The use of different oak products during the fermentation and ageing of Chenin Blanc: sensory properties, perceived quality, and consumer preference

by

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Declaration

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Summary

Wooden barrels have been the preferred method for oak maturation for wines, but the use of alternative oak products have increased options of oak maturation for winemakers, since new barrels are expensive and have a limited lifetime. The main aim of this study was to investigate the effect of different oak products used during fermentation and ageing on the sensory profile, degree of liking and perceived quality of Chenin blanc wine. The different wine treatments included an unoaked tank control wine, wines matured in 5th fill barrels, wines matured in new barrels from three different cooperages, and wines matured in 5th fill barrels with stave inserts from two different cooperages. All of the treatments, except for the unoaked tank control, were performed in triplicate, rendering a total of 19 experimental wines.

Sensory descriptive data were obtained with Pick-*K* attributes, using a trained and expert panel at three different intervals of wine maturation. These intervals included 4 months oak maturation, 9 months oak maturation, and 9 months oak maturation with an additional 6 months bottle ageing. At the third maturation interval, an untargeted consumer study was also conducted using CATA questions to obtain descriptive and hedonic data. At this interval the perceived quality of the wines were also investigated using an expert panel. The expert panel received no formal training prior to any of the testing intervals. The trained panel were trained to recognise aromas from a list of 89 descriptors used by sensory scientists and industry experts to describe Chenin blanc wines. The results obtained from the different panels at the different ageing intervals were compared.

The biological repeatability of the different treatments were satisfactory from a cooperage point of view. There were clear differences between the sensory profiles of the different wine treatments. Differences between the oak products from the different cooperages used within treatments were less pronounced. There were significant differences in the degree of liking and perceived quality of the different products, but the degree of liking and perceived quality for different products were comparable. The degree of liking and perceived quality of the 5th fill barrels and new barrels were higher than the degree of liking and perceived quality of the stave treatments. The mean degree of liking for the 5th fill barrels and new barrels were higher than for the stave treatments. There were no significant difference between the degree of liking for the unoaked tank wine and the oaked treatments.

The sensory descriptive data obtained from the trained, expert and consumer panel were comparable in terms of panel consensus and configurational congruence. This validates the suitability of CATA and its variant, Pick-*K* attributes, as rapid methods to elicit qualitative information for the sensory profiling of wine.

The results from this research made significant contributions towards method validation for CATA as rapid sensory method, and the descriptive and hedonic sensory results from this research can be used by winemakers to both inform and justify the usage of specific oak products.

Opsomming

Houtvate word uit ‘n tradisionele oogpunt verkies vir wynveroudering, maar die gebruik van alternatiewe houtprodukte het meer opsies vir wynmakers beskikbaar gestel, aangesien nuwe vate duur is en oor ‘n beperkte leeftyd beskik. Die doel van hierdie studie was om die invloed van verskillende hout produkte op die sensoriese profiel, mate van goedkeuring en kwaliteitspersepsie van Chenin blanc wyne wat in kontak daarmee gefermenteer en verouder is te ondersoek. Die verskillende wynbehandelings het bestaan uit ‘n ongehoute tenkwyn, wyne verouder in vyfde vul vate, wyne verouder in nuwe vate van drie verskillende kuipers, en wyne verouder in vyfde vul vate met stawe van twee verskillende kuipers. Behalwe vir die tenkwyn, was al die behandelings in triplikaat uitgevoer, en in totaal was daar 19 eksperimentele wyne.

Beskrywende sensoriese data is verkry deur die “Pick-K attributes” metode met die gebruik van ‘n deskundige- en opgeleide paneel by drie verskillende intervalle van veroudering. Hierdie intervalle sluit in 4 maande houtveroudering, 9 maande houtveroudering, en 9 maande houtveroudering met ‘n bykomende 6 maande bottelveroudering. Tydens die derde verouderingsinterval is ‘n ongeteikende verbruikerstudie ook uitgevoer deur gebruik te maak van die CATA metode om beskrywende en hedoniese data te verkry. Die kwaliteit van die wyne is ook tydens hierdie interval ondersoek deur ‘n deskundige paneel. Die opgeleide paneel was opgelei om Chenin blanc spesifieke aromas te herken vanaf ‘n lys van 89 beskrywers wat saamgestel is deur industrie deskundiges en sensoriese wetenskaplikes. Die resultate wat verkry is van die verskillende panele by die verskillende verouderingsintervalle is vergelyk.

Die biologiese herhaalbaarheid van die verskillende behandelings was bevredigend vanaf ‘n kuiper perspektief. Daar was duidelike verskille tussen die sensoriese profiele van die verskillende wynbehandelings. Verskille tussen die houtprodukte van die kuipers wat binne spesifieke behandelings gebruik is was minder duidelik. Daar was beduidende verskille in die mate van goedkeuring en kwaliteitspersepsie van die verskillende produkte, maar die tendens van kwaliteitspersepsie en mate van goedkeuring was soortgelyk. Die mate van goedkeuring en kwaliteitspepsie van die vyfde vul vate en die nuwe vate was hoër as dié van die vyfde vul vate met die stawe. Daar was geen beduidende verskil in die mate van goedkeuring en kwaliteitspersepsie tussen die ongehoute tenkwyn en die gehoute behandelings nie.

Die beskrywende sensoriese data wat verkry is van die opgeleide-, deskundige- en verbruikerspaneel was vergelykbaar in terme van paneelkonsensus en konfigurasionele kongruensie.

Dit bekragtig die geskiktheid van CATA en sy variant "Pick-K attributes" as vinnige metodes om kwalitatiewe inligting vir sensoriese profilering te verkry.

Die resultate van hierdie navorsing het ‘n groot bydrae gelewer om CATA as vinnige sensoriese metode te valideer. Verdermeer kan die beskrywende en hedoniese resultate wynmakers bemagtig om ingeligte en geregverdigde keuses te neem rakende die gebruik van spesifieke houtprodukte.

This thesis is dedicated to my loving cats who purred every step of the way.
Also to my family and friends- I guess they weren't that bad.

Biographical sketch

Anri Botha was born in Ceres, South Africa on 28 July 1991. She attended Hendrik Louw Primary School and matriculated at Strand High School in 2009. Anri obtained her BScAgric degree in Viticulture and Oenology in 2013 at Stellenbosch University. In 2014, Anri enrolled for an MScAgric in Oenology at the Department of Viticulture and Oenology, Stellenbosch University.

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Preface

This thesis is presented as a compilation of six chapters as indicated below.

Chapter 1 **General Introduction and project aims**

Chapter 2 **Literature review**

Chapter 3 **Research results**
The effect of different oak products used during fermentation and ageing on the sensory properties of Chenin blanc wine.

Chapter 4 **Research results**
The influence of different oak products on the sensory properties, perceived quality and consumer liking of Chenin blanc wine.

Chapter 5 **Research results**
Investigation into the suitability of Pick-K attributes and CATA to describe Chenin blanc wines when using trained, expert and consumer assessors

Chapter 6 **General discussions and conclusions**

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Chapter 1

Introduction and project aims

INTRODUCTION AND PROJECT AIMS

1.1. General introduction

Today wine is presented to consumers as a luxurious lifestyle beverage. This has placed the wine industry in the middle of a competitive field between the forces of market pull and technology push, in which tradition and innovation need to coexist in order to meet the demands of wine producers and the preferences of wine consumers alike (Pretorius & Bauer 2002). The wine industry currently needs to tailor make wine according to the needs of the market and an important step in this process is oak maturation. Traditionally, wooden barrels are used for oak maturation, however, the use of alternative oak products in old barrels or stainless steel tanks have increased options of oak maturation for winemakers (De Beer *et al*., 2008), since new barrels are expensive, require a lot of space in the winery and have a limited lifetime (Rodriguez & Gomez-Plaza, 2011).

Ageing wine in contact with oak contributes to its organoleptic characteristics, modifying and increasing the complexity of the aroma profile of wine (Baustista-Ortin *et al*., 2008). This modification is thought to derive from the extraction of volatile compounds from the oak, the subsequent transformation of some of these compounds by wine microorganisms, and the generation of additional volatile wine compounds by such wine microorganisms (Spillman *et al*., 2004a).

Recent research that reported the effect of different oak products on wine include work by Cadahia *et al.* (2001), Jaruata *et al.* (2005) and Fernandez-de Simon *et al.* (2010) that investigated the volatile constituents present in different oak products, and also some research that reported the extraction of aroma active compounds from different oak products during wine fermentation and ageing (Perez-Coello *et al.*, 2000; Perez-Prieto e*t al*., 2002; Spillman *et al.*, 2004b; Crump *et al.,* 2015). In these publications, the sensorial effect of alternative oak products have been reported, however, little research has been done of the effect of different oak products on the sensory characteristics of wine over time (Du Toit., 2010). The evolution of the aromas normally associated with these products and how wine consumers and experts perceive it is not known, especially under South African conditions.

The approach of this current research was to investigate the effect of oak maturation regimen on the evolution of the sensory characteristics of wine over time. An important aspect of this study was to investigate the effect of the oak maturation regimen on the perceived quality by experts, and in parallel also the liking thereof by consumers.

Another aim of this study was to investigate rapid sensory methods with the use of different panels. Rapid sensory profiling techniques have been applied to different types of food related products, but research regarding the suitability of the methods when applied for wine research using different types of panels is still incomplete. This research also investigated the suitability of Check-all-that-apply (CATA) and its variant, Pick-*K* attributes (Campo *et al*., 2010), to describe Chenin blanc wines when using an expert, trained, and consumer panel. Published research on the sensory profiling of different oak products is limited, and this is the first study to investigate the effect of oak maturation regiment on sensory characteristics and consumer preferences for Chenin blanc wine.

1.2. Problem statement and research questions

Oak wood can contribute to the final quality of most red wines and certain white wines. Alternative oak products became more popular with South African winemakers due to it being more cost effective than barrels. How alternative oak treatments affects the sensory properties of wine, especially over time, has not yet been investigated in detail. It is thus of industrial importance to know the differences in the aroma profiles of wines aged in contact with new oak barrels and alternative oak products. It is also important for winemakers to know whether there is a significant difference in the way both experts and consumers perceive these wines, and if the perceived differences have hedonic implications.

Sensory descriptive analysis is the most commonly used and defined method of sensory analysis and have been used in numerous wine research studies. In recent years, the use of rapid sensory profiling techniques have gained popularity since it is less time consuming and expensive. CATA and its variant, Pick-*K* attributes, are among the rapid sensory methods that have gained popularity. Campo *et al*. (2008) have reported that the use of Pick-*K* attributes with a trained panel delivers results that are comparable to descriptive analysis (DA). However, using a trained panel is more time consuming than using an expert or consumer panel. Both researchers and industry have a need for purpose fit sensory analysis techniques, and in this context it is important to evaluate the suitability of Pick-*K* attributes and CATA with a trained panel and also with expert and consumer assessors, since the time frame and resources for conducting proper sensory analysis is often a limiting factor.

1.3. Project aims

The main aim of this study was to investigate the role that different oak maturation regimen plays in the sensory characteristics of a South African Chenin blanc wine. This was divided into the following specific aims:

1.3.1 Determine the effect of different oak products on the sensory characteristics of Chenin blanc wine over time.

1.3.2 Compare descriptive and hedonic data of Chenin blanc wine elicited from expert and consumer assessors.

1.3.3 Investigate the suitability of CATA and Pick-*K* attributes as a sensory tool to describe Chenin blanc wine when using an expert, trained and consumer panel.

1.4. Experimental design summary

The experiment consisted of four main maturation treatments. Wines were sampled after respectively 4 months and 9 months of maturation, and sensory evaluation was performed at three different intervals of maturation. Results are presented in three different chapters, as represented by figure 1.1.

Chapter 3 investigated the effect of oak maturation regimen on the aroma profile of Chenin blanc wines when using a trained panel and an expert panel. It also explored the evolution of the wine aroma profiles over time. Chapter 4 investigated the sensory and hedonic properties of the different wines after a period of 9 months oak maturation with an additional 6 months bottle maturation. The sensory and hedonic data obtained from the expert panel and consumer panel were compared. Chapter 5 investigated the validity of CATA and Pick-*K* attributes as sensory tool for describing wine when expert, trained and consumer assessors are used.

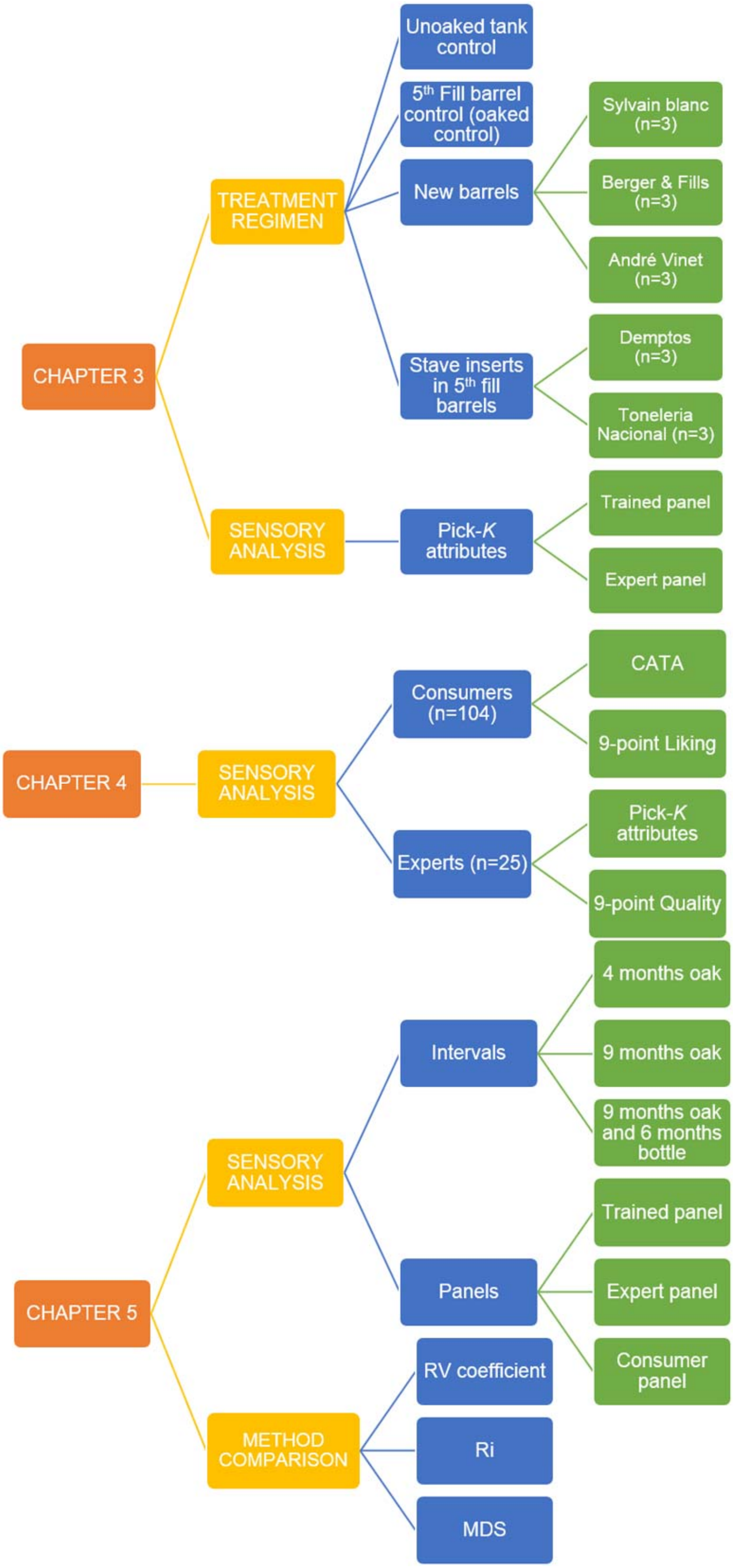

Figure 1.1 Experimental design summary as represented in research chapters.

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Chapter 2

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Literature review

LITERATURE REVIEW

2.1 PART 1 : Aromatic profiling of *Vitis vinifera* L. Cv. Chenin Blanc

2.1.1 Introduction

Wine aroma research is based on four major goals: correlating key compounds to specific varieties and geographical origin, comprehension of the contributing role of wine microorganisms, examination of the modifications brought about by viticultural and oenological practices, and understanding the biochemical and chemical pathways leading to those results (Fischer, 2007).

Wine aroma is derived from multiple sources and processes, including grape-derived aroma compounds like monoterpenes and volatile thiols, secondary metabolites formed from the metabolism of sugar, fatty acids, organic nitrogen and cinnamic acids found in grapes, oak derived aromatic compounds, chemical changes associated with enzymatic and acid catalysed modifications, and also chemical changes associated with oxidative processes in wine that are related to winery operations, storage and packaging materials (Robinson *et al.*, 2014).

This section will summarise the different volatile compounds that are extracted from the grapes or formed during the fermentation of the wine, with specific focus on Chenin blanc. It will also explore how the concentration of these compounds are affected by different viticultural and winemaking techniques.

2.1.2 Fermentation derived compounds

Fermentation derived compounds include the metabolites formed by yeasts and bacteria. This group of compounds consists of fatty acids, higher alcohols, esters and carbonyls, and they are produced through sugar and amino acid metabolism.

Fatty acids are categorized according to chain length, i.e. short-chain, medium-chain, and long-chain fatty acids. Of these, only short-chain fatty acids have a sensorial impact. The short-chain fatty acid acetic acid (C2) accounts for more than 90% of the volatile fatty acids and is formed as a metabolic intermediate in the synthesis of acetyl-CoA from pyruvic acid. Other short-chain fatty acids that have been reported to have an influence on wine aroma, include the branched chain isobutyric and isovaleric fatty acids, and also the straight chained butyric and propanoic acids. However, the aromas associated with these compounds are negative, with associated descriptors like rancid, sweaty and cheese-like

(Robinson *et al.*, 2014). Table 2.1 lists the most important short-chain fatty acids found in Chenin blanc wine.

Table 2.1 Concentrations, threshold values and aromas linked to short-chain fatty acids found in Chenin blanc wine (Lambrechts & Pretorius, 2002 ; Francis & Newton, 2005; Lawrence, 2012).

Compound	Aroma	Concentrations reported in Chenin blanc (mg/L)	Odour threshold (mg/L)
Acetic acid	sour, pungent, vinegar	22.5 - 100	200
Propionic acid	Pungent	0.4 - 100	Na.
Isobutyric acid	Na.	0.3 - 20.9	Na.
Butyric acid	Na.	0.3 - 21.2	Na.
Decanoic acid	rancid, sweat	0.6 - 56	1
Hexanoic acid	Sweat	0.4 - 29.7	0.4
Octanoic acid	sweat, cheese	0.5 -40.4	0.5
Isovaleric acid	rancid, cheesy	0.5 - 39.3	Na.
Valeric acid	rancid, cheesy	0.3 - 20.7	Na.

Higher alcohols are produced by yeasts, either from sugar metabolism via the tricarboxylic acid (TCA) cycle, or from catabolizing amino acids via the Ehrlich pathway. The branched-chain higher alcohols, including isoamyl alcohol and isobutyl alcohol, are synthesized from the branched chain amino acids. The aromatic amino acids, including phenylalanine and tyrosine produce aromatic alcohols (Robinson *et al.*, 2014). At concentrations below 300 mg/L, higher alcohols can contribute to the fruitiness and complexity of a wine, however, above concentrations of 400 mg/L higher alcohols can impart an unpleasant aroma in wine (Louw *et al.*, 2010). Table 2.2 lists the most important higher alcohols found in Chenin blanc wine.

Table 2.2 Concentrations, threshold values and aromas linked to higher alcohols found in Chenin blanc wine (Lambrechts & Pretorius, 2002 ; Francis & Newton, 2005; Lawrence, 2012).

Compound	Aroma	Concentrations reported in Chenin blanc (mg/L)	Odour threshold (mg/L)
Methanol	alcoholic	10 - 150	500
n-Propanol	stupefying	2 - 201	Na.
Isobutanol	alcoholic, fusel	1.3 - 103.8	500
Isoamyl alcohol	marzipan	0.3 - 20.3	300
Pentanol	marzipan	5.5 - 477.3	Na.
4-methyl-1-pentanol	Na.	1 - 100	Na.
n-Hexanol	resin, floral, green	1 - 100	4
3-ethoxy-1-propanol	Na.	0.3 - 30.9	Na.
2-methyl-1-pentanol	Na.	1 - 100	Na.
1-octan-3-ol	Na.	1 - 100	Na.
2-Phenylethanol	floral, rose	0.6 - 5	125

The quantity of higher alcohols produced by yeasts during alcoholic fermentation depends on viticultural practices that influence the yeast assimilable nitrogen, the concentration of the yeast assimilable nitrogen in the must, juice clarity, fermentation temperature as well as the yeast strain (Lambrechts & Pretorius, 2000; Robinson *et al.*, 2014).

Esters represent the greatest concentration of volatile compounds in wine. This group of compounds are considered to be products of yeast metabolism through lipid and acetyl-CoA metabolism. Esters can also be produced through bacterial metabolism and chemical changes, e.g. ethyl lactate is known to be directly linked to concentration of lactic acid. The most important esters and acetates in wine are considered to be fatty acid and ethyl esters and acetates (Robinson *et al*., 2014). Table 2.3 lists the most important esters found in Chenin blanc wine.

Table 2.3 Concentrations, threshold values and aromas linked to esters found in wine (Lambrechts & Pretorius, 2002 ; Francis & Newton, 2005; Lawrence, 2012).

Compound	Aroma	Concentrations reported in Chenin blanc (mg/L)	Odour threshold (µg/L)
Ethyl acetate	solvent, nail polish, fruity	3.6 - 360.8	12.3
2-Phenylethyl acetate	honey, rose, tobacco	0.3 - 20.6	250
Isoamyl acetate	banana, pear	0.2 - 19.2	30
Ethyl butyrate	apple	0.3 -22	20
Ethyl-2-methylbutyrate	floral, fruity	1 – 100	Na.
Ethyl isovalerate	apple, fruity	1 – 100	Na.
Ethyl hexanoate	fruity, apple peel, violets	0.4 - 30.6	14
Ethyl octanoate	pineapple, pear	0.07 – 4	5
Ethyl decanoate	floral	0.5 - 3.5	0.5

The concentration of esters that are produced during alcoholic fermentation depends on the yeast strain, fermentation temperature, the yeast assimilable nitrogen, skin contact time, grape maturity, sugar content of the must, juice clarity, pH, and the addition of sulphur dioxide (Lambrechts & Pretorius, 2000).

During the ageing and storage of wine, there is a hydrolytic loss of acetates and esters, resulting in a loss of fruity and floral aromas in young white wines. Storing wines at temperatures below 10°C can result in less hydrolysis and longer retention of fruity and floral aromas (Robinson *et al.*, 2014)

2.1.3 Terpenes

Terpenes are important contributors to the aroma of white wines made from Muscat varieties and aromatic non-Muscat varieties (Robinson *et al.*, 2014). Terpenes have been detected in a large number of non-aromatic white wine varieties, usually at concentrations lower than their perception thresholds. These compounds can, however, still contribute to the complexity of wine aroma in non-aromatic white wine varieties (Van Antwerpen, 2012).

The most important terpenes include geraniol, linalool, nerol and α-terpineol (Marais, 1983) and they contribute to the floral, citrus and perfume aromas of wine (Fischer, 2007). According to Marias (1983), winemaking techniques that can lead to an increase in the terpene concentration of a wine includes maceration, an anaerobic atmosphere, the use of pectolytic enzymes and pressing at higher temperatures.

Monoterpenes and sesquiterpenes are biologically synthesized from isopentyl pyrophosphate (IPP) and dimethylallyl pyrophosphate (DMAPP). Terpenes are subject to transformations under pH and temperature, for example acidic conditions may lead to the degradation of geraniol and linalool, resulting in the formation of linalool oxides and α-terpineol. During maturation and exposure to higher temperatures, terpenes can also be oxidized resulting in lower concentrations of terpenes in aged wines (Van Antwepen, 2012).

2.1.4 Norisoprenoids

Norisoprenoids are derived from carotenoids and are most abundant in aromatic cultivars (Marais *et al*, 1992). In grapes, carotenoids are generated in chloroplasts. During grape maturation when chloroplasts are lost, levels of carotenoids subsequently decrease. In grapes the most important carotenoids include β-carotene, lutein, neochrome, neocanthin, violaxanthin, luteoxanthin, flavoxanthin, lutein- 5,6 – epoxide and zeaxanthin, as well as the *cis* isomers of lutein and β-carotene. Norisoprenoids are formed from the biodegradation of carotenoids, followed by an enzymatic conversion to the glycosylated aroma precursor, and finally the acid-catalyzed conversion to the aroma active compound (Robinson *et al.*, 2014).

Cabrita *et al.* (2006) observed that β-damascenone (floral, tropical fruit and baked apple aromas) and β-ionone (violet, woody and raspberry aromas) are the two most aromatic compounds that contribute to the aroma of wines made from neutral cultivars. Other important norisoprenoids from a sensory point of view include vitispirane (camphorous and eucalyptus aroma) and TDN (kerosene aroma).

2.1.5 Volatile sulphur compounds

Volatile sulphur compounds can contribute to wine aroma in both a positive and negative manner. Compounds that impart negative aromas in wine include H_2S, thioacetic esters and mercaptans. Aroma descriptors that are typically associated with these compounds include rotten egg, cooked vegetables, garlic, onion and cabbage. These compounds may form due to too low redox potential of the wine (Coetzee & Du Toit, 2012). These compounds are extremely reactive with low sensory detection thresholds and can significantly influence the aroma of wine, even in trace amounts (Lambrechts & Pretorius, 2000). Other Sulphur containing compounds can contribute positively to wine aroma. These include 4-mercapto-4-methylpentan-2-one (4MMP), 3-mercaptohexan-1-ol (3MH), and 3-mercaptohexyl acetate (3MHA) (Coetzee & Du Toit, 2012). 4MMP and 3MH are non-existent in grapes and are released by yeast during fermentation from cysteinylated and glutathionylated precursors, while 3MHA is formed from the acetylation of 3MH by the yeast during fermentation (Coetzee *et al*., 2013). Du Plessis & Augustyn (1981) reported that neutral wines, including Chenin blanc, develop a guava-like aroma when spiked with 4MMP. The sensory detection thresholds, concentrations and associated aromas of 4MMP, 3MH and 3MHA are shown in Table 2.4.

Table 2.4 Volatile thiols contributing to wine aroma (Coetzee & Du Toit, 2012).

Compound	Abbreviation	Aroma	Ranges in wines (ng/L)	Threshold value (ng/L)
4-Mercapto-4-methylpentan-2-one	4MMP	box tree, passion fruit, broom, black currant	4 – 40	0.8
3-Mercaptohexan-1-ol	3MH	passion fruit, grape fruit, gooseberry, guava	26 - 18000	60
3-Mercaptohexyl acetate	3MHA	passion fruit, grapefruit, box tree, gooseberry, guava	0 – 2500	4.2

Viticultural factors that results in an increase in the concentration of cysteinylated and glutathionylated precursors of volatile thiols include moderate water deficit and *Botrytis cinerea* infection. Oenological factors that will lead to an increase in precursors present in the must include machine harvesting, moderate addition of sulphur dioxide and ascorbic acid during harvest and grape processing, exposure to oxygen, skin contact, higher maceration temperatures and also pressing of the grapes. Volatile thiols in wine decrease during bottle ageing, since it is not stable against oxidation, but it can be preserved by the addition of glutathione and sulphur dioxide before bottling (Coetzee & Du Toit, 2012).

2.2 PART 2 : The contribution of oak wood to wine

2.2.1 Introduction

Ageing wines in contact with oak wood contributes to its organoleptic properties. Wines that are aged in contact with oak wood are enriched with aromatic substances, have a more stable colour and mouthfeel complexity is improved. Oak wood alternatives have been developed to aid the ageing process in a cost effective manner whilst ensuring that oak wood derived volatiles are released into the wine (Bautista-Ortin *et al*. 2008).

The structural characteristics and chemical composition of oak wood have an influence on the complex physical, chemical, and biochemical processes that take place during wine ageing (Fernandez de Simon *et al*, 2010).

This section will summarise the contribution of oak wood to wine in terms of its structural, mechanical and aromatic properties.

2.2.2 Oak composition

2.2.2.1 Cell wall constituents: cellulose, hemicellulose and lignin

Wood cells consists primarily of cellulose (40-45%), hemicellulose (25-30%), lignin (20-30%), and 8-12% total tannins that are extractable with hot water (Haluk *et al.*, 1998). Cellulose is considered the framework of the oak, hemicellulose the matrix, and lignin the encrustant (Francis *et al.,* 1992). These macromolecular constituents are responsible for the physical properties that makes oak wood suitable for barrel coopering, since it is responsible for good mechanical properties, ease of splitting, curving and bending of staves, thermal isolation and slight porosity (Fourie, 2005).

Cellulose is a homopolysaccharide made up of β-D-glucopyranose units that are bound by glycosidic-bonds. Heated oak cellulose produces furanic aldehydes. Hexoses which form part of cellulose produce hydroxymethyl furfural and methyl-5-furfural which can contribute to the flavour of wine (Haluk *et al.,* 1997).

Hemicelluloses are heterogeneous polymers including xylose and other sugars, especially pentoses (Francis *et al.,* 1992). These polysaccharydes act as binding substances, along with pectins, to bind the cellulose and lignin. Heating converts some of the sugars to furan aldehydes like furfural and 5-hydroxymethyl-2-furfuralaldehyde (Fourie, 2005).

Lignin is a three-dimensional polymer of phenylpropane derivatives of guaiacyl and syringyl units substituted with an aliphatic side chain at the four position, and further cross linked by oxidation. Lignin polysaccharides are hygroscopic and insoluble in water (Francis *et al*., 1992). Thermal degradation of lignin produces volatile phenolic compounds, including phenolic aldehydes and phenylacetates (Fourie, 2005).

None of these three major classes can contribute significantly to wine aroma unless they are fragmented, since they are mostly insoluble (Francis *et al.,* 1992).

2.2.2.2 Volatile substances

2.2.2.2.1 Oak lactones

The (4*S*, 5*S*) *cis*-isomer and the (4*S*, 5*R*) *trans*-isomer of 5-butyl-4-methyl-4,5-dihydro-2(3*H*)-furanone, more commonly known as the oak or whiskey lactones, are extracted from oak wood into wine or spirits during fermentation and/or maturation. Of these two isomers, the *cis*-lactone is considered to be of greater sensory importance. In white wine the *cis*-isomer is correlated with a coconut aroma, and in red wine it is correlated with coconut, vanilla, berry, coffee and dark chocolate aromas. (Brown *et* al., 2006).

Brown *et al*. (2006) reported the sensory detection threshold for both enantiomers in red wine and white wine. The detection threshold for the natural *trans-* oak lactone, that has been reported to have a celery-like aroma in white wine and red wine, is 140 µg/L and 370 µg/L respectively. The threshold for the *cis*-oak lactone is 20 µg/L and 54 µg/L respectively in white wine and red wine.

Wilkinson *et al*. (2004) proposed that the formation of oak lactone from oak lactone precursors can occur in two steps: liberation of the ring-opened oak lactone from the oak lactone precursor by either pyrolysis or enzymatic activity, followed by ring closure to yield oak lactone. However, so far only the ring-opened *cis*-isomer oak lactone galloylglucoside has been confirmed to be present in oak wood.

2.2.2.2.2 Volatile phenols

Most research on volatile phenols have focused on vanillin and its relatives, including syringaldehyde, coniferaldehyde, sinapaldehyde, acetoaldehyde, and acetosyringae

(Spillman, 1994). This group of volatile phenols have been proven to increase with seasoning. This increase can be explained by the degradation of lignin through processes of depolymerization, and posterior hydrolytic and oxidative degradation of monomers (Cadahia *et al*., 2001). Vanillin, which is very important to wine aroma, is present in green wood but is also associated with the heating process, thus higher concentrations are to expected in the first few millimetres of the toasted oak (Rodriguez-Rodriguez & Gomez-Plaza, 2011). The sensory detection threshold of vanillin in a model wine solution of 10% ethanol, is 0.5 mg/L (Spillman *et al.*, 1997).

Other volatile phenols include phenol itself, guaiacol, 2,6-dimethoxyphenol, catechol, resorcinol, and hydroquinone. These are also the products of lignin degradation during the heating of oak and have smoky and medicinal aromas. Also important, are the 4-ethyl and 4-vinyl derivatives of phenol and guaiacol. 4-Ethylphenol, with a sensory detection threshold of 0.4 mg/L in wine, is described as unattractive, animal-like, powerful, woody and phenolic, while 4-ethylguaiacol have spicy, clove, medicinal and burnt aromas, with a sensory detection threshold of 0.4 mg/L in red wine (Singleton, 1995; Perez-Prieto *et al*., 2002; Fernandez de Simon *et al.*, 2006).

Eugenol, another volatile phenol of sensory importance, comes from the oak wood and is extracted into the wine. American oak has higher concentrations of eugenol than French oak species (Singleton, 1995). In a model wine solution of 10%, the sensory detection threshold of eugenol is 11 µg/L, and it is perceived as cloves and a general indicator of oakiness in barrel matured wines (Singleton, 1995).

2.2.2.2.3 Carbohydrate derived volatiles

Furan derivatives, including furfural and 5-methylfurfural, are formed from the pyrolysis of carbohydrates during toasting, and are subsequently extracted into wine during ageing in contact with oak wood. The pyrolysis of rhamnose leads to the production of 5-methylfurfural, while the pyrolysis of hexoses lead to the production of 5-hydroxymethyl furfural (Spillman *et al.*, 1998). These compounds have toasty and caramel aromas, and contribute to the overall perception of oak intensity and hotness in wine (Robinson *et al.,* 2014).

Maltol and 2-hydroxy-3-methyl-cyclopentanone are also products derived from the degradation of sugar. They have desirable sweet and caramelized odours. They have been found in toasted oak wood and are associated with the production of furfural (Spillman *et al.,* 1998).

2.2.2.2.4 Other volatile compounds

The majority of known volatile oak extractives can be categorized according to their biogenetic or chemical origin. Sefton *et al.* (1990) reported the identification of a group of 13-, 11-, and 9-carbon norisoprenoids as significant components of model wine extracts of American and French oak shavings. In this work it was found that there was a great variation in norisoprenoid extraction between American and French oak extracts, with a higher overall concentration and greater variety of these compounds in the American oak than in the French oak. The American oak extract included the four isomeric 3,4-dihydro-3-oxoactinidols, both *E* and *Z* isomers of the hydroxydienone, and blumenol C, together with the bicyclic ethers as major components, whereas these compounds were either absent from or present in small amounts only in the French oak extract. β-ionone was a major norisoprenoid of the French oak extract and was not observed in the American oak extract. Norisoprenoids occur mainly as glycoconjugates in both red and white grape varieties and in wines (Sefton *et al.* 1990), and is thought to be generated by an oxidative cleavage of carotenoidal molecules (Fischer, 2007). They are important to the flavour of tobacco, tea and some fruits (Sefton *et al.* 1990).

2.2.3 Non-volatile substances

2.2.3.1 Non-hydrolysable tannins

Non-hydrolysable tannins, also referred to as condensed tannins, are oligomers or polymers composed of C6-C3-C6 monomer units, linked by carbon bonds that are not susceptible to hydrolysis (Pocock *et al*., 1994).

Condensed tannins are classified according to the nature of their monomer units. The two most important classes of condensed tannin are the procyanidins and the prodelphinidins. They are composed of catechin or gallocatechin monomer units and release cyanidin and delphinidin, respectively, upon acid degredation (Pocock *et al*., 1994).

Low amounts of condensed tannins are present in oak wood and the extraction of these compounds into wine during maturation don’t have a significant influence on the condensed tannin concentration of the wine (Fourie, 2005).

2.2.3.2 Hydrolysable tannins

Hydrolysable tannins, or ellagic tannins, are present in all species of oak wood (*Quercus spp.)* and can represent up to 10% of the dry weight of oak heartwood (Versari *et al.,* 2013). Hydrolysable tannins contain a polyhydric alcohol as the basic structural unit, of which the hydroxyl groups have been esterified by gallic acid or hexahydroxydephinic (HHDP) acid (Puech *et al*., 1999)

Condensed tannins are classified as gallotannins or ellagitannins, according to the type of acid that are formed when these types of tannins hydrolyse. Although the presence of gallotannins have been indicated, no structure have been identified, and since the amount of gallic acid formed after hydrolysis is estimated to be 5% of the amount of ellagic acid formed, the latter is considered to be more important (Puech *et al.,* 1999).

The two most common ellagic tannins in oak are castalagin and vescalagin. Castalagin and vescalagin are water soluble and are soluble in hydroalcoholic mediums such as wines and spirits. Subsequently, six additional water soluble ellagic tannins (ruberins A-E and grandinin) are acknowledged as dimers of vescalagin or castalagin, and are characterized by the addition of pentose to the molecule (Jordão *et al.* 2005).

Ellagitannins have been found in highly variable concentrations in oak matured wines, with maximum reported values of 21 mg/L for castalagin and 7 mg/L for vescalagin. Reasons for these reported low concentrations may include heating, which have been shown to reduce the levels of vescalagin and castalagin by 73% and 46% respectively in the surface layer of the wood. Furthermore, studies have shown that despite a rapid hyperbolic extraction of ellagtannins, only 50% of the available ellagitannins are extracted into the wine, where further chemical transformations like oxidation and interactions with proteins or polysaccharides may take place (Puech *et al*., 1999).

Ellagitannins are not tasted in wine (Versari *et al*., 2013), but may contribute to the astringency of a wine (Fourie, 2005). Pocock *et al.* (1994) reported that oak tannins in wine are present in concentrations below their sensory detection threshold, suggesting that it is the oak derived volatile compounds that provide the primary sensory indication that a wine received oak treatment.

2.3 PART 3 : Influence of coopering on the extraction of oak compounds

2.3.1 Introduction

Three main factors have been identified as being responsible for the pool of available volatile and non-volatile extractives from oak wood. These include the oak species and their origin, seasoning and drying (both length and location), and heating or toasting (Towey & Waterhouse, 1996a). These aspects will be discussed in detail in the section that follow.

2.3.2 Oak Species

Many different woods have been used to cooper wine barrels, including red oak, chestnut, red or sweet gum, sugar maple, beech, black cherry, acacia karri, mulberry, and the oak wood used almost exclusively today, white oak (Lucio *et al.* 1999). All white oaks used for cooperage are members of the *Leucobalanus* or *Lepidobalanus* subgroup (Singleton, 1995). The most important oak species used in American cooperage is *Quercus alba*, while those in France are *Quercus robur* and *Quercus petraea. Q. robur* is most common in the south-west of France (e.g. Limousin), while *Q. petraea* is more common in the centre (e.g. Troncais, Nevers, Allier) and the north-east (e.g. Vosges) of France (Spillman *et al.,* 2004a).

Doussout *et al.* (2002) confirmed a species discrimination based on ellagitannin and lactone content, with *Q. robur* having more tannins and fewer volatile compounds than *Q. petraea*. Various studies reported that American oak is characterized by higher levels of *cis*-β-methyl-γ-octalactone than French oak. Francis *et al.* (1992) also reported that European oak has more phenols and other extractables, whereas American oak has more odourants. Contradictory to these studies, a study conducted by Spillman *et al*. (2004a) reported the levels of cis-β-methyl-γ-octalactone highest in French oak. This could be attributed to differences among studies in factors that affect cis-β-methyl-γ-octalactone content, such as seasoning and toasting intensity. Other compounds of sensory importance also varies between French oak and American oak. Sefton *et al.* (1993) reported French oak samples contained around twice the concentration of eugenol than American oak at the time of oak harvesting.

2.3.3 Forest location

The two oak species that are predominant in France are *Quercus roubur* and *Quercus petraea*, respectively covering 1.86 and 2.32 million hectares. In Europe, the selection of oak for the purpose of coopering, is based on the ring width (grain) and geographic location (Doussout *et al.* 2002).

Although the origin of oak is a determining factor when comparing amount of extractable compounds, recent research has shown that variability between individual trees are larger than variability between species (Fourie, 2005). Francis *et al.* (1992) also argued that owing to differences in tree age and growing rate, selecting oak for coopering based on forest location can lead to a lack of reproducibility in subsequent orders of barrels.

2.3.4 Grain

Grain is defined as the average size and regularity of annual growth rings (Fourie, 2005). Oak wood is porous. Springwood has large pores that are closed by tyloses when the sapwood is converted to heartwood; the fraction of the oak that is suitable for cooperage. Summerwood is denser and without major pores. Trees that grow slowly have a higher proportion of springwood to summerwood. The notion of tight grain and wide grain refers to the growth rate of the oak tree, where tight grain refers to trees that grow slow and wide grain refers to trees that grow fast.

Coopers prefer oak that was slow grown, since it is easier to bend and also has a greater extract potential of volatile compounds (Francis *et al.,* 1992). Wide grain oak have more extractable compounds and ellagitannins, and less volatile compounds like eugenol and oak lactones (Fourie, 2005). The rate at which the tree grows depends on soil, climate, tree spacing, etc. (Francis *et al.,* 1992).

2.3.5 Seasoning

Green wood cannot be used for cooperage since it contains between 40% and 60% humidity and its extractable compounds are not compatible with the objective of improving wine quality (Martinez *et al.,* 2008). Wood can change in dimension and structure if the moisture content varies and must thus be dried to a moisture content that ensures the dimensional stability required for coopering. Seasoning causes the oak wood to dehydrate until its humidity is in balance with the ambient humidity (Cadahia *et al*., 2007). Cooperage oak staves are dried to a moisture content of between 14% and 18% (Masson *et al.,* 2000).

Natural drying induces an important loss of water soluble compounds, during which oak wood loses its humidity and therefor becomes dimensionally stabilized (Doussout *et al.* 2002). Seasoning is thus an important coopering step to prevent the oak wood from shrinking after barrel construction, and hence the prevention of barrel leakage. (Spillman *et al.* 2004). Natural seasoning results in wood maturation, decreasing bitterness and astringency, and increasing aromatic properties. Seasoning primarily results in the loss of hydrosoluble phenolic compounds like ellagitannins due to different physical and chemical mechanisms, including leaching, hydrolytic oxidative degradation and fungal enzymatic activity. Enzymes that have been linked to the latter include phenol heterosidase, etherase and depsidase. (Cadahia *et al.,* 2007).

With regard to volatile compounds, contradictory results have been reported in literature, and various factors may influence their concentration during seasoning, including species, duration of seasoning, and country of seasoning. A significant decrease in ellagitannins, and an increase in oak lactones and vanillin during seasoning have been reported by Doussout *et al. (*2002). Spillman *et al*. (2004a) and Duval *et al.* (2013) reported that freshly harvested oak wood contains little of the oak lactones, but that the concentration of these oak lactones generally increased during the course of seasoning. Spillman *et al.* (2004a) further reported that the production of some volatile compounds, including furfural and 5-hydroxymethylfurfural, increased as a function of the length of the seasoning time.

Seasoning usually happen under natural conditions in open air with a time period of between 18 and 36 months (Martinez *et al.,* 2008). Cadahia *et al.* (2007) reported that wood evolution occurs primarily during the first two years of seasoning, followed by stabilization in the third year. Disadvantages associated with the traditional method of open air natural seasoning include that a large space is required along with long term planning of required wood volumes. Another disadvantage is that the final moisture content of the oak depends on the external hygroscopic balance. There is also a high risk that fungal development can lead to the degradation of the mechanical and chemical properties of the oak wood staves (Masson *et al.,* 2000). Alternatively kiln-drying is applied by some cooperages. Kiln-drying, in most cases, refers to the use forced convection which allows one to control the air flow, temperature, and humidity. This method of drying usually happens at temperatures of 40°C for 3 months or 65°C for 2 months. It has become a common practice to incorporate the two methods of drying where the wood is initially air dried and then, if necessary, the moisture content is further reduced by the use of kiln drying (Masson *et al*., 2000). Martinez *et al.* (2008) found that natural seasoning produced the better cooperage quality staves than staves produced by mixed or artificial seasoning. It was reported that natural seasoning led to a better reduction in ellagitannins and that the associated staves had higher potential to be aromatic, with higher levels of volatile phenols, phenolic aldehydes, furanic compounds and lactones.

2.3.6 Toasting

It is well known that elevated temperatures changes the nature of cellulose, hemicellulose, lignin and therefore the permeability, diffusibility, hygroscopicity, durability, bonding properties and stability of wood is modified (Ters *et* al. 2011). Heating takes place in two steps; first to allow the formation and stabilization of the bent barrel shape (Duval *et al.*, 2013; Spillman *et al.,* 2014); and then the second step which is called toasting, during which the chemical composition of the oak is changed (Campbell *et al.,* 2005; Duval *et al.* 2013). The application of coopering heat causes the disruption of chemical bonds within the oak wood macromolecules, including cellulose, hemicellulose and lignin; yielding volatile compounds that are extracted into wines and spirits during maturation in oak barrels (Spillman *et al*., 2004a; Campbell *et al.,* 2005). These volatile compounds can have a significant influence on wine aroma and flavour. Many such compounds are not present in significant quantities in raw, untoasted oak.

The important volatile phenols, including guaiacol, 4-methylguaiacol, and vanillin are formed from the hydrothermolysis of lignin during toasting. Other aromatic compounds include syringaldehyde, coniferaldehyde and sinapaldehyde and reach maximum concentrations at medium toast levels. At higher temperatures, the formation of acetic acid from hemicelluloses catalyses the depolymerization of carbohydrates, leading to further degradation products such as furfural, methyl-5-furfural and hydroxrmethylfurfural. Chantonnet (1999) documented the production of enolic compounds such as cyclotene, maltol and isomaltol derived from hexoses in the presence of nitrogenated substances. Toasting may also reduce the concentration of some sensorially important compounds. It has been reported that the concentration of *(E)*-2-nonenal, a compound responsible for the sawdust aroma in wines, is reduced by toasting (Chatonnet & Dubourdieu, 1998; Spillman *et al.,* 2004b).

The effect of toasting on the concentrations of oak lactones is less clear in the literature, with both decreases and increases reported (Campbell *et al*. 2005). Chantonnet (1999) reported a general increase in oak lactone with increased toasting, but also that a very high toasting level significantly decreased oak lactone from the surface layer of the toasted oak. An increase in oak lactone concentration can be explained by the generation of precursors and by the oxidation of lipids and fatty acids.

Doussot *et al.* (2002) reported a decrease of ellagitannin concentrations during toasting as a result of thermally aided hydrolysis, and also subsequent coupling reactions with itself or other chemical compounds, with a simultaneous increase in ellagic acid concentrations. Toasting results in the thermal degradation of tannins and these thermal products are thought to be less astringent (Fourie, 2005).

As each cooperage has its own toasting methods, the composition of heated oak can vary despite attempts to define toasting temperatures and levels (e.g. “light”, “medium”, “heavy” toast) (Spillman *et al.* 2004a). The choice and mastering of the intensity of toasting can have a significant influence on the quality and quantity of the compounds produced in the oak wood (Chantonnet, 1999).

It is not heat alone that causes changes in the oak wood constituents. The toasting process can be influenced by a number of factors, such as type of heat, the circulation of air and the use of water (Lucio *et al.* 1999). Duval *et al.* (2013) reported that even though water is supposed to have a delaying effect on the degradation of oak wood macromolecules, it can favour heat transfer and thus promote higher than expected transient temperatures in soaked wood. Distinct behaviour could be observed between thermally-generated compounds (vanillin and guaiacol) where absorbed water seemed to prevent the degradation of the parent macromolecule, and thermally degraded compounds such as eugenol where the presence of water balanced the compound degradation through a more efficient compound extraction process. Furfural showed a more complex behaviour since its production as a result of hemicellulose degradation was thermally favoured in the presence of water.

The toasting process can lead to the production of compounds with toxicological properties that cannot be detected by sensory means but have an impact on health. These compounds are commonly referred to as polycyclic aromatic carbons (PAH), and they can be produced during the heating of organic materials. However, Chatonnet & Escobessa (2007) found that if the thermal degradation process occurs under conditions comparable to those of traditional toasting, at temperatures that are not in excess of 200°C, and the quantities of oak wood used are consistent with standard coopering, there is no reason that wine will be exposed to PAH during barrel ageing.

Traditional oak wood barrels are usually toasted by means of open flame toasting. It is carried out with direct exposure of the wood to an open flame and it is usually divided into two stages; bending and applying a fine toasting, totalling between 45 to 60 minutes. The “coeur chauffe” method for barrel toasting has also been used. In this process, the oak wood is wetted in a pressurized steam chamber, and sprayed by hot purified water showers. This treatment causes a greater opening of the pores of the wood, which contributes to a greater penetration of toasting. The water can also reduce the risk of charring and it removes resinous pieces from the timber. Toasting by means of hot air convection, gas burners, or electrical infrared heaters is most commonly used for oak alternatives such as oak chips, cubes or beans, shavings or granules, dominoes and blocks or segments (Chatonnet & Escobessa, 2007; Fernandez de Simon *et al.,* 2010). During convection toasting for barrels, the air mixture is distributed evenly between the mounted, closed barrels, while in stave ovens the wood is stacked on perforated racks allowing the heated air to reach every fibre of the oak wood. This continuous and homogeneous airflow, combined with the availability of computerized process management, allows for precise control of all the variables of the toasting process, zero blistering, and zero carbon and smoke contamination, while achieving reproducible results (Fernandez de Simon *et al.,* 2010).

2.4 PART 4 : Organoleptic influence of oak wood on wine

The influence of oak maturation on the organoleptic properties of wine have been the subject of numerous studies (Cutzach *et al.*, 1997; Spillman *et* al., 1997; Perez-Prieto *et al.*, 2002; Marchal *et* al., 2013; Nevares *et al.*, 2014; Spillman *et al.*, 2014). Contact with oak wood can occur during wine fermentation and ageing or only during ageing. Wine and spirits undergo several chemical and biochemical changes during ageing, resulting in the evolution of their composition, colour stability and sensory properties (Marchal *et al*., 2013).

The complexity of wine aroma is increased due to the extraction of volatile compounds from the oak matrix during the ageing period (Bautista-Ortin e*t al*., 2008). Some of these compounds, including oak lactones and eugenol, are present in the heartwood of the oak, while others are products from the coopering processes (seasoning and toasting), e.g. guaiacol and furfural (Marchal e*t al*., 2013). The most important volatile compounds from a sensory point of view include the oak lactones, vanillin, guaiacol, 4-methylguaiacol, furfural, 5-methylfurfural, and eugenol (Rodriguez-Rodriguez & Gomez-Plaza, 2011). Each of these compounds have a different sensory perception threshold, depending on their concentration in the wine and also on the sensitivity of individual wine assessors (Bautista-Ortin e*t al*., 2008). Several factors influence the extraction of oak derived compounds, including the wine matrix, barrel fermentation and lees contact, barrel maintenance, barrel age, and the length of the maturation period. The extraction of oak derived compounds are regulated by diffusion kinetics, following a curve in which the rate of extraction is initially high due to a large concentration difference between the oak and the wine. This is followed by a decrease in extraction of oak derived compounds as the concentration of these compounds in the wine approaches the concentration on the interior surface of the barrel (Towey & Waterhouse 1996b). Rodriguez-Rodriguez & Gomez-Plaza (2011) reported that the major oak derived volatiles including the furfuryl compounds, guaiacol and 4-methylguaiacol, lactones and vanillin reach maximum extraction after approximately 3 months of oak contact.

Oak lactones are significant in the aroma of wine and are associated with aromas like coconut and pencil shavings. In higher concentrations it has also been correlated with a vanilla character in white wines. (Mosedale *et al*., 1999). Vanillin extracts rapidly during the first 3 months of oak ageing after which the concentration in the wine decreases due to the biological degradation of vanillin to its corresponding alcohols (Rodriguez-Rodriguez & Gomez-Plaza 2011). Vanillin occurs in smaller concentrations in barrel fermented wines. Spillman e*t al.* (1997) reported that the mean concentration of vanillin in wine following barrel fermentation and maturation over a period of 11 weeks was only one third of the vanillin concentration measured in model wine. The reason for this is the transformation of vanillin to vanillyl alcohol by active yeasts. An increase in the mean concentration of vanillin was reported from week 11 to week 55 of oak ageing, after the wine was racked from the yeast lees. After this, a further depletion in the vanillin concentration was observed and it is hypothesized that this was due to non-enzymatic chemical reactions. Vanillin does influence wine flavour, but oak components other than vanillin can contribute to the vanillin aroma. Toasting levels, maturation time and microbial activity also have an influence in the vanillin concentration in wine. The sensory impact thereof may vary due to other compounds that can modify, mask or enhance its aromatic properties. The furfuryl compounds contribute to toasted, caramel and coffee aromas (Cutzach e*t al*., 1997; Spillman *et al.*, 1998). Furfural has been shown to decrease after 3 months of oak maturation due to the biochemical degradation of furfural to 5-methylfurfural. Another reason for this decrease might be due to reactions with mannoproteins when wine is aged on the lees. Guaiacol and 4-methylguaiacol contribute to the smoky aroma in oak aged wines and are stable in hydroalcoholic solutions (Rodriguez-Rodriguez & Gomez-Plaza, 2011).

Oak ageing also leads to the extraction of non-volatile phenolic compounds, including ellagitannins, phenolic acids, lignin and lignin-derived products (Pocock e*t al.,* 1994; Marchal *et al.,* 2013). These compounds can theoretically influence the astringency and bitterness of oak aged wines, but the concentrations in which they are extracted are too low to have a significant influence on the sensory properties of the wine (Pocock *et al*., 1994). Barrel fermentation also reduces the possible astringency effect of ellagitannins through the adsorption of ellagitannins to yeast cell walls (Perez-Coello *et al*., 2010). Marchal e*t al*. (2013) have suggested that some non-volatile oak compounds contribute to the sweetness of oak aged wines.

Sensory modifications of oak aged wines are also brought about by the redox phenomena that exists because oak barrels allows oxygen exchange with the ambient atmosphere (Marchal e*t al*., 2013). Since the introduction of alternative oak products in tanks, micro-oxygenation have been the subject of numerous studies to replicate the uptake of oxygen during barrel ageing (Du Toit, 2010). The uptake of oxygen aids polymerization and condensation of the phenolic compounds, which leads to the formation of more stable colour pigments. Ellagitannins can regulate redox reactions in wine by acting as a buffer against oxidation reactions and in doing so, it leads to colour stability and a decrease in the astringency of the wine (Versari *et al*., 2013).

Fermentation derived compounds that are responsible for fresh and unripe aromas have been reported to decrease in barrel aged wines (Perez-Coello *et al*., 2000; Perez-Prieto *et al*., 2002; Du Toit, 2010). This loss in fruitiness is higher in new barrels, since older barrels have a lower porosity due to blockage of the pores by mineral salts and colour pigments, resulting in less evaporation. Loss in fruitiness may also be due to a masking effect by the oak derived compounds. Perez-Prieto *et al.* (2002) have reported that concentrations of 4-methylguaiacol and furfural remain unchanged during successive vintages for barrels, but that other volatile compounds including the oak lactones, vanillin and eugenol decrease from first fill to second fill.

2.5 PART 5 : Sensory evaluation methodologies

2.5.1 Introduction

Sensory tests are widely used for a variety of reasons, including quality control, process and product development and optimisation, flavour research and to understand consumer reactions to a product. The main function of sensory analysis is thus to provide measurements, with the distinguishing feature being that the measuring instrument is either a human assessor or a panel of human assessors (Piggot, 1995).

Today wine is presented to consumers as a luxurious lifestyle beverage. This has placed the wine industry in the middle of a competitive field between the forces of market pull and technology push, in which tradition and innovation need to coexist in order to meet the demands of wine producers and the preferences of wine consumers (Pretorius & Bauer, 2002). Knowing the sensory characteristics of wines among their competitors is a key priority (Cartier *et al*., 2006).

Several sensory analysis methods are being used and developed to characterise the sensory properties of food related products, including discrimination, descriptive and consumer tests. Discrimination tests determine whether two products are perceived different from one another, e.g. triangle testing. Discrimination tests are easy to conduct and require little or no training. A disadvantage of discrimination tests, however, are that they do not provide information regarding the origin or impact of differences perceived between products (Lawles & Heymann, 2010; Robinson *et al.,* 2014). Descriptive tests, for example Descriptive Analysis (DA), are used to obtain more detailed descriptions of the sensory attributes of a product. These tests assist in identifying which attributes vary due to product modification and also compare attributes between or among products. Descriptive tests may require additional time and panel training. Consumer tests are typically hedonic, and are used to determine the liking, preference and acceptability of a product according to a consumer (Robinson *et al.,* 2014). However, it has recently been demonstrated that consumer tests can be conducted in accordance with descriptive tests by means of rapid sensory profiling methods (Ares & Jaeger, 2013)

On criteria of relevance to this research project, only descriptive tests and consumer tests will be discussed in the following section.

2.5.2 Sensory profiling techniques

2.5.2.1 Conventional techniques using a trained panel

According to Piggot (1995), trained individuals can be classified into three respective categories, including trained panelists who have undergone a directed and uniform program of training, expert sensory evaluators who have longstanding experience with a product, and persons who have made it their profession to develop new products based on sensory attributes, e.g. flavour chemists. Conventional techniques using a trained assessor, as defined by Piggot (1995), will be discussed in the following section.

2.5.2.1.1 Descriptive Analysis (DA)

Descriptive analysis (DA) is used to identify sensory attributes, and the intensity of these attributes, in a given product (Cartier *et al.*, 2006). Samples are evaluated individually, and the results are expressed on a continuous numerical scale (Anzanello *et al*, 2011). Sensory data from descriptive analysis can thus be treated as both qualitative and quantitative (Cartier *et al.*, 2006; Anzanello e*t al.*, 2011). Standard application of the descriptive analysis method requires that a panel between 8 and 12 members are recruited and maintained for product evaluation (Lawless & Heymann, 2010). Campo *et al*. (2010) describes the key steps of descriptive analysis as follow:

- Familiarization of the product space and generation of attributes that describe the differences between a set of products.
- Reduction of the initial attribute list to achieve a list that describes the products comprehensively and accurately. Terms may be eliminated or grouped semantically according to the judges' consensual decisions.

- Training of the judges to reach consensus on the definition of attributes and to achieve reliable intensity ratings. During this step, a definition and physical reference standards of attributes on the descriptor list are usually presented to the panel members.
- Monitoring of judge performance in terms of discrimination ability, repeatability, and homogeneity until the performance is considered adequate.
- Evaluation of the product set, usually including replicated easurements.

Data from descriptive analysis can be statistically analyzed using analysis of variance (ANOVA) to determine which attributes are significantly different. Principle component analysis (PCA) is then conducted on the significant attributes to obtain a sensory map of the significant attributes (Valera & Ares, 2012). Many statistical methods exist to determine the performance of a panel or panelists, including agreement, repeatability, ranking and discrimination. Each specific method focuses on a specific area of performance. Panel performance in terms of efficiency, repeatability and accuracy can also be analyzed by using PanelCheck software using the workflow as suggested by Tomic e*t al.* (2010). The advantages of using this software include the rapid identification of underperforming assessors, monitoring of assessors and panels over a period of time, and quick comparison of trained panel proficiency across different markets (Tomic *et al*., 2013).

According to Lawless & Heymann (2010), descriptive analysis is the optimal method when detailed sensory information regarding a certain product is required, when a detailed list of attributes describing one specific product is required, or when quantification of specific differences between a sample set is required. The disadvantages of this method include that it forces panelists to dissect their perception into independent sensory dimensions, that it is time consuming, that it requires extensive training, and that it is expensive in cases where a panel needs to be sourced. Another disadvantage is that panelists are restricted to the use of only 15 – 20 attributes and that these attributes may in some cases be insufficient to accurately describe the sensory characteristics of products that differ vastly (Cartier *et al*., 2006; Campo *et al.*, 2010).

2.5.2.2 Rapid profiling techniques

2.5.2.2.1 Check-All-That Apply

Check-All-That-Apply, or CATA, was first introduced to sensory science at the 7th Pangborn Sensory Science Symposium and has since gained popularity due to its rapidity and ease of use for an array of different sensory and consumer studies (Giacalone *et al.,* 2013;

Ares & Jaeger, 2013a). However, drawbacks of this method include that it does not provide quantitative data, and also that it requires a large number of assessors.

The CATA method consists of a versatile multiple choice format (Ares & Jaeger, 2013a). In short, panelists are provided with an object to evaluate, accompanied with a list of descriptors (single words or phrases) to characterize it (Ares *et al.,* 2013b). Attributes can also relate to hedonic or emotional aspects, as well as product usage or concept fit, which makes it ideal for consumer research. Products should be presented to the assessor simultaneously according to a balanced randomized design (Valentin e*t al.,* 2012). In this method, the assessor can pick as many attributes as he or she deems relevant (Valentin *et al.,* 2012).

Pick-*K* attributes is a variant of CATA where the assessors receive a list of attributes and are then tasked to pick *K* attributes that are most dominant or describe the product best. This variation of CATA is most often applied in wine aroma research, especially when expert assessors are being used. Frequency of attribute citation is a variant of pick-*K* attributes where trained assessors are used. The main difference between CATA and Pick-*K* attributes is that the latter highlights the main sensory characteristics of a product, while CATA produces a more detailed description (Valentin *et al*., 2012).

Data are compiled into a frequency matrix and then correspondence analysis (CA) can be performed to obtain a sensory map (Valentin *et al.,* 2012). Several studies have shown that results obtained from CATA questions used with consumers are similar to those obtained from trained panels and that consumers find CATA an easy task (Ares *et al.,* 2013b).

2.5.2.2.2 Sorting

Sorting is a rapid sensory technique that consists of grouping a set of samples according to their similarities and differences. This method aims to detect sensory characteristics within a sample set that explain similarities and dissimilarities (Moussaoui & Varela, 2010). Sorting does not require any quantitative rating system and no forced agreement among panelists is required, thus this method can be used by both a trained and an untrained panel, however, minimum training is required in the application of the technique itself (Cartier *et al*., 2006).

The method has the advantage that it can be applied to a large sample set of between 9 and 20 samples , but it often needs to be combined with verbal descriptors in order to describe the groups formed (Moussaoui & Varela, 2010). Collected data are distance matrices which can be analysed by the following approaches. Firstly, by means of Euclidian map representations with MDS, DISTATIS, MCA, common components and specific weights. The second type of method gives tree representations and comprises of clustering techniques and additive trees (Chollet *et al.,* 2011). When groups are verbalized it leads to a perceptual map of which the dimensions can be explained (Cartier *et al.,* 2006). A disadvantage associated with sorting is that it does not provide quantitative information regarding the similarities and differences between samples (Valentin *et al.*, 2012).

2.5.2.2.3 Free choice profiling

Free choice profiling does not require screening or training of assessors and assessors are allowed to use any of their own descriptions to evaluate a set of samples. Data obtained can be analysed by means of generalized procrusted analysis (GPA), multiple factor analysis (MFA), and also multivariate analysis like STATIS, which provides product maps similar to PCA (Valentin *et al*., 2012).

The advantage of this method is that it is not time consuming and that assessors can be regarded as representing naïve consumers. Drawbacks include that the product map may be difficult to interpret due to the large diversity in vocabulary being used. Often the sensory analyst must then decide on the meaning of specific attributes which can lead to subjective product maps (Chollet *et al.,* 2011). Flash profiling can also be conducted in a manner where it is carried out in two separate sessions separated with an inter-session. During the first session the assessors receive all the samples simultaneously and are then tasked to describe the samples in a non-hedonic and discriminative manner. In the inter-session the sensory analyst compiles a global list with all the attributes pooled together. The aim of this session is not to obtain consensus, but rather to allow panelists to update their own list of descriptor by adding or replacing attributes. In the final session the assessors are task to rate the intensity on all the descriptors that they themselves have generated. (Valentin *et al*., 2012).

2.5.2.2.4 Flash Profiling

Flash profiling consists of a combination of free choice profiling with comparative evaluation of the product set (Moussaoui & Varela, 2010). The main aim of this method is to obtain relative rankings of a product and not to investigate product stability or evolution (Perrin *et al.,* 2007). Assessors are presented with a sample set and then tasked to rank the products according to intensity for each attribute that they themselves have generated. Assessors are thus forced into focusing on descriptors that are discriminative and non-hedonic.

The main advantage of this method is that it provides a product map in a short time frame because the phases of familiarization with the product, attribute generation, and ranking have been condensed into a single step. However, expert assessors are needed for this method and it could be difficult to interpret the sensory characteristics because of the idiosyncratic nature of the vocabulary (Chollet *et al.,* 2011).

2.5.2.2.5 Polarized sensory positioning

The basic idea of polarized sensory positioning (PSP), is to replace a large number of attributes by a few prototypical products or references acting as meta-attributes. The assessors first receive three reference products and then the rest of the sample set is presented simultaneously in a balanced and randomized design. Assessors are tasked to evaluate the three reference products and then to evaluate the rest of the sample set on a continuous scale according to the dissimilarity between the products.

This method is easy to perform and allows for data compilation across more than one sensory session, and previously obtained results were comparable to conventional DA. However, assessors are required to have good knowledge of the product space and descriptions are only obtained indirectly by deducting from the sensory characteristics of the most similar reference product.

Data can be analysed by means of two methods, including MFA or STATIS, and also by averaging the dissimilarities between the products and reference samples across assessors resulting in a product-by-reference matrix that can be submitted to MDS (Valentin *et al.,* 2012).

2.5.2.2.6 Projective mapping or napping®

Projective mapping was developed in order to collect a Euclidian configuration for each assessor in a single sensory session. According to this method, samples are presented simultaneously, and are then positioned by the assessor on a two dimensional platform according to their sensory distances in terms of similarities and differences. The samples are positioned in such a manner, that the smaller the difference separating the samples, the more similar they are (Moussaoui & Varela, 2010). The coordinates of each product on the two dimensional map constitutes the data. Data are analyzed by means of PCA, and more recently MFA, because this technique takes into account the differences between individual assessors (Chollet *et al.,* 2011). The number of samples presented should be limited to 10-20 samples in order to limit sensory fatigue. Hopfer & Heymann (2013) reported that the best data were obtained when the sample set is restricted to 12 units. Drawbacks of this method include that it does not describe the products in the sample set and it often needs to be completed with either instrumental or sensory data, or with a verbalization task (Moussaoui & Varela, 2010).

Various forms of Napping® were identified based on the holistic nature of the task, i.e. global napping where judges are not restricted to a single sensory modality and partial napping where judges are restricted to a single sensory modality like aroma or taste, and the descriptive attribute collection by combining napping with ultra-flash profiling (UFP) or simple sorting (Hopfer & Heymann, 2013).

2.6 PART 6 : Sensometrics

An important aspect of sensory analysis is the construction of a product map from sensory measurements. Data can be collected from different types of panels by means of various sensory methods, and the main objectives are to construct a map with a multidimensional view of all the products and to understand the similarities and dissimilarities between products (Cadoret & Husson, 2013). In this context, sensometrics is defined as the scientific discipline that applies mathematics, statistics and multivariate data analysis techniques to analyse sensory perception and consumer data (Nofima, 2014). The following section elaborates on some of the statistical techniques to analyse sensory data.

2.6.1 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is most commonly performed when more than two groups, treatments or products are compared using scaled responses, thus providing a way to examine differences among multiple treatments or levels and to compare several means at the same time (Lawless & Heymann, 2010). ANOVA is only used to determine whether there are significant differences between products or panellists (Anzello *et al.*, 2011). Two types of ANOVA are commonly used in practice, i.e. one-way and two-way ANOVA. The two-way ANOVA is used when an experiment has a complete block design, and is most commonly used in sensory analysis to investigate the significant differences between products and panellists (Lawless & Heymann, 2010). Three-way ANOVA can also be performed to investigate significant differences between products, panellists and replicates (Campo *et al.*, 2010). If significant differences are present, Fisher LSD post hoc test may be used to explore differences between individual products or assessors (Anzello *et al.,* 2011).

2.6.2 Correspondence analysis

Correspondence analysis functions as a graphical tool to study the symmetric association structure between categorical variables in lexical tables. It evaluates the correspondence or association between row and column variables in a contingency matrice (Beh *et al*., 2011). Correspondence analysis is most commonly used to analyse frequency based methods like verbalised sorting tasks, ultra-flash profiling (UFP) and Check-all-that-apply (CATA).

Sensory maps obtained from correspondence analysis provides a visualisation of the similarities between products, the similarities between attributes, and the associations between products and attributes (Kotov *et al*., 2014).

2.6.3 Cluster Analysis

Cluster analysis is a measurement of the dissimilarities between products. The most common dissimilarity measure is Euclidean distance. Euclidean distances can be used in studies where a positive correlation between variables indicate agreement, and a negative correlation implies disagreement. A wide range of clustering procedures are available when using Euclidean distances. The most commonly used procedures in sensory science are Ward's-linkages and *k*-means (Quannari *et al*., 1997).

2.6.4 Multiple factor analysis (MFA)

Multiple factor analysis (MFA) is a multivariate statistical technique for the analysis of multiple block data (Worch, 2013; Tomic *et al*., 2015). MFA is conducted by performing separate analysis on each block of data after which the first eigenvalue for each analysis is extracted in its inverse. This inversed eigenvalue is used as weight of the variables in each group. An overall PCA (principal component analysis) is performed on all the weighted groups. All of data blocks thus contribute equally to the construction of the first dimension of the MFA (Worch, 2013). MFA can be used to analyse the similarity between various sets of observations explained by different groups of variables. (Dooley *et al.,* 2010). MFA allows data of a different nature (quantitative, qualitative or frequency) in the same analysis (Worch, 2013).

2.6.5 R_V coefficients

The R_V coefficient is a measurement of similarity between squared symmetric matrices and takes on values of between 0 (full disagreement) and 1 (perfect agreement). It can be understood as a correlation coefficient between two individual sample spaces (Abdi *et al*., 2007; Campo *et al.*, 2010). R_V coefficients reflects the agreement between assessors or data sets by aggregating matrices to create a compromise matrix which represents their consensus (Abdi *et al*., 2007), thus providing a convenient way of measuring how similar the information in the two data matrices are (Tomic *et al.,* 2013). A favourable property of R_V coefficients is that it can measure similarities between data matrices with an unequal number of variables, providing that the number and order of objects or rows in both matrices are the same. This property made it possible for R_V

coefficients to have been applied in sensory analysis for the comparison of descriptive analysis versus rapid sensory analysis methods like napping, CATA, frequency of citation and sorting. R_V coefficients have also been used for the assessment of trained panel of assessor performance. Louw *et al.* (2013) have reported that an R_V-value of 0.5 could be considered as a good level of agreement or consensus.

2.6.6 Average reproducibility index (R_i)

The average reproducibility index (R_i) is calculated to assess the performance of individual trained panel members when working with citation based frequency data. The R_i index takes on values of between 0 and 1, and the minimum Ri required to keep a judge is 0.2 (Campo *et al*., 2010). To calculate this index two sensory replicates are required. The R_i for a single assessor is calculated as:

$$R_i = \left(\frac{1}{n}\right) \times [2 \times \frac{des_{com}}{des_{rep\,1} + des_{rep2}}]$$

In this formula:

n = the amount of wines tasted

des_{com} = the number of descriptors chosen by the judge in both sensory replicates

des_{rep1} and des_{rep2} = the descriptors chosen by the judge in the first and second sensory replicate respectively.

2.7 PART 7 : Concluding remarks

Chenin blanc is regarded the flagship variety of South African white wines. Chenin blanc can be classified according to six different styles, including fresh and fruity, rich and ripe (unwooded), rich and ripe (wooded), rich and ripe (slightly sweet), sweet and sparkling. Previous research conducted on South African Chenin blanc mainly focused in characterizing dry, semi-sweet, and old vine Chenin blanc, as well as characterizing Chenin blanc that was vinified by means of natural fermentation and extended skin contact. No research on the effect of oak on Chenin blanc exists under South African conditions.

It has been proven that oak maturation can contribute to the final quality of a wine. Regarding alternative oak products, little research have been conducted that explores that aromatic profiles of these products, as well as the evolution of these aromas, in comparison with traditional new barrels, especially when applied to the maturation of white wine.

Furthermore, little research have been conducted on how both experts and consumers perceive the use of alternative oak products in wine. Recent research have reported that certain sensory techniques can be used to evaluate how experts and consumers discriminate between products, and these can also include scaling of respectively liking and quality. One of these methods is CATA. Understanding the discriminative and hedonic perceptions of experts and consumers regarding the use of different oak treatments on Chenin blanc would be of immense importance to the South African wine industry.

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Chapter 3

Research results

The effect of different oak products used during fermentation and ageing on the sensory properties of Chenin blanc wine

The effect of different oak product used during fermentation and ageing on the sensory properties of Chenin blanc wine

3.1 Introduction

Chenin blanc grapes have a neutral taste and this neutrality is also reflected in the wine (Augustyn & Rapp, 1982). Van Rooyen *et al.* (1982) have reported that young Chenin blanc wines are often characterized by fruity aromas like guava and apples. Subsequently, many winemaking techniques that modify white wine aroma have been investigated. These techniques include reductive and oxidative vinification techniques, and the addition of SO_2 and ascorbic acid to the must (Coetzee & Du Toit, 2012; Coetzee e*t al*., 2013). The influence of extended skin contact (Coetzee *et al.*, 2012; Aleixandre-Tudo *et al*., 2015), and the use of different *Saccharomyces* and non-*Saccharomyces* yeasts and natural fermentation have also been reported (Fleet, 2003; Romano *et al.,* 2003; Clemente-Jimenez *et al.*, 2005; Weightman, 2014). Some authors have also investigated the effect of oak wood fermentation and maturation on the aroma of white wine (Rous & Alderson, 1983; Towey & Waterhouse, 1996; Perez-Coello e*t al*., 2000 ; Spillman e*t al.*, 2004).

Fermenting and ageing wine in oak barrels is an ancient tradition, and in most cases it leads to improvements in the organoleptic properties of the wine (Jarauta *et al*., 2005). From a sensory point of view, one of the main functions of oak wood is to enrich the wine with new compounds. These compounds can be divided into two categories, namely aroma active compounds that will contribute to the aroma of oak aged wines, and wood polyphenols that will contribute to the structure and taste of the wine (Tiquet-Lanvandier *et al.*, 2008). The concentrations at which these compounds are extracted during oak maturation depend on various factors. These factors include the concentration of these compounds and their precursors within the matrix of the wood, the rate of release of these compounds, the rate at which such compounds are consumed by further chemical or biochemical transformation, as well as the temperature and duration of storage (Spillman *et al*., 1998).

Traditionally, wooden barrels are used for oak maturation, however, the use of alternative oak products in old barrels or stainless steel tanks have increased options of oak maturation for winemakers (De Beer *et al*., 2008), since new barrels are expensive, require a lot of space in the winery and have a limited lifetime (Rodriguez & Gomez-Plaza, 2011). Alternative products for oak maturation that are currently being used in the industry include oak chips, powder, beans, shavings, staves and barrel inserts (Du Toit, 2010). Several studies have reported the evolution of oak derived volatiles in wine matured with alternative oak products, in some cases concurrent with micro-oxygenation, in order to replicate the maturation conditions achieved by traditional barrel ageing (Perez-Coello *et al.*, 2000; Fernandez de Simon *et al.*, 2010; Crump *et al.*, 2015). However, little of this research focused on white wines. Research on how alternative oak products compare to traditional new oak barrels from a sensory point of view and how this evolve over time is also limited.

The aim of this current research is to investigate the influence of traditional and alternative oak regimens on the sensory properties of Chenin blanc during a maturation trail. The wine for the maturation trail was vinified on a commercial scale. After three respective intervals of ageing the wine was subjected to sensory evaluation by both an expert panel and a trained panel using the Pick-*K*-attributes method.

3.2 Materials and methods

3.2.1 Grape origin and vinification procedures

Chenin blanc grapes of the 2014 vintage were used for this research. The grapes were sourced from Phisantekraal Vineyards located in the Tygerberg region in the Western Cape of South Africa. The grapes were harvested mechanically, and 20 mg/L of ascorbic acid (Protea chemicals, South Africa) and 40 mg/L of metabisulphite (Protea chemicals, South Africa) were added to the grapes after which it was transported to the Bellingham pressing cellar located in Wellington, South Africa.

Upon arrival at the cellar's crushing pan, 30 mg/L of metabisulphite and 40 mg/L of ascorbic acid were added to the grapes. During destemming, tartaric acid (Brenn-O-Kem, South Africa) and pectolytic enzyme (Lafazym Extract, Laffort, South Africa) additions were made at dosages of 0.5 g/ton and 20 g/ton respectively. The destemmed grapes were pumped slowly through a mash cooler and had an outgoing temperature of 12°C before going into the pneumatic press. No skin contact was applied and after separating the free run juice, the mash was pressed until a pH change of 0.2 occurred in the pressed juice. In total, 14 tonnes of grapes were pressed and 8626 L of free run juice was obtained at a recovery of 616 L/ton.

All bulk movements of the free run juice occurred under reductive conditions with the usage of nitrogen gas sparging. The settling tank analysis are shown in table 3.1. In the settling tank, of which the cooling was set on a temperature of 0°C, the total SO_2 and titratable acidity (TA) was adjusted to 40 mg/L and 7 g/L respectively. Settling enzyme (Lafazym CL, Laffort, South Africa) was also added at a dosage of 3 g/hL. The juice was left to settle for 48 hours after which it was racked to the fermentation tank along with approximately 1% of the fine lees. In total, 8360 L of juice was racked to the fermentation tank. The fermentation tank analysis are shown in table 3.1.

Table 3.1 Chemical analysis of the Chenin blanc juice in the settling tank and fermentation tank.

	Balling	TA	pH	TSO2	Glucose:Fructose	YAN
Settling Tank Analysis	25,4	5,77	3,77	21	Na.	Na.
Fermentation Tank Analysis	25,1	6,32	3,35	44,8	138:133	162

The temperature of the juice in the fermentation tank was raised to 12°C, after which it was inoculated with a yeast mixture of D254 (Lallemand, Lavin, South Africa), Cy3079 (Lallemand, Lalvin, South Africa), L2056 (Lallemand, Lalvin, South Africa) and D47 (Lallemand, Lalvin, South Africa) at a dosage of 30 g/hL. This specific yeast mixture is used for all barrel fermented white wines at Bellingham, because it is able to ferment at higher temperatures without producing any off flavours (Groenewald, D.P., 2015). The balling and temperature of the must was monitored daily. After 48 hours and 96 hours of alcoholic fermentation, the must was supplemented with 15 g/hL of Fermaid-K, a nitrogen supplement with added complex nutrients. The must was transferred to the respective maturation vessels after 3 g/100ml of sugar was consumed by the yeast (described in section 3.2.2). The reason for initiating alcoholic fermentation in a stainless steel tank and only moving it to the respective treatment vessels after the consumption of 3 g/100mL of sugar, was to achieve a homogenous fermentation rate in all the treatment barrels. Before filling, all barrels were prepared by means of the cold water method. A sulphur strip was burned in the 5th fill barrels the day prior to filling.

At the end of alcoholic fermentation (residual sugar < 5 g/L), the wine in all the maturation vessels received an addition of 30 mg/L SO_2. The barrels were topped with wine from the original tank, and was then left to mature in a controlled environment with a temperature of 16°C and a humidity that varied between 65 and 75%. The wine in the original tank was moved to a smaller tank and stored at 16°C for the duration of the experimental trial.

3.2.2 Maturation treatments

The maturation trial consisted of four main experimental treatments as represented in figure 3.2.2. The first treatment, a tank containing 2000 L wine of the same origin, served as the unoaked control for this study. The second treatment entailed the use of 5th fill barrels from the same cooperage, serving as the oaked control wines.

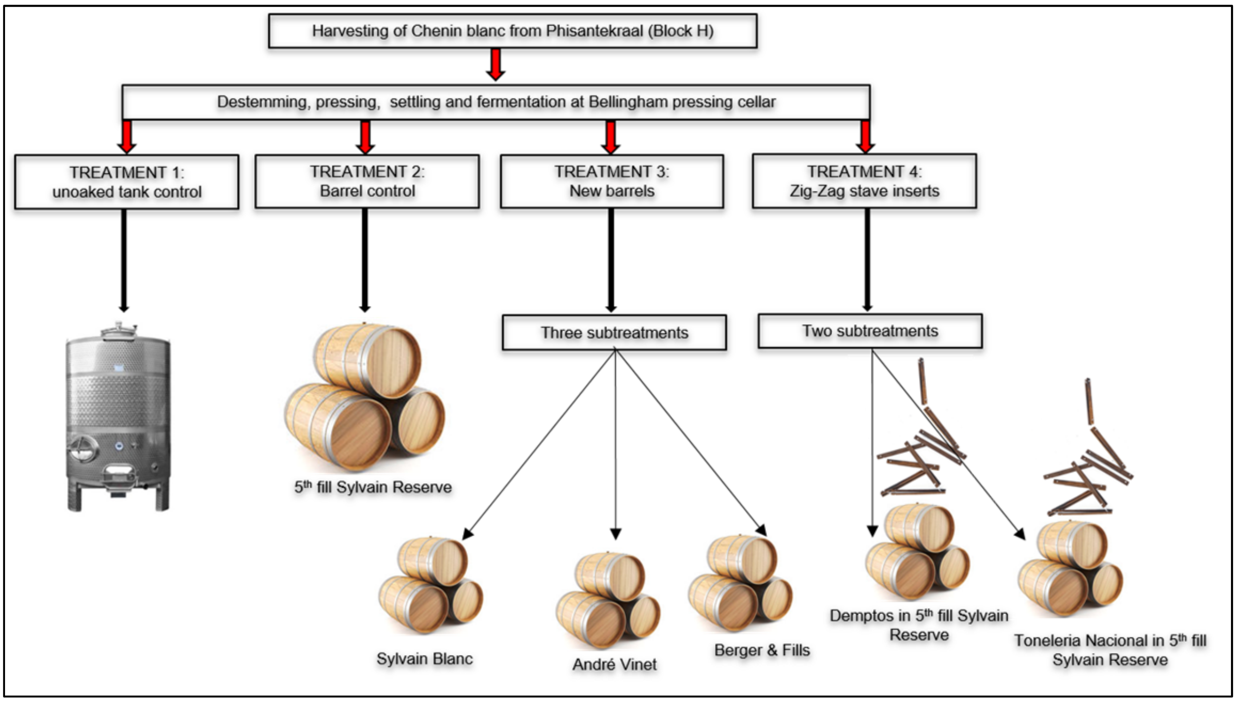

Figure 3.1 Schematic representation of winemaking process and different treatments.

Treatment three which consisted of three new types of new barrels (3a-3c), is listed in table 3.2 In each subdivision new French oak barrels, with the same toasting level, of different cooperages were used.

Table 3.2 Detailed description of new barrels used in treatment 3.

Treatment	Cooperage	Barrel type	Capacity	Oak origin	Toasting level
3a	Sylvain	Hogshead	300L	French oak	MT
3b	André Vinet	Hogshead	300L	French oak	MT
3c	Berger & Fills	Hogshead	300L	French oak	MT

The fourth experimental treatment which consisted of alternative oak products (4a-4b), is listed in table 3.3. The 5th fill barrels for this treatment were of the same cooperage and vintage as those used in the second experimental treatment. The wines matured in the 5th fill oak barrels (second treatment) thus served as a direct control for the stave treatments to investigate the influence of the barrel matrix with and without the addition of staves. The barrel inserts were customised to have 40% of the internal surface area of a 300L barrel, thus replicating the effect of a new barrel (Du Toit, 2010). All of the treatments, except for the unoaked tank control, were performed in triplicate. Only one biological repeat was used for the tank wine due to cellar space and the availability of small volume tanks in the commercial cellar.

Table 3.3 Detailed description of oak staves used in treatment 4 (stave dimensions are presented in the order of length, width and thickness).

Treatment	Cooperage of old barrel	Capacity	Cooperage of Zig-Zag stave insert	Stave dimensions (cm)	Origin of oak	Toasting level
4a	Sylvain	300L	Toneleria Nacional	35 × 3.2 × 4	French oak	MT
4b	Sylvain	300L	Demptos	45 × 2.5 × 1	French oak	MT

3.2.3 Wine sampling and storage

After 4 months maturation, wine was sampled from every individual treatment vessel into 10 L stainless steel canisters. The barrels were then topped with the same wine from a stainless steel tank. The free SO_2 was adjusted to 35 mg/L with Sterisol (EnolTech, EVER INTEC, Australia). The canisters were transported to the experimental cellar at the Department of Viticulture and Oenology, University of Stellenbosch. The free SO_2 was measured for every canister and was then adjusted to 35 mg/L with a 2.5% SO_2 solution. The canisters were stored at -4°C for two weeks before it was bottled in 750 ml green Burgundy bottles (Consol, XPRS, South Africa) and sealed with saranex screw caps. After bottling, the wines were stored in a controlled environment with an ambient temperature of 16°C until the time of sensory analysis.

After 9 months of maturation, wine was sampled again from every individual treatment vessel. The same protocol was followed as described for the 4 month sampling, except that 20 L samples were taken at this interval. A portion on this wine was used for immediate sensory analysis, and the rest of the wine was subjected to bottle maturation for a further 6 months in a controlled environment with an ambient temperature of 4°C.

3.2.4 Sensory analysis

Sensory analysis was performed on the wines after the following intervals of wine maturation: 4 months oak maturations (4OM), 9 months oak maturation (9OM), and 9 months oak maturation with an additional 6 months bottle ageing (9OM6BA). These specific intervals were chosen because it represents the two typical periods of oak ageing in industry. The bottle ageing interval was added because often commercial cellars mature wine in bottles before the releasing thereof. Nineteen Chenin blanc wines were evaluated during each session of testing by both an expert panel and a trained panel. The reason for using both panels was to determine if they could deliver similar results. This is of importance for industry, since many cellars do not have the facilities or resources to train panels, but they do have experts. In this sense an expert would be defined as a person with extensive experience with a specific product (Reinbach et al., 2013). The Pick-*K*-attributes method was used, since this method is rapid and it can accommodate the evaluation of a large sample set. Pick-*K* attributes is a variant of Check-All-That-Apply (CATA), where panellists are restricted to picking *K* attributes that describe the product best (Valentin *et al*., 2012).

3.2.4.1 Pick-*K*-attributes using a trained panel

3.2.4.1.1 Panel

The Department of Viticulture and Oenology, University of Stellenbosch, has a trained panel of 35 members that is used for frequency based sensory experiments. For this project a panel consisting of 20 trained panellists was used at all three time intervals of sensory analysis. Panellists were recruited based on their availability during the specific time frame of testing. The panel did not consist of the same people at each testing interval, but all panellists that participated received the same training. The panel of 20 members that evaluated the wines after 4OM, consisted of 15 females and 5 males. At the 9OM and 9OM6BA intervals, the panel consisted of 16 females and 4 males. The age of the panellists varied between 22 and 58, with an average age of 26.

3.2.4.1.2 Panel training

The panel received general training once a week for 13 sessions according to the method suggested by Campo *et al.* (2008). A training session typically consisted of two parts. During the first part of the training session the panellists were presented with 12-16 aroma standards which they had to smell and identify. During the second part of the session the judges were presented with 3-4 wines. They were tasked to smell the wines and write down the 3-5 most prominent descriptors. The panel then discussed each wine and the panel leader highlighted the descriptors that were used most frequently amongst the panellists. During the training period of the panel, all of the descriptors on the Chenin blanc aroma wheel was covered (CBA, 2013) (ADDENDUM A; ADDENDUM B). One week prior to testing, the panel also received Chenin blanc specific aroma standards and four wines; one from each main experimental treatment in this maturation trail.

3.2.4.1.3 Evaluation

The trained panel evaluated the single sensory modality, namely the aroma of the wines, in duplicate. Testing of the wines took place in an air conditioned and light controlled environment (ISO NORM 8589, 1988) secluded from extraneous noise and odours (Lawless & Heymann, 2010). The wines that were to be evaluated were removed from the 16°C fridge a day before testing and was stored at 20°C. The wines were poured 1 hour before testing. Samples of 30 mL were presented in ISO NORM (1977) approved black glasses labelled with random three digit codes and covered with Petri dish lids. The wines were then randomized according to a Williams design latin-square and presented in three flights. The first two flights consisted of 6 wines and the third flight of 7 wines. The panellists were provided with a tasting sheet (ADDENDUM C), and were then tasked to pick a minimum of 3 and a maximum of 5 descriptors that best describe each sample. After each flight of testing, a 10 minute break was enforced to limit fatigue of the judges.

3.2.4.2 Pick-*K*-attributes using an expert panel

An expert panel consisting of 25 winemakers with a minimum of 5 years' experience were recruited from the industry. The panel consisted of both males and females. The age of the panellists varied between 24 and 58, with an average age of 39. The expert panel received no formal sensory training and only evaluated the sample set of 19 wines (table 3.4) once for every testing interval. The same testing procedures as described for the trained panel were followed.

Table 3.4 Detailed description of encoded Chenin blanc wine samples.

Wine	Treatment	Treatment detail	Code
A	1	Tank control	TC
B	2a	Barrel control	BC_1
C	2b	Barrel control	BC_2
D	2c	Barrel control	BC_3
E	3a_1	Sylvain blanc	B1_1
F	3a_2	Sylvain blanc	B1_2
G	3a_3	Sylvain blanc	B1_3
H	3b_1	Berger & Fills	B2_1
I	3b_2	Berger & Fills	B2_2
J	3b_3	Berger & Fills	B2_3
K	3c_1	André Vinet	B3_1
L	3c_2	André Vinet	B3_2
M	3c_3	André Vinet	B3_3
N	4a_1	Demptos	S1_1

Table 3.4 (cont.)

Wine	Treatment	Treatment detail	Code
O	4a_2	Demptos	S1_2
P	4a_3	Demptos	S1_3
Q	4b_1	Toneleria Nacional	S2_1
R	4b_2	Toneleria Nacional	S2_2
S	4b_3	Toneleria Nacional	S2_3

3.2.5 Data analysis and statistics

Sensory data were captured on paper ballots and entered into Microsoft Excel 2013 (www.microsoft.co/excel). Statistical analysis was done using STATISTICA 12® (www.StatSoft.com) according to the protocol for analysing frequency data as described by Campo *et al.* (2010). Contingency tables were constructed with wine samples in rows as the objects, and attributes in columns as the variables. The number of citations of each attribute for a specific wine sample was counted. Some of the lesser cited attributes that could be regarded synonyms of part of aroma families were grouped together. Attribute grouping was done at the discretion of a panel of sensory scientists. Correspondence analysis (CA) was conducted on the contingency tables. Hierarchical cluster analysis (HCA) with Euclidean distances and Ward's linkages was performed on the first two dimensions of the CA to identify clustering of samples.

3.3 Results and discussion

3.3.1 Fermentation kinetics and post fermentation wine analyses

The balling (°B) and fermentation temperature of each fermentation vessel were recorded daily. The average of the balling and temperature obtained is represented in figure 3.2. After 20 days of alcoholic fermentation all the wines were fermented to dryness.

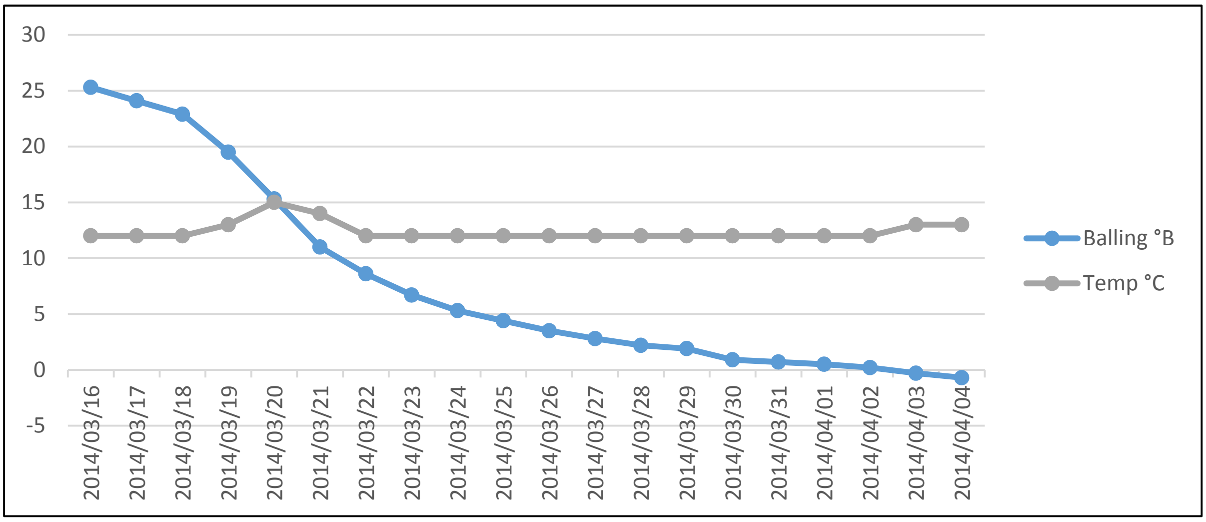

Figure 3.2 Fermentation chart representing the sugar consumption and fermentation temperature.

The final wine analyses for all the different treatments were performed using the Foss Analytical Winescan (Winescan note 180, 2001, Denmark). Results are shown in table 3.5 One-way ANOVA was performed on the chemical analyses using STATISTICA 12® (www.StatSoft.com). There were no significant differences ($p = 0.05$) between the different wines in terms of post alcoholic fermentation chemical analysis (ADDENDUM D).

Table 3.5 Chemical analysis of Chenin blanc wines post alcoholic fermentation.

Treatment	RS (g/L)	Alcohol (%)	TA (g/L)	pH	VA (g/L)
TC	2.6	13.52	6.13	3.16	0.37
BC1	2.4	13.84	6.12	3.16	0.42
BC2	2.4	13.83	6.12	3.16	0.38
BC3	2.2	13.74	6.08	3.17	0.42
B1_1	2.7	13.44	5.98	3.17	0.47
B1_2	2.8	13.38	6.02	3.16	0.47
B1_3	2.1	13.81	6.05	3.18	0.45
B2_1	2.2	13.76	5.87	3.18	0.37
B2_2	2.4	13.36	5.92	3.18	0.40
B2_3	2.3	13.82	6.24	3.15	0.41
B3_1	2.6	13.47	6.14	3.16	0.37
B3_2	2.4	13.81	6.12	3.16	0.42
B3_3	2.9	13.32	6.11	3.16	0.35
S1_1	2.5	13.29	5.93	3.18	0.43
S1_2	2.4	13.85	5.87	3.18	0.45
S1_3	2.6	13.50	6.02	3.17	0.41
S2_1	2.6	13.58	5.96	3.18	0.40
S2_2	2.5	13.61	6.13	3.16	0.42
S2_3	2.5	13.57	6.08	3.16	0.50

3.3.2 Sensory analysis

3.3.2.1 Sensory profile of Chenin blanc wines after 4 months oak maturation (4OM)

The bi-plot obtained from the data showed clear separation of the different treatments along F1, which explained 26.9% of the variance (fig 3.3). The two different stave treatments (S1_1 to S1_3 and S2_1 to S2_3) were separated from the rest of the treatments on F2, which explained 23.6% of the variation. In total, 50.6% explained variance was captured by F1 and F2.

The tank control wine was associated with lemon, pineapple and peach descriptors. The barrel control treatments showed satisfactory biological repeatability and were correlated to dried apple, yeast, papaya, pear and planky characters. These aromas are similar to those reported by Weightman (2014) in a study that investigated the effect of natural fermentation versus those that were inoculated. In this study wine from the same origin was also fermented in 5th fill barrels and the sensory properties was determined by means of projective mapping and Pick-*K* attributes.

The new barrel treatments (B1_1 to B1_3, B2_1 to B2_3 and B3_1 to B3_3) were grouped together with satisfactory biological repeatability. The biological repeatability in terms of clustering of the treatments were identified by the hierarchical cluster analyses that were performed on the CA plots (ADDENDUM E). The wines matured in the new oak barrels were associated with oak derived descriptors, including vanilla, caramel, roasted coffee, toasted bread and oaky. The first subcategory in this treatment (B1_1 to B1_3) had the strongest fruit character of the new barrel treatments after 4 months oak maturation, being associated with both the oak derived descriptors and also some fruity descriptors, including guava, apricot, grapefruit and yellow apple.

There was variation within in the stave treatments along F2, with the first treatment (S1_1 to S1_3) being associated with planky, peach, pear, apricot, grape fruit, yellow apple and dried apple. The second stave treatment (S2_1 to S2_3) was associated banana, honey, raisin and solvent/chemical descriptors. This was not unexpected, since the staves came from two different cooperages. Due to the differences in stave lengths between the S1 and S2 treatments (table 3.3), 30 and 32 staves were respectively used per barrel in the S1 and S2 treatment. Thus the stave size of the S1 treatment was smaller than the S2 stave size. It can be said that the variation between the different staves were more prominent than the variation between different barrels for this specific experiment when described by wine experts at this interval of ageing.

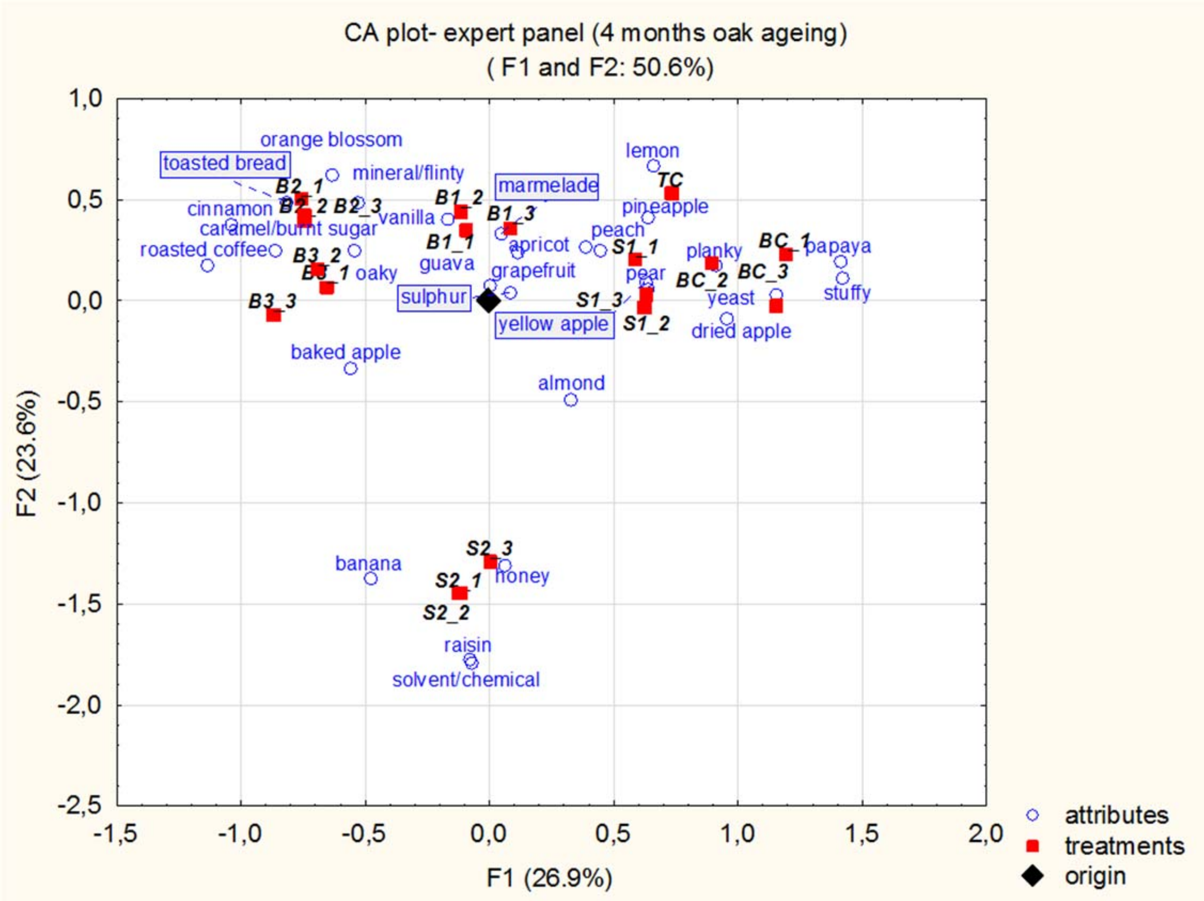

Figure 3.3 Correspondence analysis of the Pick-*K* data obtained with the expert panel (n=25) after 4 months of oak maturation. Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

Bautista-Ortin *et al.* (2008) have suggested that the size of oak chips and staves have an influence on the extraction rate of oak derived compounds, and that most oak derived compounds are extracted faster in smaller staves where the total contact area of the staves with the wine is larger than what would be the case with larger staves. In French barrels wine is only in contact with the side of the individual staves of a barrel, but when staves are used as an alternative oak product, wine comes into contact with the heads of the stave as well. The penetration of wine through stave heads is deeper than penetration through the sides, which could also explain the higher extraction from a stave (Laurie, R.,2015). This might be a possible explanation for the planky aroma that was correlated to the S1 stave treatment. The planky aroma might also be the result of *(E)*-2-nonenal. This compound is associated with undesirable sawdust and sappy aromas that are sometimes detected in wines matured in contact with new French oak (Chatonett & Dubourdieu, 1998). Toasting reduces the concentration of *(E)*-2-nonenal, but since each cooperage has its own toasting methods the composition of the heated oak can vary greatly (Campbell *et al*., 2005).

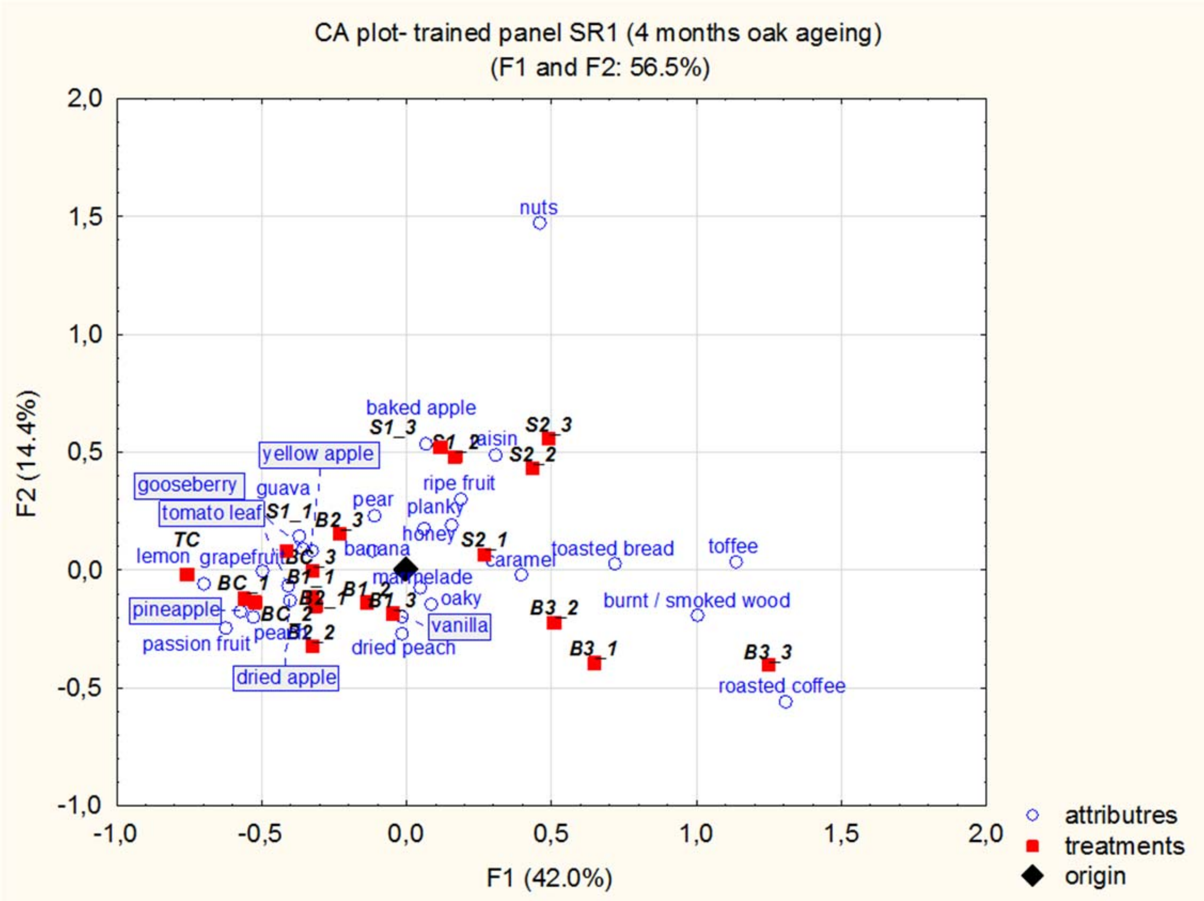

Figure 3.4 Correspondence analysis of the Pick-*K* data obtained with the trained panel (n=20) after 4 months of oak maturation (first sensory replicate). Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

In both sensory replicates of the data obtained from the trained panel (fig 3.4 and fig 3.5) the unoaked tank control (TC) was associated with fruit driven descriptors, which included lemon, grapefruit, pineapple and passionfruit. The barrel control treatments (BC) were associated with fresh fruit descriptors (peach, grapefruit and guava) and some dried fruit descriptors, which included dried apple and dried peach. Considering the treatments with new barrels, B1_1 to B1_3 were associated with roasted coffee, burnt/smoked wood, caramel and toffee characters, with this phenomena being most clear in the second sensory replicate. The other treatments within this subcategory were associated with generic oak descriptors including oaky, vanilla and toasted bread. It was also correlated to marmalade, yellow apple and dried apple descriptors.

As with the bi-plot from the expert panel data, the stave treated wine samples were affected the most with separation on F2, being associated with baked apple, honey, raisin, planky and dried apricot. The biological repeatability of the stave treatments after 4 months oak maturation was more discriminant in the second sensory replicate.

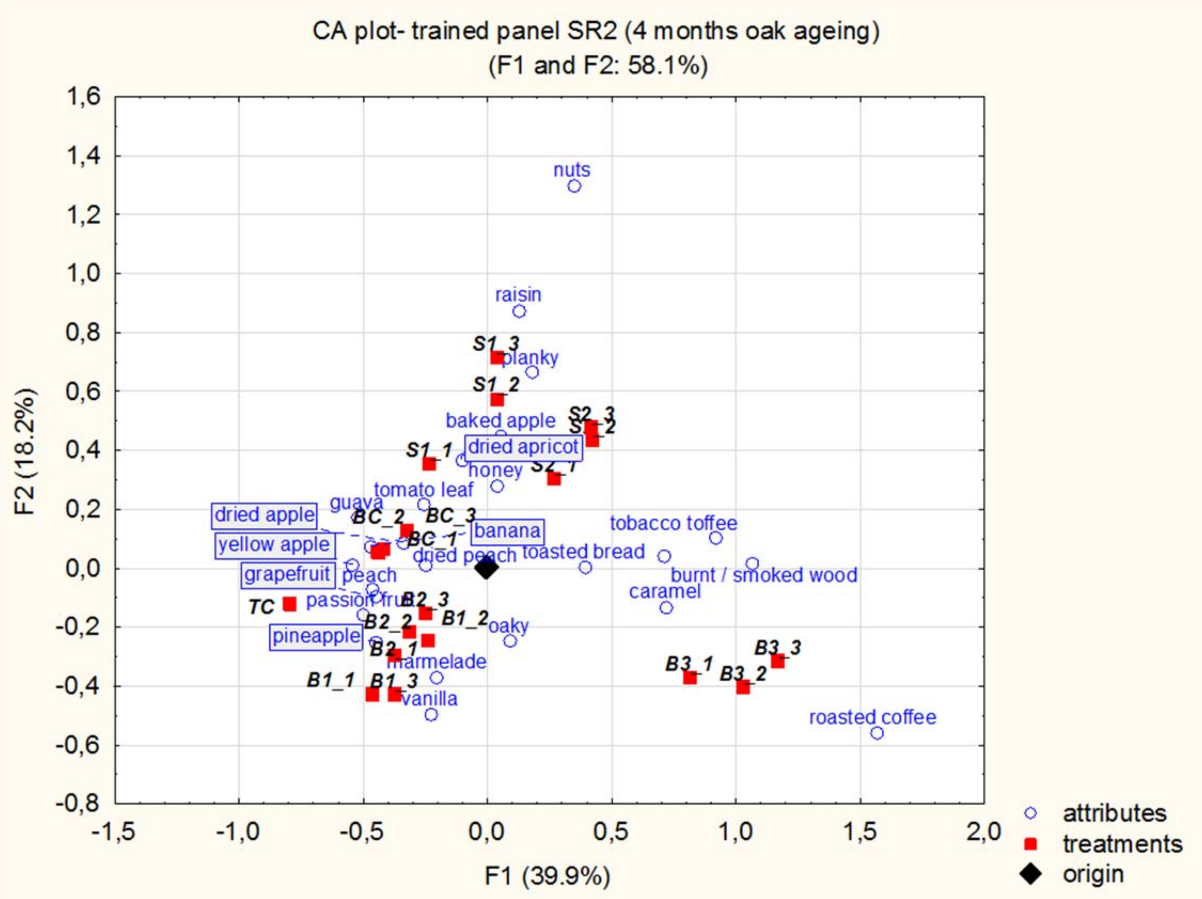

Figure 3.5 Correspondence analysis of the Pick-*K* data obtained with the trained panel (n=20) after 4 months of oak maturation (second sensory replicate). Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

3.3.2.2 Sensory profile of Chenin blanc wines after 9 months oak maturation (9OM)

The bi-plot obtained from the expert data indicated separation of the wine treatments on F1, which accounted for 25.4% of the explained variation, and F2, which explained 18.0% of the variation. In total, F1 and F2 captured 43.4% explained variance (fig 3.6). As with the bi-plot obtained after 4 months oak maturation, there were separation of the different treatments on F1 in terms of the fruitiness of the wine, with the fresh fruit wines on the left and the oak driven wines on the right. The stave treatments are affected the most with separation on the F2 axis.

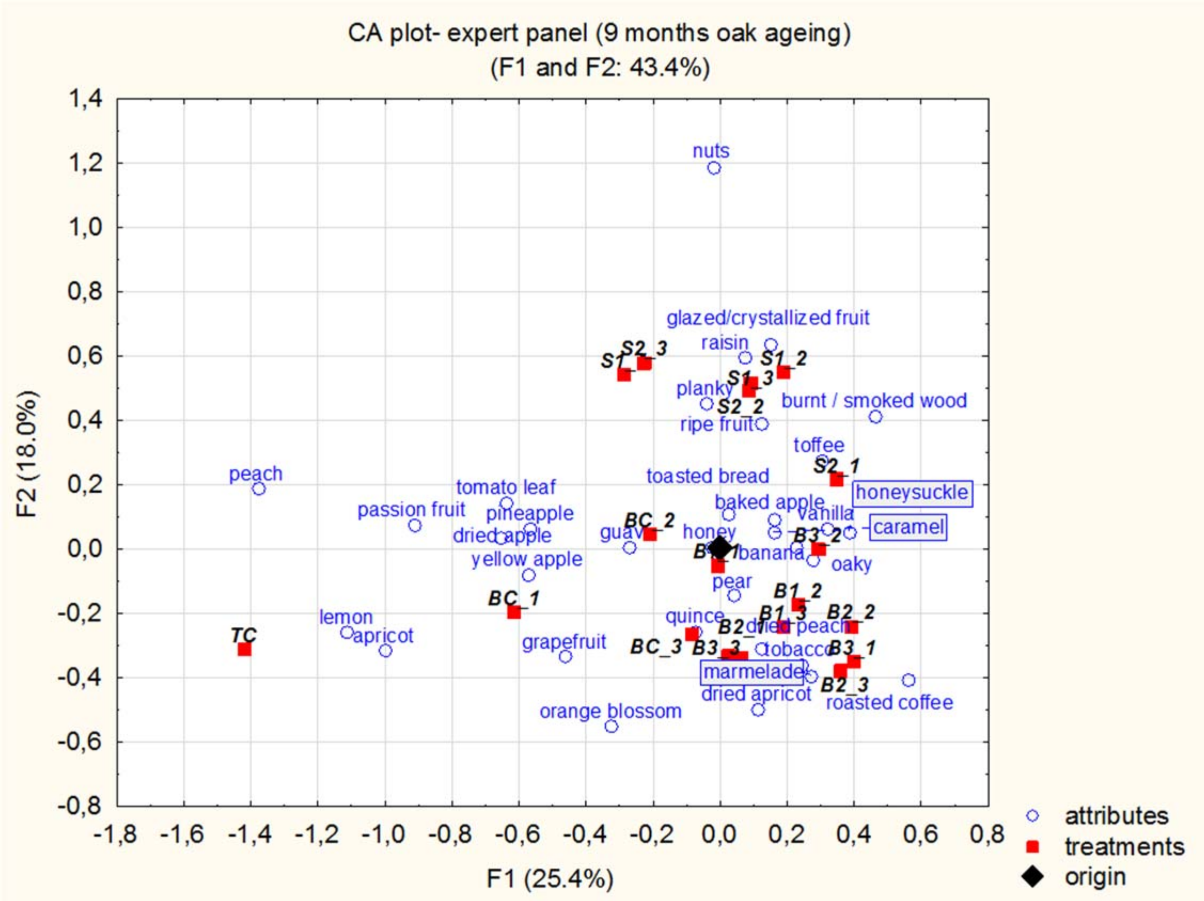

Figure 3.6 Correspondence analysis of the Pick-*K* data obtained with the expert panel (n=25) after 9 months of oak maturation. Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

The unoaked tank control wine was clearly separated from the oaked treatments, being associated with lemon, peach and apricot. The biological repeatability of the barrel control treatments have decreased from 4 months to 9 months oak maturation. Even though extensive measures were taken to select 5th fill barrels exposed to the same wines and conditions, this decrease in biological repeatability might be attributed to differences in the composition of the 5th fill barrels (Towey & Waterhouse, 1996). The composition of barrels can be affected by the alcohol concentration and acidity of the wines that were previously matured in it. The pool of possible extractives can also be influenced by previous storage temperatures and humidity, as well as the maintenance of the barrels. Variation in the porosity of the barrels due to the sedimentation of salts and minerals caused by ageing on lees can also influence the resulting aroma profiles (Singleton, 1995; Perez-Prieto et *al*., 2002). BC1 was associated with yellow apple and grapefruit, while BC2 and BC3 were associated with quince and guava, respectively.

The bi-plot obtained from the data of the first sensory replicate of the trained panel after 9 months of oak maturation showed a main separation of the treatments on F1, which accounted for 26.7% of the explained variance (fig 3.7). F2 accounted for 18.3% explained variance, and in total F1 and F2 captured 45.0% explained variance. In the second sensory replicate, F1 and F2 accounted for respectively 25.9% and 19.3% of the 45.2% explained variance (fig 3.8).

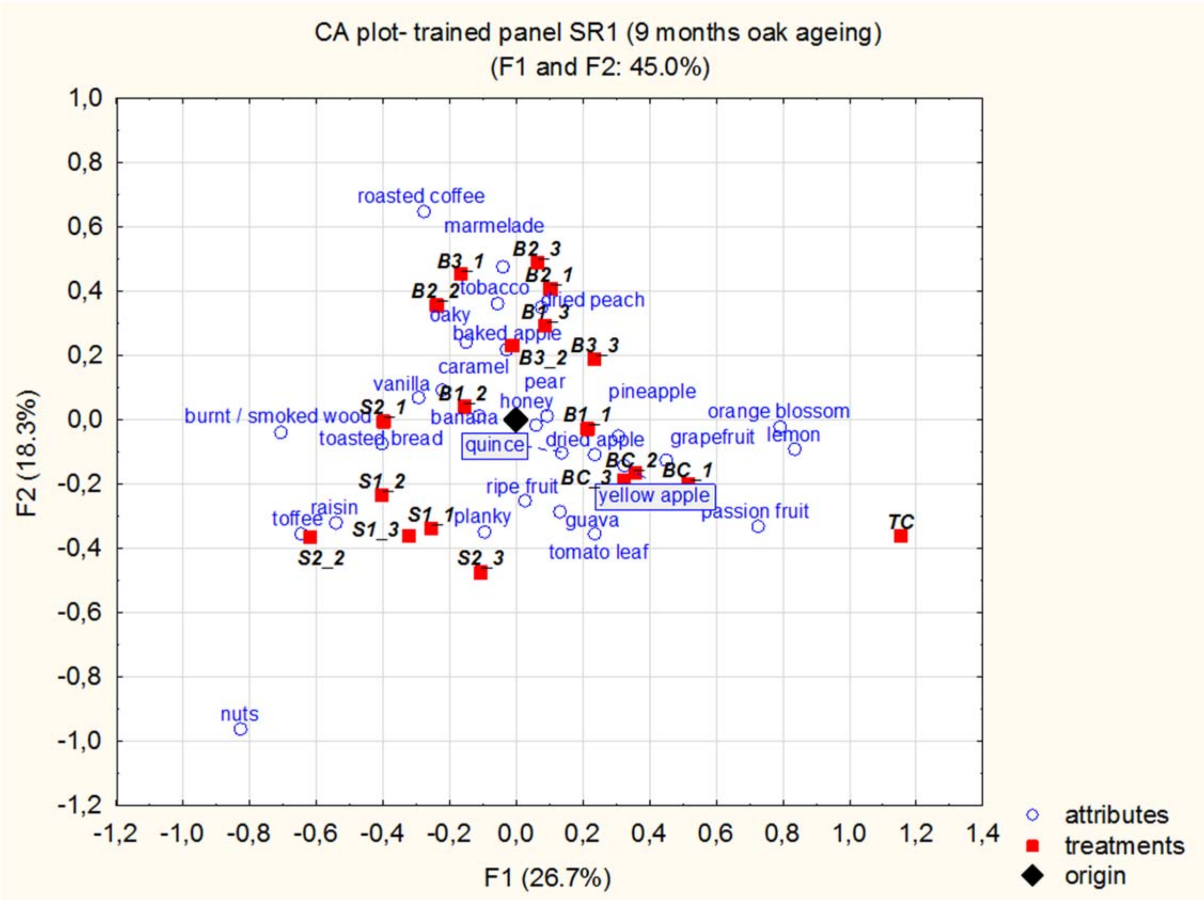

Figure 3.7 Correspondence analysis of the Pick-*K* data obtained with the trained panel (n=20) after 9 months of oak maturation (first sensory replicate). Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

In the bi-plots obtained from the data of both sensory replicates there was a clear discrimination between the tank control, barrel control and stave treatments on F1, while the new oak barrel treatments were better separated on the F2 axis. The tank control wine was associated with passionfruit, dried apple and orange blossom descriptors. The barrel control treatments were associated with honey, grapefruit, yellow apple, pineapple and planky descriptors.

All of the stave treatments were associated with ripe fruit, glazed fruit and burnt/smoked wood aromas, except for S2_1 which showed a strong positive correlation to toffee and toasted bread. In general, the wine samples from the first new barrel treatment (B1_1 to B1_3) had the most fruit associated character of all the new barrel treatments, being associated with pineapple, guava, banana, pear, yellow apple, grapefruit, dried apricot and dried peach. It was also associated with oak derived descriptors, including vanilla, toasted bread and oaky. The other wines matured in new barrels were less driven by fresh characters, being associated with more dried, ripe and oak derived descriptors, including roasted coffee, caramel and oaky.

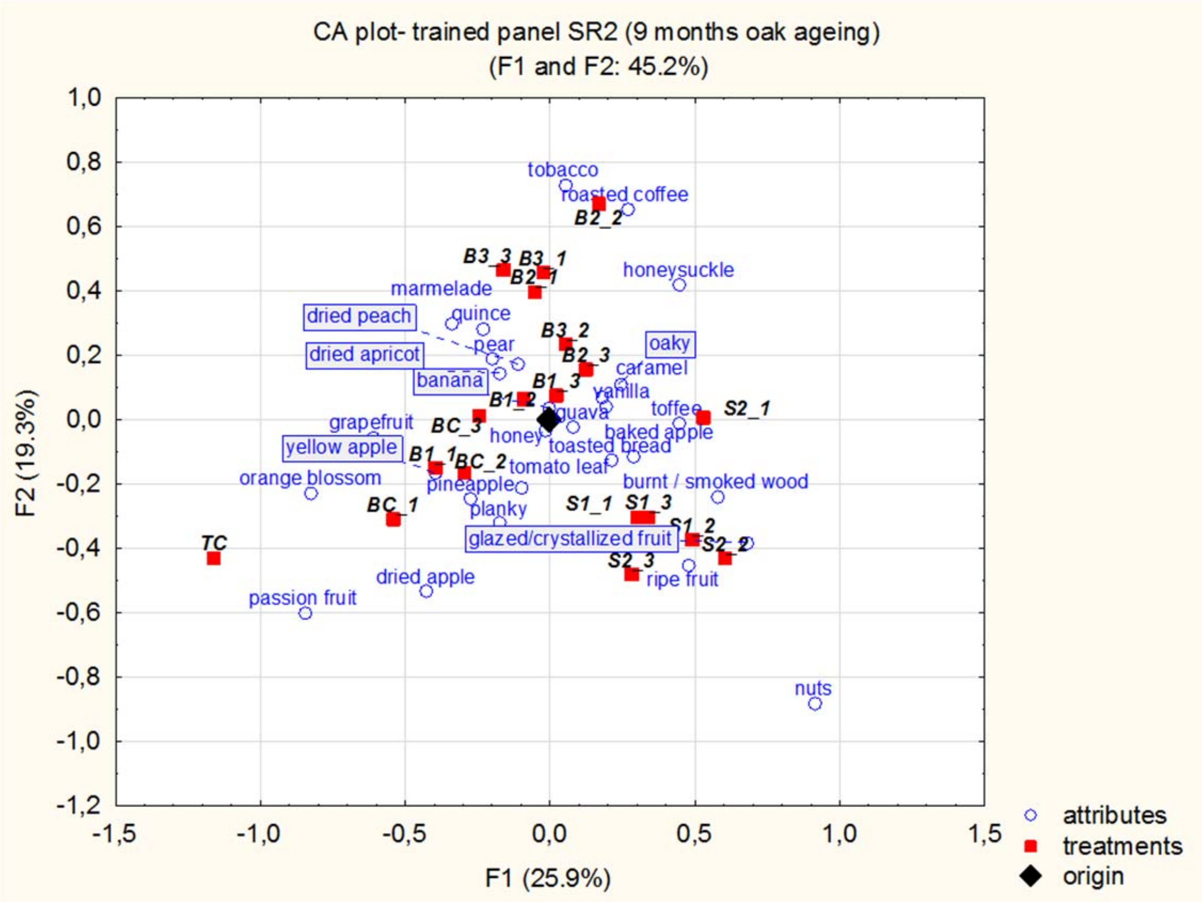

Figure 3.8 Correspondence analysis of the Pick-*K* data obtained from the trained panel (n=20) after 9 months of oak maturation (second sensory replicate). Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

3.3.2.3 Sensory profile of Chenin blanc wines after 6 months bottle ageing (9OM6BA)

The bi-plot obtained from the expert panel data showed separation of the treatments on F1, which explained 28.9% of the variance (figure 3.9). The stave treatments were clearly separated on F2, which explained 14.7% of the variance. In total, F1 and F2 captured 43.6% explained variance.

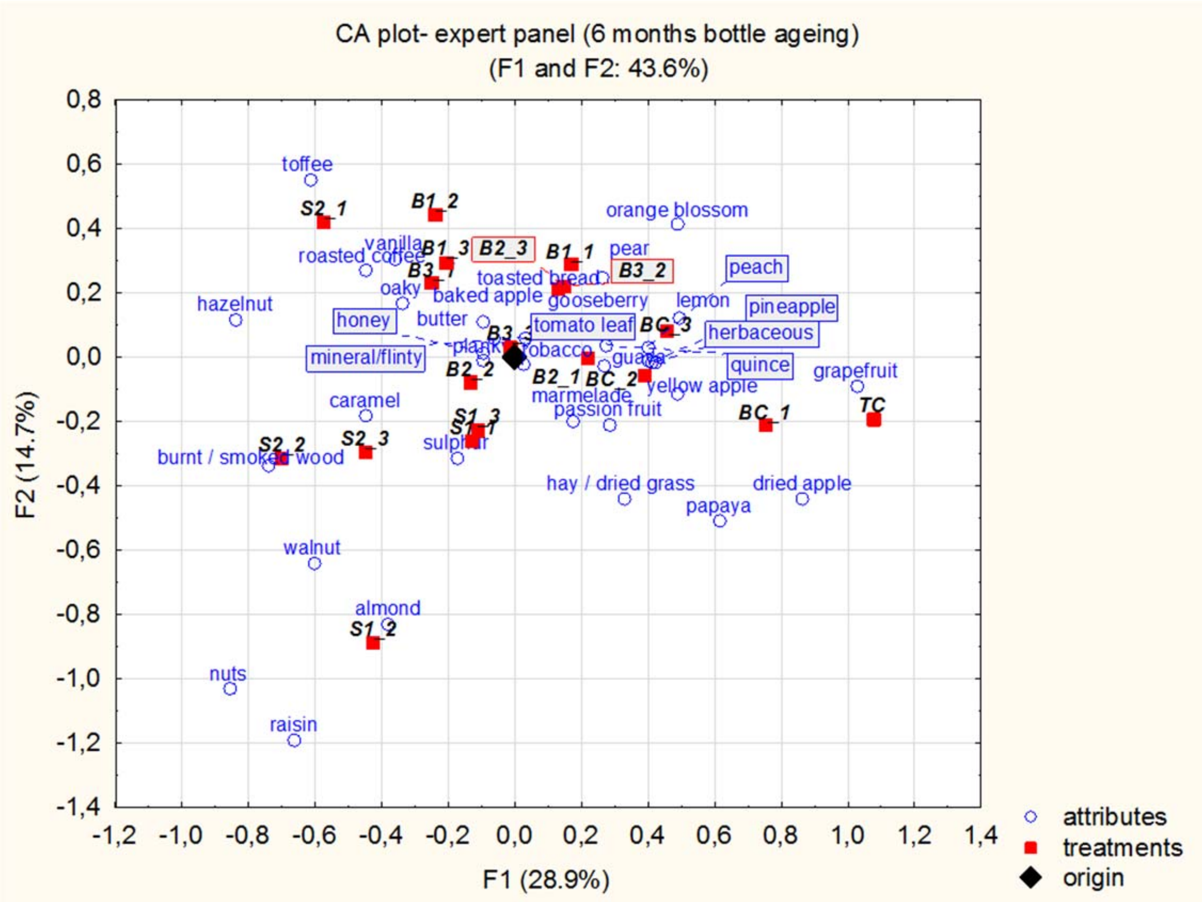

Figure 3.9 Correspondence analysis of the Pick-*K* data obtained with the expert panel (n=25) after 9 months of oak maturation and 6 months bottle ageing. Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

The stave treatments showed the weakest intra clustering of all the treatments. S1_2 were associated with nutty and raisin descriptors, while S1_1 and S1_3 were associated with sulphur and caramel characters. S2_1 was associated with toffee, roasted coffee and vanilla descriptors, while S2_2 and S2_3 were associated with caramel and burnt/smoked wood aromas. All of the wines matured in the new barrels were associated with oaky aromas which included vanilla, roasted coffee, butter, toasted bread and caramel. It was also associated with ripe ageing characters including baked apple, tomato leaf, honey and marmalade. The barrel control treatments were associated with dried characters which included descriptors like hay, dried apple and tobacco. It was also associated with some fruity descriptors like yellow apple, passionfruit, pineapple and guava. The tank control treatment was separated the furthest from oak related descriptors, being associated with grape fruit, yellow apple and dried apple.

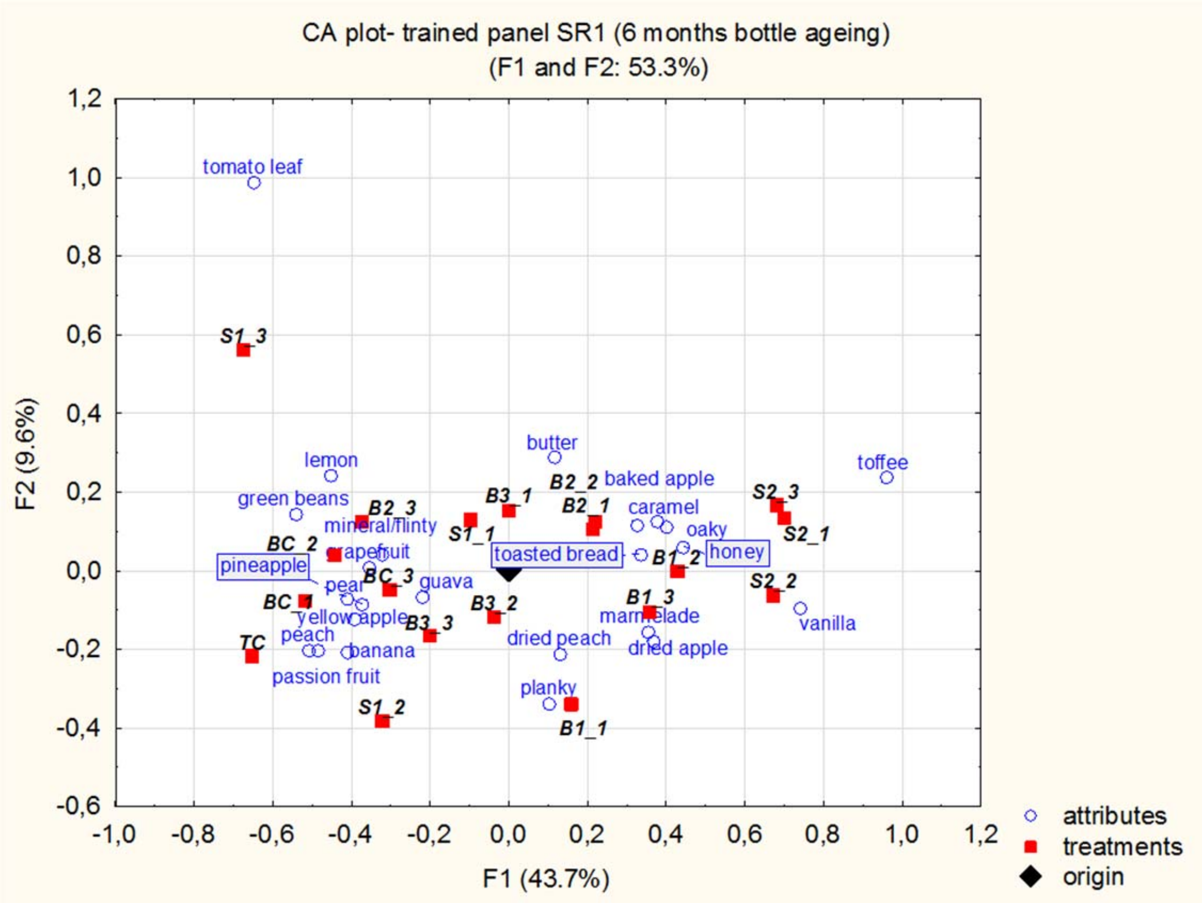

Figure 3.10 Correspondence analysis of the Pick-*K* data obtained with the trained (n=20) after 9 months of oak maturation and 6 months bottle ageing (first sensory replicate). Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

A cumulative variance of 53.3% was explained in the bi-plot obtained from the data of the first senory replicate of the trained panel, with F1 explaining 43.7% and F2 explaining 9.6% of the variance (fig 3.10). In this bi-plot, a clear separation of the treatments was visible along F1, with the S1_3 treatment being an outlier on the F2 axis. The tank control and barrel control wines were associated with fresh fruit aromas including yellow apple, grapefruit, peach, banana and passionfruit. The treatments matured in new oak barrels were related to oaky (caramel, toasted bread, planky) and dried (baked apple, marmalade, dried peach) characters. Considering the stave treatments, S2_1 to S2_3 were associated with toffee, vanilla and honey aromas. S1_1 was associated with butter and toasted bread aromas, while S1_2 was related to fruiter descriptors including passionfruit and banana. S1_3 was separated the furthest by F2 and had a herbaceous character, being associated with tomato leaf, green beans and lemon aroma descriptors.

The bi-plot obtained from the data of the second sensory replicate of the trained panel did not follow the same aromatic trends as the first sensory replicate (fig 3.11). A cumulative variance of 51.8% was explained, with F1 and F2 capturing respectively 35.9% and 15.9% of the variance.

In agreement with the first sensory replicate, the tank control and barrel control treatments were associated fruity descriptors, including banana, passionfruit, pineapple, guava and peach. Also in accordance with the first sensory replicate, are the new barrel treatments that were associated with oaky (vanilla, roasted coffee, butter, planky) and dried (marmalade, dried fruits, dried peach, dried apple) descriptors.

The stave treatments were projected differently from the bi-plot of the first sensory replicate. S2_1 was associated with roasted coffee and planky descriptors, while S2_2 and S2_3 were associated with sweet associated descriptors like baked apple and ripe fruit. S1_1 and S1_2 were associated with toasted bread, toffee, caramel and burnt/smoked wood descriptors. S1_3 was separated from S1_1 and S1_2, being associated with yellow apple.

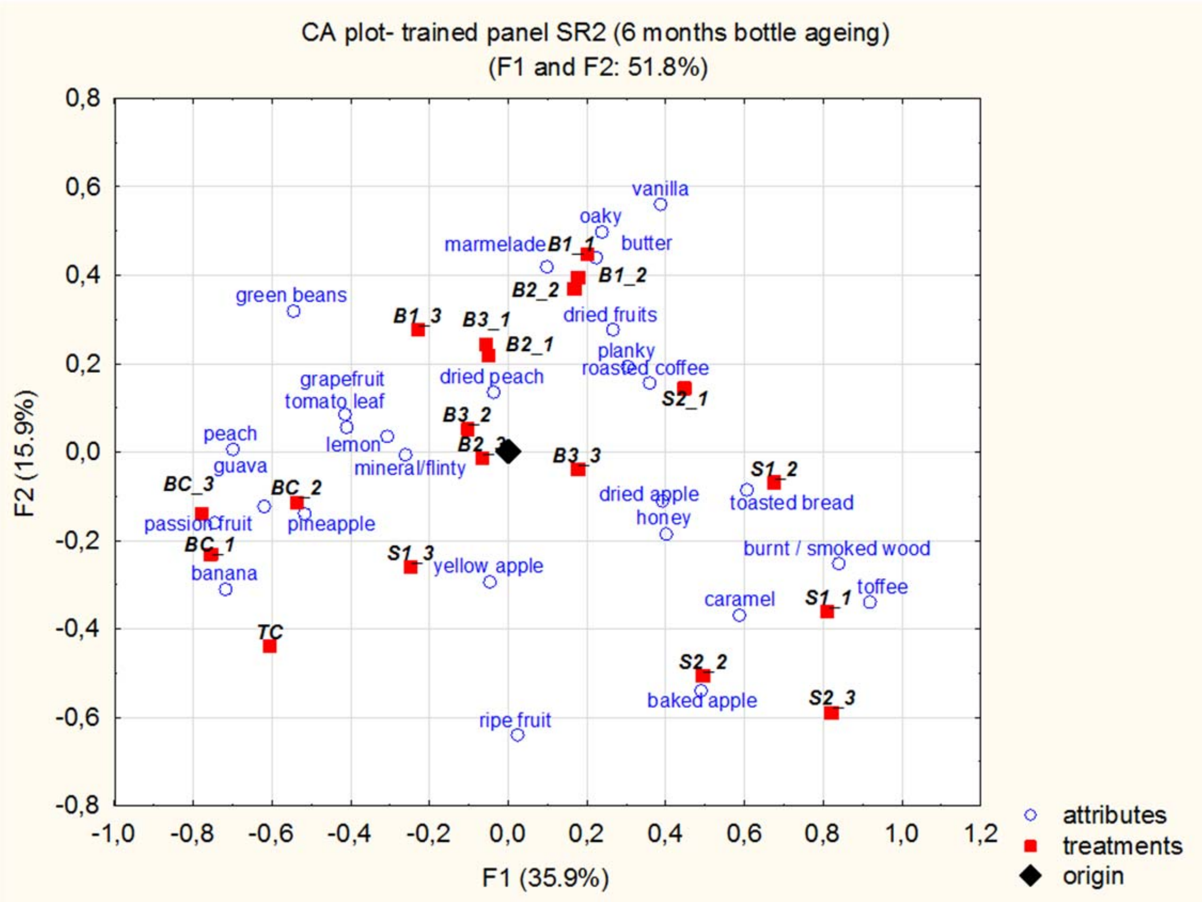

Figure 3.11 Correspondence analysis of the Pick-*K* data obtained from the trained panel (n=20) after 9 months of oak maturation and 6 months bottle ageing (second sensory replicate) (Obtained from STATISTICA 12®).

At all three intervals of ageing, no oak related descriptors were used to describe the tank control wine. It can therefore be said that both the expert panel and trained panel recognised the tank control as being unoaked. The tank control wine evolved from having strong citrus and pineapple characters after 4 months ageing to having more stone fruit (apricot and peach) and ripe characters of banana, dried peach and baked apple after 6 months of bottle ageing. Similar to the unoaked tank control, the panels also picked up that the influence of oak in the barrel control wines were minimal. This is attributed to the fact that most of the oak derived aroma compounds are diminished through leaching during previous fills (Singleton, 1995). The effect of the staves were clearly detectable in the 5^{th} fill barrels, since the stave treatment wines differed immensely from the 5^{th} bill barrel control wines. A trend that became visible with the barrel control wines were that the amount of attributes used by both the expert panel and trained panel to describe the aroma profiles of the wines became more. This might be an indication that the wines became more complex with ageing.

After 4 months oak ageing the expert panel and trained panel profiled the first stave treatment with fruity aromas (peach and pear) and also a planky character, while the second stave treatment was profiled with ripe characters of honey, banana and raisins. After nine months the profiles of the two stave treatments were similar, being associated with raisin, caramel, toffee, honey and burnt/smoked wood characters. The similarity in these aroma profiles is an indication that the initial higher extraction suggested by the S1 treatment after 4 months ageing disappeared, implying that the S2 treatment had a slower rate of extraction which could be the result of the bigger size of the staves. These aromas observed after 9 months maturation persisted in the bottle aged wines.

Considering the treatments with new oak barrels, grouping of some of the biological repeats were seen after 4 months oak ageing. This led to one of the treatments having a strong coffee character in all three biological repeats, and another treatment having a strong vanilla character. However, this phenomena did not occur after 9 months oak ageing and 6 months bottle ageing, suggesting that the cooper effect of new barrels diminish after a certain period of ageing. The poor discriminability between different coopers can also be reported as a weakness of the CATA approach, since it is not able to capture specific quantitative differences. After 9 months oak ageing with an additional 6 months bottle ageing all the wines matured in new barrels had similar aroma profiles of dried fruit, marmalade and oak derived descriptors like caramel and vanilla. The loss of fruitiness was more prominent in the wines matured in contact with the new barrels than the wines matured in the 5^{th} fill barrel control wines. These results are similar to the findings of Perez-Prieto *et al*. (2002) who have reported that old barrels retain more fruitiness, due to it having a lower porosity, thus resulting in less evaporation. Du Toit *et al*. (2006) have also reported that oak maturation can have a masking effect on the fruitiness of the wines.

Although no chemical analysis were performed to quantify and compare between the oak derived compounds in the different treatments, there were clear differences in the descriptors used to discriminate between the new barrel treatments and the stave treatments. The wines matured in new barrels were associated more with aromas derived from the seasoning and toasting process than the wines that were matured in contact with staves. The aromas associated with the new barrels include vanilla, caramel, roasted coffee and toasted. The burnt/smoked wood and planky attributes associated with the stave treatments might be an indication that the wines had a strong oaked character.

This can be attributed to the differences in the extraction kinetics between the staves and barrels as well as possible differences in the composition of the cooperage wood used to manufacture barrels and alternative staves. The extraction of oak derived compounds into barrel-aged wines is probably a longer, more continuous process than what is the case when staves are used. In the case of barrels, the extraction of oak derived compounds takes longer because of the time it takes for the wine to penetrate the oak and for the oak derived compounds to permeate back into the wine (Bautista-Ortin *et al*., 2008). Considering cooperage wood, Du Toit (2010) reported that the type of cooperage oak can have a significant influence on the extraction of oak derived aromas. In a study investigating the extraction of oak lactones with the application of different micro-oxygenation and oak treatments, significant differences were found in the concentration of *cis*-oak lactones extracted from staves produced from oak wood normally used to produce barrels, and staves produced from oak wood normally used for stave production. The extraction from the staves produced from barrel cooperage wood was comparable to the concentration of *cis*-oak lactones extracted from new barrels, while the extraction from normal alternative staves was significantly lower.

3.4 Conclusions

The main aim of this study was to investigate the effect of different oak products on the aroma profile of Chenin blanc wine at different intervals of maturation. The study was performed on a commercial scale to replicate industrial conditions.

Clear differences were observed between the different treatments at all three maturation intervals. The data obtained from the expert panel and trained panel delivered results portraying the same trend of aromatic profiles for the different treatments at the different intervals.

There were clear differences between the unoaked and the oaked wines, and also between the different oak treatments. A clear discrimination could be made between the wines that were aged in new barrels and the wines that were aged in 5th fill barrels with staves. There seems to exist a difference in the rate of release of oak derived compounds, and it is clear that longer maturation leads to a more oaky aroma profile. Longer maturation in contact with oak also leads to loss of fruitiness, with this effect being most prominent in the wines matured in new barrels. Wine producers could thus use staves or barrels to achieve a different outcome in terms of the sensory composition of Chenin blanc wine.

Further investigations into the effect of specific oak treatments will require chemical analysis and sensory descriptive analysis or rank-all-that-apply (RATA) to qualify and quantify differences between the different oak treatments.

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Chapter 4

Research results

The influence of different oak products on the sensory properties, perceived quality and consumer liking of Chenin blanc wines

The influence of different oak products on the sensory properties, perceived quality and consumer liking of Chenin blanc wines

4.1 Introduction

Information about the sensory and hedonic characteristics of wine is critical for product development and marketing (Ares *et al.,* 2013b). Sensory profiling provides a guideline for product developers in terms of which sensory properties result in the desired sensory profile for consumers. It also provides a method for detecting differences created by a change in processing or manufacturing (Moussaoui *et al*., 2010). Traditionally analytical sensory measurements are elicited from trained or expert panels, and consumers studies are performed to obtain hedonic or affective information. (Moussaoui *et al.*, 2010; Giacalone *et al*., 2013).

To understand the relationship that exists between descriptive sensory data and the hedonic consumer data, preference mapping is a useful method that have been used by various researchers. (Bernabéu *et al.*, 2013; Giacalone e*t al.,* 2013; Hopfer e*t al.,* 2014). Dooley e*t al.* (2010) defines preference mapping as a widely used group of multivariate statistical techniques that are designed to optimize products spaces by understanding the structure between consumer preference and analytical sensory data to identify the drivers of liking.

Some researchers in the field of sensory and consumer research advocate the elicitation of descriptive data from consumer panels, since it is argued that consumers may take variables into account that are not deemed important by trained or expert panellists (Ares *et al*., 2013b). To this extent, various rapid sensory profiling methods have been developed to accommodate untrained panellists in descriptive sensory research. Some of these methods include sorting, mapping, Napping® and check-all-that-apply (CATA) questions (Varela, 2012). It has also been reported that consumer data generated by these methods are comparable to the data generated by trained panels (Moussaoui *et al*., 2010; Giacalone *et al*., 2013; Ng *et al*., 2013; Reinbach *et al*., 2014; Ares *et al*., 2013a).

CATA, in particular have gained popularity, due to its ease and rapidity of use. Furthermore, it can be used to elicit analytical and hedonic data concurrently (Ares *et al.*, 2014). The CATA method have also been used by some researchers to construct preference maps to identify the drivers of liking (Dooley e*t al.,* 2010; Ares e*t al.,* 2014; Ares *et al*., 2015). Ares *et al.* (2015) reported that sensory characterizations obtained using CATA questions concurrently with hedonic assessments are unlikely to be biased and that the use of CATA questions concurrently with hedonic assessments is an adequate method to obtain information about consumers' preference and their sensory perception of products.

Sensory and consumer research can be based on intrinsic or extrinsic cues. Intrinsic cues refer to factors that can be affected by changes in processing and manufacturing, including aroma, flavour and mouthfeel (D'Alessandro *et al.*, 2013). Extrinsic cues refer to visual factors that may affect sensory perception, e.g. brand name, label and region or country of origin (Hopfer e*t al*., 2014). The focus of this study was to gain descriptive and hedonic information based on intrinsic cues, specifically on the effect that different oak products have on the sensory and hedonic properties of Chenin blanc wine.

In most cases, oak maturation leads to an improvement in the organoleptic properties and perceived quality of wine (Jarauta *et al*., 2005; Crump e*t al*., 2015). All ten wines that formed part of the annual Standard Bank Top 10 Chenin blanc challenge in 2014 received oak maturation, while this was the case for nine of the ten wines that received this prestigious award in 2015 (CBA, 2015). This supports the notion of various wine professionals that oak maturation contributes to wine quality.

The use of alternative oak products like shavings, beans, chips and staves has become a common practice in the South African wine industry (Du Toit, 2010). While several studies have reported the evolution of oak derived volatiles and aromas of wines matured with alternative oak products (Crump *et al*., 2015), research comparing new barrels with alternative oak products is limited, especially for white wine. In addition, few studies have investigated consumers' degree of liking of wines matured with alternative oak products, and so far no research has been conducted on the comparison of sensory and hedonic data elicited from both consumers and experts using the same sensory evaluation method.

The main aim of this current research was to investigate and compare the discriminative and hedonic sensory profiles of Chenin blanc wines matured with different oak products, using both an expert panel and a consumer panel. This research was conducted using CATA and its variant Pick-*K* attributes, since this sensory evaluation methods are suitable for usage with both expert and consumer panels.

The knowledge gained from this study will enable winemakers to draw definitive conclusions regarding the value that both expert and consumer tasters place on the use of oak products, and whether there is a detectable significant difference in the perception of different oak products.

4.2 Materials and methods

4.2.1 Wine samples

The sensory evaluation was performed on nineteen Chenin blanc wines that formed part of a commercial maturation trial which consisted on four main experimental treatments. These treatments included an unoaked tank control wine, oaked control wines matured in 5th fill barrels, wines matured in new barrels of three different cooperages, and wines matured in 5th fill barrels with stave inserts from two different cooperages. All of the treatments had three biological replicates, except the tank control wine of which there was only one biological replicate. The wines were evaluated after a period of 9 months in the individual maturation vessels, with an additional 6 months of bottle maturation. The vinification procedure of the different wine treatments were described in Chapter 3 in sections 3.2.1 and 3.2.2. A detailed description of the wine samples are represented in table 4.1.

Table 4.1 Detailed description of encoded Chenin blanc wine samples.

Treatment code	Treatment Description	Biological replicates	Graph codes
TC	Tank control (unoaked)	1	TC
BC	Barrel control (5th fill)	3	BC1 BC2 BC3
B1	Sylvain blanc 1st fill barrels	3	B1_1 B1_2 B1_3
B2	Berger & Fills 1st fill barrels	3	B2_1 B2_2 B2_3
B3	Andre Vinet 1st fill barrels	3	B3_1 B3_2 B3_3
S1	Demptos stave inserts	3	S1_1 S1_2 S1_3
S2	Toneleria Nacional stave inserts	3	S2_1 S2_2 S2_3

4.2.2 Assessors

4.2.2.1 Expert panel

Based on the definition by Piggot *et al*. (1995), an expert panel consisting of 25 South African winemakers with a minimum of 5 years' experience was recruited from the wine industry. The panel consisted of 13 males and 12 females. The age of the panelists varied between 24 and 58 years, with an average age of 39. The expert panel received no formal sensory training prior to the sensory evaluation.

4.2.2.2 Consumer panel

According to Lawless *et al.* (2010) a large group of consumers of between 75 and 150 people is necessary to obtain reliable results. An untargeted consumer panel (n= 104 consumers) consisting of 61 females and 43 males with an average age of 36 was recruited from Stellenbosch and the surrounding area. The consumer panel received no formal sensory training prior to the sensory evaluation session.

4.2.3 Sensory evaluation

Testing of the wines took place in an air conditioned and light controlled environment (ISO NORM 8589, 1988) secluded from extraneous noise and odours (Lawless & Heymann, 2010). The wines that were to be evaluated were removed from the 16°C fridge a day before testing and were stored at 20°C. Samples of 30mL were poured 1 hour before testing in ISO NORM (1977) approved glasses.

Testing of the wines were carried out in two sessions. In the first session, panellists received the wine samples in ISO NORM (1977) approved black glasses labelled with random three digit codes and covered with Petri dish lids. The wines were randomized across panellists according to a Williams latin-square design and presented in three flights. During this session the panellists were provided with a tasting sheet (ADDENDUM C) and were asked to only evaluate aroma as a single sensory modality. The expert panel was tasked to pick a minimum of three and a maximum of five descriptors that best describe the wine samples. The consumers had no limitations on the amount of attributes they could pick, as is standard with CATA, and were tasked to pick all attributes they deemed appropriate for describing the wine samples. In the second session, panellists received the wine samples in ISO NORM (1977) approved clear glasses that were also randomized according to a Williams latin-square design. During this session, the expert panellists were asked to indicate the quality of the wine samples on a 9-point scale (table 4.2.3.1) (Torri e*t al*., 2013), while the consumer panellists were asked to indicate their liking of the wine samples on a 9-point scale (Table 4.2) (Lawless & Heymann, 2010). During this session panellists were provided with water and crackers, and were advised to expectorate the wines. In the first session black glasses were used since aroma was the only sensory modality that was evaluated. Considering sensory quality, various sensory modalities, including visual appearance can be a contributing factor, thus clear glasses were provided (Lawless & Heymann, 2010).

Table 4.2 Code descriptions for the 9-point liking and quality scales.

Liking scale	Description	Quality scale	Description
L9	like extremely	Q9	Excellent
L8	like very much	Q8	very good
L7	like moderately	Q7	Good
L6	like slightly	Q6	fairly good
L5	neither like nor dislike	Q5	neither good nor bad
L4	dislike slightly	Q4	fairly poor
L3	dislike moderately	Q3	Poor
L2	dislike very much	Q2	very poor
L1	dislike extremely	Q1	extremely poor

4.2.4 Statistical analysis

Data were entered into Microsoft Excel 2013 (www.microsoft.co/excel). Statistical analyses were performed using STATISTICA 12® (www.StatSoft.com). Overall liking and quality scores were analysed using analysis of variance (ANOVA), considering the wine treatments as the fixed source of variation and the consumers and experts as a random effect. A 5% significant level was used for all the ANOVA analyses. The descriptive sensory data were analysed according to the protocol for analysing frequency data as described by Campo *et al.* (2010). Attributes cited by less than 20% of the panellists were either combined or discarded from the data sets. Attribute grouping was done at the discretion of a panel of sensory scientists. Contingency tables were constructed with wine samples in rows as the objects, and attributes in columns as the variables and correspondence analyses were performed. In addition, the R_V coefficient was calculated on the coordinates of the CA plots to investigate consensus between the expert and consumer panels.

The sensory quality data was converted from continuous data to categorical data by counting the number of citations for each point on the 9-point scale. This was done for all the wine samples. Contingency matrices were constructed with wine samples in the rows as objects, and the attributes and hedonic CATA counts in columns as variables. Multiple factor analysis (MFA) was performed on these contingency matrices to investigate the relationship between the descriptive attributes and the hedonic responses (Kidd, 2015). MFA can be used to analyse the similarity of various sets of observations explained by different groups of variables on comparable or contradictory scales (Dooley *et al.,* 2010).

4.3 Results and discussion

4.3.1 Comparison between sensory product maps

The CA bi-plot obtained from the consumer panel showed separation of the different treatments along F1, which captured 31.1% explained variance (figure 4.1). F2 captured 17.7% explained variance and separated the treatments based on the different types of oak treatments. In total, 48.8% of explained variance was captured by F1 and F2.

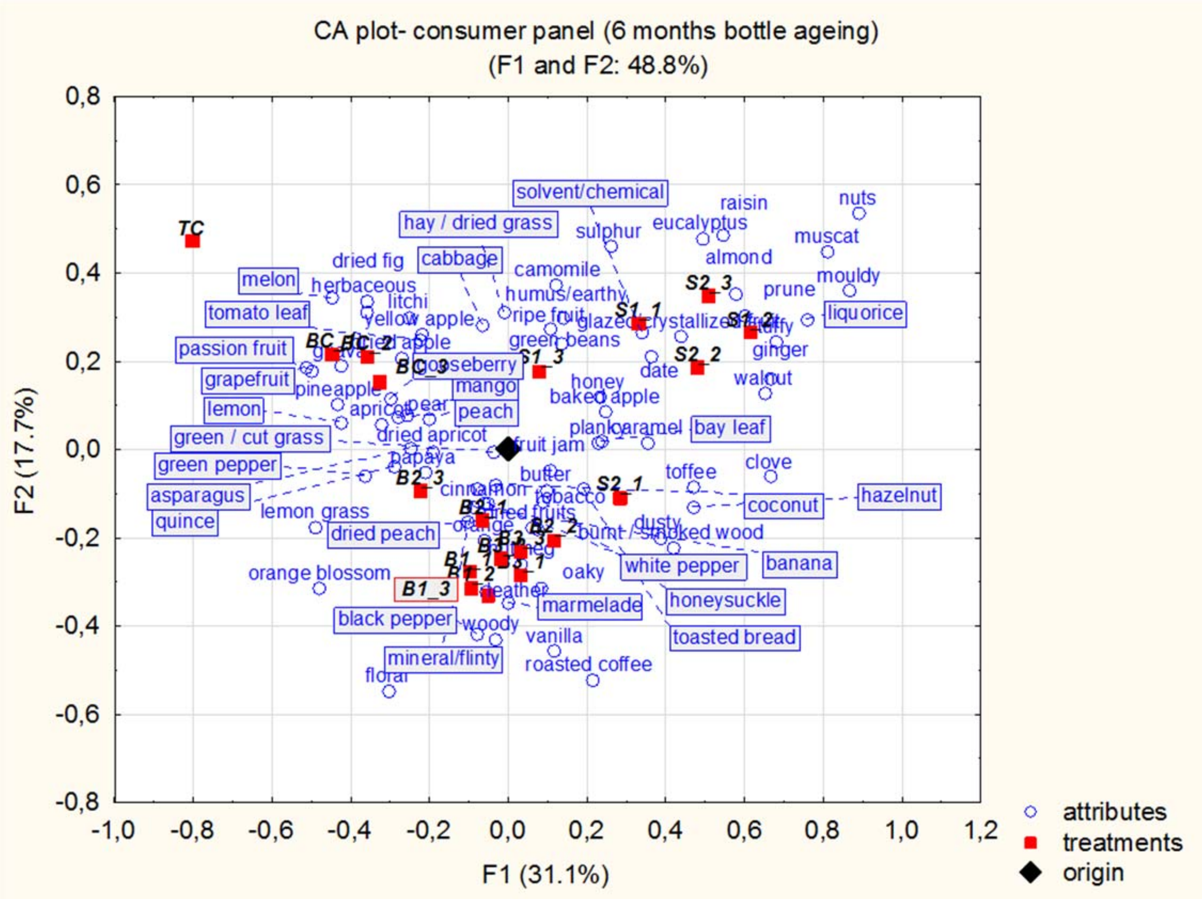

Figure 4.1 Correspondence analysis of the CATA data obtained with the consumer panel (n=104) after 9 months of oak maturation and 6 months bottle ageing. Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

Clustering of main treatments are visible. The unoaked tank control (TC) wine was separated the furthest from the other treatments and was correlated to fruity and green characters, including melon, dried fig, litchi, yellow apple and herbaceous. Of all the oaked treatments, the BC wines were the closest to the TC wine. These wines were correlated to an array of various descriptors which ranged from fruity (litchi, passionfruit, pineapple, grapefruit, pear) to green (asparagus, green pepper, green/cut grass and herbaceous). The wines matured in the new barrel treatments were clustered together, being associated with oaky descriptors like vanilla, woody, roasted coffee, vanilla and toasted bread. It was also associated with ripe and dried aroma descriptors like fruit jam, dried peach, dried fruits and tobacco. Of all the main treatments, the stave treatments showed the weakest treatment clustering, especially S1_3 and S2_1. The stave treatments were generally associated with nutty, planky, dried, spicy and earthy characters.

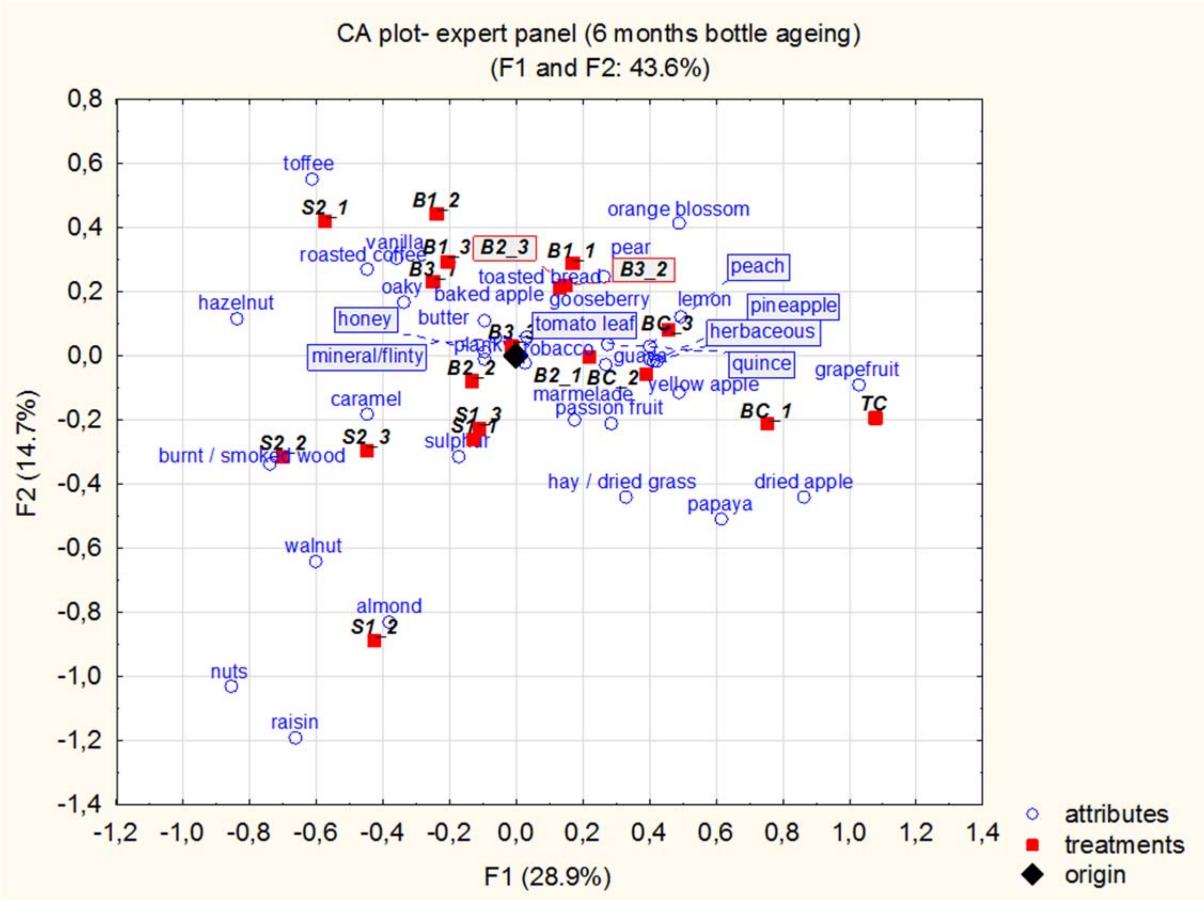

Figure 4.2 Correspondence analysis of the Pick-*K* data obtained with the expert panel (n=25) after 9 months of oak maturation and 6 months bottle ageing. Boxed descriptors indicate those which have been moved to improve the readability of the plot (obtained from STATISTICA 12®).

The CA bi-plot obtained from the expert panel data showed clear separation of the different wine treatments along F1, which captured 28.9% of the variance (figure 4.2). F2 showed a clear separation of the stave treatments and captured 14.7% of the explained variance. In total, F1 and F2 captured 43.6% explained variance.

The TC wine was separated the furthest from all the oak related descriptors, being correlated to fruity descriptors like grapefruit, dried apple and papaya. The barrel control wines were the closest to the TC wine and was correlated to aroma descriptors that are associated with dry and green attributes including hay, tobacco and herbaceous. It was also correlated to some fruity descriptors like yellow apple, passionfruit and guava. Similar to the consumers, the experts also found these wines to be herbaceous. All of the wines matured in new barrels were correlated to oak related descriptors like vanilla, roasted coffee, butter, toasted bread and caramel. It was also correlated to some ageing characters like baked apple and marmalade. The stave treatments showed the weakest treatment clustering. S1_2 was correlated to nutty and raisin descriptors, while S1_1 and S1_3 were correlated to sulphur and caramel. S2_1 was correlated to toffee, roasted coffee and vanilla descriptors, while S2_2 and S2_3 were correlated to caramel and burnt/smoked wood aroma descriptors.

The R_V coefficient between the CA plots obtained from the expert panel and trained panel is 0.85. This indicates good configurational congruence and a global consensus between the two panels, since literature reports that a R_V value of 0.5 indicates consensus (Louw *et al.*, 2013) This result supports the findings of some other descriptive sensory studies comparing trained and untrained panellists using rapid methods. Some authors have reported that consumers have the ability to provide product maps that are comparable to those elicited from trained panellists (Perrin *et al.,* 2007; Lelievre e*t al*., 2008; Reinbach e*t al.,* 2014).

Lelievre *et al*. (2008) have reported that expert assessors tend to be more efficient in their description of products. This tendency is attributed to the fact that experts and trained assessors have a better consensus regarding the meaning of certain descriptors while untrained consumer assessors do not necessarily agree on the verbal meaning of different descriptors. This notion is supported from the descriptive data elicited from expert panel and trained panel. Taking into account that the expert panel was restricted to using a maximum of five descriptors, while the consumer panel was not restricted in the amount of attributes that they were allowed to use for product description, the descriptive data elicited from these panels had similar sensory meanings. Consider the TC wine sample as example. From the consumer data, the TC wine sample is correlated to various descriptors. These descriptors can be considered idiosyncratic in the sense that most of them belong to aroma families, e.g. dried fig and dried apple can be grouped together as “dried fruit”. Litchi, melon and passionfruit describe “tropical fruit”, herbaceous and tomato leaf refer to a “green” character, and grapefruit and lemon form part of the “citrus” aroma family. In the data elicited from the expert panel the TC wine was best correlated to grapefruit, dried apple and papaya. If the same aroma families were to be used by the expert panel, the description would be citrus, dried fruit and tropical. In this sense, the wines were described by similar attributes by the experts and consumers.

4.3.2 Comparison between liking and quality

The degree of liking for the different wine treatments are represented in figure 4.3. There were significant differences in the degree of liking between two groups of the four main experimental treatments. The treatments that differed significantly are the barrel control and new barrel treatments (BC, B1, B2, B3), and the stave insert treatments (S1, S2). The tank control (TC) treatment did not differ significantly from either one of the latter groups.

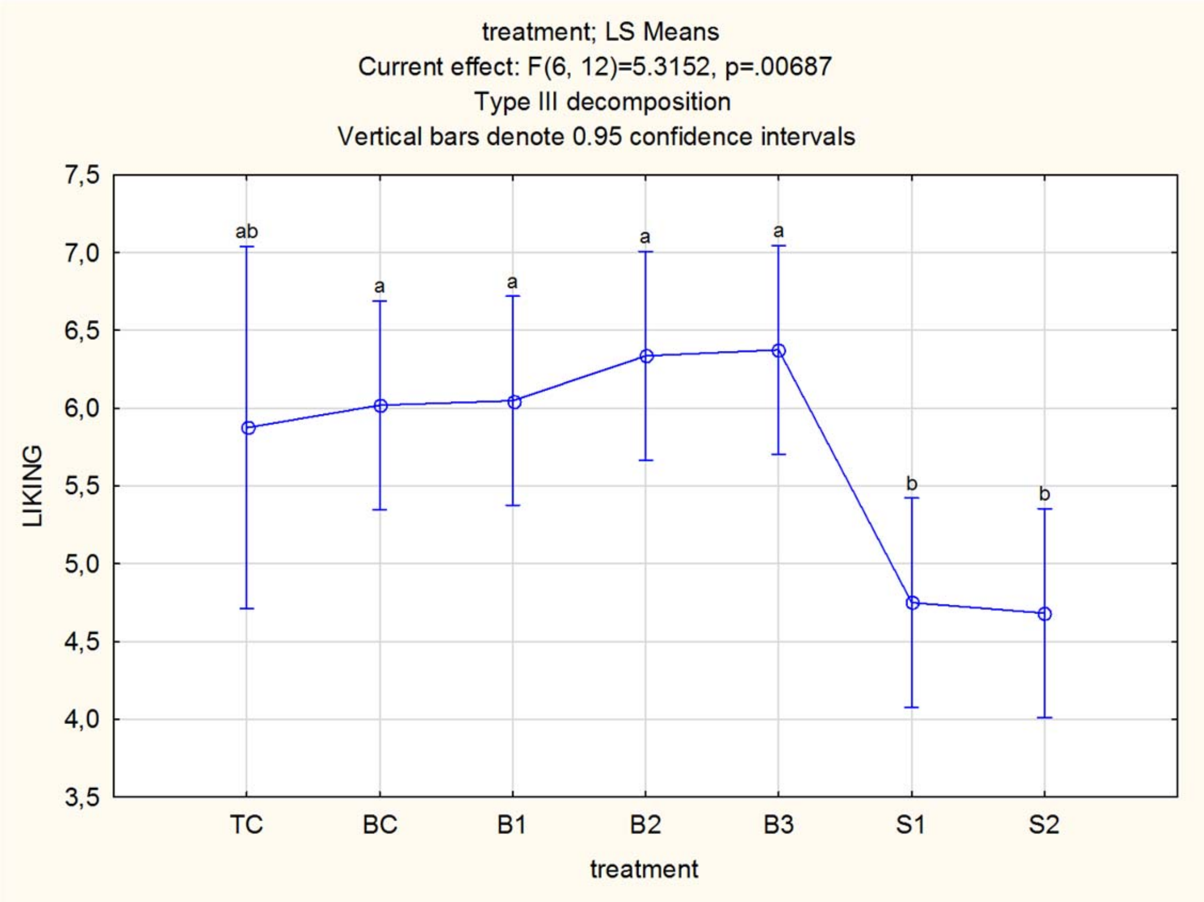

Figure 4.3 LS means plot indicating the degree of liking of the different treatments by the consumers. Different alphabetical letters indicate significant differences ($p<0.05$) and error bars indicate standard deviation (obtained from STATISTICA 12®).

Most of the consumers indicated their degree of liking for the TC wine in the range of between neither like nor dislike to like moderately. There were no significant differences between the BC wines and the wines matured in new barrels, but small differences were visible. The wines matured in the new barrels were liked slightly more than the wines matured in the 5th fill barrels, with the B3 treatment being liked the most of all the new barrel treatments. The stave treatments were liked the least by the consumers, and received liking scores ranging between dislike slightly and neither like nor dislike. Even though these scores were significantly lower, it does not necessarily indicate that the consumers disliked these wines, since the mean scores indicated were closer to the “neither like nor dislike” scale point than the “dislike slightly” scale point.

The perception of wine quality by the experts are represented in figure 4.4. There were significant differences in the perceived quality between two groups of the four main experimental treatments. The quality of the TC, BC, B1, B2 and B3 wines were perceived in a similar manner, and the S1 and S2 wines formed the second group for which the perceived quality was similar. Similar to the consumers' degree of liking, the perceived quality of the S1 and S2 treatments were significantly lower. The mean degree of perceived quality indicates that the experts perceived the quality of the stave wines as fairly poor. Although not significant, there was an increase in the perceived quality between the TC wine and the BC, B1, B2 and B3 wines, with the B3 wines receiving the highest perceived quality scores.

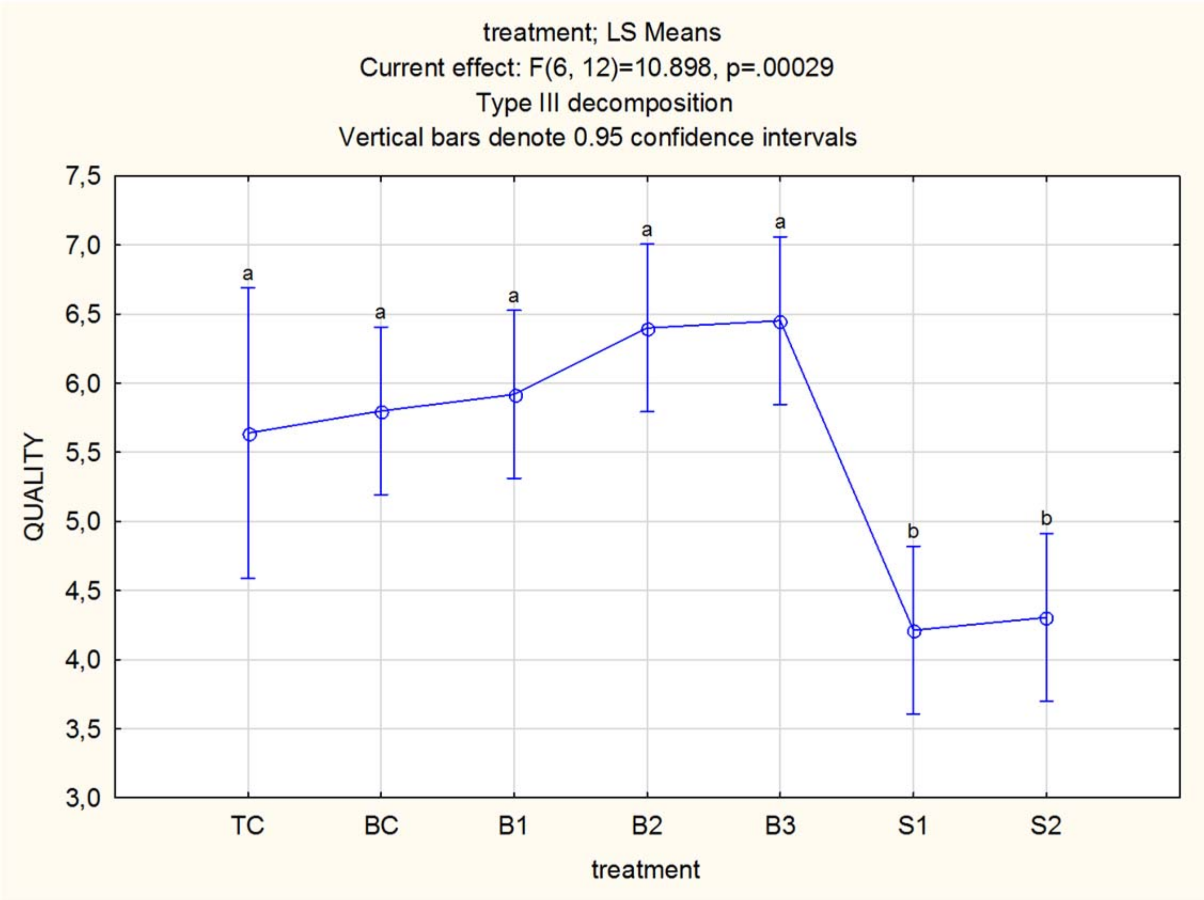

Figure 4.4 LS means plot indicating the perceived quality of the different treatments by the experts. Different alphabetical letters indicate significant differences ($p<0.05$) and error bars indicate the standard deviation (obtained from STATISTICA 12®).

From this data, it is clear that the experts and consumers perceived the wines in a similar matter. To support this notion, the Spearman's rank correlation coefficient was also calculated. The Spearman coefficient is an indication of the correlation between ranked variables, and a positive Spearman coefficient indicates correlation between the two sets of variables (Lawless & Heymann). The Spearman coefficient between the liking and quality data obtained from this research was 0.87, which indicates a strong positive correlation between the quality and liking scores, suggesting that liking will increase or decrease when quality increases or decreases, and *vice versa*.

Crump *et al*. (2015) investigated the influence of oak maturation regimen on the quality and consumer acceptance of Cabernet Sauvignon wines. Supporting the findings of this current study, these authors have reported that there were no significant differences between the quality and liking scores that were obtained from expert and consumer panels respectively. Furthermore, this study also reported that the wines matured using oak alternatives received modest hedonic ratings. The authors also reported that there is an appeal for the use of oak alternatives for certain market segments, especially for the production of wines targeted at certain price points. Segmentation of consumer data was not part of this specific study, but it could be investigated in a follow-up study to identify the perceived liking of specific target consumer groups.

4.3.3 Drivers of liking and quality

Individual product maps were created by MFA using the descriptive sensory data and hedonic CATA counts (figure 4.6 and figure 4.8). In addition MFA was used to obtain variable correlation circles comparing attributes and hedonic counts of liking and quality respectively (figure 4.7 and figure 4.9) (Kidd, 2015). Figure 4.6 represents the individual factor map of the descriptive data and hedonic liking counts that were elicited from the consumer panel. In total 47.2% of the variance was explained by the first two MFA dimensions. In this figure there is a clear separation between treatments and grouping of treatments are also visible, indicating a clear treatment effect on the liking counts.

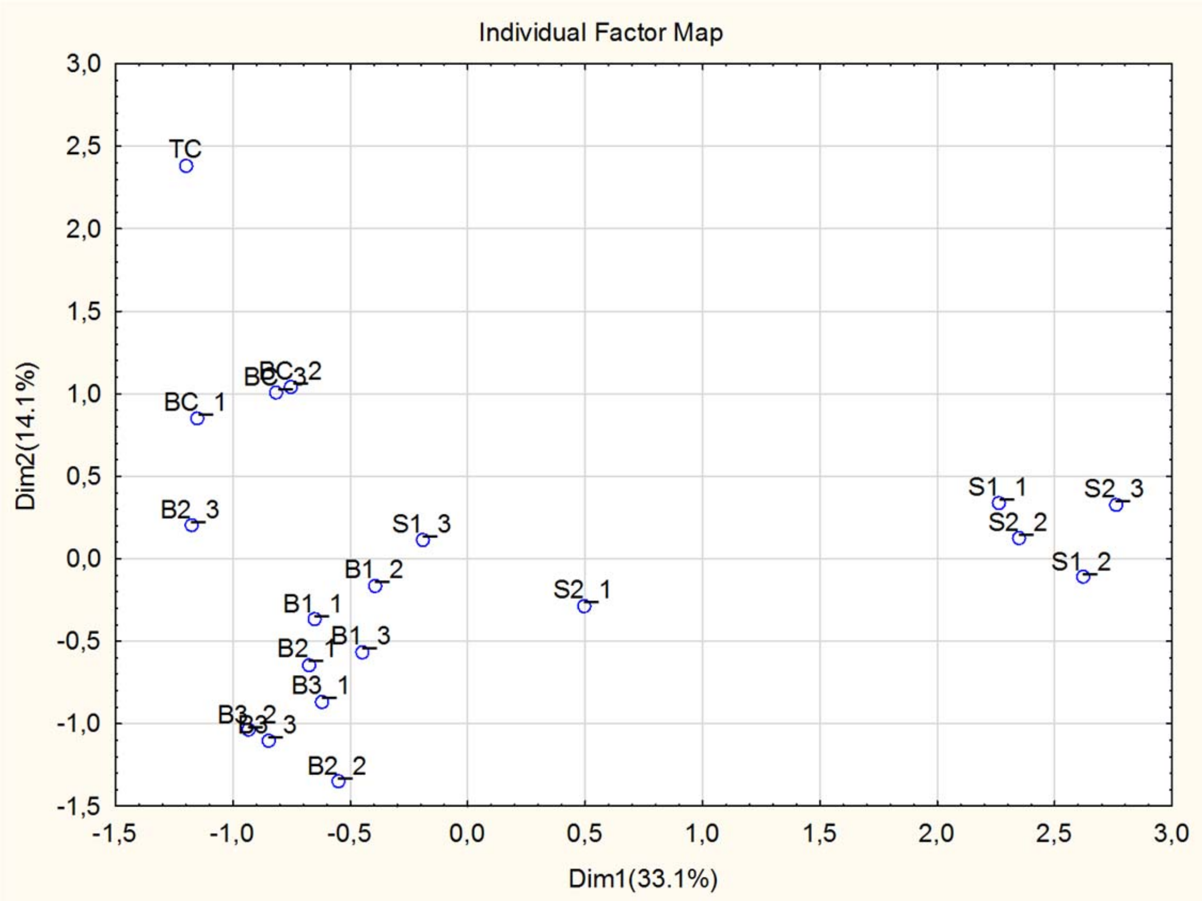

Figure 4.6 Multiple factor analysis individual product plot using descriptive data and hedonic liking counts elicited from the consumer panel (obtained from STATISTICA 12®).

The relationship between liking and descriptors are represented in figure 4.7. The vectors showed strong correlation of the liking scores of L1 (dislike extremely), L2 (dislike very much), L3 (dislike moderately) and L4 (dislike slightly). These vectors were associated with the nutty, dried, ripe, green and planky descriptors. These specific descriptors were used to characterize the stave treatments in figure 4.1. These lower liking scores for the stave associated treatments are also shown in figure 4.3, where the LS mean degree of liking for the stave treatments were significantly lower than for the other treatments. The opposite vector directions showed strong correlation in the liking scores of L6 (like slightly), L7 (like moderately) and L8 (like very much). These vectors were associated with tropical fruit, citrus, floral and oaky descriptors. It was also associated with some positive green descriptors like green pepper and lemon grass. From this correlation circle, the ideal product should be associated with dried peach, floral and citrus aromas. It should also have oak derived aromas like butter and vanilla. Considering figure 4.1, all of the wines matured in the new barrels were correlated to these types of aroma descriptors.

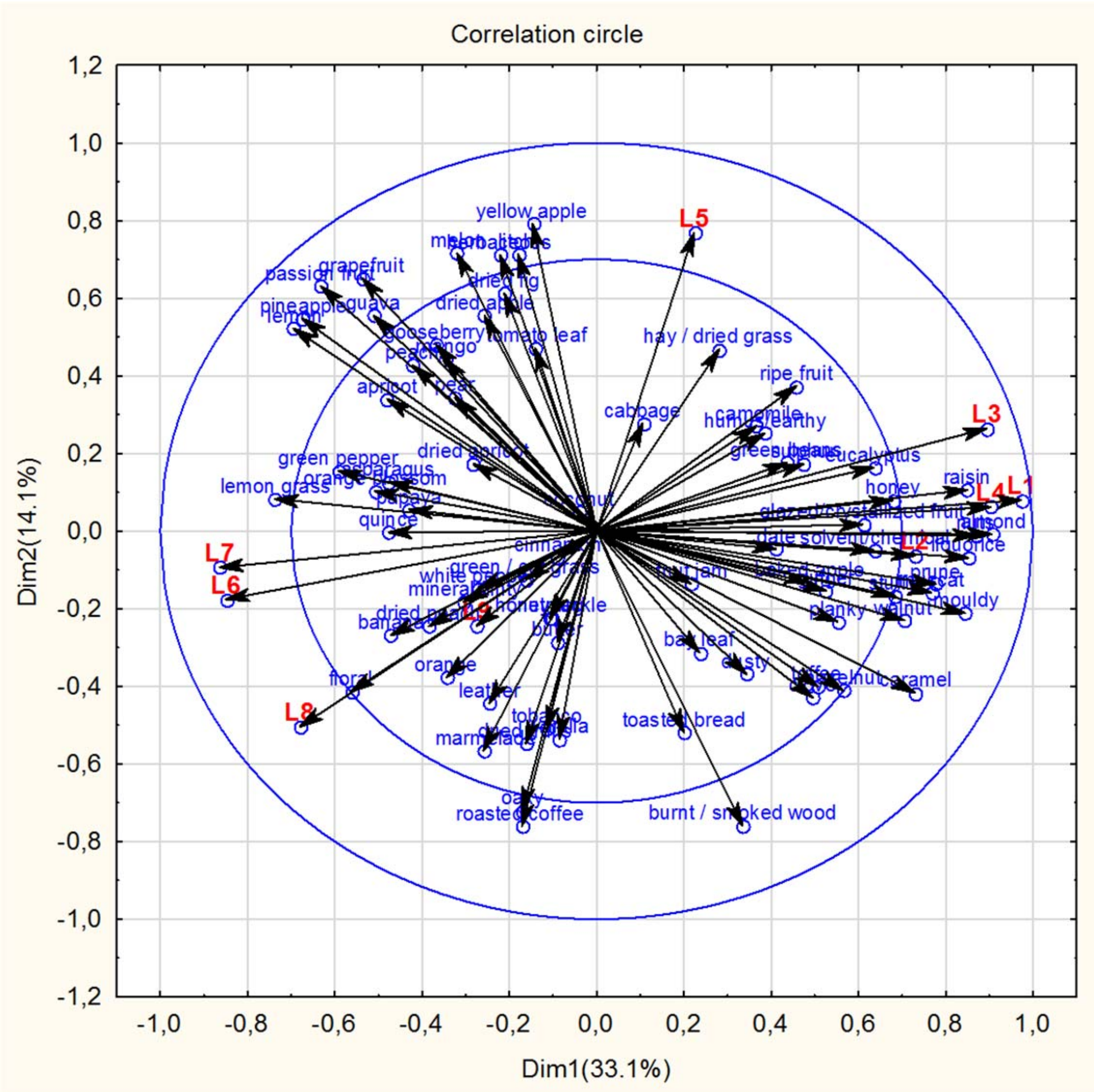

Figure 4.7 Multiple factor analysis correlation circle obtained using descriptive data and liking counts elicited from the consumer panel. Refer to table 4.2 for liking codes (obtained from STATISTICA 12®).

Figure 4.8 represents the individual factor map of the descriptive data and hedonic quality counts that were elicited from the expert panel. In total 42.3% of the variance was explained by the first two MFA dimensions. In this figure there is a clear separation between treatments and grouping of treatments are also visible, indicating a clear treatment effect on the quality counts.

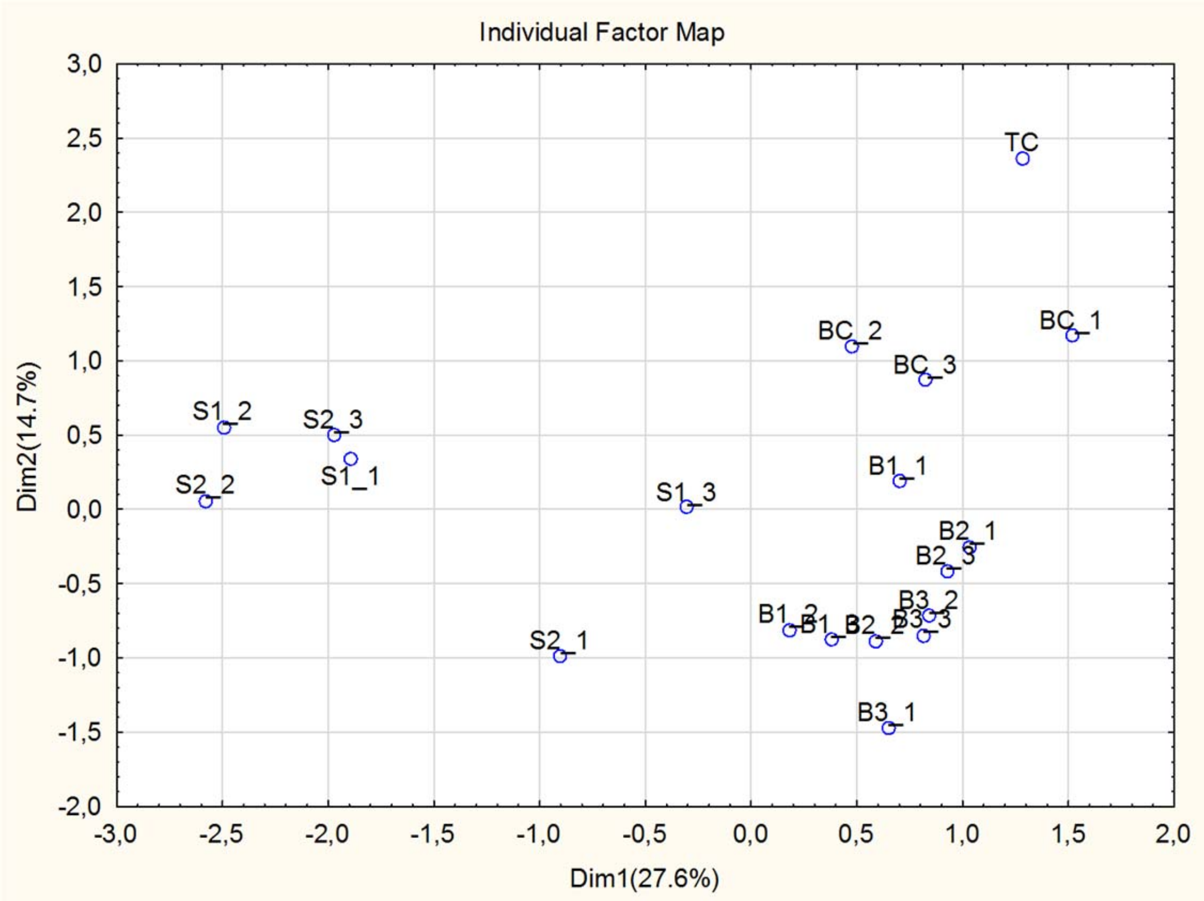

Figure 4.8 Multiple factor analysis individual product plot using descriptive data and hedonic quality counts elicited from the expert panel (obtained from STATISTICA 12®).

The relationship between perceived quality and descriptors are represented in figure 4.9. The vectors showed strong correlation between the quality scores of Q3 (Poor) and Q4 (fairly poor). These vectors were associated with the nutty, burnt/smoked wood, honey, planky and sulphur descriptors. These specific descriptors were used to characterize the stave treatments in figure 4.2. These lower perceived quality scores for the stave associated treatments are also shown in figure 4.4, where the LS mean degree of quality for the stave treatments were significantly lower than for the other treatments. The opposite vector directions showed strong correlation in the perceived quality scores of Q6 (fairly good), Q7 (good) and Q8 (very good). These vectors were associated with tropical, citrus, and oak derived descriptors like toasted bread. Both the stave treatments that received lower quality scores, and the new barrel treatments that received the highest quality scores, were described by oaky attributes like vanilla and roasted coffee. This might be the reason why the vectors of these specific attributes are located between the Q3 and Q8 quality vectors, rather than being closely correlated to either one of the Q3 or Q8 quality vectors.

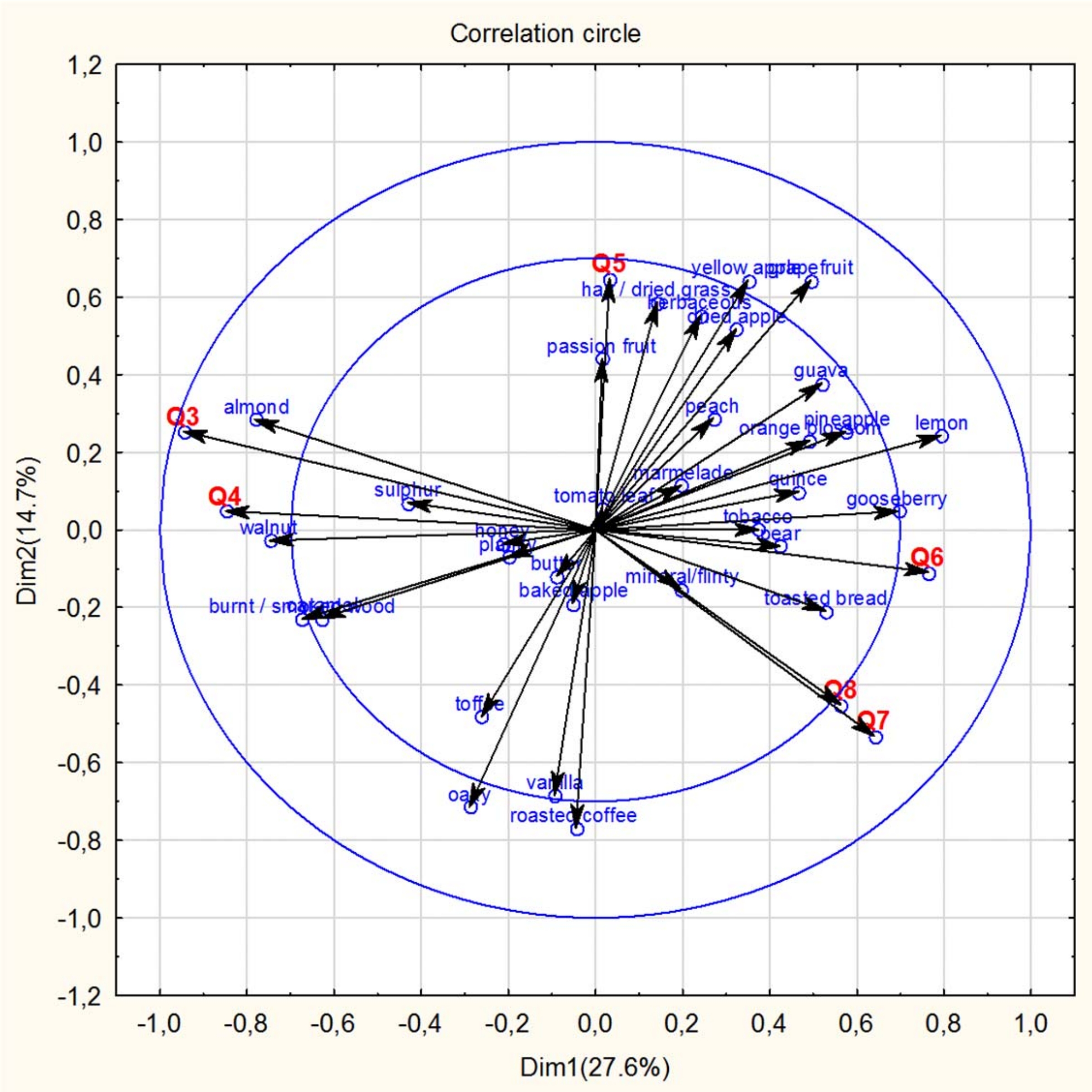

Figure 4.9 Multiple factor analysis correlation circle obtained using descriptive data and quality counts elicited from the expert panel. Refer to table 4.2 for quality codes (obtained from STATISTICA 12®).

A penalty analysis based investigation into the ideal product, as described by Ares *et al*., (2014), is advised for future research. This method consists of presenting consumers with a CATA questionnaire and asking them to pick the attributes describing their ideal product after performing CATA on the actual samples in the sample set. However, this method has also been tested on yoghurt and apples, and the differences between these respective sample spaces were pronounced. In addition, there were only 16 terms on each CATA questionnaire. It remains unclear whether this type of analysis would be applicable for wine research, especially for this specific study, in which the intrinsic cue was the subject of different oak types. From the ANOVA analysis depicting the mean degree of liking it was clear that some consumers liked the unoaked wine in the same way they liked the oaked wines, while some consumers liked the oaked wines more. Considering the results obtained from this current study, the main concern was that consumers would describe their ideal product either as oaked or unoaked. Upon consultation with Professor Martin Kidd (Centre of Statistical Consultation, Stellenbosch University), it was decided that MFA techniques would provide more detailed product information regarding the drivers of liking and perceived quality for this specific research without including an ideal product in the analysis.

4.4 Conclusions

The main aim of this study was to investigate the influence of oak maturation regimen discriminative and hedonic sensory profiles of Chenin blanc wines, using both an expert panel and a consumer panel. The descriptive sensory data elicited from the expert panel and consumer panel were comparable in terms of configurational congruence and revealed very good agreement in terms of perceived differences between treatments. These findings confirm that CATA and its variant, Pick-*K* attributes, are suitable rapid descriptive methods to obtain descriptive sensory maps. It is also a useful tool for the capturing of hedonic data to understand perceived quality and degree of liking.

The presence of oak derived aromas in the wines matured using different oak products was confirmed by sensory analysis. There were clear differences between the unoaked wine and the oaked wines, and also between the wines matured using new barrels and 5th fill barrels with stave inserts.

There were no significant differences in terms of the perceived quality and degree of liking. The wines matured in new barrels received the highest scores, while the wines matured using stave inserts received moderate scores. From this research it is clear that naïve consumers were able to discriminate between wines matured in contact with new barrels wines matured in contact with staves. It was also clear that the consumers had a higher degree of liking for the wines matured in new barrels. Winemakers should keep this in mind when they select specific oak products for wine maturation.

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Chapter 5

Research results

Investigation into the suitability of Pick-*K* attributes and CATA to describe Chenin blanc wines when using trained, expert and consumer assessors

Investigation into the suitability of Pick-*K*-attributes and CATA to describe Chenin blanc wines when using trained, expert and consumer assessors

5.1 Introduction

Sensory tests are used for various purposes in the wine industry, including quality control, process and product development, flavour research and to identify the key drivers of perceived quality and consumer acceptance that are critical for the successful development and marketing of new products (Piggot 1995; Reinbach *et al*., 2014). In the main stream paradigm of sensory science, this type of sensory information is gathered from trained panels, and consumers are only used to obtain hedonic information rather than descriptive information. Since trained panellists may take into account descriptors or product attributes that are irrelevant to consumers, sensory characterization of products by consumers are advocated by some sensory scientists (Ares *et al*., 2013b).

Wine experts is another group of tasters that are important to study in the evaluation of wine, since many wines are judged and scored by experts for wine competitions (D'Alessandro & Pecotich, 2013). Drawbacks of performing sensory experiments with expert and consumer tasters include time constraints and the availability of tasters, rendering descriptive sensory analysis unviable as profiling technique (Perrin *et al*., 2007). In this context, several rapid sensory profiling techniques have been developed in the last 10-20 years, including sorting, flash profiling, projective mapping or Napping®, and check-all-that-apply (CATA) questions (Ares & Jaeger, 2013). CATA in particular have been used in various descriptive sensory studies that include both expert and consumer tasters (Moussaoui & Varela 2010; Giacalone *et al*., 2013; Ng *et al*., 2013; Reinbach *et al*., 2014; Ares *et al*., 2014).

The CATA method gained popularity due to its ease and rapidity of use (Varela & Ares, 2012). The method consists of a multiple choice format where panellists are presented with a sample and a list of descriptors to characterize the sample. They are then tasked to pick the descriptors that characterize the sample appropriately (Ares & Jaeger, 2013). Attributes can also relate to hedonic or emotional aspects, as well as product usage or concept fit, which makes it ideal for consumer research. In this method, the assessor can pick as many attributes as he or she deems relevant (Valentin *et al.,* 2012).

Pick-*K* attributes is a variant of CATA where the assessors receive a list of attributes and are then tasked to pick *K* attributes that are most prominent or describe the product best. This variation of CATA is most often applied in wine aroma research. The main difference between CATA and Pick-*K* attributes is that the latter highlights the main sensory characteristics of a product, while CATA produces a more detailed description (Valentin *et al*., 2012). Campo *et al*. (2010) further developed this method using a trained panel of 30 members that were pre-trained with a list of generic wine descriptors. Data obtained from this method are compiled into a frequency matrix and then correspondence analysis (CA) can be performed to obtain a sensory map (Valentin *et al.,* 2012).

Several works comparing trained and untrained assessors have revealed that trained assessors tend to be more efficient in their description of complex products such as wine (Lelievre *et al.*, 2008). It is generally assumed that untrained consumers are less discriminative than a trained or expert panel due to their unfamiliarity with the experimental procedure and sensory stimuli (Ishii *et al*., 2007). Contradictory to these findings, a few studies have shown that results obtained from CATA questions used with consumers are similar to those obtained from trained panels and that consumers find CATA an easy task to perform (Ares *et al.,* 2013; Reinbach *et al.,* 2014). Research comparing different conventional and rapid methods have been conducted (Perrin *et al.*, 2007; Campo e*t al*., 2008; Lelievre *et al*., 2008; Campo *et al.*, 2010; Moussaoui & Varela, 2010). Some researchers have also investigated the responses obtained from trained and untrained assessors (Abdi e*t al*., 2007; Ishii, 2007; D'Alessandro & Pecotich, 2013; Hopfer & Heymann, 2014). Up to date, little research focused on suitability of rapid sensory techniques to accommodate trained, expert and consumer assessors.

The main aim of this current research was to evaluate the suitability of CATA and Pick-*K* attributes as a tool for sensory evaluation based on configurational congruence and panel consensus, when trained, expert and consumer assessors are used to describe the same product space. This method of sensory evaluation was chosen because winemakers are often interested in more than one sensory aspect of a wine. By using CATA, the generation of descriptors is not necessary and description of the product space is not confined since more than 20 descriptors can be included to the list. Furthermore, this method has been used in previous research using trained, expert or consumer assessors.

5.2 Materials and methods

5.2.1 Wine samples

The sensory evaluation was performed on nineteen Chenin blanc wines. The vinification procedure as well as the different wine treatments were described in Chapter 3 in sections 3.2.1 and 3.2.2. The three different intervals of testing as well as the panels used for the sensory analysis at each interval are shown in table 5.1.

Table 5.1 Testing intervals and panels used for the 19 Chenin blanc wines.

TESTING INTERVAL	PANELS	METHOD	SENSORY REPLICATES
4 months oak ageing (4OM)	Trained panel	Pick-*K*	2
	Expert panel	Pick-*K*	1
9 months oak ageing (9OM)	Trained panel	Pick-*K*	2
	Expert panel	Pick-*K*	1
9 OM + 6 months bottle ageing (9OM6BA)	Trained panel	Pick-*K*	2
	Expert panel	Pick-*K*	1
	Consumers	CATA	1

5.2.2 Assessors

5.2.2.1 Trained Panel

A trained panel of 20 members were used at all three intervals of sensory analysis. Panellists were recruited based on their availability during the specific time frame of testing. The panel of 20 members that evaluated the wines after 4OM consisted of 15 females and 5 males. At the 9OM and 9OM6BA intervals, the panel consisted of 16 females and 4 males. The age of the panellists varied between 22 and 58, with an average age of 26.

5.2.2.1.1 Panel training

Training a panel consists of taking deliberate steps to increase the effectiveness and rate at which panellists assimilate new knowledge and techniques. Training aims to develop abilities to detect, recognize and describe sensory stimuli, and the amount of training required depends on the type of product and the level at which differences are being examined (Piggot, 1995). The panel received training as described by Campo *et al*. (2008). A typical training session consisted of two parts. During the first part of the session the panelists were presented with 12-16 aroma reference standards which they had to smell and identify. During the second part of the session the judges were presented with 3-4 wines. They were then tasked to smell the wines and write down the 3-5 most prominent descriptors. The panel then discussed the attributes of each wine and the panel leader highlighted the attributes that were used most frequently amongst the panel members. During the training period of 13 weeks, all of the descriptors on the Chenin blanc aroma wheel (CBA, 2013) were covered (ADDENDUM A; ADDENDUM B). One week prior to testing, the panel received Chenin blanc specific aroma training.

5.2.2.2 Expert Panel

An expert is defined as someone with extensive experience in a product category who performs perceptual evaluations to draw conclusions about the effects of variations in raw materials, processing, storage and ageing (Piggot, 1995; Lesschaeve, 2007). Based on this definition, an expert panel consisting of 25 winemakers with a minimum of 5 years' experience were recruited from the industry. The panel consisted of both males and females. The age of panelists varied between 24 and 58 years, with an average age of 39. The expert panel received no formal sensory training prior to any of the sensory testing intervals.

5.2.2.3 Consumers

According to Lawless & Heymann (2010) a large group of consumers of between 75 and 150 people is necessary to obtain reliable results. An untargeted consumer panel (n=104 consumers) consisting of 61 females and 43 males with an average age of 36 were recruited from Stellenbosch and the surrounding area. The consumer panel received no formal sensory training prior to the sensory evaluation session.

5.2.3 Sensory evaluation

Testing of the wines took place in an air conditioned and light controlled environment (ISO NORM 8589, 1988) secluded from extraneous noise and odours (Lawless & Heymann, 2010). The wines that were to be evaluated were removed from the 16°C fridge a day before testing and was stored at 20°C. The wines were poured 1 hour before testing. Samples of 30 mL were presented in ISO NORM (1977) approved black glasses labelled with random three digit codes and covered with Petri dish lids. The wines were then randomized according to a Williams design latin-square and presented in three flights to balance first-order and carryover effects. After each flight of testing, a 10 minute break was enforced to limit the fatigue of the judges. For each panel and sensory method the panellists were provided with the same tasting sheet (ADDENDUM C).

In the case of pick-*K*-attributes, the trained and expert panel was tasked to pick a minimum of three and a maximum of five descriptors that best describe the wine samples. The consumers had no limitations on the amount of attributes they could pick, as is standard with CATA, and were tasked to pick all attributes they deemed appropriate for describing the wine samples.

5.2.4 Statistical analysis

Data were captured on Microsoft Excel 2013 (www.microsoft.co/excel). The average reproducibility index (R_i) was calculated for each trained panellist according to the method suggested by Campo *et al*. (2010), where the R_i is calculated as:

$$R_i = \left(\frac{1}{n}\right) \times [2 \times \frac{des_{com}}{des_{rep\,1} + des_{rep2}}]$$

In this formula n = the amount of wines tasted, and des_{com} the number of descriptors chosen by the judge in both sensory replicates, with des_{rep1} and des_{rep2} being the descriptors chosen by the judge in the first and second sensory replicate respectively.

After the R_i was calculated, data were handled in a step-wise manner. Attributes cited by less than 20% of the panellists were either combined or discarded from the data set. Attribute grouping was done at the discretion of a panel of sensory scientists. The citation frequencies were organised in contingency matrices and correspondence analysis (CA) were performed on the data using STATISTICA® (www.StatSoft.com).

R_V coefficients were calculated on the coordinates of all possible configurations of the CA plots. The R_V coefficients were calculated to reflect the agreement and consensus between the different data sets. In addition to the R_V coefficients, a multidimensional scaling (MDS) scatterplot was constructed. This was done by calculating the R_V coefficients of the first two dimensions of the CA-plots, after which the R_V correlation matrix was used to construct the MDS-plot.

5.3 Results and discussion

5.3.1 Average reproducibility index (R_i) of the individual trained panellists

This parameter, ranging from 0 to 1, was used in previous work (Campo *et al*., 2008; Campo *et al.*, 2010), where the minimum R_i required to keep a judges' response was set at 0.2. According to this index, an assessor can only be classified as a trained panellists if a R_i of at least 0.2 is obtained. On this principle it is necessary to discard data obtained from panellists with a R_i below 0.2. The R_i calculated for the individual panellists, as well as the average R_i for all panel members, are shown in table 5.2

All of the judges that participated at the 4OM interval of sensory testing qualified as trained judges, thus no data obtained from this panel had to be discarded. The average R_i calculated for all the judges is 0.4. At the 9OM testing interval, the R_i increased from an average of 0.4 to an average to 0.5. This increase, although not significant, may be attributed to two independent factors. Firstly, the participating panel had 5 more months of training than was the case at the 4OM testing interval. The second factor may be that the wines that were tasted at this interval had more distinguishing properties which were readily recognisable in the two sensory replicates. It must also be taken into account that judge 17 did not qualify as a trained panellists, and that the data obtained from this judge was discarded. A significant decrease in panel performance were observed at the 9OM6BA interval of sensory testing. The average R_i was 0.3 and three judges from the panel of 20 members were not repeatable. These three panellists were thus disqualified as being trained panellists. The reason for this decrease in the average R_i is not clear, but is most likely due to factors other than panel training. A contributing factor might have been bottle-to-bottle variation of the bottle matured wines.

Table 5.2 R_i calculated for trained panellists after all three intervals of sensory evaluation.

Judges after 4OM	R_i	Judges after 9OM	R_i	Judges after 9OM6BA	R_i
1	0.6	1	0.4	1	0.4
2	0.6	2	0.3	2	0.4
3	1.0	3	0.4	3	0.4
4	0.3	4	0.3	4	0.3
5	0.5	5	0.5	5	0.3
6	0.5	6	0.2	6	0.4
7	0.5	7	1.0	7	0.2
8	0.5	8	0.4	8	0.3
9	0.6	9	0.3	9	0.2
10	0.5	10	0.9	10	0.3
11	0.4	11	0.9	11	0.3
12	0.4	12	0.4	12	0.1
13	0.4	13	0.4	13	0.3
14	0.4	14	0.4	14	0.3
15	0.2	15	0.3	15	0.2
16	0.4	16	0.2	16	0.2
17	0.3	17	0.1	17	0.1
18	0.2	18	0.3	18	0.2
19	0.3	19	0.5	19	0.3
20	0.2	20	0.8	20	0.1
R_i across all panellists	0.4		0.5		0.3

5.3.2 Panel congruence and consensus

5.3.2.1 CA analysis performed on all data sets

The results of the CA analysis performed on all the data sets are represented in terms of inertia in table 5.3.

Table 5.3. Results of CA analysis performed on separate data sets.

Data set	Abbr.	Attribute count	F1 explained variance (%)	F2 explained variance (%)	F1 and F2 explained variance (%)
4 months expert panel	4E	29	26.9	23.6	50.5
4 months trained panel (SR1)	4P1	27	42.0	14.4	56.4
4 months trained panel (SR2)	4P2	25	39.9	18.2	58.1
9 months expert panel	9E	33	25.4	18.0	43.4
9 months trained panel (SR1)	9P1	28	26.7	18.3	45.0
9 months trained panel (SR2)	9P2	29	25.9	19.3	45.2
bottle ageing expert panel	EBA	36	28.9	14.7	43.6
bottle ageing trained panel (SR1)	PBA1	24	43.7	9.6	53.3
bottle ageing trained panel (SR2)	PBA2	27	35.9	15.9	51.8
bottle ageing consumer panel	CBA	78	31.1	17.7	48.8

The 4P1 and 4P2 data sets showed similar configurational congruence in separation of explained variance on F1 and F2. The 4E data set had a similar cumulative explained variance, however, it differs from 4P1 and 4P2 in terms of factorial separation along F1 and F2. For the 4P1 and 4P2 data sets most of the variance were explained on F1, while the explained variance for 4E was more equally divided between F1 and F2. The inertia of the 9E, 9P1 and 9P2 data sets were very similar with sensory maps that are globally identical. About two thirds of the variance is explained along F1, with F2 capturing the rest of the explained variance.

At the 9OM6BA testing interval the configurational congruence of the correspondence analyses showed the largest variation within and between panels. The correspondence analyses that were run on data from the expert panel (EBA) and consumer panel (CBA) showed the most configurational congruence in terms of the explained variance captured by F1 and F2. The amount of attributes used by the consumers were, however, almost twice the amount used by the expert panel and trained panel. Perrin *et al*. (2007) have hypothesized that data from untrained consumers are often more robust, since they do not share the same sensory meaning for a given descriptor, which is often the case when training or experience is involved. This may be the reason for the high attribute count of the consumer panel.

The configurational congruence of the correspondence analyses that were run on the PBA1 and PBA2 data sets are globally different. Even though the cumulative explained variance for the two data sets are similar, the factorial inertia captured by F1 and F2 were different. This phenomena can be attributed to the lower average reproducibility (R_i) that were calculated for the trained panellists at this interval of sensory testing.

5.3.2 Panel consensus

R_V coefficients were calculated on the coordinates of the CA plots that were constructed from the data obtained from the different panels that participated at the different intervals of testing. The R_V coefficients were calculated to determine the similarity in configuration of the sensory profiles. In addition, a multidimensional scatterplot was constructed to identify clustering of the different sensory data sets (figure 5.1). According to Abdi e*t al.* (2007), R_V coefficients can be used to reflect the similarity between assessors and data sets. The closer the R_V is to 1, the more similar the configurations of the data sets are, and a R_V value of 0.5 can be considered the cut-off value for the indication of good agreement between data sets (Louw *et al*., 2013). The R_V coefficients that were calculated for all possible configurations of the different data sets are shown in table 5.4, and will be discussed in terms of panel consensus at the different testing intervals.

Table 5.4 R_V coefficients as calculated on all possible configurations of the data sets.

	4E	4P1	4P2	9E	9P1	9P2	EBA	PBA1	PBA2	CBA
4E	1.00	0.45	0.49	0.41	0.49	0.50	0.40	0.38	0.36	0.47
4P1	0.45	1.00	0.88	0.32	0.31	0.39	0.40	0.11	0.26	0.45
4P2	0.49	0.88	1.00	0.34	0.35	0.39	0.33	0.07	0.23	0.43
9E	0.41	0.32	0.34	1.00	0.87	0.83	0.65	0.19	0.47	0.75
9P1	0.49	0.31	0.35	0.87	1.00	0.89	0.74	0.28	0.52	0.79
9P2	0.50	0.39	0.39	0.83	0.89	1.00	0.68	0.24	0.49	0.76
EBA	0.40	0.40	0.33	0.65	0.74	0.68	1.00	0.49	0.61	0.85
PBA1	0.38	0.11	0.07	0.19	0.28	0.24	0.49	1.00	0.35	0.35
PBA2	0.36	0.26	0.23	0.47	0.52	0.49	0.61	0.35	1.00	0.77
CBA	0.47	0.45	0.43	0.75	0.79	0.76	0.85	0.35	0.77	1.00

The R_V coefficients calculated between the 4P1 and 4P2 data sets indicates good repeatability of the trained panel (R_V = 0.88). The R_V coefficients between 4E and 4P1 (R_V = 0.45), and 4E and 4P2 (R_V = 0.49), indicates a relative good level of agreement between the panels, even though the consensus is not significantly clear. This is also visible in figure 5.1 where a clear separation between the trained panel and the expert panel can be seen. The R_V coefficients calculated at the 9OM testing interval shows clear consensus within and between panels. The R_V coefficient between 9P1 and 9P2 is 0.89, while the R_V

coefficients between 9E and 9P1, and 9E and 9P2 were calculated as 0.87 and 0.83 respectively. These high values are also represented by the close clustering of these data sets in figure 5.1.

At the 9OM6BA interval of sensory testing the data from the expert panel are globally the same as the data from the CBA and PBA2 data sets, with respective R_V coefficient values of 0.85 and 0.61. There is also a global similarity between the CBA and PBA 2 data sets (R_V = 0.77). At this specific interval, the PBA1 data set has the lowest correlation to all the other data sets, classifying it as an outlier that is clearly visible in figure 5.1. From this figure clear grouping of treatments, and not panels are visible, indicating a clear treatment effect that was observed by all the participating panels for the testing intervals.

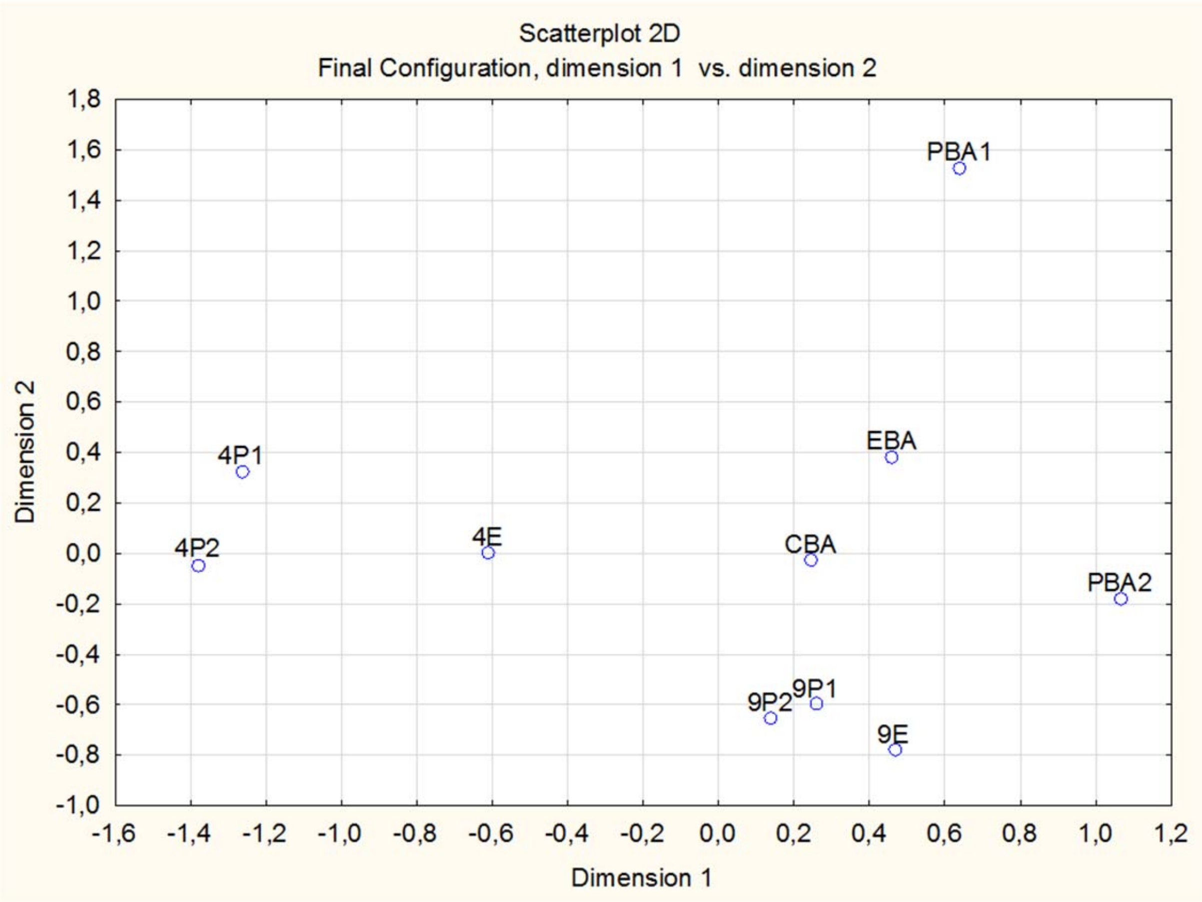

Figure 5.1 MDS scatterplot of data sets from all panels and testing intervals (obtained from STATISTICA®).

The R_V coefficient calculated between the data sets of the trained panel indicated good panel repeatability for the 4OM and 9OM testing intervals. At the 9OM6BA interval of testing the correlation between the two sensory replicates trained panel is extremely weak.

The PBA1 data set can be regarded as an outlier. It is hypothesized that the difference between the two sensory replicates for the 9OM6BA testing interval is due to factors other than panel effects. These factors may include bottle-to-bottle variation or extraneous olfactory disturbances at the time of testing. This hypothesis is further strengthened by the fact that the R_V coefficients calculated between the PBA2 data set and the CBA and EBA data sets indicates consensus between the different panels. Due to time constraints and a limited amount of wine it was not possible to test this hypothesis, and the conclusion at this stage is that the trained panel was not repeatable at the 9OM6BA interval of sensory testing.

The data sets of the different panels at the different intervals of testing showed satisfactory configurational congruence, with the best results being obtained at the 9OM interval of testing. This was also supported by the average reproducibility reaching its' highest average at this interval of testing. From these results it can be concluded that the wines were most distinguishable at this maturation interval, leading to exceptional global panel consensus.

The amount of attributes that were used by the trained panel and expert panel were similar for all maturation intervals. The consumer panel used almost twice the amount of attributes to describe the wines. This might be due to the fact that they were not restricted in the amount of attributes that they were allowed pick, and also because they were not as sensitive and precise in their sensory descriptions as the experts and trained panellists. However, due to the large amount of consumers that participated, the congruence and inertia of the correspondence analysis obtained from their data set was satisfactory.

5.4 Conclusions

The main aim of this study was to investigate the suitability of CATA and its variant, Pick-*K* attributes, as a sensory screening tool for Chenin blanc wines when different types of panels are being used. The suitability of this sensory technique was explored in terms of configurational congruence, panel repeatability and panel consensus, at three different intervals of wine maturation.

The results obtained from this study proved that the different panels were able to reach a good level of agreement in the manner that they described the wine samples. The trained panel was repeatable and comparable to the expert panel at all intervals except at the 9OM6BA interval. At this interval the trained panel was not repeatable, however, the PBA2 data set from the trained panel was comparable to the data set from the expert panel. The consumer panel was also comparable to the expert panel and the PBA2 data set from the trained panel. The good performance of CATA and Pick-*K* attributes with untrained consumers and experts makes it a reliable method that can be recommended when rapid sensory profiling is required or when a trained panel is unavailable.

This study highlighted an important obstacle that might be encountered when CATA is used with an untrained panel to describe complex products such as wine. The consumers in particular used a large number of attributes to describe the wines. The data obtained required a significant amount of clean-up, as some descriptors had to be combined or discarded at the discretion of a panel of sensory analysts. Even though data clean-up was also necessary for the data obtained from the trained panel and expert panel, these panels were more precise and consistent in the selection of attributes.

It can be concluded from this research, that CATA and Pick-*K* attributes is a viable sensory screening tool for the evaluation of wine when different panels are used, as it is stable in terms of configurational congruence and panel consensus.

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Chapter 6

General discussion and conclusions

GENERAL DISCUSSION AND CONCLUSIONS

6.1 Conclusions and future prospects

Chenin blanc wines in South Africa have received a lot of recognition in recent years, especially since the formation of the Chenin blanc association. This association was originally formed in the year 2000 by a few winemakers, and have since made invaluable contributions to the South African wine industry by promoting and raising the image of Chenin blanc as a white wine cultivar, and also by assisting in lifting the quality levels across all styles of Chenin blanc (CBA, 2015). Chenin blanc is considered a neutral cultivar (Augustyn & Rapp, 1982), and many winemakers and researchers have experimented with different winemaking techniques to modulate the flavour of Chenin blanc wine (Aleixandre-Tudo *et al*., 2015).

Most wine professionals are of the opinion that oak wood maturation leads to an increase in wine quality (Crump *et al*., 2015). This notion is supported by the fact that most of the Chenin blanc wines that have received Top 10 status in the annual South African Top 10 Chenin blanc competition were indeed matured in contact with oak (CBA, 2015). The use of alternative oak products have been investigated and applied in various South African cellars, since it is more cost effective than traditional oak barrels (Du Toit, 2010). However up to date little research have been conducted on the sensorial and hedonic properties of alternative oak products, especially for white wine and under South African conditions.

The main aim of this research was to investigate the effect of different oak products on the sensory properties of Chenin blanc wine over time, and to gain insight regarding the hedonic perception thereof by both expert and consumer assessors. Another aim of this research was method development for Check-all-that-apply (CATA) questions with the use of different panels.

Chapter 3 investigated the evolution of Chenin blanc aroma during a commercial maturation trial using different oak products. Pick-*K* attributes was used as sensory method with both an expert panel and a trained panel to elicit the descriptive sensory data. The descriptive sensory data that were elicited from the expert panel and the trained panel were comparable. There were clear differences between the different wine treatments and the different maturation intervals. Definite differences were observed between the unoaked and the oaked wines, and also between the wines of the different oak treatments. A clear discrimination could be made between the wines matured in 5^{th} fill barrels, new barrels and 5^{th} fill barrels with stave inserts. Certain differences were observed after 4 months between the wines matured in new barrels of different cooperages. This was also the case for the wines matured in the 5^{th} fill barrels with the stave inserts from two different cooperages These differences were less prominent after 9 months oak maturation, suggesting that there seemed to exist a difference in the extraction rate and release of oak related aroma active compounds between treatments. It was also clear that a longer period of oak maturation leads to more oaky wine aroma profiles. Longer maturation also led to the loss of fresh fruit character in the wines, especially considering the wines matured in new barrels. This could be due a masking effect of the fruity aromas, and also due to the fact that the concentration of oak derived aroma compounds were higher in the newer barrels. It could also have been due the higher porosity that new barrels have in comparison with older barrels, which could have led to the evaporation of some aroma compounds, or the introduction of more oxygen into the wine when new barrels are used (Towey e*t al*., 1996; Perez-Prieto e*t al*., 2002; Nevares & del Alamo-Sanza, 2015).

Further investigation into the effect of specific oak products is advised to draw definitive conclusions about the different treatment effects. Chemical analysis will be useful to shed light on the specific chemical compositions of the wines matured in contact with different oak products, as well as the concentrations and rates at which oak related compounds are extracted and related to sensory characteristics. Quantitative sensory analysis is another option to quantify significant differences between treatment effects. Proposed methods for quantitative sensory analysis include conventional sensory descriptive analysis (DA) or the rapid method, rate-all-that-apply (RATA).

Chapter 4 investigated the sensory and hedonic perception of the Chenin blanc wines after a maturation period of 9 months in contact with oak with an additional 6 months bottle ageing, using both an expert panel and an untargeted consumer panel. The sensory descriptive data obtained from these panels were comparable and there were no significant differences in terms of perceived quality and degree of liking for the different oak treatments. Wines matured with the staves received the lowest scores. However, these lower scores are considered modest scores, suggesting that there is an appeal for the usage of alternative oak products, especially in the production of wine targeting certain price classes and market segments (Crump *et al*., 2015). The degree of liking of the unoaked wine treatment was not significantly different from the wines of the different oak treatments. The consumers did, however, indicate a higher degree of liking for the wines matured in new barrels than for the wines matured with the stave inserts, suggesting that they appreciate barrel matured wines more than wines matured in contact with staves.

Future research regarding the hedonic perception of alternative oak products should include consumer segmentation. This will allow wine producers to draw definitive conclusions regarding the degree of liking and acceptability of wines when wines are produced with certain price classes or consumer targets in mind.

Chapter 5 investigated the suitability of CATA and Pick-*K* attributes as a tool for rapid sensory evaluation when trained, expert and consumer panellists are used. From the sensory data elicited at three different intervals of testing, it was found that the different panels were comparable in terms the configurational congruence and panel consensus. The trained panel was also found to be repeatable in the testing of wines. From the results obtained from this specific investigation, CATA and its variant Pick-*K* attributes, can be recommended as a viable rapid sensory profiling method for the evaluation of wine. It can also be concluded this this method is fit for usage by both trained and untrained panellists.

A general observation between the data elicited from the trained panel, expert panel and consumer panel, was that the trained and expert panellists used less, but more precise descriptors. The consumers on the other hand used a lot of attributes to describe the products, and more effort was required to handle and process the consumer data. It might be recommendable to also restrict consumers to picking only *K* attributes to describe the sample space. It must however be taken into account that consumers do not necessarily possess the product specific vocabulary that experts and trained panellists do. Further investigation is necessary to obtain information regarding the effect that a restriction in attribute selection might have on the quality of descriptive data elicited from consumer panels.

This study generated valuable knowledge regarding the sensory profiles and consumer liking for wines made using alternative oak products and new barrels. This information could be used by winemakers to inform and justify their use of alternative oak products. It also contributed to the field of sensory and consumer research in the wine industry by confirming that CATA is a suitable rapid method to obtain descriptive and hedonic sensory information.

6.2 References

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ADDENDUMS

ADDENDUM A: Chenin blanc aroma wheel

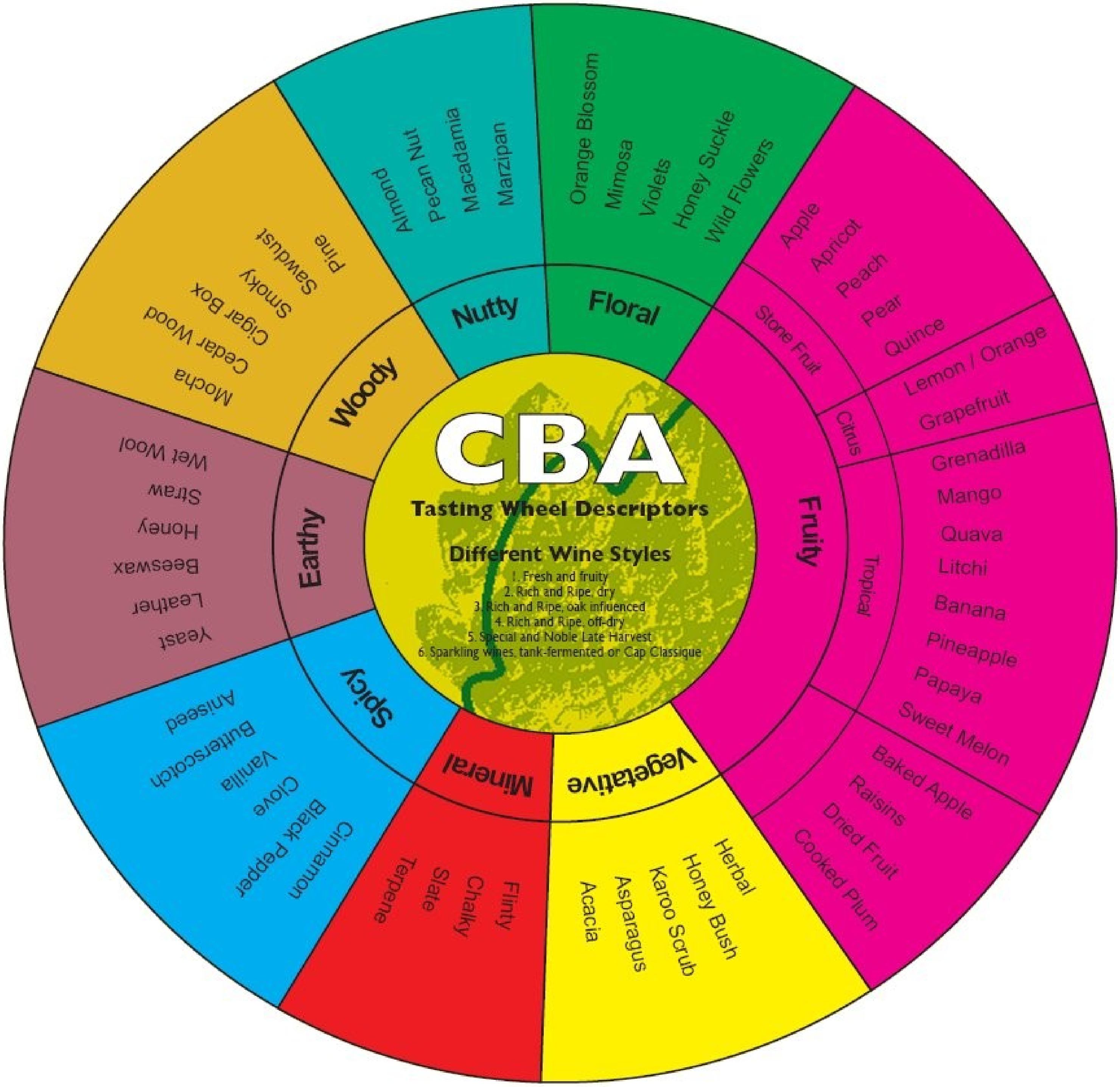

Figure A. Chenin blanc aroma wheel.

ADDENDUM B: Reference standards for aroma training

Table B. Aroma reference standards presented during panel training.

Family/Subfamily	Attribute	Composition
Citrus	Lemon	¼ slice lemon
	Orange	¼ slice orange
	Grapefruit	¼ slice grapefruit
White/Yellow fruit	Peach	20 mL Liquifruit Peach
	Apricot	20 mL Liquifruit Apricot
	Melon	1cm wedge fresh melon
	Pear	2x3cm piece canned pear
	Quince	1cm wedge fresh quince
	Yellow apple	1cm wedge fresh yellow apple
Tropical	Banana	1 µL Isoamyl acetate + 30mL distilled water
	Litchi	5ml canned litchi juice
	Passion fruit	1/3 pulp fresh passion fruit
	Pineapple	¼ slice of pineapple
	Guava	2x3cm piece fresh (ripe) guava
	Mango	2cm block dried mango roll
	Gooseberry	2 gooseberries
	Papaya	1 cm wedge fresh papaya
	Coconut	1 tsp desiccated coconut
Vegetative	Fresh cut grass	Handful fresh cut grass
	Green beans	2 green beans chopped
	Green pepper	2x3cm piece chopped
	Mint	1 sprig chopped
	Eucalyptus	3 leaves chopped
	Celery	1 stick chopped
Dried	Dry grass/Hay	Handful dry grass
	Tobacco	Dried tobacco from 2 cigarettes
Sweet Associated	Honey	Acacia honey
	Marmalade	1 tsp. orange marmalade
	Dried fruit	I piece apple, apricot, peach, prune, pear chopped
	Raisin	5 raisins chopped
Nutty	Nutty	2 drops walnut flavour + 10 mL distilled water
Floral	Orange blossom	2 drops orange blossom flavour on cotton wool
	Linden Tree Flower	1/2 teabag
Toasted / Oaky	Oak	3 g medium toasted French oak
	Planky	3 g wood shavings
	Toasted bread	1 cm cube of toasted bread
	Caramel	1 tsp. caramel sauce + 5 mL distilled water
	Toffee	1 toffee chopped + 5 mL hot water
	Vanilla	½ tsp. vanilla essence in 10 ml distilled water
	Roasted Coffee	4 roasted coffee beans
Spicy	Black pepper	1 tsp crushed black pepper
	White pepper	1 tsp white pepper
	Bay leaves	1 dry bay leave
	Cinnamon	1/2 tsp cinnamon powder
	Thyme	1/2 tsp dry thyme
	Cloves	1/2 tsp cloves
	Juniper	4 berries
	Aniseed	1/2 tsp whole aniseed
	Nutmeg	1/2 tsp nutmeg
	Ginger	1/2 tsp ginger powder
	Liquorice	1 cm block of liquorice
	Curry	1/2 tsp curry powder
Forest floor	Mouldy/ mushroom	1/2 fresh mush in 10 mL distilled water
	Earthy	Wet earth (half a bottle)
Other	Butter / lactic	2 cm^3 fresh butter
	Sulphur	15% SO_2 solution diluted in 15 mL distilled water
	Yeast	20 mL rehydrated yeast

ADDENDUM C: Tasting sheet

AROMATIC DESCRIPTORS LIST

FRUITY

WHITE FRUITS
- Quince
- Pear
- Yellow Apple

YELLOW FRUITS
- Apricot
- Peach
- Melon

RED FRUITS

BLACK FRUITS

DRIED FRUITS
- Dried Apple
- Dried Peach
- Dried Apricot
- Dried Fig
- Date
- Prune
- Raisin

CITRUS
- Grapefruit
- Lemon
- Orange

TROPICAL FRUITS
- Pineapple
- Banana
- Guava
- Passion Fruit
- Litchi
- Mango
- Gooseberry
- Papaya (Paw-paw)
- Coconut

SWEET ASSOCIATED
- Ripe Fruit
- Mamelade
- Honey
- Fruit Jam
- Glazed / Crystallized Fruit
- Muscat
- Baked Apple

VEGETATIVE / GREEN

VEGETABLES
- Artichoke
- Asparagus
- Cabbage
- Green Beans
- Green Pepper
- Green Olive
- Celery

FRESH/ PLANTLIKE
- Eucalyptus
- Herbaceous
- Tomato leaf
- Green / Cut Grass
- Lemon Grass
- Mint

DRIED
- Hay / Dried Grass
- Tobacco

SPICY
- Bay Leaf / Laurel
- Thyme
- Juniper
- Nutmeg
- Cinnamon
- Ginger
- Clove
- Anise / Fennel
- Liquorice
- Curry
- Black Pepper
- White Pepper

FLORAL
- Camomile
- Linden Tree Flower
- Honeysuckle
- Orange Blossom

FOREST FLOOR
- Humus/Earthy
- Mouldy
- Mushroom

TOASTED / WOOD

TOASTED
- Caramel / Burnt Sugar
- Toffee
- Vanilla
- Roasted Coffee
- Toasted Bread

WOODY
- Planky / Pine Shavings
- Oaky
- Burnt / Smoked Wood

NUTS
- Almond
- Hazelnut
- Walnut

ANIMAL
- Leather

MINERAL
- Chalky
- Iodine / Salty
- Mineral / Flinty
- Solvent / Chemical

OTHER
- Butter
- Lactic
- Sulphur
- Stuffy
- Dusty
- Wet mop
- Yeast

Figure C. Template of tasting sheet used by all of the panels for the different testing intervals.

ADDENDUM D: Post alcoholic fermentation chemical analysis

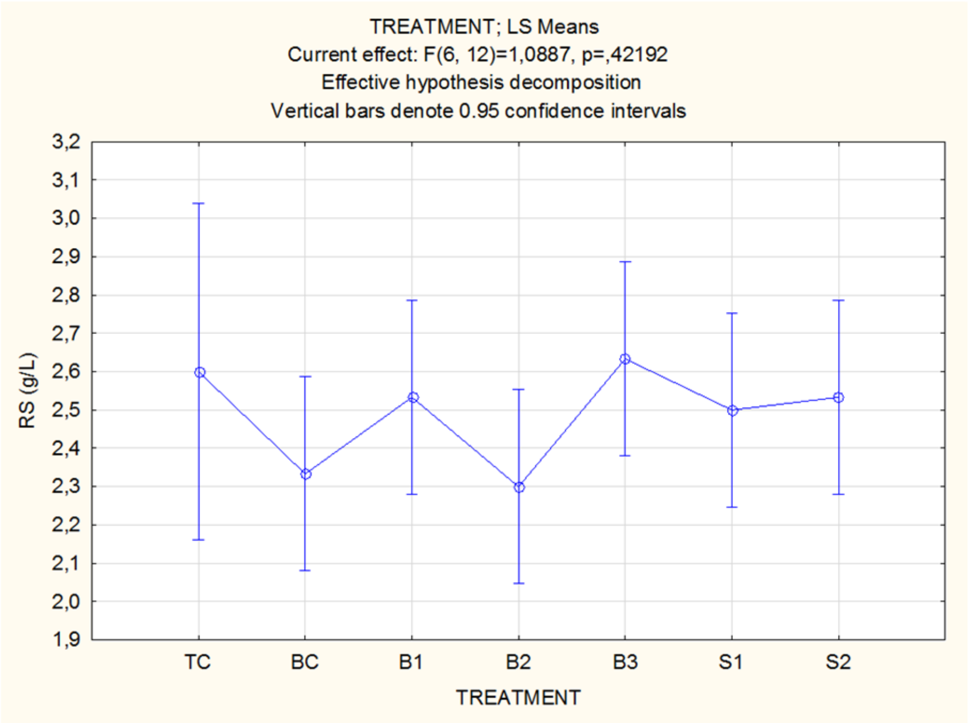

Figure D.1 LS means plot indicating RS (g/L) values between the different wine samples. Error bars indicate standard deviation (obtained from STATISTICA®).

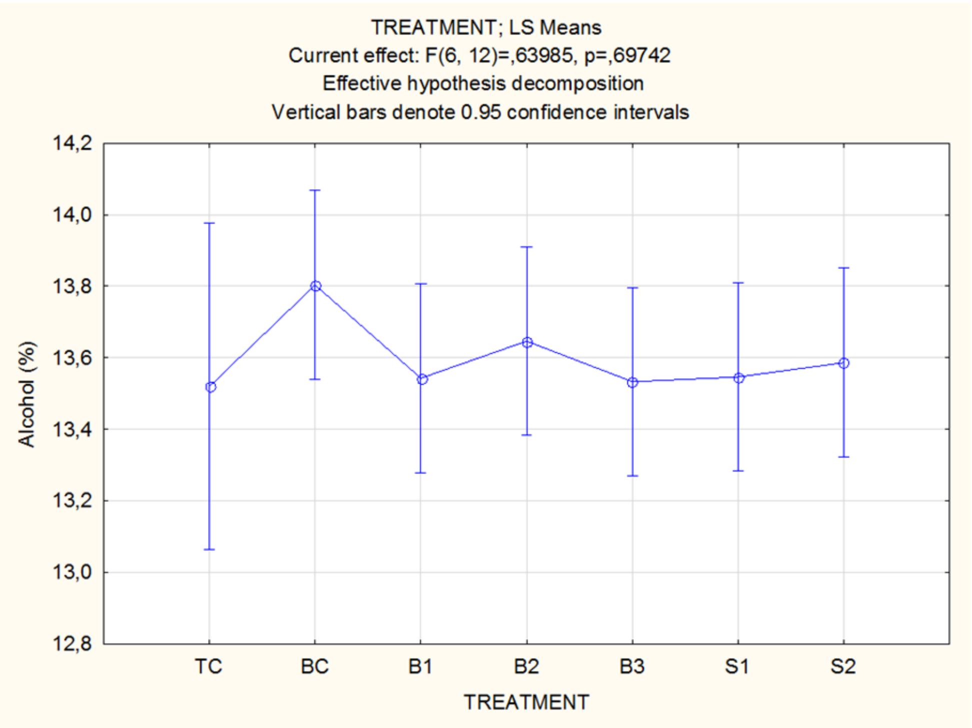

Figure D.2 LS means plot indicating Alcohol (%) values between the different wine samples. Error bars indicate standard deviation (obtained from STATISTICA®).

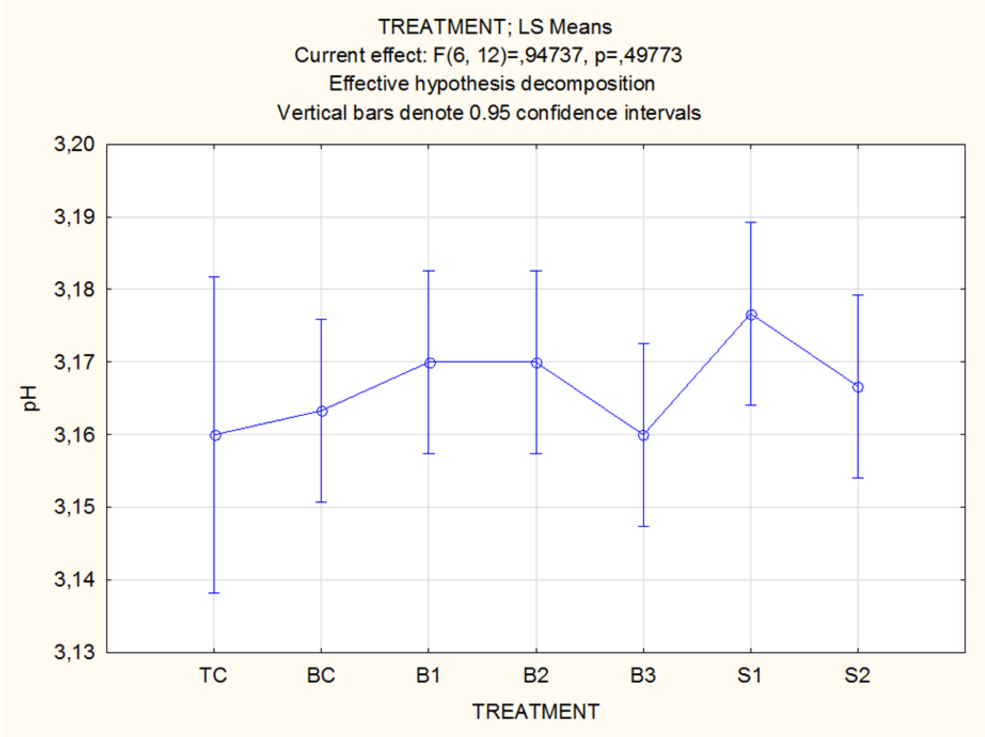

Figure D.3 LS means plot indicating the pH values between the different wine samples. Error bars indicate standard deviation (obtained from STATISTICA®).

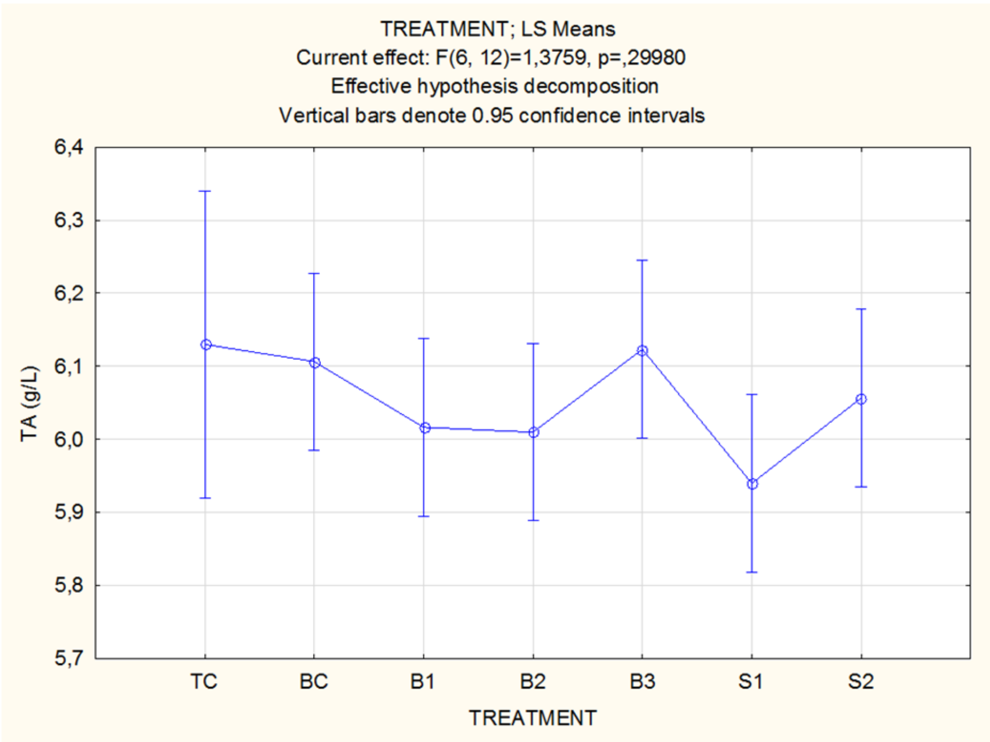

Figure D.4 LS means plot indicating the TA (g/L) values between the different wine samples. Error bars indicate standard deviation (obtained from STATISTICA®).

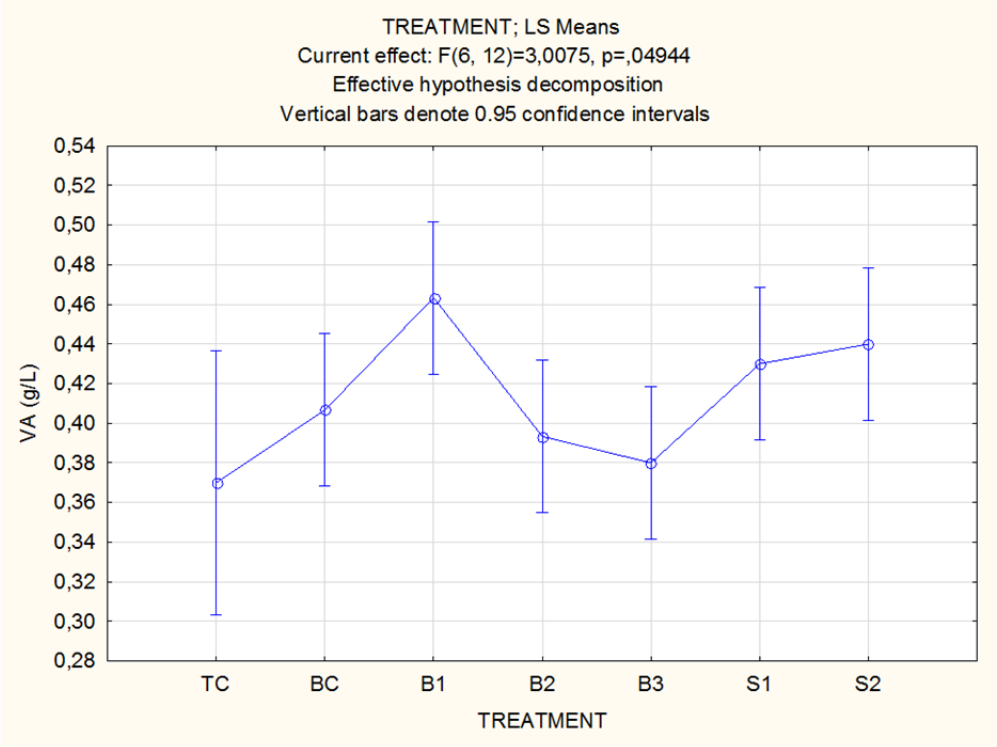

Figure D.5 LS means plot indicating VA (g/L) values between the different wine samples. Error bars indicate standard deviation (obtained from STATISTICA®).

ADDENDUM E: Hierarchical cluster analyses of CA-plots

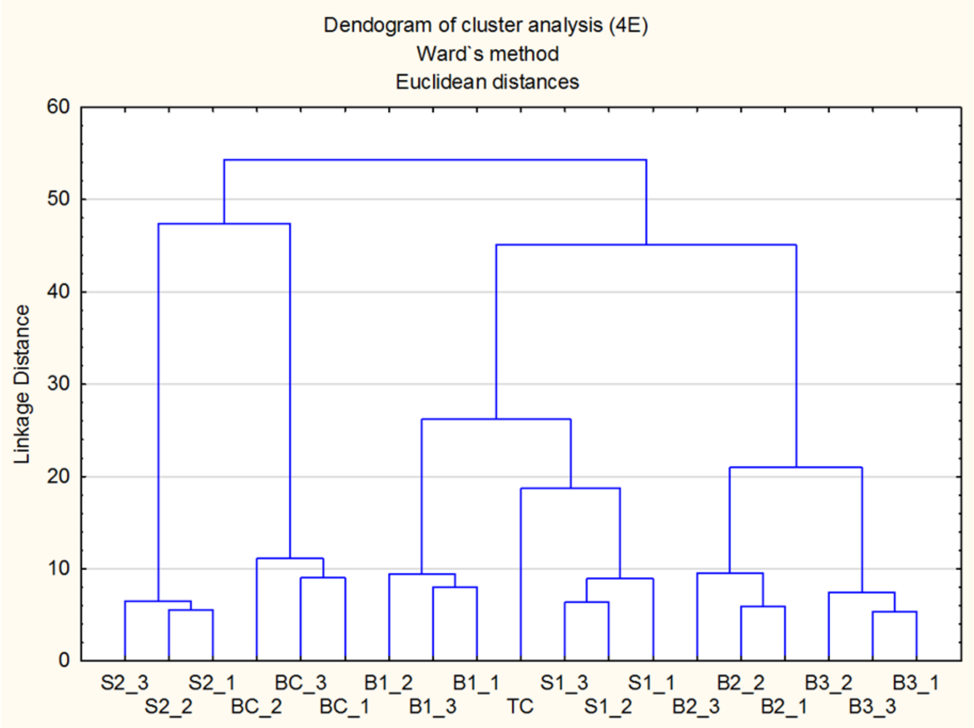

Figure E.1 Dendogram of cluster analysis performed on data obtained from the expert panel after 4 months oak maturation (obtained from STATISTICA®).

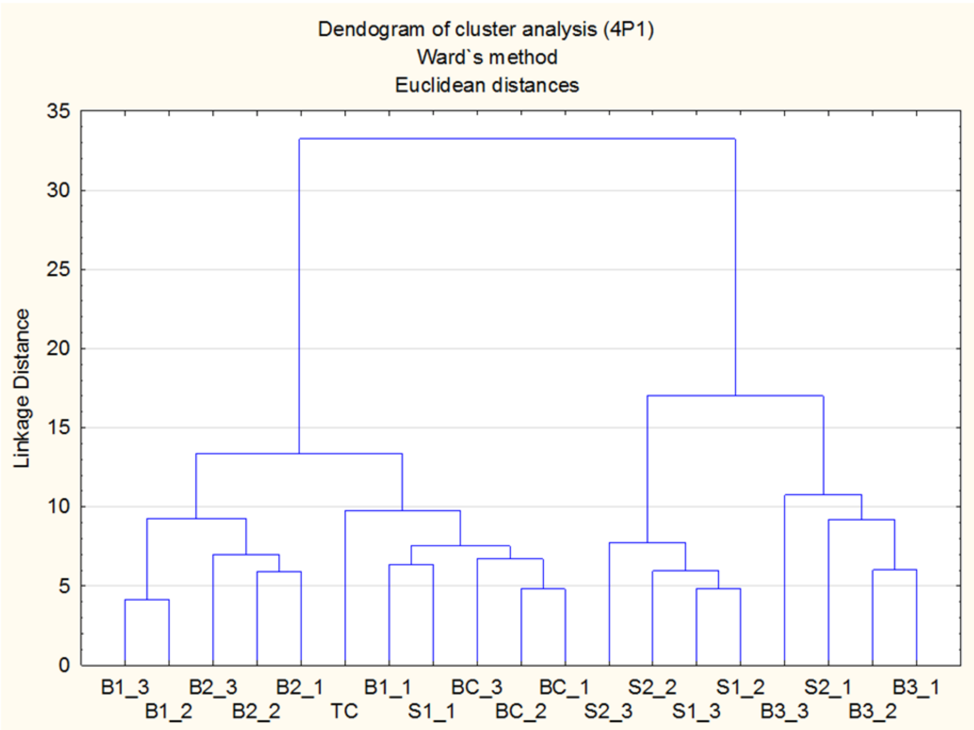

Figure E.2 Dendogram of cluster analysis performed on data obtained from the trained panel after 4 months oak maturation (first sensory rep) (obtained from STATISTICA®).

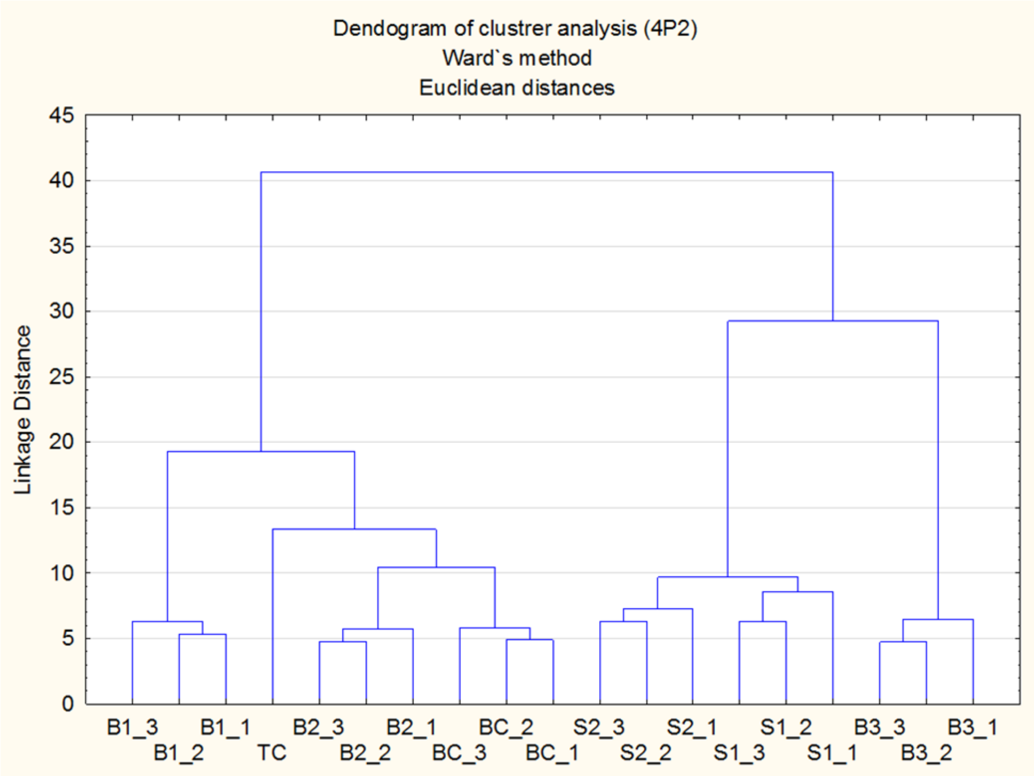

Figure E.3 Dendogram of cluster analysis performed on data obtained from the trained panel after 4 months oak maturation (second sensory rep) (obtained from STATISTICA®).

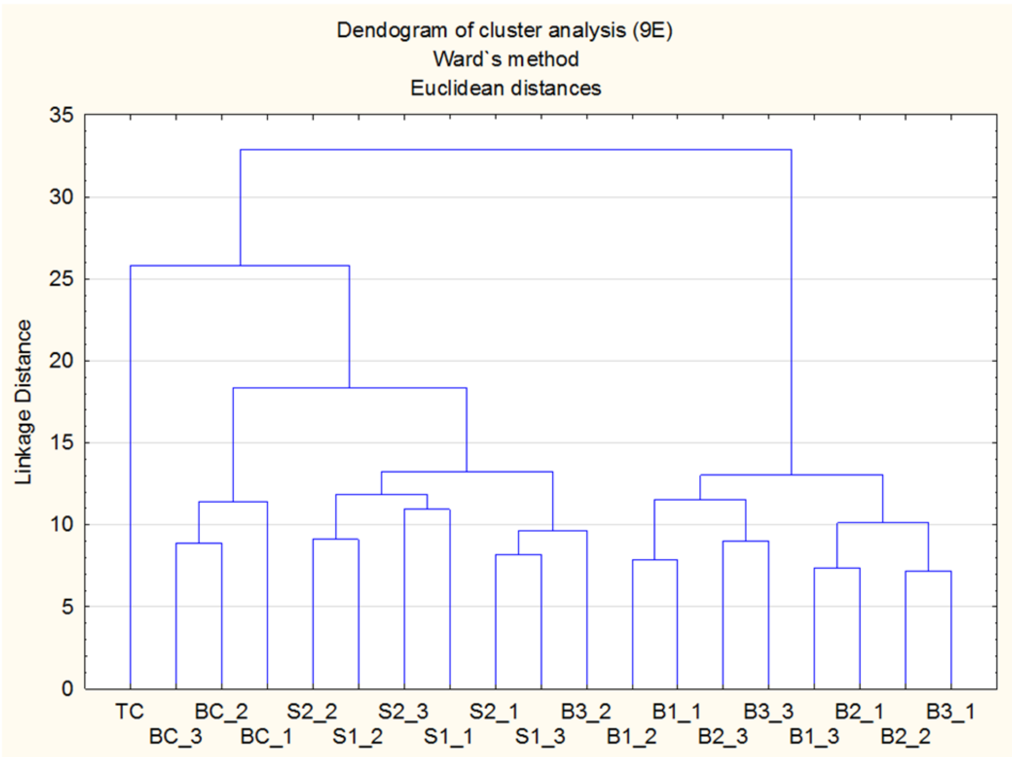

Figure E.4 Dendogram of cluster analysis performed on data obtained from the expert panel after 9 months oak maturation (obtained from STATISTICA®).

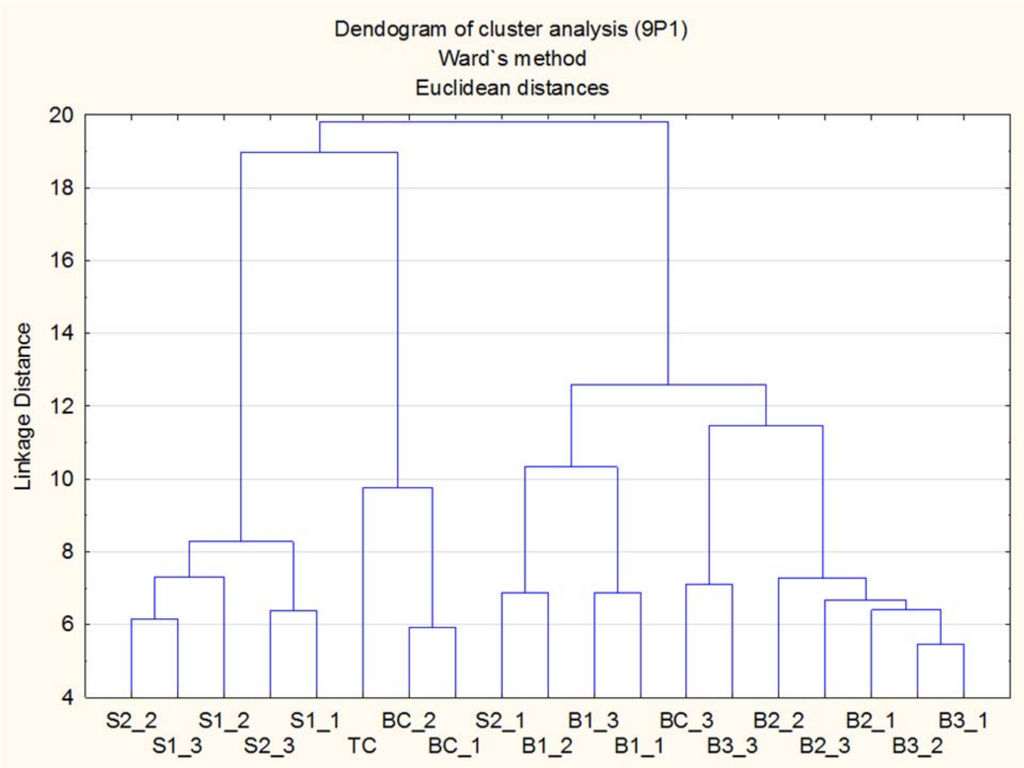

Figure E.5 Dendogram of cluster analysis performed on data obtained from the trained panel after 9 months oak maturation (first sensory rep) (obtained from STATISTICA®).

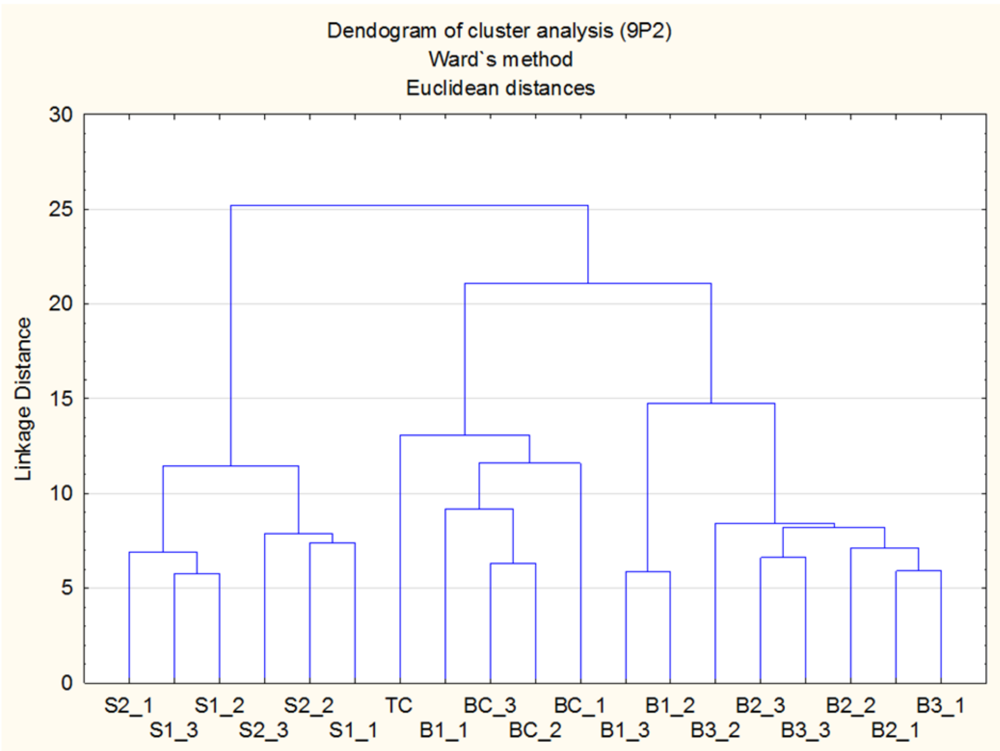

Figure E.6 Dendogram of cluster analysis performed on data obtained from the trained panel after 9 months oak maturation (second sensory rep) (obtained from STATISTICA®).

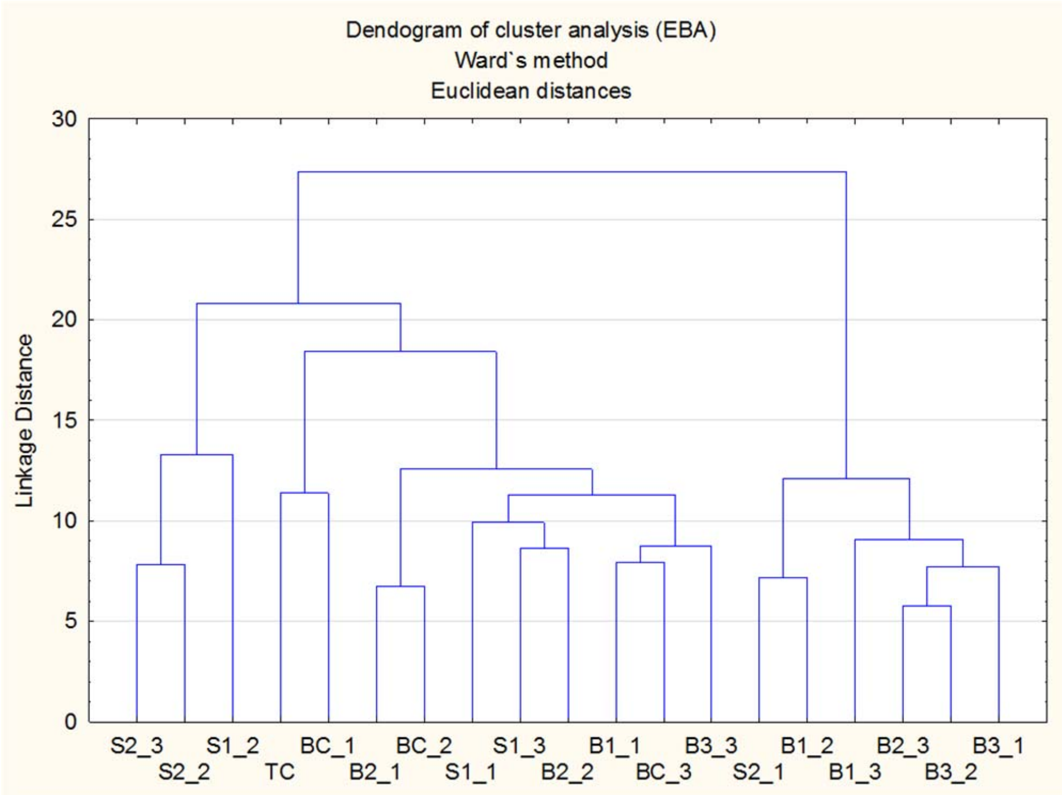

Figure E.7 Dendogram of cluster analysis performed on data obtained from the expert panel after 9 months oak maturation with an additional 6 months bottle ageing (obtained from STATISTICA®).

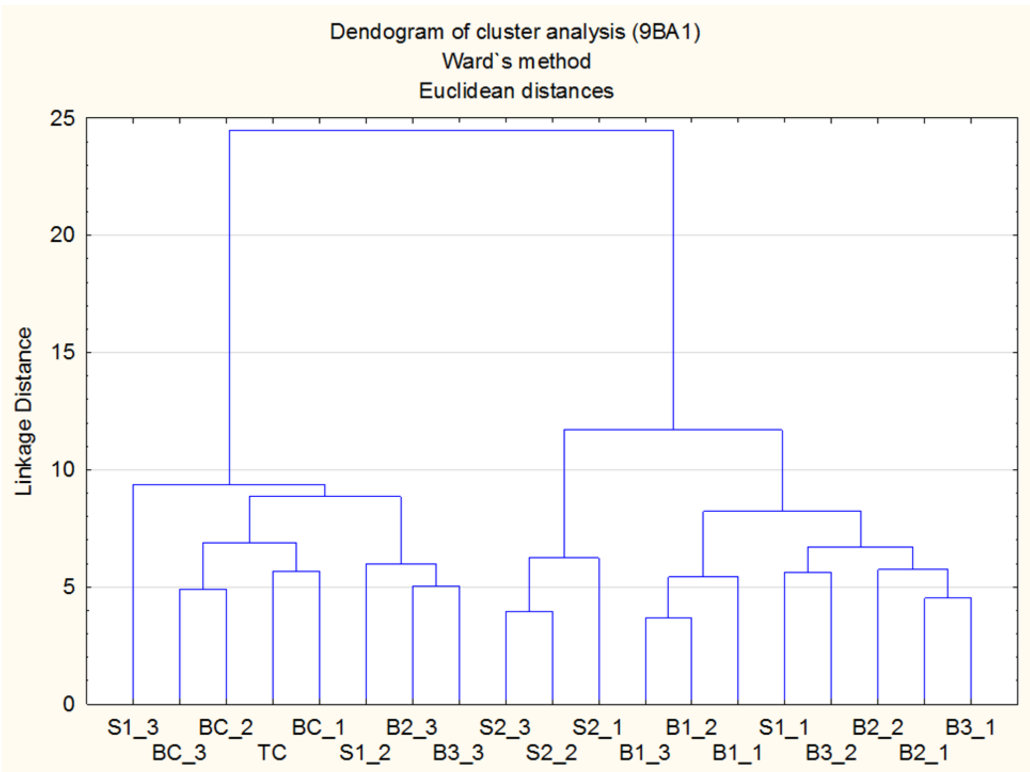

Figure E.8 Dendogram of cluster analysis performed on data obtained from the trained panel after 9 months oak maturation with an additional 6 months bottle ageing (first sensory rep) (obtained from STATISTICA®).

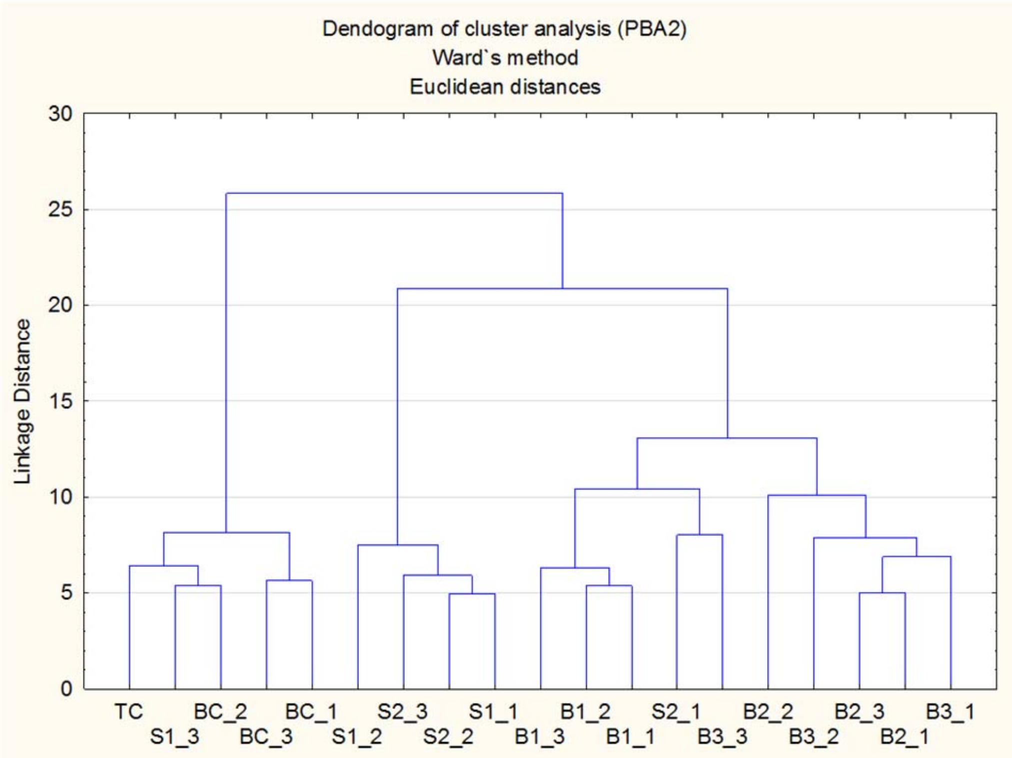

Figure E.9 Dendogram of cluster analysis performed on data obtained from the trained panel after 9 months oak maturation with an additional 6 months bottle ageing (second sensory rep) (obtained from STATISTICA®).

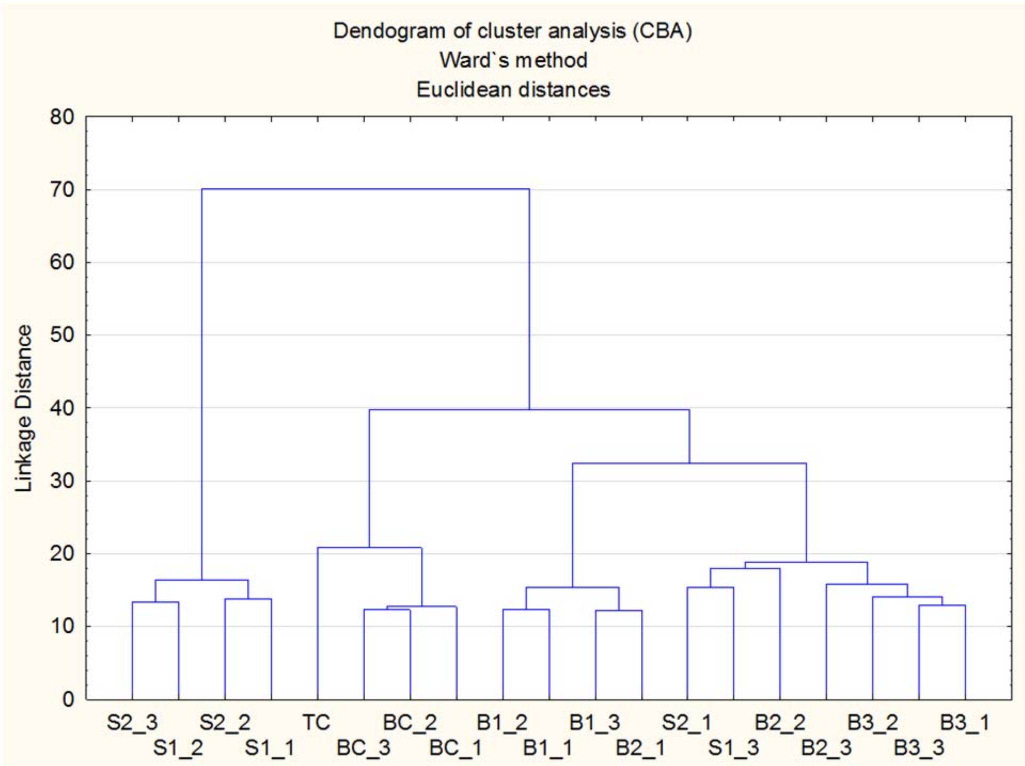

Figure E.10 Dendogram of cluster analysis performed on data obtained from the consumer panel after 9 months oak maturation with an additional 6 months bottle ageing (obtained from STATISTICA®).