Oenological evaluation of Chenin Blanc wines elaborated from different trellising systems

by

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Summary

Grape composition plays a significant role in defining wine style and typicality; and there are ways in which grape composition can be altered or modified. Among these ways are viticultural practices which include trellising systems. Trellising systems are driving mechanisms that alter canopy microclimates, consequently affecting yield and the quality of grapes. Due to the fact that most grape primary metabolites contribute to the production of secondary compounds in final wines, it is important to assess if changes in canopy microclimates induced by trellising systems can reflect in final wines. Therefore, the aim of this study was to characterise (chemically and sensorially) grape must and wines of Chenin Blanc grapes made from grapes of different trellising systems.

Basic oenological parameters (including Brix, pH, TA and alcohol) were measured for grape juice from harvest and then throughout the winemaking process. Sugar level varied in the first season with a significant difference between systems, but no significant differences were observed in other parameters. The other important factor evaluated was yield, which had differences between systems; mostly, open canopies by horizontal division produced higher yield than vertical dividing canopies and closed non-dividing canopy systems. However, those differences were not statistically significant between systems. YAN, ammonia, total (FAN) and individual amino acids in musts and major volatiles and thiols were subsequently measured. The concentrations were above critical levels for YAN. No significant differences were found across all the treatments, when the data were subjected to analysis of variance, and even by multivariate analysis no distinctive groupings were formed. However, the additional fingerprint of wine samples by high-resolution mass spectrometry produced groupings of samples according to trellising systems.

In Chapter 3, the wines of the six different trellising systems were profiled using a rapid descriptive method (CATA), using both analytical and expert panellists; further, wine overall quality was evaluated by experts. Wine samples could not be differentiated by aroma according to trellising systems. On the other hand, taste and mouthfeel profiles implied that there were differences between wine samples according to trellising systems. Additionally, the overall wine quality rating showed significant differences between wines of according to trellising systems, mostly contributed by significant differences in taste and aroma ratings.

In Chapter 4, a detailed discussion of results from Chapters 2 and 3 is presented by comparing sensory profiles with chemical composition by correspondence analysis and principal component analysis respectively. Aroma compounds showed no significant differences between trellising systems (Chapter 2). Aroma description profiles from the correspondence analysis (CA) biplot (Chapter 3), illustrated that aroma profiles of the wines were similar since no clear groupings observed., The CA score plot from taste and mouthfeel results produced a similar configuration

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pattern with the PCA score plot from the high resolution mass spectrometry (HRMS) data, which indicated that the trellis system may have an influence on chemical aspects also related to the wines' taste perception.

The results of this research contribute to information that winemakers or growers may require regarding decisions they can make in relation to choosing an appropriate trellising systems. However, other factors such as cultivar, climate, vintage, and economic advantage should not be disregarded.

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Opsomming

Druiwesamestelling speel 'n belangrike rol in die definiëring van wynstyl en tipiesheid; en daar is maniere waarop druiwesamestelling verander of gewysig kan word. Onder hierdie maniere is wingerdboukundige praktyke, wat stelsels insluit. Opknappingstelsels is dryfmeganismes wat die mikroklimaat van die lug beïnvloed, wat die opbrengs en die kwaliteit van druiwe beïnvloed. Aangesien die meeste druif primêre metaboliete bydra tot die produksie van sekondêre verbindings in finale wyne, is dit belangrik om te bepaal of veranderinge in die kloofmikroklimaat wat deur trilstelsels veroorsaak word, in finale wyne kan weerspieël. Daarom was die doel van hierdie studie om druiwemost en wyne van Chenin Blanc-druiwe (wat chemies en sintuiglik is) te karakteriseer (chemies en sintuiglik), vervaardig uit druiwe van verskillende opknappingstelsels.

Basiese oenologiese parameters (insluitend Brix, pH, TA en alkohol) is vanaf die oes en daarna gedurende die wynmaakproses gemeet vir druiwesap. Die suikervlak het in die eerste seisoen gewissel met 'n beduidende verskil tussen stelsels, maar in ander parameters is geen noemenswaardige verskille waargeneem nie. Die ander belangrike faktor wat geëvalueer is, was opbrengs, wat verskille tussen stelsels gehad het; Meestal het oop afdakke deur horisontale verdeling hoër opbrengste gelewer as vertikale skeidende afdakke en geslote afdakke nie. Hierdie verskille was egter nie statisties beduidend tussen stelsels nie. Daarna is YAN, ammoniak, totaal (FAN) en individuele aminosure in mossies en belangrikste vlugtige en toile gemeet. Die konsentrasies was bo kritieke vlakke vir YAN. Daar was geen noemenswaardige verskille tussen al die behandelings nie, toe die data aan variansie-analise onderworpe was, en selfs deur multivariate analise, is daar geen onderskeidende groeperings gevorm nie. Die bykomende vingerafdruk van wynmonsters deur massa-spektrometrie met 'n hoë resolusie het groepe monsters volgens trilstelsels opgelewer.

In hoofstuk 3, is die wyne van die ses verskillende opleistelsels met behulp van 'n vinnige beskrywende metode (CATA) geprofileer, met behulp van sowel analitiese as kundige paneellede; verder is wyngehalte meestal deur kundiges beoordeel. Wynmonsters kon nie volgens aroma onderskei word deur aroma nie. Aan die ander kant het smaak- en mondgevoelsprofiele geïmpliseer dat daar verskille tussen wynmonsters volgens trilstelsels was. Daarbenewens het die algehele wynkwaliteitwaardigheid beduidende verskille getoon tussen wyne volgens traliewerkstelsels, meestal bygedra deur beduidende verskille in smaak- en aroma-graderings.

In Hoofstuk 4, word 'n gedetailleerde bespreking van die resultate uit hoofstuk 2 en 3 aangebied deur sensoriese profiele met chemiese samestelling onderskeidelik deur korrespondensie-analise en hoofkomponentanalise te vergelyk. Aroma verbindings het geen noemenswaardige verskille

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getoon tussen die stelsels nie (hoofstuk 2). Aroma-beskrywings profiele uit die korrespondensie-analise (CA) biplot (Hoofstuk 3), illustreer dat die aroma-profiele van die wyne soortgelyk was, aangesien geen duidelike groeperings waargeneem is nie. Die CA-telling van smaak en mondgevoelens het 'n soortgelyke konfigurasiepatroon met die PCA-telling opgelewer Dit is gebaseer op die data met die hoë resolusie massaspektrometrie (HRMS), wat aangedui het dat die trellis-stelsel 'n invloed kan hê op chemiese aspekte wat ook verband hou met die smaakpersepsie van die wyne.

Die resultate van hierdie navorsing dra by tot inligting wat wynmakers of produsente mag benodig rakende besluite wat hulle kan neem met betrekking tot die keuse van 'n toepaslike versieringstelsel. Ander faktore soos kultivar, klimaat, oesjaar en ekonomiese voordeel moet egter nie buite rekening gelaat word nie.

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This thesis is dedicated to my late father **(Raimund Kashima Kaffaya Iipinge)**

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Biographical sketch

Hilaria Nelago Iipinge was born in Oshakati, Oshana region in Namibia on the 16 August 1986. She attended primary and junior secondary education at Ondjora combined school and matriculated at Mweshipandeka secondary school in Ongwediva in the year 2004. She went on to pursue her tertiary education in 2007 at Neudamm Agricultural College and graduated with a National Diploma in 2009.She further enrolled for her Bachelor Degree (Hons) in Agriscience in 2010, and graduated with Bachelor Science (Hons) in Food science and Technology in 2014 at the University of Namibia. In 2017, she enrolled for MSc in Wine Biotechnology at the Department of Viticulture and Oenology, Stellenbosch University.

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Preface

This thesis is presented as a compilation of 4 chapters.

Chapter 1	**Introduction, background, aim and objectives**
Chapter 2	**Research results** Evaluation of volatile and non –volatile compounds in Chenin Blanc wines from different trellising system
Chapter 3	**Research results** Evaluating the effects of trellising systems on the sensory profile of Chenin Blanc wines, using Check All That Apply (CATA) method and quality scoring
Chapter 4	**General discussions and conclusion**

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Chapter 1

Introduction

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Chapter 1: Introduction: Background, aim and objectives

1.1. Background

Grape and juice composition play an important role in the production of fermentation-derived volatiles (Keyzers & Boss, 2010). Knowledge of the origin of wine volatiles is important in determining the potential for the optimisation of these components during grape-growing and wine production. Grape berries are known to contain "neutral" aroma compounds common to all varieties, such as C_6 alcohols, and varietal "impact" compounds that are often found at trace levels in wines (Davies & Böttcher, 2009; Ebeler & Thorngate, 2009). Each grape berry contains a mixture of free and bound chemical compounds and concentrations that vary according to cultivar, region, and viticultural practices (Francis & Williams, 1993; Sefton *et al.*, 1994; Ubeda & Cortiella, 2017) which contribute to wine final aroma and flavour profile.

Cultivar differences provide a major source of variation in wine composition as the genetic makeup of grape berries influences the pool of compounds present in a must. Also, the place of origin has an important influence on the style, quality and prestige of regional produce such as wine. Wines made from the same grape variety have been demonstrated with differences in specific attributes (Gambetta *et al.*, 2017). This suggest that changes in berry composition other than those imposed by genetics may affect the sensory properties of the resulting wine. Therefore, one might argue that there is a correlation between chemical composition of grapes and sensory properties of resulting wines (Vilanova *et al.*, 2010).

It is clear that environmental factors, vineyard management, as well as harvesting time play a role (Koundouras *et al.*, 2006; Conradie *et al.*, 2002; Kliewer &Dokoozlian, 2005; Fang and Qian, 2006; Pereira *et al.*, 2006; Kalua & Boss, 2009). The vast majority of wine volatiles (in terms of concentration) are esters, alcohols, and acids formed by yeast as by-products of fermentation (Cole & Noble, 2003). It is considered that most of the acids, esters, and alcohols produced during fermentation of grape juice originate from the sugars and amino acids present in the must (Swiegers *et al.*, 2005). To date, many studies have been conducted where the manipulation of various fermentation parameters such as yeast strain selection, temperature control, and the availability of yeast nutrients have shown that these variables have an important impact on the formation of these compounds (Reynolds *et al.*, 2001; Swiegers *et al.*, 2005). However, differences in the wines from the same cultivar may occur due to changes in the compounds responsible for varietal characters (Fang & Qian, 2006). As fermentation volatiles are produced by yeast from primary metabolites, the assumption is generally made that grape composition plays a major role in the production of wine acids, esters, and alcohols sourced from sugars, amino acids, and nitrogen concentrations (Burin et al., 2015; Keyzers & Boss, 2010; Dennis *et al.*, 2012). These primary metabolites are altered by vineyard practices including canopy management practices and trellising systems (Cavallo *et al.*, 2001; Bruwer, 2018).

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Conflicting results have been shown in various studies on canopy architecture. In some cases, the trellis system appears to have no impact on wine composition based on sensory analysis, showing no differences among systems (Peterlunger *et al.*, 2002; Reynolds *et al.*, 2004; Bordelon *et al.*, 2008; Vanden Heuvel, et al., 2013). However, other studies report that trellis systems have significant effects on berry quality, such as pH, sugar content (Brix), anthocyanins, and phenols (Cavallo *et al.*, 2001). Although not evaluated from the perspective of the impact of a trellising system, berries exposed to sun react differently in their synthesis of amino acids (Pereira *et al.*, 2006; Šuklje *et al.*, 2016); the same has been noted as positive response of important compounds for wine organoleptic properties to sunlight exposure (Li *et al.*, 2011).

Canopy microclimate differences in terms of sunlight level, humidity, temperature, evaporation and wind speed are influenced by various techniques including trellis systems (Smart, 1985). For example, phenomena such as evaporation rate are among the aspects that get regulated by temperature. With higher temperature, higher evaporation rate and lower humidity play a significant role in the reduction of fungal diseases in grapes which affect wine aroma (Lopez Pinar *et al.*, 2017). Several studies have demonstrated the important of canopy light for fruit zone, which is essential for yield and grape composition (Archer & Strauss, 1989; Oliveira *et al.*, 2014; Somkuwar *et al.*, 2018). Exposing berries to sun affects metabolites such as thiols precursors present in grapes (Martin *et al.*, 2016). However, in most cases all these studies did not evaluate the subsequent wines profiles based on the affected compounds.

Viticulture practices studies have looked at the influence of canopy microclimatic factors on grapes composition. Previous measurements covered in all studies (in grapes or wines) are the basic oenological parameters such as sugars Brix, pH, and TA (Turkington *et al.*, 1980; Vanden Heuvel *et al.*, 2004). Moreover, in few cases, organic acids (namely malic acid, tartaric acids and free amino acids) were evaluated (Van zyl and Van Huyssteen, 1980a; Volschenk & Hunter, 2001b; Zoecklein *et al.*, 2008; Trought *et al.*, 2017). However, it is still unclear whether a change in grape composition, especially in grape derived compounds, can significantly affect sensory properties and perceived in the corresponding wines.

1.2. Viticulture practices affecting grape and wine composition

Several ways of managing vine growth and optimising yield by increasing photosynthesis active reactions can be achieved by modification or manipulation of the canopy (Heilman *et al.*, 1996). The strategies used can either target a specific developmental stage, for example at berry set, véraison and at harvest, or can be done on a long term basis, like establishing a suitable permanent vine architecture or converting it only when necessary. However, both strategies come with drawbacks: short term techniques are labour intensive, but less expensive; long term techniques require less input on a yearly basis, but are expensive to establish or convert. Hence, it is essential for winegrower or winemaker to make the initial correct decisions regarding the type of techniques that can maximise yield while sustaining quality.

1.2.1 Seasonal techniques to manipulate canopy microclimate

Depending on certain circumstances such as specific cultivar vigour or soil fertility, vineyards might suffer from excessive vegetative growth. As a result, canopy density increases and negatively affects the grapevine microclimate. To avoid such a situation, canopy management actions are implemented that bring vines vegetative and fruiting balance by reducing shoot, leaf density, and number of clusters per vine. Those techniques eventually improve light in the canopy environment, and also a key requirement in fruitiness and vegetative growth (Scholefield *et al.*, 1977; Sommer *et al.*, 2000).

The most common canopy management techniques utilised in the vineyard (defoliation; shoot and cluster thinning around cluster zone) aim to improve microclimate within the canopy. Pioneer studies have illustrated that the application of seasonal practices have a great impact on grape and wine composition (Volschenk & Hunter, 2001a). For example, components such as total soluble solids increased when partial defoliation is practiced; at the same time this practice reduces titratable acidity, malic acid and pH in fruit (Hunter & Visser, 1988). This is not always the case though, as other investigators have demonstrated no significant effects on grape composition (Kliewer *et al.*, 2000), and pointing to the fact that possibly the variety plays a more dominant role. In addition to basic oenological parameters, other components such as odour and flavour molecules are affected by alteration of the canopy environment. Šuklje *et al.*, (2016) reported the significant role of defoliation on specific compounds sensitive to light and their effect on the characters of the resulting wines.

The timing of seasonal practices is of outmost importance, as this can affect the synthesis and accumulation of certain compounds. Previous studies have shown the necessity of proper timing when defoliation is carried out to control yield and improve grape composition (Poni *et al.*, 2006; Karoglan *et al.*, 2014; Martin *et al.*, 2016). Beside beneficial effects on bunch and berry characteristics, leaf removal has positive results on *Botrytis* incidence reduction and accumulation of anthocyanins, the latter being of vital importance for colour properties in red grapes and wines (Zoecklein *et al.*, 1992; Tardaguila *et al.*, 2010). In other work, leaf removal was shown to increase anthocyanins and volatile concentrations (Cangi *et al.*, 2017; Sun *et al.*, 2017). Uncontrolled high vigour and consequent excess of shoots or clusters can result in unhealthy berries and insufficient nutrient accumulation and could possibly have a negative impact on produced wines. Shoots and cluster thinning are possible viticultural practices which lead to improved balance of foliage and fruits hence wine quality (Sun *et al.*, 2012).

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1.2.2 Permanent techniques aimed at modifying canopy microclimate

In the vineyard, the bunch zone environment is variable due to uneven light distribution in the canopy. The vineyard row orientation (Hunter *et al.*, 2016) and the architecture of the vine, in terms of height of the canopy, determines the amount of light intercepted and distributed around the canopy (Pieri & Gaudillère, 2003). All this has a direct impact on photosynthetic capacity and vegetative and reproductive growth, which consequently has an effect on berry sugars, organic acids and secondary metabolites content (Smart *et al.*, 1990).

The effects of trellising systems have received considerable attention. It has been shown in previous studies that different trellising systems create their own effective micro-climatic conditions reflected by differences in air movement, bunch temperature as well as air temperature around vine canopies. Therefore, the conditions created by trellising systems are of great importance for vegetative growth, grape composition (Van Zyl & Van Huyssteen, 1980b; Volschenk & Hunter, 2001; Ji & Dami, 2008) and wine composition and quality (Zoecklein *et al.*, 2008).

Beside fruit and wine properties, trellising systems also have an impact on water usage (Van Zyl & Van Huyssteen, 1980a), which may address water efficiency during dry seasons. Trellis type influences transpiration of grapevines; for example, grapevines on a horizontally orientated trellis systems have higher transpiration rates than those on vertical trellises (Myburgh, 2006). One of the biggest effects of trellis architecture is the ability to increase yield by increasing leaf surface area (Swanepoel *et al.*, 1990), improve canopy appearance and incidence and severity of *Botrytis* rot, as well as labour requirements (Volschenk & Hunter, 2001). Not much has been investigated on trellising systems' effect on grapes and wine composition. Many studies have not tried to eliminate as many variables as possible, and were carried out in less controlled as well as commercial blocks. For example, factors such as different vineyard location or site, can have a possible variation of mesoclimate and macroclimate, even when the same cultivar or variety is investigated.

Effects of trellising systems on shade and light

One of the impacts that trellis systems impose on the canopy around the fruit-zone is alteration of light microclimate (Reynolds & Vanden Heuvel, 2009), potentially affecting the concentration and content of grape berry compounds. Trellising systems offer the additional benefit of reducing spring freeze hazard in area susceptible to this problem as it encourage shoot growth from a position relatively high above the ground (Reynolds et al., 2004b). Another benefit of trellising vines is the significant role they have on yield, although results are site- and cultivar-dependent (Reynolds et al., 2004b).

Canopy division promotes increases in yield and quality (Shaulis *et al.*, 1966), and improvement of training systems overcome canopy shading. Canopy shade is a common problem in vineyards which can cause reductions in vineyard yield and wine grape quality. In grapevine canopies, depending on architecture, foliage and fruit berries can develop in conditions varying from shaded through to fully exposed (open). In general, berries developed from open canopy conditions have higher juice sugar concentration, improved acid balance, less unripe herbaceous fruit characters and berry phenolics concentration increases including anthocyanins in red varieties as opposed to shaded canopy conditions (Gladstones, 1992). Shaded canopies entail trellising systems such a Santorini and Stok-by Paaltjie, whereas open canopies include systems such as Ballerina and Smart Dyson (vertically divided); T-frame and Lyre (horizontally divided) canopies.

Overview of training systems investigated in this study

Trellising involves the development and maintenance of the permanent woody structure of the vine in a particular form. The structure attempts to achieve optimal fruit quality and yield, consistent with prolonged vine health, and maintain economically viability. Certain trellising allows mechanized grape harvest, which is cost-effective. However, harvest losses have to be considered as well with mechanised harvest. Figure 1.1 shows the six trellising systems investigated in this study.

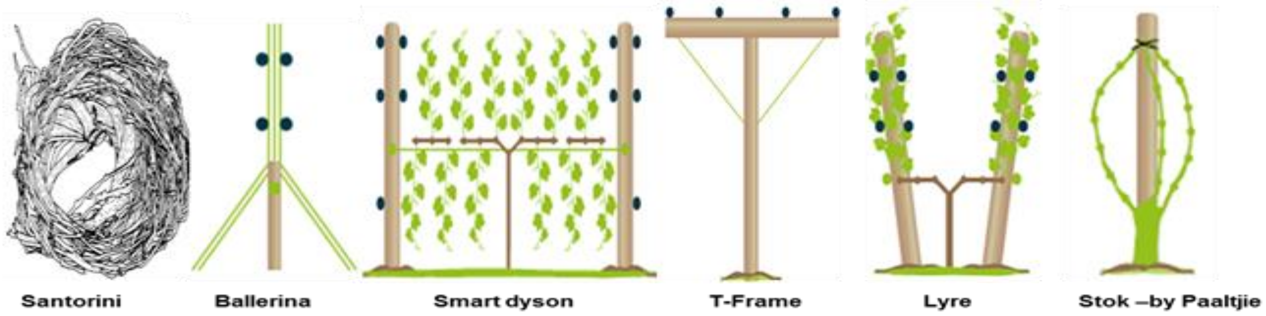

Figure 1.1. The six trellising systems that were investigated in this study for the profiling of chemical and sensory characteristics of the resulting wine. As shown they are: Santorini; Ballerina; Smart Dyson; T-frame; Lyre; and; Stok-by-Paaltjie trellising systems as captured from the Vinpro website (vinpro.co.za), 2019.

Santorini

Santorini trellising system commonly known as *"kouloura*" (Greek), "wreath" or "basket", originated from the Santorini region in Greece (New Wines of Greece). It is a unique way of training the vines to grow sheltered within their "woven" basket. The system was developed to protect against strong winds in the region, and it has now extended into other regions like South Africa. Although not commonly used in South Africa, it could give wine growers an option, especially in windy areas. However, the system is very difficult to harvest, and not suited for machine harvesting.

Ballerina

Ballerina originate from Victoria in Australia) is a common trellising system used around South Africa vineyards and it is a modification of the Smart–Dyson system (Smart & Robinson, 1992). The appearance of this trellis is composed of a Vertical Shoot Positioning (VSP), with the addition

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of shoots drooping downwards. It has one canopy divided into three sparse canopies which allows more sunlight to reach the vines. It is suitable for the vines planted in fertile soil and vigorous rootstock, and thus results in high production. However, for less vigorous vines in very hot regions it may not be suitable as it may expose the fruit zone to excessive sunlight. Another benefit of this system is that mechanical harvesting can be used and existing systems, such as hedging, can be easily converted to Ballerina.

Smart Dyson

Smart Dyson system was created by an Australian, Richard Smart, and an American, John Dyson. It is a variant of a VSP system, with a double canopy with cordon facing downwards and upwards along vertical positioning shoots. Due to the arrangement of the shoots, this system permits better photosynthesis and it is therefore suitable for vigorous vines (Smart & Robinson, 1992). Moreover, despite of more shoots producing a higher number of bunches and consequently bigger yields, the system exposes both foliage and fruit to sunlight, which eventually leads to optimal ripening (Smart & Robinson, 1992).

T-frame

The T- frame trellis one of the trellises which originated in Australia (Smart & Robinson, 1992) It has a bilateral cordon which give a greater exposure of foliage to sunlight, at the same time give optimum light penetration to the bunch zone. The canopy under this system is opened in a horizontal set up, which improves grape in terms of greater leaf surface area and canopy volume (Gladstone & Dokoozlian, 2003). However, with this system is not suited to mechanical harvesting.

Lyre

Lyre system was developed by Dr Alain Corbonneau in the 1890s in the Bordeaux region of France. It is a horizontally divided trellis positioning in which the shoots are orientated in an upward direction and vertical angling outward and it is suitable for upright growing cultivars. It than spread all over the world and become a popular trellising system for most wine producing countries, including South Africa. The system trains vines to grow upwards, rather than hanging down. By doing so, it opens up the canopy in a horizontal way and allows air circulation and sunlight interception through the vines. It is one of the systems which is suitable to prevent fungus diseases, and accommodates overly vigorous vines which would have problems with overshadowing (Carbonneau, 1985).

‘Stok-by–Paaltjie’

The ‘Stok-by-Paaltjie’ also known as ‘*Echalas*’ trellis, is a very simple system. Each vine has its own stake around which it twirls and twist around and uses as a supportive pole. Ideally, this system is suitable for vines on uneven or difficult terrains that cannot support a complex, interlinked

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trellising structure. It is suitable for windy areas, and vineyards where viticulture practices are done manually. Sunlight is filtered because all directions of the canopy are exposed to sunlight. It has been reported that cultivars such as Viognier vines with sprawling growth habit are suited to be trained by this system (Heyns, 2017).

1.3. Effect of trellising system on grape and must composition

1.3.1 Trellis effect on yield

In viticulture, yield is the measurement pertaining to the quantity of grapes at harvest time. Two different types of yield measures are commonly used, mass of grapes per vineyard surface and or volume of wine per vineyard surface. Trellis improves the canopy microclimate and leads to improvement in yield and quality because of better leaf and fruit exposure to sunlight. As vine density can differ according to the planting, mass of grapes per vine is sometimes used in the scientific literature. Canopy division has been demonstrated to be an effective vehicle for accommodating high vine vigour by enhancing leaf and fruit microclimate (Shaulis *et al.*, 1966; Shaulis & May, 1971; Shaulis, 1980), although results are site and cultivar dependent. For most of the cultivars investigated, it was shown that horizontally divided canopies have positive effects on yield (Smart *et al.*, 1982; Reynolds *et al.*, 1995). Horizontally divided canopies trellis systems increase shoots exposure and improve bud fruitfulness due to good sunlight penetration (Perez & Kliewer, 1990; Swanepoel & Archer, 1990). Furthermore, Shaulis *et al.*, 1966 and Smart *et al.*, 1982 have also found a positive correlation between sunlight and yield.

Some of the important ways that may assist in estimating yield can be done by measuring grape bunches per vine, berry weight or canopy volume as demonstrated by Reynolds et al., 1996, 2004. Canopy volume includes the entire live canopy of a tree from the base of the crown to the highest point and from the centre of the crown out to the furthest tips. Vine architecture that is able to support a larger canopy can ensure proper light exposure which may produce quality grapes and therefore wines (Reynolds *et al.*, 2004a). Ji & Dami, (2008) established that trellising could improve yield without compromising quality. However, this is may not always be the case, as other factors may play a role.

1.3.2 Trellis effect on grape or must composition

Generally, berries maturing in densely shaded canopy interiors are generally associated with low total soluble solids, high titratable acidity, and elevated pH among others when compared with berries in open or exposed canopies (Smart, 1985). Vineyards cultivated in areas with low average temperatures during the growing season, generally produce grapes with higher total acidity than vineyards in warm climates (Sabbatini *et al.*, 2015). However, this phenomena is arguably related to the variety, for example; Zoecklein et al., (2008) found no significant impact of temperature

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differences on pH, TA and total acidity for Viognier grapes must and wine. Solar irradiation affects the levels and pattern of sugar accumulation, organic acids, and amino acids across grape clusters (Reshef *et al.*, 2017). At the same time, an increase in sunlight exposure is associated with lower accumulation of organic acids (Heeswijck *et al.*, 1992).

1.3.3 Trellis effects on phenols and aroma compounds concentrations

Grape varieties, terroir, and viticulture practices, such as the training system, canopy management and harvest date influence aroma variations (Reynolds et al., 2004; Gómez-Míguez et al., 2007) The training system can affect the surface leaf area and percentage of total leaf surface area exposure to sunlight during berry development. Wine characteristics have been shown to have been influenced by grape composition. For instance, Ji & Dami, (2008) found that VSP trellising system, which is characterised by moderate sunlight exposure, produced the highest amount of flavour compounds. According to previous studies, different grape berries on a single vine may be subject to different light microclimates (Pereira et al., 2006), because they receive different amounts of sunlight radiation depending on their position within the canopy. However, the composition vary according to variety, but the variation involves other factors (Reynolds *et al.*, 2004). Marais *et al.*, 1992; Smart & Robinson, (1992) have shown a positive effect of sunlight on the synthesis of grape aroma compounds. Grape berries and their chemical compounds are sensitive to microclimate (Bureau *et al.*, 2000; Hernandez-Orte *et al.*, 2014). In various studies, (Ryona *et al.*, 2008; Šuklje *et al.*, 2012) extreme exposure to light has been found to have an influence on methoxypyrazines levels (decrease) in grapes.

Light has been shown to affect the accumulation of aroma precursors, volatiles compounds and phenol free glycosides (Zoecklein *et al.*, 2008; Fragasso *et al.*, 2012) which, as consequence, affect the sensory properties of wine. For example, in red varieties, the accumulation of anthocyanin's changes with light intensity (Jogaiah *et al.*, 2013; Liu *et al.*, 2015). Other compounds such as flavan-3-ols, total phenolic content are influenced by the intensity of light (Bavougian *et al.*, 2012; Liu *et al.*, 2018). Therefore, the effect of trellis systems on the thiols, major volatiles, phenolic content and oenological parameters as well as yield as measure in grape per vine may exhibit differences in those compounds. Grape varieties, terroir, and viticulture practices, such as the training system, canopy management and harvest date influence aroma variation (Reynolds et al., 2004; Gómez-Míguez et al., 2007). The training system can affect the surface leaf area and percentage of total leaf surface area exposure to sunlight during berry development.

Interestingly, most work done on grape composition regarding trellising systems comes from aromatic varieties like Riesling, and Muscat Gordo Blanco (Turkington et al., 1980; Reynolds et al., 1996b), and numerous in red cultivars (Vanden Heuvel et al., 2004; Bordelon et al., 2008). Only few investigations have been done in the South African environment and its climate, especially on white varieties and more specifically Chenin Blanc and Chardonnay, which play a relevant role for the South African wine industry. Nevertheless, the findings of Van Zyl & Van Huyssteen, (1980b) demonstrated a significant effect of trellising on Chenin Blanc grapes composition whereas, Volschenk & Hunter, (2001b), found a significant impact on grape composition mostly on aroma and flavour descriptors. Trought *et al.*, (2017) further demonstrated the importance of long term techniques (trellis type) incorporated seasonal practices in the modification of microclimate elements like sunlight to improve Sauvignon Blanc grape juice.

1.4. Effect of trellising systems on wine composition

The grapevine's response to a treatment, or set of imposed conditions, and the subsequent effects on grape berry composition, is the result of a series of interactions between genetic characteristics, environmental conditions and cultural practices. With the hypothesis that grape composition can be changed by vineyard practices and surrounding factors, it is therefore of the outmost importance to investigate how the altered berry composition translate into the chemical and sensory properties of the final wines.

The evaluation of wines made from different trellising systems has been included in only few studies, either from chemical or sensorial perception viewpoint. Nevertheless, in the few published studies, only the overall wine quality was evaluated. Among those are the results of Van Zyl & Van Huyssteen, (1980) who found differences in organoleptic ratings between wines of different systems, specifically discriminated by colour. Data presented in the literature suggest that divided canopy trellis produced superior wines due to better light interception (Reynolds et al., 2004). In contrast, Volschenk & Hunter, (2001) did not find a significant impact on wine quality for trellis systems which have been converted. One of the latest studies, which evaluated individual organoleptic characters, is by Zoecklein et al., (2008), who demonstrated differences in Viognier wines aroma and flavour between Geneva Double Curtain (GDC), Vertical Shoot Positioning (VSP) and Smart-Dyson (SD) trellising systems, GDC- trained vines differed from SD wines in aroma and flavour.

1.4.1 Effect of trellising system on wine chemistry

The desired wine characters start with berry composition in addition to winemaking and ageing process. The chemical composition of the finished wines thus depends on both grape and winemaking practices.

Colour is among the most important sensory characteristics in evaluating wine quality and the first to be perceived, and can drive wine consumer's decisions. The phenolic composition is responsible for certain organoleptic properties intimately related to, among other things, to red wine colour, astringency and bitterness. De Beer, (2015) suggested that VSP trellising systems have a positive impact on the phenolic composition, whereas SD has no significant effect. Another study by Segade *et al.*, (2009) reported the varietal response to training systems on chromatic characteristics. Likewise, compounds that are important for colour and astringency in red grapes and wines, such as anthocyanin’s, are proven to increase with the Lyre system (González-Neves *et al.*, 2012).

Another significant organoleptic characteristic which plays a vital role for wine quality and typicality is aroma (Perestrelo *et al.*, 2006). It also influences fruit maturation and alter wine aroma profile (Kliewer & Dokoozlian, 2005; González Barreiro *et al.*, 2015). For example, (Zoecklein *et al.*, 2008) found that the GDC training, which has as main objective increasing sunlight interception around fruit-zone, indicated higher fruity and floral aromas to wines made from other compared systems.

Berry quality is affected by viticulture practices like training system, which influence aroma, taste and mouthfeel as well as chromatic compounds (Ji & Dami, 2008; Zoecklein *et al.*, 2008; Segade *et al.*, 2009). Overall quality assessments are vital for decision making in wine production for both oenologists and researchers. Volschenk & Hunter, (2001) found that wine quality can be maintained even when an established training system is converted. Overall, it is reported that training systems with divided canopies potentially increase grape and wine quality due to canopy volume and a greater percentage of the leaf surface area (Kliewer & Dokoozlian, 2005).

Chenin Blanc is the most planted cultivar in South Africa according to South African Wine Industry Information and Systems (SAWIS, 2018).The grapes of Chenin Blanc belong to a class of varieties defined as ‘neutral’. This means that the wines produced from it lacks primary aromas derived directly from the grapes, but obtain their aroma characteristics from secondary and tertiary aromas which develop during the production phase (Augustyn & Rapp, 1982). Chenin Blanc also possess versatility properties and so it has the potential to produce premium wines. Because of its flexibility it can be easily subjected to winemaking practices and viticulture techniques, such as training systems, to maintain or improve the wine style (Kritzinger, 2012; Beer, 2015). Chenin Blanc aroma descriptors vary based on wine style, but are mainly characterised by ‘fruity’, ‘floral’ and ‘guava’ descriptors (Hanekom, 2012; Botha, 2015). Those attributes are basically derived from the fermentation process and grape precursor such as glutathione-related compounds (Bruwer, 2018; Wilson *et al.*, 2018)

1.4.2 Sensory evaluation

In recent years, researchers have become increasingly interested in sensory characterisation as a tool to maintain and control product quality. It is generally accepted that organoleptic properties, like aroma, taste and mouthfeel, are very important indicators for wine quality. As explained above, training system management could influence the composition of grapes, may influence some properties of wines such as aroma, colour and taste perceptions (Ribéreau-Gayon *et al.*, 2006).

Common methods used in evaluating food and beverages including wine are descriptive tests. These type of tests give descriptions and their relative intensities for products analysed. One of them is Descriptive Analysis (DA). DA has been extensively used in sensory science to characterise wines according to variety (Elmacı *et al.*, 2007), wine quality (McCloskey, 1995), grapevine age (Crous, 2016), region (Heymann & Noble, 1987 ;), grapes ripeness levels (Bañuelos, 2018) and production practices (Thiollet-Scholtus *et al.*, 2014). The descriptive sensory test involve the detection and description of qualitative and quantitative sensory components of a product (Meilgaard, 1991). Using the specific aspects of aroma, flavour, texture and after-taste it is possible to distinguish products from each other. Descriptive analysis provides detailed information about the products and has an ulterior advantage in the fact that it is possible to relate this the type of data obtained to chemistry data. Despite the many advantages, such method is time consuming and therefore expensive to execute. Alternative methods to DA have been developed and they produce similar results (Ares *et al.*, 2014).There are categorised into verbal and similarity based methods and comparison based methods (Valentin *et al.*, 2012).The advantages of rapid methods are that they do not require a training phase and can be performed either by trained or untrained assessors.

Many studies make use of rapid profiling methods to characterise wine of different cultivars (Campo *et al.*, 2008) and chemical composition (Wilson *et al.*, 2018). Whereas, some have used quick and simple similarities tests (like the triangle test) to differentiate wine from training systems (Zoecklein *et al.*, 2008). For instance, they found differences between GDC and SD in wine aroma and flavour and between VSP and SD in flavour. Triangle test is a discriminant method used to determine if there is a sensory difference between two products and it is mostly applicable in product development (Meilgaard et al., 1999). It is a rapid, simple method of evaluating similarities, but its drawbacks are that it does not provide detailed information about the source of differences.

Check All That Apply (CATA) method

One of the rapid methods which has proven successful and popular in sensory science is Check All That Apply (CATA). A CATA questionnaire consists of a list of attributes from which assessors should select the ones they consider appropriate to describe the product at hand. Samples are presented one at a time to the assessors. Although CATA has never been used to evaluate wines from different training systems with the aim of profiling them, it has been used elsewhere to evaluate other aspects of wine making. Botha, (2015) has used this method to assess the effect of fermentation and ageing conditions on Chenin Blanc wines. Another study that has used CATA was by Weightman, (2014) to characterise Chenin Blanc wines produced under two different fermentation conditions and methods. CATA has also been used to evaluate the sensory characteristics of wines made from old vines grapes (Crous, 2016). Given the extensive literature reporting the successful use of CATA for profiling of many different types of food products, it is possible that it can be the best alternative descriptive method to characterise wines made from various trellising systems.

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1.5. Aims and objectives

Despite the importance of trellising systems in viticulture, few researchers have studied the specific effect of various trellising systems on the derived wine characteristics with respect to chemical and sensorial properties. Therefore, the question remains: does the effect of trellising systems on microclimatic conditions, which eventually influence grape composition, reflect in wine characteristics? To answer this, it is of interest to compare wines of various trellis systems from a chemical and sensorial point of view, under controlled conditions.

The aim of this work was to evaluate the influence of six different trellis systems most (except one) commonly used in South Africa, namely Santorini, Ballerina, Smart Dyson, T-Frame, Lyre and Stok-by-Paaltjie, on the composition of grapes and on the composition and sensory profiles of the corresponding wines, using a model Chenin Blanc vineyard.

The objectives were:

- Measure yield and basic oenological parameters of the grapes at harvest.
- Chemically characterise the juice/must in aspects that can potentially affect the wine's sensory and chemical profile (amino acids, YAN and its components, and phenolic content).
- Chemically evaluate the classes of compounds most likely to be affected by the vineyard practices directly and indirectly (phenolics in juices and wines, thiols and major volatiles in wines).
- Sensory profile the wines and investigate whether the profiles can be used to distinguish between the wines from different trellising systems.

Additionally:

- Fingerprint the wines using untargeted methods and statistically explore their potential to better differentiate between wines from different trellising systems compared to targeted analyses.
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Chapter 2

Evaluation of volatile and non-volatile compounds in Chenin Blanc wines from different trellising systems

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Chapter 2: Evaluation of volatile and non-volatile compounds in Chenin Blanc wines from different trellising systems

2.1. Introduction

The overall quality of wine is determined by several properties including colour, aroma and taste perceptions all equally important for consumer acceptance (Charters & Pettigrew, 2006). For example, consumers are interested in fresh and fruity aromas (Zalacain *et al.*, 2007; Hellín *et al.*, 2010; Obreque-Slier *et al.*, 2010), which puts pressure on winemakers to meet these demands. The aroma profiles of a wine results from a combination of various compounds present in grapes or derived from fermentation and ageing processes (Ribéreau-Gayon *et al.*, 2006). Volatile compounds are usually present in concentrations at µg/L, however they play a significant role in wine aroma nuances. These compounds emerge from heterogeneous classes such as alcohols, esters, acids, terpenes, phenols, aldehydes, as well as sulphur compounds (Perestrelo *et al.*, 2006; Hart *et al.*, 2017).

It has been already demonstrated that training systems influence grape quality components such as sugars, acids, phenols and primary aroma compounds (Reynolds *et al.*, 2004; Ji &Dami, 2008; Zoecklein *et al.*, 2008); assessing the evolution of these components through to wine is not as complete (Chapter 1). Neutral varieties like Chenin Blanc obtain aromas from the fermentation process (Du Plessis & Augustyn, 1981; Augustyn *et al.*, 1982), namely from major volatiles; thiols have also been demonstrated to contribute to Chenin Blanc wine aroma (Wilson, 2017), and thiol precursors are one of the classes of molecules influenced by various vineyard practices (Kobayashi *et al.*, 2011). It has been shown that practices (like leaf removal) have a significant influence generally on grape composition and wine quality (Marais *et al.*, 1992; Marais *et al.*, 1999). The trellis' capacity to expose canopies to sunlight and eventually impact on the surrounding environment and the accumulation of organic compounds (Van Zyl & Van Huyssteen, 1980a, 1980b) as well as wine quality (Volschenk & Hunter, 2001b) make no exception.

The main analytical technique applied for the investigation of volatile compounds in the wine is gas chromatography (GC) coupled to mass spectrometry (MS). Such techniques have received great attention in determination of volatile fraction of wines, responsible for the attributes of global aroma (Perestrelo *et al.*, 2006). The GC-MS technique has been used to characterise and differentiate wines of different grape varieties (Câmara *et al.*, 2006; Welke *et al.*, 2013) and also for structural identification of aroma compounds (Kotseridis & Baumes, 2000). Although this technique is applicable to targeted and untargeted analysis, it has limitations and disadvantages such as the inability to directly identify non-volatiles and its high cost equipment. Hence, the alternative is gas chromatography coupled to flame ionization detector (GC-FID) which requires a lower cost equipment in comparison to GC-MS.

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GC-FID methods have been introduced for quantification of volatile compounds (Louw *et al.*, 2010). Recently, it was used to determine the relationship between attributes, character and chemical composition of wine (Parr *et al.*, 2016). This means that GC-FID can be a useful technique to characterize wines based on volatile composition and further link them to sensory profiles. But in case where a list of analysis is incomplete and also when wine matrices have a significant effect in suppressing or enhancing aromatic expression, additional methods are worthwhile. The most viable approach is untargeted metabolomics, a comprehensive analysis of metabolites which reveal a chemical fingerprint. Metabolic profiling was successful in characterizing grape and wine typicality and quality (Atanassov, *et al.*, 2009), profile wine according to variety (Vaclavik *et al.*, 2011), and phenolic compounds (Salvatore *et al.*, 2013). Fingerprinting allows the extraction of hidden information from the acquired multidimensional data, like to authenticate wine using LC-HRMS (Rubert *et al.*, 2014) or attribute wine styles to commercial Chenin Blanc (Buica *et al.*, 2017a).

Each trellis system has some defined “canopy microclimates”, exposes grapes or leaves to sun or causes shading, eventually affecting the accumulation of primary metabolites (increase or decrease). Primary metabolites are responsible for secondary metabolites in wines as precursors therefore affecting the chemical profile of corresponding wines. Even with more available advanced analytical methods for identification and quantification of chemical composition of wines together with multivariate analysis, to date no work has been done on characterisation of wines made from different trellising systems. Therefore, this work aimed to evaluate the influence of the trellising systems on chemical composition of wine made from grapes grown on six training systems: Santorini (S), Ballerina (B), Smart-Dyson (SD), T-Frame (TF), Lyre (L) and Stok-by-Paaltjie (P). To achieve the chemical profiling of the products, amino acids, YAN components, thiols, major volatiles, phenolic content and wine fingerprinting were done. The technique used were: HPLC, UPC2-MS/MS, GC-FID, UV-Vis spectroscopy, LC-HRMS and the data processing was done using analysis of variance (ANOVA), principal component analysis (PCA) and hierarchy cluster analysis (HCA).

2.2. Methods and materials

2.2.1 Experimental vineyard

Grapevines (*Vitis vinifera* L. cv. Chenin Blanc clone SN 24B grafted on 110R rootstock) were planted in 2010 in a single block in the Franschhoek valley region and trained to six different systems, namely: Santorini (S), Ballerina (B), Smart Dyson (SD), T-Frame (TF), Lyre (L) and ‘Stok-by-Paaltjie’ (P) (also known as staked vines or *Echalas*), each system on a different row, oriented in south west –north east (SW-NE) (Figure 2.1). The vineyard is located in one of the oldest Cape Dutch farms which lies at 33°49’23.4’’S latitude and 18°55'29.4"E longitude. The experiment was conducted over two vintages, 2017 and 2018. All vineyard practices such as irrigation and pruning were uniformly applied to all treatments. The vineyard experimental block layout illustrating the planted grapevines is presented in Figure 2.1; every letter represents a vine Table 2.1 briefly summarises the shown layout.

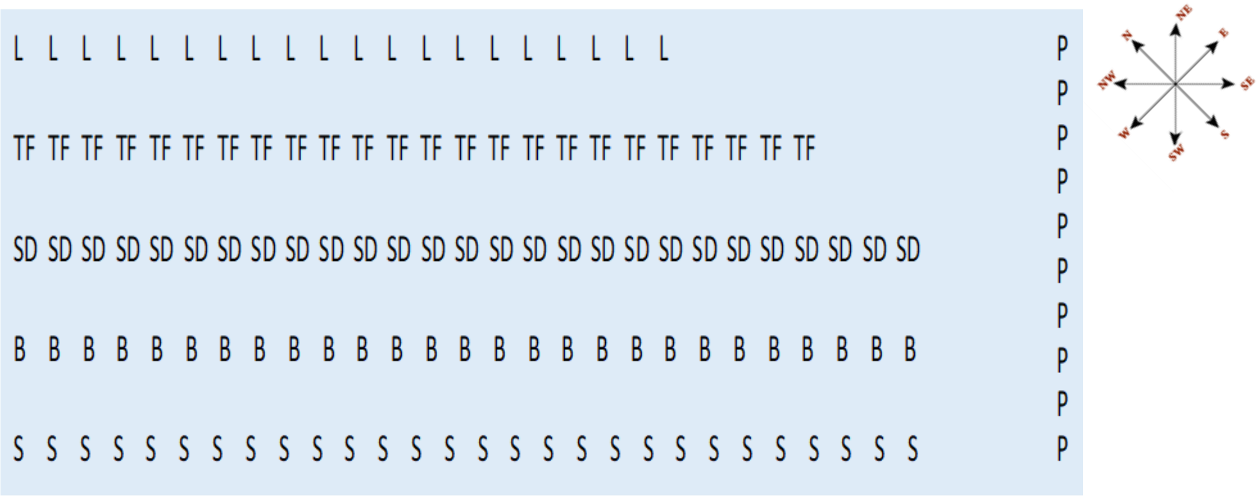

Figure 2.2. The experimental block layout illustrating the systems rows and their respective number of vines planted per system.

Table 2.1. The codes labels, number of vines, and biological repeats for each trellising system over the two seasons (2017 and 2018).

Trellis	**Code designated**	**Number of vines**	**Biological repeats**	**Vintage**
Santorini	S	28	3	2017:2018
Ballerina	B	27	3	2017:2018
Smart Dyson	SD	27	3	2017:2018
T-Frame	TF	24	3	2017:2018
Lyre	L	20	3	2017:2018
Stok-by -Paaltjie	P	10	2	2017

2.2.2 Winemaking process

Grapes were harvested at 22±0.5°B in both vintages. Harvested grapes from the vineyard were transported to the Department of Viticulture and Oenology (DVO) experimental cellar of Stellenbosch University.

Prior to destemming and crushing, the grapes were measured for yield per trellising system and then refrigerated at 4°C overnight. The grapes were destemmed and crushed with the addition of 40 mg/L SO_2, and 0.03 g/kg pectolytic enzyme (Lafazym Extract enzyme, Laffort, South Africa), for skin contact 2-3 hours. Pressing was done by vertical hydro-press at one cycle up to 1 bar. Rapidase Clear Enzyme (4 mL/100 L, Laffort,South Africa), was added to the juice overnight in a 4°C room to help juice settling and clarification. Biological repeats were separated in the cellar before inoculation. The must was treated with 50 mg/L SO_2, inoculated with *Saccharomyces cerevisiae* strains Vin7 (Zymasil, AEB Group SpA, Bologna, Italy), and Vin13 (Zymasil, AEB Group SpA, Bologna, Italy), in a 50-50 ratio, previously rehydrated according to manufacturer instructions, and then transferred into 20 L stainless-steel tanks for vinification according to the replicates Table 2.1.

All wines were made in triplicate except for P treatment in the 2017 season where there was only enough crop to have two replicates. Fermentation was carried out at 15°C until dryness (about 14 days). At less than 4 g/L residual sugar content, fermentation was considered completed. Wines were racked into 20 L stainless-steel tanks for lees contact in the 15 °C room. All wines were left in contact with the fine lees for three months prior to bottling and gently stirred twice a week without opening the canisters to avoid oxidation. After lees contact, the wines were racked off and 50 g/hL of bentonite added prior to cold stabilisation in a -4°C cold room for two weeks. The cold stabilised wines were bottled and stored for six months at 15°C until chemical and sensory analysis.

2.2.3 Chemical analyses and methods

Sampling stages

Samples were taken throughout the winemaking process Figure 2.2. Racked juice was also analysed for Yeast Assimilable Nitrogen (YAN) and amino acids before inoculation. At sensory evaluation stage, targeted (major volatiles and thiols), and untargeted (UV-Vis and HRMS), analyses were performed.

Yield and Oenological parameters

Grape berries were monitored before harvesting and analysed after crushing for sugar concentration (Brix), using a hand-held refractometer (PAL1, Atago). Glucose and fructose in the racked juice were analysed by enzymatic reaction (Arena X20, Konelab). Free SO_2, pH and TA, were measured with a potentiometric titrator (702 SM Titrino, Metrohm). Wine ethanol, residual sugars, and glycerol were quantified by infrared spectroscopy using the Winescan FT120 spectrometer (FOSS Analytical, Denmark, 2001), and in-house calibrations as described by Nieuwoudt *et al.*, (2004).

Yeast Assimilable Nitrogen

Racked juice samples were analysed for ammonium and free amino nitrogen (FAN), their sum giving Yeast Assimilable Nitrogen (YAN). The analysis was done for both 2017 and 2018 harvest years at VinLab (Stellenbosch), according to ISO 17025 standards using enzymatic methods.

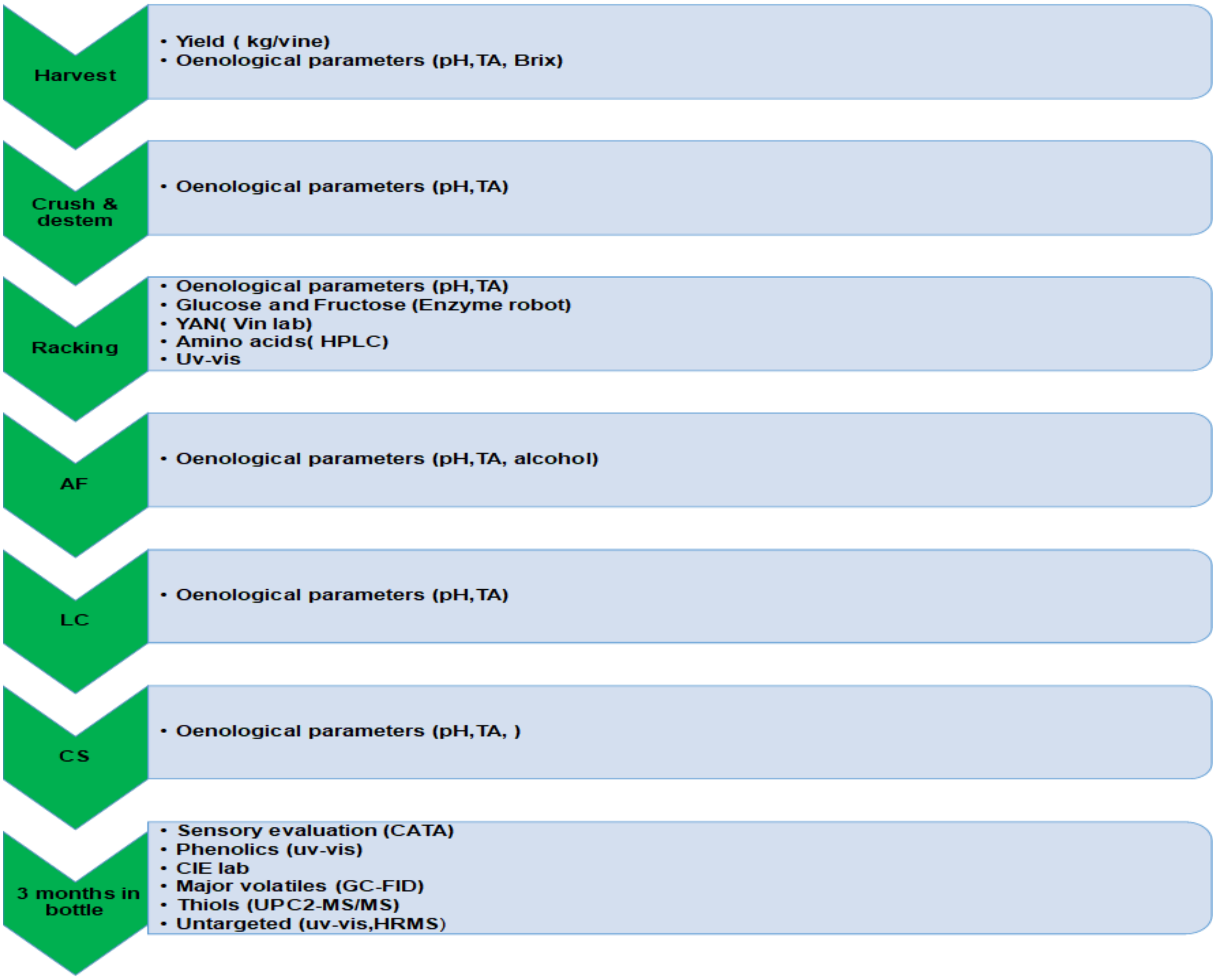

Figure 2.3.The sampling stages, types of analysis carried at every stage during winemaking process over the two seasons (2017 and 2018). AF represents: alcohol fermentation, LC for lees contact and CS stands for cold stabilisation.

Amino Acids

Twenty amino acids were quantified for 2017 juice samples as described in Petrovic *et al.*, (2019), using a derivatization method based on labelling with AccQTag© (Waters), with Norvaline (Nvl), as Internal Standard, followed by determination by LC-UV/Vis at the Mass Spectrometry Unit of the Central Analytical Facility of the Stellenbosch University. Alanine, arginine, asparagine, glutamic acid, glutamine, glycine, histidine, hydroxyproline, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, valine, gamma-aminobutyric acid (GABA), and ornithine were quantified.

UV-Vis spectroscopy and CIE Lab parameters

UV-Vis spectrophotometry (Thermo Scientific Multiscan Go, SkanIt RE 5.0, Finland), from 280-780 nm was used to measure various phenolic parameters. The values obtained were used further to calculate: total phenolics (TP, absorption at 280 nm), yellow colour (absorption at 420 nm), phenolic acids (PA,absorption at 320nm), flavanols (FL,absoption at 360nm), and CIE Lab parameters (L*, a*, b*, chroma, hue) according to OIV, (2016).

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Major Volatiles

Wines samples for 2017 and 2018 were quantified for major volatiles, using the GC-FID method described by Louw *et al.*, (2010). In brief, 5 mL wine samples were spiked with methyl-[1]-pentanol as Internal Standard, and extracted with 1 mL ether. The extract was dried over anhydrous Na_2SO_4 and injected in duplicate into a GC-FID (HP-6890, Agilent).

Thiols

The volatile thiols, 3-mercaptohexan-1-ol (3MH), methyl-4-mercaptopentan-2-one (4MMP) and 3mercapto-hexylacetate (3MHA), were quantified following the method of Mafata *et al.*, (2018), using DTDP derivatisation, SPE sample clean up, and injection into a convergence chromatography – tandem mass spectrometry instrument (UPC2-MS/MS, Waters).

High Resolution Mass Spectrometry (HRMS)

High-resolution mass spectrometry coupled to liquid chromatography (LC-HRMS) was used for wine fingerprinting. The samples were analysed by UPLC (Waters Corporation) equipped with a Synapt G2 quadrupole time-of-flight mass spectrometer (Waters Corporation). The separation was done on an Acquity UPLC HSS T3 column (1.8 µm internal diameter, 2.1 mm x 100 mm, Waters Corporation) using 0.1% formic acid (mobile phase A) and acetonitrile (mobile phase B) and a scouting gradient. Flow rate was 0.3 mL/min and the column temperature 55 ºC. The injection volume was 2 µL.

The data was exported as a matrix of (RT_m/z, abundance), resulting in a table with the number of rows equal to the number of samples, and the number of columns equal to 10224. The software is directly integrated with SIMCA-P (Umetrics) and the statistical algorithms are directly applied to the processed data sets (Buica *et al.*, 2017).

2.2.4 Statistical Analysis

The effect of trellising systems on volatile and non-volatile compounds namely amino acids, major volatiles, and thiols were evaluated by analysis of variance (ANOVA), followed by post-hoc test (Kruskal –Wallis at $p< 0.05$), using Statistica© 2013 (TIBCO, USA). Multivariate data analysis was applied to juice and wine data. To this end, principal component analysis (PCA) and hierarchical cluster analysis (HCA), were applied in order to find natural configurations in the data according to treatments and samples by grouping/clustering (SIMCA 14.1, Umetrics, Sweden). Additional data analysis and graphical representations were performed by Microsoft Excel 2013.

2.3. Results and Discussion

2.3.1 Yield and Oenological parameters

The yield (measured in kg grape/vine) varied between the systems over the two years. In 2017, P had the lowest grape yield, while L was the highest, but comparable to the TF system (Figure 2.3). The following year (2018), the grapes berries from P system were not harvested because of uneven ripening therefore they were excluded. The systems with the highest yield were TF and S, whereas the lowest yield was recorded in the L and SD trellising systems.

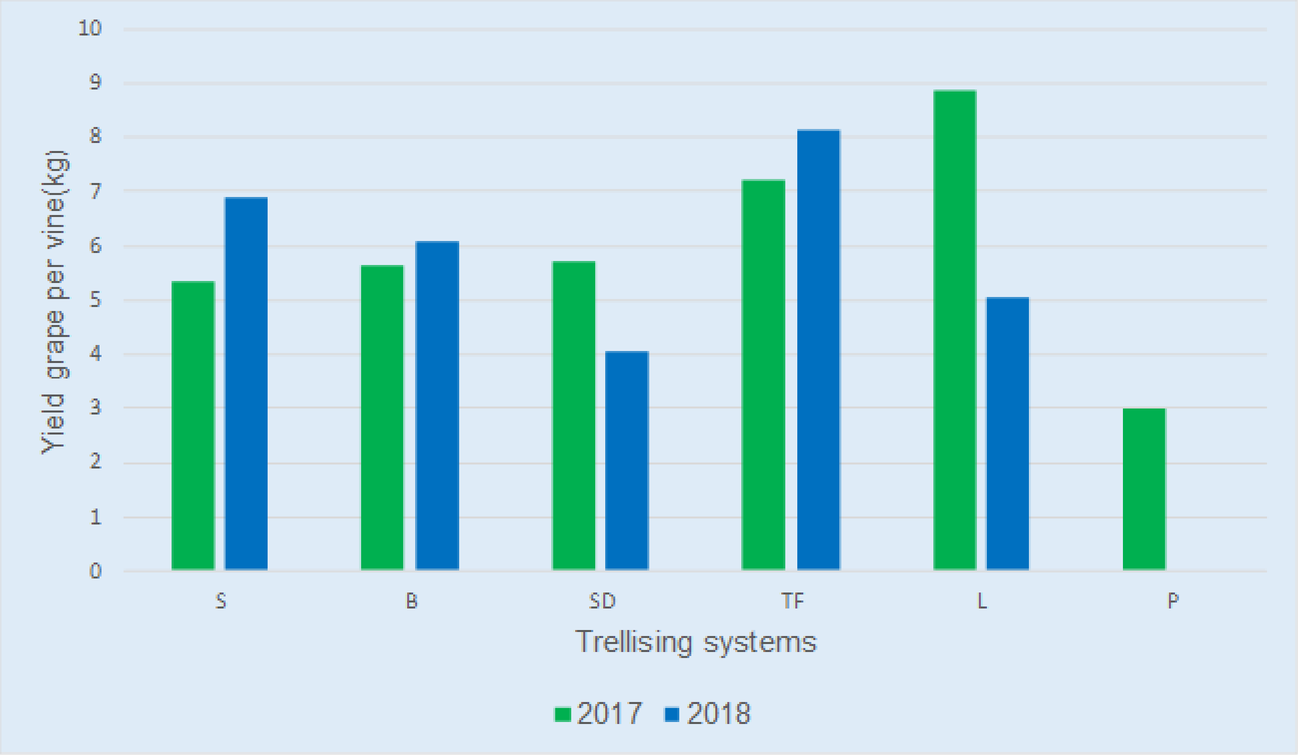

Figure 2.4. The mean yield for the six trellising systems measure in kilograms per vine: the bars in green represent the 2017 season, whereas 2018 vintage is shown in blue colour.

Although there were some trends, the results were not consistent with treatments over the two seasons. Zoecklein *et al.*, (2008) reported higher yield per vine from dividing canopies of Smart Dyson and Geneva double cordon than Vertical Shoot Positioning. Looking at the systems with highest yield per vine, dividing systems which open up canopies had higher yield in 2017, although it was not the case in season 2018. One possible reason could be berry shrinking and sunburn which resulted in SD berries to be small and hence the system had reduced yield in comparison to the previous season. Smart Dyson is known for its ability to increase yield in vigorous vines, but also another factors to consider is row orientation with regards to sunburn and its effects on berry size.

The horizontal open-canopy trellis (TF) system produced higher average grape yields than other systems, over both seasons. These results are comparable to Swanepoel & Archer, 1990 and Reynolds *et al.*, (1996), who reported an increase in yield from horizontally divided canopies over

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vertical trellis systems in Sultanina and Riesling. Horizontal divided canopies have a tendency of increasing leaf surface area, and therefore increase yield through greater percentage of leaf surface area (Kasimatis *et al.*, 1975). Other factors, such as training systems conversion are seen as an effective approach to increase yield as reported in Chenin Blanc grapes subjected to a system converted from vertical trellised to Lyre system (Volschenk & Hunter, 2001b).

On the contrary, Swanepoel & Archer, (1990) and Van Zyl & Van Huyssteen, (1980) found higher yield from the vertical trellis in Chenel and Chenin Blanc vines. However, it should not be ignored that other factors such as climate, vineyard location, row orientation in conjunction with training systems can also affect yield (Duchêne *et al.*, 2014). For example, in the present study both SD system (vertical) and L system (horizontal) dividing canopies were recorded with the lowest yield in the second season, which possibly suggest that variation may have another cause.

On the basis of oenological parameters there were differences in sugar levels, pH, and TA between the systems (Table 2.3). The sugar level in the S systems musts was lower in both 2017 and 2018, but this was statistically significant only in the first season; eventually, this led to lower alcohol levels in the subsequent wine in comparison to the other systems. Due to its architecture, the positioning of bunches on the S vines made it difficult to obtain a representative sample, which led to a harvest date decision that turned out to be too early. Differences in must pH were not significant between trellising systems. The pH values were the lowest in 2017 for the SD must, and in 2018 in the S system must. For TA, the S and the L systems were significantly the highest and lowest in 2017. In 2018, TF was highest while B system had the lowest value; however, those differences were not significant.

Differences in must pH and soluble solids in response to light exposure induced by training systems may be the subject of consideration. From previous work, Reynolds *et al.*, (2004) reported that alternate double cross arm systems cause a significant decrease in soluble solids of Riesling grapes; however, the pH and TA values were similar with other systems. In the case of the present study, a similar situation was noted in S system's must which had the lowest solid soluble (Brix) in the two season, but pH and TA were comparable to the rest of the systems. In other words, the sugar accumulation was slower for the S trellising system, but the rate of degradation of acids was similar to the one in the other systems.

Wine analyses showed that the S system wines alcohol level was the lowest in the two seasons, corresponding to the low sugar concentrations in the must. On the other hand, TF wines had the highest alcohol level in 2017 and SD in 2018 corresponding to the highest sugar levels at harvest (Table 2.2). The differences in alcohol were large especially in 2017, which can potentially impact the sensory evaluation of the wines.

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Wine pH values in 2017 were found between 3.3 (S and B) and 3.8 (L). Even though this variation between systems can be seen as relevant, it was not found as statistically significant. On the other hand, in 2018 the variation in pH was smaller, between 3.4 (S, B, TF) and 3.6 (SD and L).

Table 2.2. The standard oenological parameters (Brix, pH and TA) measured in musts, and wines (pH, TA, and Alcohol) in 2017 and 2018 vintages.

Vintage	Trellis		Must			Wine	
2017		**°Brix**	**pH**	**TA(g/L)**	**pH**	**TA(g/L)**	**Alcohol (%)**
	S	17.8^{d}	3.6	8.4^{a}	3.3	5.3	10.2
	B	22.6^{c}	3.6	8.1^{a}	3.3	4.6	12.7
	SD	23.1b^{c}	3.5	8.3^{a}	3.4	4.8	13.6
	TF	23.9^{a}	3.7	6.9^{ab}	3.7	4.1	14.6
	L	23.2^{b}	3.6	6.3^{b}	3.8	4.3	14.1
	Mean	**22.1**	**3.6**	**7.6**	**3.5**	**4.6**	**13.0**
2018	**S**	21.1	3.7	5.0	3.4	3.8	12.7
	B	23.0	3.9	4.6	3.4	4.0	13.8
	SD	24.0	3.8	5.5	3.6	3.9	14.1
	TF	23.5	3.9	5.9	3.4	3.9	13.9
	L	23.6	3.9	5.8	3.6	3.9	13.8
	Mean	**23.1**	**3.8**	**5.2**	**3.5**	**3.9**	**13.7**

Means with same letters mean no significant differences, whereas different letters indicate a significant difference

2.3.2 Yeast assimilable nitrogen (YAN) and amino acids

The measurement of yeast assimilable nitrogen prior to fermentation is essential for yeast growth and proliferation to prevent stuck fermentation (Spayd & Andersen-Bagge, 1996). The two main sources of yeast assimilable nitrogen are free amino acids (FAN) and ammonium ions. YAN levels of musts were higher in 2018, ranging from 270 mg N/L to 353 mg N/L, compared to 2017, with a range of 173 mg N/L to 267 mg N/L. All values were above the “critical level” of 140-150 mg N/L (Figure 2.4). The concentration differed significantly between the systems in 2017, whereas in 2018 there were no significant differences. The juices from the L system had the highest level of YAN concentration on average at 247 mg N/L and 353 mg N/L in the two seasons, while the lowest YAN concentration was found in the SD at an average of 173 mg N/L and the S system at 270 mg N/L for 2017 and 2018, respectively.

The current results are in agreement with the average concentration of free amino nitrogen and ammonia concentration in South African Chenin Blanc must (Petrovic et al., 2019). Ammonia concentration varied between trellising systems, as shown in table 2.3; S had the highest concentration of 70 mg N/L while SD had the lowest in the 2017 season. In the second season 2018, L had the highest concentration 90 mg N/L whereas S had the lowest 70 mg N/L, however remain the same like the previous year. Overall, ammonia concentrations for 2018 increased from previous year with the exception of S system.

It can be hypothesised that vintage effect could have play a role in this instance. Free amino acids concentration varied between systems with an average of 143 mg N/L (B) and 207 mg N/L (L) for 2017 and 200 mg/ N/L (S) and 260 mg N/L (L) in 2018. Previously, from the canopy manipulation point of view (Shoot positioning, defoliation, topping and suckering), no variation was observed between FAN must concentration of different seasonal practices in Chenin Blanc (Volschenk & Hunter, 2001). Other than that, there are no other reports on trellising systems effects on free amino nitrogen.

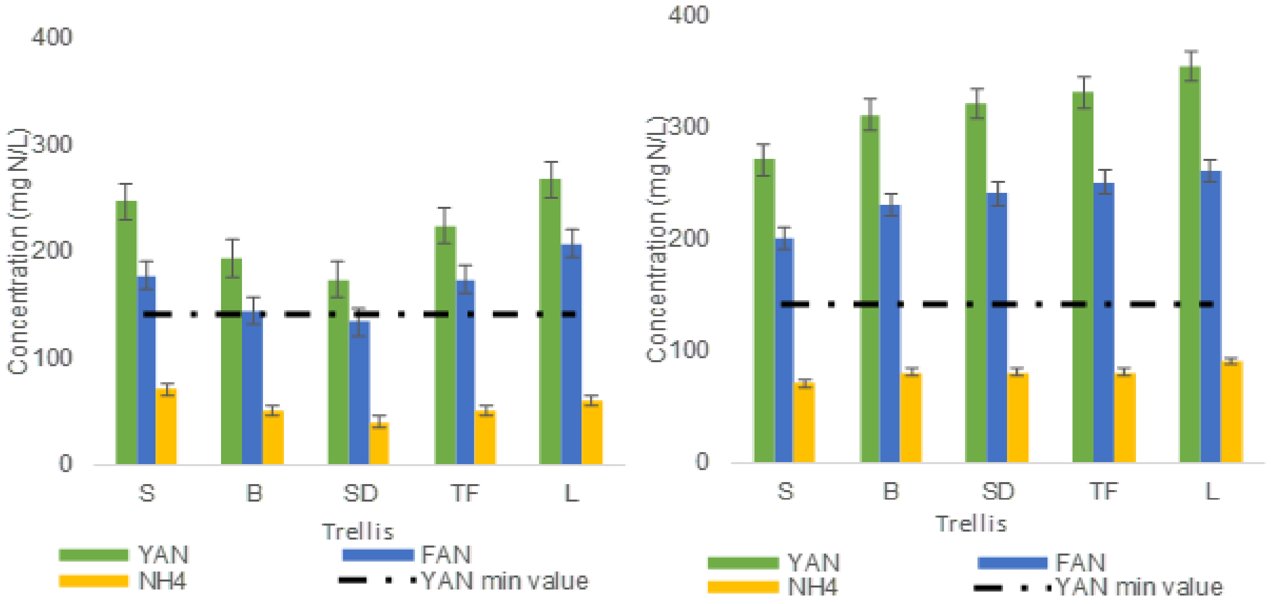

Figure 2. 5. Concentration in mg N/L for quantified YAN(green), FAN (blue) and ammonia (yellow) for Chenin blanc juices made from five trellising systems, the bar graph on the left shows the year 2017 and on the right represents 2018.

Table 2.3. The yeast assimilable nitrogen components concentrations; the analysis of variance was done on the data over the two years.

Trellis	**FAN (mg N/L)**		**NH4(mg N/L)**		**YAN (mg N/L)**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**
S	177^{b}	200	70	70	247^{b}	270
B	143^{c}	230	50	80	193^{d}	310
SD	133^{c}	240	40	80	173^{e}	320
TF	173^{b}	250	50	80	223^{c}	330
L	207^{a}	260	60	90	267^{a}	353

The order of the letters indicates descending order of concentration; different letters mean a significant difference.

With the exception of the cited report on seasonal canopy manipulation, there is no literature available on the amino acid composition of juices or values of YAN or its components as influenced by trellising systems.

Amino acids

ANOVA showed statistical differences between the juices based on specific amino acids (Table 2.4). Amino acids (AA), can be grouped according to the order in which yeast (*Saccharomyces*

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spp.) metabolises them. The group of yeast-preferred amino acids consists of individual amino acids such as alanine, arginine, aspartic acid, glutamic acid, glutamine and serine (Ljungdahl & Daignan Fornier, 2012). This group was found with the highest concentration in the L system must, with glutamic acid, glutamine, and alanine significantly higher than for the other systems.

Table 2. 4. The concentration in mg N/L for the 20 amino acids measured in the musts of six trellising systems in 2017.

Amino acid	**Trellis**				
Yeast preferred	**S**	**B**	**SD**	**TF**	**L**
Alanine	96.2^{bc}	79.3^{c}	77.4^{c}	113.5^{b}	180.7^{a}
Arginine	353.6^{ab}	285.2^{bc}	242.7^{c}	305.0^{bc}	424.1^{a}
Aspartic acid	101.2^{a}	66.2^{bc}	66.6^{bc}	52.3^{c}	85.5^{ab}
Glutamic acid	104.7^{c}	111.9^{bc}	112.8^{bc}	128.3^{b}	169.3^{a}
Glutamine	80.4^{b}	60.8^{c}	48.9^{c}	76.4^{b}	100.8^{b}
Serine	58.5^{b}	57.6^{b}	58.4^{b}	77.9^{a}	85.3^{a}
Branched amino acids					
Valine	24.6^{cd}	29.3^{bc}	22.2^{d}	39.4^{a}	34.1^{b}
Leucine	26.9^{b}	25.3^{b}	21.1^{b}	36.1^{a}	27.3^{b}
Isoleucine	12.5^{b}	15.7^{ab}	12.1^{b}	19.2^{a}	14.9^{ab}
Phenyl alanine	25.5^{b}	36.5^{ab}	25.7^{b}	43.3^{a}	32.6^{ab}
Tryptophan	95.6^{b}	132.6 ^{ab}	82.1^{b}	188.8^{a}	101.2^{b}
Others					
Hydroxyproline	2.4^{b}	8.3^{a}	6.4^{ab}	8.3^{a}	9.4^{a}
Proline	170.6^{d}	297.5^{c}	306.6^{c}	534.1^{b}	676.4^{a}
Methionine	1.0^{a}	1.3^{a}	0.1^{a}	1.7^{a}	0.1^{a}
Lysine	2.6^{a}	3.0^{a}	2.7^{a}	4.0^{a}	4.1^{a}
Threonine	101.3^{b}	112.9^{ab}	95.3^{b}	121.5^{a}	124.6^{a}
Glycine	2.5^{a}	3.1^{a}	2.8^{a}	3.8^{a}	4.3^{a}
Histidine	32.9^{a}	22.2^{b}	22.2^{b}	30.4^{a}	31.0^{a}
Ornithine	1.9^{a}	0.3^{b}	0.0^{b}	0.4^{b}	1.9^{a}
GABA	34.8^{c}	38.8^{c}	48.9^{bc}	64.9^{ab}	70.5^{a}

ANOVA was used to compare data using LSD at $p \leq 0.05$

The S and SD musts were the lowest for yeast preferred AA. Another subgroup of AA is branched chain and aromatic amino acids (BCAAs, valine, leucine, isoleucine, phenylalanine, and tryptophan). These amino acids play an important role as precursors to certain aroma compounds (Bell & Henschke, 2005). The TF trellis produced juices with a significantly higher concentration of valine and leucine and also higher in the other three BCAAs though not significant, whereas the SD trellis was found with the lowest concentration of BCCAs.

The data shown in Table 2.4, illustrates secondary amino acids proline and hydroxyproline concentrations significantly higher in the musts of the L system (676 mg N/L), while S had the lowest concentrations (170 mg N/L). Even if the concentration of proline is the highest among amino acids, secondary AA are not usually metabolised by yeast. Proline is, however, seen as an indicator of stress in the vineyard as found by Ashraf and Foolad, (2007). A similar trend is seen in other amino acids (GABA, ornithine, and threonine). Notably, the juices from the S system were only significantly higher in histidine while the SD and the B systems were recorded with the lowest average value.

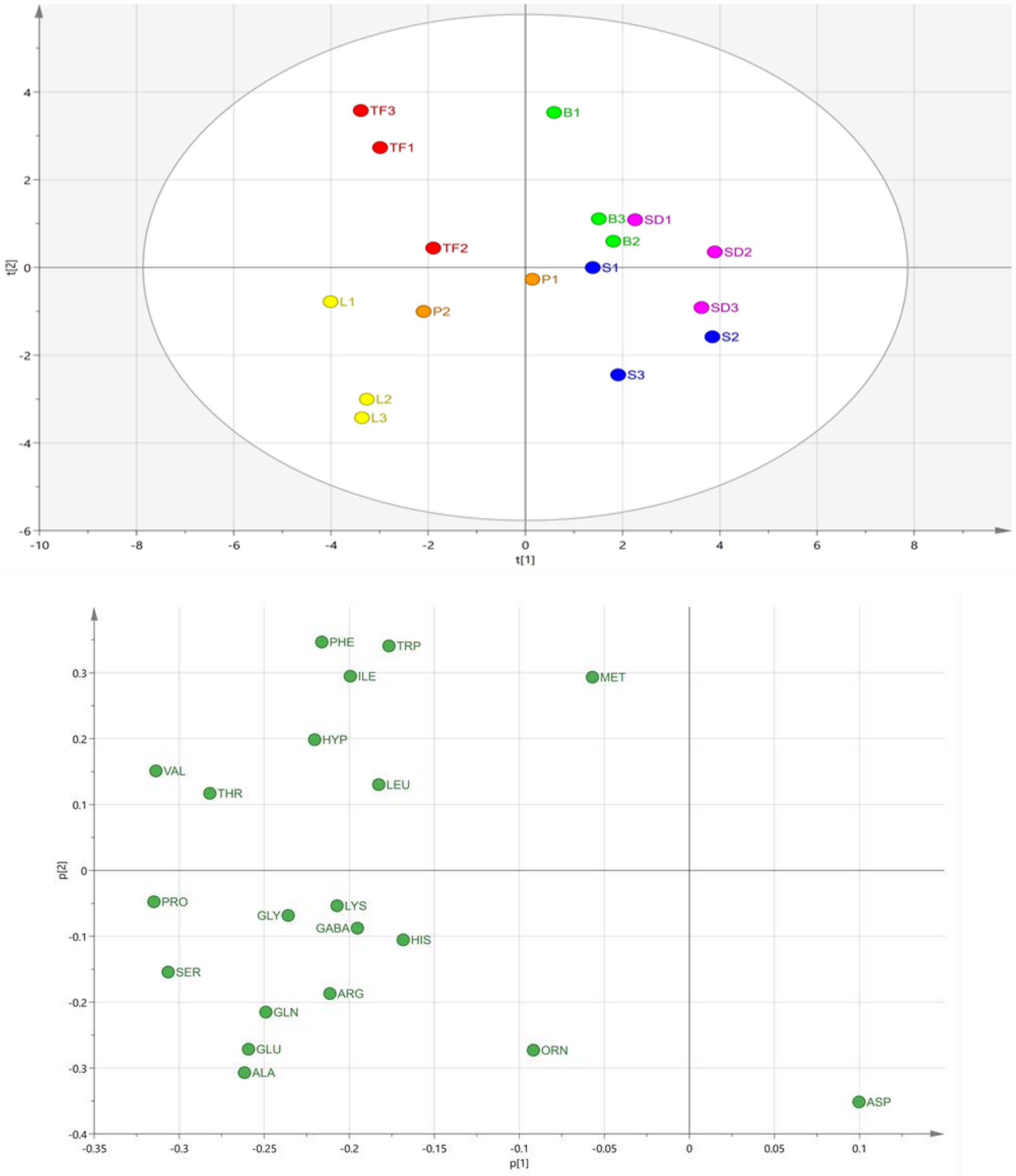

Figure 2.5. PCA score plot (top), and the loading plot (bottom) for the samples based on the amino acid concentration for the juices of different trellising systems in 2017. The samples are colour-coded according to the treatment.

The PCA using the AA concentrations (Figure 2.5, PC1 39.4 and PC2 21.2%, respectively) showed that the samples belonging to one system tended to group together, but samples from different systems were also interposed. A further projection of samples was done by cluster analysis (Figure

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A1) which separated the juice samples or into four groups. The juices of the L system are in the same group together with one repeat of the P system. Another group is made up of the S repeats only, whereas the third group consist of two repeats of the TF and one from the B trellis. The last group had the SD repeats and sample repeats from the TF, P and B trellises.

Although amino acids concentration varies according to cultivar (Kliewer, 1970), it is also known that trellis types can influence grape amino acids composition and concentration through differences in either bunch or leaf exposure to light (Kliewer *et al.*, 1991). In the present study, it can be speculated that a particular trellis also resulted in a specific leaf and bunch exposure, which possibly influenced the concentration of individual amino acids. Looking at the similarities of multivariate and ANOVA, it could mean that the effect of the trellising on the concentration of amino acids played a consistent role only on the L and S systems. Pereira et al., (2006) found higher amino acids concentrations in the juice of unshaded berries of Merlot compared to shaded berries.

Other studies (Friedel *et al.*, 2015) have also provided evidence that sun exposure through leaf and bunch removal increases amino acids of Riesling grapes. However, the variety itself could play a role in response to factors such as light; for example, Gregan, (2012) found a reduction in total amino acids from berries exposed to sunlight in Sauvignon Blanc. However, other studies like that of Šuklje *et al.*, (2016) confirmed that the differences in amino acids concentration were also due to the different clones' responses to bunch exposure. As mentioned earlier, TF musts specifically were significantly higher in BCAAs. TF trellises have open canopies which may result in the berries exposed to better light interception consequently affecting amino acid metabolism. Similarly, Pereira *et al.*, (2006) also found a higher level of BCAAs (valine and leucine) in sun-exposed berries of Merlot.

2.3.3 Phenolic measurements and CIE Lab parameters

The results presented in this section are for discrete phenolic measurements (A280, A320, A360, A420), CIELab parameters (a*, b*, L*, Chroma, and hue), as well as UV-Vis absorption spectral data (280 nm to 780 nm). The phenolic measurements and CIELab parameters were statistically analysed with ANOVA and PCA, while the spectral data was only for PCA. In 2017, only the wines were submitted to these measurements, while in 2018, both musts and wines were analysed.

For the juice analysis (2018 only), ANOVA of the phenolic and CIE Lab parameters indicated that there were significant differences between the systems with the exception of yellow colour (420 nm) (Table 2.5). S had the highest values for 280 nm (phenolic content) and 320 nm (phenolic acids), while B and SD had the highest absorption at 320 nm (flavonols). None of the differences between the systems were relevant. For the CIELab parameters (a*, b* and Chroma), there was a similar trend for the SD and B with the highest values whereas, the TF and L systems were the lowest.

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Table 2.5. The selected phenolic and CIE lab parameters for juices made from the grapes of five trellising systems in 2018.

Trellis	**Phenolic**				**CIELab parameters**				
	280nm	**320nm**	**360nm**	**420nm**	**a***	**b***	**L***	**Chroma**	**hue**
S	3.53^{a}	2.38^{a}	0.08^{c}	0.07	0.06^{b}	1.14^{ab}	94.64^{ab}	1.14^{b}	86.60^{a}
B	3.49^{b}	2.27b^{c}	0.09^{a}	0.07	0.13^{a}	1.31^{a}	94.20^{bc}	1.32^{a}	84.10^{b}
SD	3.50^{b}	2.34^{ab}	0.09^{ab}	0.06	0.14^{a}	1.32^{a}	93.98^{c}	1.43^{a}	84.69^{ab}
TF	3.50^{b}	2.24^{c}	0.08^{abc}	0.07	0.08^{b}	1.05^{b}	94.45^{abc}	1.05^{b}	85.49^{ab}
L	3.51^{ab}	2.20^{c}	0.08^{bc}	0.07	0.06^{b}	1.06^{b}	94.95^{a}	1.05^{b}	86.51^{a}

The order of the letters indicates descending order of concentration; different letters mean a significant difference.

Chromatic characteristics measurements (a*, b*, L*, Chroma and hue) would serve as a quick guide to reveal the polyphenolic content of a given juice or wine and its quality as reflected in the colour. To date no literature is available on chromatic characteristics of white grapes must from different trellising systems. L system was recorded with the highest value in lightness, L* (94.95), and the SD system with the lowest (93.98). Since the scale has a maximum of 100 for L*, all the juices were rated very high in lightness. The juices from the S and L systems were highest in hue (86.60 and 86.51) and the lowest value was observed from B systems (84.10). Generally, the differences shown by these parameters are not relevant for the wines studied here.

Looking at the PCA for phenolic and CIELab parameters (Figure 2.6, PC1 47.9 and PC2 17.9%), the samples belonging to one trellis system tended to group together, but samples from different systems were also interposed. SD and B systems were separated from the rest along the PC1. Even the PCA conducted on full spectra data (Figure A2), showed that no distinctive grouping was observed between juice samples.

The ANOVA of phenolic and CIELab parameters showed there were no significant differences between any of the parameters evaluated in 2017 wines, with the exception of absorption at 420 nm and b* (Table 2.6). Both these parameters are utilised to describe the yellow colour, in the absorption spectra and in the CIE Lab space, respectively. Similar to juices, there are no reports in the literature on the wine CIELab parameters or phenolic measurements as affected by trellising systems. The only mentions for Chenin Blanc wines influenced by trellis were in terms of colour quality determined sensorially (Van Zyl &Van Huyssteen, 1980).

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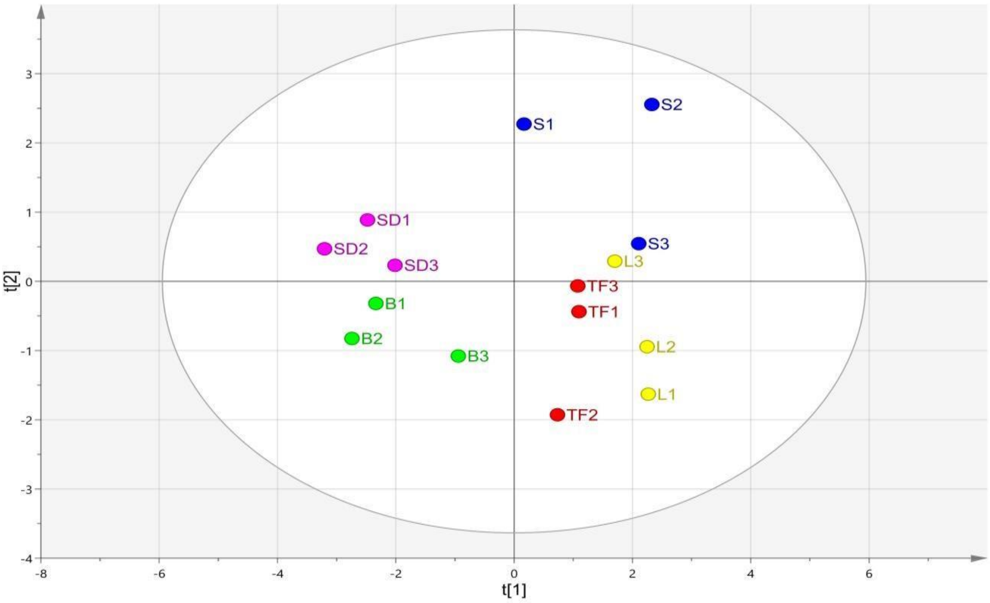

Figure 2. 6. PCA score plot for the results for selected phenolic-related parameters (Total phenols/A280 nm, Total phenolic acids/A320 nm, Total flavonols /A360 nm, yellow colour/A420 nm) CIELab parameters (a*, b*, L*, Chroma and hue) for 2018 juices. Samples are colour-coded according to treatment.

Moreover, the PCAs of phenolic and CIELab parameters also showed the same pattern as ANOVA. The scattering of samples showed that the values for the trellising system were not different in such a way as to distinguish between the treatments. Even when using the full spectral data (280 – 780 nm), the PCA could not result in grouping based on systems (Figure A3).

Table 2.6. The wine selected total phenolic content (AU) and CIELab parameters measured in 2017 and 2018.

Trellis	**Phenolic**				**CIELab parameters 2017**				
	280 nm	**320 nm**	**360 nm**	**420 nm**	**a***	**b***	**L***	**Chroma**	**hue**
S	3.24	2.12	0.58	0.07^{a}	0.30	2.37^{a}	95.95	2.39^{a}	82.57
B	2.69	1.78	0.50	0.06^{b}	0.29	1.87^{b}	96.13a	1.89^{b}	81.32
SD	3.13	1.96	0.57	0.06^{ab}	0.30	2.09^{ab}	93.85	2.11^{ab}	81.60
TF	3.20	1.88	0.55	0.07^{a}	0.27	2.41^{a}	96.05	2.42^{a}	83.36
L	3.34	2.00	0.56	0.07^{ab}	0.27	2.37^{a}	96.16	2.38^{a}	83.46
Trellis	**Phenolic**				**CIELab parameters 2018**				
	280 nm	**320 nm**	**360 nm**	**420 nm**	**a***	**b***	**L***	**Chroma**	**hue**
S	3.50	2.18	0.61	0.07	0.04	2.42	95.91	2.42	88.83
B	3.49	2.15	0.63	0.08	0.14	3.33	95.66	3.33	87.53
SD	3.48	2.20	0.65	0.08	0.12	3.27	95.75	3.28	87.87
TF	3.47	2.06	0.60	0.08	0.07	2.82	95.70	2.82	88.38
L	3.52	2.25	0.64	0.08	0.06	3.70	95.66	3.70	88.81

Based on ANOVA, in 2018, there were no significant differences observed between treatments (Table 2.6). As it was the case with wine from the previous season, the PCA for phenolic and CIE lab parameters indicated no separation between wines (Figure 2.7, PC1 49.8 and PC2 27.6%,

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respectively). Likewise, the full scan spectra data by UV-Vis (Figure A4) showed no groupings between samples.

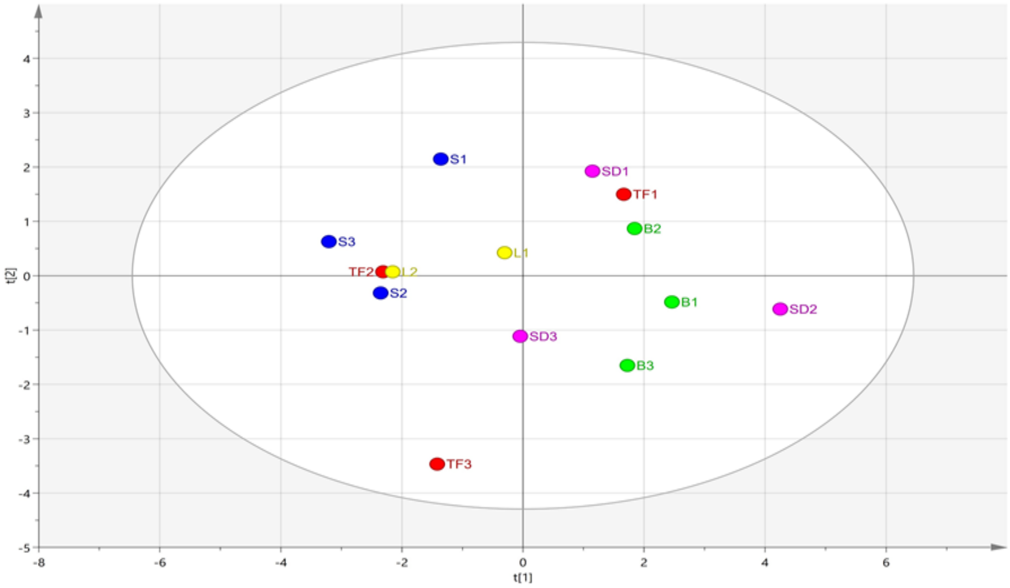

Figure 2.7. PCA score plot for the results for selected phenolic-related parameters (Total phenols/A280 nm, Total phenolic acids/A320 nm, Total flavonols/A360 nm, yellow colour/A420 nm) CIELab parameters (a*, b*, L*, chroma and hue) for 2018 wines. Samples are colour-coded according to treatment.

Overall, the ANOVAs for the two seasons found similar trends in phenolic and CIE lab parameters. The exception is for yellow colour parameters (A420nm and b*), which were significant in 2017 but not in 2018. In addition to that, the dataset means values from 2018 were higher than for 2017 with the exception of a* and L*. Even if a positive value for a* puts the colour in the red region, the values are very close to 0. On the other hand, the values for b* (>0, yellow) are higher on the range. The composite between the two resulted in yellow/light brown wines. For both seasons, the value of L* was very close to the maximum (100), so relatively speaking, all wines were very light in colour.

2.3.4 Aroma composition

A total of 25 major volatile compounds were identified and quantified in the Chenin Blanc wines using GC-FID; for discussion they have been classified into five groups: esters, acetates, ethyl esters, acids, and alcohols, according to their functional groups and metabolic formation (Table 2.7 and 2.9). ANOVA was performed on individual volatile compounds and on the groups

Table 2.7 shows the mean concentration of individual major volatiles and groups for the season 2017. Wines from the P training system had the highest concentration in total volatile compounds and alcohols, respectively, followed by L, while the B system had the lowest. Three groups namely

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Table 2.7. The analysis of variance (ANOVA) calculated from major volatiles concentrations (mg/L) and thiols compounds (µg/L) concentrations of wines made from the six trellising systems (2017 vintage).

Individual compounds

	S	**B**	**SD**	**TF**	**L**	**P**
Ethyl acetate	29.17	36.45	41.52	48.86	68.31	48.97
Ethyl lactate	6.19	4.86	5.15	3.74	4.64	3.74
Ethyl caprylate	1.61	1.46	1.16	1.28	1.60	1.16
Ethyl caprate	1.67	1.42	1.37	1.54	2.0	1.95
Ethyl phenelthylacetate	1.03	1.07	1.18	1.36	1.40	1.67
Ethyl hexanoate	6.80	6.80	9.46	6.63	1.08	9.50
2-Phenylethyl acetate	4.88	4.26	3.38	3.59	4.05	3.41
Diethyl succinate	2.62	2.94	2.59	3.06	3.21	3.08
Isoamyl acetate	5.13	5.27	4.88	5.18	6.05	5.28
Isobutanol	21.91	19.90	25.86	31.29	32.59	35.60
Pentanol	5.74	6.10	5.74	7.57	7.45	6.29
Isoamyl alcohol	170.12	157.27	183.06	173.88	176.49	204.26
Hexanol	1.40	4.01	6.73	5.94	8.22	6.94
Butanol	4.34	7.40	8.12	4.11	1.60	1.21
Propanol	21.25	18.67	18.75	30.80	52.47	33.64
2-phenyl ethanol	4.08	3.83	3.13	2.38	1.78a	2.04
Propionic acid	1.37	1.49	1.73	2.23	2.62	2.29
Isobutyric acid	1.59	1.15	1.45	1.46	1.70	2.25
Butyric acid	1.61	1.16	1.39	3.97	1.32	2.05
Iso-valeric acid	5.79	3.91	1.24	1.40	1.55	1.47
Valeric acid	5.84	5.34	5.98	1.65	2.35	2.05a
Hexanoic acid	24.36	25.33	19.55	26.55	22.17	31.6
Octanoic acid	4.69	6.14	6.70	5.42	5.61	5.13
Decanoic acid	4.69	6.14	6.70	5.42	5.61	5.13
Groups of volatiles						
Total volatiles	341.22	337.52	371.66	381.13	421.60	425.84
Esters	62.46	69.69	75.53	77.06	98.06	83.86
Acetates	39.18a	45.98	49.78	57.63	78.41	57.66
Ethyl esters	52.45	60.16	67.27	68.29	87.96	75.17
Acids	49.94	50.65	44.75	48.11	42.93	52.01
Alcohols	228.82	217.18	251.38	255.96a	280.61	289.97

Trellis	**3MH**	**3MHA**	**4MMP**
S	149.77	0.18	n.d
B	354.44	34.40	n.d
SD	111.62	17.63	n.d
TF	339.94	15.97	n.d
L	337.93	n.q	n.d
P	135.00	1.52	n.d

n.d. – not detected; n.q. – not quantified

esters, acetates and ethyl esters had a similar trend, in which L system wines were the highest whereas the S system had the lowest concentrations. For the last group (acids), P system had the highest, and L the lowest concentration. However, none of the differences were statistically significant. Another class of odour compounds measured were thiols (Table 2.7). TF wines were the highest in 3MH and SD the lowest. As for 3MHA, the highest concentration was recorded in the B system wines and S treatment had the lowest. Technically, the L system concentration were below detection limit thus the missing value. The third compound, 4MMP, was not detected in 2017 in any of the samples. Noteworthy mentioning is that the samples did not differ significantly.

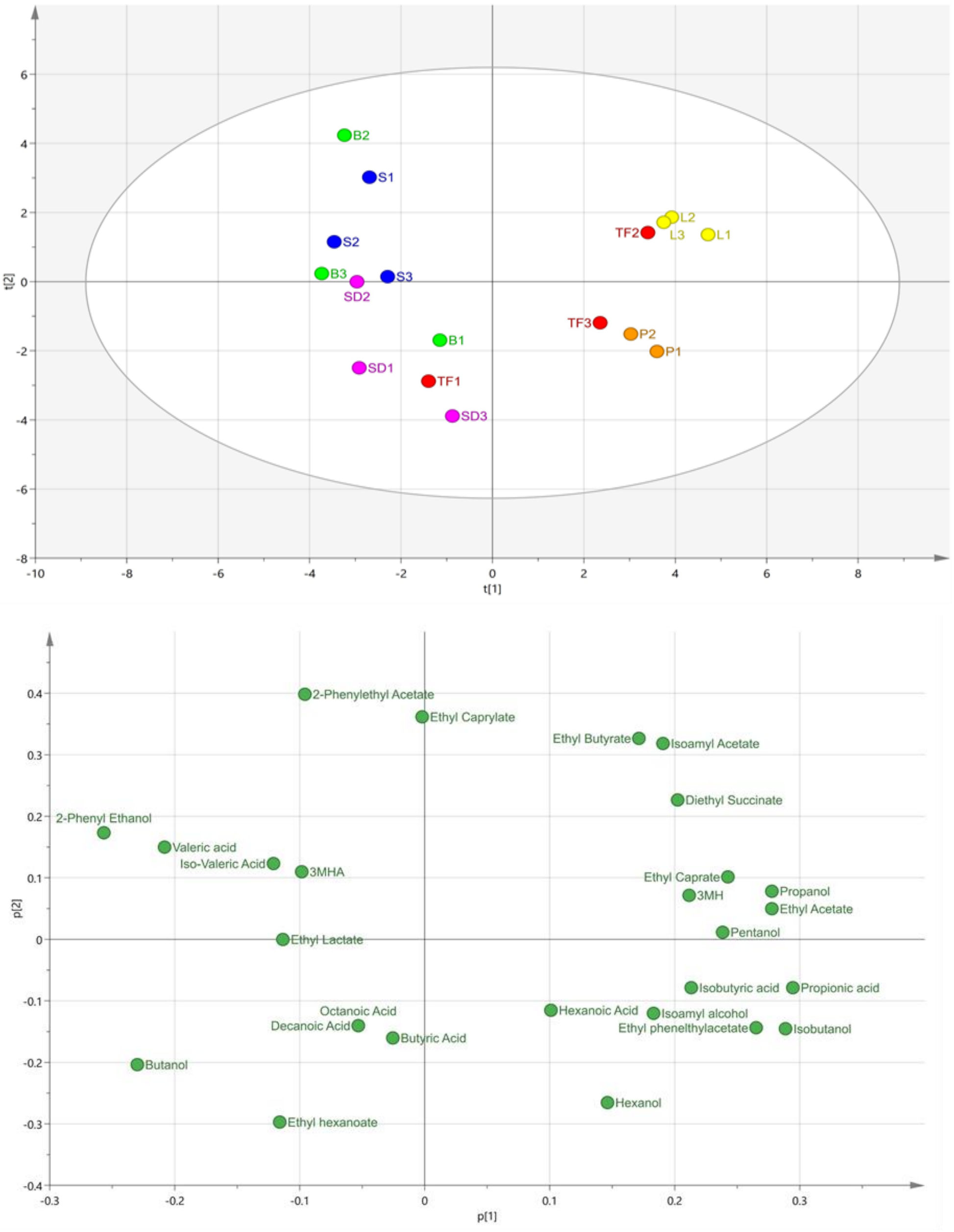

Figure 2.8. PCA score plot (top) and loading plot (bottom) obtained from major volatiles and thiols data, illustrating groupings and distribution of wine samples and measured compounds according to trellising systems in 2017 wines.

PCA was performed using all the 2017 volatiles' data (major volatiles and thiols, PC1 37.9 and PC2 18.8%, respectively), to see if there was any grouping of based on these compounds (Figure 2.8). PCA showed a pattern in which P and L samples are grouped together (with two of the TF

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samples), separate from the rest of the system samples along PC1, additionally the loading plots (Figure 2.8) showed no discriminant to produce clearer groupings (HCA results, Figure A5). As shown by ANOVA, the two treatments were comparably the highest in total volatiles.

Table 2.8 The concentrations (µg/L) of major volatiles in the wines from the 2018 vintage.

Individual compounds					
	S	**B**	**SD**	**TF**	**L**
Ethyl acetate	57.24	84.78	69.19	78.22	81.30
Ethyl lactate	3.35	9.13	2.01	2.15	2.24
Ethyl caprylate	2.28	2.40	1.97	2.05	2.19
Ethyl caprate	3.25	3.84	3.69	3.83	4.00
Ethyl phenelthylacetate	1.27	1.34	1.50	1.33	1.39
Ethyl hexanoate	1.14	1.15	1.13	1.15	1.17
2-Phenylethyl acetate	5.00	6.95	4.43	5.51	5.03
Diethyl succinate	4.14	2.22	3.69	3.85	3.13
Isoamyl acetate	6.17	7.95	6.70	7.98	8.32
Isobutanol	31.18	40.71	34.85	34.95	32.04
Pentanol	8.63	1.15	1.02	4.01	8.97
Isoamyl alcohol	203.93	219.43	211.97	203.56	209.54
Hexanol	8.82	7.55	7.86	7.52	7.31
Butanol	7.09	1.13	3.82	3.76	4.01
Propanol	42.43	63.96	63.95	71.20	79.47
2-phenyl ethanol	35.26	38.96	28.55	26.58	22.88
Propionic acid	2.07	2.94	2.88	2.64	2.90
Isobutyric acid	1.69	1.86	1.65	1.66	1.57
Butyric acid	1.33	1.48	1.37	1.33	1.42
Iso-valeric acid	2.37	4.01	3.65	6.42	8.95
Valeric acid	3.30	3.62	3.58	4.05	3.47
Hexanoic acid	3.29	4.35	3.93	4.29	4.50
Octanoic acid	4.12	4.17	3.91	4.36	4.62
Decanoic acid	8.82	8.96	8.63	1.02	3.58
Groups of volatile					
Total volatiles	454.06	530.23	480.81	489.98	510.53
Esters	89.72	125.95	99.20	112.63	115.31
Acetates	68.40	99.68	80.31	91.71	94.64
Ethyl esters	78.56	111.05	88.08	99.14	101.97
Acids	26.99	31.39	29.60	25.78	31.00
Alcohols	337.34	372.89	352.01	351.58	364.22

As in 2017, in 2018 ANOVA performed on the concentration of major volatiles did not find a significant difference between trellises (Table 2.9). The wines of the B system were the highest in total volatiles, esters, acetates, and ethyl esters but comparable to other systems, with the exception of the S. TF and S treatments were the highest and lowest in higher alcohols respectively.

On the other hand, ANOVA for thiols' results indicated significant differences between the systems for 3MHA (Table 2.11) but only for the highest concentration. The L wines had the highest mean concentration of 3MHA, whereas the SD had the lowest. The wines of the B trellis were highest in 3MH, whereas L wines were the lowest. Moreover, L system wines were highest in 4MMP and TF were the lowest in the same compound.

Table 2.9. Thiols concentrations (ng/L) in wines of 2018 vintage.

Trellis	**3MH**	**3MHA**	**4MMP**
S	333.97	37.18^{b}	2.41
B	390.10	38.43^{b}	2.50
SD	307.34	29.53^{b}	2.54
TF	297.93	37.34^{b}	2.38
L	292.435	63.45^{a}	2.56

Samples designated by different letters differ significantly

PCA was performed on the volatiles using major volatile compounds and thiol concentrations. No separation of wines according to the treatment was observed (PC1 31.6 and PC2 24.7%, respectively). Despite the significant differences for 3MHA in the L wines, this was not a strong enough discriminant factor to separate these samples in the PCA. Similarly, the cluster analysis and loadings shows no specific compound which highly associated with specific wines or groupings based on trellising systems (Figure A6).

Aroma compounds come from either grapes, fermentation processes, or ageing. Those derived from grapes are likely to be influenced by environmental conditions including as result of a training system (Zoecklein *et al.*, 2008). Most importantly, light or sunlight exposure is one of the factors which affects the accumulation and synthesis of aroma related compounds (Ford, 2007). From previous work, it has been shown that UV-C light irradiation amplifies the thiols precursors (Kobayashi *et al.*, 2011); however, it is not fully understood how there is a correlation between thiols precursors and wine thiols. Parish-Virtue *et al.*, (2019), reported a positive response of light on Sauvignon Blanc from grapes to corresponding wines.

It is hypothesised from literature that a similar design exposes the fruit-zone to light intensity in a similar way and influences the type and level of chemical compounds synthesised consequently affecting the aroma profile (Šuklje *et al.*, 2016). This only applies to compounds directly affected by sun exposure, in this case, thiols. Light (for example driven by trellising systems) may have induced variations in 3MHA concentrations. However, this effect maybe revised in the case of the current study because in the first season 3MHA was not detected in the wines from the L system.

And looking at other treatments, there was an increase in the concentration of 3MHA with from the first season to the second, which is similar to Drenjančević *et al.*, (2018) and Louw *et al.*, (2010) who demonstrated that vintage is the source of variation for the volatile composition of Cabernet Sauvignon, Sauvignon Blanc, Chardonnay, Pinotage, Merlot, and Shiraz wines. Microclimatic conditions were not measured in the current study, but based on previous research, moderate cluster exposure to sunlight increases flavour compounds in Traminette grapes (Ji & Dami, 2008). Common compounds that are documented as being influenced by light are C_6 compounds (Zoecklein *et al.*, 2008), and these are among the potential precursors involved in 3MH and 3MHA formation (Harsch *et al.*, 2013).

Esters, higher alcohols and organic acids are among the compounds contributing to the bouquet of a young wine (Morakul et al., 2013). The ethyl esters of hexanoic, octanoic, and decanoic acids and isoamyl and isobutyl acetates are often considered to give wine its characteristics (Ferreira *et al.*, 2000). From previous work, Marais *et al.*, (1981) who found a correlation between amino acids in the musts and ester formation. Because of this phenomena, the hypothesis would be that a significant difference in certain amino acids in must corresponds to a significant difference in the resulting esters' concentrations in wine. For the major volatiles, as derived from AA metabolism, a configuration similar to the AA results was found, with L, P, and TF samples grouped together in both cases (Figure A7).

Additionally, some trellising systems like Lyre optimise leaf surface area which may lead to optimisation of sunlight use. It is possible that, for the current study, other chemical compounds like terpenes were influenced. Marais, (1983), generated data which suggests that Chenin Blanc leaves are rich in terpenes, and later Bruwer, (2018), confirmed the presence of monoterpenes in wines.

Therefore, there is a chance that compounds other than major volatiles and thiols (i.e. terpenes) may have contributed to the wines aroma profile because it was demonstrated that sunlight influences the concentration of terpenes in wine (Marais *et al.*, 1992).The manner in which the canopies in the L system are opened up permits good interception of light, which improves fruit exposure which may lead to an increases in thiols precursors concentrations in berries. It has been confirmed that an increase in Gluy-3SH level in grapes and must of Sauvignon Blanc resultant from nitrogen status on 3MH content (Helwi *et al.*, 2016). Another study of Lloyd, (2013) reported green characters enhancement in Sauvignon Blanc wines as a result of light exposure modification

2.3.5 Untargeted analyses

The untargeted LC-HRMS analysis was used to evaluate the effect of trellising systems on the chemical characteristics of corresponding wines. PCA was used to explore the samples grouping according to the positive and negative ionization dataset generated for the two seasons (2017 and 2018).

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Firstly, the PCA plot for 2017 treatments illustrated in Figure 2.9 shows a grouping between the six trellises, according to their treatment fingerprint. According to HCA, the samples were separated into groups according to trellising systems (Figure 2.9 bottom). This led to the following groups: L treatment samples in one group, TF and P samples in the second group, B and SD samples in the third group, and S samples in their own group. Since polyphenols are compounds that give an MS signal in negative ionisation mode, the results could be relevant for some of the sensory aspects of the wines, which will be further discussed (Chapter 3). Considering that polyphenols have a relevant contribution to sensorial properties such as taste and mouthfeel (Gawel *et al.*, 2017), and that they are affected by light exposure; it is possible that the groupings formed may be related to the architecture of the canopies regarding shading and open canopy to sun.

The PCA plot illustrated in Figure 2.10 shows the sample configuration for 2018. According to the cluster analysis (Figure 2.10), three groups are formed: the first group with L and SD samples, second group made of TF and B samples and the third group has S wine samples. One SD sample was distributed with the S group, but it was an exception. Just like the results of 2017 vintage, the PCA results corresponds well to the taste and mouth feel profile in the sensory Chapter

The results from the two vintages illustrate that trellising systems design can play a role in the manner in which grapes or foliage are subjected to light, either in shade or exposed. Based on the grouping illustrated by data captured from fingerprinting; the trellis with similar structure are grouped together. Phenolics are responsible for taste and texture characters in wine in the interaction of other components, are influenced by practices in the vineyard, and there is a correlation between phenolics and sunlight (Šebela *et al.*, 2017). Because the differentiation of wines according to trellising systems by fingerprint is mostly based on phenolics, it can be hypothesised that sunlight exposure played a role in the samples’ configuration.

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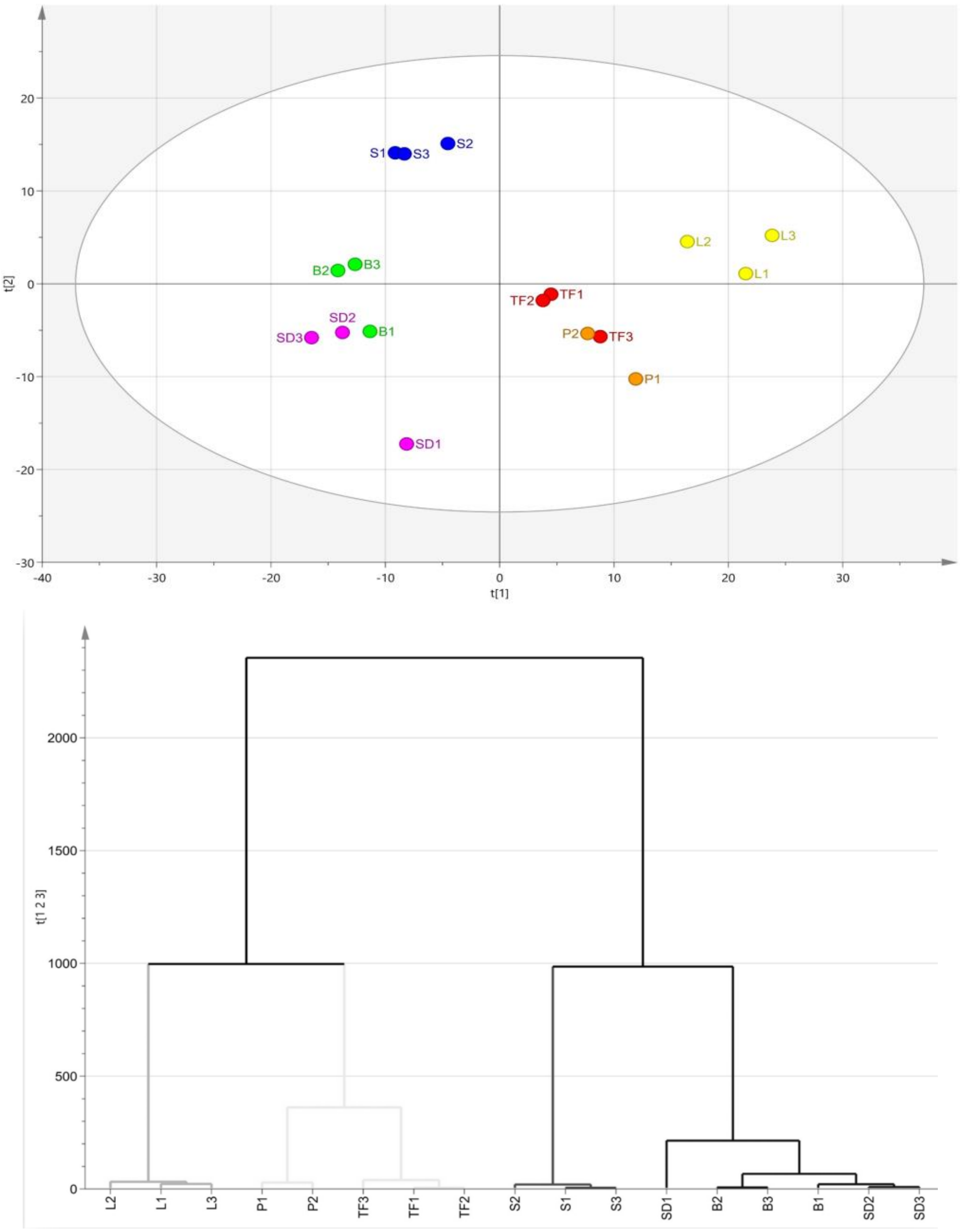

Figure 2.9. (Top) PCA score plot of Chenin blanc samples obtained for fingerprint scan of positive and negative ionization mode, n=17 analysed in 2017, colour-coded by treatment. (bottom) Dendrogram derived from the HCA on the same data, colour-coded by linking distance.

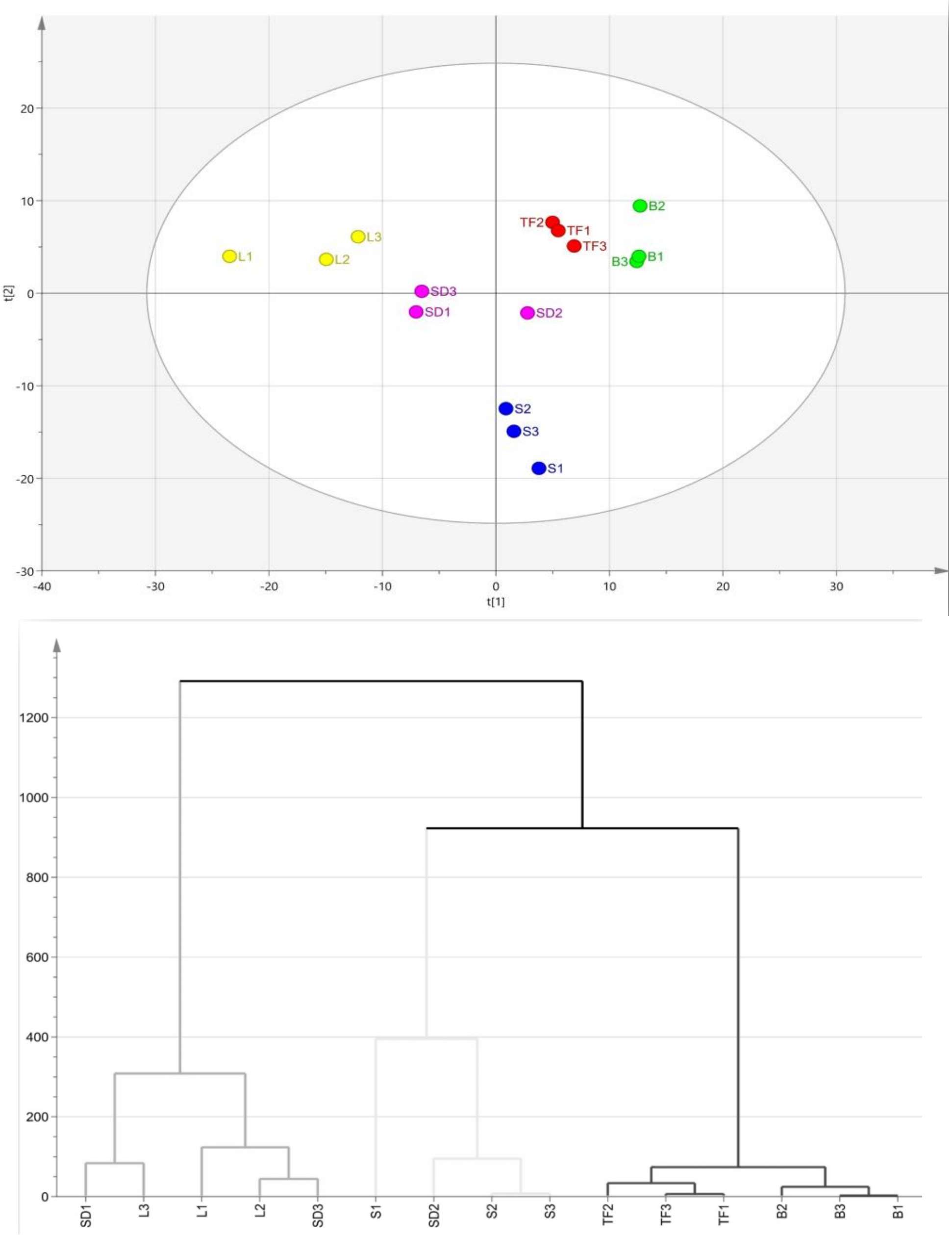

Figure 2.10. (top) PCA score plot of wine samples derived from positive and negative ionisation mode and grouped according to trellising systems 2018 colour-coded by treatment. (bottom) Dendrogram derived from the HCA on the same data, colour-coded by linking distance.

Looking at the canopy structure, SD and B are similar in structure, as Ballerina is derived from Smart Dyson. . This may explain why they can produce wines of analogous fingerprint profile thus seen place close to each other. Equally, T-frame and Lyre open canopies in a horizontal way, could be that light distribution may be intercepted in an alike manner leading to possible related composition, hence positioned next to each other. To date no published work has looked into the LC-HRMS profile of wines made from trellising systems, to compare with the results of this study.

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2.4. Conclusion

The chemical composition of grapes is an important aspect in winemaking, as it determines the characteristics of wine in addition to fermentation and ageing processes. The content, concentration and level or certain compounds in grapes can be modified by several factors including vineyard practices. One possible way of evaluating the impact of vineyard practices including trellising systems on wine characteristics is through analytical methods. Chemical composition entails volatile and non-volatile compounds which contribute to defining wine typicality and style.

From a training system perspective, trellising systems creates their own microclimates and that causes changes in sugar accumulation and acid degradation. The systems with divided canopies played a role in increasing yield, as previously reported (Smart and Robinson, 1992). In the current study, the dividing canopies (L, and TF) produced higher yield; however, those differences were not large. Like previous studies, the increase in yield did not come at any cost (quality), as measured by basic oenological parameters, which did not vary significantly between systems.

Similar type of trellises were found to have similar responses to nitrogenous compounds like amino acids and their yeast assimilable nitrogen components. Amino acid profile was able to differentiate the TF and L systems musts different from the rest of the systems. Even if individual and groups of amino acids varied between systems, the differences did not reflect in wine major volatiles, in particular amino acids that are involved in ester production.

The ultimate aim of this work was to characterise the wines using their chemical composition. Differences were not apparent. No clear distinction was observed between wines despite significant differences observed in some aroma compounds namely 3MHA. Again, the horizontal dividing or open canopy type of trellis (L and TF) in this study had higher concentrations of thiols compounds and major volatiles than the rest of the systems, although comparable in practical terms.

Both univariate and multivariate analyses were not able to differentiate wines/treatments from each other. In this study, the phenolics from six treatments were investigated and their variation in absorbance and composition was explored. The phenolic profile of the spectra data and CIELab parameters were also evaluated with the idea that metabolites in wines from different treatments differ even within one variety when grown in different conditions in the same vineyard.

According to the profiles provided in this study, trellising systems may influence other wine aspects as revealed by fingerprinting. Other than that, other factors such variety, vineyard location, vintage, water usage, and yield could be enough tools for wine growers to make decision on the type of system to use. The results in this study may not be extrapolated to other regions or cultivars because of genetic makeup of a vine or cultivar and its response to external factors or other aspects such as clone. Based on the results of this research, selecting the appropriate trellising system for

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any variety should be a choice of producer based on their respective goals. What the work does suggest, is an indication of direction to how to important to consider chemical evaluation with the aspect of yield without compromising on quality when choosing a suitable system.

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Chapter 3

Evaluating the effects of trellising systems on the sensory profile of Chenin Blanc wines, using the Check All That Apply (CATA) method quality scoring

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3.1. Introduction

Chenin Blanc grapes belong to a group of varieties defined as ‘neutral’ (Augustyn & Rapp, 1982); for that reason, the style of the resulting wines is dictated by the winemaking process as well as the manipulation of the vines’ microclimate. Young Chenin Blanc wines exhibit a fruit-like aroma as a result of volatile esters formed during fermentation, but additional or different aromas can be induced by canopy management practices aimed at modifying the physiology of the grapevine and therefore of the deriving grape precursors (Reynolds & Van den Heuvel, 2009). Furthermore, choice of yeast strains (Reynolds *et al.*, 2001), yeast strain nutrition (Van Rooyen & Tromp, 2017), skin contact time (Marais and Rapp, 1988) and pressing (Somers & Pocock, 2015) are amongst the oenological practices which alter volatiles and non-volatiles content and concentration in juices or wines.

One of the significant ways of manipulating the canopy and subsequently grapes, juice, and wine composition and sensory profile, is modifying the architecture of the vines with various trellis systems. Generally, training systems make a difference, such as maintaining a balance between the fruit producing parts and the energy producing structure, different degrees of exposure to light in the bunch zone (Marais *et al.*, 1992), as well as a proper air flow through the canopy to avoid conditions favourable to fungal infections (Van Zyl & Van Huyssteen, 1980). In the specific case of sun exposure, such factors affect the content of vine metabolites constituting grape volatile profile and aroma reservoir (Reynolds *et al.*, 1996), and consequently wine aroma (Zoecklein *et al.*, 2008). Many of these influences occur in aromatic varieties such as Riesling (Reynolds *et al.*, 1996), Viognier (Zoecklein *et al.*, 2008), Sauvignon Blanc (Marais *et al.*, 1999) and to some extent in Chardonnay grapes (Zoecklein *et al.*, 1998).

To characterise and assess the quality of food and beverages, a number of sensory evaluation methods have been used (Lawless, & Heymann, 1998). In the evaluation of wines, the judgment of quality is consigned to winemakers or experts. Quality judging systems have been applied based on points, a popular method called 20-point scale scheme was developed by the University of California (Davis) to evaluate wine sensory properties for quality control and commercial purposes. In this method, points are assigned in sensory categories such as appearance, aroma, taste and overall quality with a possible totalling of 20 points, and wines are penalised for deviating from the typicality of a style. This system is commonly used to assess quality aspects of particular wine styles in a less formal setting, but has also been used for research aspects. For instance, Brand *et al.*, (2018) used this method to determine the most important aroma attributes in the wine quality

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characteristics of Sauvignon Blanc. In comparison to other systems such as 100 point scale, no greater differences were observed in quality ratings of New Zealand Sauvignon Blanc wines between the two systems evaluated (Parr *et al.*, 2006).

While this method is suitable for general quality assessment, it may not distinguish between groups of wines with similar quality. Also point allocation for each category gives different weight to the sensory characteristics which may or may not reflect the importance in the overall quality. Due to these issues, an additional descriptive analysis is usually coupled to this system to characterize sensory differences in wines across multiple attributes. For example, in Australia, Niimi *et al.*, (2018) profiled and assessed the wine quality of three vintages for Cabernet Sauvignon and Chardonnay wines.

Descriptive analysis uses both qualitative and quantitative methods in the evaluation of a product with the purpose to obtain a detailed description of aroma, flavour, and oral texture attributes ("mouthfeel"). It is therefore suited for research and development, product development, to track sensory changes, and product specification. Besides detailed information, descriptive analysis also has some drawbacks: panellists need training, so it is time-consuming and leads to additional costs. Because of these disadvantages, researchers developed alternative applicable methods in the characterisation of wines, which produce similar results but using rapid techniques (Valentin *et al.*, 2012).

One of the alternative methods that have gained popularity, is Check-All-That-Apply (CATA), originally used in marketing (Rasinski *et al.*,1994) and subsequently proposed as an alternative method to gather information about consumers' perception in the food industry (Adams *et al.*, 2007). CATA is a rapid sensory profiling technique, which uses a questionnaire consisting of a list of attributes (in the form of words or phrases) from which trained or untrained panellists can select all the descriptors they consider appropriate to characterise each sample (Valentin *et al.*, 2012). The methodology has proven to be simple and reliable for sensory product characterisation of a wide range of foodstuffs, because it has produced similar results to descriptive analysis with trained assessors (Ares *et al.*, 2010). In the South African wine industry, CATA was used to characterise the aroma profile of Chenin Blanc in both experimental (Botha, 2015) and commercial wines (Panzeri & Buica, 2016) as well as Pinotage commercial wines (Panzeri *et al.*, 2019).

The objective of this study was to investigate the effects of canopy microclimate manipulation through trellising systems on the sensory profiles of Chenin Blanc wines. The hypothesis being tested was that aroma, taste, and mouthfeel are affected by changes in the canopy. While previous studies have assessed the impact of oenological and other viticulture aspects from a chemical point of view, there is no study that has evaluated the sensory profile of wines from different trellising systems. Given the previously outlined advantages of the method, CATA was chosen for this study.

In addition, quality rating with industry experts was investigated to evaluate the effect of yield variation on the marketable characteristics of the wines produced.

3.2. Materials and methods

3.2.1 Vineyard

Grapevines (*Vitis vinifera* L. cv. Chenin Blanc clone SN 24B grafted on 110R rootstock) were planted in 2011 in one single block in the Franschoek valley region and trained to six different systems namely: Santorini, Ballerina, Smart Dyson, T-Frame, Lyre and 'Stok-by-Paaltjie' (also known as staked vines or *Echalas*) each system on a different row. The vineyard is located in one of the oldest Cape Dutch farms which lies at 33°49'23.4''S latitude and 18°55'29.4"E longitude. The experiment was conducted over two vintages, 2017 and 2018. All vineyard practices such as irrigation and pruning among others were uniformly applied to all treatments. Grapes were harvested at 22±0.5°B in both vintages. All wines were made in triplicate except for -Stok-by-Paaltjie treatment in the 2017 season, where there was only enough crop to have two replicates (Table 3.1)

Table 3.1 Vineyard summary of the type of trellising systems, their number of vines per system, number of biological repeats, and vintage

Treatment	Codes designated	Number of vines	Biological repeats	Vintage
Santorini	S	28	3	2017 ; 2018
Ballerina	B	27	3	2017 ; 2018
Smart Dyson	SD	27	3	2017 ; 2018
T-Frame	TF	24	3	2017; 2018
Lyre	L	20	3	2017 ;2018
Stok-by-Paaltjie	P	10	2	2017

3.2.2 Wines

Harvested grapes from the vineyard were transported to the Department of Viticulture and Oenology (DVO) cellar of Stellenbosch University. The wines were made in accordance with DVO winemaking standard protocols (Chapter 2). Biological repeats were separated in the cellar before inoculation. All wines were left in contact with the fine lees for three months prior to bottling. After six months of bottle ageing, screening of wines was done and some wines were blended. Considering the volume of wine and the number of experts (30) in comparison to analytical panel (10), it was necessary to blend wines to allow for the number of assessors and the logistical

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aspects. Therefore, experts evaluated six wines (blended) representing six trellising systems, while the analytical panel evaluated the six wines with their biological repeats.

3.2.3 Panels

Two separate groups of participants were selected for the project: a panel of thirty industry experts and a panel of ten analytical (trained) panellists. Experts were recruited on their basis of experience, interest, and availability. The age group varied from 26 years to 45 years old (6 females and 24 males, 30 answers in total). Experts only assessed wines for 2017 vintage. The analytical panellists were selected based on their experience in wine profiling using multiple sensory methods and often recruited by the Department of Viticulture and Oenology (Stellenbosch University) for sensory evaluations. The age varied from 26 to 66 years old; in 2017 they were ten females, whereas in 2018 the panel consisted of eight females and two males.

3.2.4 Sensory Evaluation

The evaluation was done after six months from bottling. The sensory tests were carried out in two separate sessions. The first session involved the industry experts and was carried out at the Paul van der Bijl Laboratory (Stellenbosch University) in a well ventilated, naturally lit room kept at ± 20°C. Experts were tasked to evaluate aroma, taste, and mouthfeel using CATA method and secondly the quality using the 20-points scale method. The second session involved analytical panellists and was carried out in the sensory laboratory of the Department of Viticulture and Oenology of Stellenbosch University. The laboratory is specifically designed for sensory analysis (ISO 8589) containing individual tasting booths, in which the temperature and humidity are controlled. For the CATA method both experts and analytical panellists used black glasses, and wine samples were poured 20 minutes prior to testing and covered with food grade plastic lids (Petri dishes). In addition, the expert tasters were served a supplementary set of the same wines in clear ISO glasses for the quality scoring in order to allow them to evaluate the appearance of the samples as well. Twenty millilitres sample was dispensed using a measuring device, and maintained at a temperature of 20°C.

CATA aroma terms used in this study were selected from *the South African Chenin Blanc aroma wheel.* The taste and mouthfeel attributes were chosen by a focus group after a preliminary screening of the wine samples. The total list of descriptors used for this exercise comprised of forty words (Appendix B). Analytical and expert's panels were instructed to evaluate aroma as well as taste and check all the terms they considered appropriate for describing each sample. The samples were coded with individual three digit codes and randomized across panellists according to a William Latin square design. With experts, the exercises were conducted in one day. They evaluated two flights as follows: in the first flight, they were asked to evaluate aroma taste and in the second flight wine quality based on the three aspects (appearance, aroma and taste) using the

20-point scale scorecard. The analytical panel were tasked to evaluate aroma and taste only, done in three flights over three days (three technical repeats, resulting in 30 answers).

3.2.5 Data Analysis

Data was captured using Compusense® at-hand software (West Guelph, Ontario, Canada) and analysed on XLStat 2018.5 (Microsoft, www.xlstat.com). Correspondence analysis (CA) was performed on a contingency table using Statistica® 13.3 software. Graphical representation of the sensory profiles including aroma, taste, and mouthfeel characteristics were provided as bi-plot by plotting the mean values for the sensory descriptors. Least Significant Differences (LSD) were calculated between wines by analysis of variance (ANOVA) using the Statistica ®13.3 program and the results were evaluated at 95% confidence level for quality scores.

3.3. Results and discussion

3.3.1 Aroma profile of Chenin Blanc wines

The raw data (frequency of citation) from experts in the first season (2017) shows that the most frequently cited attribute for all the wines was 'passion fruit'. This attribute had the highest citation frequency for the L trellising system wine. Overall, it appeared that the differences were small with regards to the number of terms used per treatment to characterise wines. The SD and B were comparable as they were the treatments with the least terms (25 and 26) used out of the total of 40. P, S and L treatments which were described by 28 and 29 words, and finally TF used all the 30 terms to describe the corresponding wines. This might be already an indication of how difficult it was to differentiate the wines from one another.

For 2017 expert panel, the bi-plot obtained from CATA showed an overlapping trend for a set of wines from different trellising systems along dimension 1 (dim1) and dimension 2 (dim 2), which explained 33.8% and 26.0% of the variance, respectively, and totalling 59.8% (Figure 3.1).

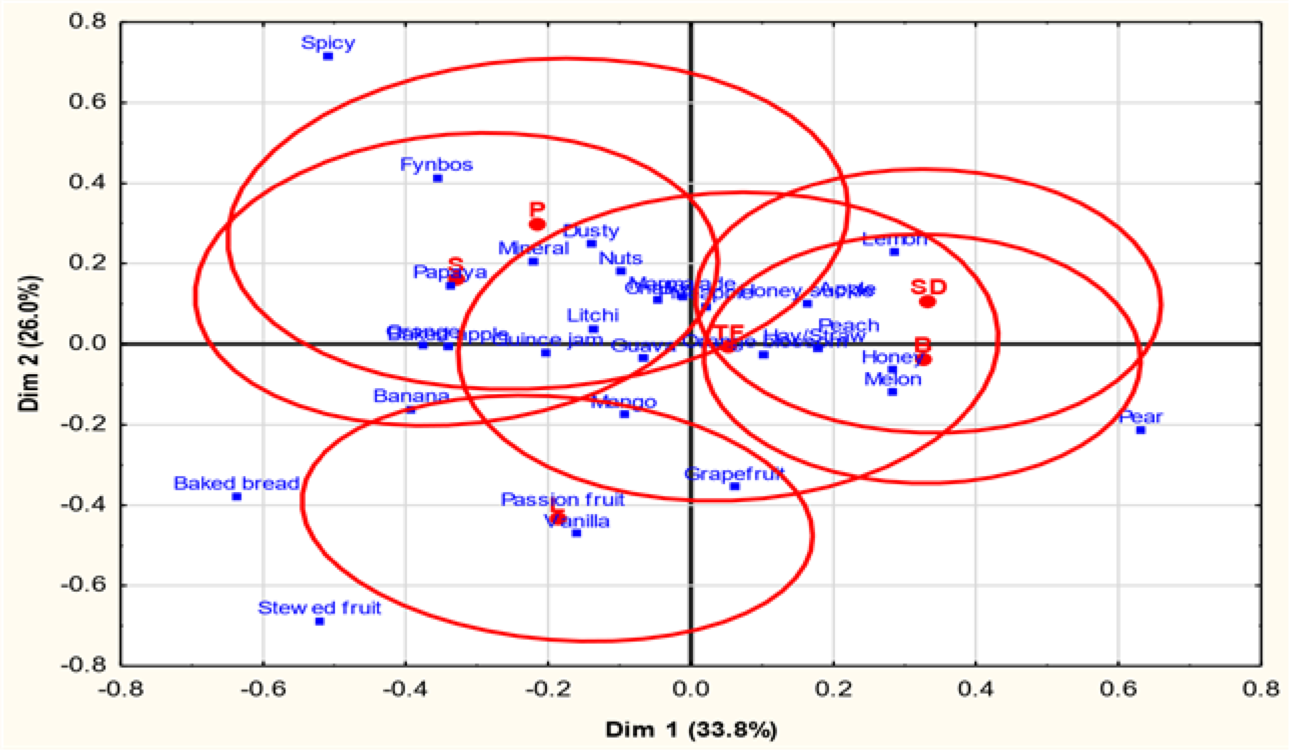

Figure 3.1. Correspondence analysis biplot obtained from expert's data (n=30) for the 2017 wines illustrating samples and the descriptor terms used. Samples (trellising systems) are represented in red. Confidence ellipses at 95%.

All wines were grouped, except for L system wines. The wines of S and P systems were associated with 'spicy' and 'fynbos' descriptors whereas SD and B systems wines were associated with 'lemon', 'honey' 'melon' and 'pear' descriptors. In addition, the TF system wines were associated with 'grapefruit', 'lemon', 'mineral', 'mango' and 'guava'. L system produced wines perceived with 'baked bread', 'stewed fruit', 'banana', 'mango', 'passion fruit' and 'vanilla'. To further investigate the individual attributes used, compiling a 'top five' and 'top ten' lists based on frequency counts helped explain the groupings of correspondence analysis. According to that list, the term 'pineapple' was frequently used across all treatments, while, 'lemon' 'melon' and 'peach' appeared in four to five treatments. 'Honey suckle' and 'hay'/ 'straw' appeared in the top five frequently cited notes associated with SD and TF respectively as unique attributes for these treatments. In spite of unique attributes like in some treatments, there was no clear separation between samples. The overall visualisation shows that all treatments had a common fermentative origin 'fruity' and 'floral' and no discriminant attribute was identified.

L system wines were characterised by 'grapefruit' and 'passion fruit' descriptors, which are typically associated to 3MHA which is formed by the esterification of 3MH with acetic acid during fermentation (Tominaga *et al.*, 1998). 3MHA levels were the highest in the first season and significantly higher in the L system wines compared to the rest of the systems as seen from the chemical results of this study (Chapter 2). The architecture of L systems opens up for good light interception, and enhances fruit exposure which might have led to increased concentrations of

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precursors of this class of aroma compounds. This can be correlated to ripening at harvest induced by light exposure Lloyd, (2013).

Also, non-volatile precursors found in the berries and the must can be increased. Helwi *et al.*, (2016) found an increase of Gluy-3SH levels in grapes berries and must of Sauvignon Blanc as a result of a positive effect of nitrogen status on 3MH content. Additionally, L wines were significantly higher in yeast preferred amino acids namely glutamine and alanine, the same trend seen with FAN which plays a vital role in esters production (Chapter 2) although the difference was not reflected in the aroma descriptors of the resulting wines.

The analytical panel used all fourty terms to describe wines samples of the six treatments. Unlike in the case of the expert panel, the term ‘pineapple’ was frequently used, not only observed the most frequently in B treatment but across all treatments. A possible reason why the analytical panel made use of more words than experts could be that blending masked characters of some attributes. In addition to ‘passion fruit’ being common to all sample wines treatments; ‘guava’ and ‘lemon’ appeared as the most frequently cited attribute in four out of five treatments. Another attribute which was prominent was ‘grapefruit’; although cited the least than other top five aroma attribute, it appeared in all six treatments. Moving to ‘top ten’ aroma attributes, the ‘green herbaceous’ was present in five treatments, whereas ‘tobacco/cigar’ and ‘floral’ attributes were also perceived in three treatments. Based on the raw data, the similarity between wines’ perceived aroma is pronounced and confirmed by multivariate analysis (CA). To experts, all wines were predominantly characterised by ‘fruity’ and ‘floral’ attributes in addition to certain attributes that were associated to particular treatments, however did not contribute significantly.

Correspondence analysis obtained from the analytical panel for the same 2017 vintage using CATA results shows a total of 48.4% explained variance (Figure 3.2). Dim 1 and 2 have an explained variance of 26.5 % and 21.9% respectively. As seen in aroma profiles obtained from experts (Figure 3.1), a similar scenario is seen here (Figure 3.2) in terms of sample grouping. The trend observed is that the wines from TF and S systems were perceived with ‘orange blossom’, ‘tobacco/cigar’, ‘floral’, and ‘sweet associated’ and ‘lemon’. B and SD systems produced wines associated with ‘peach’, ‘guava’, ‘pineapple’, ‘stewed fruit’ and ‘litchi’. P systems wines perceived with ‘nuts’, ‘minerals’, green herbaceous’, ‘passion fruit’, and ‘pear’ whereas, L system wines are associated with ‘fynbos’ and
‘oak’.

Even though the grouping is similar for the analytical panel and the experts and the panels used the same CATA list, the two panels described the wines differently. Experts profiled wines from L systems as ‘baked bread’, ‘vanilla’ and ‘stewed fruits’, whereas the analytical panel perceived them as having ‘oak’ and ‘fynbos’ characters. Despite the terminology used by the two type of panels being different, which is to be expected given the nature of their background, both group of descriptors implied a certain degree of 'toasted', 'woody' and 'sweet associated' characters.

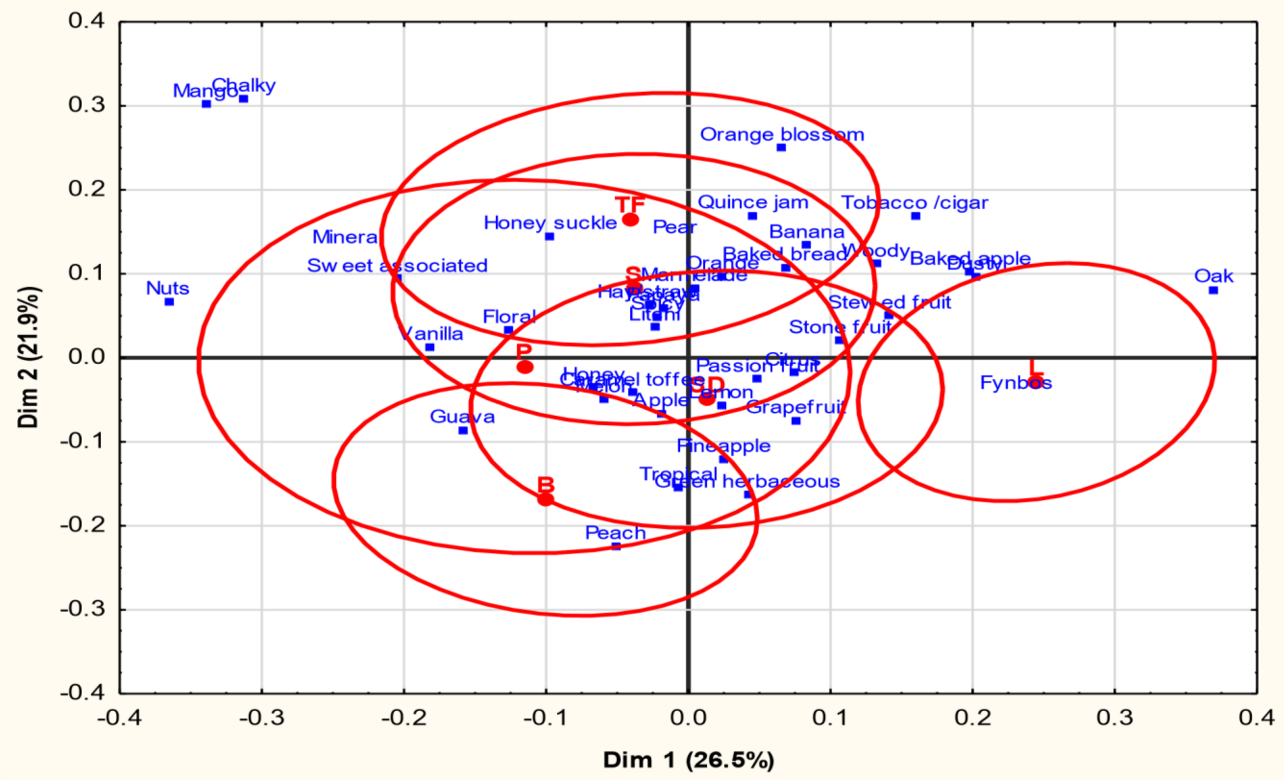

Figure 3.2. Biplot of correspondence analysis illustration aroma profiles of wines made from six trellising systems in 2018 season, evaluated by analytical panel (n=10).

In the second season, the analytical panel used 36 terms. The most frequently cited term was 'pineapple '. Unlike previous season this attribute was highly associated with L system; however, it was present in all treatments. Other terms that were frequently cited were 'passion fruit', 'apple' and 'orange'. Moreover, 'lemon' was commonly used in all treatment as part of top ten most used terms, and 'peach' was the least attribute used among the top ten. Overall, three of the top five attributes used were the same ('pineapple', 'apple' and 'passion fruit') in both vintage across all treatments.

Furthermore, a similar trend is observed with raw data of 2017 and 2018 from panels, that all wines were described by 'fruity', 'guava', and 'floral' notes which relate to esters, thiols and possibly other aromatic chemical compounds (terpenes) not analysed in the current study.

The 2018 vintage aroma profiles in the bi-plot obtained from correspondence analysis of CATA showed better separation than previous vintage (Figure 3.3). The separation is derived from dim 2 which captured 25.4 %, while dim 1 captured 46.5% explained variance totalling 71.9% explained variance.SD wines were associated with attributes such as 'sweet associated', 'baked apple', 'papaya', and 'caramel', B system wines with 'marmalade', 'tobacco /cigar', 'baked bread' and 'fynbos'. L and S systems wines with 'honeysuckle', 'floral', 'pear', 'chalky', 'tropical', and 'dusty ‘and the wines produced from the TF system were described as ‘grapefruit’, ‘passion fruit’, ‘banana’, ‘lemon’, ‘orange ‘and ‘green herbaceous’.

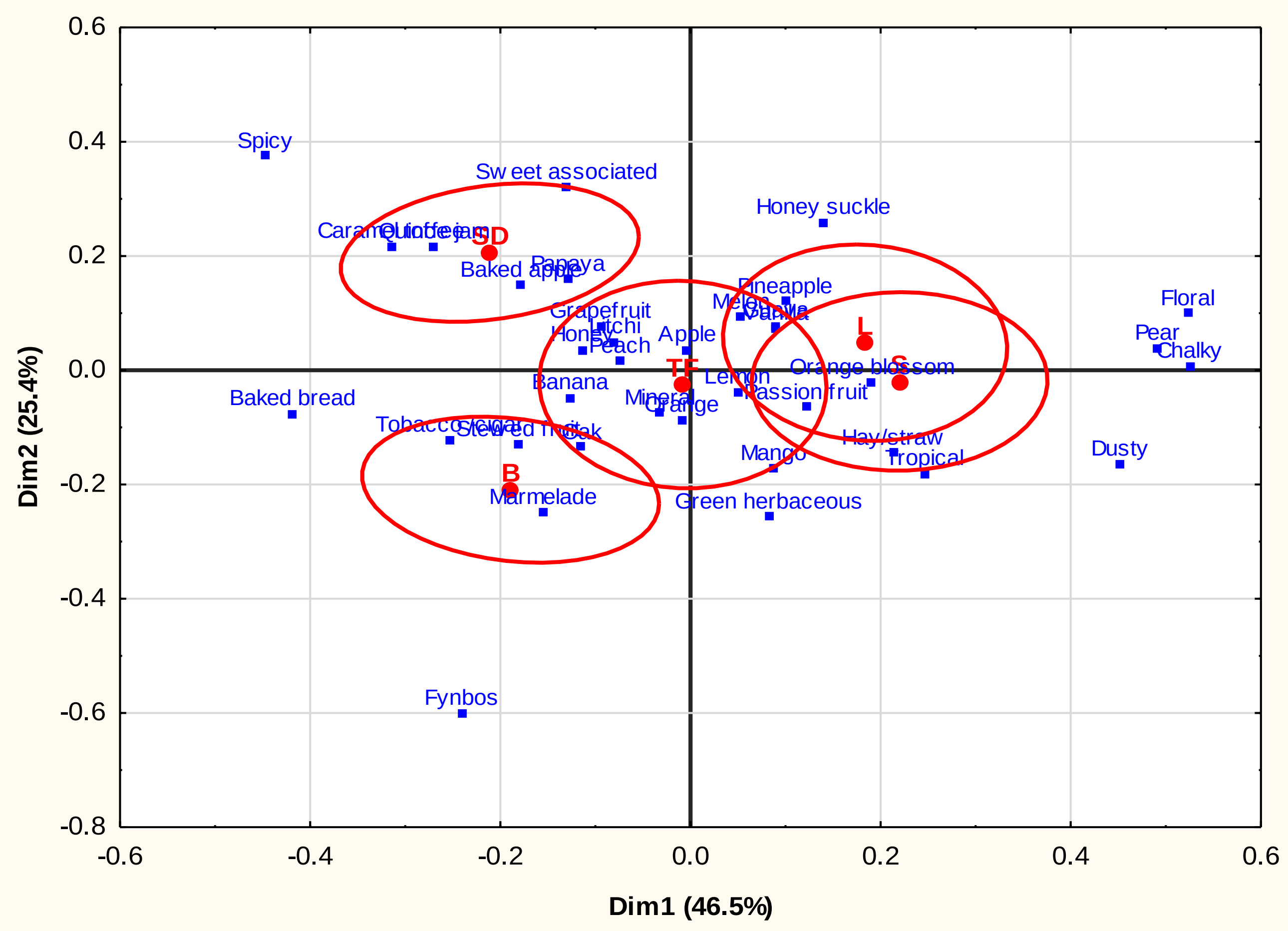

Figure 3.3 .The biplot from correspondence analysis of aroma data from analytical panel (n=10) in 2018 showing the wine's profiles of the fifteen wines,

The attributes associated with the formed groups may be linked to the volatile and non-volatile composition of must and wine described in Chapter 2. SD system wines descriptors namely ‘caramel’ and ‘sweet associated’ might be related to grape ripeness level and associated aroma composition, which was higher than for any of the other systems. Equally important, the sugar content of grape juice influences alcohol content of wine which is known to impart a sweet flavour to wine (Peynaud, 1987). In 2018, the berries of SD system were exposed to sunlight which lead to sunburn in most of the berry bunches. Additionally, this could have further affected the yield, (Chapter 2) and flavour of resultant wines based on the aroma profile.

The characterisation of wine aroma is a simple practice that can easily be done on wine after wine bottling ageing. Although the aroma is complex, the smell is one of the vital components of consumer purchasing decisions. For a neutral variety such as Chenin Blanc, aroma compounds are mostly derived from the fermentation process rather than grapes, hence practices such as

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trellising system may make a difference which would not be significant. From the results above, vintage effect manifested in the more pronounced differentiation of wines in one of the seasons. In addition to trellis type, row orientation may also play a pivotal role in exposing the berries to sunlight as shown for Sauvignon Blanc and Shiraz which eventually affect the biosynthesis of grape aroma precursors (Naylor, 2001; Hunter *et al.*, 2016).

3.3.2 Taste and mouthfeel of Chenin Blanc wines

CA results of the evaluation of taste and mouthfeel of the 2017 vintage wines by experts explained 92.5% of the total variance among the wines samples with the first dimension mainly responsible for the separation with 84.6 % (Figure 3.4). The first dimension clearly shows the trend among wines based on the body, along the first dimension from negative to positive a separation from full body to medium through to light body. The TF, L, and P wines were associated with the ‘full body’ and the ‘long after taste driven by alcohol’. SD and B wines were associated with the ‘medium body’ with the ‘medium after taste’ driven by ‘bitterness’ and ‘flavours’. S system wines were associated with the ‘unbalanced light body’ with ‘short aftertaste’ was driven ‘acidity’.

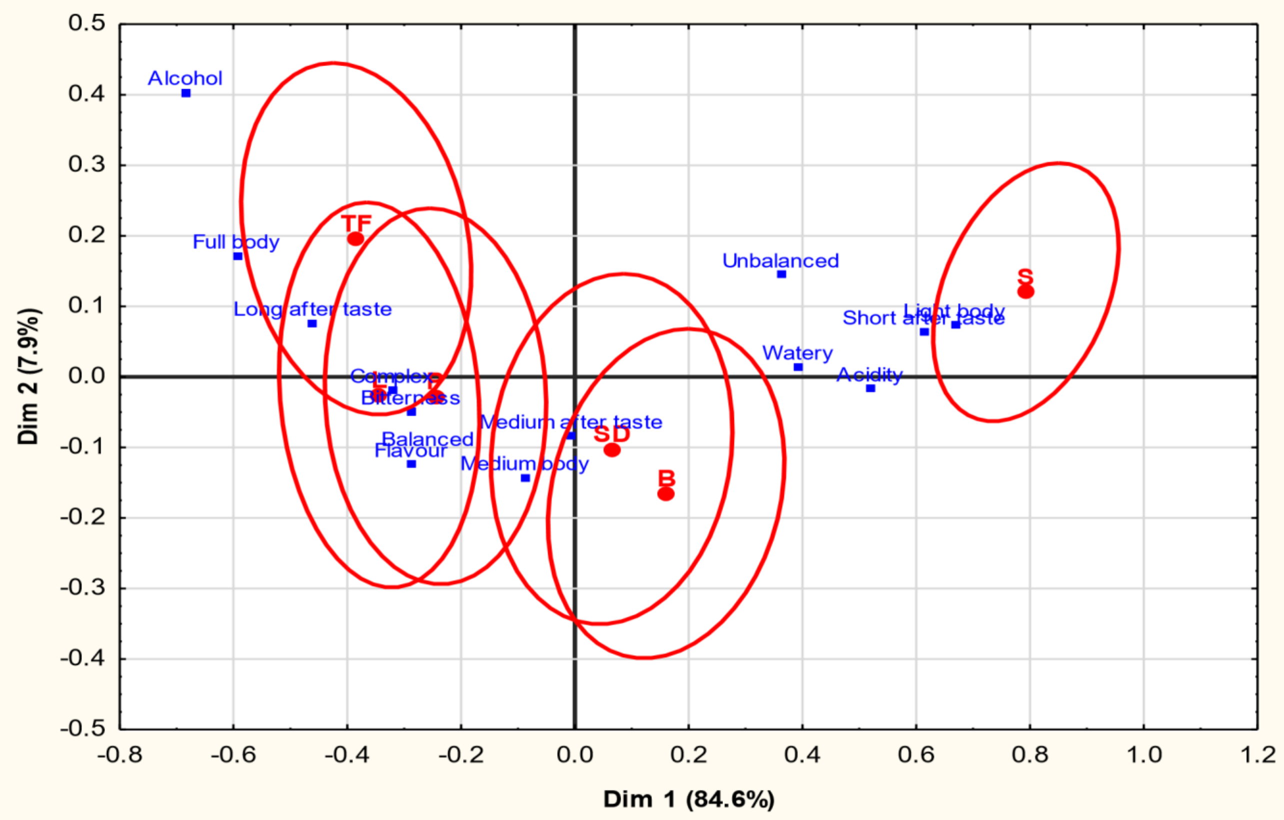

Figure 3.4 .Biplot of correspondence analysis performed on data from expert (n=30) indicating the taste and mouthfeel profiles in 2017.

Figure 3.5 illustrates the taste and mouthfeel profiles for the 2017 from the analytical panel. The biplot captured 86.2 % explained variance along dim 1 whereas dim 2 captured 10.0% explained variance to total up to 92.2% explained variance.

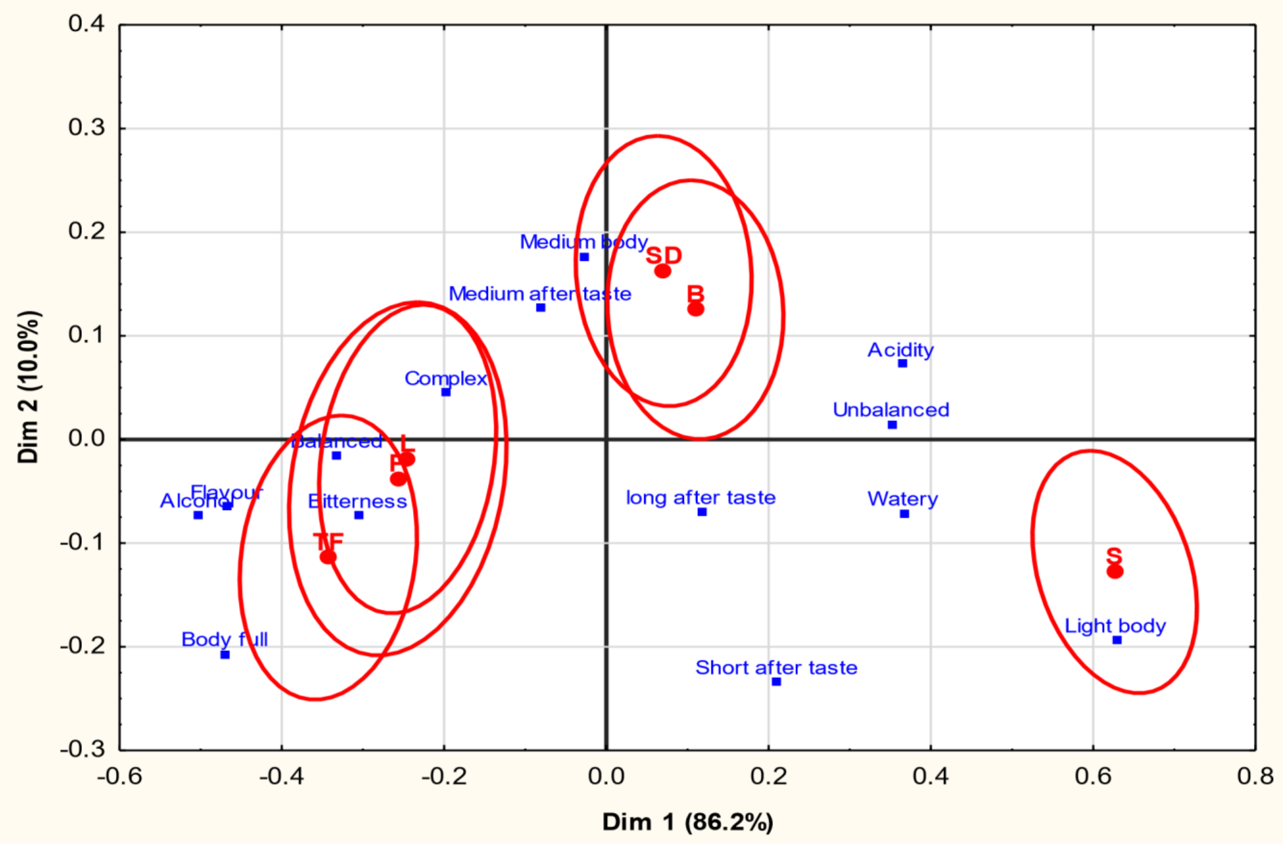

Figure 3.5. Biplot obtained from correspondence analysis of data from analytical panel on the evaluated wines of six different trellising systems in 2017.

The data from experts figure 3.5 shows that wines from similar trellis systems are perceived as similar. SD and B treatments are variant of each other, which indicate that the canopy exposure and their respective chemistry may be comparable and different from other treatments. Again, the same scenario seen with horizontal open canopies of TF and L grouped together with P treatment. Moreover, S treatment falling under the umbrella of shaded canopies, clearly separated further away from the open canopy treatments, therefore described by characters such as light body, watery and acidity.

The taste and mouthfeel profiles obtained from the analytical panel data (Figure 3.5) (and that of experts (Figure 3.4) showed a similar trend and configuration. However, for the analytical panel data, there is a visible separation between wines notably forming three groups. The first group consist of TF, L, and P systems associated with complex wines with the ‘full body’ and defined by ‘long after taste’ which was driven by ‘alcohol’ and ‘flavour’. The second group is characterised with ‘medium

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body', 'medium after taste' (wines from B and SD systems). The third group had wines from the S system, described by 'light body', 'short aftertaste was driven by acidity'.

The taste and mouthfeel profile for vintage 2018 assessed by the analytical panel is shown in Figure 3.6. The bi-plot obtained from the analytical panel data showed a trend pattern along dim 1, which explained 60.5% variance whereas dim 2 which captured 31.1% of the variance explained. A total of 91.6% explained variance is captured by Dim 1 and 2.

S system wines were characterised as 'watery', potentially linked to the sugar level at harvest, which was significantly lower than any other system and resulted in a lower percentage of alcohol (Chapter 2).

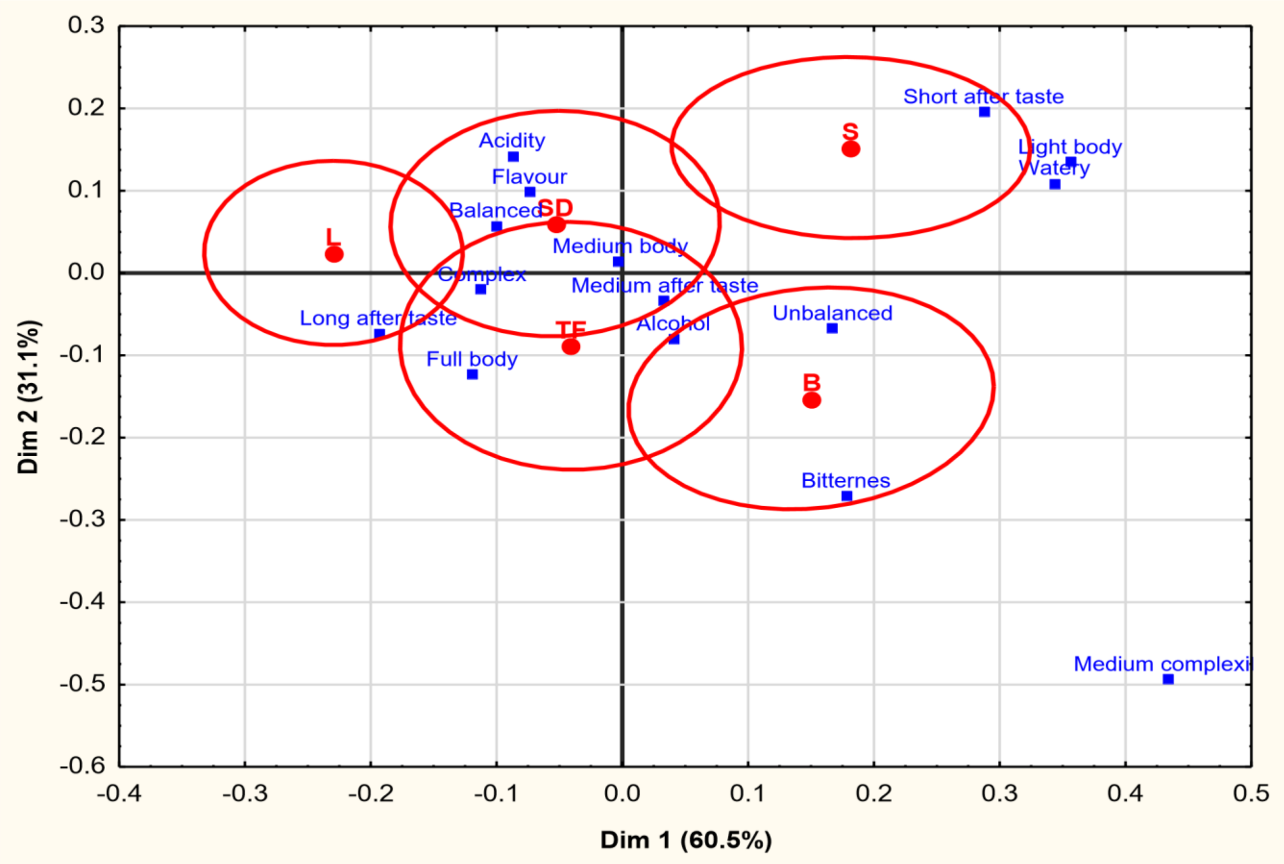

Figure 3. 6. The taste and mouthfeel biplot analysed from correspondence analysis of fifteen wine samples of five trellising systems by analytical panel in 2018.

The raw data already displayed citations of S treatment dominantly associated with negative attributes like 'acidity', 'water', 'light body' and 'unbalance' related possibly to the shaded bunches. Multivariate analysis hence confirmed the trend of S separated from the rest of the samples in both vintages. Further, other samples could not clearly be ascribed simply by looking at the raw data; however, multivariate analysis was able to separate them. TF treatment perceived with a taste driven by flavour, could be linked to the optimal interception of light by the system, as well as the alcohol percentage which was higher than for the other systems.

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Grape berries exposed to sunlight are generally higher in sugars and phenolic compared to shaded (Morrison & Noble, 1990). The systems with open canopies and canopies which allow sunlight exposure (TF, and L) are expected to produce wines higher in sugars, therefore produce full body wines. Not all wines are expected to be big, full bodied wines. However, they should present a pleasing entry into the palate and finish. The three aspects: balance, body and astringency in wines are categories which are always in consumer's mind when consuming wine. The importance of balance in wine complements the aroma, highly acidic wines tend to be thin, watery with a dry perception (Conde et al., 2007). It is possible that the wines produced from S system may be acidic due to the canopy architecture which led to berries being in the shade. Sugars' contribution can counteract the acidity and build body to a wine. S systems wines started with the lowest sugar therefore there is nothing to counteract the acidity.

3.3.3 Overall quality assessment

Wine quality is usually evaluated by wine experts, as their knowledge enables them to identify wine defects and also evaluate whether the wine being assessed is typical of the style it should represent. In this study, the overall quality was assessed based on three parameters: appearance/colour, aroma, and taste on a 3, 7, and 10 points scales, respectively.

Differences between the wines based on appearance, aroma, taste, and overall quality (Figure 2.28) were obtained from one-way ANOVA results at p value < 0.05. Among the sets, TF and L wines scored the highest and S wines the lowest for overall quality with significant differences. Taste scoring showed the same trend as for overall quality; aroma and appearance had similar trends although no significant differences were observed.

Considering that bush vines and S systems have a similar canopy architecture, it may be expected that they produce wines with similar characteristics. However, the quality scoring for S wines in the current study and those of Van Zyl & Van Huyssteen, (1980) are conflicting. In the investigation by Van Zyl & Van Huyssteen, (1980), the Chenin Blanc wines from bush vines were rated the highest based on colour, whereas in the current study, the wines from a similar canopy architecture (S) systems have scored the lowest among all the systems.

Aroma, taste and mouthfeel played a part in quality assessment scores in the present work, whereas appearance (colour) had no significant influence. Similar findings of Valentin *et al.*, 2016) showed that colour was not the major contributor to overall quality of Sauvignon Blanc and Pinot Noir wines in a study comparing Burgundy to New Zealand wines. On the contrary, Van Zyl & Van Huyssteen, (1980) found colour as a determinant to Chenin Blanc wine quality differences; however, the cause of colour differences were the result of infected grapes by fungus, rather than driven by canopy microclimates.

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As part of canopy management, temperature around the canopy could be the cause of lower sugar level and consequently affecting organoleptic properties of S system wines. Other wines such of B and SD systems produced similar wines of the same taste and mouthfeel, and again the design could play a role here because these two systems are similar (B system being a variant of SD system). Also TF and L systems are quite similar (vertical divided canopies). The wines from these systems had desirable characters ‘long after taste’, ‘after taste driven by flavour’, and had a ‘full body’. Opening the canopy makes room for good light interception and also prevents sunburn and controls sugar level.

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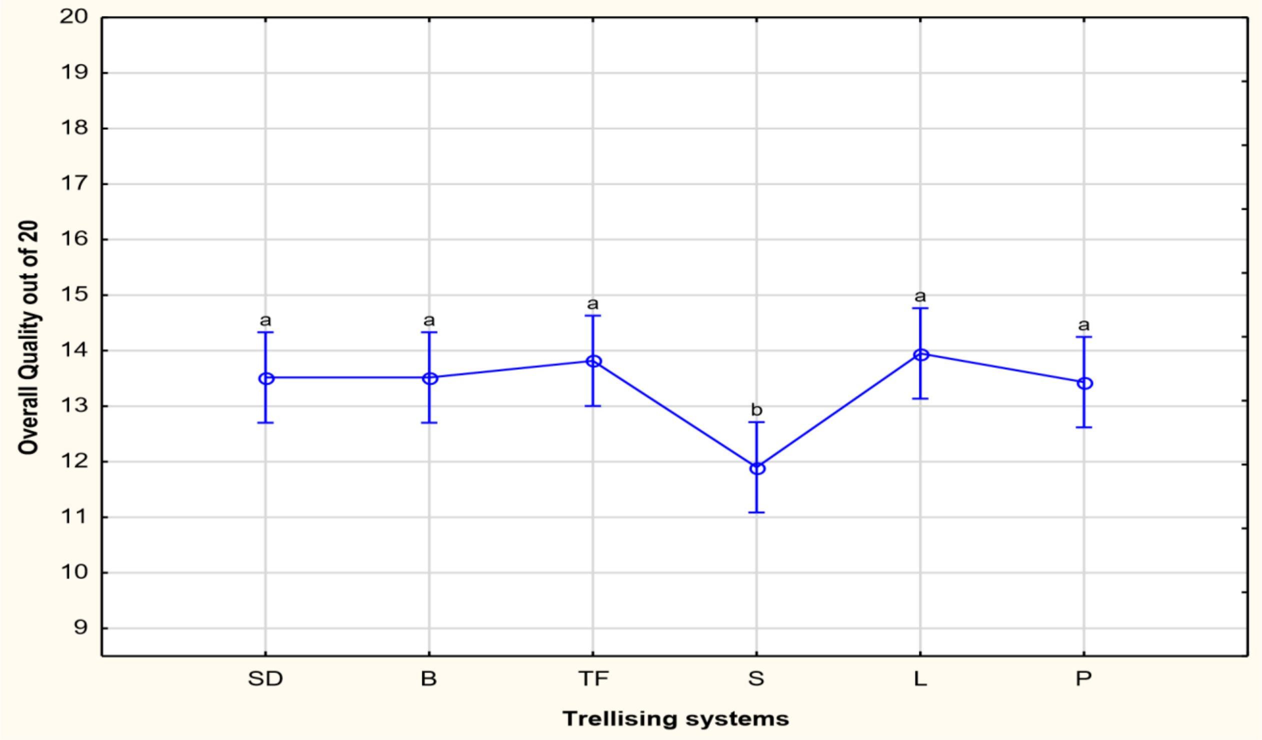

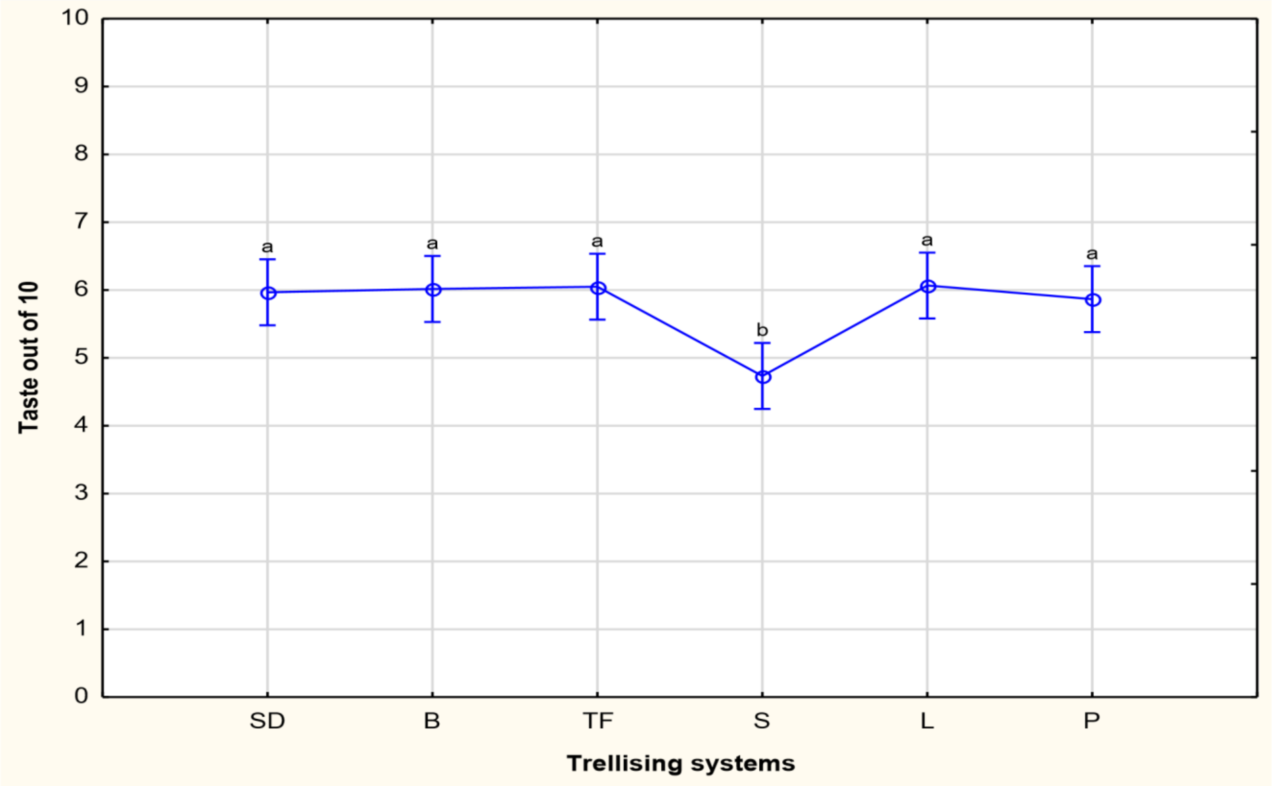

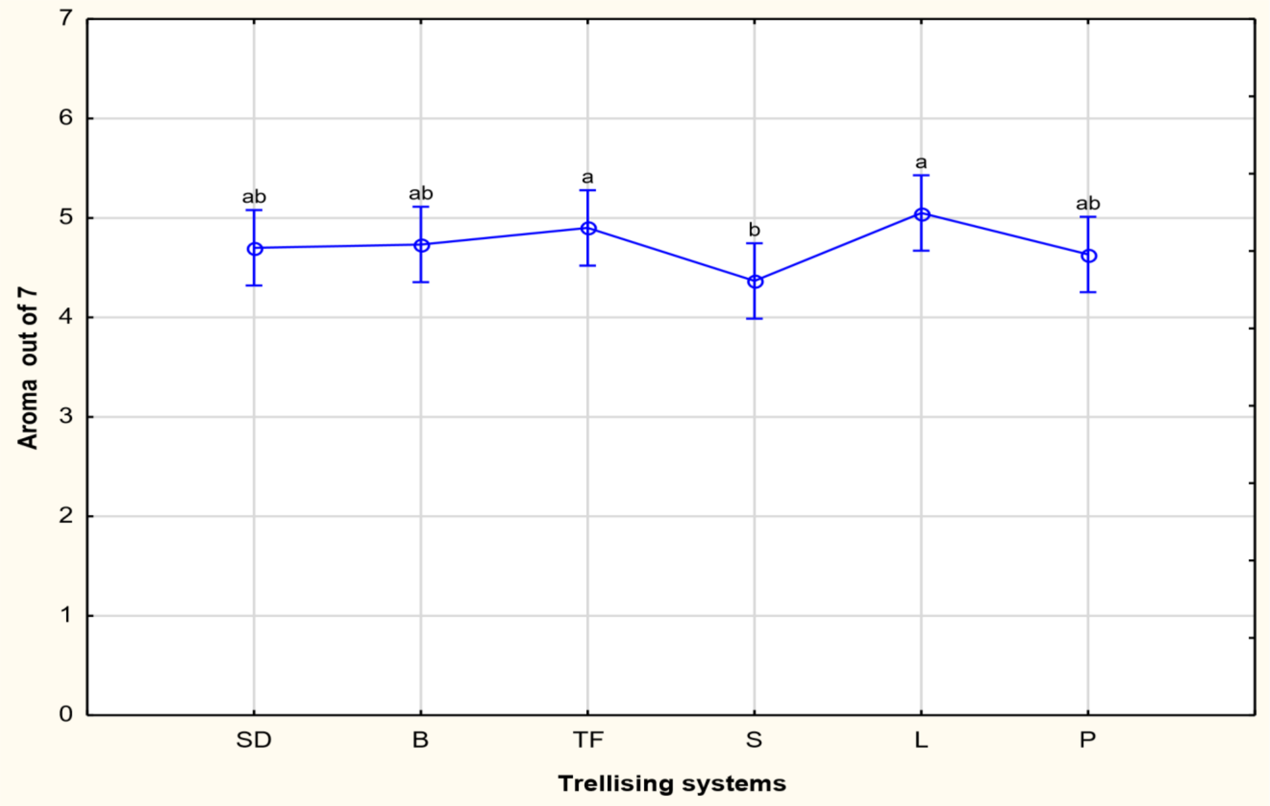

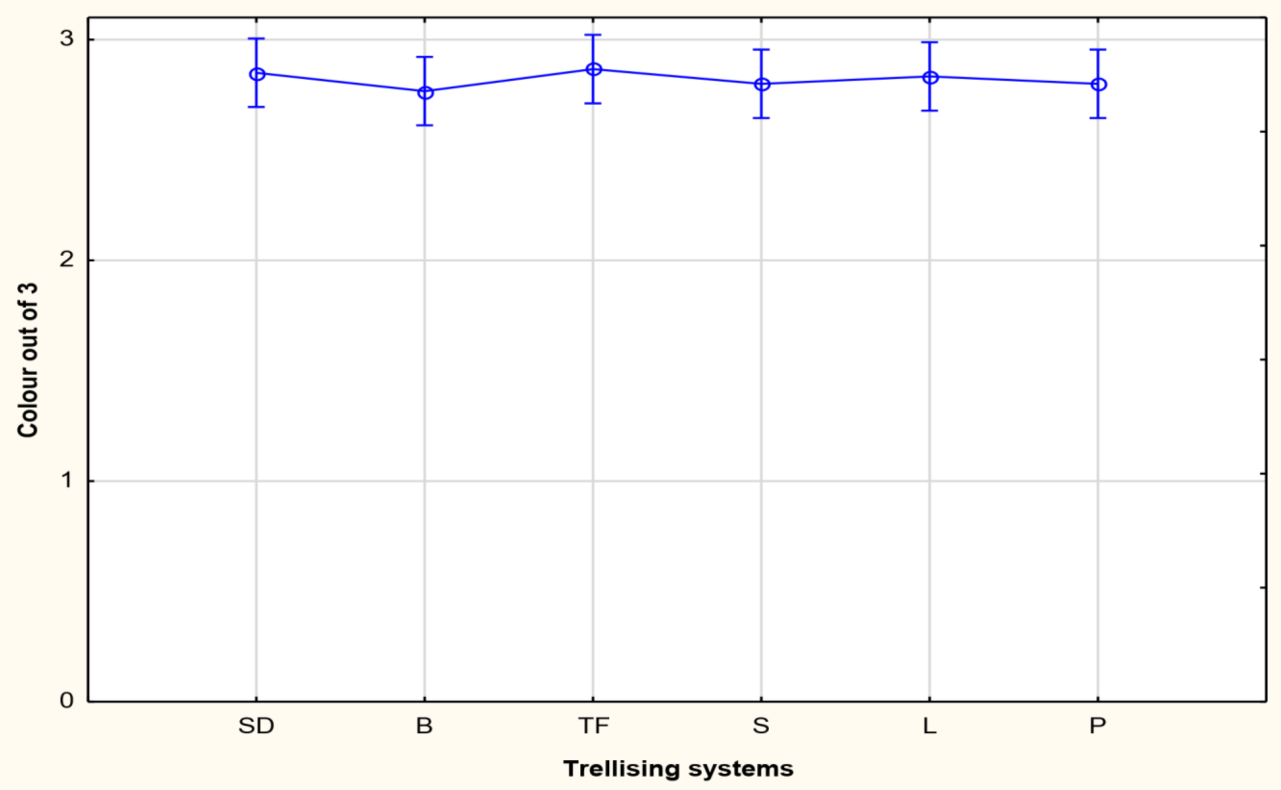

Figure 3.7. The LS mean plot derived from post hoc of analysis of variance form the rating scores of by experts for wines of 2017 vintage. The 1st plot shows overall rating, 2nd represent taste, 3rd plot show aroma and 4th plot indicate colour or appearance ratings.

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3.4. Conclusion

It is significant for winegrowers to make the right choice of a suitable trellising system which can maintain or even improve wine organoleptic properties and overall quality. One way to evaluate the improvement of sensory characteristics and quality aspects, is to profile resultant wines. The current work evaluated the effects of wines made from six different trellising systems on sensory characteristics and quality rating using CATA for profiling and quality assessment.

Regardless of the panel (experts or analytical), it was shown that the different trellising systems in this study did not have effects on the aroma perception of Chenin Blanc wines. One possible major factor could be because Chenin Blanc grapes are neutral – which means they lack a typical character and hence their aroma is highly dependent on winemaking process rather than on viticulture practices.

On the other hand, taste and mouthfeel were more prominently affected as the systems have an impact on phenolic compounds responsible for mouthfeel and on other compounds, as discussed in the text (sugar levels at harvest correlated to alcohol levels in resulting wines). The differences in taste and mouthfeel further played a role in the wines' quality scores. S systems wines were associated with negative attributes 'acidity', 'light body', 'watery', and 'short after taste' and scored the lowest. In brief, with trellising systems there is no one size that fits all. Under equitable conditions in the same vineyard, there were differences in relevant aspects related to taste, mouthfeel and quality, but not aroma. These results should be carefully considered before extrapolating them to wines from a vineyard with a different terroir and more specifically to wines from a different cultivar. Particularly in the light of climate change, drought, and consumers requiring lower alcohol wines. Choosing a trellis should be based on the objectives of the winemaker, but should not underrate the significance of consumer preference and economic factors.

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Chapter 4

General discussions and conclusion

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Chapter 4: General discussion and conclusions

4.1. General discussion

The experiment was designed to study the influence of microclimate driven by trellising systems on the main components of must and wine composition within the framework of a few basic assumptions. It was hypothesised that trellising systems create their own microclimates (Van Zyl & Van Huyssteen, 1980a), therefore can alter the accumulation of primary metabolites. Secondly, the modification of grapes primary metabolites may result in the different chemical profiles (secondary metabolites) and sensory characteristics in the resulting wines (Ji & Dami, 2008; Trought *et al.*, 2017; Vilanova *et al.*, 2017). Possible approaches to examine how trellising systems can affect wine profile are by characterising the chemical and sensory properties of subsequent wines. The data showed that these assumptions were met; the basic oenological parameters (Brix, pH, and TA) showed no difference between trellising systems. Amino acids however, had differences but had no apparent consequence. Secondary metabolites such as major volatiles and phenolic, as demonstrated no relevant effect by both analysis of variance (univariate) and cluster analysis patterns (multivariate) (Chapter 2 and 3).

The quantification of chemical compounds uses well-recognised methods and may play a role in establishing a relationship between the product's chemical composition and its sensorial attributes. With sensory evaluation, one of the popular methods is CATA, which, through profiling, can complement the results of the chemical composition of wines. Chemical composition has been used to classify wine base on their styles (Grosch, 2001; Culleré *et al.*, 2008), and there are also ways of characterising wine aroma's using sensory method (Niimi *et al.*, 2018). Although no correlation analysis was done in the current study, the comparison of chemistry and sensory profiles was quite important by relating sensory aroma to the quantified key odour compounds.

In this exercise, the provided CATA list allowed panellists (experts and analytical panel) to evaluate the samples using fifty-two aroma attributes. Due to the difference of how experts and analytical panellists described the wines, experts used thirty terms, whereas analytical panellists used forty, ten more words than the experts did. However, it was noted that in the second season, the analytical panel used fewer attributes (thirty-six) than in the previous season. This could be explained by the fact that in the second season there were fewer treatments for evaluation, thus the possibility for a reduced number of terms is worthwhile considering. Experts used fewer terms than the analytical panellists which may have been a result of the lower number of wines they evaluated. The experts tasted blended wines (six, each corresponding to a trellising system), unlike the analytical panel, which tasted all the biological repeats. Nevertheless, neither panel could differentiate the wines based on treatments.

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Data captured from the two panels provided a general aroma profile of each treatment. All wines were described as ‘fruity’ and this can be linked to esters. S system wines had the lowest concentration of thiols, which can explain the lack of ‘passion fruit’ and the presence of ‘mineral’ as an attribute (Parr *et al.*, 2016). Generally, Santorini system is specifically designed for hot and windy climates where bunches need to be protected. The wines of the B system were characterised by attributes that fall under ‘rich’ and ‘dry’ categories according to the *Aromas of South African Chenin Blanc wines* wheel. The SD treatment wines showed ‘sweet’ attributes related to the higher sugar content. L system wines were characterised by ‘guava’, and that related to the concentration of 3MHA which was significantly higher than for any of the other systems.

The determinant factors for taste and mouthfeel in this study were ‘acidity’, ’flavour’, and the body (ranging from light-medium-full body). However, it should be no be disregarded that phenolic content may have an effect, even though measurements by UV-Vis and CIE lab could not find significant differences. Another way to examine the data is to look at the differentiation among the samples by the groupings from both univariate and multivariate analysis. Using CA (for aroma sensory data) and PCA (for volatile compounds chemistry data) it is apparent that both analyses could not differentiate between the treatments (Chapter 2 and 3). Future studies could include compounds such as terpenes which may give better separation between the treatments based on chemical data. Terpenes are among the compounds significantly affecting the chemical profile of Chenin Blanc wines (Lawrence, 2012); moreover, geraniol and C_6 aldehydes are affected by light exposure (Bravdo, 2001; Ji & Dami, 2008; Vilanova *et al.*, 2017).

Another way to show differences and similarities is by chemical fingerprinting. The method has been applied to identify, discriminate and classify of red wines origin (Corvina Veronese, Primitivo, and Negro Amar, Mayr et al., 2018), variety (Cabernet Sauvignon, Merlot, and Pinot Noir, Vaclavik et al., (2011), and style (Chenin Blanc, Buica et al., 2017), it might be used to characterise wines from vineyard practices such as trellising systems. Information-rich techniques such as HRMS could be the answer to these complex scenarios. The results indeed indicated that wine matrices differed according to treatment, as a clear separation was seen along the two dimensions. Interestingly, the taste and mouthfeel data also showed a similar grouping pattern. Even though it is not clear which chemical compounds were responsible for the groupings, it is hypothesised that matrix composition prompted the configuration (especially the phenolics, which are one of the main groups of compounds detected by LC-HRMS). Maybe identification and quantification of individual phenolic compounds present in the wine and the interaction with volatile and other non-volatile compounds would help with further explaining the groupings.

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4.2 Conclusions

Chenin Blanc wines made from six different trellising systems were characterised. Starting from the beginning, yield is a primary objective across all wine growers, and can be maximised by trellising systems. Besides yield per vine, synthesis and further evolution of chemical compounds may be altered by vine architecture, and this is the core subject for the current study.

The present study showed that trellising systems influenced yield per vine, amino acids, yeast assimilable nitrogen, phenolic content, and aroma compounds as well as sensory characteristics concerning this neutral grape variety. In this case study, maximisation of yield was addressed without compromising wine quality. In general, open canopies by dividing systems allow optimum leaves and bunches sunlight interception. Evidently, higher yield was exhibited by open dividing canopy systems (TF, L, SD and B) than those from non-dividing canopies (P and S). However, the lower yield from non-dividing canopies was comparable to those from open –vertical canopy systems (SD and B). Trellising systems did not affect the pH, TA and ethanol level, with the exception of one system (Santorini), which was slow in accumulation of sugar but this does not impact significantly the pH and TA levels at harvest. The S system (Santorini) design makes it difficult in obtaining a representative sample to decide on harvest. That may have led to picking the berries which earlier showed that the sugar level was at the same level with the rest of the systems. However, Santorini systems has benefits of berries protection from wind.

Furthermore, it was expected that phenolic content may vary. Phenolics as determined through selected parameters (CIELab parameters, Total Phenolics, Total phenolic acids, Total flavonols) and UV-Vis spectra (280 nm-780 nm) showed no differences between the treatments. Chemical profiles based on individual aromatic compounds (major volatiles and thiols) also did not result in differentiating between the systems. Many of the compounds had a common fermentative origin, and no discriminant compounds or levels could be identified.

It was important to examine the wines using an approach that is more appropriate by including what targeted analysis have omitted. Indeed, the fingerprints for the wines indicated that the matrices could be separated according to trellising systems. Vine training systems as tools to modify microclimate-related factors can affect wine matrix and possibly contributed to differences in phenolic compounds that are responsible for taste and mouthfeel of wines. From comparing profiles produced from LC-HRMS data to the taste and mouthfeel (sensory) data, there is an indication of the effect a trellising has on wine.

This study contributes to enhancing the knowledge about the role training systems have on wine composition, sensory perception and overall wine quality, in addition to yield benefits. It is up to oenologists and viticulturists to take advantage of the differences (in grapes as raw materials) to produce wines with varying characteristics. The information provided could be exploited in both viticulture and oenological fields to improve the effects on vineyards with the aim of maintaining or improving wine quality.

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Appendix A

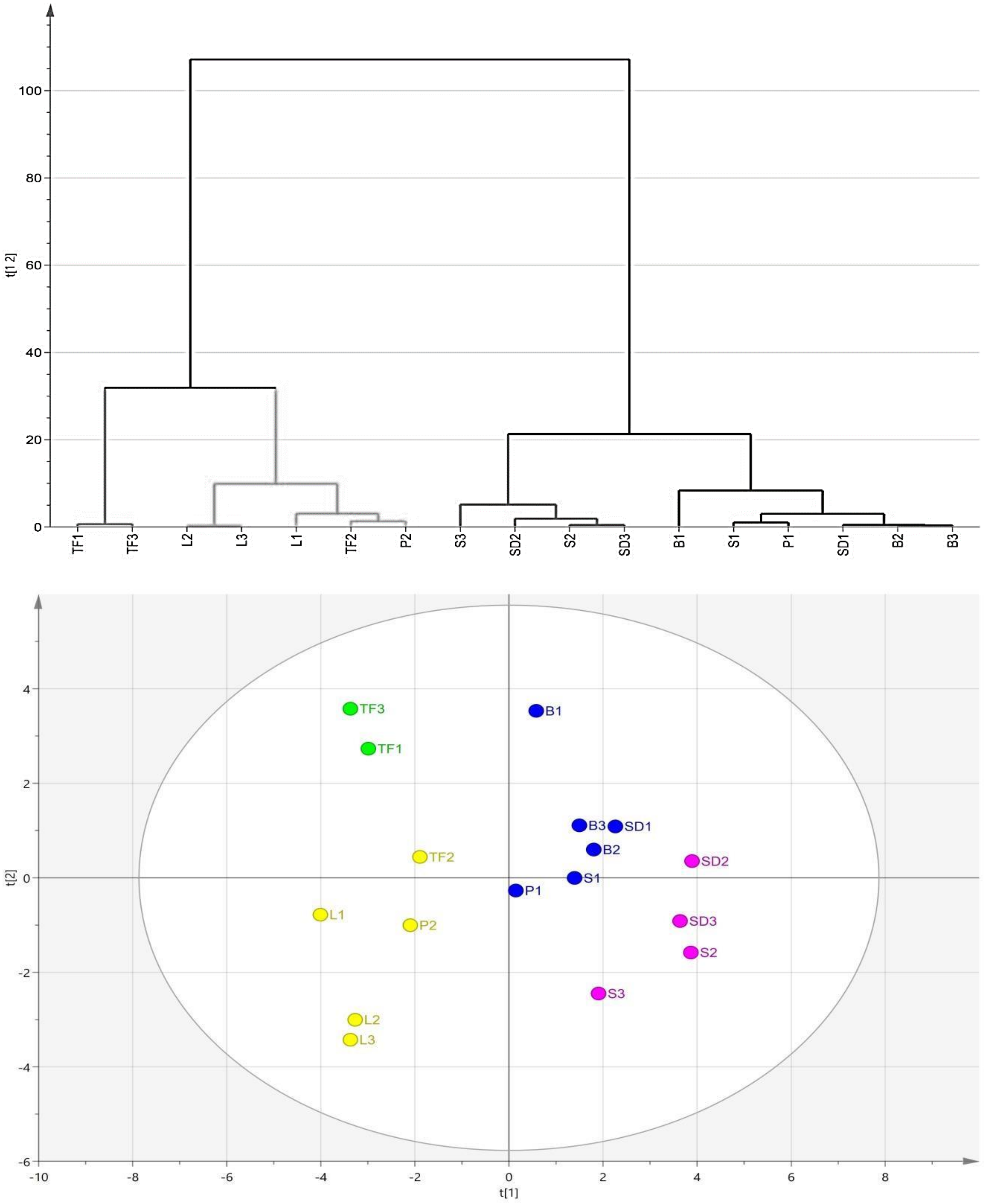

Figure A1. HCA dendrogram (top) and the PCA score plot (bottom) for the analysed amino acids, colours indicate groups according to the distances on the dendrogram, 2017 juices.

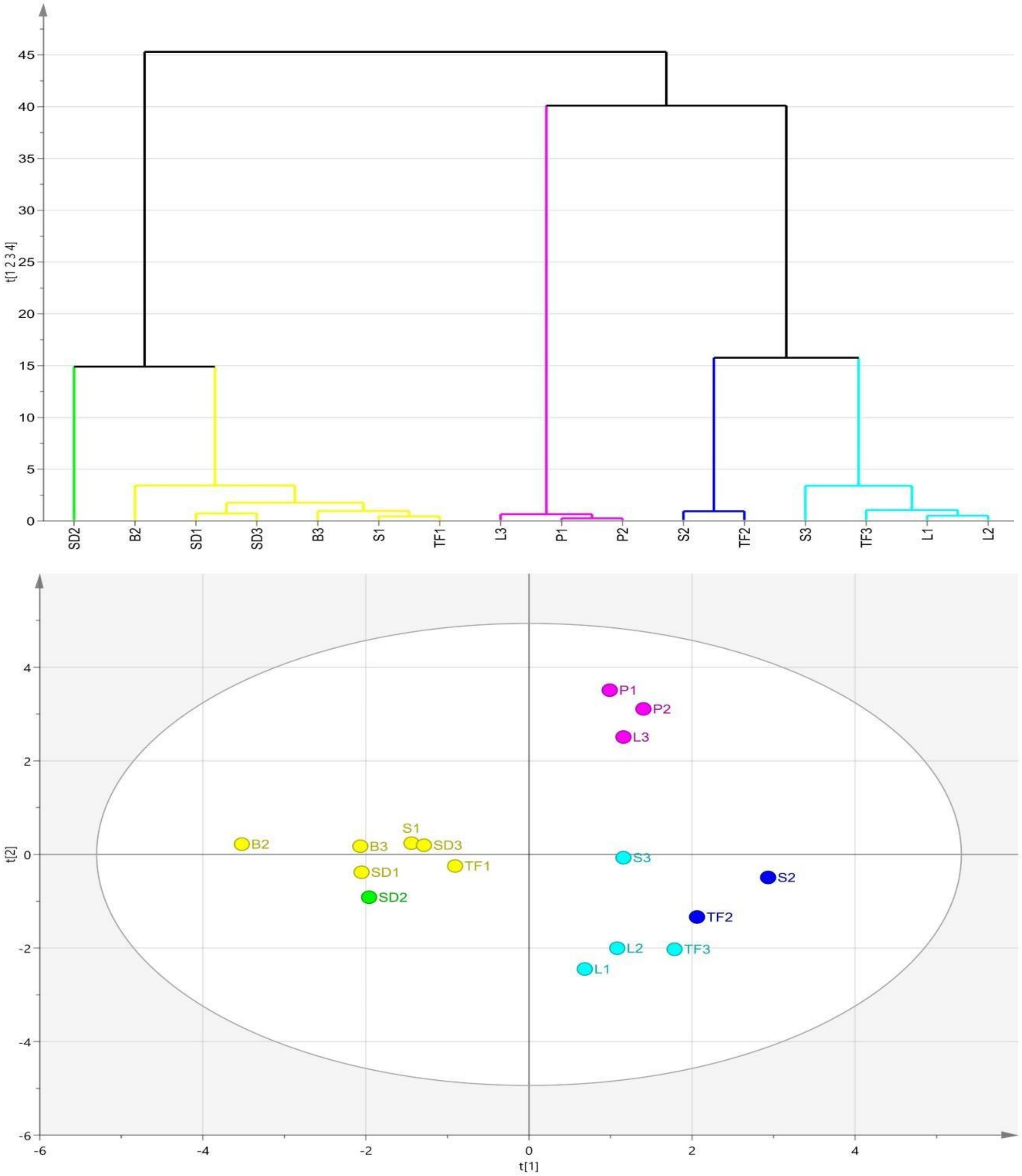

Figure A2. HCA dendrogram (top) and the PCA score plot (bottom) for the phenolics-related parameters (A280, A320, A360, A420) and CIELab parameters (a*, b*, L, chroma, hue), colours indicate groups according to the distances on the dendrogram, 2017 wines

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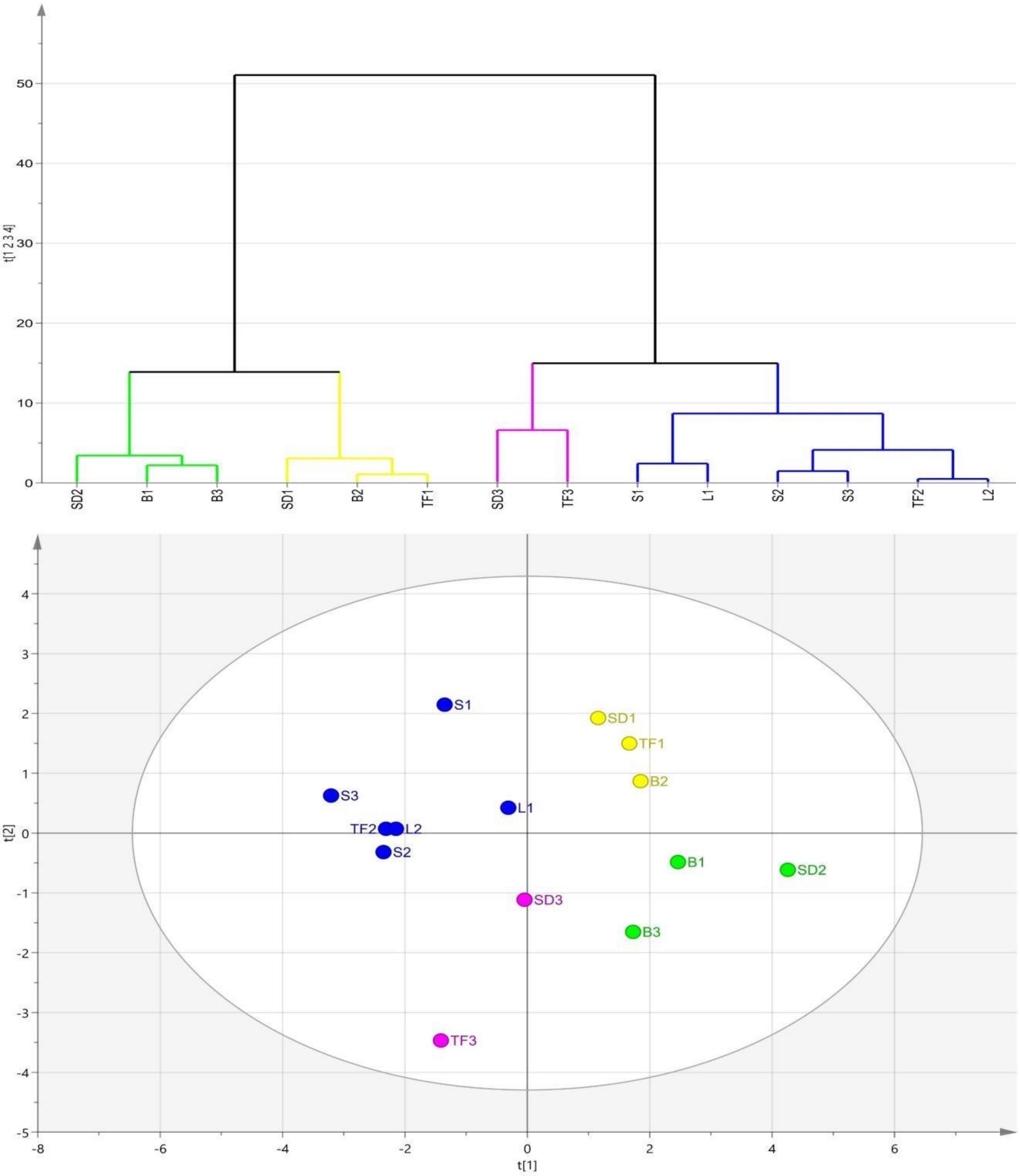

Figure A3. HCA dendrogram (top) and the PCA score plot (bottom) for the phenolics-related parameters (A280, A320, A360, A420) and CIELab parameters (a*, b*, L, chroma, hue), colours indicate groups according to the distances on the dendrogram, 2018 wines

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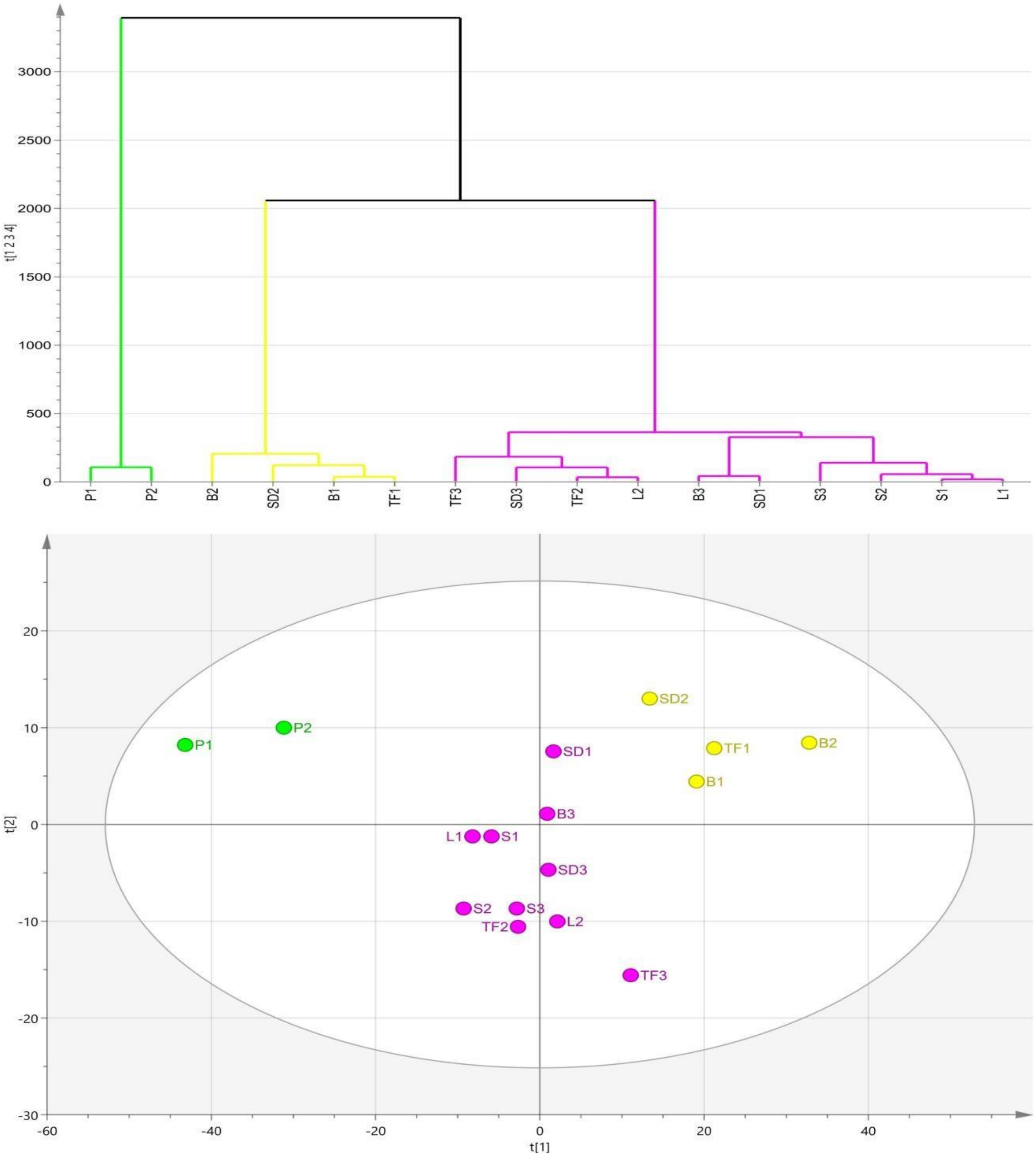

Figure A4. HCA dendrogram (top) and the PCA score plot (bottom) for the UV-Vis spectral data (280 – 780 nm), colours indicate groups according to the distances on the dendrogram, 2017 wines

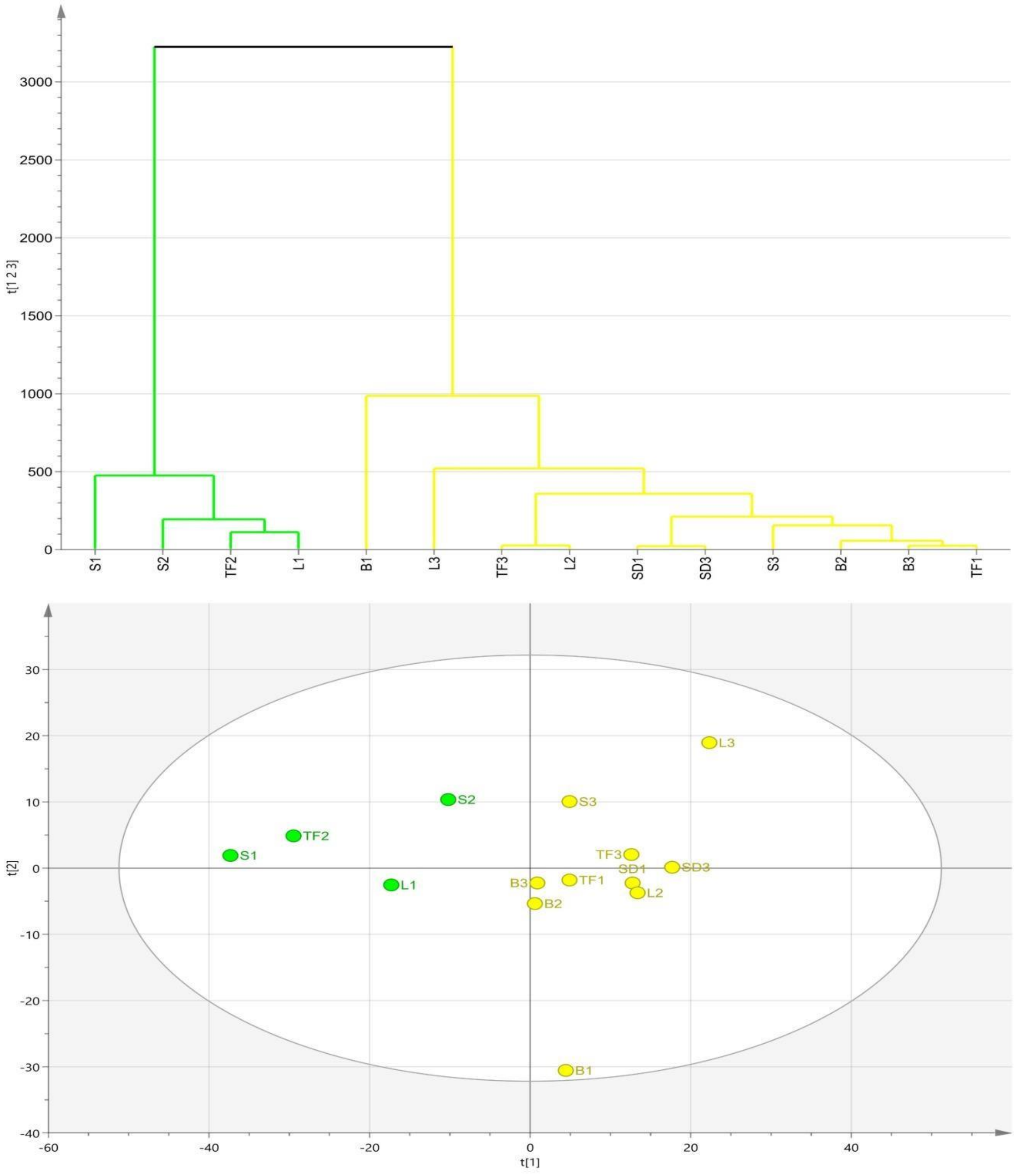

Figure A5. HCA dendrogram (top) and the PCA score plot (bottom) for the UV-Vis spectral data (280 – 780 nm), colours indicate groups according to the distances on the dendrogram, 2018 wines

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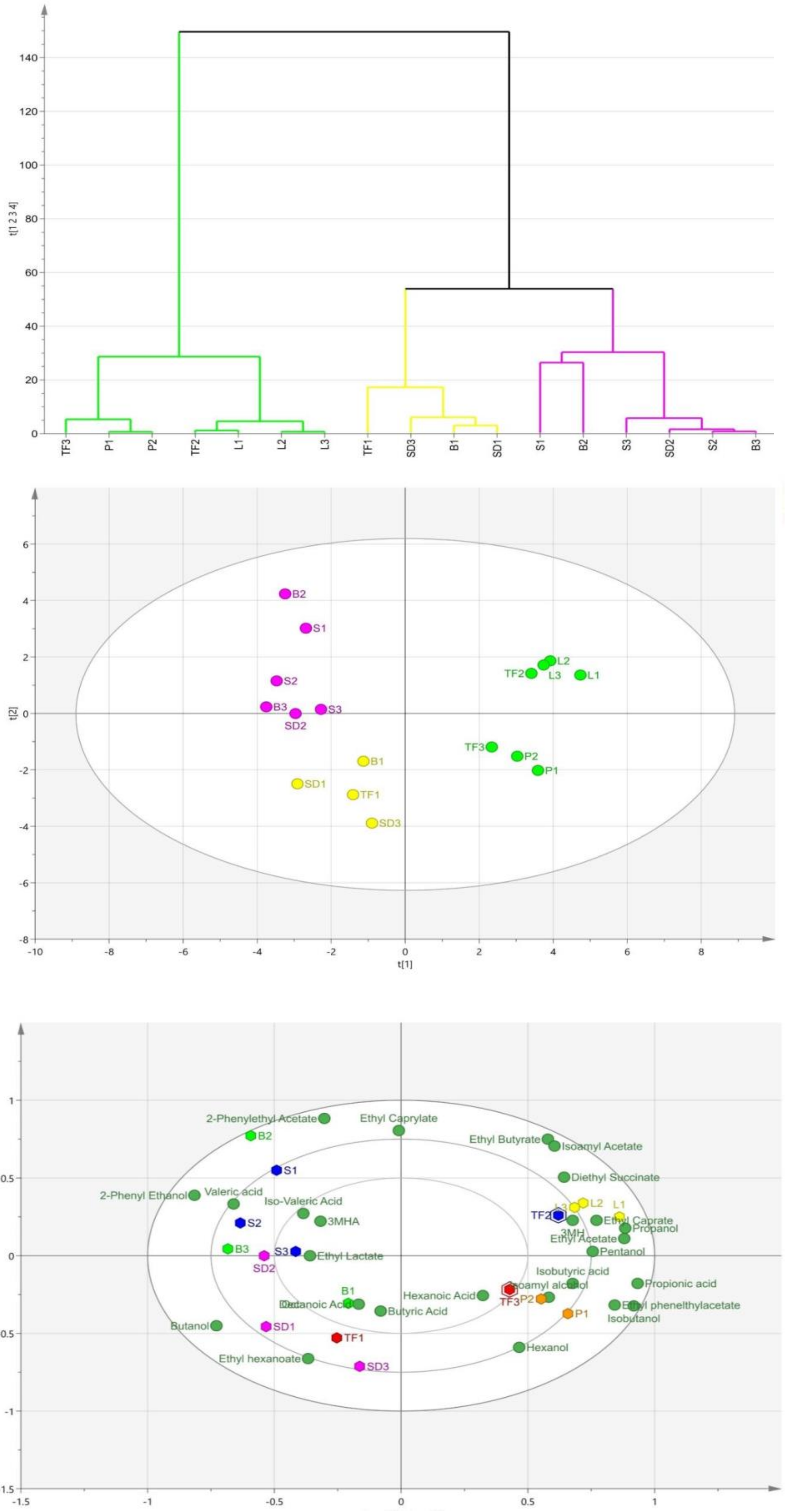

Figure A6. HCA dendrogram (top), PCA score plot (middle), and PCA biplot (bottom) for the major volatiles and thiols data, colours indicate groups according to the distances on the dendrogram, 2017 wines

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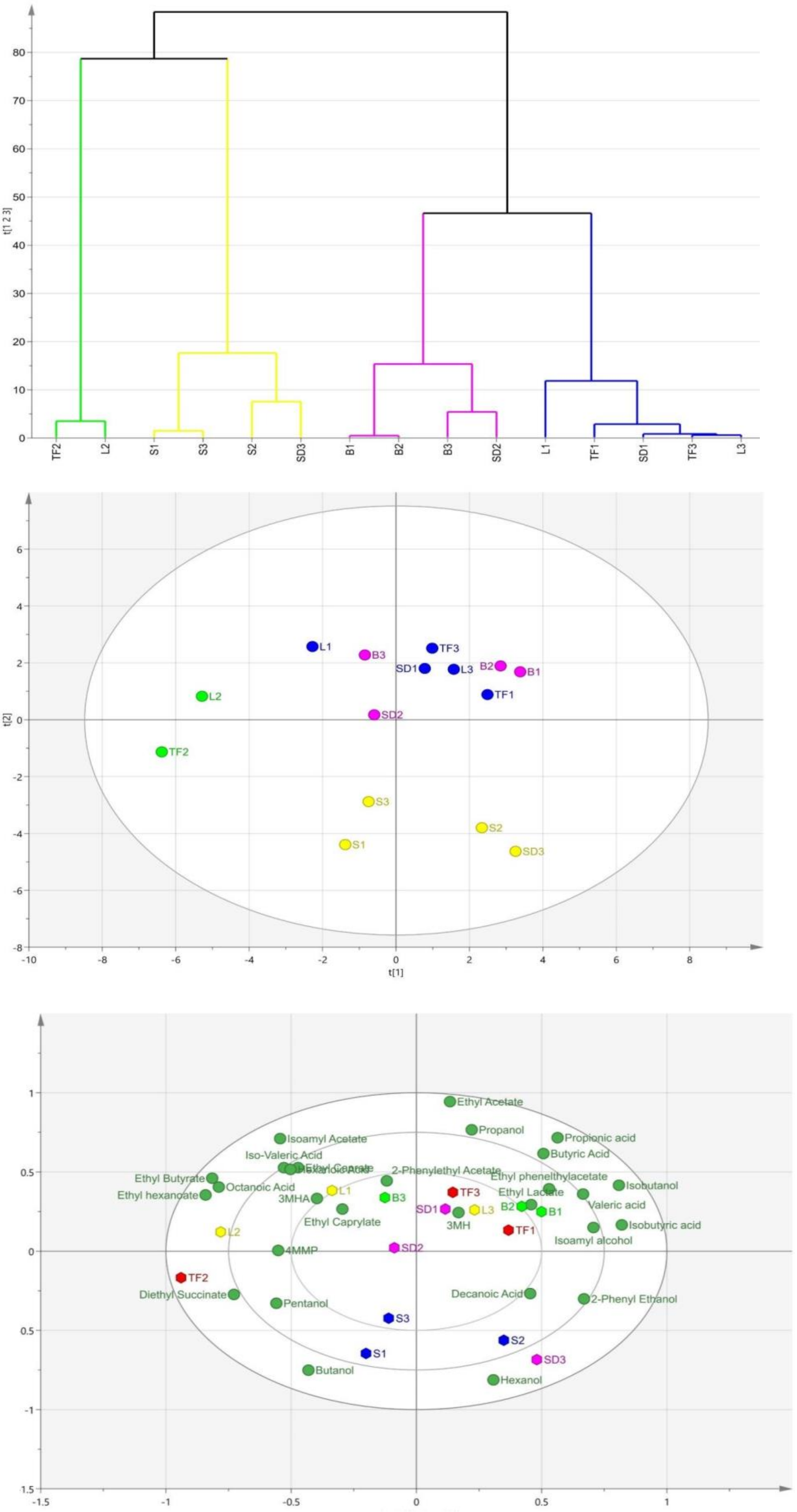


Figure A7. HCA dendrogram (top), PCA score plot (middle), and PCA biplot (bottom) for the major volatiles and thiols data, colours indicate groups according to the distances on the dendrogram, 2018 wines

Appendix B

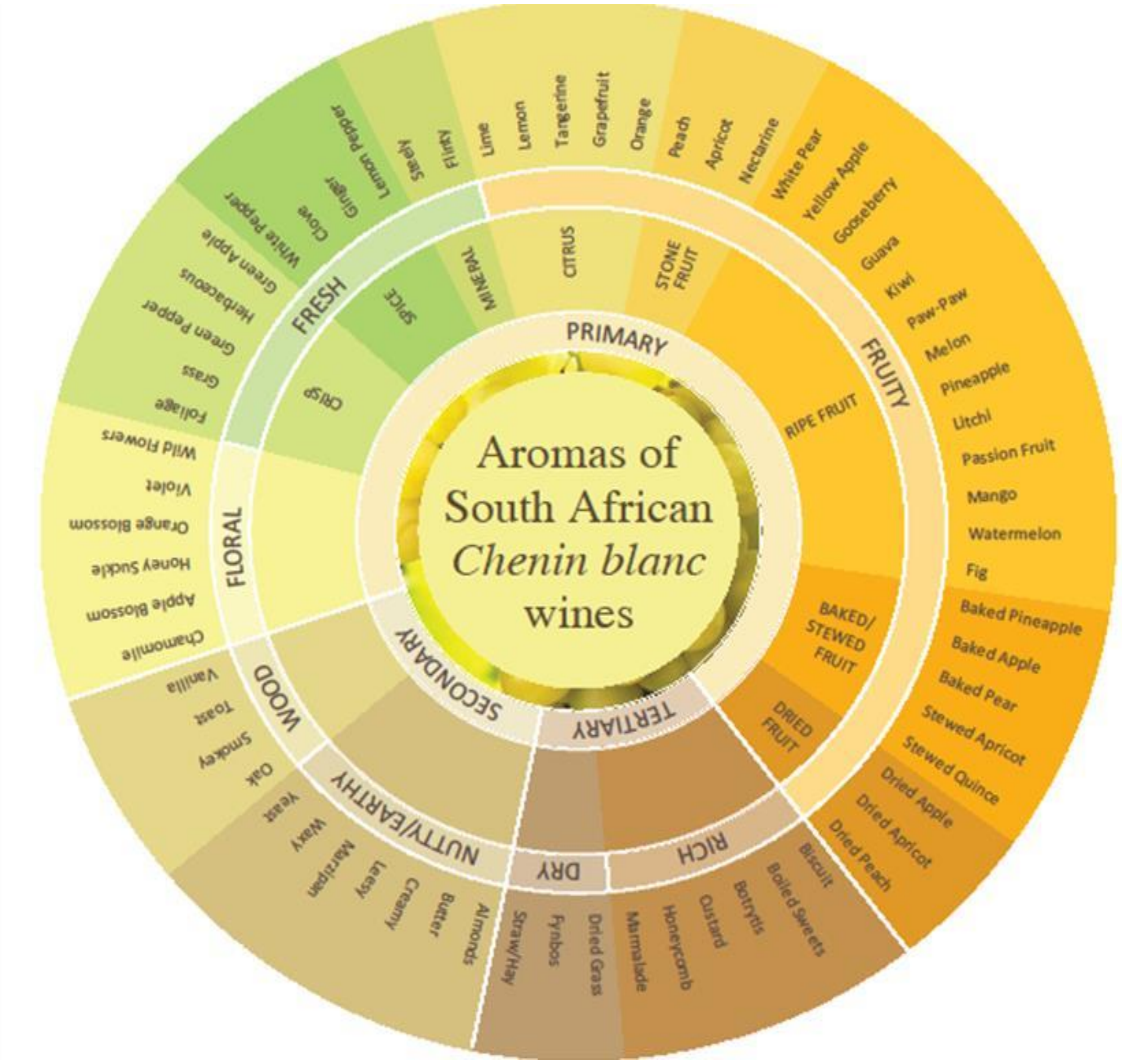
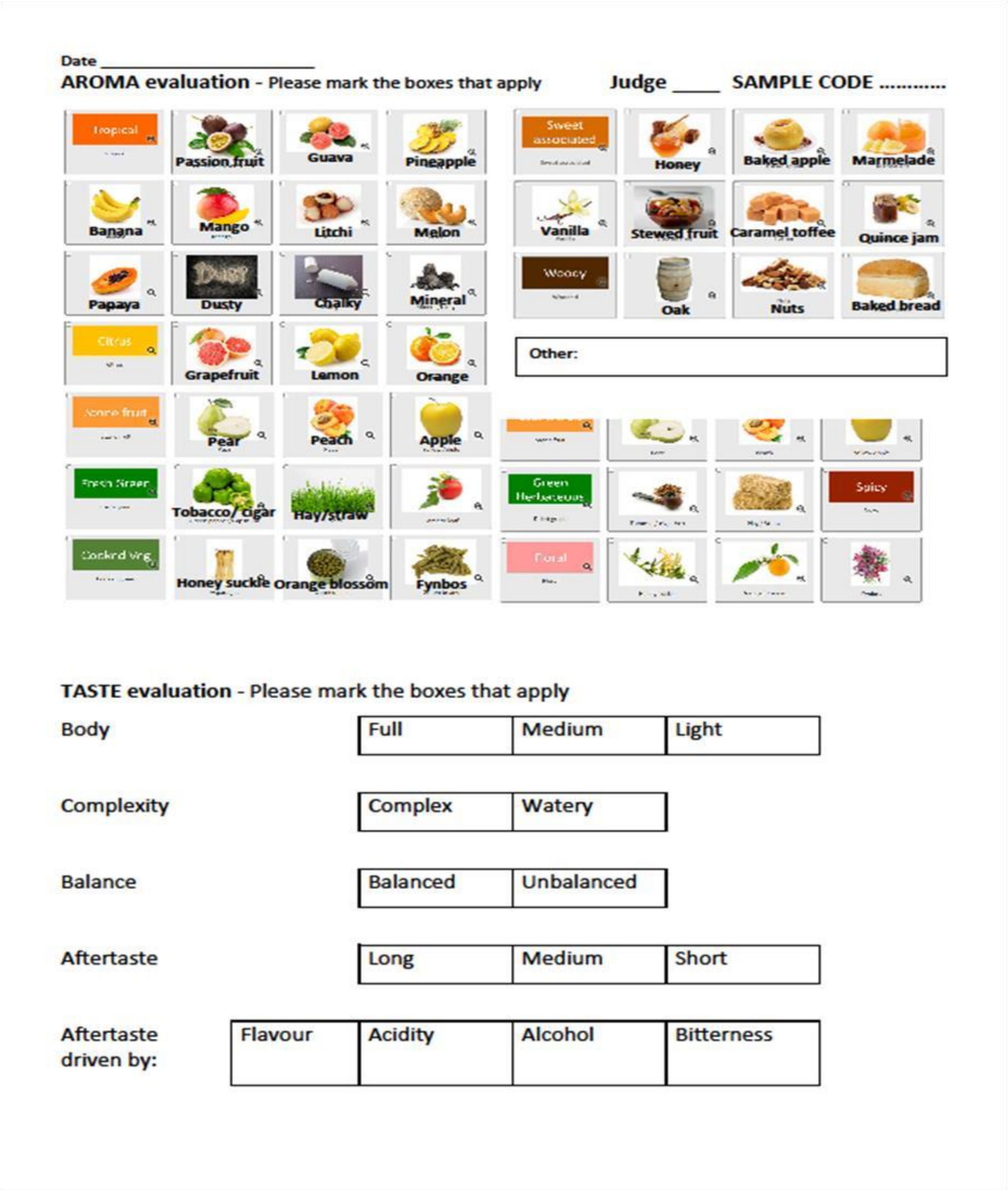


Figure B1. South Africa Chenin Blanc aromas wheel captured from South Africa Chenin Blanc Association (SA-CBA) website. Accessed on the 17/05/2019.



Date ______________________

AROMA evaluation - Please mark the boxes that apply **Judge** ____ **SAMPLE CODE** ....

Tropical	Passion fruit	Guava	Pineapple	Sweet associated	Honey	Baked apple	Marmelade
Banana	Mango	Litchi	Melon	Vanilla	Stewed fruit	Caramel toffee	Quince jam
Papaya	Dusty	Chalky	Mineral	Woody	Oak	Nuts	Baked bread
Citrus	Grapefruit	Lemon	Orange	Other:			
Stone fruit	Pear	Peach	Apple				
Fresh Green	Tobacco/ cigar	Hay/straw		Green Herbaceous			Spicy
Cooked veg	Honey suckle	Orange blossom	Fynbos	Floral			

TASTE evaluation - Please mark the boxes that apply

Body		Full	Medium	Light
Complexity		Complex	Watery	
Balance		Balanced	Unbalanced	
Aftertaste		Long	Medium	Short
Aftertaste driven by:	Flavour	Acidity	Alcohol	Bitterness

Figure B2. CATA sheet for the analytical panel used to evaluate Chenin Blanc wines of different trellising systems for 2017 and 2018 seasons.

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AROMA evaluation - Please mark the boxes that apply **Judge ____** **SAMPLE CODE …………**

Other:

TASTE evaluation - Please mark the boxes that apply

Body		Full	Medium	Light
Complexity		Complex	Watery	
Balance		Balanced	Unbalanced	
Aftertaste		Long	Medium	Short
Aftertaste driven by:	Flavour	Acidity	Alcohol	Bitterness

Please score the quality of the wine

Colour/Visual	1	2	3							
Aroma	1	2	3	4	5	6	7			
Taste/Palate	1	2	3	4	5	6	7	8	9	10

Overall Quality out of 20 ☐

Figure B3. CATA sheet including quality assessment for the expert panel used to evaluate Chenin Blanc wines of different trellising systems for 2017.