared to higher-involvement consumers, whose approach is more cognitive (Steenkamp, 1990; Charters and Pettigrew, 2007). This means that a basic, 'entry-level' wine could be produced to meet the 'basic' requirements of low-involvement consumers as they see the product more like a mass production product such as milk or bread. This, however, would not suffice for high-involvement consumers. Thus, depending on the type of market that the producer is aiming at selling to, they could adhere either to the basic requirements of less involved consumers, or to the more complex expectations of high-involvement consumers, or both.

2.1.2. The influence of wine professionals on quality and quality perception

The different quality cues of wine are not solely determined by the consumers that purchase them, but also by the wine producers and other wine professionals. Producers add complexity to the quality of wines. They produce different styles within the various cultivars which often starts unique trends within industry and which could change the requirements for producing a wine of higher quality. An example of such a trend would be the production of, what is referred to as, natural wines (Chan, 2016). Natural wines are made by applying organic farming and having little to no interference during winemaking, such as, for example, allowing natural fermentation. The winemaker, therefore adds a sense of craftsmanship to wine by using or omitting certain techniques, creating what can be described as a 'quasi-aesthetic' product (Johnson *et al.*, 2006). This means that wine can almost be seen as a form of art. And as art, the only way to fairly analyse the quality would then have to be

within specified categories, taking objective information and subjective opinion into consideration. This evaluation is the task of wine judges. Wine judges evaluate the quality of wines in competitions or in wine reviews and blogs and are professionals considered to have a high level of expertise (Picard *et al.*, 2015). Studies have shown they have impeccable discrimination abilities as well as the skill to identify the sensory characteristics associated with different cultivars and wine styles (Hughson and Boakes, 2001; Zamora and Guirao, 2004). When the concept of ageing in Bordeaux wines was explored, it was decided that when looking at a new, undefined and complex concept in wine, it would be advised to seek the expertise of wine professionals to define the concept, rather than to rely on consumer preferences (Picard *et al.*, 2015). Although some sources have questioned the level of consensus amongst these wine professionals (Quandt, 2007), other sources were of opinion that although the consensus of these professionals is not perfect, there is a high level of agreement amongst wine experts in the evaluation of wine (Stuen *et al.*, 2015).

In an effort to guide the general public in assessing the quality of wines in South Africa, a platform was established where wine professionals could convey their expertise and opinion. Platter's South African Wine Guide is based on the opinion of 15-20 expert assessors who are all considered as established wine professionals within the South African wine industry, many of whom have served on international wine judging panels. Each judge is given the task of evaluating all of the wines from a specific winery for no more than three years. The tastings are not done blind and wines can be assessed within the comfort of their own homes. Based on their wine knowledge and expertise to generate descriptors for the wines and give them an overall rating out of 5, based on both flavour and aroma. This rating is accredited in South Africa with a sticker indicating the Platter's rating of a vintage which may be displayed on the wine bottle. Each vintage is assessed and a new rating is given. It has been shown that these types of ratings are valued by consumers and influence their hedonic ratings of the wine as well as their willingness to pay a certain price for the bottle (Siegrist and Cousin, 2009). The guide does not only give an indication of the intrinsic quality of the wine, but some information is also provided on the wine producer and often even the vineyards that the wines are produced from. It was noted by Siegrist and Cousin (2009), that providing consumers with certain extrinsic information prior to tasting, influenced their perception of the quality of wine. Similar responses were noted by Hanekom (2012) when consumers were informed that certain Chenin blanc wines had been produced from bush vines or old bush vines and by Vannevel (2016) where packaging and the opinions of experts increased the liking of South African Pinotage wines.

Wine producers and wine professionals therefore also form an integral part in determining wine quality and the consumer's rating or judgement of the quality of wine.

2.1.3. Determining wine quality dimensions

The theory of quality perception has led to the division of quality into two variables – extrinsic cues and intrinsic attributes. The extrinsic cues in wine include price, label, bottling, wine origin, wine ageing, variety, the reason for purchase, ratings and awards, consumer involvement, brand or product (Saenz-Navajas *et al.*, 2013), while intrinsic cues in wine referred to what is perceived when drinking the wine (Veale and Quester, 2009). Researchers, however, have mainly chosen to focus their studies on the perception of quality on one of the two domains in their research. In wine the focus has more often been on the extrinsic cues when determining perceived quality. The reason for this, according to Jover *et al.* (2004), is the fact that the intrinsic factors cannot be assessed before consumption. This is further complicated by the fact that a prior consumption experience might not be a quality indicator for future purchase due to, amongst other things, the variability between production techniques and vintages. Many of the terms used to describe wine quality, for example concentration, have also been seen as vague and it is suggested that such terms not be analysed with sensory evaluation techniques (Heymann *et al.*, 2014).

In the analysis of the complexity of wine, it was found that consumers tend to focus more on the sensory attributes of wine and linked 'complexity' more to the intrinsic quality attributes (Parr *et al.*, 2011). Wine professionals, however, associated the term 'complexity' in wine with extrinsic cues such as vine, soil and production methods. Even though the professionals in this study concentrated more on production and technicalities when describing complexity in wine, they also deemed the organoleptic qualities important. The emphasis of professionals was mainly on palate sensations and the structure of the wine, including balance, length, body, weight, mouthfeel and texture and the fact that these factors are influenced by the extrinsic complexity. In a number of studies, it was also noted that involved consumers were concerned with the sensory phenomena, especially those aspects concerning the palate (Veale and Quester, 2009; Saenz-Navajas *et al.*, 2013). From these studies it seems that what both consumers and experts most importantly agree on, is the fact that quality is a multi-dimensional phenomena and the in-mouth elements make an important contribution in their assessment of wine quality.

An extensive study was done by Charters and Pettigrew (2007) on how consumers perceive wine quality. It was the first study to shift the focus from concentrating on the consumption behaviour of low-, medium- and high-involvement consumers, to rather address what they consider as important determinants of wine quality. The results from the study were used to construct a diagram (Figure 2.2), combining and mapping the most important attributes according to all three groups (low-, medium- and high-involvement) of consumers into the extrinsic cues and intrinsic attributes they associate with wine quality.

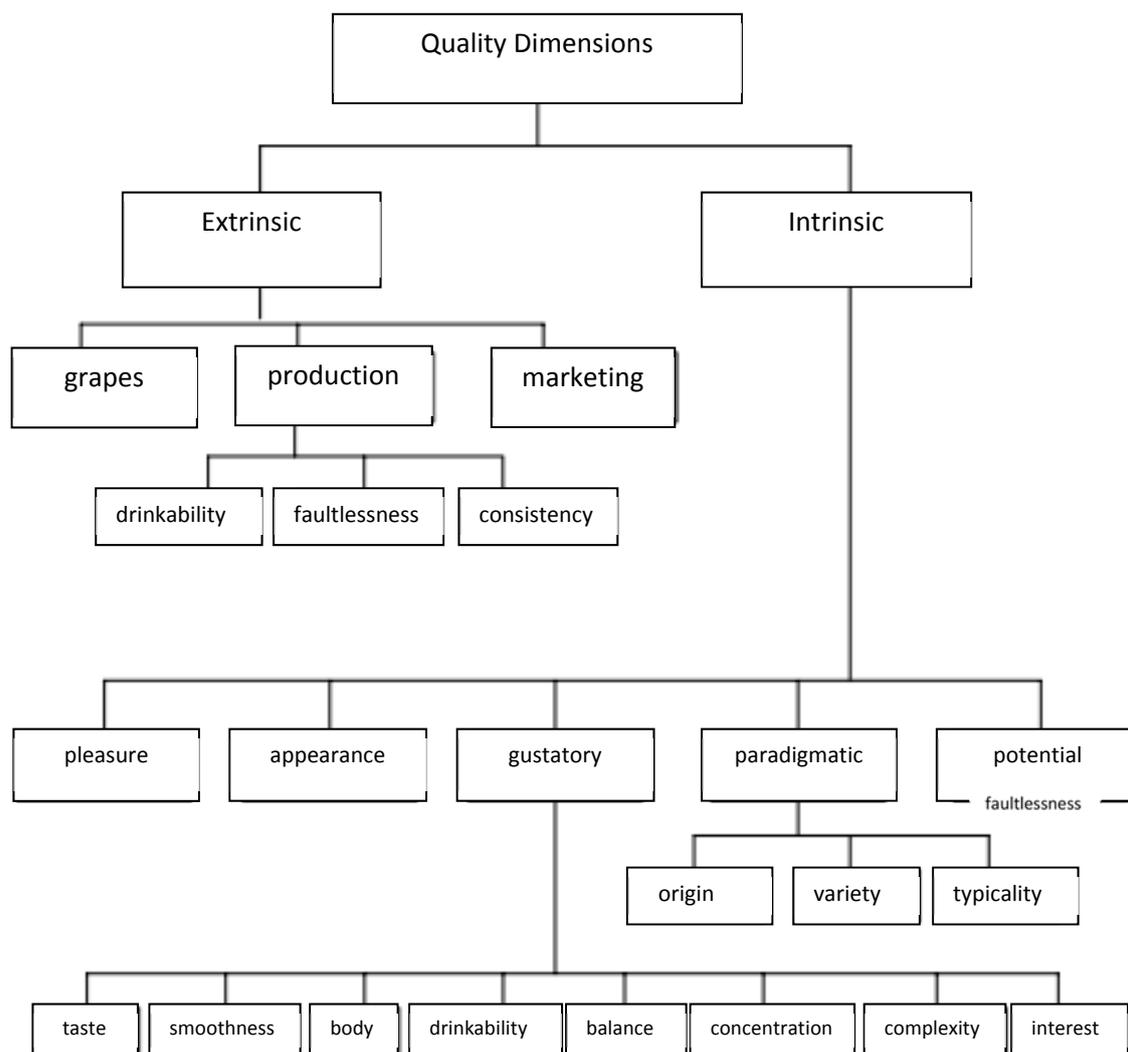


Figure 2.2 The dimensions of wine quality as developed by Charters and Pettigrew (2007).

The importance of focusing on consumers' overall quality description, and all aspects that they associate with quality, was also highlighted by Rahman and Reynolds (2015). Therefore, instead of pre-selecting quality parameters to focus on in the study, these studies allowed the consumers to generate their own terminology in describing quality. According to Parr *et al.* (2011), the study by Charters and Pettigrew (2007), made valid conclusions on the perception of wine quality. The same approach was therefore used for defining complexity in wine, in the study by (2011). Many other papers studying perceived quality (Lockshin and Corsi, 2012; Saenz-Navajas *et al.*, 2013, 2015; Hopfer and Heymann, 2014), whether it be that of experts' or consumers', often referred to the research done by Charters and Pettigrew (2007), usually when referring to the complexity of quality and the fact that it can be divided into many different dimensions.

If prior research on the quality of wine is considered, this diagram would be a good representation of all parameters that have been identified to form part of the dimensions of quality, similar to those shown in Figure 2.1. A study on red wine quality by Jover *et al.* (2004) had also previously stated that it is possible to include both extrinsic cues and intrinsic quality attributes when analysing the dimensions of wine quality. Although the diagram (Figure 2.2) gives only a global break down of extrinsic cues, it more importantly, identifies further gaps for research concerning intrinsic quality attributes. The extrinsic cues such as price and labelling have been evaluated extensively, as mentioned, and their influence on consumers' expectations of quality have been proven continuously (Miyazaki *et al.*, 2005; Siegrist and Cousin, 2009; Saenz-Navajas *et al.*, 2013, 2014). There has, however, been little research done on evaluating certain intrinsic attributes associated with quality.

The sensory evaluation of wine has mainly focused on analysing wine aroma and basic tastes, but has not included other attributes which have been deemed as important intrinsic quality factors (Charters and Pettigrew, 2007; Parr *et al.*, 2011) such as balance, weight, length, complexity and concentration. In an article written by Michael Fridjhon (Fridjhon, 2016a), who has been described as one of the most renowned wine experts in South Africa, he states that the focus in winemaking has shifted from aroma and basic tastes, to mouthfeel and texture, indicating that there should also be a shift in the evaluation of wine characteristics. In *Wines and Spirits: Understanding Style and Quality*, a book specifically written to be a textbook for the Wine and Spirits Education Trust (WSET) Level 3 Award in Wines and Spirits, these terms were also listed under 'Quality Assessment' (WSET, 2012), yet these terms are not being evaluated in wine.

It was noted by Peri (2006) that to evaluate the quality of a product such as wine, all of the characteristics have to be taken into consideration. Mueller *et al.* (2010) also stated that the two dimensions (extrinsic and intrinsic) cannot be separated, as: 'product consumption can only occur after a product is actually purchased, and consumption experience affects future purchases'. According to them, there is not much research that integrates the two aspects of extrinsic and intrinsic, therefore most research in this field is approached in an unrealistic manner. Thus, when investigating the intrinsic attributes of a product, it is important to understand and have context on the extrinsic cues of the product.

2.2. The quality of Chenin blanc wine

2.2.1. A brief history of Chenin blanc

Chenin blanc was first cultivated in Anjou situated in the Loire Valley in France (Clarke, 2007; Forrester, 2011). The grapes were named 'Chenin blanc' in the 15th century from Mont Chenin – a monastery near Croméry, France (Robinson *et al.*, 2012). After that it was cultivated in Touraine, also situated in the middle region of the Loire Valley (Wilson, 1998; Forrester, 2011). Here, it was often referred to as Pineau de la Loire (Wilson, 1998). Chenin blanc was introduced to South Africa with the arrival of Jan van Riebeeck in 1655 and was first known as *Steen* (CBA, 2016). During an interview with Bruwer Raats (B Raats, personal communication, 30 May 2016), he stated that the first clones of Chenin blanc are unknown, but they were believed to be easily adaptable to various climates and had vigorous growth. The adaptability of Chenin blanc to the South African climate was also noted by Goussard (2008) in a book on South African grape cultivars. Since then, a variety of Chenin blanc clones had been developed which could cater to the producer's needs, whether it be high-yielding vines (20 tons per hectare) for bulk production, or lower yielding (4 tons per hectare) with smaller berries for more concentrated wines (B Raats, personal communication, 30 May 2016).

2.2.2. The shift in the quality perception of South African Chenin blanc

To date, Chenin blanc is still the most widely planted variety in South Africa, covering more than 18% of all planted vineyard area (SAWIS, 2015). Until recently, quality Chenin blanc wines had been mainly confined to the Loire Valley in France, according to Asimov (2007). Already then, Asimov (2007) was, however, of opinion that South African Chenin blanc had become the only contender that could compete and possibly surpass that of the Loire Valley. Since then, the quality and potential of South African Chenin blanc grapes and wines had been noted (Buzzeo, 2016; Du Preez, 2016).

Previously, Chenin blanc was mainly seen as a 'workhorse variety' (Goodie, 2011; Gawel *et al.*, 2014b) and was used for brandy distillery, in blends or to produce bulk wines. The reason for Chenin's popularity was due to its adaptability to nearly any climate and ability to consistently grow and produce fruit vigorously. Chenin blanc grapes' lack of primary grape derived aroma compounds, for example methoxypyrazines, also meant that the grapes could be easily manipulated by using different winemaking techniques (Marais, 2006).

The shift in the perception of the quality of South African Chenin blanc, was perhaps mostly driven by a few individuals that established the Chenin Blanc Association (CBA). The CBA had identified six different styles of Chenin blanc in South Africa which were classified using sugar content as a guideline (CBA, 2016). The six styles include fresh and fruity, rich and ripe (unwooded), rich and ripe (wooded),

for dry (<5g/L sugar) and semi-dry (<9g/L sugar) wines, as well as, rich and ripe (slightly sweet), sweet and sparkling (CBA, 2016). Research had, however, proven that consumers and even trained panellists could only distinguish between two of three of the styles in the evaluation of dry and semi-dry wines, (van Antwerpen, 2013). Yet, the styles are still recognised as such by the CBA, which still proved that there was more versatility to this variety than previously recognised. The emergence of the different styles could also be attributed to the start of new trends in winemaking, such as focussing on the palatability and not just the aroma of the wine. According to Michael Fridjhon (2016a), there has been a shift in the wine producing culture of South Africa to a more artisanal production type, where winemaking practices are focused on producing wines with more mouthfeel and texture. This is the same type of trend that was started in beer brewing with the production of craft beer. With beer, the focus shifted from only producing different styles of traditional mass-produced products, to producing unique beers, characteristic of its producer, with more complexity to its palate structure (Hesseling, 2014). The aim of craft beer was to promote locality and for the product to display a sense of ownership from its producer (Porter, 2013; Hesseling, 2014). There exists no formal definition or legal requirements for a 'craft beer', but it has been described as micro-brewing with certain unofficial requirements such as good brewing practices, pure ingredients and good packaging. In an article in WineLand magazine, the craft beer trend was described as an 'explosion' in the beer industry and its popularity has drastically been increasing in markets across the world (Hesseling, 2014). A similar trend has also taken shape in the wine industry and specifically in the production of Chenin blanc wines (Fridjhon, 2016b). Wine producers aim at producing wines that have a palate that is characteristic of their grapes (Fridjhon, 2016a), grown on their soil and their terroir. In this sense it could be said that winemakers are producing 'craft wines' that also promote the sense of locality and are thus unique to their region or farm. If referred back to Figure 2.2 in section 2.1.3. the reason for the shift in quality in Chenin seems to be driven by a change in the focus of production, which in Figure 2.2 forms part of the extrinsic quality cues of wine. This would therefore have an influence on the intrinsic quality of Chenin blanc wines. For South Africa, this trend would promote the production of wines unique to our soils from our most widely planted cultivar, Chenin blanc.

This is one of the reasons why old-vine Chenin blanc has become an important wine style category for South Africa (Fridjhon, 2016c). As in the case of craft beer, there exists no formal definition for an 'old-vine', but just as for craft beer, these wines are produced on small scale, as the vines have become lower yielding with age. The old-vine wines are produced from quality grapes and good production practices and packaging are used when making them. These old vines are said to produce 'fine wines' and they cater for a niche market, according to Vinpro viticulturist Hanno van Schalkwyk (H van Schalkwyk, personal communications, 29 April 2016), as was the case for craft beer. The production is

focused on minimising the winemaker's influence and rather aiming at promoting the characteristics of the grapes. If the packaging of these wines is inspected, the words *Old Vine*, *Reserve* or *Family Reserve* can often be found on the label and the labels often have a sense of tradition and history about them. These 'old world' style labels have been linked to a higher perceived quality as quality perception has been found to be influenced by tradition and history (Saenz-Navajas *et al.*, 2013). It was also found that words such as "old bush vine" on labels, increased consumers' liking of Chenin blanc wines (Hanekom, 2012). An example of such a label is displayed in Figure 2.3. This is a South African Chenin blanc made from vineyards, planted in 1905, now 111-years old. The font on the label has a historic look to it, with the words "die ouwingerdreeks", meaning 'the old-vine range'. Only 80 cases are produced from this vineyard, which could be considered as micro-production within the wine industry. This wine exemplifies the 'craftsmanship' of old-vine Chenin blanc wine. The definition and characteristics of old-vine wine will be discussed in the next section (section 2.3.).



Figure 2.3 Example of an old-vine Chenin blanc label: The Sadie Family Wines Mev. Kirsten is made from vineyards planted in 1905.

2.3. Old-vines

Due to a lack of scientific research on old-vines and the theories surrounding the age that defines them and the grapes and wines they produce, this section is based mainly on empirical evidence sourced from blogs, magazine articles and interviews. This, however, highlights the growing interest around these vineyards in the media, which was also pointed out recently by Fridjhon (2016c), and the opportunities for scientific research within this field which would be beneficial not only to the world of science, but also to industry.

2.3.1. How old is an 'old-vine'?

In South Africa, the life expectancy of vines is around 25 years (Lloyd, 2014). This means that most vineyards are uprooted by the time they reach the age of 25, as this is the age where they start losing vigour and less wine can be produced from them as a result of lower yields. Provided they even reach this age and did not have to be uprooted earlier due to virus infections (Lloyd, 2014). One of the leading specialists on old-vines in South Africa is Rosa Kruger (Mkhwanazi, 2016). As there is no legal age to define the term 'old-vine', through her expertise and experience in working with old-vines in South Africa and from across the world, she has deemed 35 years and older to be an acceptable age to describe an 'old-vine'. To create awareness of the old-vines in South Africa, Kruger started an informal project to create a blog (available from www.iamold.co.za) which is a directory of all the old vineyards over 35 years found in South Africa (Heyns, 2011). The directory includes the regions in which the vineyards are grown, the age of the vineyards, which cultivars are grown on the farms, how many hectares they cover and the farmers to whom the vineyards belong. The blog also serves as a communication system where farmers can declare their old vineyards or supply any further information regarding old-vines to help complete the directory.

Old-vine is not a term unique only to South African vineyards. This term has also been used in all of the oldest wine producing regions, including the Barossa Valley in Australia, California in the United States and France. As is the case in South Africa, these countries also have no legally defined age for the term 'old-vine'. Similar projects to Kruger's have been conducted in these different regions, with the aim of preserving their old vineyards and to help ensure that they are managed properly.

In the Barossa Valley a 'Charter' was designed to help classify the old vineyards and help increase the merit of their oldest vineyards. This valley has vineyards that date back as far as 1834. With some of the oldest vineyards in the world, their Charter included different classifications of 'old' (available from www.barossa.com). The Charter, designed by Robert Hill-Smith from Yalumba winery in the Barossa Valley, was divided into four categories, starting from Old; Survivors; Centenarians and Ancestors. The age classification for the Charter is displayed in Table 1. With the design of the Charter, Hill-Smith stated that 'The Old Vine Charter is dedicated to the recognition, preservation and promotion of these old vines,' (BGWA, 2007). Therefore, even though this classification is not official, it is aimed at creating awareness of the status and the value of the old-vines of the region, as was the aim with Kruger's project.

Table 1 Barossa Valley vine age classification Charter adapted from Barossa Grape and Wine Association (2007).

Term	Vine age
Old Vine	≥35 years
Survivor Vine	≥70 years
Centenarian Vine	≥100 years
Ancestor Vine	≥125 years

In an attempt to create awareness and preserve California's oldest vineyards, a non-profit organisation was established – The Historic Vineyard Society (HVS, 2013). In contrast to South Africa and the Barossa Valley, this is an official organisation. It was founded in 2013 with the aim of creating a registry of California's old vineyards. All vineyards have to conform to certain requirements and undergo a reviewing process before they are able to qualify for the registry. To reach their goal, the founders drew up a resolution to state what the aim is of the organisation, which had been accepted by the California Assembly Agriculture Committee to indicate that the committee recognised the cause behind the society (HVS, 2013).

France is notably also one of the oldest wine producing countries in the world and has been producing wine dating back to biblical times. Even though they have a very complicated and thorough classification system, AOP (Appellation d'Origine Protégée), they have no legally or even informally accepted age which defines an old-vine. It is accepted that the term '*Vieilles Vignes*' (translated as 'old-vine') refers to a vineyard which is considered as 'old' (Meuse, 2015).

It has also been said that the term 'old' can depend on the variety and the terrain that the vine is grown on. Some varieties are more prone to disease than others and some varieties are better adapted to handle various environmental challenges. Thus, in certain harsher conditions, even 20 years could be considered as 'old' (Kruger, 2016). It therefore seems as though the term 'old-vine' is not necessarily bound to the vineyard being a certain age, but to it eliciting certain characteristics.

2.3.2. Characteristics of old-vines and their wines

In the media, the most controversial question surrounding old-vines, is whether they produce wine of a different quality or even better wine, which includes both red and white wine (Botha, 2012). In a recently published article by Rosa Kruger (2016) who has been deemed as the 'Mother Theresa for old vines' in Wineland Magazine (Mkhwanazi, 2016), she stated that officially and scientifically, this question remains unanswered. According to her there is definitely some truth to this belief. Something that has been proven with research, however, is that for both red wines as well as white, the ageing potential of wines made from old vineyards, over 30 years, is better compared to those produced from vines aged 4-8 years (Zufferey and Maigre, 2008).

When confronted with the question on the quality of old-vine wines, a few explanations have been offered by wine connoisseurs, producers and viticulturists. One of the leading theories is the fact that these old-vines have developed a large and deep-reaching root system (Ross, 2011; Harvey, 2012; Easton, 2016). According to this theory, a deeper root system helps the vines to survive better in dry-land conditions as it can reach down further to moist soil/plant available water (Zufferey and Maigre, 2007). A deeper root system is also less influenced by climate change scenarios. It also means that when it rains, the vineyard does not use up all the water in the top soil causing it to produce watery grapes, as a young vine might do. With a deeper root system, an old-vine might also be able to reach different minerals adding more dimensions to the vines' recourses and enabling it to produce more complex and concentrated fruit. It was found in a study by Heymann and Noble (1987) that older vines were significantly correlated with high intensity berry aroma, vanilla aroma and in-mouth fruit flavour. Another study done to compare the physiology of old and young vines which acknowledged the difference in quality between vines of different ages, concluded that, older vines were less susceptible to water stress than young vines (Zufferey and Maigre, 2007). They attributed this to the fact that the young vines had a more 'superficial' root system compared to the old vines. The study also showed that older vines have more vegetative expression, with higher levels of nitrogen and chlorophyll in their leaves. In this study, vines over 30 years were labelled as 'old' and vines between 4-8 years were 'young'.

According to Rosa Kruger and Eben Sadie, one of South Africa's old-vine specialist winemaker, as the vines age, the vineyards become more accustomed to their environment (Heyns, 2011). The vines are said to have developed a 'memory' of their environment and therefore produce more balanced yields and crops (Kruger, 2016). According to them, this balance can presumably only be achieved once the vine reaches a certain age, allowing the vine to produce layered wines that have more structure than wine from younger vines. These old-vines, according to Kruger (2016), are also generally more resistant to viruses and diseases and the vine's survival resistance to these infections could often help add to the complexity of the vineyards. In one of the few published articles researching old-vine (Bruez *et al.*, 2016), it was established that there was a lack of foliar symptoms amongst the old vineyards and that this could indicate an equilibrium or balance between pathogens and beneficial microbes in the functional wood tissues of the trunk. This indicates that there is clearly a need for research to support Kruger and Sadie's beliefs on old-vines.

As vineyards age, they lose vigour. They produce less fruit with smaller berries and thicker skins. This has also been mentioned as a reason for the quality of old-vine grapes. A study on the influence of berry size on red wine colour and chemical composition, found that the titratable acidity, phenolic and flavonol content of smaller berries differed significantly from that of medium and larger berries

(Gil *et al.*, 2015). The difference in chemical constituent levels between old and young vines was also noted by Zufferey and Maigre (2007). It was proven by Barbagallo *et al.* (2011). that in order to produce wines of better quality, a reduction in berry size is important, based on measuring the differences in the phenolic content of the berries.

Another factor that adds to the value of these old-vines is that they are believed to be a true expression of their terroir (Heyns, 2011). They therefore, have the potential to produce wines that are unique to the soil and environment they are grown in. This would mean that wines could be produced that are characteristic of a specific region which could not be mimicked anywhere else in the world. This would also then increase the perceived quality of old-vine wines as studies have found that high importance is given to wine origin, as it is associated with tradition and originality of the wines (Saenz-Navajas *et al.*, 2013).

Apart from the quality of the grapes and wine attached to the term 'old-vine', another reason for the value associated with old-vines, is the sentiment and the history that forms part of them. In South Africa, for instance, some of the vineyards had been planted before the Anglo Boer War and had lived through numerous political and economic changes in our country (Kruger, 2016). They are seen as survivors and form part of 'old world' South Africa. In Chile they developed an unofficial organisation called Vignadores de Carignan (VIGNO) (available from: www.vigno.org). This scheme aimed to promote the area where some of the first grapes were planted in Chile, the Maule Valley. The purpose of VIGNO was to keep these vines from being uprooted and aid in producing wines that were unique to the Maule Valley. Unfortunately, however, the scientific evidence to cement the beliefs surrounding old-vines and their quality are scarce and fragmented.

2.3.3. Economics and reality for old-vines

The only proven reality that faces old-vines across the world, is the fact that they are often economically unviable. The problem with losing vigour and producing less grapes is that the price for the grapes stays the same, regardless of the quality. The vineyards still have to be maintained and pruned after every harvest, thus the same amount of work (if not more) goes into the vineyards, but they are producing smaller and less grape berries per bunch. The total cost of producing grapes from these vineyards amounts to roughly R 24000 per hectare (Joubert, 2016). If the vineyards then only produce 3 tons (which some of them do) the grapes would have to be sold for between R10000-R12000 per ton for the farmer to be able to make a profit. In most countries, and especially in South Africa, this is currently not viable. According to Fridjhon (2016c), this is still due to the fact that grapes had long only been priced per ton, and not necessarily on quality. This could have a detrimental effect on the vineyards as well as the farmers producing the grapes. If the farmers cannot make a profit, the vineyards have to be uprooted or sold (Fridjhon, 2016c).

The aim of creating awareness and giving status to the term 'old-vine' is, therefore, ultimately to increase the price at which these grapes should be sold, which in 2014 averaged at R2682 per ton (van Niekerk and van Zyl, 2014), and keeping those who cultivate them, from having to uproot the vines (Heyns, 2011). According to Kruger (2016), to achieve this, the price of the wines, should be the estimate for the price of the grapes. Thus, high quality grapes should be offered a higher price, as they produce more expensive wines. The way that this could be achieved in South Africa, is by establishing a classification system for old-vines, similar to the Historic Vineyard Society in California, where the price of the wines already reflects the price of grapes, and creating a platform for the certification of old-vines (Fridjhon, 2016c). Thus, if a vineyard is certified as an old-vine, the grapes automatically move into a higher price bracket.

2.4. Sensory methodologies for the analysis of in-mouth sensations

2.4.1. White wine in-mouth sensations

Wine, in terms of sensory analysis, is considered as a complex medium to evaluate (Valentin *et al.*, 2012). The three main sensory perceptions in terms of which wine can be evaluated, include visual, oral and olfactory, where oral can further be split into taste and tactile sensations (Pickering and Demiglio, 2008). Wine is anything but one-dimensional and each stimulus is affected by layers of different components. For example, the tactile perceptions are influenced by a range of, so-called, mouthfeel sensations. Mouthfeel in wine is often deemed as a key quality characteristic, as referenced by Pickering and Demiglio (2008), but there seems to be a lack in agreement amongst professionals as to what the different mouthfeel sensations are that wine elicits (Gawel *et al.*, 2000). The lack of understanding mouthfeel sensations was first identified in beer. In an effort to clarify the concept of mouthfeel in beer and classify all the sensations that contribute to beer mouthfeel, a study was conducted to alter the beer flavour wheel to include mouthfeel terms (Langstaff and Lewis, 1993).

In order to clarify the same shortcoming in wine mouthfeel evaluation, a Red Wine Mouthfeel Wheel (RWMW) was constructed in a study done by Gawel *et al.* (2000). Red wine was the natural choice for the first mouthfeel wheel as mouthfeel in wine is mainly associated with red wine due to its astringency (Gawel, 1998). Astringency has mostly been linked to phenolic compounds, known as tannins and possibly their interaction with pigmented polymers (anthocyanins) (Gawel, 1998; Vidal *et al.*, 2004). It was found that when white wine is treated the same as red wine during production, the only difference in the phenolic content is the absence of colour pigments in white wine (Oberholster *et al.*, 2009). The sensory astringent profile elicited by the white wine was, however, very different compared to that of red wine (Oberholster *et al.*, 2009). Gawel (1998) therefore concluded that the

interaction between tannins and pigmented phenols seems to be responsible for the difference in astringency in red and white wine. As astringency is the primary mouthfeel characteristic, the RWMW mostly focused on identifying the different astringency sensations. Due to the difference in astringency for white wine, a separate mouthfeel wheel would be required and was developed (Pickering and Demiglio, 2008).

The White Wine Mouthfeel Wheel (WWMW) aimed at identifying and classifying all of the subtle mouthfeel sensations associated with white wine. Figure 2.4 shows that the 'discrete' sensations were presented as a function of time. The time factor was incorporated as it was believed that the intensity or presence of certain sensations could change over time once it is consumed (Pickering and Demiglio, 2008).

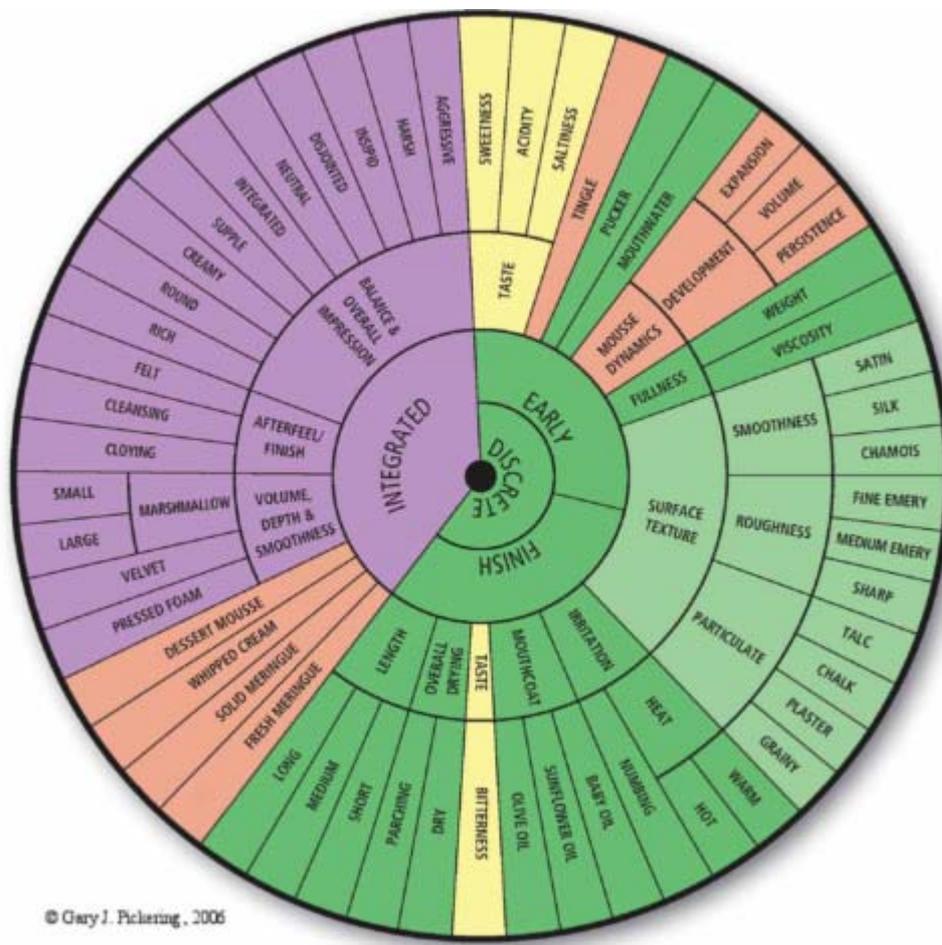


Figure 2.4 White wine mouthfeel wheel as designed by Pickering (2006).

Different white wine cultivars were included in the design of the wheel as well as several styles of wine, including table wine, late-harvest/dessert wine, ice wine, fortified wine, sparkling wine and de-alcoholised wine. With the inclusion of all of these categories, the wheel resulted in having a very complex design (Figure 2.4).

Both the RWMW and WWMW succeeded in providing a comprehensive tool that could aid in the evaluation of the mouthfeel sensations elicited by wine. In both studies, however, it stated that the goal was mainly for the wheels to serve as a guidance tool for further research. Not all of the attributes in the wheel are applicable to all cultivars or different wine styles. Presenting this wheel, as is, to assessors could be confusing and overwhelming. In a study which applied the RWMW, it was established that there were, in fact, too many descriptors on the wheel which potentially described the same sensation (King *et al.*, 2003). It would therefore be wise only to select the descriptors characteristic of the wine style category being analysed. The most important contribution that these wheels perhaps made, however, was to develop reference standards and provide written definitions for these terms that could be used when analysing them in wine. For the purpose of the evaluation of in-mouth sensations in old-vine Chenin blanc wine, the wheel could therefore be used to create reference standards and definitions for the in-mouth sensations associated with this product style category.

2.4.2. Wine sensory evaluation

The food and beverage industry has always been a competitive market and even more so with the development of new technologies and the expansion of digital marketing strategies. With these developments and changes in consumer trends, the industry faces the challenge of having to keep up with the ever-changing landscape of consumer preference as well as having to maintain high standards of quality. In order to do so, producers have to evaluate the sensory characteristics of their products to see how it compares to their competitors or whether the sensory quality of the product is being maintained (Cartier *et al.*, 2006; Moussaoui and Varela, 2010; Valentin *et al.*, 2012).

Sensory evaluation relies on the use of human stimuli to evaluate the characteristics of the product (Varela and Ares, 2012). According to Varela and Ares (2014) the use of sensory characterisation methods has been on a rapid increase into the 21st century, when considering the amount of publications per year from 1966-2011. The publications have focused on the development of different methodologies to meet the requirements of the information required from sensory characterisation. The methodologies can be divided into classical sensory descriptive analysis (DA) and novel techniques (Varela and Ares, 2012).

Classic sensory descriptive analysis uses trained assessors, which have undergone extensive training on the product category that is being evaluated and is the most time consuming of all the methods (Stone and Sidel, 2004). Novel techniques, however, can be used with either everyday consumers (untrained) of the product or with experts on the product category. Novel techniques are focused on revealing how consumers or experts perceive a product. This information could be used as a guideline for new product development and to obtain this information in the least amount of time (Varela and

Ares, 2012). Three categories of novel techniques have been developed, which include: verbal description of products, similarity based methods and reference based methods (Valentin *et al.*, 2012). Although these techniques have managed to overcome the shortcomings of classic DA, such as avoiding the need for highly trained assessors, eliminating the need for any training and allowing the increase of sample sets, they still have not managed to completely replace the use of classic DA (Varela and Ares, 2012). This is especially true when the product category has to be described in extensive detail (Varela and Ares, 2012). DA is still seen as one of the most sensitive techniques for the sensory characterisation of products within a specific space and yields robust and consistent results (Lawless and Heymann, 2010; Moussaoui and Varela, 2010).

2.4.2.1. Descriptive analysis

Descriptive Analysis (DA) is specifically used to identify the difference in sensory attributes between products and to describe the sensory space of a specific product set. It also allows for the generation of quantitative data as the intensities of the attributes present can be rated on an unstructured scale ranging from 0-100 (Cartier *et al.*, 2006). It also makes it possible to compare to other measurable chemical and physical parameters (Murray *et al.*, 2001; Varela and Ares, 2012). In a review of the all types of DA, Murray *et al.* (2001) listed that there are 6 different types of descriptive analysis techniques that can be applied, depending on what the desired approach of the analysis is. In the latest book reviewing sensory evaluation techniques, by Varela and Ares (2014), they, however, state that the latest generic DA methodology is a combination of three of these techniques, including Flavour Profile (FP[®]), Quantitative Descriptive Analysis (QDA[®]), and the Spectrum Method[®]. From these three methods, two different training methods emerged for DA: consensus training and ballot training (Heymann *et al.*, 2014).

Descriptive analysis procedures and considerations

The panel for DA generally consists of between 8-12 assessors, depending on the difficulty of the analysis (Lawless and Heymann, 2010; Heymann *et al.*, 2012). The number of judges can, however, be less or more than this range, depending on the difficulty of the sample set being assessed (Heymann *et al.*, 2014). One of the most important factors of DA is the analysis of samples in replicate. Although it has been found that it is not needed to do as many as 6 replicates, as was suggested by the QDA[®] methodology, as referenced by Heymann *et al.* (2014), samples should still be at least analysed in triplicate to ensure reliable results. It was suggested by Mammasse *et al.* (2011) that, if panellists were trained extensively and reproducibility is ensured, no replicates would be required. Due to the unlikelihood of keeping the panel members consistent for every analysis, using replicates, however, is

a much more sustainable and less time-consuming alternative, apart from being statistically more viable.

The number of samples analysed with DA is greatly dependent on the difficulty of the sensory space and the type of analysis required (Heymann *et al.*, 2014). The oral and nasal analysis of samples has been noted to cause panellists to easily become fatigued (Heymann *et al.*, 2014). Although it is suggested by Heymann *et al.* (2014) that 6 samples be used as an estimate for difficult in-mouth, this number is very conservative. It is still up to the discretion of the panel leader to decide on the amount of samples that the panel would be able to handle and to ensure a sufficient sample from which conclusions could be drawn.

The difference between consensus training and ballot training DA comes in with the selection of the attribute list to be analysed in the samples set (Heymann *et al.*, 2014). For consensus training, the panel is presented with the samples set at the start of training. The panel is then required to generate descriptors for each sample for either the aroma, taste or mouthfeel, depending on what is required from the experiment. The first few training sessions then focus on establishing a list of attributes which represents the product sensory space and also on reducing the list of descriptors to a manageable number (Campo *et al.*, 2010). The list of attributes to be analysed is therefore generated by the panel. In the analysis of wine, for example, consensus training is usually used when evaluating the aroma profile of a sample set. When using ballot training however, the list of attributes is predetermined prior to training. This method is usually applied when the project requires only the analysis of specific attributes associated with the samples set. For example, when a sample set is characteristic of having specific attributes and the project only requires evaluating how the samples differ in terms of these specific attributes, like astringency or bitterness. Or when extensive knowledge is required of the product category.

Once the attribute list has been established by either consensus or ballot training DA, the panellists are presented with reference standards which they can use to familiarise themselves with how the attributes are perceived. Reference standards are an important tool for aligning the panel. Heymann *et al.* (2014) stated that in the past, chemicals had been used to simulate the attributes, but that this was declared as being environmentally unfriendly. Therefore, reference standards are usually physical objects that represent the selected attributes (Campo *et al.*, 2010) and can either be consumed orally or by physical touch. For certain attributes, however, only a written definition can be used to describe the sensation. An example of such a sensation would be integration of a wine. In a study done by Pickering and Demiglio (2008) for the construction of a white wine mouthfeel wheel, such a term was considered as conceptual and for 'integrated' the definition of '*an impression that oral sensation are in good proportion*' was given. With the use of only a written definition, reaching panel consensus

could be difficult and evaluating the intensity of these sensations could prove to be a daunting task. This might require more extensive panel training and the panel would have to be monitored during training to establish whether they are in agreement or not.

The repeatability and panel performance is evaluated using the proposed workflow by Tomic *et al.* (2010) by using PanelCheck software. The statistical data analysis for DA then mainly consists of analysis of variance (ANOVA) and principal component analysis (PCA) which then displays the profile of the different samples and what the key differences are within the sensory space. This will be discussed below.

Descriptive analysis data analysis

Analysis of variance

The first step in the analysis of DA data is the analysis of variance (ANOVA). ANOVA is used when either comparing differences between samples or differences between panellists to determine what the key differences between them are (Clewer and Scarisbrick, 2001; Lawless and Heymann, 2010; Anzanello *et al.*, 2011). There are three types of ANOVA, including one-way, two-way and three-way ANOVA. For a complete block design experiment, where all panellists evaluate each sample in triplicate, a two-way ANOVA is used (Lawless and Heymann, 2010). With ANOVA, the null hypothesis is tested, which determines whether the different groups within the sensory space, have equal means. The ANOVA then identifies the attributes that cause significant differences between the groups that have formed and these differences can then be used to evaluate the sensory space. Once this had been determined with the ANOVA, a pairwise comparison, the Fisher's Least Significant Difference test is used to investigate the individual differences between each product as well as between different assessors (Meier, 2006; Anzanello *et al.*, 2011). This is an important step when it is of importance to determine whether there are small differences present between samples in the set.

Principal component analysis

According to Borgognone *et al.* (2001) Principal Component Analysis (PCA) is the most frequently used multivariate analysis when analysing sensory evaluation data, especially for descriptive analysis. PCA is the suggested multivariate analysis tool to illustrate the relationship between products and their descriptors. When analysing DA data, the matrix consists of the samples in rows and the descriptors in columns. The term 'principal component' then comes from the reduction of the original amount of variables to only those that play a significant role in explaining the sensory space. The aim of the PCA is, therefore, to explain as much variation as possible, with the least amount of principal components. Common practice when using PCA for descriptive analysis, is to transform the original data matrix into a correlation matrix. The raw data can, however, also be transformed into a covariance matrix. The

difference is that in a correlation matrix, all means are weighted equally, whereas with a covariance matrix the means are weighted according to their variance. For a correlation matrix, this would mean that all non-significant attributes would have to be removed when constructing the PCA, as non-significant attributes could skew the data. With a covariance matrix, however, the 'less' significant attributes would just be weighted less and could still be included in the PCA plot. Borgognone *et al.* (2001) noted that upon revising published articles where PCA was used, out of 52 papers, 22 stated that they use the correlation matrix, almost half did not mention how their data matrix was transformed and only 7 stated that they used a covariance matrix. One of the first publications on PCA was by Vuataz 1976/1977, as referenced by Borgognone *et al.* (2001), in which they stated normal practice would be to use covariance PCA, but if the scales used for the analysis differed, a correlation matrix PCA would have to be used. The study by Borgognone *et al.* (2001) concluded that, if the scales used for analysis indeed did not differ and the configuration obtained seemed not to be skewed, the covariance matrix could be used to illustrate the profile of a complex sensory space.

A problem that could arise when using a covariance matrix is that even if the scales did not differ, there could still be variation in the use of the scales. If the data is then not scaled, as it would be with a correlation matrix, information on small systematic differences and correlations between attributes will be lost (Westad *et al.*, 2003). The correlation matrix therefore eliminates differences in the use of the scales and this is why it is most mentioned in papers using PCA to evaluate their data.

2.4.2.2. Novel sensory evaluation techniques

Although descriptive analysis holds many benefits and has proven its accuracy and robustness in numerous studies (Meilgaard *et al.*, 1999; Stone and Sidel, 2004; Valentin *et al.*, 2012), it does have its limitations. The main limitations include the extensive panel training required to ensure reliable results and the limited amount of samples that can be evaluated per analysis (Varela and Ares, 2014). In an effort to overcome these limitations as well as allow for the use of consumers to evaluate products, different novel techniques have been designed. As mentioned, there are three types of novel techniques: verbal-based methods, similarity-based methods and reference-based methods.

Verbal based methods were designed based on the free-choice profiling method (Dairou and Sieffermann, 2002) and include Flash Profiling (FP) and Check-all-that-apply (CATA) (Valentin *et al.*, 2012). In both methods, assessors are allowed to provide their own descriptors for the products and there is no need to reach consensus on their selections. In this way, a description is provided for each sample, but there is no need for time-consuming training, as with DA. FP and CATA are both suggested as good methods for obtaining a rapid list of the key attributes that describe products (Louw *et al.*, 2013). Therefore, if the aim is to establish which in-mouth sensations describe the sensory profile of

a product category according to consumers or even experts, either of these rapid methods would be suitable.

The generation of terminology and descriptors in verbal-based methods, can be proved a daunting and tiring task for assessors. To overcome this, similarity-based methods were developed which allowed for a more global assessing of the products (Valentin *et al.*, 2012). The assessors are instructed to group samples according their similarities and only once they have formed these groups do they have to provide a list of attributes to describe each group. The methods that have been developed with this approach include Free sorting task (FST) and Projective mapping or Napping®. These methods do, however, also have shortcomings. For both these methods, it can often be a difficult task to process the descriptors generated by the assessors and the information on the attributes that are responsible for small differences between samples within the groups formed, is lost (Perrin *et al.*, 2008).

Although these novel methodologies have many advantages, the amount of samples that can be analysed per session, is still limited. Assessors can become fatigued if the sample set is too large and as with DA, it still has to be restricted to a manageable amount. In addition, if a new sample is to be introduced to a set, assessors would have to repeat the analysis with the whole original set. The novel reference-based methods, however, pose a solution to this problem. The idea of these methods is to have reference samples or products which, if kept stable in each analysis, would allow the aggregation of data sets (Valentin *et al.*, 2012; de Saldamando *et al.*, 2013; Antunez *et al.*, 2015). Apart from now being able to analyse more samples in different sessions, this eliminates the issue when only certain products are available at certain times of the year or if a new sample has to be introduced to the set. The two referenced-based methods that have been developed include Pivot Profile® (PP) (Thuillier *et al.*, 2015) and polarised sensory positioning (PSP) (Teillet *et al.*, 2010). Both methods have proven to yield good results in the analysis of complex products. The short coming of Pivot Profile® is, however, that assessors are still expected to generate their own terminology and having to continuously compare each sample to the reference, can become tedious. The analysis of in-mouth sensations would certainly prove to be a daunting task for assessors and it could be wise to analyse a small set of samples in different session. Thus a reference-based method could aid in the ease of the analysis. PSP has successfully been used on the taste of water (Teillet *et al.*, 2010), cosmetic products (Navarro *et al.*, 2011), chocolate flavoured milk (Antunez *et al.*, 2015), powdered orange drinks (de Saldamando *et al.*, 2013), functional yogurt (Cadena *et al.*, 2014) and astringent stimuli (Fleming *et al.*, 2015), but has not yet been applied to wine before. This would, therefore, be an opportunity to test its suitability for a complex product such as wine. PSP would allow for a more global evaluation of the wine,

eliminating the need for assessors to have to generate the terminology. PSP will be discussed in detail below.

PSP - polarised sensory positioning

PSP was first used by Eric Teillet (SensoStat, Dijon, France) and Pascal Schlich (INRA, Dijon, France) to test the different tastes of water, which proved to yield similar results to DA (Teillet *et al.*, 2010). The method is based on comparing samples to a set of reference samples, referred to as ‘poles’. Upon analysis, the assessors are instructed to first evaluate the poles and thereafter compare each sample to them. The comparison to the poles can be applied on a continuous scale or triadic. When compared on a continuous scale, each sample is compared to each pole on separate line scales anchored from ‘same taste’ to ‘completely different taste’. Figure 2.5 shows an example of such a comparison. With a triadic approach, the assessor is only required to indicate to which pole the sample is most similar to (Antunez *et al.*, 2015). In the example shown in Figure 2.5, the sample would be most similar to pole C. One of the limitations of PSP, however, is that the sensory characteristics of the sample could only be deduced from those that describe pole C. Therefore, small, individual difference between samples are lost (Valentin *et al.*, 2012).

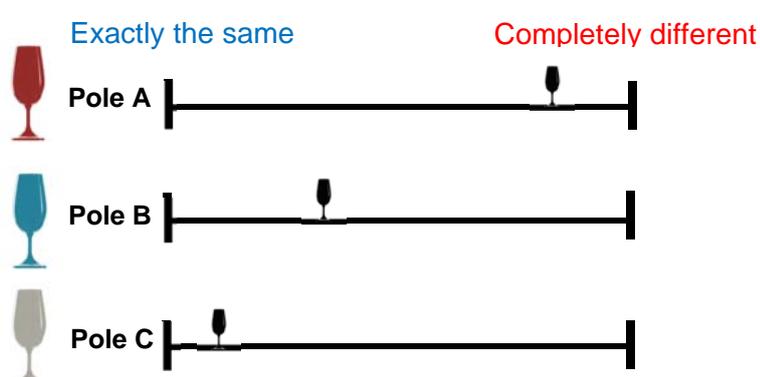


Figure 2.5 Example of PSP scales on a continuous scale basis, where sample 403 is compared to pole A, B and C, adapted from (Teillet, 2014).

The most important consideration of this method is the reference poles (de Saldamando *et al.*, 2013; Ares *et al.*, 2015a,b). To ensure reliable results, the poles have to be representative of all the different groups that could be present within the sensory space (de Saldamando *et al.*, 2013; Teillet, 2014). In order to do so, extensive knowledge of the product category would be required, which is not always possible and can be seen as a limitation of the method (Valentin *et al.*, 2012). In a study conducted by de Saldamando *et al.* (2013), it was investigated whether the choice of different poles might influence the results. It was concluded, however, that if poles are selected with similar characteristics to another set of poles which still represent the different groups in the sensory space, similar results could still

be guaranteed. The number of groupings in the sensory space would therefore determine the amount of poles needed for analysis (Ares *et al.*, 2015a). To stabilise either a two- or three-dimensional sensory space, however, a minimum of three poles would be required according to Teillet (2014). Even though more poles could possibly be used, it would be advised to keep in mind that this could cause panellists to become fatigued and render the method tedious (Ares *et al.*, 2015b). Ares *et al.* (2015b) investigated the cognitive aspects behind PSP and pointed out that the discriminatory ability of assessors could be increased if they found it easy to identify key drivers for the differences between the poles. Therefore, the results could possibly be improved by instructing them to focus on certain characteristics when comparing samples to the poles.

PSP is a relatively novel method and the protocol has not yet been set in stone, hence there is still room for adjustments and improvements. Fleming *et al.* (2015) suggested that to obtain more specific information from the method, PSP could be combined with a frequency based method like Check-All-That-Apply (CATA). To date, no research has been published on the inclusion of a CATA list with PSP.

Analysing PSP data

Teillet (2014) suggested two methods for analysing PSP data, depending on how the method was used. If the assessors were instructed to evaluate the dissimilarities between samples, then these dissimilarities between the products and the reference samples could be averaged. This would then result in a product-by-reference matrix which could be analysed with MDS unfolding (Valentin *et al.*, 2012). If, however, the samples had to be analysed based on their similarities to the poles, any classical factor analysis could be used, which would preserve the individual data (Teillet, 2014). Due to the likelihood of variation in the use of the scale by assessors, STATIS, MFA and GPA have been strongly recommended (Teillet, 2014). It seems though, that in most the studies done on various products with PSP (mentioned previously above) multiple factor analysis (MFA) was used to present results.

Multiple Factor Analysis

Multiple factor analysis (MFA) is used to analyse data which consists of multiple blocks, where individuals (samples or products) are described by a set of variables (Escoffier and Pages, 1994, cite: Worch, 2013). MFA essentially provides information on the overall consensus on the configuration of the products (Tomic *et al.*, 2015). This is done in two steps: firstly, a separate analysis is done on each block to construct a PCA, from which the first eigenvalue is obtained (Worch, 2013) after which each block is then divided by the inverse of the first eigenvalue. This is done to weight or normalize the variable of the different groups (Abdi and Valentin, 2007; Worch, 2013). A global PCA is then performed on the groups and the similarities in the matrix can be evaluated (Worch, 2013). Therefore,

MFA enables the analysis of different groups of variables which describe the same observation (Abdi and Valentin, 2007).

RV coefficient

RV coefficients are a useful tool to compare the similarity of configurations obtained by two different methods (Robert and Escoufier, 1976; Reinbach *et al.*, 2014). It is often applied in sensory science to evaluate how comparable novel techniques are to descriptive analysis or to different novel sensory techniques, because it can compare matrices with an unequal number of variables. The RV coefficient is determined by aggregating the matrices of two multivariate data sets to create a comparable matrix and determine the similarity between the multivariate configurations (Ares and Jaeger, 2013; Reinbach *et al.*, 2014). A value between 0 and 1 is then obtained, where a value close to 0 would indicate disagreement and a value close to 1 would indicate good agreement between matrices. For a complex product, such as wine, an RV coefficient of 0.5 is said to show enough similarity between two matrices and the methods can be deemed as comparable (Louw *et al.*, 2009; Chollet *et al.*, 2011; Dehlholm *et al.*, 2012).

2.5. In-mouth sensations of white wine: a review of the chemical compounds linked to these sensations

Wine elicits a wide range of different mouthfeel and in-mouth sensations. As stated, the most characteristic sensation for red wine has been identified as astringency, as is apparent from the Red Wine Mouthfeel Wheel (Gawel *et al.*, 2000). With the development of the White Wine Mouthfeel Wheel, it was, however, evident that the mouthfeel attributes elicited by white wine, differ from that of red wine (Oberholster *et al.*, 2009). In both studies on the mouthfeel wheels (Gawel *et al.*, 2000; Pickering and Demiglio, 2008) as well as a study on the mouthfeel of beer (Langstaff *et al.*, 1991), it became clear that along with astringency, warming and carbonation, the body of these alcoholic beverages makes an important contribution to mouthfeel (Nurgel and Pickering, 2005; Runnebaum *et al.*, 2011). There is no concrete definition for the body of wine, but it has been linked to the perceived viscosity and density of wine (Pickering *et al.*, 1998) and is believed to be influenced by alcohol, glycerol, sugars, total phenolics (Jackson, 2009) and organic acids (Runnebaum *et al.*, 2011). Considering the importance of body as an in-mouth characteristic of wine, this section will address specific wine parameters and what research has found regarding the influence of these parameters on wine body, with specific focus on white wine.

2.5.1. Viscosity and Density

The viscosity of white wine has been investigated in a few studies and all have found this physical parameter to be positively correlated with the body of wine, or what is often referred to as perceived viscosity (PV) (Košmerl *et al.*, 2000; Gawel and Waters, 2008; Runnebaum *et al.*, 2011). Another physical characteristic of wine linked to body is the density, referred to as perceived density (PD) (Gawel and Waters, 2008; Neto *et al.*, 2014). It was found by Nurgel and Pickering (2005), Runnebaum *et al.* (2011), as well as Yanniotis *et al.* (2007), that the viscosity of wine was significantly correlated with perceived viscosity. It could, therefore, be assumed that factors that influence the viscosity and density of white wine, would have the same effect on the overall perceived body of the wine. Yanniotis *et al.* (2007) found that ethanol and dry extract correlated positively with the viscosity of wines. It was concluded, however that glycerol was present at too low concentrations (5.8-9.3 g/L) to influence the viscosity, and the viscosity would only increase at a concentration of 28.2 g/L glycerol (Yanniotis *et al.*, 2007). The effect of glycerol on viscosity in wine was also found to be minimal by Nurgel and Pickering (2005), even at concentrations above 20 g/L. Research on glycerol will, however, be further discussed in section 2.5.3. The findings by Yanniotis *et al.* (2007), were supported by Neto *et al.* (2014) who also found a positive correlation between ethanol and dry extract and the viscosity and density of wine. Instead of glycerol, however, the study looked at reducing sugars (also referred to as residual sugar), which proved to make no contribution to the viscosity or density (Neto *et al.*, 2014). In contrast to this, however, Košmerl *et al.* (2000) discovered that when investigating the rheological properties of red and white wine, wines with lower concentrations of residual sugar had significantly lower viscosities. These findings show that dry extract and ethanol had the most consistent influence on the viscosity of wine, the effect of glycerol was negligible and that findings on reducing sugars were inconsistent. Findings on the influence of each of these parameters, as well as organic acids and phenolics, on the body of wine, will be discussed in more detail below.

2.5.2. Ethanol

The effect of ethanol content on the body has perhaps been most evident with the production of wines with a lower alcoholic content. In a review by Pickering (2000) on low- (0.5-1.2% v/v) and reduced- (1.2-6.5% v/v) alcohol wines, it was found that, apart from causing various alterations to the sensory profile of wine, lowering the alcohol content produced wine with a thin palate or insufficient body. One of the first studies done on the effect of alcohol on the perceived viscosity (PV) and perceived density (PD) (Pickering *et al.*, 1998), found that the PV was the highest at 10% ethanol and the PD at 12% ethanol, but that there were no significant differences in the body of the wine in ranges from 7-14% v/v ethanol. In further studies it was once again found that in model wines with alcohol ranges between 11.7 – 13.7% v/v, there was only a small difference in the body of the wines (Gawel

et al., 2007). It was concluded that in realistic, commercial wine alcohol ranges (11-14%), ethanol did not contribute significantly to the body of white wine. When the viscosity of wines was compared to a water solution that contained the same ethanol concentration as the wines, the viscosity of the water solution was much lower than that of the wines (Košmerl *et al.*, 2000). Therefore, ethanol, in isolation, would not notably influence body. The fact that it was, however, found to be positively correlated with the viscosity of wine by Yanniotis *et al.* (2007) and Neto *et al.* (2014) in commercial wines, would suggest that it could influence the body of wine in combination with other factors present in wine. In a study on the correlation between non-volatile components and wine quality, it was found that alcohol content was strongly correlated to the perception of wine quality (Sáenz-Navajas *et al.*, 2010).

2.5.3. Glycerol

The influence of glycerol on wine quality has often been pursued in research (Nieuwoudt *et al.*, 2002). Due to the fact that glycerol is believed to have an influence on the perceived body of wine (Scanes *et al.*, 1998). On its own, glycerol is a liquid that is characteristic for its viscous nature and studies have been done on the viscosity ranges of different purity glycerol (Sheely, 1932). It is, therefore, natural to assume that it would have the same effect in wine. Glycerol is a non-volatile by-product of yeast fermentation and the levels of glycerol in dry white South African table wines has been determined to range from 5.21 – 9.36 g/L (Nieuwoudt *et al.*, 2002). Studies that investigated the contribution of glycerol to the body sensation of wine, however, found that an increase in perceived viscosity was only noted when an additional 25.8 g/L glycerol was added to white wine (Noble and Bursick, 1984). The same findings were later made by Nurgel and Pickering (2005), as mentioned in section 2.5.1. It was also found that this threshold could further increase in the presence of acidity and ethanol (Scanes *et al.*, 1998). More recent research once again proved that at realistic glycerol levels in commercial white wines, glycerol had no significant influence on the body of wine (Gawel *et al.*, 2007, 2014a). From this information it can therefore be concluded that, at normal concentrations found in dry white wine (5.21-9.36 g/L (Nieuwoudt *et al.*, 2002)), the influence of glycerol to wine body, is minimal. The fact that the effect of glycerol was dampened by the ethanol and acidity of wine, would suggest that more insight into the effect of glycerol in wine could be given if it is researched in ratio to those parameters. It was determined by Nieuwoudt *et al.* (2002), however that although glycerol did not have a significant impact on the viscosity of wines, it was significantly ($p < 0.05$) correlated to the quality perception of dry white wine, even though the difference in glycerol concentrations between the wines was small (5.21-9.36 g/L).

2.5.4. Dry extract

The dry extract of wine is composed of all of the constituents of the wine that remain after evaporation under physical conditions (Moreno and Peinado, 2012), and mainly consists of glycerol and organic acids (Kunkee and Eschnauer, 2000). Runnebaum *et al.* (2011) described the extract of wine as all of the non-volatile wine constituents excluding sugar and ethanol and found that it was significantly correlated with the perceived viscosity of wine. Long before the study by Runnebaum *et al.* (2011), Zoecklein *et al.* (1999) also reported that wines with 20 g/L dry extract were perceived as having a 'thin palate', while wines with a dry extract of 30 g/L or more had a 'fuller palate' or more body. Kunkee and Eschnauer (2000) noted that the dry extract of white wine did not generally exceed 25 g/L. Therefore, it could be assumed that white wines with a dry extract over 30 g/L should be perceived as full bodied, which would be in accordance with the findings of Zoecklein *et al.* (1999). Dry extract seemed to be the only constituent that was consistently correlated with the viscosity as well as the body of wine, yet, research on its influence on the body sensation in wine was scarce. Dry extract should, therefore, be investigated when analysing the body of wines.

2.5.5. Residual sugar

Residual sugar (RS) in wine consists of glucose and fructose, which are reducing sugars. In South Africa, wine classified as 'dry white table wines', may not have a RS greater than 5 g/L, or, if the total acidity (g/L) is less than 2 g/L below that of the RS, the RS may not exceed 9 g/L (Anon., 1990). Beverages with higher sugar levels have been shown to have a higher perceived body. This was evident in a study done on different carbonated beverages where all beverages with normal sugar levels had higher perceived body than reduced sugar or 'diet' versions of the beverages (Kappes *et al.*, 2006). In wine, the direct effect of RS on the perceived body has not been investigated as such, but it is commonly accepted that sweeter white wines, like semi-sweet or late harvest, have a higher perceived viscosity than dry and extra dry white wines. In a recent study, however it was found that reducing sugars had no significant influence on the measured viscosity or density of red wine (Neto *et al.*, 2014). This could however, differ for white wines and analysing the overall perception of body may also present different results. Nurgel and Pickering (2005) reported that different RS levels did have an effect on the perceived viscosity of white wine, but the study was done on ice wines with RS levels far above that of dry white table wines (>15 g/L). A recent study, Gawel *et al.* (2014a) also reported that polysaccharides (compounds that consist of sugar molecules) made no significant contribution to the perceived viscosity of white wines. Even though the levels of RS or reducing sugars needed to make a significant difference in the perceived viscosity of wine are far above those found in dry table wines, RS showed a strong correlation to the perception of wine quality, as was also seen with the alcohol content of wine (Sáenz-Navajas *et al.*, 2010).

2.5.6. Organic Acids

Organic acids were found to elicit certain astringent mouthfeel sensations, but this had mainly been associated with red wine astringency and, as has been mentioned, the perception of astringency in white wine is different from that of red wine. In white wine, the two major organic acids that have been linked to body are lactic acid and succinic acid (Runnebaum *et al.*, 2011). Lactic acid is produced by lactic acid bacteria (LAB) in the conversion of malic acid during malolactic fermentation which takes place after alcoholic fermentation (López *et al.*, 2011; Chen and Liu, 2016). This reaction can be induced by deliberately adding malolactic acid bacteria or it can happen spontaneously if the wines are fermented and aged in old barrels where the bacteria is still present. The reaction has been noted to increase the mouthfeel and complexity of wooded style Chenin blanc wines (Bester, 2011) as well as reducing the tartness of the wine (Volschenk and Van Vuuren, 2006; Chen and Liu, 2016). Publications on the link between organic acids and wine body are, however, scarce and lack in confirmation of findings. What has been reported, however, is that organic acids play an important role in the balance of the wine (Volschenk and Van Vuuren, 2006). Therefore, even though organic acids might not make a noticeable contribution to the body of wine, it could be correlated with other in-mouth sensations, such as the balance of the wine.

2.5.7. Phenolics

Phenolics, are compounds that consist of one or more aromatic rings, called benzene rings, with hydroxyl groups attached to them. The compounds with only one aromatic ring and hydroxyl group are referred to as 'simple phenols', which are not present in wine (Waterhouse, 2002). The complex phenolics present in wine include both flavonoids and non-flavonoids and are associated with differences in wines styles and quality (Balga *et al.*, 2014). Phenolics have been found to play a key role in the mouthfeel of wine, but this was mainly linked to astringency (Komes *et al.*, 2007; Gawel *et al.*, 2014b). Although there is no other perceived attribute in wine which is strongly correlated with the total phenolic content of wine apart from astringency, it has been shown to play a role in certain characteristics, amongst which viscosity was listed (Gawel *et al.*, 2014b). Gawel *et al.* (2014a), also reported that total phenolics was positively correlated with wines that had a higher pH (less acidic wines), which was once again established by Gil *et al.* (2015). Although the direct link of phenolics to the perceived body of wine has not been extensively researched, the fact that phenolics have a prominent impact on the gustatory attributes experienced in wine, is evident. The phenolic content of white wine can be influenced by different extraction and processing techniques as well as the grape variety (Costa *et al.*, 2015), vineyard practices, region (Balga *et al.*, 2014) and what is considered the most important influential factor, is environment (Lampíř and Pavloušek, 2013). Another factor that has been found to have a large impact on the phenolic content of wine is the berry size. The smaller

the berry, the higher the phenolic content in the wines (Gil *et al.*, 2015). Studies have also shown that the phenolic content of wine could be used as an indicator of its origin (Fanzone *et al.*, 2010) and is a good tool for the differentiation of wines (De Villiers *et al.*, 2005), as well as wine classification (De La Presa-Owens *et al.*, 1995). The specific compounds that make the greatest contribution to this phenomenon, include procatechuic acid, p-hydroxybenzoic acid, gallic acid, cis-piceid, and (+)-catechin and (-)-epicatechin (Lampíř and Pavloušek, 2013). Therefore, not only does the phenolic content of wine influence in-mouth sensations, but it could also potentially be used as a distinguishing factor between terroir and origin.

2.6. Concluding remarks

Chenin blanc has been labelled as an important cultivar in South Africa, often referred to as the flagship white varietal. Research on this varietal had, however, mainly focused on the volatile compounds and the aroma profile of the different styles of Chenin blanc. They had also not specifically focused on the product category of old-vine (≥ 40 years) Chenin blanc wines. Wine made from old-vines are believed to produce wines of better quality. Although a hot topic in popular press, there is very little published research on old-vines. Intrinsic attributes, used to describe the perceived quality of wine, have been shown to be of high importance to both experts and all types of consumers, yet, many of these terms have never been evaluated quantitatively in wine. This study, therefore, aims at characterising the sensory profile of old-vine Chenin blanc with specific focus on training a Descriptive Analysis panel to evaluate attributes used to describe the intrinsic quality of this product category. The knowledge of wine professionals is recognised within the wine industry, therefore, this study will rely on their expertise to identify the gustatory quality cues used to describe this product style category. It is also clear that world-wide, there is no formal age for an old-vine, therefore for the purpose of this study, vines aged 40 years and older, will be referred to as old-vines.

Descriptive Analysis (DA) is the most used sensory evaluation method and would naturally be the first route to follow in the analysis of difficult new concepts in wine, but it only allows for the analysis of a small sample set. In addition, the more difficult the analysis, the smaller the sample set is recommended to be. Polarised sensory positioning (PSP) could potentially pose a solution to this problem. This study will be the first to apply this rapid method to wine in the analysis of in-mouth sensations in old-vine Chenin blanc wine. If this method could be successfully applied to wine, it would allow for the evaluation of larger sample sets, overcoming the limitations of DA.

The physicochemical parameters associated with the body of wine clearly play a distinct role in the mouthfeel of wine and some are strongly correlated to quality perceptions. There is, however, still a

lack in understanding what exactly the influence of each component is and more research is still required.

The importance of understanding the extrinsic quality cues of a product such as wine when investigating the intrinsic attributes, has been highlighted. The aim of obtaining this information, will therefore, be to provide context on certain extrinsic factors such as the vineyard management used for old-vine Chenin blanc and the production practices used to produce these wines.

2.7. References

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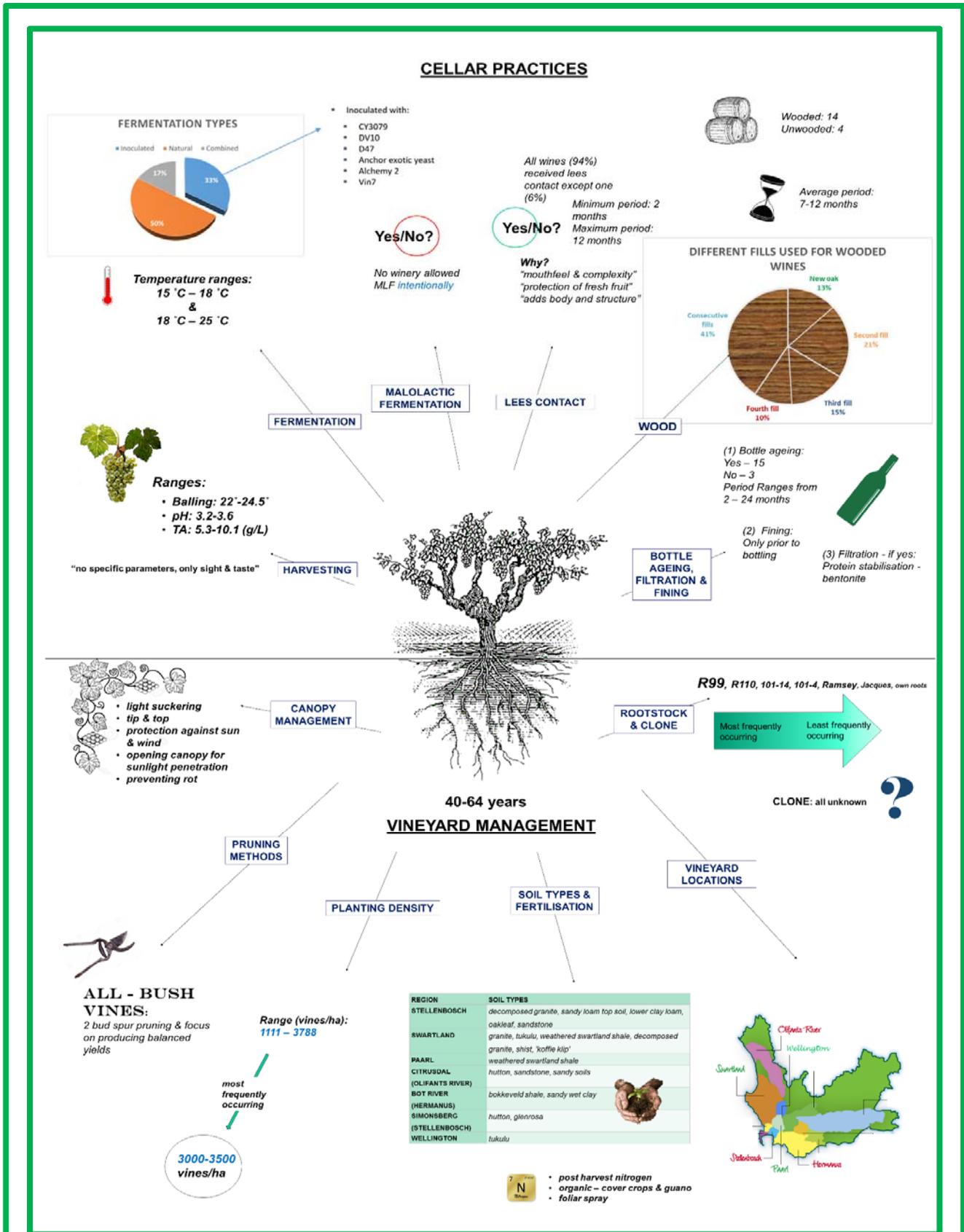
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Chapter 3

Vineyard management and cellar practices for crafting old-vine Chenin blanc wines

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3.1. Introduction

Chenin blanc grapes can be influenced by the terroir they are grown in, the yield of the vineyards, the ripeness at which the grapes are harvested, whether the wine had any wood contact and the presence of noble rot on the grapes. Due to the lack of grape derived primary aroma and flavour compounds of Chenin blanc (Marais, 2006), it is believed that the grapes can easily be manipulated into different styles with the use of various winemaking techniques (Loubser, 2008). Therefore, to fully understand Chenin blanc as a category of wine, it is important to understand the *terroir*, grapevines and how the wines were produced. It was also suggested by García-Muñoz *et al.* (2014) that reporting on these type of extrinsic factors could help to improve the quality of wine. The aim of this chapter was, therefore, to obtain information on how the old Chenin blanc vineyards investigated in this study, are managed and the winemaking practices used to produce wines from these vineyards. This was done by means of a questionnaire sent to all the wineries. This information could highlight potential research opportunities that would aid in understanding the quality of these wines, but, for the purpose of this study, would give context on the wines analysed in this study in chapter 4 and chapter 5.

Research has shown that in the wine industry specifically, the knowledge of wine professionals is invaluable when investigating specific wine style categories (Zamora and Guirao, 2004). Therefore, two experts from industry who have extensive knowledge on working with old-vines and, specifically, Chenin blanc were also consulted to gain further insight into the viticultural aspects addressed. The two experts included Vinpro (Picardi Farm, Cecilia St, Paarl) viticulturist Hanno van Schalkwyk (H van Schalkwyk 2016, personal communications, 29 April) and vineyard manager, Rosa Kruger (R Kruger 2016, personal communications, 8 April). The questionnaire was also used to guide the discussions with the two experts.

An overview report on Chenin blanc in January 2015 by South African Wine Industry Information and Systems (SAWIS), South Africa's main source for obtaining information and statistics on different aspects of the wine industry, showed that, of the 17965 hectares of Chenin blanc grown, 6468 hectares were over 20 years old (SAWIS, 2015). It also showed that the major rootstock for Chenin blanc in all regions is Richter 99 (SAWIS, 2015). Further information on export figures and total litres of production in South Africa could be found on the SAWIS website, but no information is provided on the vineyard management or the type of winemaking techniques used to produce Chenin blanc wines.

Information on the vineyard and winemaking techniques can sometimes be sourced from the websites of the wine cellars, but the type of information provided is not regulated and inconsistent between different producers. Therefore, the information on the practical aspects used to produce Chenin blanc wine is scarce, and if provided, it is fragmented. This is even more so for those wines made from old-vines. The reason for this is simple: the only people that have this information are the viticulturists and winemakers themselves. The only way to obtain this information would, therefore, be to contact each viticulturist and each winemaker from every cellar, which logistically, could become a time consuming and tedious process. It was highlighted by South African wine writer, Michael Fridjhon, that more information on South African old-vines is required in order to understand what their potential is, in terms of wine quality, as well as to keep these vines from being uprooted before this ability can be comprehended (Fridjhon, 2016).

The aim of this study was therefore not only to provide valuable and needed information on the set of wines investigated in this study, but also to create further awareness of the old-vines of South Africa's flagship grape varietal, Chenin blanc.

3.1.1. Questionnaire design

The questionnaire was compiled with the guidance of Rosa Kruger as well as the input of individuals from the environment with specific domain knowledge on vineyard management and winemaking. It comprised of 7 vineyard management questions as well as 11 winemaking questions. It was sent out electronically to 17 producers to obtain information on 18 old-vine Chenin blanc wines. Addendum I contains an example of the questionnaire. After a period of 5 months, 15 responses were received and it was necessary to personally interview 3 producers as they had difficulty completing the questionnaire electronically. The questions were designed to only require easy, straightforward answers, in an attempt to obtain enough information, without expecting the winemakers and viticulturists to sacrifice too much of their time. The findings were not reported and explained as a case-by-case scenario, but rather used to give overall context and give more insight into the viticulture and oenology behind the wines assessed in this study. The information generated with the questionnaire was qualitative. Qualitative data is often used to compliment quantitative data by providing information to explain the data or by providing insight into the reasoning behind a quantitative study (Forman *et al.*, 2008).

Table 2 and Table 3 will be referred to in a brief discussion of certain aspects addressed in the questionnaire. The discussion will also include some of the comments made by the two experts of industry on the different aspects addressed.

3.2. Vineyard management

This section will briefly discuss some of the vineyard management techniques applied to the old-vine Chenin blanc wines investigated in this study. The aspects listed in Table 2 were those aspects that showed interesting results and that could potentially contribute to the character of the old-vine Chenin blanc wines and further investigation into them would be recommended.

Table 2 Summary of selected vineyard management aspects of old-vine Chenin blanc wines investigated in this study, as determined from the questionnaires.

Vineyard management	
Selected aspects	Types/range
Soil (types)	granite, shale, sandstone, ferricrete and schist
Clone (types)	Unknown
Rootstock (types)	Richter 99; Richter 110; 101-14; 101-4; Ramsey; Jacquez; own roots
Planting density (range: vines per ha)	1111 - 3788
Pruning methods	2 bud spur pruning (VSP); 1 carrier per arm with 5-7 arms per vine (Bush vine)
Canopy management	Focused on: sunlight penetration; preventing rot; normal suckering Otherwise: no management required

3.2.1. Soil types

The old-vine Chenin blanc vineyards researched, came from a variety of different regions which consisted of various soil types, as shown in Table 2. Soil is known to influence the grape composition and the vigour of the vines (Wang *et al.*, 2015). According to Kruger (2016), the older vineyards are not generally found on dry soils, but more on rocky soils near river beds with good water retaining abilities. Van Schalkwyk commented that soils that induce low vigour, while preventing rot, would be preferable for Chenin blanc vineyards in South Africa. It could, therefore, be valuable to investigate exactly what types of soil these vineyards have been cultivated on and how this links to the quality of the wines.

3.2.2. Clones

Table 2 shows that there were no records on the clones of any of the 18 Chenin blanc old-vines investigated. According to van Schalkwyk, in the times that these vineyards were planted, the farmers themselves probably would not even have known what clone they were planting. The clones were supplied by Koöperatiewe Wijnbouers Vereniging of South Africa (KWV) upon the farmer's request to plant vineyards of specific yields. The exact clones planted were, therefore, unknown, but van Schalkwyk stated that they would have been clones for higher yielding vines. The clones of old-vines in South Africa are, therefore, generally unknown. The clones, however, have a large influence on the final product (Chien, 2008) and could provide a lot of insight into the quality of these wines. Despite

the importance of understanding the clonal status of vineyards, research on this aspect is, however, limited. This is, reportedly, due to the high cost of this type of research as well as the time and commitment this research requires (Hansen, 2010). The importance of this factor was, however, noted by researcher Prof Johan Burger at Stellenbosch University. It was mentioned in an article in WineLand Magazine that Prof Burger started conducting research on determining the genetic composition of old-vine Pinotage and comparing it to that of young Pinotage vines (Heyns, 2013). The information from the study by Prof Burger was aimed at understanding how the environment influenced the gene expression of vineyards (Heyns, 2013). This type of knowledge on the genes of old-vine Chenin blanc could also provide valuable answers to the characteristics of these grapes and wines.

3.2.3. Rootstock

Rootstock is an important factor to take into consideration when farming in areas where there is little or no irrigation available (Alves *et al.*, 2012). Another important factor to consider is the adaptability of the rootstock to the soil and environment (Teubes, 2014a). Therefore, the choice of rootstock is likely to differ not only between regions but also between blocks within a single farm. Most of the old-vines were grafted onto Richter 99 (R99) rootstock, which is in accordance with the statistics reported by SAWIS on Chenin blanc rootstock in South Africa (SAWIS, 2015). According to van Schalkwyk (2016) and Kruger (2016), most of the old Chenin blanc vineyards were grafted on to either the Richter 99 or Richter 110 (R110) rootstock, due to their robustness and adaptability to various environments. A characteristic of R99 is that it has high vigour growth in various soils, ranging from compact soils to deep sandy soils (Teubes, 2014a). High vigour growth could be advantageous in dry, warm areas and R99 has shown good tolerance to 'harsh' conditions (Teubes, 2014a). This rootstock also has the potential for supporting high yields, which further adds to its popularity (Teubes, 2014a).

Table 2, however, shows that there was variation in the types of rootstocks of these old-vines. It was also of interest to note that only one of the vineyards was still growing on its own roots (Table 2). The reason why most vineyards were grafted onto rootstocks, was due to a pest outbreak, called phylloxera. This insect attacked the roots (Benheim *et al.*, 2012) or the leaves (Goussard, 2015) of the vines, which dampened the vines' ability to produce quality fruit (Teubes, 2014b) and made it susceptible to viral and fungal infections (Granett *et al.*, 2001), which often lead to the death of the vines. The most characteristic symptom of root phylloxera is the discolouration of feeding roots first to yellow and later to dark brown due to the formation of what is referred to as nodosities (Goussard, 2015). Phylloxera has also been observed on the leaves of grapevines where it forms galls at the bottom of the leaves (Goussard, 2015). In a review on the management of phylloxera by Granett *et al.* (2001), it was concluded that the only effective control mechanism was grafting the vines onto phylloxera resistant rootstock, sourced from America. Various types of rootstocks were developed

with different characteristics and all were tested in the Western Cape to evaluate their compatibility to the different cultivars and environments and establish which would be most suitable to use in South Africa (Teubes, 2014b). The old-vine that is still growing on its own roots, was planted in isolation in the Citrusdal region in 1964, amongst fynbos and rooibos plantations and would, therefore, not have been in danger of being affected by phylloxera.

Understanding the microbial diversity of the rootstock of the old-vines could also reveal important information about the character of the grapes and wines. The influence of the microbial communities on fermentation will also be briefly discussed in section 3.3. A recently published article on the fungal communities on old vineyards in France reported that there seemed to be a balance amongst the microbial communities on the grapevines, which could influence the chemical composition of the grapes produced (Bruez *et al.*, 2016). The influence of viruses and microbes on the grape characteristics of old vineyards, was also noted by Prof Burger (Heyns, 2013).

3.2.4. Pruning method & canopy management

Almost all of the vineyards for this study were bush vines and only one vineyard had been mounted onto a cordon trellising system, using two foliage wires. Van Schalkwyk (2016) suggested a possible reason for trellising an old bush vine, would be to lift the canopy off the ground to prevent the grapes from being scorched by heat reflected from the soil. In a study done by van Zyl & van Huyssteen (1980) on different trellising systems, it was found that, on average, the bunch temperatures of bush vines were 6.73°C higher compared to Perold trellised systems, which could be due to the bunches' close proximity to the ground. Bush vines could be trellised by using a support pole to allow the bush vine to grow upward, away from the ground (van Schalkwyk, 2014).

According to van Schalkwyk (2014), there has been a decline in the cultivation of vineyards as bush vines. For example, just in the Stellenbosch area, the percentage of bush vines decreased from 59% in 1971 to 23% in 2012 (van Schalkwyk, 2014) and the main reason for this was due to difficult economic times (Mkhwanazi, 2016). Bush vines are lower yielding and labour intensive and can, therefore, become unprofitable when the price of grapes is dependent on tons produced per hectare, as is the case in South Africa. In a recent article in WineLand Magazine, however, it was mentioned that there is an increased interest amongst winemakers to start cultivating more vineyards as bush vines, due to the quality and concentration of fruit produced from these vines (Mkhwanazi, 2016). These producers aim at producing quality wines and cultivating lasting vineyards, instead of catering for the mass production market. Therefore, the quality of the fruit from bush vines could be the reason why farmers had refrained from uprooting the old-vines investigated in this study.

For the vines in this study, normal two bud spur pruning was generally used. According to one of the winemakers, the growth of individual old-vines within a vineyard could vary and it is important to thoroughly inspect each vine to determine the diameter of the shoots. If a shoot is thick, up to 3 buds could be left per shoot while for a very thin shoot, only one bud should be left per spur. This is important for keeping the vine in balance, which is the ultimate goal when pruning (van Schalkwyk, 2016). Kruger (2016), however, emphasised that only light suckering should be applied to old-vines and care should be taken to not cut back into the old wood when pruning. This is in accordance with a new pruning method developed in Italy, specifically inspired by old-vines, with some of the vines as old as 70-80 years. The method is called the Simonit&Sirch method (available from www.simonitesirch.com/simonitsirch-method), named after viticulturists Marco Simonit and Pierpaolo Sirch (Lee, 2016). According to a recent article (Lee, 2016), the method was based on the principle of following the pathway which allows growth in the permanent wood, by not cutting back into the old wood.

One of the other important points highlighted in this article, was that vines need space to grow. Simonit and Sirch based the development of their method on which types of vines have lasted the longest. What they found was that bush vine or 'gobelet' (*alberello* in Italian) trained vines had the ideal growing conditions. According to the developers, bush vines have had enough space for growth and the pruning techniques used for bush vines allow for upward growth and no cuts are made on the downward facing side of the vine, where the pathway for sap flow is located. This type of pruning is, however, considered as out-dated in newly trained and trellised vineyards (Lee, 2016). The aim of this pruning method is producing vineyards that reach their peak only after 30-40 years, instead of already at 20 years, because according to them, vines that live longer produce wines of better quality fruit (Lee, 2016). This method is currently being used on four wine farms in South Africa in an effort to conserve their old-vines and increase the lifespan of their young vineyards.

Canopy management of old-vines seemed to focus on using normal suckering, allowing sunlight penetration and preventing rot (Table 2). Van Schalkwyk (2016) stated that Chenin blanc vineyards in South Africa are prone to rot and sunburn, due to the harsh climatic conditions. There were, however, some of the farms who stated that their vines showed balanced growth and that there was no need for canopy management. The canopy of the old-vine mounted onto a cordon trellising system also required little management, but was mounted onto two foliage wires to lift the grape bunches to keep them away from the soil surface.

3.2.5. Planting density: low density vs high density

From Table 2 it is evident that there is a large variation in the planting density of these old-vines. According to van Schalkwyk, normal planting density would range between 3000-3500 vines per

hectare, which is what was most frequent for the old-vines. This would allow for wide spacing between vines. One of the respondents stated that in the times that these vineyards were planted, the same tractor was used to work on all of the different farmlands and the vines were often spaced to allow wheat tractors to move through them. In an effort to overcome the economic strain of low yielding bush vines, farmers have started planting bush vines in high density that could yield up to 20 tons per hectare (Mkhwanazi, 2016). It was reported by Volschenk and Hunter (2014), however, that weeds could become a problem to control in high density planting and Kruger (2016) commented that weed control is very important in old vineyards. Weeds compete with plants for nutrients and could, therefore, deprive them of the necessary nutrients needed to produce fruit. As mentioned, according to the developers of the Simonit&Sirch method, vines need space to grow (Lee, 2016), therefore, the planting density of the old-vines could therefore also offer an explanation as to why these vineyards had lasted for over 40 years and why the vineyards investigated in this study, are still producing quality fruit.

3.3. Winemaking practices

This section will discuss selected winemaking techniques used to produce the wines investigated in this study. The aspects shown in Table 3 were selected from the questionnaire as those that either showed trends between the different wineries or displayed large variability, which could provide insight into the quality of the 18 wines.

Table 3 Summary of the winemaking techniques used for old-vine Chenin blanc as determined from the questionnaires.

Winemaking practices	
	Types/range or Yes/No
Fermentation:	
Yeast	natural, inoculated or combination
Average temperature (°C)	11 - 23
Wood:	yes(14) / no(4)
Period (months)	7 - 12
Type	new oak; consecutive fills (2 nd , 3 rd , 4 th -12 th)
Lees ageing:	yes(17) / no(1)
Period (months)	3 - 12
Malolactic Fermentation	yes(5) / no(12)
Fining	None

3.3.1. Fermentation: natural vs. inoculated

The different aspects of fermentation play a large role in the outcome of the final product, especially for a neutral variety such as Chenin blanc. Of these, the type of yeast used could probably be seen as

one of the most influential factors. The feedback from the questionnaire revealed that half of the old-vine Chenin blanc wines were naturally fermented and the other half had either been inoculated with various different commercial yeasts or natural fermentation was allowed up to a certain point after which fermentation was continued with inoculated yeast. Inoculation is often preferred, however, as there is a much lower risk of a fermentation becoming stuck, which would result in a wine with higher residual sugar (Malherbe *et al.*, 2007). Inoculation is used to ensure a controlled fermentation with the aim of producing a wine with certain characteristics, but it could reduce the complexity of wine (Holt *et al.*, 2013). Certain yeast strains have been found to produce distinctive aroma compounds in specific cultivars, which could cause the wines to become predictable and one-dimensional (Hyma *et al.*, 2011).

Allowing natural fermentation is in accordance with one of the latest wine producing trends for the production of, what is referred to as, natural wines (Chan, 2016). Natural fermentation occurs with yeast and microbial communities that are naturally present on the grapes. These organisms are known to have a large impact on the chemical and sensory characteristics of a wine (Setati *et al.*, 2012; Beckner Whitener *et al.*, 2016). The influence of various factors on these microbial communities have been investigated (Setati *et al.*, 2012), but vineyard age was not included amongst these factors. Due to the influence of different microbes present on grapes on the characteristics of the final product, it could be of great value to research the microbial environment of old-vine Chenin blanc grapes. It was also highlighted by Prof Burger that understanding the microbial communities on old-vines could provide much-needed insight into the characteristics of old-vines (Heyns, 2013).

Another aspect of fermentation known to, especially, influence the aroma profile of wines, is the fermentation temperature (Molina *et al.*, 2007). The fermentation temperatures of the old-vine Chenin blanc wines ranged from 11 – 23°C, but producers commented that no effort was made to alter the fermentation temperature. Therefore, the type of yeast used would be more likely to influence the composition of the wines investigated in this study, than the fermentation temperature.

3.3.2. Wood contact

In a study done by Parr *et al.* (2011), one of the main factors that played an important role in the complexity of a wine, was barrel fermentation. The complexity factor has two aspects in this sense. It refers to the complexity of the aromas as well as added taste of oak in the wine. The selection of the wine barrels could have a large influence on the quality of the wine. The extraction rate of new oak barrels has been proven to be higher than that of consecutive fill barrels (Gómez-Plaza *et al.*, 2004). The wood aromas especially that of new oak could, therefore, overshadow the fresh and fruity aromas. It was evident that the winemakers used very little new oak in the wooded old-vine Chenin

blanc wines and the largest percentage of the wooded wines were fermented and aged in consecutive fill barrels.

3.3.3. Lees ageing

A reoccurring factor in the production of these wines is lees ageing. All 18 wines were aged *sur lie*, except for one. According to the winemakers interviewed, the main reason for lees ageing was to add mouthfeel and complexity to the wine. This is in accordance with other studies, where lees contact proved to give more full-bodied wines (Marais and Jolly, 2005) and added mouthfeel characteristics to Chenin blanc wine tempering the perception of astringency (Vidal *et al.*, 2004; Del Barrio-Galán *et al.*, 2015). Lees ageing also protects the wines against oxidation during ageing and helps with the retention of fruit characteristics (Rodriguez-Bencomo *et al.*, 2009).

3.3.4. Malolactic fermentation

Malolactic fermentation (MLF) plays a significant role in the sensory characteristics of a wine. Malolactic fermentation is the conversion of L-malic acid to L-lactic acid and CO₂ by lactic acid bacteria (LAB) (López *et al.*, 2011). MLF can be induced intentionally by adding LAB to the wine after primary fermentation. It can, however, sometimes occur spontaneously if there are LAB naturally present on the grapes or if they are present in the barrel that the wines are aged in (López *et al.*, 2011). One of the sensory properties of wines that undergo MLF is that they have a fuller body (López *et al.*, 2011). In total, 12 of the wineries said that they did not allow for MLF and the rest of the wineries stated that MLF did sometimes occur during ageing in oak barrels, but that this happened spontaneously and they did not intentionally mean for the wines to undergo MLF. Therefore, MLF is not common practice in the production of old-vine Chenin blanc wines.

3.4. Concluding remarks

The vineyard management was similar between the farms, mainly due to the fact that they were all bush vines. Their age, however, did influence the care taken when pruning the old wood and it seems as though most viticulturists felt that the vines were already balanced and little canopy management was needed. It was clear that there is large variability in the winemaking techniques used to produce these old-vine Chenin blanc wines. What does, however, seem to be common practice is the ageing of the wines on lees. The farmers commented that this was mainly to enhance the palate of the wines by adding mouthfeel and complexity.

The information gathered makes a valuable contribution to the growing database on one of South Africa's most important cultivar, Chenin blanc. The information obtained also highlights that there are areas in South African viticulture and winemaking, that are of high importance to understanding the

quality of wine, but that have not received sufficient attention. Apart from having provided valuable context on the old-vine grapes and wines, documenting this information also contributes to the great efforts being made to preserve the old vineyards of South Africa, that form part of the country's heritage.

Information on two experts

Rosa Kruger is an expert on old-vines and forms an integral part of locating, managing and preserving them in South Africa. Kruger's qualifications include an M.A. in Communications and a Bachelor of Law degree. She practised law in Johannesburg before settling on a farm in the Western Cape. Here, she gained her practical knowledge on viticulture and developed a passion for managing vineyards and preserving the oldest vineyards in South Africa. Today, Kruger is recognised as the old-vine connoisseur of South Africa and an expert on how these vineyards should be managed. She has worked on vineyards such as Rupert and Rothschild and Cape Point Vineyards and on an international level has consulted vineyards in countries such as France, Spain and Italy. Her input and knowledge in this project was, therefore, invaluable.

Hanno van Schalkwyk graduated with a degree in Viticulture and Oenology at Stellenbosch University, after which he became a viticulturist at Riebeek Cellars and is currently a viticultural consultant at Vinpro. Van Schalkwyk has comprehensive practical experience in working on Chenin blanc vineyards and has knowledge of what the past and present trends are in Chenin blanc viticulture, as well as what is expected for the future. Van Schalkwyk also specifically worked with old Chenin blanc vineyards as the viticulturist at Riebeek Cellars.

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Chapter 4

Sensory characterisation of old- vine Chenin blanc wines

Sensory characterisation of old-vine Chenin blanc wines

4.1. Introduction

Chenin blanc is a white wine cultivar and has been increasingly mentioned in the media in South Africa in recent years as it has been recognised as an important single varietal capable of producing statistically different wines of high quality (Asimov, 2007; Goodie, 2011; Nieuwoudt *et al.*, 2013; Fridjhon, 2016a). The grape has a neutral sensory profile, due to the absence of primary flavour compounds, and can be manipulated with various winemaking practices to add complexity to the wine and create different wine styles (Marais, 2006). In a review of Chenin blanc research, Marais (2006) stated that the focus was on showcasing the quality of this cultivar and that there is much more diversity to this cultivar than previously believed. Since then, the cultivar has been further investigated, to determine the sensory and chemical classification of different Chenin blanc wine styles, but research had mainly focused on the volatile aroma compounds and excluded in-mouth sensations that contribute to the overall quality of this cultivar (Bester, 2011; Hanekom, 2012; Lawrence, 2012; van Antwerpen, 2013).

The aroma profile of wine forms part of its intrinsic quality attributes (San-Juan *et al.*, 2011). Various studies that investigated the perceived quality of experts (Jover *et al.*, 2004; Parr *et al.*, 2011; Hopfer and Heymann, 2014), as well as consumers (Charters and Pettigrew, 2007), concluded that the quality of wine is perceived as multidimensional. Therefore, in addition to the aroma, other factors that contribute to the intrinsic quality of wine include associative relations to variety, origin or typicality, as well as physical appearance, chemical characteristics and gustatory elements, which are experienced in-mouth (Jover *et al.*, 2004). Research has shown that of these, the gustatory factors are considered the most dominating elements when evaluating the intrinsic quality of wine (Bredahl, 2004; Charters and Pettigrew, 2007; Saenz-Navajas *et al.*, 2013). According to consumers, the gustatory elements include balance, body, concentration and complexity (Charters and Pettigrew, 2007), which was similar to how experts describe perceived wine quality (Johnson *et al.*, 2006; Parr *et al.*, 2011). Although these attributes are, therefore, important to both experts and consumers and are often used when describing the quality of wines, most of them have not been quantitatively analysed in wine before, specifically not in white wine.

Descriptive Analysis (DA) is the most used for sensory evaluation method (Murray *et al.*, 2001; Heymann *et al.*, 2014b), and involves identifying attributes (qualitative) and rating the intensity of these attributes (quantitative) in a product (Meilgaard *et al.*, 1999; Cartier *et al.*, 2006) by trained assessors (Næs *et al.*, 2010). The quantitative data can then, in turn, also be compared to other

chemical and physical parameters of the product (Murray *et al.*, 2001). Many studies have recently been dedicated to exploring the use of rapid methods, which are less time-consuming and can include larger data sets. In a review of these methodologies, however, Heymann *et al.* (2014b) stated that no method can replace the accuracy and precision with which DA can characterise a product, in the sensory profiling of products. DA is used to identify differences in sensory attributes between products. It is especially sensitive for the analysis of subtle differences between products (Heymann *et al.*, 2014b), as is often the case with white wines.

Limited research has been done on what influences the quality of Chenin blanc table wines (Loubser, 2008), but vine age was listed amongst these factors (Heymann and Noble, 1987). This, however, mainly refers to the fact that vines start producing better wines as they age and did not specifically highlight old-vines. It is of popular opinion, though, that wine made from older vineyards are more complex and concentrated (Lloyd, 2014; Fridjhon, 2016b) and it is often debated in the media on whether they produce better quality wines. There is, however, limited research on the wines made from these old vineyards and the type of sensory profile that they exude.

According to popular opinion, old-vines are believed to produce quality wines, yet the sensory profile of the old-vines of South Africa's most important wine cultivar, Chenin blanc, has not been investigated scientifically. Also, the concepts often associated with the intrinsic quality attributes of wine and used to describe wine, have not been evaluated and rated as such in wine, by a trained panel. For the purpose of this study, the attributes selected to be evaluated in the set of wines will be referred to as in-mouth sensations. These sensations included body, heat, acidity, balance, concentration, complexity, integration and length. The objective of the study was to characterise the sensory aroma profile of old-vine Chenin blanc wine and evaluate the in-mouth sensations associated with this wine style category, according to experts of industry. The physicochemical composition of wine plays an important role in how it is perceived, therefore this study will also report on the levels of these constituents in the wines and how they relate to the in-mouth sensations.

4.2. Materials and Methods

4.2.1. Selection of wine samples

Sixteen Chenin blanc old-vine wines, out of an estimated total pool of 32 wines that fit the age criteria (>40 years) were selected for analysis. To our knowledge there are only 32 different wines that make up this wine style category, therefore the selected sample set was representative. One wine produced from 30-year-old vineyards was also included in the sample set as the producer already contributed to the old-vine sample set.

Due to the limitations on the number of samples that can be analysed in a set with DA (Heymann *et al.*, 2014b), the wines were analysed in two sets, four months apart. This allowed, for the analysis of all selected wines, without the risk of the panel becoming fatigued. Each set of wines analysed was compiled with the same panel used for the selection of the in-mouth sensations. The selection procedure is explained in Addendum B. During this selection procedure, a reference sample was selected and included in each set analysed. The purpose of the reference wine is discussed in section 4.2.4.

All of the wines included in the study were single varietal, wooded and unwooded Chenin blanc wines. They were not all from the same vintage, but were sourced on availability and convenience within the vineyard age criteria. The final selection of wines is included in Addendum B (Table 1 & 2).

4.2.2. Selection of in-mouth sensations

The lexicon which describes the in-mouth sensations elicited by the wines and which are characteristic of the old-vine Chenin blanc wine style category was selected by a panel. The panel consisted of six experienced panellists and two members of industry who have extensive domain knowledge and experience in both local and international wine judging. Consensus was reached amongst the panel on a final list of 8 descriptors, including body, heat, acidity, complexity, balance, concentration, integration and length (Table 4). During the selection of the wines for set two, with the same panel, the list of descriptors selected for set one were revised to ensure that it was still representative of the new sample set as well as to verify that the standards and definitions used for the in-mouth sensations were sufficient.

4.2.3. DA Sensory evaluation panel

The panel consisted of professional tasters with extensive experience in the evaluation of different food products and wine. For the analysis of the first set of wines, the panel consisted of 10 members (4 men and 6 women, aged 22 – 50 years) and 9 members for the analysis of set two (2 men and 7 women aged, 23 – 50). An effort was made to keep the panel members consistent for the analysis of set one and two. Due to other commitments, however, the panel for set two included four new members. According to Heymann *et al.* (2012), the ideal number of panellists is between 8 and 10, depending on the difficulty of the analysis. With this considered, 9 to 10 panel members were deemed adequate for this experiment.

4.2.4. Panel training

Training of the panel for set one and set two, both consisted of 13 2-hour training sessions, each over a period of 5 weeks. The same protocol was followed in both sets. The training workflow for aroma attributes and in-mouth sensations followed two different types of DA training protocol, because the

panel has had extensive training on aroma attributes, but this would be the first time the panel would have to evaluate the selected in-mouth sensations.

Consensus training on aroma attributes

The first few training sessions focused only on the aroma attributes of the wines. The panel was presented with all the wines in the sample set and instructed to generate 3-5 descriptors for each wine. Once all potential descriptors had been identified in the first session, the panel was provided with reference standards in the next session, which they then had to identify during a blind tasting. Aroma training was dedicated to ensuring that the panel could consistently identify the reference standards that were representative of the attributes. It also involved trying to condense the total list of attributes present in each set to a manageable number. A final list of 32 attributes was compiled for set 1 and 24 for set two. The attributes and the reference standards used for each are listed in Addendum A, Table 1.

Ballot training on in-mouth sensations

Once the panel had reached consensus on the aroma attributes, the next training sessions focused on in-mouth sensations. The panel was provided with the list of predetermined descriptors including body, heat, acidity, complexity, balance, concentration, integration and length (Table 4), as compiled by the selection panel (described in section 4.2.2. . What added to the difficulty of analysing these descriptors, was that most of the in-mouth sensations were concepts and reference standards could not be created. This meant that they could only be analysed by written definition (see definitions in Table 4). Therefore, due to the difficulty of a panel reaching consensus on the definitions of attributes, extensive panel training was required which consisted of three steps, discussed below.

In step 1 the panel was presented with reference standards for certain attributes, as well as providing them with a compilation of written definitions for the other concepts (Table 4).

For body, acidity and heat, reference standards were provided that could be tasted in-mouth and the evaluation protocol for these standards was therefore referred to as 'oral' in Table 4. During step 1 of training, the judges were provided with line scales for each of the attributes that had oral reference standards (body, heat and acidity). The purpose of this was reaching consensus amongst the panel on where to place the reference standards on the unstructured line scales. Therefore, even though the standards, represented different levels, for example, low, medium/low, medium/high and high levels (see Table 4) of each of these attributes, it was still important to establish exactly how the panel perceived them in order to standardise the use of the line scales.

The panel was provided with a compilation of different definitions for each of the concepts that had to be analysed by written definition. For many of these concepts, there exist no formal, scientific

definition. Therefore, definitions were obtained from different popular press for each attribute, including websites such as www.vinology.com and www.winespectator.com (Table 4). Each definition used is displayed in Table 4, with the corresponding source shown in the Reference column. The aim of this was to ensure that all the different ways that each concept could be defined, were considered, whether there are different opinions on the concepts, or just to identify what is generally meant by each of these concepts. The definitions provided for each term were discussed with the panel and it was of high importance that consensus was reached amongst panel members on the definitions. For length, however, the definition was slightly adapted from that of the source. Pickering and Demiglio (2008) used the definition “*How long the pleasant sensations last after the wine is swallowed/expectorated*”. The definition was adapted to exclude the word “pleasant” and the panel was then required to indicate on line scales whether the lasting sensations were driven by flavour, oak flavour or the acidity, or a combination of any of them (see Addendum E for an example of the tasting sheets). Flavour referred to a dominating fruit driven length, while oak flavour length was driven only by the taste of oak and acidity driven referred to a length that lacked in flavour and was dominated by acidity. The intensity on the line scales would indicate how long the length was considered to be driven by those factors.

Table 4 Reference standards and written definitions used in training for in-mouth sensations analysed in old-vine Chenin blanc wines, adapted from (Pickering and Demiglio, 2008).

Term	Standard	Evaluation protocol	Reference
Body	5% CMC solution – 0.5g/L (<i>low</i>), 1.0g/L (<i>medium/low</i>), 1.5g/L (<i>medium/high</i>), 2g/L (<i>high</i>)	Oral	(Pickering and Demiglio, 2008)
Heat	96% Ethanol – 13% (<i>low</i>), 15% (<i>high</i>)	Oral	(Pickering and Demiglio, 2008)
Acidity	Tartaric Acid – 1g/L(<i>low</i>), 2g/L (<i>medium/low</i>), 3g/L (<i>medium/high</i>), 4g/L (<i>high</i>)	Oral	(Pickering and Demiglio, 2008)
Complexity	An element in all great wines and many great wines; a combination of depth, flavour intensity, focus, balance, harmony and finesse ¹ ; A wine exhibiting numerous odours, nuances and flavours ² ; Complexity can come from the fruit character alone or it may come from the combination of secondary and tertiary characteristics ³ .	Written definition	www.winespectator.com ¹ ; www.vinology.com ² ; Wine and Spirits Education Trust, 2012 ³
Balance	When the elements of wine - acids, sugars, tannins, alcohol - come together in a harmonious way ¹ ; When no single element dominates, the "hard" components - acidity and tannins - balance the "soft" components - sweetness, fruit and alcohol ²	Written definition	www.vinology.com ¹ ; www.winespectator.com ²

Table 4 (cont.)

Term	Standard	Evaluation protocol	Reference
Concentration	When evaluating aroma and flavour, the more pronounced or evident the characteristic, the more intense the wine ¹ ; Concentration of flavours and structural components ²	Written definition	www.winespectator.com ¹ ; Wine and Spirits Education Trust, 2012 ²
Integration	Oral sensations are combined in good proportion, a good integration of aroma flavours into taste	Written definition	(Pickering and Demiglio, 2008)
Length	How long the sensations last after the wine is swallowed/expectorated - was the length driven by <i>oak flavour, (fruit) flavour or acidity?</i>	Written definition	(Pickering and Demiglio, 2008)

The panel was provided with a reference wine with predetermined values on the line scales for all the in-mouth sensations, including those with oral reference standards and written definitions, in step 2. This had previously been done successfully for the descriptive analysis of tea by Koch *et al.* (2012), as well as later by Jolley (2014), where the reference had been referred to as a 'control sample'. The reference sample is used as a means of calibration for the panel, to minimise drift in the use of the scale by providing an anchoring point to which panellists could compare samples. The selected reference wine sample was a commercial wine and the values selected for anchoring were determined by the same panel that selected the in-mouth sensations and the wines for evaluation in section 4.2.2. and 4.2.1. These values for each attribute are shown on line scales in Addendum E. The reference wine was rated low in body, heat, complexity, concentration and integration, but high in acidity and had a long length, driven by acidity (Addendum E). As this was the first attempt at using this wine as a reference, the values were also discussed with the panel to ensure that they had consensus on where the reference wine should be on the line scale. The reference wine was presented at every training and during testing and the same reference wine was used for the analysis of both set one and set two. The panel's performance was monitored in step 3 with PanelCheck software (Version 4.1.0, Nofima Mat, Norway). This software is specifically designed to provide a rapid, yet insightful overview of the panel's repeatability, reproducibility and whether the panel is able to discriminate between samples (Tomic *et al.*, 2010). As proposed in the workflow of Tomic *et al.* (Tomic *et al.*, 2010), Tucker-1 plots were used to assess the panel's agreement on the in-mouth sensations by analysing the correlation loadings plots. Figure 1 in Addendum C shows the Tucker-1 plot for Balance. All assessors were grouped together on consensus component 1, except J6. This would show that overall, the panel had consensus on the evaluation of the attribute (Dahl *et al.*, 2008). When compared to Figure 2 in Addendum C, however, even though all panel members had 100% explained variance, they were scattered over consensus component 1 and therefore did not have consensus on heat.

4.2.5. Sensory product evaluation

For set one, the panel analysed 9 samples split into two flights and in set two, the sample set consisted of 10 wines also split into two flights. Panellists were instructed to take a 15-minute break between flights, before the second flight would be presented to them. The reference sample was added to each flight, marked as a reference ('R'). The panel was not required to evaluate the 'R', but it was also included as a blind duplicate in both sets. Samples were presented in a randomised order with unique 3-digit codes as generated with Compusense[®] *five* software (Compusense, Guelph, Canada). The software only allowed the presentation of 18 aroma attributes per page, therefore aroma attributes were listed on the first two pages, but panellists were allowed to move back and forth between the two aroma pages. All in-mouth sensations (attributes shown in Table 4) were listed on the third page. Panellists were only required to mark the relevant and most prominent aroma attributes on the line scales for each wine, but panellists were required to analyse each in-mouth sensation and mark it on the line scales before they could analyse the next sample. The line scales were unstructured and ranged from an intensity of 0 (undetectable) – 100 (extremely intense). They were also instructed to take a 3-5 minute break between each sample to avoid fatigue.

Samples were analysed in triplicate and the three replications were done over three consecutive sessions, with only one replication (split into two flights) done per day, to prevent fatigue. The samples were kept at 15°C until they were presented to the panel for testing in a sensory laboratory with air conditioning and controlled lighting, in accordance to ISO NORM 8589 (1988), where each panellist was seated in individual booths, with a computer to work on. Panellists were given water and crackers, as suggested by Lawless and Heymann (2010), to cleanse their pallets between samples. All data were captured in Compusense[®] *five*.

4.2.6. Analysis of general wine parameters

The general wine parameters, ethanol, pH, volatile acidity, titratable acidity, reducing sugars, ethanol and glycerol were quantified with infrared spectroscopy using the Winescan FT120 spectrometer (Foss Analytical, Denmark, 2001). In-house calibration models for bottled dry white wine as described by Nieuwoudt *et al.* (2004) were used.

4.2.7. Physicochemical analysis

4.2.7.1. Dry Extract

The dry extract of the wines was analysed by an ISO17025 accredited laboratory, VinLAB (Oude Molen Building, Distillery Road, Stellenbosch). The method of analysis was the OIV approved Pycnometer

Method (FTIR, pycnometry, AOAC 920.6) for the analysis of extract in beverages and beverage materials/wines.

4.2.7.2. Organic Acids

L-Malic acid was analysed with the Winescan FT120 (Foss Analytical, Denmark, 2001), while L-lactic acid was analysed with a Konelab Arena 20XT Enzyme Robot (Thermo Electron Corporation, South Africa) using a Enzytec Fluid kit (Brand: Roche, R-biopharm), ID no. E5260 (Supplier: AEC Amersham).

4.2.7.3. Phenolic compounds

Phenolic compounds were analysed by high performance liquid chromatography using a SpectraSYSTEM HPLC instrument (Thermo Separations Products, Inc., New Jersey, USA). The method described by Waterhouse *et al.* (1999) was used. Separation was performed on a polymeric polystyrene divinylbenzene reversed phase analytical column (PLRP-S 100 Å, 5 µm, 250 x 4.6 mm, Polymer Laboratories®, USA) at *ca.* 22°C. Gradient elution was performed using mobile phases comprising water/phosphoric acid [985:15 v/v (pH *ca.* 1.35) eluent A] and water/phosphoric acid/acetonitrile [185:15:800 v/v/v (pH *ca.* 1.25) eluent B]. The gradient program is listed in Table 5. The column was equilibrated for 20 minutes after each injection and the flow rate was 1 mL/min (Table 5). A volume of 20 µL of each sample was injected with an auto sampler. The target compounds were eluted using a gradient elution programme. A photodiode array was used for detection and data acquisition and calibration were performed using ChromQuest® software (Thermo Separations Products, Inc., New Jersey, USA).

Table 5 Gradient program used for the HPLC-DAD separation of wine-phenolics.

Time (min)	Eluent A (%) composition	Eluent B (%) composition
0	94.00	6.00
73	69.00	31.00
78	38.00	62.00
86	38.00	62.00
90	94.00	6.00

4.2.8. Data analysis

The sensory analysis results were directly exported to NOFIMA PanelCheck V1.4.0 from Compusense® *five* to check the panel performance and repeatability and determine which attributes were significant under test conditions, as was done during training. StatSoft STATISTICA 12® (Statsoft Inc.,

www.statsoft.com) was used to do the ANOVA on the Descriptive Analysis results and Fischer's LSD test was used to evaluate the individual differences between samples. For data analysis, a correlation matrix Principal Component Analysis (PCA) plot was constructed in *Microsoft XLStat*. The correlation matrix PCA was preferred to a covariance PCA as all means are weighted equally so that the data is normally distributed (Borgognone *et al.*, 2001). PCA plots were used to determine the relationship between the wines (observations), also to see the relationship between the sensory attributes (variables) and then to show how the wines and the attributes were related. This would make the information comparable to previous research done on the sensory evaluation of Chenin blanc wines. The correlation between sensory attributes and the physicochemical parameters was determined by examining a Partial Least Squares Regression-coefficient (PLSR) plot. PLSR is suggested as a good way to illustrate the relationship between sets of well-related responses (Martens and Naes, 1989). This correlation was done using SIMCA-P 13.0 software, (Umetrics, Sweden).

4.3. Results and Discussion

4.3.1. Attribute selection process

In order to determine whether both the in-mouth and aroma descriptors identified, explain the sensory space of the old-vine Chenin blanc wine evaluated, the R^2 values were calculated for each attribute. The R^2 value is a representation of how close the attribute is to the fitted regression line of the plot (Luciano and Naes, 2009). Those attributes that best describe the model would have an R^2 value close to 1, and those that did not contribute to the overall configuration of the model on the first (PC1) and second (PC2) principal component, would have a value close to 0. As a norm, 0.5 has been used as a cut-off (Westad *et al.*, 2003), and only those attributes that explain 50-100% of the variance would be included in the plot. Each data set, however, is unique and for the purpose of this study, the regression lines were inspected first, before determining this cut-off point.

4.3.2. Sensory analysis: the aroma profile

4.3.2.1. Selection of aroma attributes

The aroma attributes used for the evaluation of the aroma profile of the wines analysed, were the common attributes identified in set one and set two. For these aroma attributes, the R^2 line plot revealed that all data were correlated above an R^2 of 0.5 (Figure 4.1). Table 6 and Table 7 contain all the aroma attributes which could possibly contribute to the overall sensory space of the wines analysed. The common attributes used to create the PCA plot (Figure 4.2), are shaded in grey and their corresponding numbers in the line plot (Figure 4.1) are shown in brackets next to each attribute. The

ANOVA values for each attribute are displayed in the last column of Table 6 and Table 7. Those variables (attributes) that were rated, or observed, by less than 20% of the panel was excluded from any further analyses, and are not shown in Table 6 and Table 7, but will further be elaborated on in section 4.3.4. where the overall sensory space of the old-vine Chenin blanc wines analysed, is discussed.

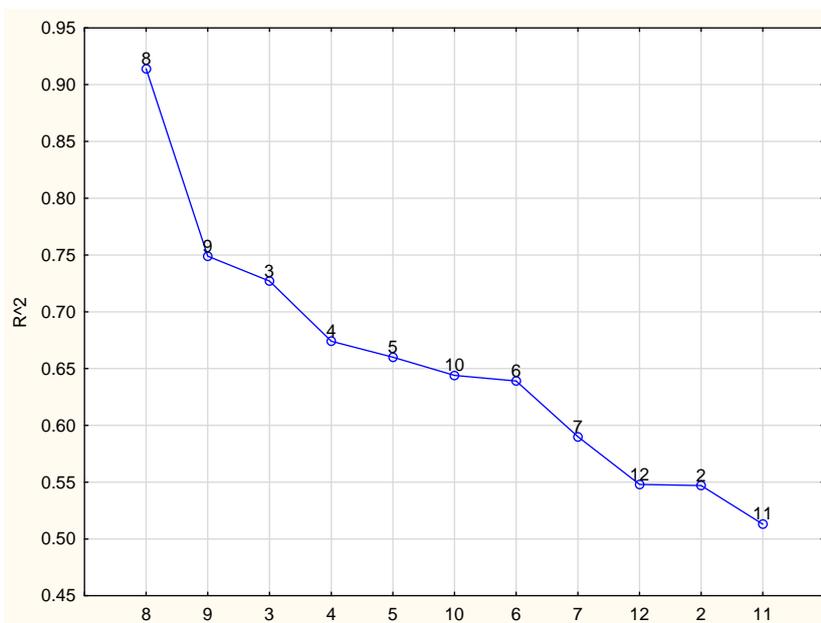


Figure 4.1 Line plot showing the R^2 values of the common aroma attributes between set one and set two of the old-vine Chenin blanc wines analysed, displaying how the attributes correlated to the model of the wines analysed. The corresponding numbers for the attributes are shown in brackets after each attribute in each set in Table 6 and Table 7. These attributes were used to create the PCA plot in Figure 4.2.

4.3.3. Analysis of the aroma profile

The PCA plot in Figure 4.2 was used to analyse the aroma profile of the old-vine Chenin blanc wines included in this study and to establish the aroma characteristics of these wines. A PCA plot would also create a matrix that could be compared to previous research done on the aroma characteristics of Chenin blanc wines. The PCA was only constructed of the first and second principal components (PC1 and PC2, which explained 66% of the variance. Higher order principal components (figures not shown) defined those wines that were not explained on PC1 and PC2, but for the purpose of this discussion, Figure 4.2 provided all relevant information. The plot in Figure 4.2, displays a similar picture to what has been seen in previous research done on the aroma characteristics of commercially produced dry Chenin blanc wines by Bester (2011), Hanekom (2012) and van Antwerpen (2013). All the old-vine Chenin blanc wines included in this study were cultivated as bush vines, therefore, the aroma profile would be comparable to a study done by Hanekom (2012), which investigated the aroma profile of commercial Chenin blanc wines cultivated as bush vines. In the study by Hanekom (2012), the aroma

attributes (the variables) evaluated were grouped into three groups. The first group included tropical, fresh and fruity aromas, the second included wooded aromas and the attributes included in the third group were marmalade, sweet associated, rich fruit, honey and raisin. The groups were then divided into two clusters. One cluster (cluster A) contained the fresh, tropical and fruity aromas from group one and the other cluster (cluster B) contained the aromas from group two and group three.

The aroma attributes analysed in the old-vine Chenin blanc wines could be grouped into the same three groups as well as the same clusters, as was done on the wines evaluated by Hanekom (2012). In Figure 4.2, the fresh, fruity aromas are grouped on the left side of PC1 and the wooded and richer aromas are grouped on the other side of PC1. The fresh, fruity aromas are grouped on the left of PC1 and include tropical aromas (pineapple, gooseberry), citrus aromas (grapefruit, lemon) and stonefruit aromas (quince jelly). These aromas are similar to those included in cluster A as described by Hanekom (2012). The wooded aromas (toasted oak) and sweet associated aromas (caramel, marmalade, honey) were all grouped to the right of PC1. This is similar to the aromas grouped in cluster B by Hanekom (2012). Thus, overall, the attributes identified in old-vine Chenin blanc wines, showed similar correlations as had previously been established in commercial dry Chenin blanc wines. Where the aroma attributes, however, differed from the study by Hanekom (2012), were the type of floral (chamomile) and spice (white pepper) attributes used.

The old-vine Chenin blanc wines (the observations) did, however, not cluster into the same distinct groups as the bush vines had in the study by Hanekom (2012). The old-vine Chenin blanc wines were more spread out across the aroma space (shown in Figure 4.2). As was found in dry Chenin blanc wines by van Antwerpen (2013), although the aroma attributes form distinct clusters, the wines are spread out over these clusters. This would suggest that, even though some wines are still prominent in certain aromas, the old-vine Chenin blanc wines appear to have a large combination of aromas in each sample. In Table 6 and Table 7, it can be seen that the most prominent aromas were the tropical aromas, including pineapple and grapefruit, as well as the wooded aroma, toasted oak, which defined certain wines, for example, W9, W15 and W19. These attributes had the highest rated means, compared to the other attributes. The aroma attributes of Chenin blanc wine are, however, greatly influenced by winemaking practices (Marais, 2006). These type of aromas can, therefore, easily be produced either with the use of specific yeasts (Swiegers *et al.*, 2008), or by adding wood products (Pérez-Coello *et al.*, 2000), if a specific style of wine is desired. The type of oak and age of the barrel used would also have an influence on how intense the wooded aromas are perceived (Gómez-Plaza *et al.*, 2004).

The wine included as a reference sample (W1) for in-mouth sensations as well as the wine from 30-year-old vineyards (W5) were most defined by the fresh and fruity aromas on the left of PC1. W17, W19, W15 and W13 had the highest intensities of toasted oak aroma. The rest of the aroma

descriptors seem to have a subtler presence in all of the wines. The term ‘concentrated’ is often used when describing the wines made from old-vines (Mobley, 2016). According to the definition used in this study (refer to Table 4 in section 4.2.3), concentration refers to the flavour of the wine and was therefore evaluated as an in-mouth sensation. The intensity ratings of the aroma descriptors would, therefore, suggest that the concentration of the wines would not be noted in the aroma of the old-vine Chenin blanc wines, but rather in the flavour, as described in the definition of this term.

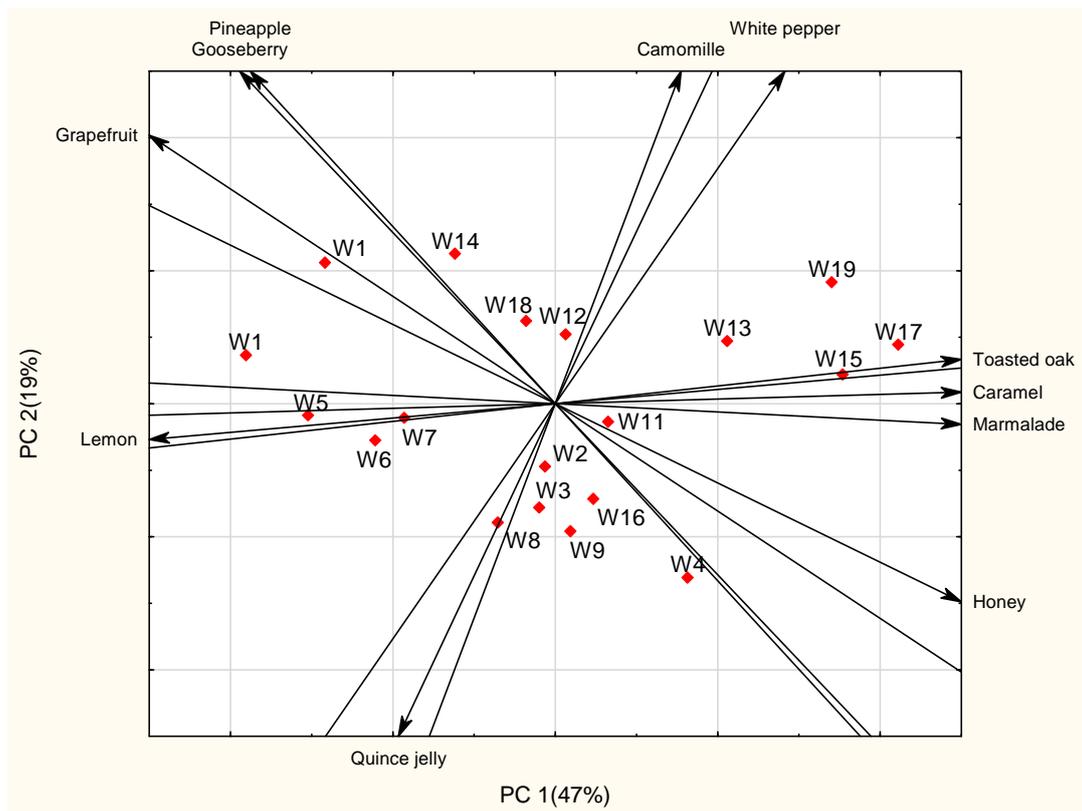


Figure 4.2 Principal Component Analysis (PCA) plot for the aroma attributes for set one and set two old-vine Chenin blanc wines, analysed with descriptive analysis (DA). Set one included W1-W9 and set two included W1 and W11-W19. The overall explained variance on this plot is 66% where 47% is explained on PC1 and 19% is explained on PC2. W1 was the blind duplicate of the reference wine provided for the analysis of in-mouth sensations.

Table 6 Set one: the aroma attributes that contributed to the sensory space of old-vine Chenin blanc wines ($R^2 > 0.4$) were shaded in grey and those attributes that did not contribute to the model of the sensory space ($R^2 < 0.4$) were shaded in white. The corresponding number of each attribute in Figure 4.1 is shown in brackets.

Attribute	W1	W2	W3	W4	W5	W6	W7	W8	W9	LSD test (p-values)
Pineapple (11)	42.467 ^a	16.567 ^{cd}	11.383 ^d	8.917 ^d	33.283 ^{ab}	32.500 ^{abc}	32.167 ^{abc}	15.167 ^d	18.433 ^{bcd}	0.004
Grapefruit (5)	37.233 ^a	20.550 ^{bcd}	19.783 ^{bcd}	6.467 ^d	31.433 ^{ab}	25.550 ^{abc}	23.350 ^{abc}	21.600 ^{bcd}	13.867 ^{cd}	0.025
Toasted oak (3)	11.067 ^c	26.133 ^{abc}	32.067 ^a	30.000 ^{ab}	12.900 ^{bc}	11.550 ^c	17.033 ^{abc}	24.300 ^{abc}	33.567 ^a	0.053
Gooseberry (12)	12.533 ^{ab}	6.717 ^{bc}	5.400 ^{bc}	3.067 ^c	11.433 ^{ab}	17.783 ^a	9.267 ^{bc}	6.000 ^{bc}	3.267 ^c	0.015
Marmalade (8)	2.767 ^b	16.033 ^{ab}	15.283 ^{ab}	21.367 ^a	7.033 ^{ab}	14.600 ^{ab}	7.950 ^{ab}	12.467 ^{ab}	13.917 ^{ab}	0.268
Caramel (2)	5.000 ^a	10.933 ^a	9.150 ^a	7.367 ^a	4.633 ^{ab}	5.867 ^a	7.650 ^a	9.867 ^a	11.467 ^a	0.737
Chamomile (6)	7.600 ^a	14.100 ^a	10.617 ^a	6.250 ^a	9.167 ^a	8.983 ^a	10.100 ^a	13.733 ^a	6.033 ^a	0.553
Honey (7)	4.967 ^b	12.433 ^{ab}	14.550 ^{ab}	19.917 ^a	8.933 ^{ab}	14.600 ^{ab}	4.767 ^b	15.800 ^{ab}	12.200 ^{ab}	0.421
Quince jelly (9)	10.433 ^b	13.950 ^{ab}	15.400 ^{ab}	15.500 ^{ab}	14.733 ^{ab}	18.467 ^{ab}	14.083 ^{ab}	21.600 ^a	13.333 ^{ab}	0.668
Lemon (4)	26.900 ^{ab}	22.067 ^{ab}	27.483	15.950 ^b	28.500 ^a	23.833 ^{ab}	20.633 ^{ab}	24.967 ^{ab}	21.600 ^{ab}	0.490
White pepper (10)	5.900 ^a	4.967 ^a	8.617 ^a	10.917 ^a	6.300 ^a	5.383 ^a	8.850 ^a	5.083 ^a	3.900 ^a	0.603
Biscuit	9.850 ^b	17.533 ^{ab}	13.333 ^{ab}	21.700 ^{ab}	12.400 ^{ab}	10.883 ^b	17.417 ^{ab}	16.767 ^{ab}	25.283 ^a	0.346
Vanilla	3.733 ^b	9.517 ^{ab}	12.217 ^{ab}	12.617 ^{ab}	5.967 ^{ab}	6.467 ^{ab}	9.517 ^{ab}	7.667 ^{ab}	15.433 ^a	0.308
Baked apple	10.233 ^a	17.533 ^a	17.867 ^a	24.717 ^a	15.100 ^a	19.383 ^a	14.017 ^a	18.850 ^a	23.783 ^a	0.717
Green guava	19.367 ^a	6.667 ^{bc}	6.133 ^{bc}	1.300 ^c	15.083 ^{ab}	14.233 ^{ab}	14.617 ^{ab}	10.567 ^{abc}	8.500 ^{abc}	0.094
Yellow apple	27.883 ^a	24.067 ^a	17.633 ^a	17.567 ^a	23.783 ^a	27.017 ^a	26.883 ^a	16.217 ^a	15.183 ^a	0.312
Dried herbs	4.767 ^a	5.300 ^a	8.100 ^a	6.467 ^a	3.083 ^a	4.033 ^a	6.267 ^a	3.150 ^a	6.000 ^a	0.938
Orange blossom	16.650 ^a	11.200 ^{ab}	5.683	9.600 ^{ab}	3.817 ^b	15.750 ^{ab}	7.033 ^{ab}	8.900 ^{ab}	6.867 ^{ab}	0.368
Orange zest	2.167 ^a	6.783 ^b	8.650	16.833 ^{ab}	3.667 ^b	9.950 ^{ab}	7.533 ^b	10.350 ^{ab}	10.100 ^{ab}	0.083
Green apple	12.867 ^b	3.567 ^{ab}	7.767	4.433 ^{ab}	5.383 ^{ab}	7.300 ^{ab}	10.633 ^{ab}	5.800 ^{ab}	2.500 ^b	0.412
Thyme	4.333 ^a	7.633 ^a	3.567 ^a	4.033 ^a	9.667 ^a	9.167 ^a	7.583 ^a	7.417 ^a	8.267 ^a	0.686
Stewed fruit	10.083 ^a	18.033 ^a	10.167 ^a	25.000 ^a	12.100 ^a	13.667 ^a	11.367 ^a	19.833 ^a	12.100 ^a	0.556
Dried peach and apricot	9.267 ^{ab}	13.017 ^{ab}	21.717 ^a	18.100 ^{ab}	15.233 ^{ab}	14.167 ^{ab}	15.400 ^{ab}	13.783 ^{ab}	13.733 ^{ab}	0.521

Table 7 Set two: the aroma attributes that contributed to the sensory space of old-vine Chenin blanc wines ($R^2 > 0.4$) were shaded in grey and those attributes that did not contribute to the model of the sensory space ($R^2 < 0.4$), were shaded in white. The corresponding number of each attribute in Figure 4.1 is shown in brackets.

Attribute	W1	W11	W12	W13	W14	W15	W16	W17	W18	W19	LSD test (p-values)
Toasted oak (3)	5.981 ^f	31.333 ^{cd}	21.370 ^{ed}	40.296 ^{bc}	18.056 ^{ef}	49.741 ^b	16.241 ^{ef}	35.111 ^c	32.833 ^{cd}	64.037 ^a	0.000
Quince jelly (9)	9.444 ^{bc}	12.944 ^b	8.370 ^{bc}	8.185 ^{bc}	8.259 ^{bc}	2.833 ^{bc}	24.185 ^a	5.778 ^{bc}	9.519 ^{bc}	1.185 ^c	0.017
Marmalade (8)	5.481 ^d	18.296 ^{ad}	17.889 ^{db}	20.481 ^{abc}	12.444 ^{dc}	27.685 ^{ab}	20.148 ^{abc}	31.704 ^a	15.852 ^{db}	22.981 ^{abc}	0.040
Honey (7)	7.407 ^c	21.593 ^{ab}	6.870 ^c	17.685 ^{cb}	10.611 ^{cb}	23.630 ^{ab}	28.685 ^a	29.352 ^a	13.407 ^{cb}	13.315 ^{cb}	0.010
Pineapple (11)	34.593 ^{abc}	36.222 ^{abc}	28.370 ^{ad}	22.463 ^{dc}	38.852 ^{ab}	24.630 ^{db}	41.370 ^a	13.667 ^d	30.185 ^{abc}	22.704 ^{db}	0.044
Grapefruit (5)	29.907 ^a	13.111 ^b	16.019 ^b	19.556 ^{ab}	23.315 ^{ab}	17.426 ^{ab}	13.426 ^b	12.926 ^b	13.944 ^b	20.519 ^{ab}	0.219
Lemon (4)	28.407 ^a	22.537 ^{ad}	13.907 ^{db}	22.519 ^{ad}	26.074 ^{ab}	12.611 ^{dc}	19.315 ^{ad}	12.352 ^{dc}	24.852 ^{abc}	9.852 ^b	0.072
Caramel (2)	8.630 ^{cb}	19.667 ^{ab}	8.556 ^{cb}	21.556 ^a	1.333 ^c	25.574 ^a	19.241 ^{ab}	13.741 ^{ab}	9.185 ^{cb}	19.759 ^{cb}	0.010
Gooseberry (12)	19.370 ^{ab}	13.667 ^{ac}	14.426 ^{ac}	3.185 ^c	10.981 ^{ac}	5.648 ^{cb}	9.130 ^{ac}	5.593 ^{cb}	20.870 ^a	6.241 ^{ac}	0.217
White pepper (10)	14.833 ^{bc}	17.926 ^{bd}	22.463 ^{bc}	22.148 ^{bc}	30.389 ^b	10.315 ^{dc}	4.000 ^d	50.407 ^a	16.444 ^{bd}	25.389 ^{bc}	0.001
Chamomile (6)	22.037 ^a	9.056 ^b	14.741 ^{ab}	25.444 ^a	23.759 ^a	17.944 ^{ab}	16.759 ^{ab}	18.222 ^{ab}	18.944 ^{ab}	21.407 ^{ab}	0.463
Cooked apple	12.833 ^{cb}	30.426 ^a	22.315 ^{ac}	23.611 ^{ab}	9.333 ^c	32.722 ^a	25.944 ^{ab}	30.444 ^a	25.407 ^{ab}	26.500 ^{ab}	0.040
Raisins	8.056 ^d	30.241 ^a	12.852 ^{dc}	19.963 ^{abc}	10.611 ^{dc}	25.907 ^{ab}	29.000 ^{ab}	17.204 ^{db}	19.907 ^{abc}	13.519 ^{dc}	0.007
Fresh green/Herbaceous	16.889 ^{ab}	11.815 ^{ac}	17.019 ^{ab}	6.963 ^{ab}	20.370 ^a	2.222 ^c	7.333 ^{cb}	12.389 ^{ac}	13.352 ^{ab}	6.630 ^{cb}	0.058
Muscat/Litchi	31.519 ^{abc}	35.963 ^{ab}	26.556 ^{eb}	17.593 ^{ec}	28.278 ^{abcd}	12.370 ^e	42.685 ^a	22.333 ^{eb}	33.407 ^{ab}	14.537 ^{ed}	0.007
Sweet spice	12.519 ^{cb}	12.870 ^{cb}	10.630 ^c	13.315 ^{cb}	10.241 ^c	27.630 ^a	16.722 ^{ac}	24.056 ^{ab}	21.148 ^{ac}	27.222 ^a	0.042
Biscuit/Butter	8.111 ^{cd}	17.815 ^c	15.556 ^{cd}	20.537 ^{cb}	3.648 ^d	32.722 ^{ab}	12.463 ^{ed}	13.074 ^{cd}	18.315 ^c	41.241 ^a	0.000
Fresh apple	26.333 ^a	3.648 ^c	16.537 ^{ac}	18.389 ^{ab}	27.352 ^a	8.926 ^{cb}	18.556 ^{ab}	3.759 ^c	11.167 ^{cd}	9.259 ^{cb}	0.013
Pear	13.556 ^{ab}	10.481 ^b	13.648 ^{ab}	9.463 ^b	15.833 ^{ab}	9.426 ^b	24.630 ^a	9.741 ^b	9.407 ^b	11.481 ^{ac}	0.277
Banana	11.333 ^{ac}	12.204 ^{ab}	10.796 ^{ac}	3.815 ^{cb}	6.722 ^{ab}	4.815 ^{cb}	17.296 ^a	2.944 ^{cb}	2.537 ^c	3.407 ^{cb}	0.045
Guava	27.296 ^a	18.648 ^{ab}	15.685 ^{ab}	11.352 ^{cb}	25.889 ^a	2.056 ^c	12.630 ^{cb}	11.593 ^{cb}	15.574 ^{ab}	11.463 ^{cb}	0.014
Peach	37.074 ^{ab}	34.889 ^{ab}	27.778 ^{ac}	30.333 ^{ac}	26.963 ^{ac}	21.963 ^{cb}	36.093 ^{ab}	18.222 ^c	24.667 ^{ac}	18.333 ^c	0.095
Hay/Straw	9.593 ^{ab}	21.722 ^a	23.000 ^a	18.537 ^{ab}	16.685 ^{ac}	13.500 ^{ac}	11.500 ^{ac}	18.204 ^{ab}	5.815 ^c	16.963 ^{ac}	0.113

4.3.4. Sensory analysis: in-mouth sensations

4.3.4.1. Evaluation of panel performance

PanelCheck was used to evaluate the panel performance on the final testing data, following the suggested workflow by Tomic *et al.* (2010), as was done during panel training (Addendum C), for both aroma and in-mouth sensations. Panel performance determines the quality of the data. Therefore, to further validate the panel performance for the analysis of in-mouth sensations, the agreement of the panel was also analysed using Statistica software. Figure 4.3 displays Intraclass Correlation Coefficient (ICC) graphs for the panels used for set one and set two, respectively. ICC graphs have been suggested as a measurement of consensus and agreement amongst a panel (Bi and Kuesten, 2012). The higher the ICC value, the less variation there is amongst the panel. For a DA panel, however, the value is seldom above 0.5 and consensus is indicated by little variation in the ICC values. The difficulty of analysing the in-mouth concepts was previously highlighted by Jones *et al.* (2008), therefore achieving ICC values close to 0.5, indicated sufficient agreement amongst panel members. The graphs (Figure 4.3) also show that in each panel, at least 8 assessors had an ICC value above 0.35 and their values varied by less than 0.1 ICC value in each set. In the study by Bi and Kuesten (2012), no specific values were given to indicate what would be the ideal ICC values for panel agreement, but it was pointed out that a value below 0.1, would indicate poor panel agreement and that those results would have to be treated with caution.

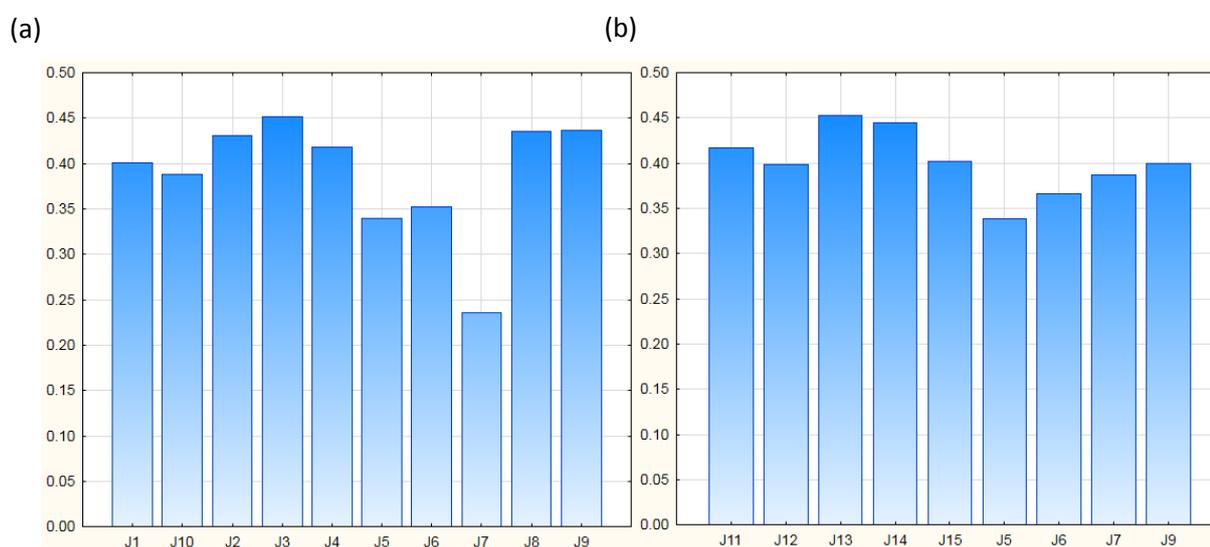


Figure 4.3 Intraclass Correlation Coefficient (ICC) graph of panel agreement in the analysis of in-mouth sensations for set one (a) and set two (b) of old-vine Chenin blanc wines.

4.3.4.2. Selection of in-mouth attributes

The R^2 values were determined for the attributes in each set of wines analysed. For set one a cut-off of 0.6 was used, after inspecting line plot (a) (Figure 4.3). For set two (b) (Figure 4.3), no cut off was needed as all attributes explained more than 70% of the variance. Table 8 and Table 9 show the

corresponding numbers for Figure 4.3 (a) and (b) in brackets, next to each attribute. In set one, the attributes that the panel did not have consensus on included acidity, heat and whether the length of the wines was driven by acidity (numbered 2, 10 and 3 in Figure 4.4 (a)). This is indicated by the R^2 values that are below 0.4 in Figure 4.4 (a). Table 8 shows that there was very little difference in the means rated for acidity in the samples in set one and no significant difference in the means rated for a length driven by acidity. Table 8 and Table 9 show the mean intensity of each in-mouth attribute analysed in each set, as rated for each sample. The tables (Table 8 and Table 9) also show the ANOVA results in the last column for each attribute, and the significance of the differences between sample means for each attribute is indicated with the alphabetic letters 'a' to 'f'. Means with the letter 'a' had the highest significant intensity rating. The intensities rated for all the in-mouth sensations are generally high, compared to how intensities would often be rated for aroma attributes. This could indicate that in-mouth sensations are a more prominent in wine, while aroma attributes are subtler. Acidity, heat and acid driven length, were re-evaluated during training on set two, and it was decided that heat was not a prominent perceivable sensation in any of the wines. Heat was, therefore, removed from the list of descriptors that was analysed in the second set of wines. Higher ethanol content has been shown to influence the 'hotness' of wines (Pickering *et al.*, 1998), but that glycerol relieved this sensation (Jones *et al.*, 2008). The ratios at which this occurs are, however, unknown. The effect of glycerol was only observed in the absence, 0%, versus the presence, 11%, of glycerol in wine by Jones *et al.* (2008). The levels of ethanol and glycerol in the wines will later be discussed in section 4.3.6.

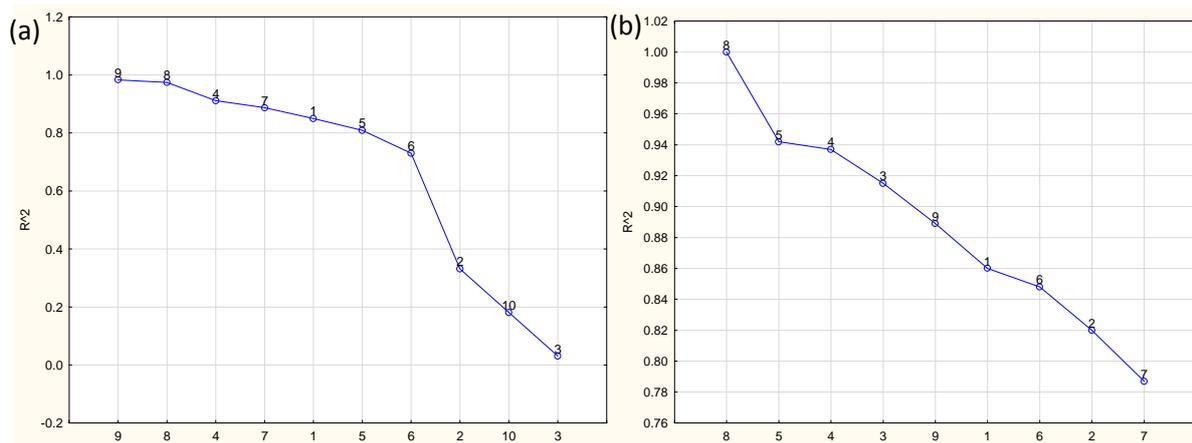


Figure 4.4 Line plots for the R^2 values of the in-mouth sensations analysed in set one (a) and set two (b), for old-vine Chenin blanc wines. Number allocations which represent certain attributes are shown on the X-axis and correspond to the numbers on the line plot and are explained in brackets in Table 8 and Table 9.

Table 8 The mean intensities of each attribute for each old-vine Chenin blanc wine from set one with the corresponding number of each attribute in plot (a) in Figure 4.3 in brackets.

Attribute	W1	W2	W3	W4	W5	W6	W7	W8	W9	LSD test (p-values)
Body (1)	48.6 ^c	53.8 ^{ac}	53.3 ^{ac}	57.8 ^{ab}	50.0 ^{cb}	56.1 ^{ac}	52.2 ^{ac}	59.2 ^a	57.5 ^{ab}	0.125
Acidity (2)	58.1 ^a	57.3 ^{ab}	53.8 ^{ab}	54.5 ^{ab}	54.6 ^{ab}	51.7 ^b	54.0 ^{ab}	53.9 ^{ab}	55.5 ^{ab}	0.451
Heat (3)	31.8 ^b	33.6 ^{ab}	33.7 ^{ab}	34.2 ^{ab}	38.8 ^{ab}	35.8 ^{ab}	33.7 ^{ab}	36.4 ^{ab}	35.5 ^{ab}	0.511
Concentration (4)	53.3 ^c	59.2 ^{abc}	54.2 ^c	58.8 ^{abc}	53.3 ^c	63.5 ^a	55.0 ^{bc}	61.5 ^{ab}	61.9 ^{ab}	0.038
Complexity (5)	51.0 ^c	56.8 ^{abc}	53.5 ^{bc}	58.0 ^{abc}	52.7 ^{bc}	62.7 ^a	53.5 ^{bc}	61.5 ^a	59.6 ^{ab}	0.039
Balance (6)	53.8 ^{ab}	56.6 ^{ab}	51.9 ^{ab}	55.3 ^{ab}	50.4 ^b	58.1 ^a	53.3 ^{ab}	57.9 ^a	57.2 ^{ab}	0.268
Integration (7)	55.9 ^{ac}	58.8 ^{ac}	55.3 ^{ac}	57.6 ^{ac}	51.6 ^c	62.1 ^a	53.5 ^{cb}	59.7 ^{ac}	61.6 ^{ab}	0.167
Flavour driven (8)	45.1 ^b	51.3 ^{ab}	41.9 ^b	46.4 ^{ab}	42.5 ^b	57.2 ^a	49.2 ^{ab}	53.0 ^{ab}	51.6 ^{ab}	0.144
Oak driven (9)	9.2 ^b	25.7 ^{ab}	23.8 ^{ab}	35.0 ^a	13.0 ^b	10.5 ^b	12.0 ^b	22.2 ^{ab}	26.8 ^{ab}	0.079
Acid driven (10)	28.8 ^a	32.1 ^a	33.6 ^a	27.5 ^a	29.1 ^a	21.6 ^a	35.0 ^a	29.8 ^a	29.6 ^a	0.727

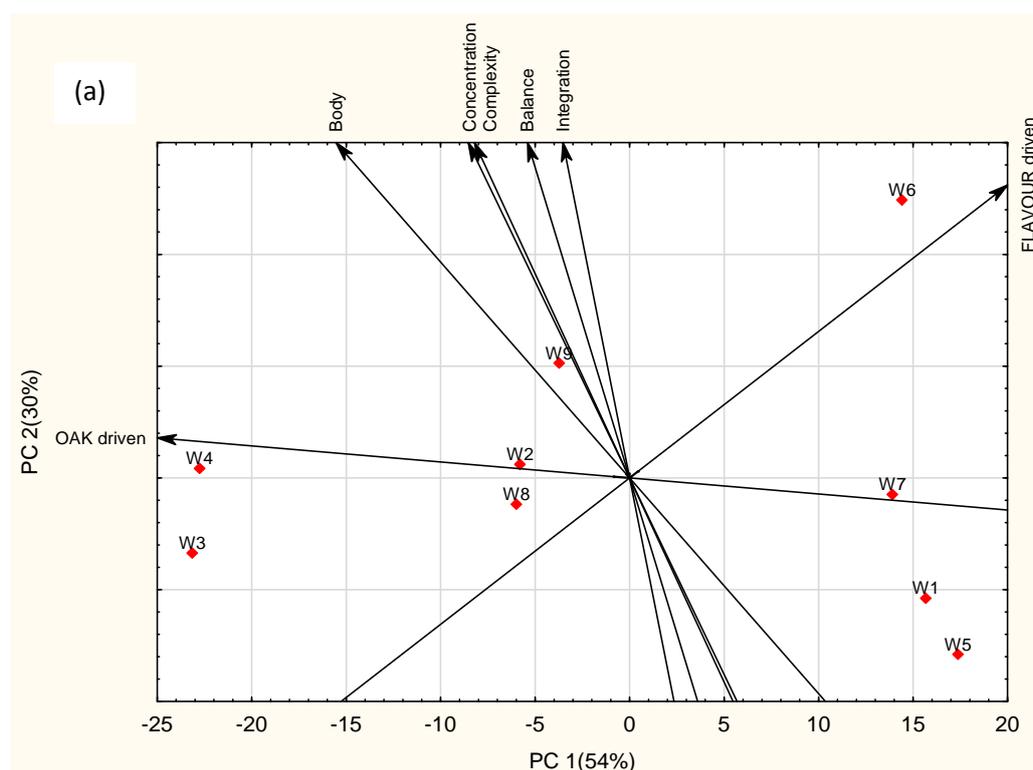
Table 9 The mean intensities of each attribute for each old-vine Chenin blanc wine from set two with the corresponding number of each attribute in plot (b) in Figure 4.3 in brackets.

Attribute	W1	W11	W12	W13	W14	W15	W16	W17	W18	W19	LSD test (p-values)
Body (1)	48.3 ^d	63.2 ^a	54.7 ^{db}	58.4 ^{abc}	51.7 ^{dc}	57.7 ^{abc}	52.4 ^{db}	54.4 ^{db}	58.5 ^{ab}	61.6 ^a	0.004
Acidity (2)	53.8 ^{ab}	44.5 ^d	51.8 ^{abc}	56.2 ^a	54.0 ^a	47.8 ^{db}	53.6 ^{ab}	52.9 ^{ab}	56.4 ^a	46.8 ^{dc}	0.005
Concentration (3)	49.4 ^c	60.9 ^a	53.7 ^{cb}	55.6 ^{ab}	53.9 ^{cb}	58.0 ^{ab}	53.4 ^{cb}	55.1 ^{ac}	57.0 ^{ab}	58.6 ^{ab}	0.051
Complexity (4)	48.4 ^c	57.2 ^{ab}	53.4 ^{cb}	53.8 ^{ac}	52.7 ^{cb}	59.4 ^a	53.0 ^{cb}	53.5 ^{ac}	56.8 ^{ab}	58.4 ^{ab}	0.032
Balance (5)	47.5 ^e	58.1 ^{ab}	50.1 ^{de}	50.8 ^{de}	52.7 ^{dec}	60.3 ^a	51.8 ^{de}	54.8 ^{db}	54.5 ^{db}	57.4 ^{abc}	0.001
Integration (6)	50.6 ^e	60.5 ^{ab}	52.0 ^{ed}	53.9 ^{ec}	55.2 ^{ae}	61.3 ^a	54.4 ^{eb}	55.6 ^{ae}	57.4 ^{abcd}	58.4 ^{abc}	0.027
Flavour driven (7)	37.8 ^d	56.1 ^a	45.2 ^{db}	40.3 ^{dc}	48.8 ^{abc}	52.8 ^{ab}	46.7 ^{ad}	45.6 ^{ad}	52.1 ^{ab}	46.3 ^{ad}	0.048
Oak driven (8)	5.3 ^f	21.5 ^{de}	16.8 ^{df}	35.7 ^{bc}	11.7 ^{fe}	42.8 ^b	13.8 ^{df}	20.5 ^{de}	26.3 ^{dc}	57.8 ^a	0.000
Acid driven (9)	33.4 ^{ab}	22.1 ^{db}	27.4 ^{abc}	28.7 ^{ab}	35.6 ^a	15.7 ^{dc}	36.5 ^a	24.3 ^{ad}	27.4 ^{abc}	14.4 ^d	0.014

4.3.4.3. Analysis of in-mouth sensations

The PCA plots created to determine the correlations between the in-mouth sensations and how they describe the samples analysed in both set one (a) and set two (b) (Figure 4.5). In plot (a), 54% of the variance is explained on PC1 and 30% of the variance is explained on PC2. In plot (b), 87% of the variance is explained on PC1 and 8% of the variance on PC2. Higher order principal components (plots not shown) would explain those attributes not defined by this plot, for example, W18 in plot (b) (Figure 4.5), but for the purpose of this study enough variance was explained on PC1 and PC2 to illustrate the in-mouth profile of the wines. The plots in Figure 4.5 both showed that the terms body, concentration, complexity, integration and balance were positively correlated. Plot (b) also indicated that these variables were negatively correlated to acidity as well as length that was driven by acidity. Therefore,

wines that were concentrated, complex, well integrated and balanced and had high body, were overly dominated by an acidic taste. All the positively correlated terms were associated with the intrinsic quality of wine. The connection of these terms to intrinsic wine quality was also noted by Jover *et al.* (2004) and Charters and Pettigrew (2007). Terms including body, complexity and concentration were also listed under quality indicators of wine in *Wines and Spirits: Understanding Style and Quality*, a book specifically written as a textbook for the Wine and Spirits Education Trust (WSET) Level 3 Award in Wines and Spirits (WSET, 2012). If acidity was then negatively correlated to these terms, it could be assumed that overtly perceived acidity is a negative attribute related to wine quality. This would then give truth to the definition used for the in-mouth sensation of balance, which states that “no single element dominates” (refer to Table 4). If a wine is perceived as having a dominating acidic taste, the wine would, therefore, be unbalanced. Due to the correlation between balance and other in-mouth sensations, the wine would then also have low concentration, complexity, integration and body. If the acidity is, however, present in good proportion in the wine, the acidity is often described as adding an element of ‘freshness’ to the wine (WSET, 2012). This is especially true in Chenin blanc, as the grapes are known to have naturally high acidity.



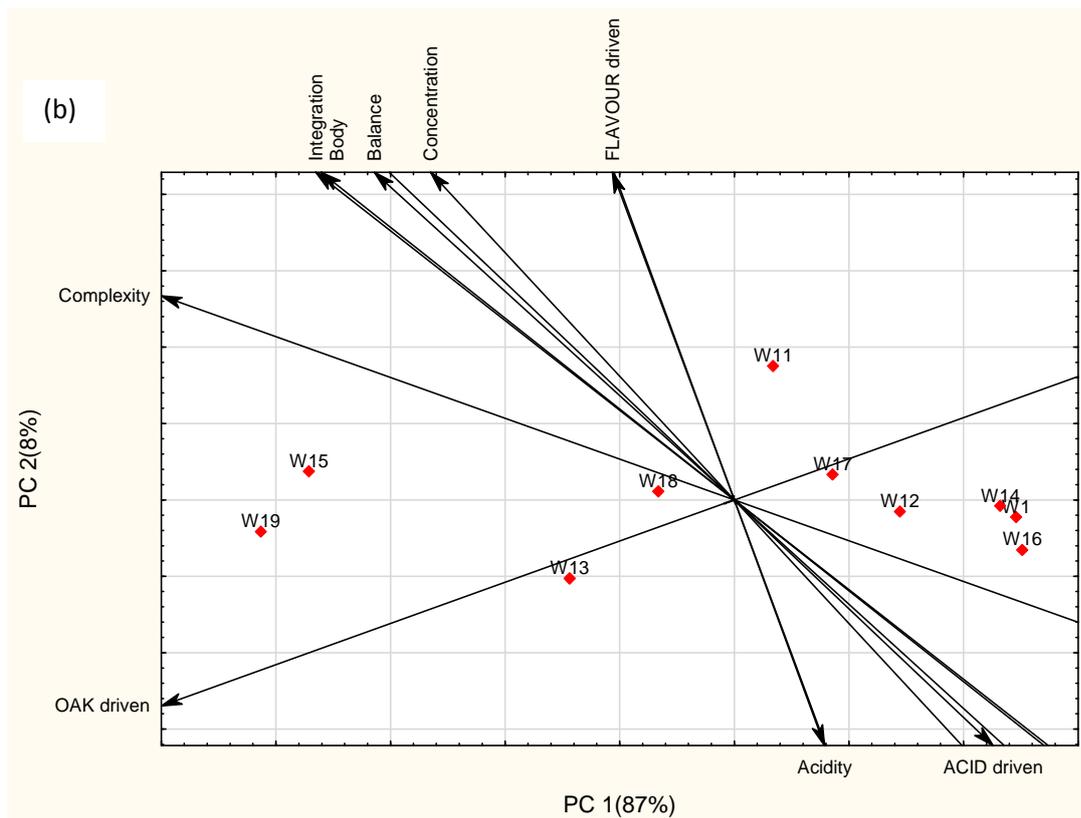


Figure 4.5 Principal Component Analysis (PCA) plots for in-mouth sensations evaluated for set one (a) and set two (b) of old-vine Chenin blanc wines. Set one (a) included W1-W9, where 54% of the variance was explained by PC1 and 30% by PC2. Set two (b) included W1 and W11-W19, where PC1 explained 87% of the variance and PC2 explained 8%. W1 in both plot (a) and plot (b) represents the blind duplicate of the reference wine.

W1 was the sample included as a blind duplicate for the reference wine. When the positions of the wines are considered in Figure 4.5, W1 was rated high in acidity with a length driven mostly by acidity in plot (b) and was rated low in all other in-mouth sensations in both plot (a) and (b). This is in accordance with the determined values for the reference wine as shown in Addendum E. The reference wine was anchored on the line scale as being low in body, concentration, complexity, balance and integration and to have a medium length, driven by acidity. This result, therefore, proved the robustness of the methodology. The wine made from 30-year-old vineyards (W5) was most correlated with the reference wine (W1), which indicates that this wine had a similar in-mouth profile to that of the reference wine. The reference wine was not part of the old-vine Chenin blanc category. W6 and W11 was the same vintage of the same wine, included in both sets of wines analysed. In Table 8, W6 was rated amongst the highest in body, concentration, complexity, balance and integration and it had the lowest intensity in perceived acidity. Similarly, in the analysis of W11 in the second set, Table 9 shows that it was rated as the highest in body and high in concentration, complexity, balance and integration. The fact that the panel could consistently rate the in-mouth sensations of this wine in both sets, also shows the robustness of the methodology. This wine, overall, had the longest length

driven by flavour (Figure 4.5). In a study done by Gawel *et al.* (2007), it was found that high flavour ratings of white wine, were associated with fuller bodied wines. Similar results were observed with W6 and W11 that had high intensities for body as well as a long length driven by flavour.

Figure 4.5 shows that there is a gradient in in-mouth sensations of the old-vine Chenin blanc wines analysed. This would suggest that, as for body and acidity, there are low, medium and high levels of balance, concentration, complexity and integration in wines. Therefore, even though these terms are associated with the quality of wine (Charters and Pettigrew, 2007), there are different levels of these sensations present in wine and this study provides a framework for the analysis of these sensations in future research.

Considering both plot (a) and (b) in Figure 4.5, the length drivers, flavour and acidity, were negatively correlated with each other. The intensity of these sensations was linked to the length of time it was perceived after expectoration. Wines with a length driven by flavour, therefore, had a longer aftertaste. Wines with a length driven by acidity, however, had a shorter aftertaste. It is also clear that wines with high perceived acidity had a length driven by acidity. Wines with a length driven by oak had the longest length. If the vectors for the three length drivers in plot (b) (Figure 4.5) are inspected, it appears as though oak driven length, to some extent, was also influenced by both acidity and flavour. Therefore, although oak was the dominating flavour for length, the overall flavour and acidity also persisted in the aftertaste of some wines. In one of the few in-depth studies on wine aftertaste, it was found that fruity flavours induced a shorter aftertaste than oaky flavours (Goodstein, 2011), which was also observed in the old-vine wines. The same observation was also made by Baker and Ross (Baker and Ross, 2014).

4.3.5. Sensory analysis: the sensory space

The purpose of using descriptive analysis (DA) to analyse the old-vine Chenin blanc wines, was to investigate the sensory space. DA was used to determine the aroma attributes that describe this set of old-vine Chenin blanc wines as well as evaluate in-mouth sensations associated with these wines.

Table 10 contains the qualitative elements established from this experiment. All the 'common' attributes that were used as descriptors in set one and set two, the 'unique' attributes that described the aroma profile of one of the sets, but not the other, as well as those attributes that did not contribute to the sensory space of any wines (<20%), are listed in this table (Table 10). The common and unique attributes are the aroma descriptors that represent the sensory space of the evaluated wines. This large number of attributes illustrates the complexity of this set of wines from the old-vines. Complexity is not only used to describe the flavour of the wine, but the definition (see Table 4) also refers to the complexity of the 'odour'.

These results also highlighted that certain aroma descriptors that were used to profile the old-vine Chenin blanc wine style category, are not mentioned on the current Chenin blanc aroma wheel (Addendum G). The purpose of the wheel was to provide consumers with a visual representation and help clarify the attributes associated with the different styles of Chenin blanc. The attributes not currently on the aroma wheel include, quince jelly, marmalade, white pepper, sweet spice, biscuit, caramel, gooseberry, muscat/litchi, chamomile and orange zest. These results suggest that the old-vine category of Chenin blanc wine might offer unique aromas that had previously not been associated with Chenin blanc wine.

The attributes that did not contribute to the profiling of these wines, included smokey, bruised/oxidised apple, sherry and mineral. Statistically, these attributes were all rated less than 20% of the time by panellists, which indicates that most panellists did not pick them up in any of the samples, and if they did, it was inconsistent and at very low intensities. The bruised/oxidised apple and sherry descriptors are characteristic of more oxidative style wines. It would, therefore, suggest that none of the wines included in this study was made in an oxidative style. Minerality in wine has become a controversial topic in wine sensory analysis (Deneulin and Bavaud, 2016). This concept has been linked to the aroma as well as taste in wine. Previous studies have associated this term with aromas such as citrus, fresh and wet stone (Heymann *et al.*, 2014a). One of the latest published articles on minerality reported that flinty/smokey and chalky/calcareous were also aromas that were correlated with wine minerality (Parr *et al.*, 2015). It was concluded, however, that there is no consensus on a clear definition for minerality, what causes it and precisely how it is perceived (Deneulin and Bavaud, 2016). The standard used for mineral, a wet stone, is what has often been used in literature (Heymann *et al.*, 2014a). Even though this standard was used in this study, the difficulty in describing and standardising this term could be the reason that assessors did not perceive it consistently. Lastly, the hay/straw descriptor is seen as an earthy descriptor. Even when presented with the reference standard for this descriptor, a piece of hay or straw (Addendum A, Table 1), the intensity of the aroma is low. This aroma may, therefore, never be a prominent characteristic in wine and is easily overshadowed by more intense aromas. It does, however, not mean that this aroma is not present. For further analysis of such a subtle aroma, studies should perhaps be dedicated to only identifying this aroma in the wine, as has been done with minerality.

Table 10 The common and unique aroma attributes identified in the combined sets of old-vine Chenin blanc wine as well as those attributes that were rated by less than 20% of the panel and did not form part of the aroma profile.

<i>Profile</i>	<i>Attributes</i>
<i>Common</i>	pineapple, grapefruit, gooseberry, quince jelly, honey, marmalade, caramel, toasted oak, white pepper
<i>Unique</i>	lemon, pear, banana, peach, yellow apple, fresh apple, green apple, guava, green guava, orange zest, orange blossom, muscat/litchi, fresh green/herbaceous, raisins, biscuit, biscuit/butter, vanilla, thyme, dried herbs, baked, cooked apple, dried peach/apricot, sweet spice
<i><20% rated</i>	smokey, sherry, hay/straw, bruised/oxidised apple, mineral

The overall sensory space shows that these old-vine Chenin blanc wines have a complex array of aroma attributes, but that the intensities of the attributes are subtle. Here, 'subtle' does not refer to a wine that has a flat aroma, but rather that a combination of different aromas is present, but at low concentrations. This could be an indicator of the quality these old-vine Chenin blanc wines as the complexity of the aroma attributes in wine, is highly valued as a quality characteristic (San-Juan *et al.*, 2011). The sensory space of the wines also included new aromas that had not been associated with the aroma profile of Chenin blanc wines before.

The drivers of the sensory space would, therefore, rather be the in-mouth sensations used to describe these wines, as they were more prominent than the aroma attributes. There are perceivable differences in the in-mouth sensations of these wines, which differed from the two wines, W1 and W5, that did not fit the age criteria of the other wines. This would give cause to analyse the in-mouth sensations of more old-vine Chenin blanc wines and compare it to Chenin blanc wines made from younger wines. This could then ultimately prove whether the in-mouth quality of the old-vine wines is characteristic and can be used to define this wine style category, where previously, Chenin blanc wine styles had mainly been based on sugar content and aroma profile.

4.3.6. Chemical analysis: physicochemical constituents

The results shown in this section are of compounds and parameters that, according to literature have been linked to certain in-mouth sensations. The values of all measured parameters are displayed in

Table 11. The value of L-malic acid was below the limit of quantification (LOQ), which is indicated with an <LOQ.

In section 4.3.4.2. it was stated that heat was not a distinguishing characteristic of any of the wines evaluated and was therefore excluded from further analysis. It was also pointed out that the levels of glycerol have an influence on how the ethanol concentration is perceived in wine (Jones *et al.*, 2008). In Table 11 it can be seen that the glycerol levels are in proportion with the alcohol content of all of the wines. This means that wines with higher ethanol, have higher glycerol levels. This would suggest that the glycerol and ethanol are present at balanced ratios in all of the wines, which would explain why the sensation of heat was not perceivable in any of the wines.

Table 12 shows how the general wine parameters, organic acids and dry extract were correlated to the perceived in-mouth sensations of the wines. No colour indicates almost no correlation (close to 0) and dark orange indicates either a strong negative (close to -1) or a strong positive (close to 1) correlation.

The organic acids analysed were selected as those that are believed to contribute to the in-mouth sensations in wine, namely L-malic acid and L-lactic acid (Runnebaum *et al.*, 2011). It is clear from Table 12, however, that volatile acidity, L-malic acid and L-lactic acid did not show strong correlations to any of the in-mouth sensations in these two sets of wines. The only attribute that the organic acids had a moderate positive correlation with, was balance (Table 12). This had also been noted in previous research (Volschenk and Van Vuuren, 2006), although the relationship between organic acids and balance does not appear to be as strong in the selected old-vine Chenin blanc wines. If referred to Table 12 below, the regression coefficient between L-malic acid and balance is only 0.21 (Table 12) and L-acid and balance is only 0.16 (Table 12). In a previous study, however, L-malic acid was found to be positively correlated to the body of white wine, while volatile acidity showed a negative correlation to the body, but a positive correlation to the acidity of white wine (García-Muñoz *et al.*, 2014).

Table 11 General wine parameters, organic acid and dry extract levels in old-vine Chenin blanc wines analysed including W1, W2-W9 and W11-W19.

Wines	Ethanol	pH	Titratable acidity (g/L)	Volatile acidity (g/L)	L-Malic (g/L)	L-Lactic (g/L)	Glycerol (g/L)	Reducing sugars (g/L)	Dry extract (g/L)
W1	12.6	3.42	5.2	0.2	3.6	0.7	6.3	2.8	20.6
W2	14.2	3.33	6.2	0.4	3.2	0.5	7.6	4.1	23.6
W3	13.2	3.21	5.6	0.7	0.5	0.8	6.5	1.5	17.9
W4	14.2	3.25	6.2	0.8	0.1	2.1	8.2	4.5	21.7
W5	14.2	3.25	6.2	0.8	0.1	<LOQ	8.2	1.4	21.4
W6	14.2	3.71	5.7	0.5	3.4	<LOQ	7.4	6.3	30.6
W7	14.0	3.45	6.0	0.5	2.2	0.5	7.5	2.1	21.2
W8	14.2	3.47	5.9	0.5	1.4	0.7	7.2	3.7	21.1
W9	14.0	3.49	6.3	0.6	1.7	0.7	7.6	3.9	24.6
W1	12.3	3.32	6.0	0.4	3.6	<LOQ	6.5	2.6	20.8
W11	13.7	3.55	5.9	0.5	3.4	<LOQ	7.5	6.3	31.1
W12	13.9	3.35	5.9	0.6	0.9	1.2	6.9	1.8	19.5
W13	13.7	3.19	6.5	0.5	2.6	<LOQ	8.3	3.3	21.5
W14	13.1	3.31	6.2	0.6	3.6	<LOQ	6.7	3.3	22.9
W15	13.1	3.31	6.2	0.6	3.6	1.0	6.7	3.7	21.6
W16	13.4	3.4	5.9	0.5	2.4	0.3	6.7	2.1	20.0
W17	12.8	3.44	6.0	0.8	0.3	2.1	7.8	3.3	23.0
W18	14.1	3.34	6.6	0.6	2.4	0.3	7.4	2.9	23.6
W19	13.3	3.28	6.2	0.5	2.4	<LOQ	8.2	2.6	23.3
Range	12.3-14.2	3.2-3.7	5.2-6.6	0.2-0.8	0.1-3.6	0.0-2.1	6.3-8.3	1.4-6.3	17.9-31.1
Standard Deviation	0.6	0.1	0.3	0.1	1.3	0.7	0.6	1.4	3.3
Average	13.6	3.4	6.0	0.5	2.2	0.6	7.3	3.3	22.6

Table 12 PLS regression coefficients of different wine parameters and dry extract to perceived in-mouth sensations of old-vine Chenin blanc wines including W1-W9 from set one and W1 and W11-W19 from set two.

	Body	Acidity	Concentration	Complexity	Balance	Integration
Ethanol	0.43	0.12	0.62	0.62	0.31	0.33
pH	0.15	-0.22	0.53	0.44	0.46	0.51
Titratable acidity	0.38	0.05	0.15	0.19	0.03	0.04
Volatile acidity	0.16	-0.04	0.09	0.16	0.003	-0.02
L-Malic	-0.01	-0.14	0.07	0.01	0.21	0.26
L-Lactic	0.03	0.1	0.04	0.08	0.16	0.07
Glycerol	0.49	-0.06	0.41	0.35	0.2	0.15
Reducing sugars	0.55	-0.33	0.76	0.65	0.67	0.76
Dry extract	0.5	-0.43	0.68	0.54	0.56	0.63

4.3.6.1. Relationship between physicochemical parameters and body

Figure 4.6 models how the other measured wine parameters relate to body, acidity, concentration, complexity, balance and integration.

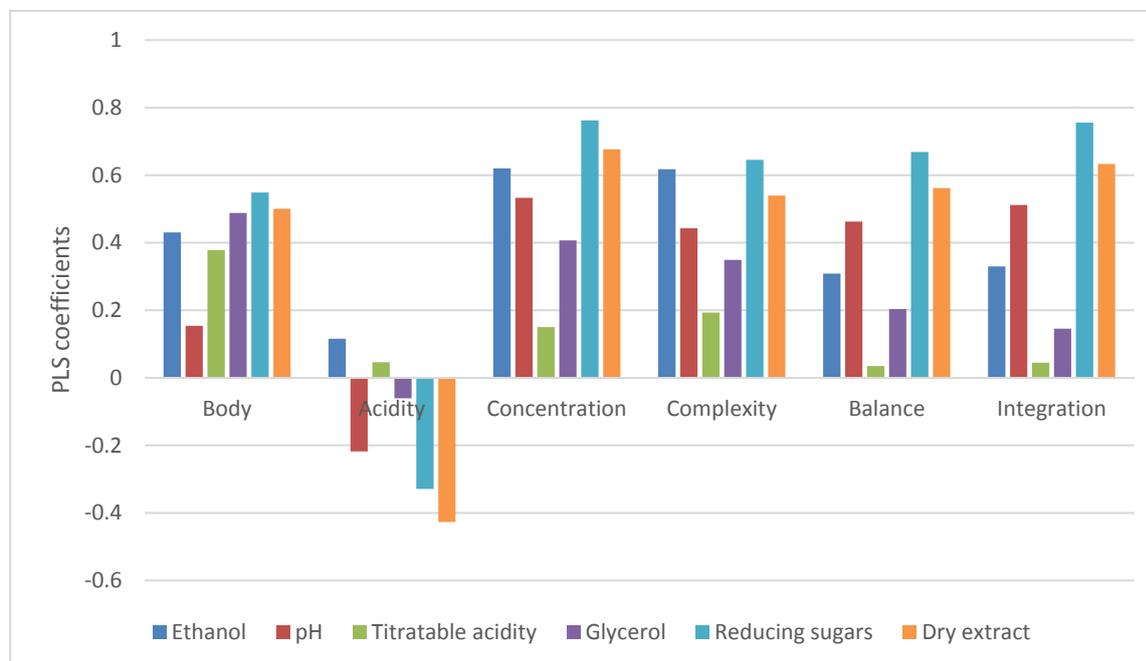


Figure 4.6 Partial least squares regression coefficients, illustrating the relation of selected wine parameters to body, acidity, concentration, complexity, balance and integration of the old-vine Chenin blanc wines.

Since these parameters are mostly associated with the body sensation of wines, it is expected that all these parameters would be correlated with body, as is seen in Figure 4.6. The three parameters that had the highest correlation with body were reducing sugars, dry extract and glycerol. This is in accordance with previous studies done on the influence of these parameters on perceived viscosity, or body (Gawel *et al.*, 2007; Yanniotis *et al.*, 2007; Runnebaum *et al.*, 2011; Neto *et al.*, 2014). Nieuwoudt *et al.* (2002) reported that glycerol levels in South African white table wines, can range from 4.7 g/L up to 9.36 g/L, for this set of wines the range was from 6.3 – 8.3 g/L (Figure 4.6). Noble and Bursick (1984), however, reported that perceivable differences in the body of wines could only be noted with the addition of at least 26 g/L glycerol. Therefore, even though glycerol might contribute to higher perceived body, it does not cause a linear increase in perceived viscosity in wine. This could be due to the unnatural process of descriptive analysis, which forces assessors to analyse each attribute individually, where the perception of a sensation could actually be a combination of different factors. This was also noted by Yanniotis (2007) and Jones *et al.* (2008), who suggested that in analysing the perceived viscosity of wine, factors that influence the viscosity should be presented in different ratios, instead of trying to analyse each component separately. The reason for this is that each of these wine constituents could have an influence on the perception of the other. In *Wine Analysis and Production*, Zoecklein *et al.* (1999) stated that dry white wines that had an extract of less than 20 g/L were related to having a thin palate, while wines with an extract greater than 30 g/L, were related to having a fuller body. According to the PLS regression plot (Figure 4.6), high levels of dry extract were correlated with high body, which is in accordance with what Zoecklein *et al.* (1999) found. Body, although not strongly correlated, is associated with a higher pH (Figure 4.6), while acidity is strongly correlated with a lower pH. This would suggest that wines that were high in acidity, would have a lower or thinner body. This observation was also made in a study by Gawel *et al.* (2007) where most assessors associated wines with higher total acidity to have lower perceived body. If referred back to section 4.3.4.3. body was also negatively correlated to perceived acidity.

It is commonly assumed that alcohol influences the viscosity of wine and especially that it increases the perceived viscosity in wine. In early studies, there was no significant difference in the perceived viscosity of wines with low alcohol and wines with higher alcohol within realistic ethanol levels in wine (Pickering *et al.*, 1998). Later, however, it was established that alcohol significantly influenced the density and viscosity of wine and that this would certainly have an influence on the body and structure on the palate (Neto *et al.*, 2014). Figure 4.6 shows that ethanol was amongst the highest correlated factors with the body of old-vine Chenin blanc wines.

4.3.6.2. Relationship between physicochemical parameters and concentration, complexity, balance, integration and acidity

The physicochemical parameters have previously been associated with the body of wine and their influence on the perceived viscosity in wine has been repeatedly researched, but this was the first time that the other in-mouth concepts were measured in wine and it was interesting to note which measurements correlated with which attributes. It was clear from Figure 4.6 and Table 12 that high reducing sugar levels were positively correlated with concentration, complexity, balance and integration. This was also evident in the dry extract of the wines, while both reducing sugars and dry extract were negatively correlated with the perceived acidity of the wines. Ethanol proved to have a strong influence on the concentration and the complexity of the wines. Although pH did not have a strong influence on the perceived body of the wines, it did, however, play a role in the concentration, complexity, balance and integration of the wines. Glycerol showed the strongest correlation with concentration (Table 12).

These findings would, therefore, suggest that wines with a higher alcohol content, pH, reducing sugars and dry extract, would be balanced, concentrated, complex and integrated and have a low perceivable acidity. It would also suggest that the glycerol levels in wine could have an impact on the perceived concentration in wine.

4.3.6.3. Correlation between physicochemical constituents and length

The correlation circle in Figure 4.7 was used to display the relationship between the three length drivers and the physicochemical parameters analysed. The three drivers are shaded in blue (Figure 4.7). A wine with good length is often described as 'long' and involves the taste experienced after the wine is expectorated and the length of time that the taste persists. Length forms part of the intrinsic quality terms of wine (Charters and Pettigrew, 2007) and is said to be a trait of fine wines (Parker, 2016). The physicochemical constituents that influence this length, however, are unknown. Therefore, it was of interest to see which of the measured parameters correlated with the three different selected drivers of length in the wines analysed. Acid driven length, in contrast to the connotation to a 'long' wine, is a negative trait. This length driver was negatively correlated to all the measured physicochemical parameters (Figure 4.7). This would suggest that if all physicochemical parameters in the wine are low, the length of the wine is likely to be driven by acidity. It was also noted in section 4.3.4.3. that a length driven by acidity is shorter compared to the other two length drivers. Oak driven length was positively correlated with the glycerol and ethanol levels. This is in accordance with Baker and Ross (2014), that also found the finish of wine positively correlated with ethanol. Glycerol was previously found to be strongly correlated to white wine quality (Nieuwoudt *et al.*, 2002), therefore, the fact that length is associated with the quality of wine (Charters and Pettigrew, 2007) could be due

to its correlation with glycerol. A length driven by flavour was strongly correlated to the reducing sugar and dry extract content of the wine. These parameters were also strongly correlated with the concentration of the wine. This would, therefore, suggest that a wine with high reducing sugar levels and high dry extract would be concentrated and have a long length, driven by flavour.

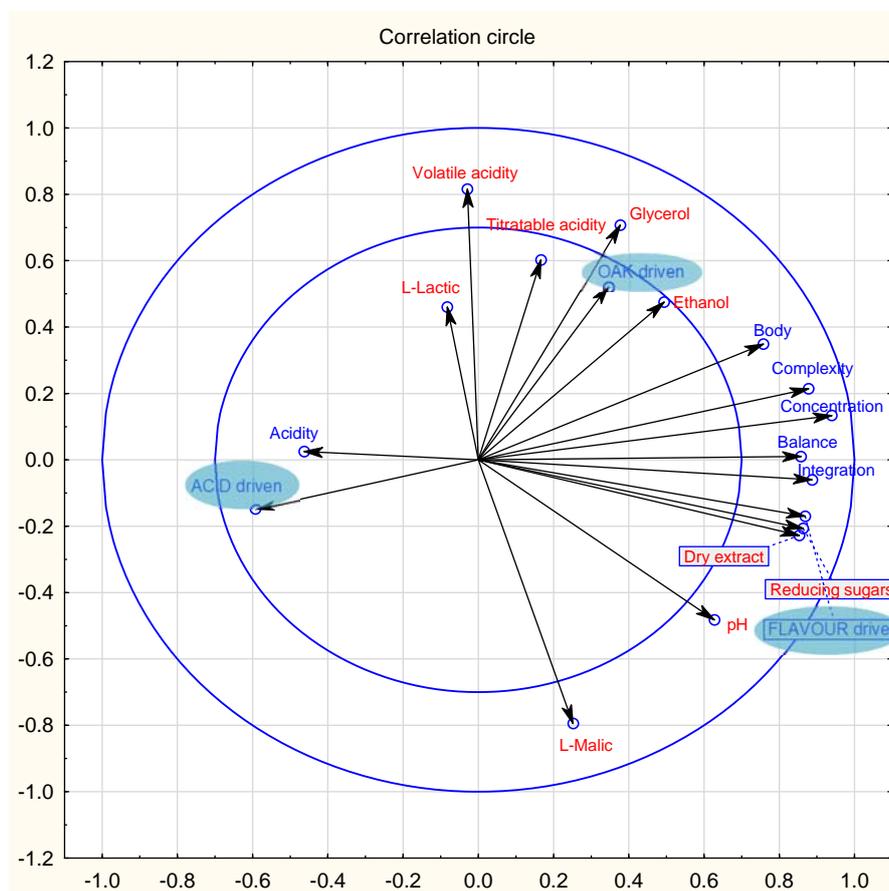


Figure 4.7 Correlation circle of the relation of physicochemical parameters to in-mouth sensations analysed in old-vine Chenin blanc wines.

4.3.6.4. Phenolic Compounds

In total, the method allowed for the analysis of 16 phenolic compounds in white wine. Of this 16, however, the only 7 that were quantifiable, included: Gallic acid, (+)-Catechin, (-)-Epicatechin, Epigallocatechin 3-O-gallate (EGCG), Caffeic acid, p-Coumaric acid, Chlorogenic acid (unquantifiable phenolics are listed in Addendum F, Table 1). This is due to the fact that phenolic levels in white wine are low if compared to that of red wine and mostly consists of hydroxycinnamates (Goldberg *et al.*, 1999; Waterhouse, 2002; Smith and Waters, 2012). The total phenolic content of white wines, vinified with minimal skin contact, either range between 100 mg/L and 250 mg/L (Komes *et al.*, 2007) or 165 to 331 mg/L (Frankel *et al.*, 1995). Apart from skin contact, fermentation and other winemaking practices (Komes *et al.*, 2007), the phenolic compounds are said to be unstable and the content can

be influenced by the grape variety, maturity, climatic and geographical conditions as well as winemaking practices (Tian *et al.*, 2009; Lampíř and Pavloušek, 2013; Balga *et al.*, 2014).

The levels in the old-vine Chenin blanc wines ranged from 77.2-242.1 mg/L (Table 13). This is quite a wide range and could have been influenced by any number of the factors mentioned above. The old-vine wines were all made from different grapes from different regions and the winemaking practices used to produce the wines were all different, therefore it is to be expected that the phenolic levels would differ between them. When compared to Chenin blanc wines V_1 – V_8 from 30-year old vines, the phenolic levels were considerably higher in the old-vine Chenin blanc wines, where the range in total phenolics was only 34.72-49.37 mg/L. The wines were made according to the ARC Infruitec-Nietvoorbij approved winemaking protocol at the Nietvoorbij experimental cellar using Vin 13 yeast with grapes harvested at different ripeness levels (procedure explained in Addendum F). Due to the different winemaking practices used and the large influence of environmental aspects on phenolic content (Lampíř and Pavloušek, 2013), the grapes would have to undergo the same harvesting procedures and winemaking protocols, to truly be able to compare the phenolic content of the wines. The quantifiable phenolics in these wines differed slightly from that of the old-vine wines and included Gallic acid, (+)-Catechin, (-)-Epicatechin, Caffeic acid, *p*-Coumaric acid and Ferulic acid. The Vin 13 wines were all from 2013 vintage, where the old-vine wines were from different vintages, which could also contribute to the difference in the levels (Brossaud *et al.*, 1999). In a comparison between the chemical composition of wines made from old and young vines, the phenolic content of old vines differed from that of young vines, but this was only tested in red wines (Zufferey and Maigre, 2007).

Table 13 Quantifiable phenolics of W1 and W11-W19 old-vine Chenin blanc wines measured in mg/L.

Wine code	Gallic acid	Catechin	Epicatechin	EGCG	Caffeic acid	<i>p</i> -coumaric acid	Chlorogenic acid	Total Phenolics
W1	3.38	3.09	4.98	ND	7.35	8.73	34.13	61.67
W11	7.51	8.24	5.28	6.03	14.16	11.73	49.84	102.79
W12	21.26	2.36	5.44	2.79	9.53	4.03	67.04	112.45
W13	6.23	7.57	4.77	3.03	6.97	4.28	47.13	79.99
W14	14.68	4.55	6.01	3.08	6.89	6.31	200.62	242.14
W15	9.17	7.45	6.05	2.77	7.06	4.46	102.48	139.44
W16	13.78	1.63	5.67	7.89	8.22	5.52	87.61	130.31
W17	32.75	3.91	5.03	6.14	13.05	8.33	24.11	93.31
W18	30.07	7.61	5.40	8.50	28.25	17.64	54.13	151.59
W19	11.13	6.91	5.40	7.69	5.77	5.18	35.07	77.16
W20	14.47	BLD*	6.01	3.21	5.63	6.15	199.92	235.39
W21	14.76	20.39	5.46	7.52	27.27	15.29	10.97	101.66
W22	18.18	11.54	5.01	9.34	14.62	15.30	66.81	140.80
W23	15.10	7.08	5.73	7.62	11.20	7.93	168.50	223.17
W24	13.29	20.60	5.69	7.29	9.19	8.88	59.84	124.78

*BD = Below limit of detection

EGCG = Epigallocatechin 3-*O*-gallate

Catechin = (+)-catechin

Epicatechin = (-)-epicatechin

Table 14 Quantifiable phenolics of wine prepared from 30-year old Chenin blanc vineyards inoculated with Vin 13 measured in mg/L.

No of wines	Gallic acid	Catechin	Epicatechin	Caffeic acid	<i>p</i> -Coumaric acid	Ferulic acid	Total Phenolics
1	12.99	11.77	8.83	8.90	6.48	4.78	44.84
2	12.30	12.34	5.46	9.65	5.50	3.86	39.47
3	12.35	17.75	9.03	8.88	6.90	3.34	49.37
4	11.47	16.73	9.04	9.34	7.30	4.20	48.75
5	13.02	11.08	9.84	8.77	7.04	3.24	44.22
6	14.35	10.24	9.44	9.49	7.06	5.16	46.31
7	15.50	12.35	6.89	8.91	6.73	4.92	36.07
8	13.37	14.67	8.57	9.48	6.54	5.33	34.72

4.4. Conclusions

The sensory analysis of the aroma profile displayed the true complexity of the old-vine product category and that it does indeed contribute to the versatility of South African Chenin blanc wines. What was also revealed by this analysis, was the subtlety of the intensities that the array of aroma attributes of these wines are present. This made it difficult for the panel to evaluate the aroma profile of these wines, as there were very few distinguishing characteristics. In order to evaluate the true complexity of the aroma profile of these wines, a temporal dominance of sensations (TDS) analysis could be applied. This is the ideal method for evaluating a sensory space with multiple dimensions (Labbe *et al.*, 2008), like that of the old-vine Chenin blanc wines. In this method, the development of different aromas over time is considered. The most dominant attributes at a certain point in time are selected and their intensity is rated. The wines analysed were all commercial wines and subjected to various different winemaking techniques. Therefore, in order to determine the true aroma profile of old-vine Chenin blanc wines, the wines would all have to be made with the same standard winemaking practices, in order to determine the characteristic aroma attributes of this category. A comparison to younger vine wines is also suggested to aid in understanding exactly how old-vine wines differ from wines made from younger vines.

The evaluation of in-mouth sensations in white wine, proved to be a difficult task, as expected. It required extensive training and even then the panel struggled in the analysis. Despite the difficulty of these concepts, however, the panel could consistently rate subtle differences in these concepts between samples, indicating that the reference standards and, more importantly, written definitions were successful. This study, therefore, provided a framework for the analysis of these sensations in wine, which could in future be used to compare the old-vine Chenin blanc category to Chenin blanc wines made from younger vineyards. This framework could also be used and adapted to the analysis of other white wine varieties and even the in-mouth sensations of red wines. The aim of this study was also to make the framework applicable for use in industry. For future research, it would perhaps be wise to only focus on the in-mouth sensations and not include the analysis of the aroma profile as well. The DA results also showed that within this category the different in-mouth sensations occur at a range of intensities. Therefore, it would be worthwhile to compare the old-vine Chenin blanc category to a different Chenin blanc wine style category to see how they would compare and whether this would also differentiate the old-vine category, apart from its complex aroma sensory space.

As has previously been concluded in literature, certain wine parameters are correlated with in-mouth sensations of white wine, like, for example, with the body of the wine. From the results, it can be concluded that these parameters, including ethanol, pH, dry extract and reducing sugars are also correlated with other in-mouth sensations such as concentration, complexity, integration and balance. Therefore, a wine that has high levels of all of these parameters, would be high in body as well as in all of those in-mouth sensations. This also indicates a correlation between the body of wine and the other measured in-mouth sensations. It is also clear that these wine parameters are negatively correlated to the perceived acidity in wine.

The comparison between the phenolic content of old-vine Chenin blanc wines and Chenin blanc made from 30-year old vineyards showed a difference in the quantifiable phenolics as well as a remarkable difference in the ranges of total phenolics between the two categories Chenin blanc wines. There were, however, too many variables to determine whether this was distinctly caused by the difference in age of the vineyards, but it gives cause for further investigation into the matter due to the importance of phenolic content on the palate of wines. The focus on the importance of phenolics in Chenin blanc has only recently come to realisation. The findings in this study suggest that the difference in the phenolic content of old-vine Chenin blanc and Chenin blanc from younger vineyards could be a key distinguishing factor in the difference in the quality of these wines. This gives cause for much more in-depth research into the phenolic content of these wines.

This study, therefore, showed that old-vine Chenin blanc wines are characteristic in having a subtle, yet complex aroma profile. In contrast to this, the old-vine Chenin blanc wines elicit prominent and

distinguishing in-mouth characteristics, which are perceivable by a trained panel. The study also showed that the physicochemical composition of these wines plays a key role in the in-mouth profile of these wines.

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Chapter 5

**Use of a rapid method, polarised
sensory positioning, to analyse in-
mouth sensations in old-vine
Chenin blanc wines**

Use of a rapid method, polarised sensory positioning, to analyse in-mouth sensations in old-vine Chenin blanc wines

5.1. Introduction

The role of the sensory characterisation of food products has become an integral part of the food industry (Noble *et al.*, 1984; Vannier *et al.*, 1999; Gambaro *et al.*, 2003; Næs *et al.*, 2010; Varela and Ares, 2014). Sensory characterisation allows for the determination of how a product compares to other products within the same competitive market segment, how different processes or time influence the perceived quality of a product (Varela and Gambaro, 2006) or to evaluate the consistency of a product year after year (Lawless and Heymann, 2010; Næs *et al.*, 2010). The first method developed for the sensory characterisation of food products, was Descriptive Analysis (DA) (Lawless and Heymann, 2010; Valentin *et al.*, 2012). Even though this method is believed to be one of the most sensitive methods to use to obtain accurate and discriminative information on the sensory profile of a product (Lawless and Heymann, 2010; Varela and Ares, 2012), it does, however, have its limitations (Varela and Ares, 2014).

Apart from the fact that extensive panel training is required which can become time consuming and costly to ensure reliable results (Valentin *et al.*, 2012; Varela and Ares, 2014), DA only allows for the analysis of a specific sample set. Depending on the difficulty of the analysis, the sample set is often also limited (da Silva *et al.*, 2013; Heymann *et al.*, 2014). For the analysis of the aroma attributes of a complex product such as wine, it is even suggested that the sample set should not exceed six samples (Heymann *et al.*, 2014). In an effort to overcome these restrictions, a lot of research has been dedicated to developing rapid methods which would be able to yield results of similar reliability to that of DA (Varela and Ares, 2014). In reviewing the different novel methods developed thus far for sensory and consumer science, Varela and Ares (2014) pointed out that free sorting and polarised sensory positioning (PSP) were amongst the techniques found to yield similar results to DA in the global evaluation of products (Teillet *et al.*, 2010; Navarro *et al.*, 2011; Valentin *et al.*, 2012), with PSP having the advantage of allowing the analyses of different samples in multiple sessions (Valentin *et al.*, 2012; de Saldamando *et al.*, 2013; Antunez *et al.*, 2015).

PSP was developed by Eric Teillet (SensoStat, Dijon, France) and Pascal Schlich (INRA, Dijon, France) as a method to analyse different samples of water (Teillet *et al.*, 2010; Teillet, 2014). The study focused on the use of classical methodologies such as sensory profiling, Temporal Dominance of Sensations and free sorting task compared to this new method, PSP, which was believed to overcome any limitations associated with the classical methodologies (Teillet *et al.*, 2010). Teillet *et al.* (2010)

concluded that sorting and PSP had even better discriminatory ability than DA, but the free sorting task did not allow for the aggregation of data sets, as is the case with PSP.

PSP is a reference based method where the samples analysed are compared to a selected set of reference samples called 'poles' (Teillet *et al.*, 2010; Valentin *et al.*, 2012; de Saldamando *et al.*, 2013; Ares *et al.*, 2015). Each sample is globally rated in comparison to each pole on a continuous scale based on the sample's similarity or dissimilarity to the pole (Teillet *et al.*, 2010). The selection of the poles is deemed as the most critical part of the methodology (de Saldamando *et al.*, 2013; Ares *et al.*, 2015). Each pole should be a representation of all the different groups present in the sensory space of the set (de Saldamando *et al.*, 2013; Teillet, 2014). Teillet (2014) suggested that three poles are a sufficient number to stabilize a two-dimensional sensory space, but that this number is dependent on the number of groupings present in the sensory space and could increase, depending on the characteristics of the sample set (Ares *et al.*, 2015). The main advantage of using PSP is the fact that, if the reference poles are kept stable, they allow for the analysis of different samples at different times and enable the aggregation of different data sets (Teillet *et al.*, 2010). It is proposed as a good method for analysing a large samples set that has complex sensory attributes which require concentration and might lead to fatigue (Ares *et al.*, 2015). In light of these considerations, PSP would be an ideal method for comparing samples in terms of difficult concepts such as in-mouth sensations. Analysing these types of product descriptors, can be tiring and only allow for the analysis of a small sample set at a time.

PSP has been successfully used in the analyses of products, such as water (Teillet *et al.*, 2010), cosmetics (Navarro *et al.*, 2011), yogurt (Cadena *et al.*, 2014), astringent stimuli (Fleming *et al.*, 2015), orange-flavoured powdered drinks and chocolate milk beverages (Antunez *et al.*, 2015), it has never before been used for the analysis of wine. Furthermore, thus far, the comparison between samples has been holistic. The disadvantage of this approach is that information is lost as to which descriptors are responsible for the individual differences between samples (Valentin *et al.*, 2012; de Saldamando *et al.*, 2013). This information can only be obtained indirectly from the reference poles most similar to the samples (Valentin *et al.*, 2012). Fleming *et al.* (2015) suggested that PSP be combined with a frequency based method like Check-All-That-Apply (CATA) to compensate for this.

The aim of this study was therefore to compare the use of a rapid method, PSP, to a classical method, DA, in the analysis of in-mouth sensations in old-vine Chenin blanc wine over multiple sessions, with an increased sample set and to include a CATA section with the in-mouth sensations body, balance, concentration, complexity and integration in the analysis, to try and directly identify the attributes driving the differences or similarities between samples.

5.2. Materials and Methods

5.2.1. Wines

A total of 15 wines were analysed using PSP (Addendum D). The wines were chosen by the same focus group of experts and experienced tasters that screened the wines for DA. The samples included 9 old-vine wines used for set two of DA and 5 new old-vine samples. The set also included the wine used as a reference sample in DA. A list of the wines evaluated is included in Table 2 in Addendum D. It was decided that the sample set would not be increased further as this number would be sufficient to prove the reliability of the method and allow for the comparison with the DA results.

5.2.2. Polarised Sensory Positioning

The method used was developed by Teillet *et al.* (2010), but it was modified to fit the purpose of this study. The experiment consisted of three sessions: the first was training to familiarise the panel to the new method and the second and third were test sessions. The panel was instructed to concentrate on the following attributes when analysing the wines: body, concentration, complexity, integration and balance.

5.2.2.1. Pole Selection

Pole selection is a crucial part of the PSP methodology and has an important influence on the results. The developers of the method, Eric Teillet and Pascal Schlich suggested that the poles should represent the different domains of the sensory space which are responsible for the main differences in the set (Varela and Ares, 2014). The recommended number of poles is three (Teillet, 2014). This number ensures that the space is stabilized when a two-dimensional sensory space is analysed (Ares *et al.*, 2015). For this study, the pole selection was based on an informed decision based on conclusions drawn during the screening of the wines for DA and the selection of the in-mouth lexicon. Pole A was selected to be low in all the selected in-mouth attributes, pole B as a medium wine and pole C as having a high intensity in all the in-mouth attributes.

5.2.2.2. Panel

The panel consisted of 10 (7 females and 3 males, aged 23-50) expert panellists. All panellists were experienced tasters with knowledge on analysing wine to the required attributes in old-vine Chenin blanc wine. They had, however, never before analysed any product using polarised sensory positioning.

5.2.2.3. Panel training

Training was conducted with a set of seven Chenin blanc wines different from the experimental set, with the aim of training the tasters on the method and not on gaining knowledge of the product. The training set was selected based on the same criteria that the poles were selected for the testing set included 3 poles and 4 samples. One pole (A) was selected to be low in all in-mouth attributes, one (C) high in all attributes and one (B) medium. The accuracy of the poles was not of importance, as the main focus of training was to illustrate the experiment, clarify any uncertainties or confusion and to see whether the panel understood the task. The purpose of training was also to determine how large the sample set could be for each testing session, before fatiguing occurred.

The panel was provided with the same tasting sheet as seen in Addendum H. The panel was instructed to rate the similarity of the samples to each pole individually on a 10 cm unstructured line-scale anchored from 'exactly the same' to 'completely different'. This meant that if a sample and a pole were seen as 'exactly the same' the distance between the sample and the pole would be 0 cm and if they were 'completely different' the distance between them would be 10 cm.

Alteration to classic PSP methodology

The application of PSP has used a holistic approach thus far, only focussing on the global similarities or dissimilarities of products in terms of certain in-mouth characteristics, but none of the experiments allowed for the determination of exactly what the attributes were that were responsible for these differences. In an attempt to obtain more in-depth information from PSP, a CATA approach was used to try and determine which attributes were responsible for the differences between samples. Once the panel had rated the similarity of the sample to a pole on the line-scale, they were asked to mark the attributes on which they had based their ratings (Figure 5.1). If their decision was determined globally by all the attributes, they were required to mark all of them.



Figure 5.1 An example of the CATA section on the PSP tasting sheet in evaluating selected in-mouth sensation attributes in old-vine Chenin blanc wines

5.2.2.4. Wine evaluation

The evaluation of the wines was split into two sessions: in session one the sample set consisted of 8 wines which included pole B and C as blind duplicates and session two consisted of 7 samples where pole A was included as a blind duplicate. The reference poles are included in the sample set, to test the robustness of the method and the accuracy of the panel (Fleming *et al.*, 2015). The experimental

design was generated using Compusense[®] *five* software to create a complete randomised block design with 3-digit coding constructed by Williams latin-square and samples had to be analysed in triplicate. The panel was forced to take a 15-minute break between each replicate to give their palate a chance to rest and prevent fatigue. The results collected with the CATA section, were recorded in a contingency table in *Microsoft Excel 2013* where the attributes were in columns and the poles and samples in rows. The cells indicated which attributes were selected for each sample when comparing it to each pole with either a '1' or a '0'.

5.2.2.5. Statistical Analysis

The analysis was conducted with StatSoft STATISTICA 12[®] (Statsoft Inc., www.statsoft.com). The data analysis was split into two parts: firstly, determining the similarity of the PSP results to the 2016 DA results on the in-mouth sensations and secondly Correspondence Analysis (CA) of the wines to the attributes in terms of each pole. A classical factor analysis, called Multiple Factor Analysis (MFA) was used for the analysis of PSP results, as is proposed by Teillet (2014). MFA is described as a multi-block method (Abdi and Valentin, 2007) which looks for similar configurations between the different blocks and creates a picture of the relationships between them (Tomic *et al.*, 2015). The similarity of the PSP data and DA was compared using RV coefficients. RV coefficients allow for this comparison by aggregating the matrices of the two data sets to create a comparable matrix with which the similarity between the multivariate configurations can be determined (Robert and Escoufier, 1976; Ares *et al.*, 2013; Reinbach *et al.*, 2014). An RV coefficient of 0.5 has been deemed acceptable in the analysis of a complex product such as wine (Louw *et al.*, 2009; Chollet *et al.*, 2011; Dehlholm *et al.*, 2012).

5.3. Results and Discussion

5.3.1. Comparison of DA and PSP results

The MFA constructed with the PSP data was used to display the relationship between the samples and is shown in Figure 5.3. This was compared to the configuration of a PCA (Figure 5.2) constructed with the DA results of set two on the in-mouth sensations analysed. This approach was used in order to have to comparable matrices that could visually be inspected to evaluate the similarity of the results from the two methods. Table 15 contains the wines that correspond to the selected poles and that were included as the blind duplicates of the poles in PSP. The colours on both Figure 5.2 and Figure 5.3 correspond to these wines. W10 was selected as pole A, W12 pole B and W15 pole C for PSP. From the PCA plot and MFA, the configurations appear similar. If Figure 5.3 is considered, W15 was high in all of the selected in-mouth sensations, as was intended for pole C. W1 was perceived as the lowest

in all sensations, as it was in the DA results (Figure 5.2) and W12 was perceived as being in-between W15 and W1. The fact that the wines used as poles were perceived similar to how they were described in DA and had the same configuration as intended with the poles, can be seen as a validation of the poles and of applying PSP to wine.

Table 15 The wines analysed with descriptive analysis (DA) that were selected as the reference poles for polarised sensory positioning (PSP) and that were included as blind duplicates in PSP.

Pole	Corresponding blind duplicates of poles	Colour in Figure 5.2 and Figure 5.3	Intensity of selected in-mouth sensations
Pole A	W1	green	low
Pole B	W12	blue	medium
Pole C	W15	grey	high

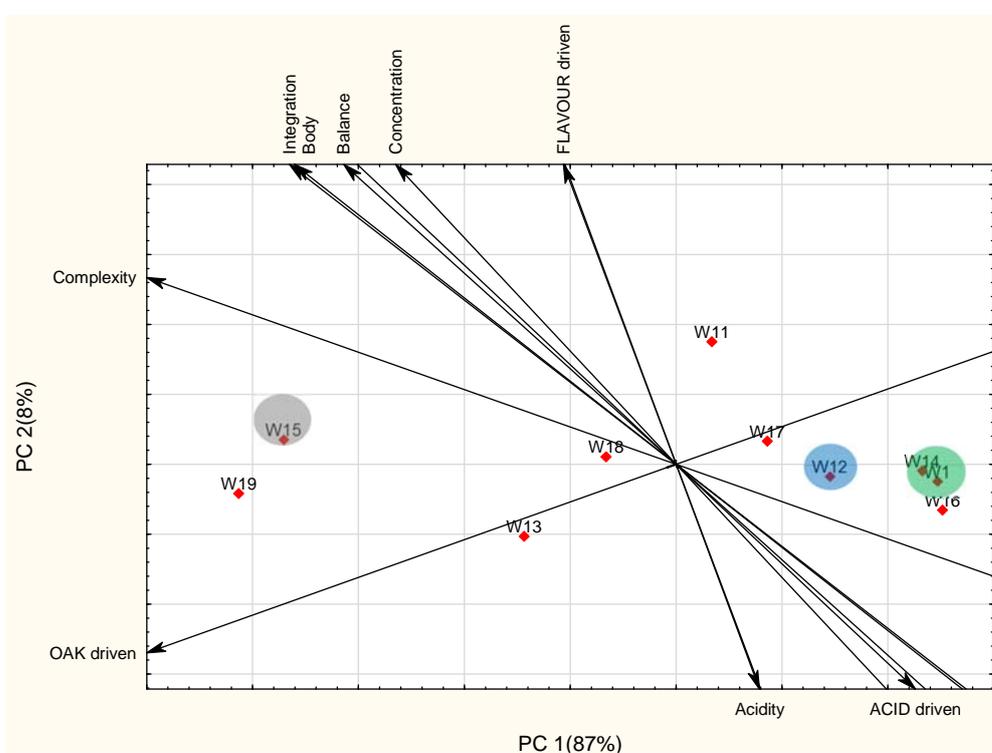


Figure 5.2 PCA plot of the in-mouth sensations analysed in set two of the old-vine Chenin blanc wines of descriptive analysis (DA). The set included W11-W15 and W1 was the blind duplicate of the reference wine used for DA. The wines selected as poles for PSP were W15, W12 and W1, coloured grey, blue and green.

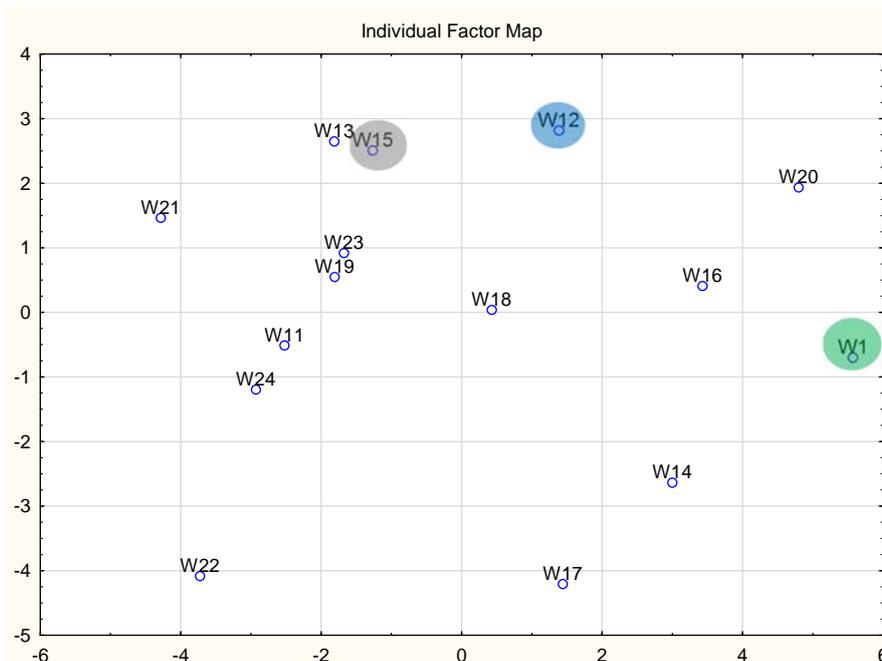


Figure 5.3 Multiple Factor Analysis plot of the Chenin blanc wines analysed with polarised sensory positioning (PSP). The wines analysed included W1 and W11 – W19 used for Descriptive Analysis (DA) and W20 -W24 were new samples included only in PSP. The blind duplicate of the wines selected as reference poles were W15, W12 and W1, coloured grey, blue and green.

From the MFA it is clear, however, that W20, W16 and W14 were most similar to pole A (W1) and W18 and W17 are similar to W12. The configuration of the PSP plot (Figure 5.3) is therefore similar to that of the DA plot (Figure 5.2). It is evident, however, that W21, W24 and W22 caused the configuration of the PSP results to shift. These wines were clearly even higher in all analysed attributes than pole C. The only notable difference between Figure 5.2 and Figure 5.3 is that W11 was more similar to the wines with high in-mouth sensations (W21, W24 and W22) in the PSP analysis than it was in DA. In both analysis methods, however, W11 is not correlated with pole A. It seems as though the length of W11, which was driven by flavour, was its most powerful in-mouth sensation when analysed in DA, but when this sensation was not considered in the PSP analysis, the influence of the other in-mouth sensations on W11 became more prominent.

The wine available for evaluation with PSP was limited, therefore the experiment was only repeated once. To compare the similarity between the matrices obtained with the DA results and the PSP results, however, the RV coefficient can be calculated (Valentin *et al.*, 2012). The RV coefficient obtained in this experiment was 0.56. A configuration close to 1 shows good consensus between two matrices, but an RV of >0.5 is considered sufficient in the analysis of a complex product such as wine. The results therefore confirmed that PSP did yield similar results to DA.

Correspondence Analysis (CA) was done on the CATA data. The matrices of the CA plot and the DA results (Figure 5.3) were compared, but the RV coefficient was very low at a value of 0.2. This indicated that there was little similarity between the configurations of the two methods. The addition of the CATA list slightly complicated the PSP method and post analysis interviews with the panellists revealed that there was confusion in how to use the CATA section. During their analysis, panellists misunderstood the instructions and used the CATA list differently. The CATA list adds complexity to the data analysis as each pole has its own CATA list, therefore, for each sample there are different drivers for the similarity and dissimilarity to each pole creating a very complicated matrix.

5.4. Conclusions

PSP proved to yield a similar configuration to DA when globally comparing samples to the selected poles. This was further validated by an RV coefficient higher than 0.5. The CATA section of the experiment was, however misunderstood. The attributes responsible for the differences between samples, therefore, could only be derived indirectly from the poles. In future, training on the CATA section should be optimised by focussing mainly on how to indicate the drivers for similarities or dissimilarities between samples and poles. A simpler data matrix could also be achieved by reducing the CATA list to even fewer attributes. The results showed that if the poles are kept stable, different samples could be analysed in different sessions and in future, the sample set could be increased to even more than 15 samples. For the analysis of in-mouth attributes in wine, however, the sample set should not exceed more than 8 samples per session, to prevent the panel from becoming fatigued. Even though the attributes responsible for the difference between samples could not be determined with the inclusion of a CATA list, PSP is still a suitable method to give an overview of the main groupings within a sample set and the differences can be derived indirectly from the selected poles.

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Chapter 6

General discussion and conclusions

General discussion and conclusions

6.1. General discussion, conclusion and recommendations

Historically, Chenin blanc was one of the first varietals planted in South Africa and, is not only the most abundantly planted cultivar in the country, but has also recently acclaimed international status. The Kleine Zalze Family Reserve Chenin blanc was, for instance, voted the best white wine amongst 320 competitors in 2015 at the international wine competition, Concours Mondial de Bruxelles, in Italy (Henderson, 2015). This Chenin blanc was made from ‘old-vines’, aged 40-years. The term ‘old-vine’ is said to be a relatively new concept in South Africa according to Fridjhon (2016a). In popular press, old-vines are described as low-yielding vines (4 tons per hectare), with small berries and the wines produced from their grapes are believed to be of a certain quality. Research on these vines and their wines is, however, limited. The exact age of an old-vine is also undefined, but from what has been reported in the media on the term ‘old-vine’, it can be assumed that a vine that is aged 40-years and older, would be defined as ‘old’.

This study focused on the sensory characterisation of a selected set of old-vine (≥ 40 -years) Chenin blanc wine, using traditional descriptive analysis (DA). Although the sensory and chemical profile of Chenin blanc wines in South Africa have been extensively researched, previous research mainly focused on the aroma compounds to showcase the versatility of this grape cultivar. Aroma, however, is only one of the factors associated with wine quality. An important factor reported to be the new focus in producing quality wines, is how the wine is perceived on the palate (Fridjhon, 2016b). One of the main objectives was, therefore, to analyse the sensory profile of a representative set of old-vine Chenin blanc wines in terms of aroma as well as pre-selected palate concepts, that were referred to as in-mouth sensations, and also determine what could characterise these wines as a product style category.

In the analysis of the aroma profile, the old-vine Chenin blanc wines did not cluster into distinct groups, as had been found in previous research on Chenin blanc wines. The results revealed that the old-vine Chenin blanc wines had a complex array of aromas that were present at subtle intensities. The set of wines also included aroma attributes that had previously been excluded from the original Chenin blanc aroma wheel, including, quince jelly, marmalade, white pepper, sweet spice, biscuit, caramel, gooseberry, muscat/litchi, chamomile and orange zest. This suggests that the old-vine Chenin blanc wines could have a different sensory profile compared to that of other categories of Chenin blanc wines. Although the same aromas found in other categories of Chenin blanc wines, were also present in this set, the prominence of these attributes in old-vine Chenin blanc wines seemed to be less.

Chemical analysis on the volatile compounds of the old-vine Chenin blanc wines could provide further insight into the complexity of this set's aroma profile. Comparing the chemical composition of the old-vine grapes to that of grapes from younger vineyards or prior Chenin blanc research, would also be advised. If differences are found, it could provide valuable insight to the beliefs behind the quality of old-vine grapes. The theory behind the research of Prof Burger at Stellenbosch University on the genetics of old-vines is that the old-vines have a different gene expression compared to that of younger vineyards (Heyns, 2013), which would suggest that the chemical composition of the grapes could differ.

The DA panel could be trained successfully to analyse the selected in-mouth sensations, even though some of these terms had previously been described as too vague (Varela and Ares, 2014), to analyse with DA. The panel were trained using a three-step process as a framework. The framework comprised of firstly, providing the panel with reference standards and a compilation of written definitions for the in-mouth concepts. For step two, the panel were provided with a reference wine to aid in understanding how the in-mouth sensations are perceived in wine. Step three consisted of evaluating the performance of the panel during training with PanelCheck software (Version 4.1.0, Nofima Mat, Norway) to determine which attributes required more attention before testing. The selected old-vine Chenin blanc wines displayed different intensities of the various in-mouth sensations. It is suggested that the framework is used to train a panel to evaluate the in-mouth sensations of Chenin blanc wines made from younger vines. It was already evident from the two younger vine wines included in the set (W1 and W5) that there was a difference in in-mouth sensations between these wines and the old-vine Chenin blanc wines. The analysis of the length of the wines, however, proved to be a difficult task and it is recommended that perhaps this in-mouth sensation should be the sole focus of a study, as it is complex and requires a lot of concentration from panellists. It is also suggested that the length be analysed as a factor of time by using either time intensity (T-I) or temporal dominance of sensations (TDS).

The physicochemical parameters that showed the strongest correlation with the in-mouth sensation body, included dry extract, reducing sugars and ethanol, this is accordance with what had been found in literature by (Gawel *et al.*, 2007; Yanniotis *et al.*, 2007; Runnebaum *et al.*, 2011; Neto *et al.*, 2014). Dry extract and reducing sugars were strongly correlated to concentration and complexity, balance and integration while ethanol was correlated mainly with concentration and complexity. These results show that certain physicochemical constituents have an impact on in-mouth sensations associated with the intrinsic quality of wine. Organic acids and volatile acidity, however, were not strongly correlated with any of the in-mouth sensations.

Another important chemical compound to consider is the phenolic composition of the wines. There were distinctive differences between the old-vine Chenin blanc wines and the Chenin blanc wines made from 30-year old vineyards. Research, however, has shown that winemaking practices could have a large influence on the phenolic content of wines. Therefore, to ultimately determine the difference between the phenolics of wine made from old-vines and wine made from young-vines, all other viticultural and winemaking variables would have to be eliminated.

Overall the sensory space of the wines investigated suggested that the old-vine wines have a complex aroma profile, with many attributes present at low concentrations and the difference between samples are subtle. The in-mouth sensations in these wines were, however, more prominent. The data collected in this study would, however, not be sufficient to prove that the old-vine Chenin blanc wines are a product style category with distinct characteristics. The results, however, did show that the wines included that were not of the age category (W1 and W5) had different in-mouth profiles compared to the old-vine wines. To, therefore, be able to draw definitive conclusions on what characterises old-vine Chenin blanc wines as a product style category, it is suggested that the in-mouth profile, as well as the volatile and non-volatile composition of these wines, be compared to Chenin blanc wines that do not meet the age criteria. In-depth chemical analyses on the old-vine grapes and wines could reveal invaluable information about their character. Furthermore, the large Platter's Wine Guide data base could also make an important and vital contribution to identifying the characteristics of old-vine Chenin blanc wines.

The total of 19 wines that could be analysed with DA, had to be split into two sets, one with 9 wines and one with 10 wines, to prevent the panel from becoming fatigued. Polarised Sensory Positioning (PSP), is a referenced based rapid method that allows for the analysis of different sample sets of which the data could be aggregated if the reference samples, referred to as poles, are kept stable. This was the first application of PSP to wine and the results yielded similar configurations to the DA results of set two in the analysis of in-mouth sensations, with an RV coefficient of 0.56. The method allowed for the analysis of 15 samples in total over a period of two days, compared to a maximum of 10 samples that could be analysed with DA. A CATA list was added to the PSP method to increase the sensitivity of the method. The use of the CATA list was, however, not completely understood by the panel and it is recommended that a shorter list be used in future applications. Although no training session were included when PSP was used for the analysis of other products, one training session proved to be useful to eliminate any unclarities amongst the panel and it is especially recommended for the inclusion of a CATA list. Although the method requires further reviewing as a method for wine sensory analysis, it could be used as an alternative to DA in research. This method could also prove valuable to industry where it could, for example, be used in benchmarking.

As there is a lack of information and research on old-vines, especially in South Africa, the qualitative data discussed on the old-vine Chenin blanc wines in Chapter 3, provided much-needed context on how these vineyards are managed and how the wines were produced. This information also identified that there are many factors that have not been addressed in research on these vines that could offer insight into the beliefs about old-vines in popular press.

This research provided a framework that could be used in future research on in-mouth sensations in Chenin blanc and potentially any wine style category. As a contribution to the sensory science community as well as industry, this research proved that PSP could successfully be applied to wine, eliminating the constraint of analysing limited sample sets. This research on some of the oldest vineyards of South Africa's most widely planted varietal, also increases awareness of these old-vines and could contribute to their preservation. The value of these old vineyards can only truly be proven by in-depth research.

6.2. References

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Addendums

Addendum A

List of aroma attributes, definitions and standards

Table 1 List of aroma attributes selected for set one and set two with the definitions for each term and the reference standard used

Family/Sub-family	Attribute	Product used	Quantity	set one	set two	
Citrus	Lemon	Fresh lemon	1/4 slice Lemon	x	x	
	Grapefruit	Fresh grapefruit	1/4 slice Grapefruit	x	x	
			3 slices orange peel	x		
White/Yellow fruit	Orange Zest	Fresh orange Peel				
	Peach	Fresh peach	1/4 slice peach	x	x	
	Pear	Fresh pear	1/4 slice pear		x	
	Green Apple	Fresh green apple	1 cm wedge fresh green apple	x		
			Koo sliced unsweetened apples			
	Canned Apple		1/4 slice canned apple		x	
	Yellow Apple	Fresh yellow apple	1 cm wedge fresh yellow apple	x		
			Fresh Apple	1 cm wedge fresh red apple		x
Bruised/Oxidised Apple	Oxidised yellow apple	1/4 slice oxidised apple	x			
Tropical	Guava	Fresh guava	2x3 cm piece fresh (ripe) guava		x	
			2x3 cm piece green (unripe) guava	x		
	Green Guava	Green guava				
	Gooseberry	Fresh gooseberries	2 halved gooseberries	x	x	
			1/4 slice of pineapple	x	x	
	Pineapple	Fresh pineapple				
Banana	Fresh banana	1 cm thick slice of fresh (ripe) banana			x	
Sweet Associated	Honey	Spar Choice Grade Honey		x	x	
	Caramel			x	x	
	Vanilla	Vanilla Man vanilla seeds	1 tsp	x		
	Quince Jelly	Ann's Kitchen quince jelly			x	x
			Goedvertrou lime marmalade jelly	1 tsp	x	x
	Stewed Fruit	Safari mixed dried fruit		Safari dried fruit salad - cooked with 5 mL water for 30s on high in microwave	x	

Table 1 (cont.)

Family/Sub-family	Attribute	Product used	Quantity	set one	set two
Dried Fruit	Raisins	Safari raisins	5 raisins chopped	x	x
	Dates	Safari dates	2 chopped dates	x	
	Dried Peach/Apricot	Safari dried peaches; Safari dried apricots	1 dried peach and 1 dried apricot chopped	x	
Floral	Orange Blossom		2 drops orange blossom flavour on cotton	x	
		Chamomile	Twinnings pure chamomile tea	Chamomile teabag in boiling water	x
	Muscat/Litchy		2 drops muscat flavour on cotton		x
Fresh	Fresh Green Beans	Fresh green beans	2 green beans chopped	x	
	Fresh Green/Herbaceous	Fresh green grass	Handful of fresh grass		x
Dried	Hay/Straw	Straw	Handful of straw	x	x
Spicy	Dried Herbs	Robertson dried thyme; Robertson dried oregano	tsp dried thyme and dried oregano	x	
	Thyme	Robertson dried thyme	tsp dried thyme	x	
	White Pepper	Robertson white pepper	1 tsp white pepper		x
	Sweet Spice	Robertson cinnamon; Robertson cloves	1 tsp cinnamon and 1 tsp	x	x
Other	Mineral/Flinty	Wet granite	1 slab	x	
	Coconut	IMBO fine desiccated coconut	1 tsp coconut	x	
	Sherry	Old Brown	20 mL Old Brown sherry	x	
	Smoky	Lion matches	1 stroke match		
	Toasted	Toasted Oak		Medium toasted french oak chips	x
	Biscuit	Bakers original tennis biscuits	1 cm biscuit	x	
	Butter	Blossom 50% fat spread (lite)	1 tsp spread	x	
	Biscuit/Butter	Bakers original tennis biscuits; Blossom 50% fat spread (lite)	1 cm biscuit; 1 tsp spread		x

Addendum B

Sample selection procedure for set one and two

To ensure a representative sample set, 26 wine samples were sourced for screening by consulting the Chenin Blanc Association (CBA) on wines that were from the specified vine age category and which, to their expert knowledge, would be a true expression of the old-vine Chenin blanc category. The screening of the samples took place in what was referred to as two Master Classes, which consisted of a member from the CBA, (Ina Smith – chair of the CBA), an expert on the wine style category, Cathy van Zyl and six experienced panellists. Cathy van Zyl is currently the Masters of Wine education committee chair and has been a wine judge both locally and internationally. She is also an editor for Platter's South African Wine Guide and has extensive knowledge of the characteristic sensory attributes associated with different wine style categories. In the first Master Class, held in March 2015, 11 samples were screened and 9 samples were selected to be analysed in set one. Wines that were described as being 'overly wooded' or 'faulty' in the screening, were discarded from the sample set one. The Master Class was repeated in February 2016 with the same panel where 15 samples were screened, but only 10 were selected for Descriptive Analysis for set two. Although a number of 15 to 20 samples per analysis is acceptable for Descriptive Analysis, literature states that depending on the difficulty of the attributes analysed and the likeliness of the onset of fatigue, the sample set should be less (Heymann *et al.*, 2014). That is the only reason the sample set was reduced to 10 wines for set two.

Addendum C

Monitoring panel performance with Tucker-1 correlation plots using PanleCheck software.

Tucker-1 correlation plots were used to assess panel agreement during training and testing.

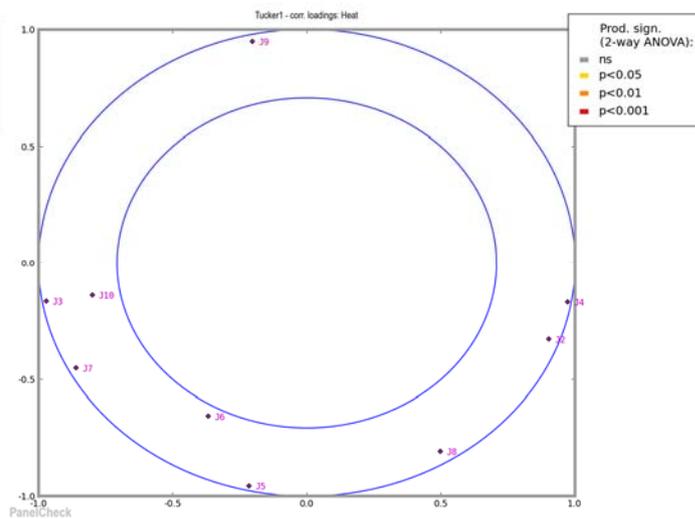
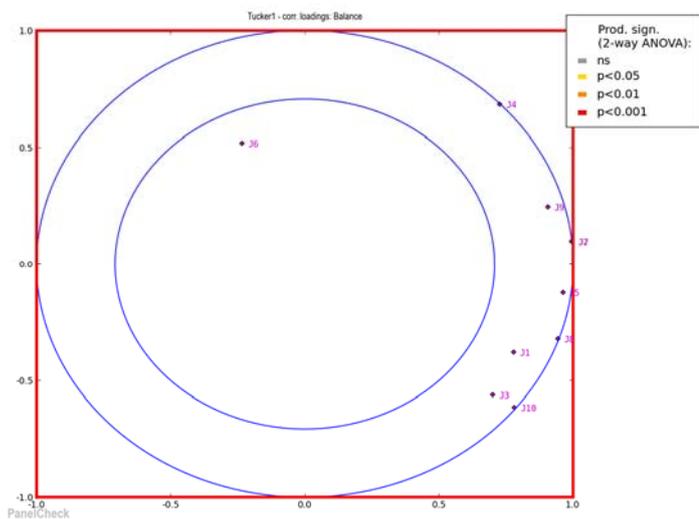


Figure 1. Tucker-1 plot for the correlation between panellists in set one for the in-mouth sensation balance ($p < 0.001$).

Figure 2. Tucker-1 plot for the correlation between panellists in set one for the in-mouth sensation heat ($p > 0.05$).

Addendum D

List of wines for set one and set two

Table 1 Wines used in set one for descriptive analysis (DA) with the age of each vineyard, vintage of the wine and the region where the vineyards are located

Winery	Wines	Age of vineyard	Vintage	Region
De Morgenzon	Chenin blanc	≥40	2012	Stellenbosch
Raats Family Wines	Original	30	2013	Stellenbosch
Raats Family Wines	Old Vine	≥40	2013	Stellenbosch
Zonquasdrift	Chenin blanc	≥40	2013	Swartland
Bellingham Wines	The Bernard Series	≥40	2012	Coastal
Botanica Wines	Mary Delany	≥40	2013	Citrusdal
Bosman Family Vineyards	Optenhorst	≥40	2012	Wellington
Rudera Wines	De Tradisie	≥40	2011	Stellenbosch
Riebeek Cellars	Chenin blanc	<30	2014	Swartland

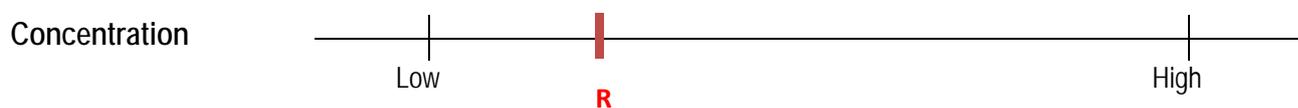
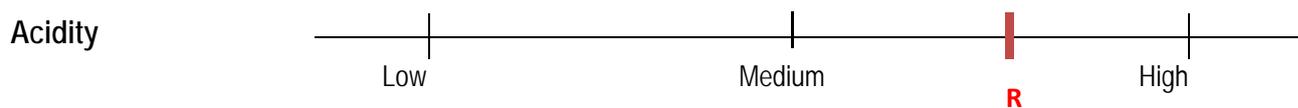
Table 2 Wines used in set two for descriptive analysis (DA) and polarised sensory positioning (PSP) with the age of the vineyards, the vintage of each wine and region where each vineyard is located

Winery	Wines	Age of vineyard	Method	Vintage	Region
Anthonij Rupert Wines	Van Lill & Visser	≥40	DA & PSP	2014	Citrusdal
Babylon's Peak	Chenin blanc	≥40	DA & PSP	2014	Swartland
Delaire Graff	Chenin blanc	≥40	DA & PSP	2014	Swartland
	Family Reserve Range	≥40	DA & PSP		
Kleine Zalze Wines	Chenin blanc			2014	Stellenbosch
Mooiplaas Wine Estate	Bush Vine	≥40	DA & PSP	2015	Stellenbosch
Sadie Family Wines	Skurfberg	≥40	DA & PSP	2014	Citrusdal
Beaumont Family Wines	Hope Marguerite	≥40	DA & PSP	2014	Bot river
Mount Abora	Koggelbos	≥40	DA & PSP	2014	Swartland
Riebeek Cellars	Chenin blanc	<30	DA & PSP	2014	Swartland
Zonquasdrift	Chenin blanc	≥40	DA & PSP	2013	Swartland
Morgenhof Estate	Chenin blanc	≥40	PSP	2014	Stellenbosch
Graham Beck	Bowed Head	≥40	PSP	2014	Paarl
Mooiplaas Wine Estate	Houmoed	≥40	PSP	2013	Stellenbosch
Babylon's Peak	Chenin blanc	≥40	PSP	2014	Swartland
Stellenrust Wines	Barrel Fermented Chenin blanc	≥40	PSP	2014	Stellenbosch

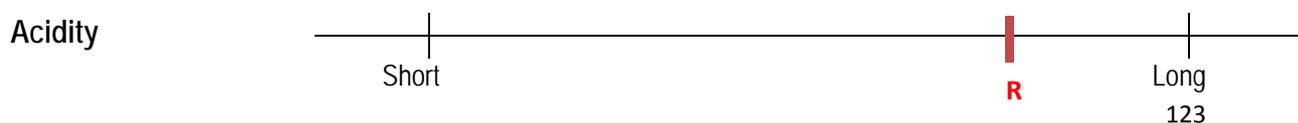
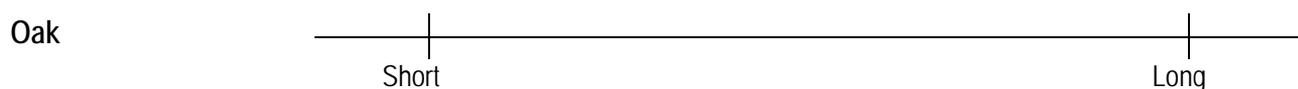
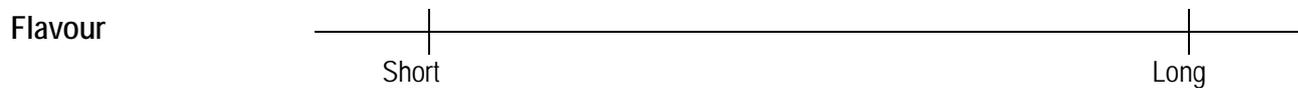
Addendum E

Tasting sheets with reference wine values

Taste



LENGTH / AFTER TASTE



Addendum F

List of quantifiable and unquantifiable phenolics in old-vine Chenin blanc wine and explanation of Chenin blanc wines made from Vin13

Table 1 List of quantifiable and unquantifiable phenolics for old-vine Chenin blanc wines in 2016

QUANTIFIABLE	UNQUANTIFIABLE
Gallic acid	Quercetin
Catechin	Rutin
Epicatechin	Isoquercetin
EGCG - Epigallocatechin 3-O-gallate	Keampferol
Caffeic acid	Isorhamnetin
p-Coumaric	Ferulic acid
Chlorogenic acid	Protocatechuic acid
	Sinapic acid

Chenin blanc wines made from Vin13

The vineyards were planted in 1986 at Nietvoorbij experimental farm in Stellenbosch. The vineyards are trellised and their rootstock is Richter 99. The vineyards are also irrigated.

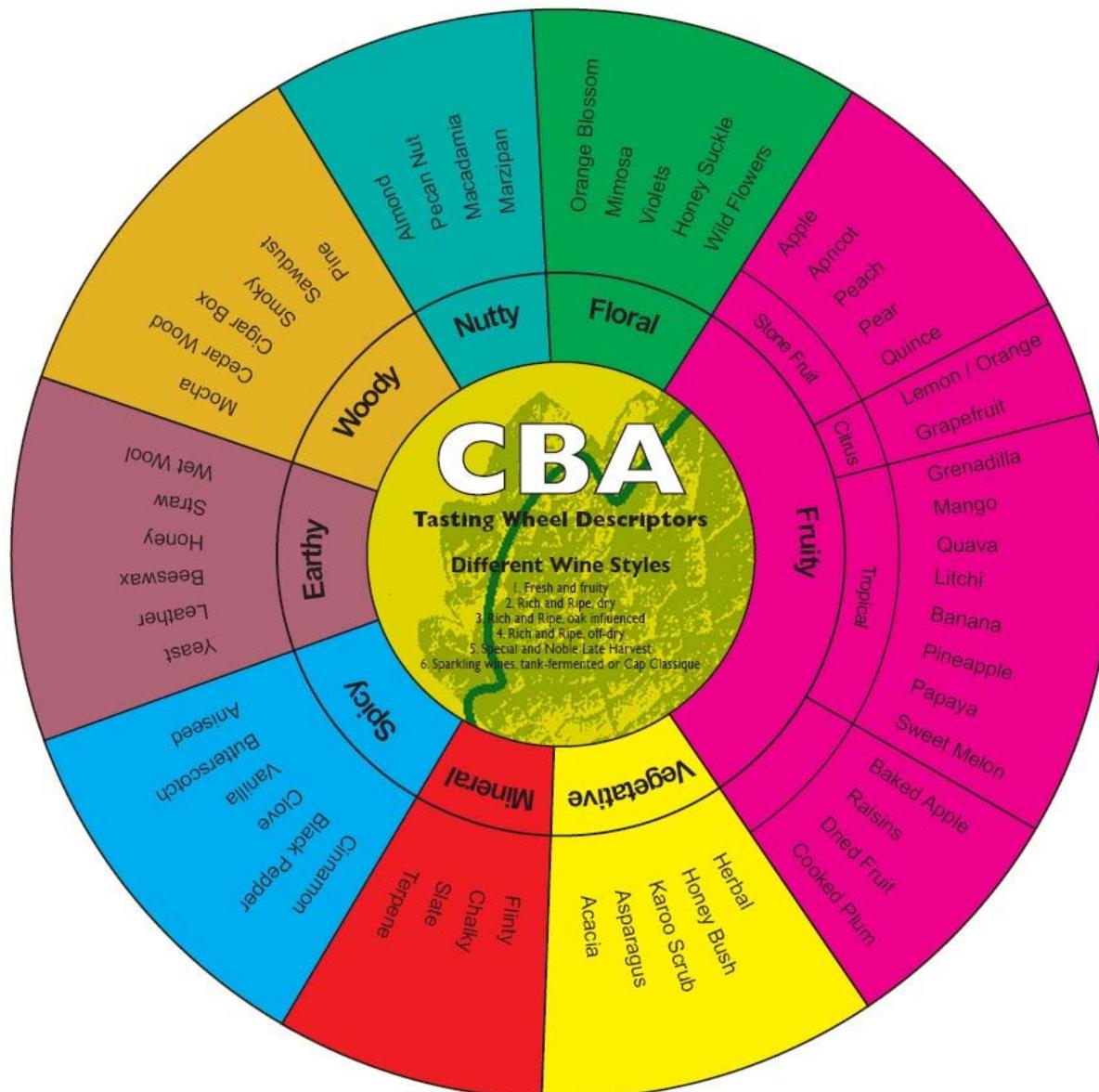
Winemaking procedure

Chenin blanc wines were made according to the ARC Infruitec-Nietvoorbij approved winemaking protocol at the Nietvoorbij experimental cellar. Di-ammonium hydrogen phosphate (0.50 g/L) and SO₂ (50 mg/L) were added to the inoculated Chenin blanc grape must. The clarified grape must aliquots (18 L) were placed in 20 L stainless steel containers fitted with fermentation caps. Fermentations, with Vin 13*, were conducted at *ca.* 15°C and monitored by CO₂ weight loss. The fermentations were allowed to continue until the residual sugar was less than 2 g/L. If the fermentation was not completed within 32 days, the yeast lees was racked off and the free SO₂ was adjusted to 35 mg/L. Residual sugar analyses were done on all wines to confirm the end of the fermentation. The wines were filtered and transferred to bottles according to standard practices for white wine production. The wines were stored at 14°C after bottling.

*Vin 13 is patented by Anchor Wine Yeast (<http://www.oenobrand.com/en/our-brands/anchor/new-world-wine-yeasts/product-data-sheets/vin-13>). This yeast is a hybridization of two different *Saccharomyces cerevisiae* subspecies and is used for Chenin blanc to produce fruity and floral aromas.

Addendum G

Chenin blanc Aroma Wheel as developed by the Chenin Blanc Association



Addendum H

Polarised sensory positioning tasting sheet

Judge no. _____

Rep _____

Date _____

Compare this sample with the 3 references labelled A, B and C. Indicate on the line scale how similar they are to each reference from 'Exactly the same' to 'Completely different'. Evaluate the sample only from a **taste and mouth feel perspective** concentrating on the following attributes: **body, concentration, complexity, integration and balance**. Once you have marked the line scale, tick the respective attributes boxes which mainly influenced your decision.

Wine Code



- Body
- Concentration
- Complexity
- Integration
- Balance



- Body
- Concentration
- Complexity
- Integration
- Balance



- Body
- Concentration
- Complexity
- Integration
- Balance

Addendum I

Questionnaire as sent electronically to all wineries

Practices used for Chenin blanc wine made from old vineyards

Please note: The aim of this questionnaire is to get a general idea of the viticultural practices used in old vineyards as well as the specific winemaking techniques used to preserve the character of the grapes. The information will not be linked to any of the individual wines or vineyards.

Oenology:

1. **Harvesting**
 - a. **Balling:**
 - b. **pH:**
 - c. **TA:**
 - d. **Any specific techniques used for the Old-Vines?**
2. **What yeast is used for Fermentation or is natural fermentation used?**
3. **Fermentation temperature?**
4. **Wooded:**
 - a. **For what period are the wines oaked?**
 - b. **% New oak:**
 - c. **Any other % oak used (second/third fill barrel)?**
5. **Do you make use of:**
 - a. **Filtration? Yes/No**
 - b. **Maturation? Yes/No**
 - i. **If yes, how long?**
 - c. **Bottle ageing?**
 - i. **If yes, how long?**
6. **Lees ageing – if yes: how long and why?**
7. **Do you allow any malolactic fermentation? Yes/No**
8. **Do you do any fining on the wine? Yes/No**
9. **Do you make any effort to alter the absorbed CO₂ levels in the wine? Yes/No**
 - a. **If so, how and why?**

Viticulture:

1. **On what rootstock are the vines grafted?**
2. **Is it a clone & does it still express the intended clone?**

3. **Planting density – between vines & rows**
4. **Pruning method**
5. **Canopy Management**
6. **Fertilisation**
7. **What type of soil are the vines grown in?**

General:

1. **Do you specifically treat the vines differently and use different techniques to make wine from these old vines? Why?**
2. **Do you think Old-Vines produce better wine? Why?**

Thank you so much for you time and effort

